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FINAL REPORT

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Wetland drainage management technology development in support of San Joaquin River real-time water quality management

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This project was financially supported by the California Department of Water Resources under Agreement No. 4600003430 with the University of California, Merced. Additional funding for various components of the study was provided by the US Bureau of Reclamation, State Water Resources Control Board (SWRCB) under SWRCB Grant Agreement No. 04-312-555-1 and the CALFED Bay-Delta Program. This project has been one of the most collaborative the author has been involved with in 25 years of working in the San Joaquin Valley. This was due in large part due to an early decision to share resources with two independent State-funded projects - one focusing of waterfowl response to changes in wetland hydrology and the other on improving wetland flow and water quality monitoring. The resulting collaborative project has resulted in enhanced drainage water quality, soil salinity and moist soil vegetation monitoring that has allowed more comprehensive assessment of the impacts of real-time wetland salinity management on soils, biota and waterfowl response.

Fusion of the DWR, SWRCB and CALFED- sponsored projects allowed the addition of two paired wetland experimental sites to the four paired sites initially proposed for the project. This helped to improve the range of habitats covered by the project and provided added statistical power to the analysis of impacts of real-time salinity management as effected by delayed wetland drawdown. The project wouldn't have been possible without the courage and foresight of the late Don Marciochi, former Grassland Water District General Manager who decided to take a proactive position well in advance of salt TMDL legislation and championed the first comprehensive real-time data collection program. Grassland Water District staff including Ric Ortega, Patrick Rahilly, District Manager Dave Widell, Administrators Diane Wright and Veronica Woodruff were all instrumental in making the project a success.

Thanks to the DWR, Fresno staff who championed and oversaw the project including Jose Faria, Ernie Taylor, Joe Tapia and Laura Castro. UC Merced faculty Professor Tom Harmon and Sponsored Projects Director Thea Vicari were essential to facilitating Berkeley National Laboratory involvement in the project. Thanks also to project cooperators at the California Fish and Game including Bill Cook and John Beam, who gave permission to instrument ponds within the Los Banos Wildlife Management Area and provided essential support. Also to Lara Sparks, Melissa O'Dell and a host of other employees who provided GIS, monitoring and field assistance. Tracy Slavin, the late Michael Heaton and Jeff Milliken at the US Bureau of Reclamation were involved at various times with the project. Lastly to my colleagues and student assistants at Berkeley National Laboratory including Kevin Randeni, Caleb Royer, Jos Burns, Adam Morse and Lance Webber who were variously involved with data processing.

CHAPTER 1 : PROJECT EXECUTIVE SUMMARY

The objectives of the project funded by the California Department of Water Resources were as follows:

1. Develop techniques to allow the development of water and salt balances for seasonally managed wetlands in the San Joaquin Basin.
2. Contribute to an existing State Water Resource Control Board study by expanding the monitoring and analysis to include two additional study sites for a total of six-paired study sites in the watershed. The goal of the paired study design is to directly compare traditional and modified wetland drawdown practices.
3. Work cooperatively with refuges, water districts and regulatory agency staff to develop wetland simulation models and enhance system-wide monitoring that will allow the formulation of interim wetland salt load targets.

1.1 Project Summary

The project has provided science-based tools for the long-term management of salinity in drainage discharges from wetlands to the SJR. The results of the project are being used to develop best management practices (BMP) and a decision support system to assist wetland managers adjust the timing of salt loads delivered to the San Joaquin River during spring drawdown. Adaptive drainage management scheduling has the potential to improve environmental compliance with salinity objectives in the Lower San Joaquin River by reducing the frequency of violation of Vernalis salinity standards, especially in dry and critically dry years. The paired approach to project implementation whereby adaptively managed and traditional practices were monitored in a side-by-side fashion has provided a quantitative measure of the impacts of the project on the timing of salt loading to the San Joaquin River. The most significant accomplishments of the project has been the technology transfer to wetland biologists, ditch tenders and water managers within the Grasslands Ecological Area. This "learning by doing" has build local community capacity within the Grassland Water District and California Department of Fish and Game providing these institutions with new capability to assess and effectively manage salinity within their wetlands while simultaneously providing benefits to salinity management of the San Joaquin River.

1.1.1 Flow and salinity monitoring

Flow and electrical conductivity (EC) monitoring was initiated in 2005 and continued at the six paired wetland pond sites through the drawdown of 2009. Four wetland inflow and outflow monitoring sites including one paired inflow and outflow monitoring site have been continued into the 2010/2011 wetland flood-up season. The final project report focuses on the data collected during the 2007-2008 and 2008-2009 flood-up seasons. The continuous flow and EC data collected for the project resides on the YSI-EcoNet NIVIS server. The url for the project website is : http://www.ysieconet.com/public/WebUI/Default.aspx?hidCustomerID=99

1.1.2 Wetland vegetation mapping

Prior to the project there were few successful attempts at constructing accurate vegetation maps for the 140,000 acres of moist soil plant wetlands in the Grasslands Ecological Area, even with the aid of high resolution multispectral imagery. Mapping the changes in areal extent of the most desirable wetland moist soil plants and making annual comparisons of moist soil plants can provide direct evidence of impacts due to salinity management actions. The hypothesis going into this study was that a set of spectral signatures could be developed for certain common moist soil plant associations that could be used for annual vegetation surveys in the Grasslands Ecological Area wetlands. However high resolution multispectral imagery - flown in 2006, 2007 and 2008 - showed that spectral signatures were not consistent from year to year. We discovered that wetland moist soil plant associations were also not consistent from year to year – stands of swamp timothy could blend with several common moist soil plants depending on germination conditions in a particular year – leading to a unique spectral signatures for that particular association. The work involved performing ground-truth surveys to develop a new spectral signature classification each year would be cost prohibitive. Hence we concluded that these surveys should be undertaken every few years between wetland rehabilitation activities.

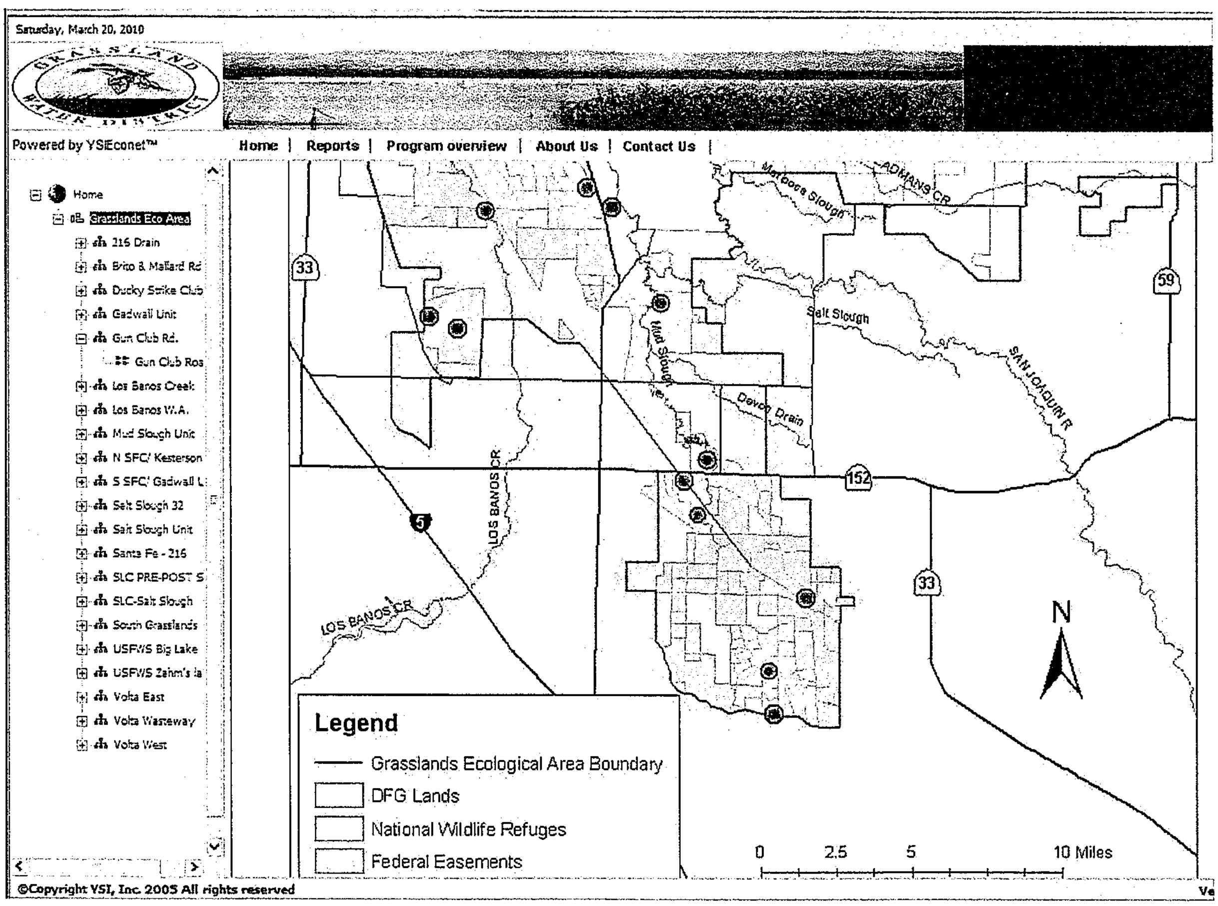


Figure 1. 1. YSI EcoNet project site accessible through the NIVIS data server. The map includes inflow and outflow sites at each of the six paired wetland pond sites as well as flow and EC monitoring stations that are part of the Ag Waiver monitoring program.

1.1.3 Wetland Soil Salinity Mapping using Electromagnetic Surveys

The electromagnetic instrument (Geonics Inc.- EM-38 ®), was used to map the near-surface soil salinity of the study sites immediately after wetland drawdown. The data produced by the EM-38 instrument was supported by analytical software, based on the DPPC (Dual Pathway Parallel Conductance) model developed by James

Rhoades et al. at the USDA Salinity Laboratory in Riverside, California. This technology has been show to be effective in the prediction of soil salinity across vast landscapes in agricultural settings. At the start of the project concerns were raised by Department of Fish and Game personnel about possible damage to swamp timothy seed heads during the salinity mapping survey. Hence all surveys were conducted by foot.

New GPS tracking software was acquired to facilitate the surveys in 2007, that allowed field personnel to trace their path on a hand-held GPS units. The data logging software designed for this application was TrackMaker ® which creates a visual trace of the current GPS location of the person conducting the survey on the Allegro Cx. The software retains the previous survey locations as a continuous line of closely spaced sample points. After some practice field personnel were able to use the screen trace to make evenly spaced passes across each wetland pond. The ESAP software package was created by USDA-ERS Salinity Laboratory to correlate EM-38 *xyz* (apparent bulk conductivity) data to readings of soil saturated extract electrical conductivity (EC). For each field, the RSSD software selected 12 sample locations based on even-increment sampling of a frequency distribution of values from which to collect soil samples for analysis. For the 2007 and 208 EM-38 field surveys two sampling depth intervals were chosen in order to improve the accuracy of the surveys and improve correlation with the laboratory measurements of soil saturated extract EC. The first sample depth was chosen to be 6 inches (15 cm) and the sample ideally collected in the 6 – 10 inch (15 – 25 cm) depth range. The second depth range was chosen as 18 – 24 inches (45 – 60 cm) – which is approximately mid-way within the range of the instrument in vertical measurement mode. The two sample depths were sufficiently separated to provide useful information on the possible migration of salt within the profile.

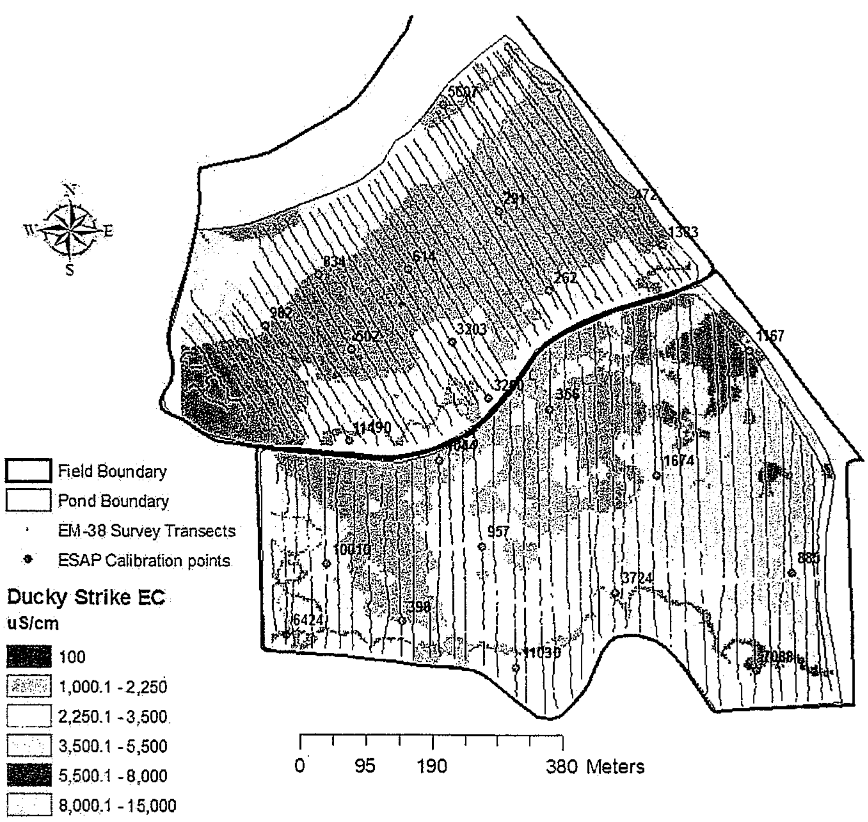


Figure 1.2 Ducky Strike North and South surface bulk soil salinity - 2008: 0 – 30 cm.

Soil moisture was assessed within hours of the completion of each EM-38 survey which also improved data consistency across experimental sites. Typically by the middle of May, the upper foot of soil has become desiccated whereas deeper subsurface soils may remain near field capacity. These soils develop fissures soon after drawdown – some of these fissures can be several feet thick. The tendency for these soils to crack can also explain the high degree of spatial non-uniformity of bulk salinity and well as other physical and chemical characteristics of these wetland soils. The optimal timing for wetland salinity surveys (after three years of survey data analysis) was shown to be shortly after drawdown as soon as the soils are able to accommodate foot traffic (in the case of the walking surveys) or an ATV (in the case of the motorized surveys). The map (Figure 2.1) shows clearly the areas of significant salt accumulation within each wetland and provides a useful guide to wetland managers for planning remediation measures during periodic wetland rehabilitation.

The final soil salinity survey, conducted in May 2010, was focused on the Ducky Strike wetland ponds ostensibly to investigate the impact of first-year landscape reclamation. The survey utilized the ATV-pulled rig that was designed and fabricated to conduct the vegetation surveys in 2006 but which was not used because of the potential damage to the biological survey of wetland moist soil plants.

1.1.4 Shallow Groundwater Monitoring

Four wells were instrumented within the Los Banos Wildlife Management Area to obtain better estimates of wetland groundwater losses during flood-up and to more accurately track the rate of fall of groundwater levels after the start of wetland drawdown. Groundwater data was corrected using the pressure data obtained from a barometric sensor in order to provide the true groundwater level elevation during the wetland drawdown period in the vicinity of the instrumented well.

Preliminary analysis of wetland hydrology and salinity balance data showed much improved control of sensor variability during 2007-2008 with far fewer instances of sensor and modem failure. Quality assurance protocols were well-honed – which resulted in only short periods of monitoring station down-time when sensors fell out of calibration or modems failed to transmit. The most significant source of error in the hydrology and salinity mass balance analysis continues to be wetland evaporation and emergent plant evapotranspiration. Wetland seepage is another poorly controlled source of error. Despite these limitations the project has allowed the first credible water and salinity balances of these areas to be produced.

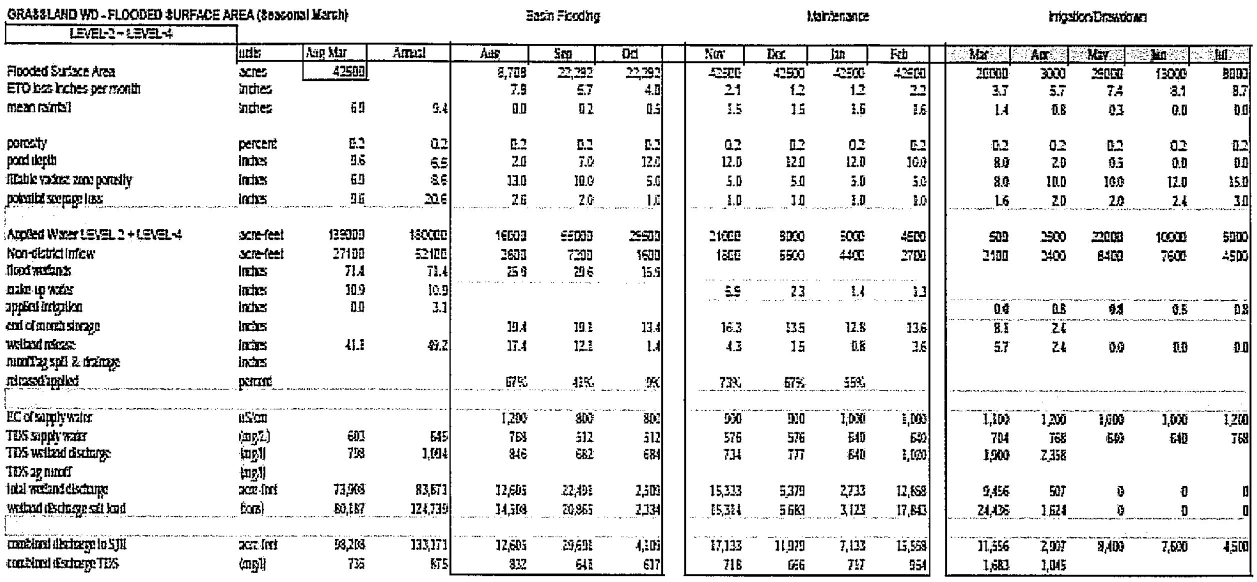
1.1.5 Wetland Salinity Balance- Conceptual Model

The WETMANSIM (Wetland Management Simulator) conceptual spreadsheet model was initially developed by the author in 1991 to simulate the impacts of Level IV water supply on water quality conditions in the San Joaquin River. The spreadsheet was formulated using information obtained during meetings with Grasslands Water District and State and Federal refuge managers who provided sets of assumptions and model heuristics that was combined with wetland delivery data from Reclamation's Central Valley Operations office. Until the current project WETMANSIM (Quinn, 2004) was the most commonly used conceptual model of flow and salinity mass balance in the wetland areas and was used to simulate wetland hydrology in the current CALSIM II water allocation model.

The conceptual model has not been field verified. Hence the current DWR sponsored project provides the first opportunity to field validate the conceptual models for two of the three wetland entities covered by WETMANSIM.

Table 1.0 WETMANSIM conceptual model parameters

parameter	units	Aug-Mar	Annual
1. Flooded Surface Area (example)	acres	2293	
2. ETO loss inches per month	inches		
3. mean rainfall	inches	6.9	9.4
4. porosity	percent	0.2	0.2
5. target pond depth	inches	9.1	6.2
6. fillable vadose zone depth	inches	6.9	8.6
7. potential seepage loss	inches	9.6	20.6
8. applied water - LEVEL-2/4	acre-feet	19000	19000
9. non-district inflow	acre-feet	0	0
10. flood wetlands	inches	80.5	80.5
11. make-up water	inches	42.7	42.7
12. applied irrigation	inches	0.0	10.5
13. end of month storage	inches		
14. wetland release	inches	76.2	84.8
15. runoff/ag spill & drainage	inches		
16. released/applied	percent		
17. EC of supply water	uS/cm		
18. TDS supply water	(mg/L)	603	645
19. TDS wetland discharge	(mg/l)	706	898
20. TDS ag runoff	(mg/l)		
21. total wetland discharge	acre-feet	10,387	11,540
22. wetland discharge salt load	(tons)	9,969	14,099
23. combined discharge to SJR	acre-feet	10,387	11,540
24. combined discharge TDS	(mg/l)	706	898



GRASSLAND WD - FLOODED SURFACE AREA (Seasonal Marsh)

LEVEL-2 + LEVEL-4

	units	Aug-Mar	Annual	Aug (Basin Flooding)	Sep (Basin Flooding)	Oct (Basin Flooding)	Nov (Maintenance)	Dec (Maintenance)	Jan (Maintenance)	Feb (Maintenance)	Mar (Irrigation/Drawdown)	Apr (Irrigation/Drawdown)	May (Irrigation/Drawdown)	Jun (Irrigation/Drawdown)	Jul (Irrigation/Drawdown)
Flooded Surface Area	acres	42500		8,708	22,292	22,292	42500	42500	42500	42500	20000	3000	25000	13000	8000
ETO loss inches per month	inches			7.9	5.7	4.0	2.1	1.2	1.2	2.2	3.7	5.7	7.4	8.1	8.7
mean rainfall	inches	6.0	9.4	0.0	0.2	0.5	1.5	1.5	1.6	1.6	1.4	0.8	0.3	0.0	0.0
porosity	percent	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
pond depth	inches	9.6	6.5	2.0	7.0	12.0	12.0	12.0	12.0	10.0	8.0	2.0	0.5	0.0	0.0
fillable vadose zone porosity	inches	6.0	8.6	13.0	10.0	5.0	5.0	5.0	5.0	5.0	8.0	10.0	10.0	12.0	15.0
potential seepage loss	inches	9.6	20.6	2.6	2.0	1.0	1.0	1.0	1.0	1.0	1.6	2.0	2.0	2.4	3.0
Applied Water LEVEL 2 + LEVEL-4	acre-feet	139000	180000	16600	55000	29500	21000	9000	5000	4500	500	2900	22000	10000	5000
Non-district inflow	acre-feet	27100	52100	2600	7200	1600	1800	6500	4400	2700	2100	3400	8400	7600	4500
flood wetlands	inches	71.4	71.4	25.9	20.6	15.5									
make-up water	inches	10.9	10.9				5.9	2.3	1.4	1.3					
applied irrigation	inches	0.0	3.1								0.4	0.6	0.4	0.5	0.8
end of month storage	inches			19.4	19.1	13.4	16.3	13.5	12.8	13.6	8.1	2.4			
wetland release	inches	41.1	49.2	17.4	12.1	1.4	4.3	1.5	0.8	3.6	5.7	2.4	0.0	0.0	0.0
runoff/ag spill & drainage	inches														
released/applied	percent			67%	41%	9%	73%	67%	55%						
EC of supply water	uS/cm			1,200	800	800	900	900	1,000	1,000	1,100	1,200	1,000	1,000	1,200
TDS supply water	(mg/L)	603	645	768	512	512	576	576	640	640	704	768	640	640	768
TDS wetland discharge	(mg/l)	798	1,004	846	682	684	734	777	640	1,020	1,900	2,358			
TDS ag runoff	(mg/l)														
total wetland discharge	acre-feet	73,968	83,671	12,605	22,491	2,309	15,333	5,379	2,733	12,658	9,456	507	0	0	0
wetland discharge salt load	(tons)	80,187	124,739	14,304	20,865	2,134	15,324	5,683	3,123	17,843	24,436	1,624	0	0	0
combined discharge to SJR	acre-feet	98,208	133,171	12,605	29,691	4,109	17,133	11,979	7,133	15,558	11,556	2,907	9,400	7,600	4,500
combined discharge TDS	(mg/l)	735	875	832	641	617	716	666	717	954	1,683	1,045			

Figure 1.3 WETMANSIM conceptual spreadsheet model (Quinn, 2004)

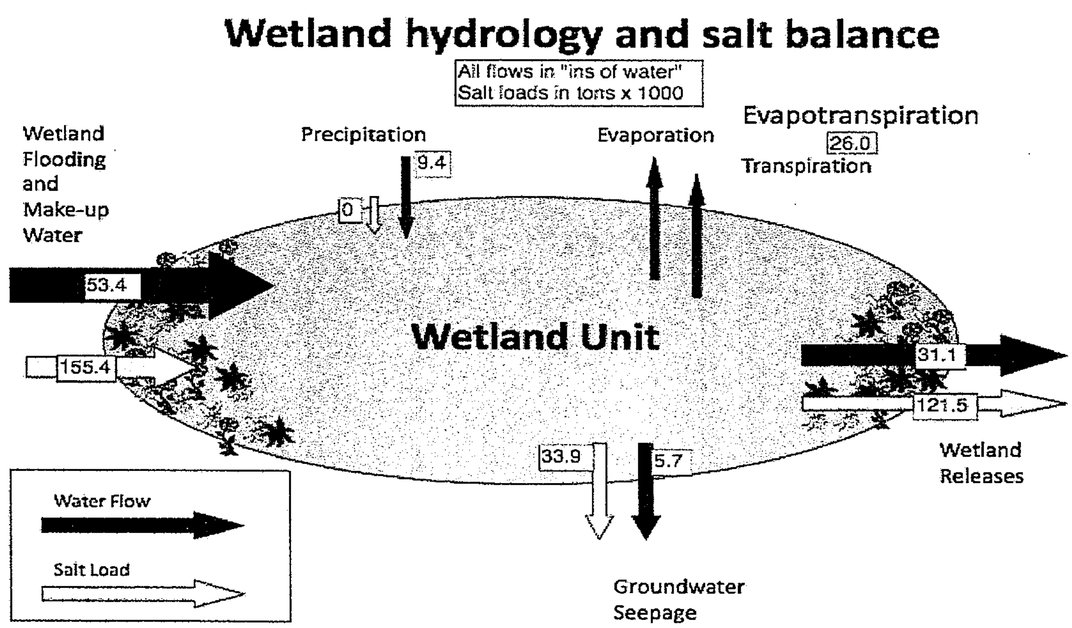


Figure 1.4 Conceptual salt balance model for Grassland Water District using year 2000 data and Level II water supply (Quinn, 2004).

Assumptions made in the development of the WETMANSIM conceptual model were as follows:

- The flooded surface area for each wetland complex was obtained from wetland water managers from GWD and the State and Federal refuges. This represented the best guess for a normal water year of the acreage of ponded water during each month. ETO was the potential monthly water loss from each flooded wetland.

- The model used mean monthly rainfall from CIMIS stations in Panoche Water District and at Kesterson NWR for year 2000.
- Porosity. This parameter is used to help estimate the amount of water that is required to displace the air-filled pores in the vadose zone of the regional aquifer. A higher porosity of 0.3-0.4, typical of sands, would require more water to fill and thus the wetland would exhibit greater water losses during flood-up. Monthly seepage would also be high and reach a steady-state once the initial flooding had filled all available pores. A value of 0.2 was used for most wetlands – which is indicative of a tighter soil with a high clay fraction.
    - Pond depth. The monthly average pond depth in seasonal wetlands will rise during flood-up to a level known as "shooting depth" (about 12 inches), which is a water depth that attracts diving ducks and other bottom-feeding waterfowl. This depth was assumed to be the average ponding depth once flood-up was completed.
    - Fillable vadose zone depth. This depth specifies the depth of the vadose zone and therefore help to define the volume of fillable pores that must be filled before water can pond on the surface.
    - Potential seepage loss. This is calculated as : fillable vadose zone depth * porosity. It is the estimated depth of surface applied water that will move into the groundwater in any given month.
    - Applied water. The volume of water (acre-ft) diverted from surface channels and applied as groundwater to each wetland area. This quantity is greater for level IV water supply since it includes water allocated under CVPIA. Most incremental Level IV water is applied during the summer months and not uniformly distributed over the year. Monthly surface applied water for Level II and Level IV was developed in a series of open discussions with wetland managers. Level IV water used after the month of April will produce less impact to the San Joaquin River than Level IV water used between Feb 1 and April 30.
    - Non-district inflow. The volume of return flows from adjacent agricultural land. This mostly applies to return flows from CCID and San Luis Canal Company that have historically been conveyed through Grassland WD channels. These flows are occasionally used in GWD and supplement Reclamation water deliveries to the District.
    - Flood wetlands. The depth of water applied to the average flooded area during each month during flood-up. For ease of accounting the spreadsheet begins in August. In most years flood-up occurs in September to minimize evaporative losses that would occur if flood-up occurred earlier. Shooting depth is achieved at different times in different parts of each wetland area. It is used as a calibration variable in the spreadsheet model.
    - Make-up water. The depth of water added after initial flood-up to bring water level to the desired average depth within each wetland management area.
    - Applied irrigation. The depth of water applied in the late spring and early summer months after initial drawdown to encourage the propagation of desirable moist soil plants.
    - End of month storage. A calculated water depth equivalent to the remaining depth of water after accounting for inflows and outflows to the wetland management area : EOMS = flood wetlands + mean rainfall – potential evapotranspiration – seepage loss – target pond depth.
    - Wetland release. Calculated depth of water equivalent to the remainder when the monthly target pond depth is subtracted from the end of month storage depth. Is the equivalent depth of water returned to Mud or Salt Slough which discharge to the San Joaquin River. This can be converted to a volume by multiplying by the monthly average flooded surface area.
    - Runoff / ag spill. This water depth refers to any return flows generated during wetland irrigation. This volume is typically small owing to high evaporation during the late spring and early summer months.
    - Released/applied. The ratio of released water to water applied is expressed as a percentage. This is an index of wetland flushing – a higher percentage indicates a greater amount of wetland flushing.
    - EC of supply water. Most water applied to seasonal and permanent wetlands in the Grassland Ecological Area, other than groundwater pumping, derives from the Delta and is delivered via the Delta Mendota Canal. This EC is the average salinity (measured in umhos/cm) of the supply water. The monthly EC values were based on monitoring conducted by Quinn and others in the Volta wasteway and on personal observation of Scott Lower.
    - TDS of supply water. The ratio of EC to TDS varies depending on the salt composition of the water. For Delta water an average factor of 0.64 is used to convert EC to TDS.
    - TDS wetland discharge. Water ponded in seasonal and permanent wetlands is subject to evaporation resulting from wind energy and heat which remove pure water leaving saltier water behind. Dust and bird excreta also add to wetland salt loads. Evaporation increases in the summer months when temperatures are higher resulting in elevated wetland TDS concentrations.
    - TDS agricultural runoff. In cases where summer irrigation results in drainage runoff - the salinity of this runoff is elevated owing to dissolution of surface salts and solubilized bird guano. Runoff was assumed negligible in the model.
    - Total wetland discharge. Obtained by multiplying the wetland release depth of water by the flooded surface area.
    - Wetland discharge salt load. Obtained by multiplying the total wetland discharge by the TDS of wetland discharge and adjusting the total using a conversion factor to convert acre-ft * mg/l to tons of salt.

1.1.6 Wetland water and salinity mass balances

The flow and electrical conductivity data for the twelve experimental wetland ponds were downloaded from the NIVIS website and processed using the spreadsheet procedure for the 2006-2007 data and using the Aquatic Informatics Inc. Aquarius software for the 2006-2007 and 2007-2008 data. The 2008-2010 data are currently being analyzed using the Kisters Inc. hydrologic data management system WISKI. The initial spreadsheet model used for data processing proved slow, inefficient and very wasteful of computer resources. Each spreadsheet was in excess of 10MB. The Aquarius software is object-based and proved to be easy to use and very efficient. However the software was not well integrated with database tools used to pull in and

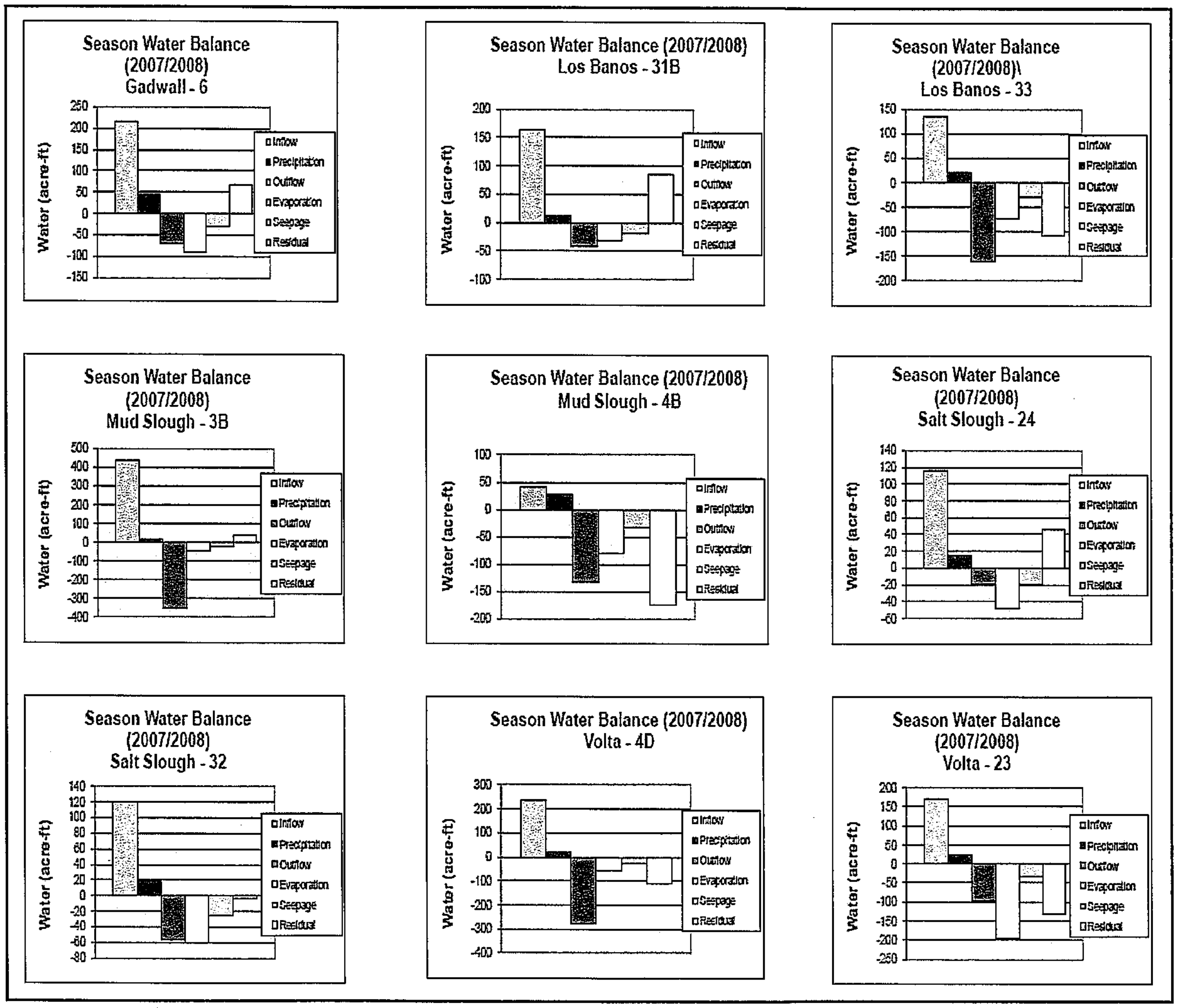


Figure 1.5. Summary water balances for all sites for the 2006/2007 flood-up season. Sensor failures at certain pond sites compromised the computation of hydrology and salinity mass balances.

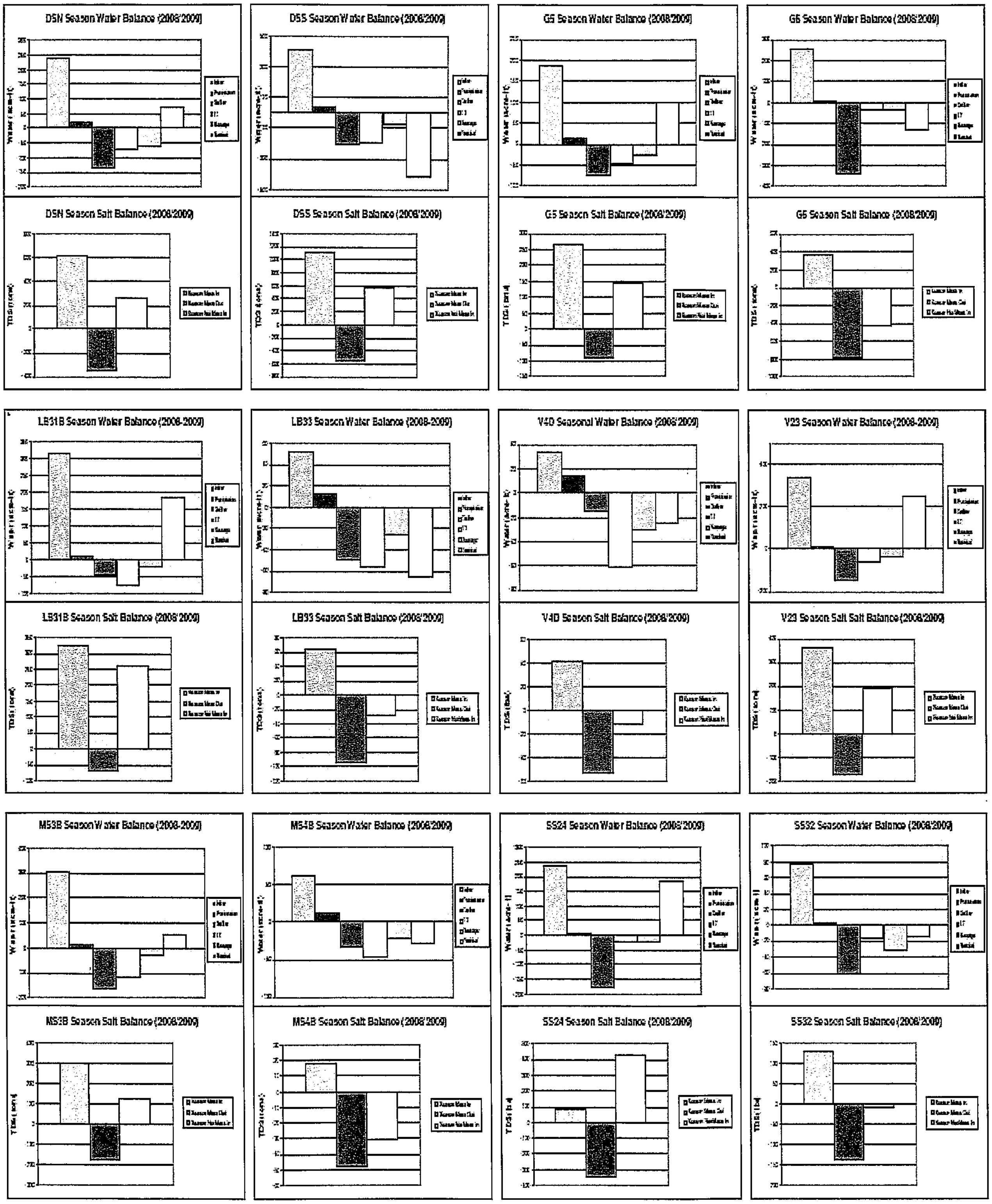


Figure 1.6 Summary water and salt balances for all sites for the 2008/2009 flood-up season. By 2007/2008 the majority of the sensor problems had been solved and the water and salt balances were completed for all sites.

export the data and the current software did not appear to be a good long-term solution for data management within the Grasslands Ecological Area. The WISKI software was acquired for the 2009-2010 data processing and all future data management tasks. WISKI is practically identical to HYDSTRA (the US version of the software also developed by Kisters Inc.) and is well integrated with database and webs services tools as well as with software used to make direct downloads of datalogger data.

The water and salinity balance plots in Figures 1.5 were derived from a subset of the data collected for the six-paired wetland sites (a total of 24 monitoring stations) – only those with complete data sets for each site pair are included. In both Figures 1.5 and 1.6 the salt balance plot is shown immediately below the water balance plot. Figure 1.6 shows both water balance and salt balance plots for all six paired sites. The monitoring equipment at two paired sites - Ducky strike North (DSN) and South (DSS) and Mud Slough ponds 3B and 4B was left in place after the end of the project in order to obtain a long-term data record of the treatment and traditional managed sites. Data downloading to YSI EcoNet and monitoring site quality assurance has been continued at each monitoring station.

Evaporation, transpiration and groundwater seepage from each pond were estimated based on local weather station data (for evapotranspiration) and shallow well elevation data (for seepage). In the modified Penman-Monteith equation (used to calculate evapotranspiration) evaporation rates were based on ambient air temperature and wind speed, whereas transpiration rates were based on plant species and extent of plant coverage (determined by remote sensing data analysis). Due to the heterogeneous nature of wetland soils and the wide distribution of plant species in any given wetland pond, accurate estimation of both direct evaporation and plant transpiration was difficult. Likewise groundwater seepage rates were difficult to determine with accuracy due to temporal variation in soil hydraulic conductivity. At the time of flood-up the clay-dominated wetland soils are highly desiccated and cracked to depths greater than 1 foot – leading to high initial seepage rates – up to one foot of water is lost to groundwater during initial flood-up. However as cracks fill and the clays absorb moisture – they swell, closing the surface and subsurface cracks – leading to a rapidly declining rate of seepage. By the time the vadose zone is fully saturated and the clay soils at saturation groundwater seepage below the ponds is negligible.

Analysis of the plots for the 2006/2007 wetland flooded season (Figure 1.5) shows significant residuals for both the water and salt balance. Error residuals are shown in yellow and, in the case of the water balance, are the result of summing water inputs - water inflow and precipitation and subtracting outputs – evaporation, transpiration, seepage and outflow. The water balance determines the salt balance – hence large water balance residuals cause proportional imbalances in the salt balance. If the water balance is perfect (i.e. inflow = outflow) then the error residual becomes zero. There are a similar number of water balance error residuals above the line as there are error residuals below the line – suggesting no systematic bias in the estimation of seepage and evapotranspiration losses. The error residuals are quite large relative to the other component factors in the case of Los Banos 4B and Volta Pond 33 for the 2006/2007 flooded season. This could be the case of errors in inflow or outflow in addition to the potential errors in seepage and evapotranspiration. The magnitude of the error residuals is significantly diminished for these two sites in 2007/2008 – suggesting that there is no inter-annual bias in the data.

In Figure 1.6, water balance and salt balances are provided for all six paired wetland pond sites – a total of twelve plots. As mentioned above - wetland salt loads appear directly beneath wetland water balance plots. The salinity balances show residuals above and below the line – suggesting that there is still insufficient control of the estimates of evapotranspiration and seepage to develop successful salt balance estimates.

1.1.7 Technical workshops and training sessions

More than a dozen water managers within the California Department of Fish and Game and Grassland Water District have been trained to date in the installation, maintenance and troubleshooting of real-time flow and water quality monitoring stations. These staff have performed weekly quality assurance and developed experience troubleshooting sensor and telemetry system failure and malfunction in the field. Field personnel typically begin each day monitoring sensor current status from the project website (Figure 12). Any sensor anomaly that is noticed from routine inspection is reported to the field personnel who can quickly respond to the problems at the site. This system has reduced monitoring site down-time and provided an almost continuous data stream for each deployed sensor. It has also improved overall data quality.

Periodic tours of the monitoring system have been given by project personnel over the past three years. The monitoring system has been suggested as an exemplar for a basin-wide real-time monitoring system to satisfy the requirements for the TMDL salinity load relaxation. The current system contains many of the features that would be contained in a basin-wide system including data sharing between different stakeholder groups – namely State and Federal Refuges and over 160 privately managed duck clubs. Salt storage options and real-time pond salt load scheduling options can be developed for individual refuges, duck clubs.

CHAPTER 2 : PROJECT SCOPE AND GOALS

2.1 Background

The Porter-Cologne Act is the principal law that governs water quality regulation in California. It applies to agricultural drainage and wetland drainage alike - both point and non-point return flows. The California Regional Water Quality Control Board (CRWQCB) regulates these discharges through the issuance of NPDES and waste discharge requirement (WDR) permits (SWRCB, 2004). The WDR permits usually specify the allowable discharge concentration or load or the resulting condition of the receiving water. After the demise of the San Joaquin Basin "Master Drain" the CRWQCB made amendments to the Basin Plan promoting a regional solution to the drainage problem, involving all contributors of salt within the Basin, to achieve compliance with water quality objectives. Resolution No. R5-2004-0108, passed by the CRWQCB on September 10, 2004, further modified the Basin Plan to address persistent non-compliance with lower San Joaquin River water quality objectives, that were not being addressed through voluntary adoption of irrigation and drainage Best Management Practices (BMP's). In this resolution the CRWQCB declared its intention to promote salinity management schemes including timed discharge releases, real-time monitoring and source control for all agricultural and wetland dischargers of salt to the River.

2.1.1 Concept of real-time water quality management

In response to deterioration conditions in the San Joaquin River during the late 1980's the California Department of Water Resources formed the San Joaquin River Management Program (SJRMP), a stakeholder group representing many of the agencies, landowners and other parties interested in improving the San Joaquin River ecosystem. One of the SJRMP's mandates was to reconcile and coordinate the various uses and competing interests along the river. The SJRMP created a number of working subcommittees – one of which was the Water Quality Subcommittee (SJRMP-WQS) which comprised active members from the Department of Water Resources, the California Regional Water Quality Control Board, Berkeley National Laboratory and the US Bureau of Reclamation. This subcommittee applied for grants, one of which supported early work on real-time water quality management in the SJR. One of the Water Quality Subcommittee's initial tasks was to develop solutions like real-time drainage management to address the occurrence of high salinity levels in the lower San Joaquin River at critical times of the year such as the onset of pre-irrigation in Delta agricultural lands.

For four years, the SJRMP-WQS made regular weekly forecasts of salt assimilative capacity in the San Joaquin River, demonstrating to San Joaquin Basin stakeholders that the concept of real-time water quality management was feasible. Although the SJRMP-WQS was unable to influence policy within either the Department of Water Resources or US Bureau of Reclamation several important conclusions were drawn by team members during this four year experiment :

1. Real-time water quality management cannot be practiced in a piece-meal fashion. There needs to be a commitment made by the federal and state water resource management agencies and by local stakeholders to basin-level continuous monitoring. This monitoring has to be telemetered and available in near real-time. A distributed data management system needs to be developed that allows simple public domain access to all basin level flow and water quality data at key monitoring locations to allow automated forecasting of water quality conditions and san Joaquin River assimilative capacity for salt.

2. To advance the concept at the Basin-scale a project would be needed that put east and west-side water users in the basin on equal footing. Until this occurred there would be little incentive for east-side water districts to coordinate operations and share data with west-side salt exporters and those interested in improving water quality management basin-wide.

3. While seeking a catalyst to stitch together east and west-side Basin stakeholders into a single water quality management coalition a project was needed that would champion the cause of real-time salinity management. This would help to promote a continuous effort to improve flow and water quality monitoring within those parts of the Basin that had received little attention in the past but were critical to a committed Basin-level water quality management strategy. Because of limited State and Federal funding for monitoring an optimal strategy would be to build stations with State and Federal dollars and then turn these stations over to trained staff within local stakeholder institutions such as local water districts.

4. An improved modeling tool was needed to replace the legacy SJRIO-2 model, that was developed over 20 years ago by the State Water Resources Control Board in support of hearings on selenium drainage issues. The model would be in the public domain, easy to run with adequate documentation and a GIS-based user interface and most importantly – it should simulate flow and water quality of the entire San Joaquin River – from Friant Dam through the Stockton Deep Water Ship Channel. This latter point is significant because the model needs to be able to simulate conditions for both upstream and downstream stakeholders and needs to consider water quality factors other than salinity.

2.1.2 Field-based impacts studies

Studies conducted initially under the SJRMP-WQS oversight and subsequently by Berkeley National Laboratory and UC Merced, have addressed the issue of pursuing a "champion" for sub-Basin real-time salinity management (as was suggested above). Unlike agriculture, seasonal wetlands cannot be sustained without salt export to the San Joaquin River. Real-time water quality management is the only option available to the Basin wetlands if these wetlands are to avoid restrictive Waste Discharge Requirements – especially during dry and critically dry years when allowable salt loading is typically curtailed. Studies have shown that modified wetland hydrology on a portion of State, Federal and private wetlands can match drainage salt loads with peak assimilative capacity in the San Joaquin River to help improve downstream water quality (Grober et al., 1995; Quinn et al., 1997; Quinn and Karkoski, 1998). The number of wetland impoundments called upon to delay drawdown or schedule drawdown earlier would depend on Basin hydrology, usually described as water year type. Dry and critically dry water years are the most limiting in terms of River assimilative capacity for salt loads and also the most restrictive for allowable agricultural and wetland salt loading.

Increased surface water supply allocations under the Central Valley Project Improvement Act (CVPIA) have created a greater need than existed previously to coordinate the release of seasonal wetland drainage with the assimilative capacity of the San Joaquin River, because of the additional salt load diverted to San Joaquin Basin wetlands. Coordinated releases will help achieve salt and boron water quality objectives and improve both downstream agricultural draws and fish habitat in the main stem of the San Joaquin River and Sacramento-San Joaquin Delta. Improved scheduling of west-side discharges can assist in avoiding conflict with critical time periods for early season irrigation as well as fish rearing and remove an important stressor leading to improvements in the San Joaquin River salmon fishery.

Preservation and enhancement of wetlands in California's Central Valley is important to ensuring wildlife and habitat diversity. The regional wetlands are home to millions of waterfowl and shorebirds, a diverse community of moist-soil vegetation, and other common and endangered wildlife (Mason, 1969; Small, 1974; Cogswell, 1977; Grassland Water District, 1986; Shuford et al., 1998; Sibley, 2000). The fall flood-up occurs during the months of September and October, and the spring drawdown during the months of February, March, and April. Wetland drawdowns are timed to make seed and invertebrate resources available during peak waterfowl and shorebird migrations and to correspond with optimal germination conditions (primarily soil moisture and temperature) for naturally occurring moist-soil plants (Smith et al., 1995). By timing flood-up and drawdown in the San Joaquin Valley, managers mimic the wet/dry seasonal cycle that these historical wetlands once experienced. This seasonal cycle aids life's processes and can be adapted to promote desired species (Frederickson, 1991).

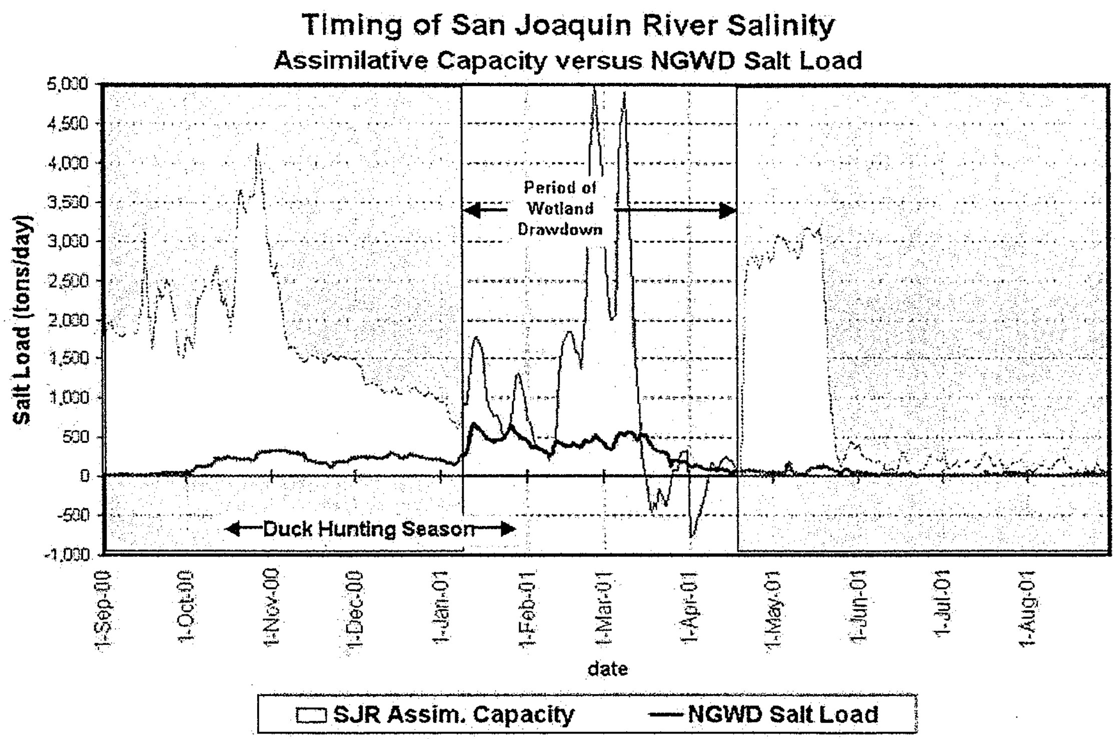


Figure 2.1 Wetland salt loads superimposed on San Joaquin River assimilative capacity showing period in late March and early April where wetland salt loads contributed to violation of San Joaquin River salinity objectives at Vernalis.

Current and ongoing research in the Grasslands Basin, undertaken by Berkeley National Laboratory and UC Merced in collaboration with the California Department of Fish and Game and Grassland Water District has focused on improving understanding of the role of water manipulation, irrigation, waterfowl habitat requirements, vegetation species diversity and waterfowl use responses to different management techniques. Altering wetland drainage schedules affects the timing and rate of drawdown of wetland ponds and hence the forage value of the wetlands for migrating and wintering shorebirds and waterfowl. However, spring drainage, timed for optimal habitat conditions occurs at a sensitive time for agriculture in the South Delta in that these drainage releases occur during the time crops are being irrigated or the first time and are germinating – potentially affecting crop yields. These studies have suggested that approximately 10% of the San Joaquin River's annual flow, and 30% of its annual salt load, passes through wetlands within the Grasslands Basin, which includes the Grassland Water District (Grober et al., 1995; Karkoski et al., 1995; Quinn et al., 1997; Quinn and Karkoski, 1998). Wetland salinity management measures also affect the productivity and diversity of vegetation that can be grown in the watershed (Rosenberg and Sillett, 1991; Mushet et al., 1992).

2.1.3 Assimilative capacity forecasting and decision support models

Although there have been significant advances in continuous telemetered monitoring in the Basin and in the infrastructure that allows west-side agriculture to manage salinity exports to the River there has not been equivalent improvement in the simulation and decision support models needed to forecast San Joaquin river assimilative capacity. A more interactive, graphics-based decision support tool was needed, easily usable by Basin stakeholders to be able to simulate the impacts of improved coordination of east-side reservoir releases and west-side to improve compliance with River water quality objectives. The San Joaquin River Restoration Program and the San Joaquin River Dissolved Oxygen TMDL have offered unique opportunities to develop a "next generation" simulation model of the entire San Joaquin River from Friant Dam through the Stockton Deep Water Ship Channel that could be used to operate the Basin for water quality. The typical institutional constraints to data sharing, that are common in all stakeholder-led monitoring efforts can partially relaxed through the use of comprehensive simulation models and Basin-wide decision support tools. The WARMF-SJR model is an outgrowth of these recent research and planning efforts. The current WARMF-SJR model simulates flow and water quality model using the principles of mass balance and simple flow routing and takes account of all the tributary and drainage inflows, pump diversions and groundwater accretions and losses from the River every ½ mile along the 70 mile reach between Lander Avenue and Mossdale. The extended WARMF-SJR model will incorporate reaches of the River above Lander Avenue to Friant Dam.

Forecasting of San Joaquin River flow and salinity was initiated under first Reclamation and later CALFED grant funding using the San Joaquin Input-Output Model (SJRIO-II and an interactive graphical user interface that allowed simulation runs to be easily interpreted by model users and stakeholders (Quinn et al., 1997; Quinn and Karkoski, 1998). Ongoing work within the US Bureau of Reclamation and Systech Engineering is directed further developing the WARMF model's forecasting capabilities and developing information technologies to facilitate the communication of forecast results.

2.1.4 Project location

The project area includes approximately 90 miles of wetland channels and is bounded by the Main Canal and Delta Mendota Canal to the west and the San Luis Drain to the east. The two US Bureau of Reclamation water contractors are involved in the study are (a) the Grassland Water District, which serves water to 160 individual duck clubs and land and cattle operations institutions; and (b) the State Wildlife Management Area operated by the California Department of Fish and Game. Wetland sites were sites within the Los Banos, Mud Slough, Gadwall, Salt Slough and Volta Units of the Los Banos Wildlife Management Area Complex.

The Grassland Water District contains approximately 43,000 acres of flooded wetlands within its boundary situated both north and south of the city of Los Banos. Wetland drainage from the Grassland Water District is conveyed to the San Joaquin River through either Mud Slough (north) or Salt Slough. Water deliveries to the Grassland Water District are primarily made through the Agatha and Camp 13 Canals which divert from the Main Canal in the southern division of the GWD. The northern division of the GWD obtains supply from the San Luis Canal, which diverts from the Main Canal; the Santa Fe Canal, which routes south GWD supply into the northern Division; and the Volta Wasteway, which diverts directly from the Delta Mendota Canal, and provides water supply to the western sector of the northern Division of the GWD.

The State Los Banos Wildlife Management Area Complex is split into separate management units, each with its own management objectives. The Los Banos WMA, which is located north of Los Banos is the largest of the management units, and has an area of approximately 3,000 acres. Project deliveries to this wetland unit is from the Santa Fe Canal and San Luis Canal. The Mud Slough, Gadwall and Salt Slough Units range in size from 500 acres to 1100 acres and obtain their water supply from the same sources. The Volta WMA is located on the western margins of the Grasslands Ecological Area and contains approximately 2200 acres of flooded wetlands. The Volta WMA is served by diversions from the Volta Wasteway.

Given the various delivery points within the Basin for wetland water supply - it was important in the design of this project to monitor both influent water supply and wetland drainage. In general, the further south the diversion point along the Delta Mendota Canal – the poorer water quality becomes. This is explained by pump-ins along the Delta Mendota Canal alignment – where groundwater is pumped from large interceptor drains, designed to relieve high groundwater conditions caused by the invert of the Delta Mendota Canal. The Delta Mendota Canal acts like a dam to the regional groundwater flow system – the interceptor drains allow farmers to continue to grow crops in the formerly inundated areas. Water that arrives at the Mendota Pool and is diverted back north into the Main Canal or any of the CCID distribution canals is typically of poorer quality, except during high rainfall years when flood flows from the Kings River or the middle San Joaquin River reach the pool and help to dilute the Mendota Pool Supply. Since Sierra-derived water often has an EC of 50 ppm or less – the effects of this dilution can be significant.

2.1.5 Project Linkage

This project takes advantage of the experience gained in developing real-time monitoring networks in the San Luis National Wildlife Refuge and in the Grassland Water District with funding from two CALFED-sponsored water quality management projects and one State Water Resources Control Board-sponsored project. These projects provided useful background information on wetland management, allowed the development of remote sensing techniques for developing habitat inventories and provided theoretical adaptive real-time management scenarios that helped in formulating the design of the current DWR-sponsored implementation project. The project was carried out on six paired wetland study sites located in (a) the Grassland Water District; (b) the State Wildlife Management Areas (Los Banos, Volta, Mud Slough, Salt Slough and Gadwall) all managed by the California Department of Fish and Game.

The current project has informed a number of important recent San Joaquin Basin water resource and water quality management projects. These include the San Joaquin River Restoration Project, the San Joaquin River Dissolved Oxygen TMDL Upstream Studies and Agricultural Waiver monitoring in response to the CRWQCB Salt and Boron TMDL. The US Bureau of Reclamation signed a Management Agency Agreement (MAA) in 2009 with the CRWQCB to develop a multi-agency coordinated strategy for implementation of Real-Time Water Quality Management. The wetland entities, which comprise 140,000 acres of seasonally flooded wetland within the Basin, provide an excellent test-bed to further develop the concept. Most importantly these seasonal wetlands have no choice but to drain to the San Joaquin River if their function and productivity is to be preserved. Ponded water that is allowed to evaporate would quickly poison the soils with alkali and effloresced salts – this would very quickly reduce the germination of moist soil plants such as swamp timothy, smartweed and watergrass and reduce the area's value as an overwintering refuge for migratory water fowl. It would also severely impact the local economy, especially in the City of Los Banos, which gains significantly from duck hunters and outdoor enthusiasts many of whom live outside Merced County.

CHAPTER 3 : DATA ACQUISITION AND PROCESSING

3.1 Project Monitoring and Data Quality Assurance Project Plan

A comprehensive project quality assurance project plan (QAPP) was developed for the project according to Surface water Ambient Monitoring Program (SWAMP) requirements and accepted scientific practices. The Quality Assurance protocol for continuous data was based on the protocol adopted for the Grasslands Bypass Project and the Grassland Water District Agricultural Waiver monitoring program. The project has improved upon these protocols by utilizing real-time data served in continuous fashion (every 15 minutes) through a commercial website (NIVIS Data Center). This has allowed more frequent checks to be made of sensor performance at each of the 24 stations and rapid response to problems identified by inspection of the data. Given the highly variable flow conditions at these wetland monitoring stations and the high susceptibility for fouling by algae, sediment or biota – this has helped to reduce station "down-time" and resulted in much improved data quality than has been possible in the past. Appendix A describes some of the unique features of the Quality Assurance Program as well as some of challenges faced in program implementation. It provides a physical description of each monitoring station, describes the types of sensors deployed at each station and their manufacturer. Appendix A has been provided to CDFG, Grassland Water District and the US Bureau of Reclamation. This document has been shared with the US Fish and Wildlife Service to initiate discussion on the development of common monitoring framework for the three wetland entities – a necessary step in the development of a CRWQCB-approved real-time water quality monitoring program.

At the beginning of the project it was suggested that a review panel be formed to provide oversight of real-time monitoring activities in the GEA. For the past 18 months a Real-time Water Quality Monitoring and Management interest group has been convened by Grassland Water District with active participation by wetland managers from CDFG, USFWS, private wetland representatives wetlands, GWD staff and independent consultants.

3.2 Design and Implementation of Paired Monitoring Experiment

3.2.1 Experimental design

The initial project design envisaged the use of solar-powered auto-samplers equipped with continuously monitoring water EC, temperature, depth (stage) and flow velocity at each of the project sites. Autosamplers had been used with some measure of success in the Salinas Duck Club during the first CALFED sponsored real-time water quality management project. In the previous project (Quinn and Hanna, 2003) the auto-samplers were housed beneath simple wooden shelters, to be inconspicuous to duck club members, and were powered by 10 Watt solar panels fixed to the shelter roof. Analysis of the data produced by the monitoring stations showed that the acoustic Doppler technology chosen (American Sigma/HACH) was not of sufficient sensitivity to produce good flow estimates – acoustic Doppler technology has improved significantly in the intervening five years for the current monitoring network design. ISCO Inc. had recently developed a CDMA mobile phone telemetry system which worked with the auto-samplers and which would have allowed real-time data access to each station. The company had designed a data console that allowed a HydroLab EC and temperature sonde and HACH acoustic Doppler and pressure sensor to be plugged into the unit and the data from these instruments logged by an on-board data-logger. The major disadvantages to this system were the vulnerability of the auto-samplers to vandalism and the high cost of telemetry – since this design would have required a cell phone account for each monitoring station.

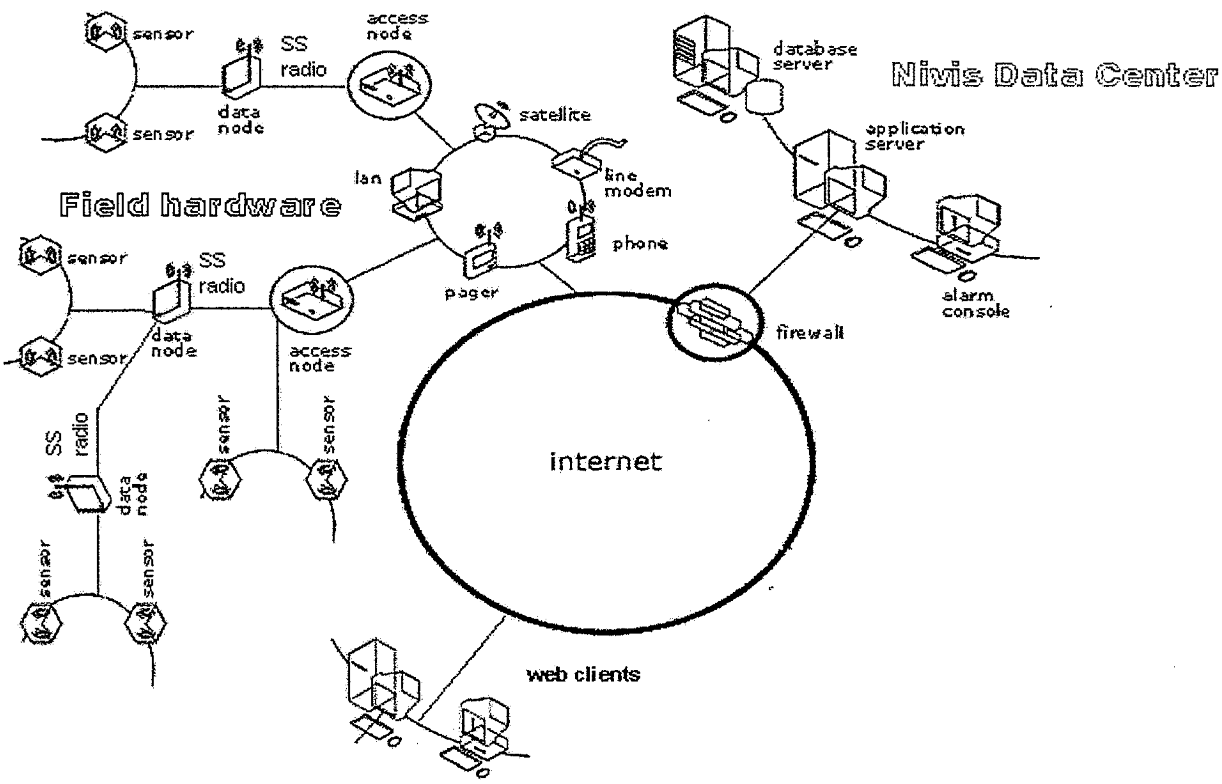


Figure 3.1 Sensor network architecture using YSI-EcoNet. Sensors are connected to dataloggers at either data node (RF telemetry) or Access Node (CDMA telemetry) sites. All data is reported to the NIVIS data server which polls each station at 15 minute intervals. The NIVIS server allows users to customize graphical data output from the monitoring stations.

Two months before the purchase orders were finalized for acquisition of ISCO auto-samplers - YSI (Yellow Springs International) Inc. sent a sales and technical representative to California to meet with the Principal Investigator. YSI Inc. had just announced the development of a networked environmental monitoring system known as YSI EcoNet which combined cellular and radio telemetry and a paid subscription to an automated data retrieval and web posting service. The EcoNet system architecture offered significant long-term cost savings over the initial monitoring design. The system uses radio telemetry to transmit data between individual "data" nodes within the monitoring network (provided they are within line of sight), one or more of which communicate with a single "access" node which transmits to a data warehouse (NIVIS Data Center). Current networking software allows "data" nodes to "daisy-chain" with each other, allowing more extensive networks to be realized than in the past where every "data" node needed to be in close proximity to a central "access" node for radio telemetry to be reliable. EcoNet incurs a cost of between $250 and $400 per year per "data" node (depending on the scale of the monitoring system and number of stations supported) and between $2,000 and $4,000 per year per access node. This provides continuous access to all stations, the data from which is downloaded and parsed to the website every 15 minutes, provided all networked stations are reporting properly.

The project website configuration on the NIVIS Data Center server can be customized from within EcoNet, using an object oriented user interface to select the sensor data that will display on either the private or the public website. The private website is password protected and typically would include sensitive data or data that might be misinterpreted if it were to appear on the publicly accessible site. This could also apply to sensor data from troublesome sites that might be temporarily removed from public display. The public site is viewable by anyone with the project website url : http://www.ysieconet.com/public/WebUI/Default.aspx?hidCustomerID=99.
For project data QA purposes, current station data posted to the private website is reviewed several times per week to check for sensor drift, unusual data values or sensor malfunctions. This allows problems to be resolved quickly with minimum loss of data.

The public website has proved to be a very powerful tool for educating stakeholders about the potential benefits of real-time monitoring and the importance of real-time access to site data for providing data quality assurance. The need for real-time data access continues to controversial within the Grasslands Ecological Area with the attendant fear by other agencies that real-time monitoring will automatically lead to a push for real-time water quality management of wetlands with a potential loss of autonomy of wetland drainage management decisions. The field experience of project team members over the past three years is has led to an insistence that real-time data be provided for site quality assurance - it helps to minimize data loss and provides a quantitative learning environment for wetland water managers, who may not have known how water quality changes during the season. Real-time data is also critical for making day-to-day water management decisions that previously were not constrained by drainage water quality.

3.2.2 Seasonal wetland pond selection

The original project design called for eight project sites – four of which would be managed using traditional drawdown practices and the other four would be drawn down at a later date to coincide with a period of high San Joaquin river assimilative capacity. It was decided to pair the traditional and modified hydrology sites, recognizing that no two sites are likely to be identical in size, soil characteristics, drainage, bird use and moist soil vegetation. Adjacent wetland field sites were considered to be ideal since these would be the most likely to receive similar supply water quality and are likely to share some of the same soil morphology, drainage and chemical characteristics. An opportunity arose, through the Department of Fish and Game, which was supporting related research at UC Davis and the Los Banos Wildlife Management Area to expand the scope of the original study with the addition of wetland biological data. The biological data directly complements the soil and water quality data by providing potential causal linkage between these data, habitat quality and bird wetland use. However, in conjoining the studies, it became apparent to the wetland biologists that six-paired sites rather than four were needed to discriminate between irrigated and non-irrigated seasonal wetlands and the traditional and modified hydrology drainage sites. This experimental design requirement necessitated expanding the monitoring program by 50% and a need for additional funds to pay for an addition of two paired-sites sites. Since each seasonal wetland has an inlet and an outlet – this would require four additional full monitoring stations. The US Bureau of Reclamation was approached by the project Principal Investigators and provided $100,000 in project cost-share funding with which the additional monitoring equipment was purchased.

The initial project goal was to distribute the experimental wetland sites across private, state and federal lands. However the US Fish and Wildlife Service and the Salinas Duck Club, where preliminary research had been conducted, were reluctant to participate on the grounds that it would compromise optimal wetland management on the ponds that experienced delayed drawdown. Other duck clubs were approached with similar result. The Duck Club managers, though eager to help, could not afford to work against the interests of their client wetland owners, whose primary interest is in good hunting success. The Ducky Strike Duck Club, was persuaded to cooperate, largely on account of the close relationship between the Club Water Master and the Grassland Water District. The Ducky Strike Water Master has also been a supporter and proponent of the concept of real-time water quality management – improving the timing of salt loading to the River to make better use of River assimilative capacity.

Twelve sites (six wetlands pairs) were selected for the adaptive drainage drawdown experiment within State and private wetlands that are part of the Grasslands Ecological Area. The State wetland management units chosen were within the Los Banos, Gadwall, Mud Slough, Salt Slough and Volta Wildlife Management Areas; the private wetland chosen was the Ducky Strike Duck Club. All but one wetland pair were adjacent wetland impoundments and were of similar size and shape. The water delivery systems are common for each of the stations and all of the wetlands discharge into a common drainage conveyance during drawdown, except for the Volta experimental where wetland sites which are located either side of the Volta Wasteway. In the case of Volta - drainage return flows eventually combine upstream of the Mud Slough Gun Club Road monitoring station. Given that it is impossible to exactly replicate conditions within a single wetland the study team agreed that this approach produced the best outcome.

Each paired site consists of a control site, which represents typical management practices for the particular wetland impoundment, and a treatment (intervention) site on which wetland drainage is delayed until the Vernalis Adapative Management Program (VAMP) flow release begins. The VAMP flows typically commence on April 15 each year and are continued until May 15, and are designed to improve escapement of salmonids to the ocean to continue their life cycle. Since VAMP fish flow releases are programmatic and are set according to a formula that considers water year type and current flow conditions leading up to the VAMP flow release. The flows create significant salt assimilative capacity in the River and provide a safe window of opportunity for discharge of wetland drainage.

In this study the "treatment wetland " has continued as the wetland subjected to delayed drawdown for the past two years – in the final year of the study, which will end in June of 2009, the fall flood-up and drawdown sequence will be the third. Moist soil plant change assessment using remote sensing, soil salinity mapping using an electromagnetic bulk salinity sensor and biological assessments to assess waterfowl use and forage availability are being conducted each year, post-drawdown, to develop quantitative measures of both short and long-term impacts of wetland salinity management using a modified wetland hydrology.

3.2.3 Installation of Monitoring Sites

Inlet and outlet monitoring stations were installed at each of the twelve wetland sites chosen for this implementation study. A more detailed description of the installation procedures and monitoring site images are provided in Appendix A. The EcoNet data acquisition, telemetry and data reporting system is also described in Appendix A as well as a detailed account of some of the technical issues encountered in deploying this system and the systems integration with YSI and MACE sensors.

The wetland experimental sites are especially challenging on account of the great range of flow encountered. There are periodic episodes of high flow through the inlet and outlet structures – however most of the time flows over the outlet weirs are of the order of 1 cfs or lower. A sensor that can measure high rates of flow is often too insensitive at the low flow range. The MACE acoustic Doppler sensors have proved capable of an accuracy of less than 1/10th cfs and have also shown to be capable of measuring the high flows associated with initial flood-up and the first discharges during drainage drawdown. Most of the problems we encountered with the MACE AgriFlo (series II) units, and more recently their MACE FloPro (series III) units were related to the integrated acoustic and pressure sensors themselves. The first problems were related to poorly sealed sensors, the bonding used to seal the electronics into the epoxy body was not properly cured, leading to leakage. The sensitive electronics in the sensor body corrodes on contact with water. The pressure sensor needs to be properly vented to read accurately. Other problems related to the vent tube, which was easily kinked, thus compromising the air exchange between the atmosphere and the sensor. It took well over 12 months to resolve all these technical issues with a result that the 2006 flow data was not complete at all sites.

A second flow-related problem that was identified during the 2006/2007 season was related to record keeping of weir board addition and removal and weir board elevation. The initial design of the flow monitoring system called for acoustic velocity sensors to be use at all inlets where screw gates prevented the use of weir boards to measure flow. During the 2006/2007 wetland flooded season flow at all of the pond outlets was measured using stage over modified "V" notch weirs which replaced the wooden riser boards at each outlet weir structure. Although this system provided much improved accuracy compared to the measurement of flow over rectangular boards at the outlet weir structures – the development of a robust field data protocol proved challenging. Ditch tenders would forget to note the position of the boards in the outlet riser after making adjustments to the flow – resulting in a significant amount of data uncertainty. Ditch tenders also disliked the "V" notch weirs since they had already developed a schema for pond operation based on the numbers of whole or half boards in the outlet weir structures and were forced to recalibrate. Communicating the correct procedures to all staff with responsibility for making pond water elevation adjustments proved difficult resulting in incomplete records. In addition the process of analyzing the records to arrive at the correct coefficients for calculating the flow proved very time consuming and tedious. The experience gained during the 2006 drawdown suggested upgrading of all of the drainage outlet monitoring stations by installing the same MACE Doppler acoustic technology as had been installed at the inlet sites. By the time the new equipment was ordered MACE Inc was shipping their new MACE Series III FloPro units that offered some design improvements on the AgriFlo system – however the firmware on these new units displayed only flow and total flow – not the four parameters (velocity, stage, flow and total flow) that the older units were capable of displaying. Real-time stage data is of great utility in making quality assurance checks of flow. At the drainage outlets flow can be measured both at the weir structures and within the culverts by the acoustic Doppler sensor – providing a redundant measurement that is useful as a check on flow.

Design features that were improved in the MACE Series III monitoring units include (a) a roomier box allowing the Doppler and serial communication cards to be swapped out individually and with less effort; (b) lighter weight and more room to store the desiccant tube within the box; (c) redesigned sensor cable connection inside box. A resolved design flaw with the early units for the project purpose was related to the fact that the manufacturer is based in Australia where these sensors are used to measure irrigation diversions off large canals. The acoustic Doppler sensor cable is terminated inside the box to prevent farmers from disconnecting the sensor from the internal data processor and logger – and thus causing the meter to record a lower diversion volume (both Series II and Series III units). Terminating the Doppler cable inside the box makes it difficult to protect the electronics from moisture – making desiccation of the box more critical and requiring that desiccant be changed more often.

We are trying to persuade the manufacturer to produce a fully sealed box with an external acoustic Doppler sensor connector more suitable for the California market.

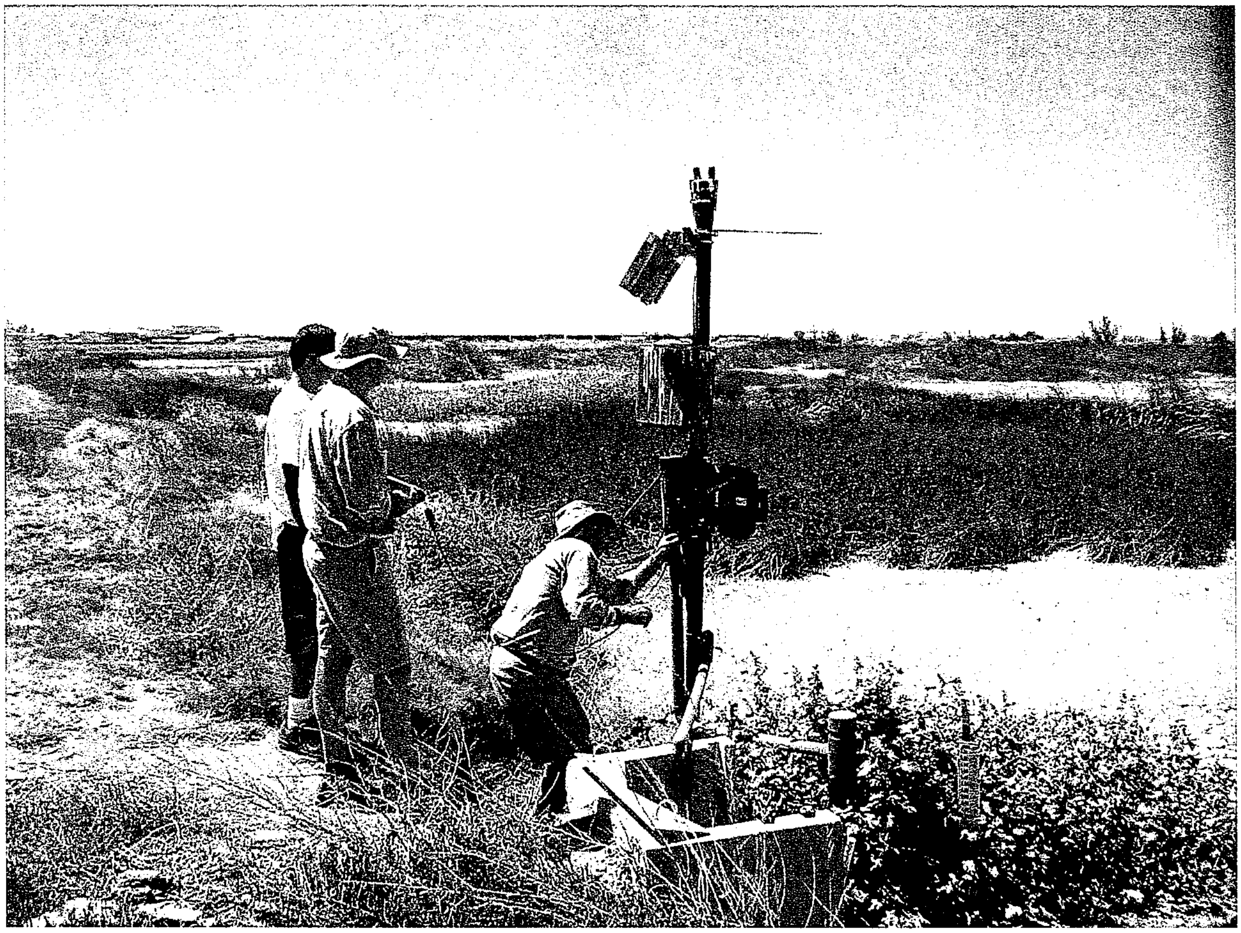


Figure 3.2. MACE USA President Mathew Campbell in the field with Tim Quinlan (sales rep), Ric Ortega (DFG) and Nigel Quinn (photographer) replacing the circuit boards in the Series III instrument boxes to restore output parameters (stage and velocity) and solve the decimal point placement issue .

3.2.4 Data acquisition and telemetry

The YSI EcoNet data acquisition and telemetry system is built into a hardware "brick" mounted inside the fiberglass enclosure, deliberately designed for easy removal. The SDI-12 connectors that carry the data signal from both the YSI EC/temperature sonde and the MACE Agriflo or FloPro units attach to a single SDI-12 input terminal on the EcoNet "brick". A terminal strip was found to be helpful to ensure a good electrical connection, especially at the Ducky Strike South pond and the Mud Slough 3B pond sites where two YSI EC/temperature sondes and two MACE Agriflo units are supported by single EcoNet monitoring site. Achieving good grounding is critical to the reliable performance of the YSI Econet telemetry system. Ensuring good contact between the radio and CDMA modem antennae screw connectors and the cable to the antennae that are mounted atop each pole was also found to be important. Each "access" node needs to be within line of sight of one or more data nodes if the telemetry system is to keep all sites up to date. Unfortunately there is no easy way to download data directly from a station that has fallen behind or which needs to be removed from the network temporarily.

Most of the problems that related to the YSI EcoNet system were failure of the CDMA modem cards. The YSI EcoNet data acquisition and telemetry system is built into a hardware "brick" mounted inside the fiberglass enclosure, deliberately designed for easy removal. A procedure was negotiated with YSI Inc. to replace problem cellular and radio modem boards (within each EcoNet "brick") rather than remove the "brick" and send it back to the east coast for service. Sending the "brick" back was costly in time and mailing expense and causes site down-time for 2 – 4 weeks at a time. A new procedure was worked out with YSI Inc. by which we were sent spare modems and replaced them ourselves as the need arose which considerably reduced the potential for loss of data. The modem re-registration was handled by technical support at YSI over the telephone. This was critical in the case of the CDMA modems since none of the data nodes or the access node was being updated during the down-time period

The data acquisition hardware, sensors and telemetry system selected for this project has proved to be a wise choice despite the problems encountered during 2005 and 2006. The US Bureau of Reclamation is currently looking to expand the current network of real-time monitoring sites within the Grasslands Ecological Area. The project team would like to see the current system used as a model for the expanded monitoring network.

3.2.5 Analysis and Reporting of Monitoring Data

The greatest benefit of the EcoNet monitoring system is that it encourages real-time access to current conditions at each of the monitoring sites, facilitates and makes more efficient data quality assurance procedures with the result that project personnel "stay on top" of the data. "Staying on top" of the data is one of the most difficult issues for most intensive environmental monitoring projects. The penalty for not staying current with the data often occurs at the time the data is analyzed – crucial missing data or a badly calibrated sensor can sometimes result in the loss of whole datasets. Cutting out the data downloading and data reduction steps and having the raw data posted on a project website has made a significant difference in time expenditure with a result that more time could be devoted to correcting problems as they arose in the field.

Data quality assurance for continuous data is not well evolved in the United States – European countries have much more evolved systems of integrated tools available to them specifically designed to support sensor networks. Figure 1 shows the functional domain architecture for a sensor network used for air monitoring and modeling, supported by the European Union. Since these applications must work across national boundaries and typically support wide bands of sensors (SANY = Sensors Anywhere) the tools that have been developed are the product of work teams across many institutions, countries and disciplines. Some of the design principles gleaned from the Lead Principal Investigators annual interaction with members of the SANY development team are being applied in the current project.

There are very few either public domain or commercially available software packages in the United States that can be readily deployed for dealing with both the flow and water quality data. Standard operating procedures for water quality have been modified from those in the Quality Assurance Plan published at the beginning of the project to adapt to water management practices and the staff resources available within Grassland Water District and the California Department of Fish and Game. Data quality assurance procedures for electrical conductivity have been made with a portable YSI 650 recorder attached to a portable YSI 600XL sonde - calibration parameter adjustments to the YSI sonde at the monitoring site are made directly if the error between QA measurement and the actual reading (after the sonde at the monitoring site has been cleaned) is greater than 5%. Continuous flow QA has proved to be more difficult. There are no standard operating procedures published that are applicable to the acoustic Doppler sensors we are using for this project. The most convenient method of performing flow data quality assurance is to use the "V" notch weir (in the case of the drainage sites) as a check of the acoustic Doppler reading in the culvert. The only way to reliably check the culvert flow rate at the inlets is with a Marsh McBurney or similar velocity sensor, that reads velocity a single point within the flowing water column. This sensor is pushed up into the culvert at approximately the 6/10ths depth of flow and an estimate of the flow depth and cross-sectional area of flow is made at the point of 45measurement. This estimate is crude and the resultant flow estimate is unlikely to be any better than +/- 5% of the true discharge. There is no easy way to make adjustments to the MACE instrument itself to correct for major differences between measured and actual discharge measurements. This is usually done in the office as part of the data quality assurance process and results in the development of a calibration factor which is applied to the measured flow to match the actual flow estimate.

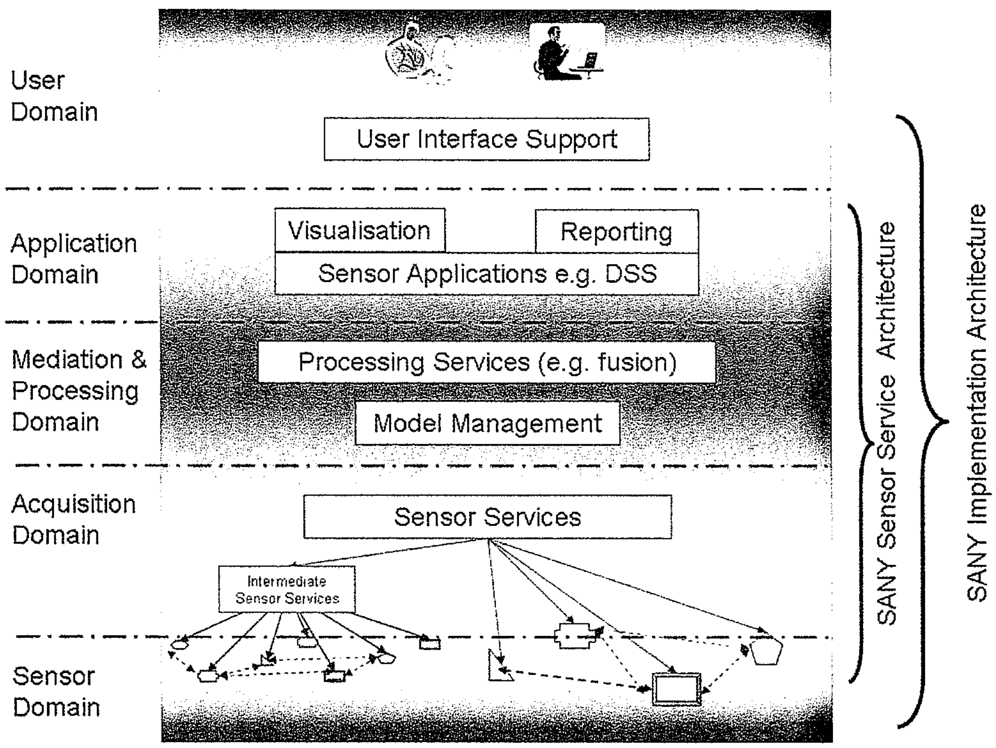


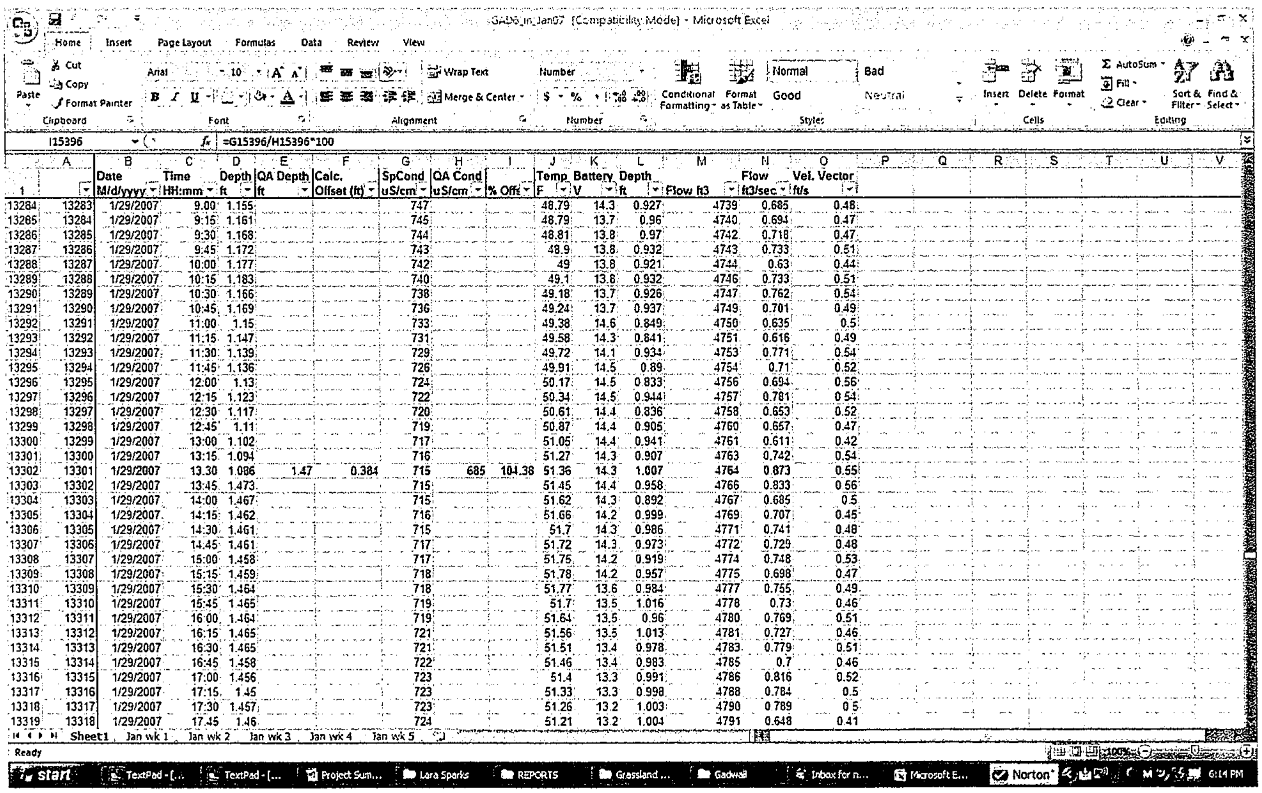
Figure 3.3. Conceptual model of the functional domains of a sensor network (Uslander, 2007)

The initial project design, during the time Berkeley National Laboratory was actively involved in the project, was to perform the data quality assurance step at the Laboratory and store the validated data on one of the Laboratory's commercial database management systems. The NIVIS database, previously described, which is accessible for raw data downloads, is not able to store the validated data. At the time of writing this report there are discussions between YSI EcoNet and NIVIS to create a mechanism for serving both the raw and validated data. This would allow YSI-EcoNet to more fully develop its potential since the project and wetland entity participants are reluctant to share potentially sensitive water quality and salt load data with the general public.

Data processing to perform data quality assurance was initially undertaken by the study team using an Excel spreadsheet format, developed by GWD/CDFG. The steps involved in this procedure have been summarized below :

1.	Log in to Private Website (www.ysieconet.com) using your Username and Password.
2.	Click on the "Reports" tab and on a report listed under "User Defined Time Range
3.	Enter a "Start Date" and "End Date" and click "Export as .csv" button.
4.	Save and label the file with site name and current date of download the file
5.	Start a new month, by saving a copy of the previous months Excel file for the site you are working on and update labels etc.
6.	Open the site's .csv file as well as its current excel file. Copy the data from the .csv file and paste it at the bottom of the rows of data under Sheet 1. If data gaps you need to insert those missing rows of data with no values in the actual data columns.
7.	QA data collected within the time frame can added that into the row of the spreadsheet corresponding to the time the QA data was taken.
8.	Update your Source Data Values on your graphs to reflect the new range of data you are graphing.
9.	Make any changes to labels as necessary, such as the date labels.

This procedure proved very time consuming and tedious. Meetings convened to go over QA data and results were held infrequently – by that time it was difficult to resolve major methodological issues. Performing QA corrections in Excel also proved to be difficult – annual Excel files for each site were over 10MB.



1		Date M/d/yyyy	Time HH:mm	Depth ft	QA Depth ft	Calc. Offset (ft)	SpCond uS/cm	QA Cond uS/cm	% Offs	Temp F	Battery V	Depth ft	Flow ft3	Flow ft3/sec	Vel. Vector ft/s
13284	13283	1/29/2007	9.00	1.155			747			48.79	14.3	0.927	4739	0.685	0.48
13285	13284	1/29/2007	9:15	1.161			745			48.79	13.7	0.96	4740	0.694	0.47
13286	13285	1/29/2007	9:30	1.168			744			48.81	13.8	0.97	4742	0.718	0.47
13287	13286	1/29/2007	9:45	1.172			743			48.9	13.8	0.932	4743	0.733	0.51
13288	13287	1/29/2007	10:00	1.177			742			49	13.8	0.921	4744	0.63	0.44
13289	13288	1/29/2007	10:15	1.183			740			49.1	13.8	0.932	4746	0.733	0.51
13290	13289	1/29/2007	10:30	1.166			738			49.18	13.7	0.926	4747	0.762	0.54
13291	13290	1/29/2007	10:45	1.169			736			49.24	13.7	0.937	4749	0.701	0.49
13292	13291	1/29/2007	11:00	1.15			733			49.38	14.6	0.849	4750	0.635	0.5
13293	13292	1/29/2007	11:15	1.147			731			49.58	14.3	0.841	4751	0.616	0.49
13294	13293	1/29/2007	11:30	1.139			729			49.72	14.1	0.934	4753	0.771	0.54
13295	13294	1/29/2007	11:45	1.136			726			49.91	14.5	0.89	4754	0.71	0.52
13296	13295	1/29/2007	12:00	1.13			724			50.17	14.5	0.833	4756	0.694	0.56
13297	13296	1/29/2007	12:15	1.123			722			50.34	14.5	0.944	4757	0.781	0.54
13298	13297	1/29/2007	12:30	1.117			720			50.61	14.4	0.836	4758	0.653	0.52
13299	13298	1/29/2007	12:45	1.11			719			50.87	14.4	0.905	4760	0.657	0.47
13300	13299	1/29/2007	13:00	1.102			717			51.05	14.4	0.941	4761	0.611	0.42
13301	13300	1/29/2007	13:15	1.094			716			51.27	14.3	0.907	4763	0.742	0.54
13302	13301	1/29/2007	13.30	1.086	1.47	0.384	715	685	104.38	51.36	14.3	1.007	4764	0.873	0.55
13303	13302	1/29/2007	13:45	1.473			715			51.45	14.4	0.958	4766	0.833	0.56
13304	13303	1/29/2007	14:00	1.467			715			51.62	14.3	0.892	4767	0.685	0.5
13305	13304	1/29/2007	14:15	1.462			716			51.66	14.2	0.999	4769	0.707	0.45
13306	13305	1/29/2007	14:30	1.461			715			51.7	14.3	0.986	4771	0.741	0.48
13307	13306	1/29/2007	14:45	1.461			717			51.72	14.3	0.973	4772	0.729	0.48
13308	13307	1/29/2007	15:00	1.458			717			51.75	14.2	0.919	4774	0.748	0.53
13309	13308	1/29/2007	15:15	1.459			718			51.78	14.2	0.957	4775	0.698	0.47
13310	13309	1/29/2007	15:30	1.464			718			51.77	13.6	0.984	4777	0.755	0.49
13311	13310	1/29/2007	15:45	1.465			719			51.7	13.5	1.016	4778	0.73	0.46
13312	13311	1/29/2007	16:00	1.464			719			51.64	13.5	0.96	4780	0.769	0.51
13313	13312	1/29/2007	16:15	1.465			721			51.56	13.5	1.013	4781	0.727	0.46
13314	13313	1/29/2007	16:30	1.465			721			51.51	13.4	0.978	4783	0.779	0.51
13315	13314	1/29/2007	16:45	1.458			722			51.46	13.4	0.983	4785	0.7	0.46
13316	13315	1/29/2007	17:00	1.456			723			51.4	13.3	0.991	4786	0.816	0.52
13317	13316	1/29/2007	17:15	1.45			723			51.33	13.3	0.998	4788	0.784	0.5
13318	13317	1/29/2007	17:30	1.457			723			51.26	13.2	1.003	4790	0.789	0.5
13319	13318	1/29/2007	17.45	1.46			724			51.21	13.2	1.004	4791	0.648	0.41

Figure 3.4 Spreadsheet used to compare time series and discrete QA water quality data as part of the data validation procedure. Plots are made of the weekly data with the QA data superimposed to aid the validation process. The procedure is time consuming and in need of automation if real-time water quality management is to be realized within the Grasslands Ecological Area.

3.2.6 Real-time data QA using Aquarius

In 2008 a software program Aquarius $_{TM}$ which has been developed by Aquatic Informatics Inc. (www.aquaticinformatics.com) was acquired which allowed easier import of EcoNet data and the ability to make graphical manipulations to the measured data based on QA datapoints – rather than the manual steps required using the Excel spreadsheet. The Aquarius data platform was specifically designed for processing time series sensor data and uses many of the MATLAB routines in the MATLAB signal processing toolbox. This software tool allowed preliminary flow and water quality data to be compared continuously with data that has passed through the project's quality assurance program – after it had been screened for errors and for consistency.

It became clear that each wetland entity would feel more secure having local control over its own data initially. Most are reluctant to share data publicly until the data has been processed and field validated. The software allowed these manipulations to be annotated within the viewing screen – allowing any future user to understand what had been performed. Initially the public was only able to view the current data at all of the project monitoring sites – public data downloads were prohibited from the public site until such time as quality assurance issues had been resolved. An associated database management system (DBMS) product was also acquired and integrated with the Aquarius data processing software to allow uploads to the NIVIS database. A distributed database system that supports automation of data downloads, real-time data processing, rule-based quality assurance analysis and graphics-based data sharing and dissemination is a necessary technical

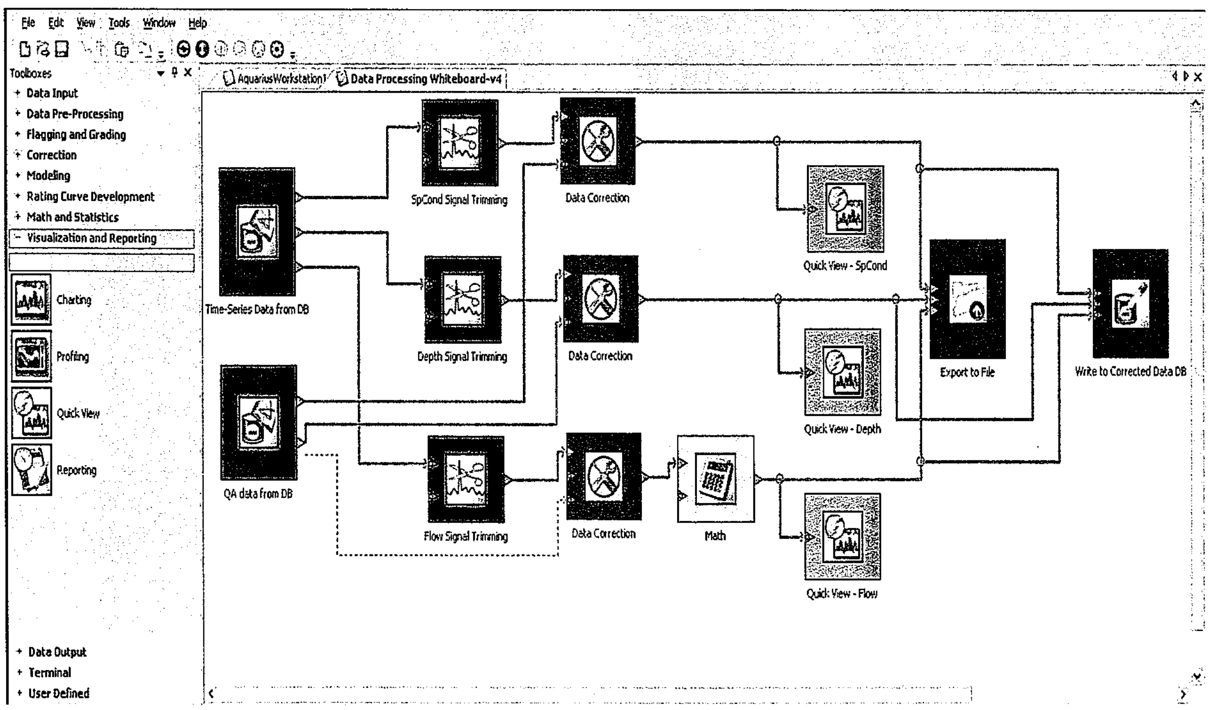


Figure 3.5. Data processing schematic in Aquarius$_{TM}$ for making corrections to electrical conductivity based on the field QA data in the Gadwall Field 6 inlet. Time series data for the sonde (top object) is compared with the discrete QA data (bottom object) and the two plots combined in the output.

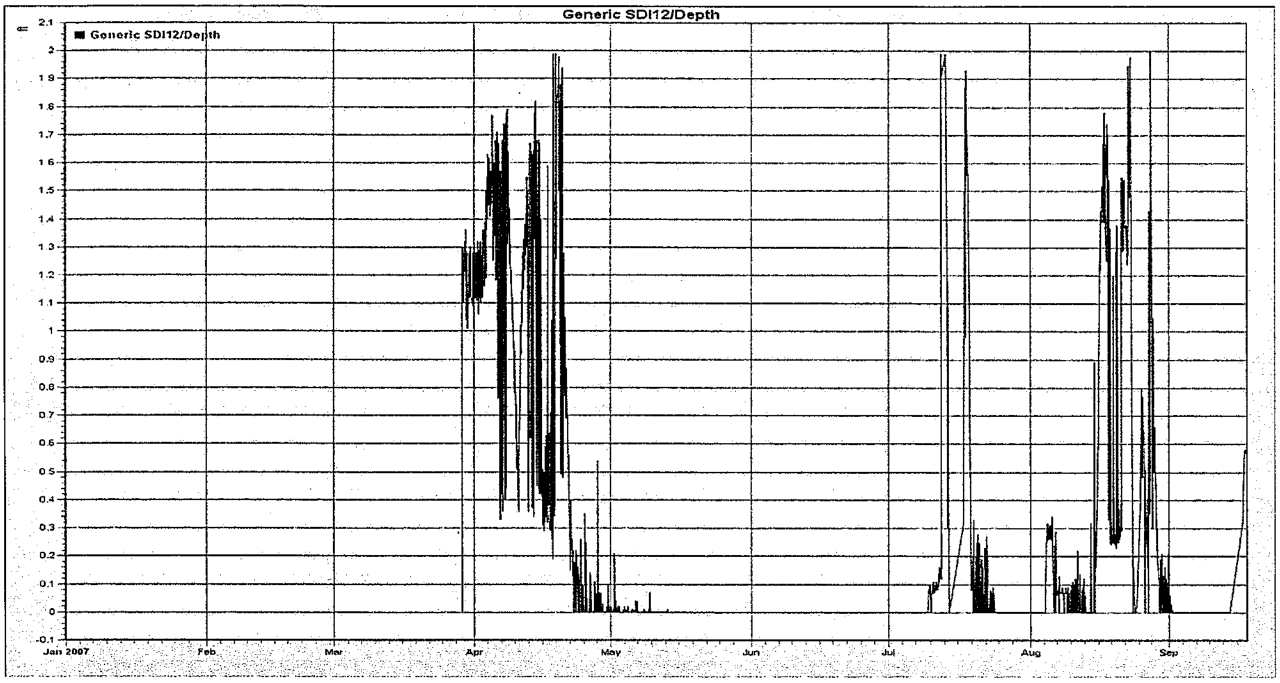


Figure 3.6. YSI sensor time series depth readings at Ducky Strike South. Smoothing algorithms in Aquarius were applied to reduce some of the noise in the data. YSI sondes are unvented and can be affected by changes in atmospheric pressure. Barometric data for the watershed used to make corrections to the YSI stage data to account for weather related shifts in barometric pressure.

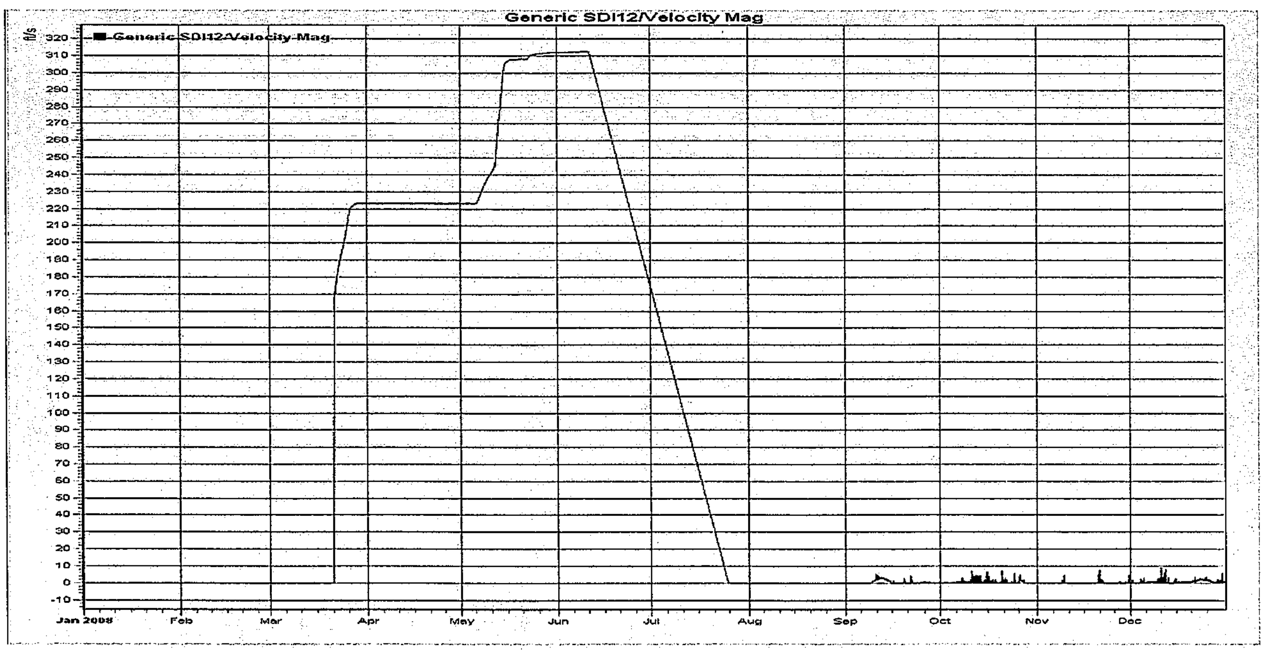


Figure 3.7. MACE velocity data for 2008 after spring drawdown in late March. High velocity data is an artifact of high temperatures combined with the loss of water head above the acoustic sensor. In early September the introduction of flow produces velocity values between 0 and 10 ft/sec.

requirement if real-time water quality management is to be fully implemented both within the Grasslands Ecological Area and eventually at the Basin-level.

The Aquarius software was used to review the 2007/2008 and 2008/2009 project data for consistency with the discrete QA data records. Aquarius has allowed the time series data to be scaled interactively - which allows the maximum and minimum data values to be viewed for the period of record and also short duration trends in the data to be observed that might be indicative of sensor failure, sensor loss of contact with water or sensor fouling. The software provides algorithms for interpolation, data shifts and trend analysis. In some circumstances corrections were most effectively made by hand – especially where analysis of data from other sensors confirmed the occurrence of an unusual event. For example an erratic velocity trace – when combined with stage data - might show insufficient head over the MACE acoustic Doppler sensor to produce a reasonable reading. As previously noted – the software visualization capability of Aquarius has significantly reduced the time required to organize, review and error correct the time series data.

3.2.6 Data QA processing within WISKI

Although Aquarius proved an excellent choice for the project - the desire for more integration between data acquisition tools, data storage, processing and visualization tools as well as a desire to emulate the software being used by more advanced water districts and water agencies within the watershed – led to experimentation with two hydrological data management systems – first, the Hydrologic Information System (HIS) developed for Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI); and second the KISTERS WISKI Hydrologic Data Management System.

The first distributed monitoring database design tested and implemented for the Grassland Water District real-time monitoring project was the CUAHSI-HIS software platform developed by Professor David Maidment at the University of Texas. CUAHSI is an umbrella organization which supports the HIS (Hydrologic Information System) platform – a suite of public domain hydrologic data management tools to download, store and access continuous hydrologic data. The platform includes the standardised WaterML format for hydrologic data transfer. This format is easily readable by computers and easily transmitted over the internet, enabling data providers to access others' hydrologic data efficiently. The HIS developed for the Grassland Water District contains the ODM (Observations Data Model) which is a database model compatible with Microsoft SQL Server 2003. The database produced was used for storage of all project-related hydrologic information for 2007/ 2008 for the wetland ponds associated with the State Water Resources Control Board-sponsored real-time salinity management project. Data was collected at the six paired monitoring sites and read into CUAHSI-HIS database system for the Los Banos Wildlife Management Area Complex (including Volta, Mud Slough, Gadwall, Los Banos and Salt Slough Units) and at the Ducky Strike Duck Club within Grassland Water District. The Grassland Water District webaccess site was registered within CUAHSI – which allowed public access to the real-time data. The ODM data loader is a tool developed to load YSI EcoNet data into the ODM Database from CSV (comma separated values) files exported from YSI EcoNet. These data were used to develop the WaterOneFlow web services application – which is a group of files located on a local server accessible by the internet. WaterOneFlow was installed on the stand-alone server cuahsi.lbl.gov located at Berkeley National Laboratory. When these files are read by a browser, the cuahsi.lbl.gov server requests data from the ODM database and provides them in a browser-readable format.

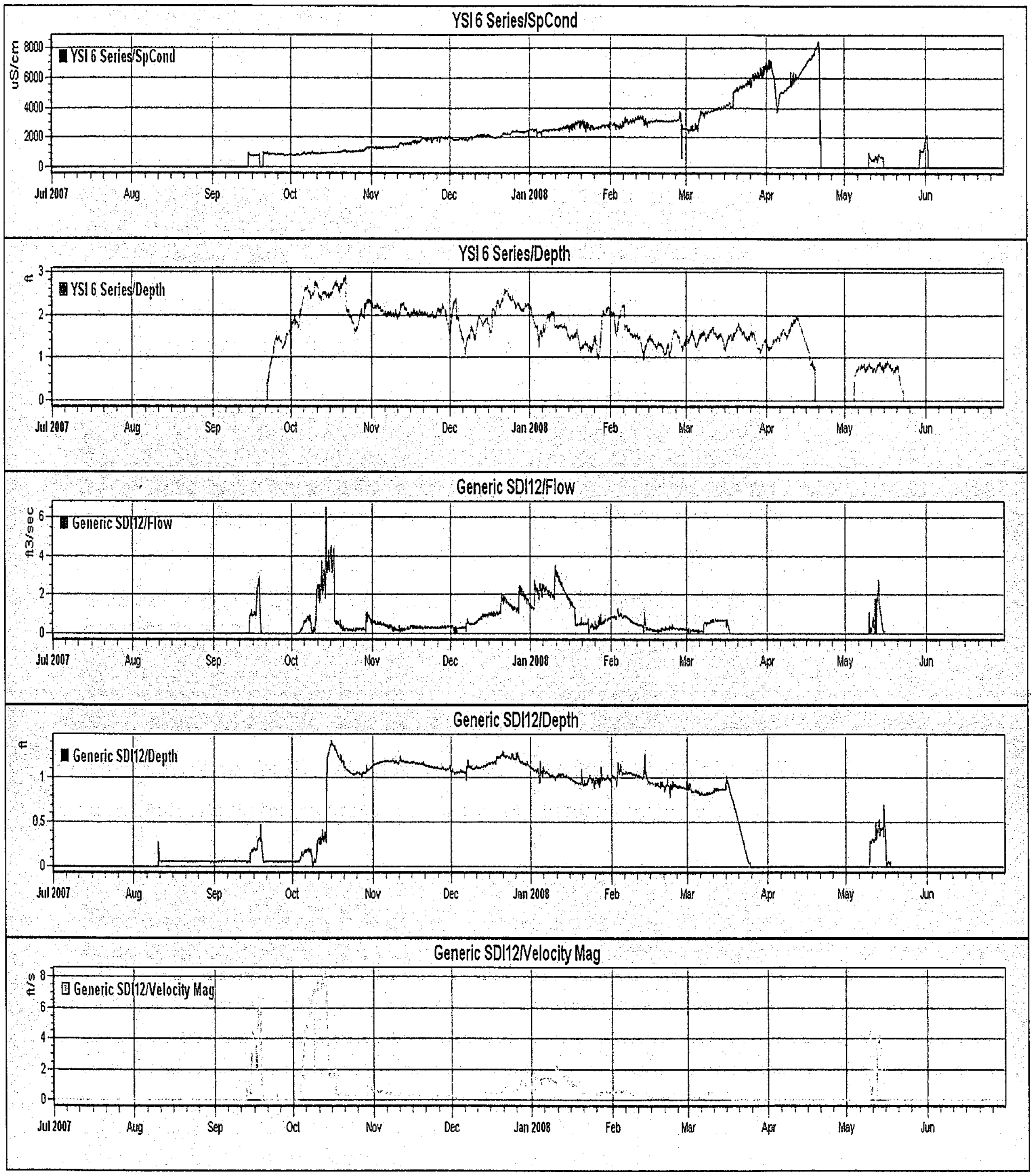


Figure 3.8. Example of the Aquarius data plots used in the data review sessions involving Grassland Water District, Berkeley National Laboratory and California Department of Fish and Game employees. Having multiple sensor values shown on a single plot helps to troubleshoot sensor problems.

Aquarius allows the horizontal data scale to be expanded so the viewer can "zoom in" to periods where data is problematic.

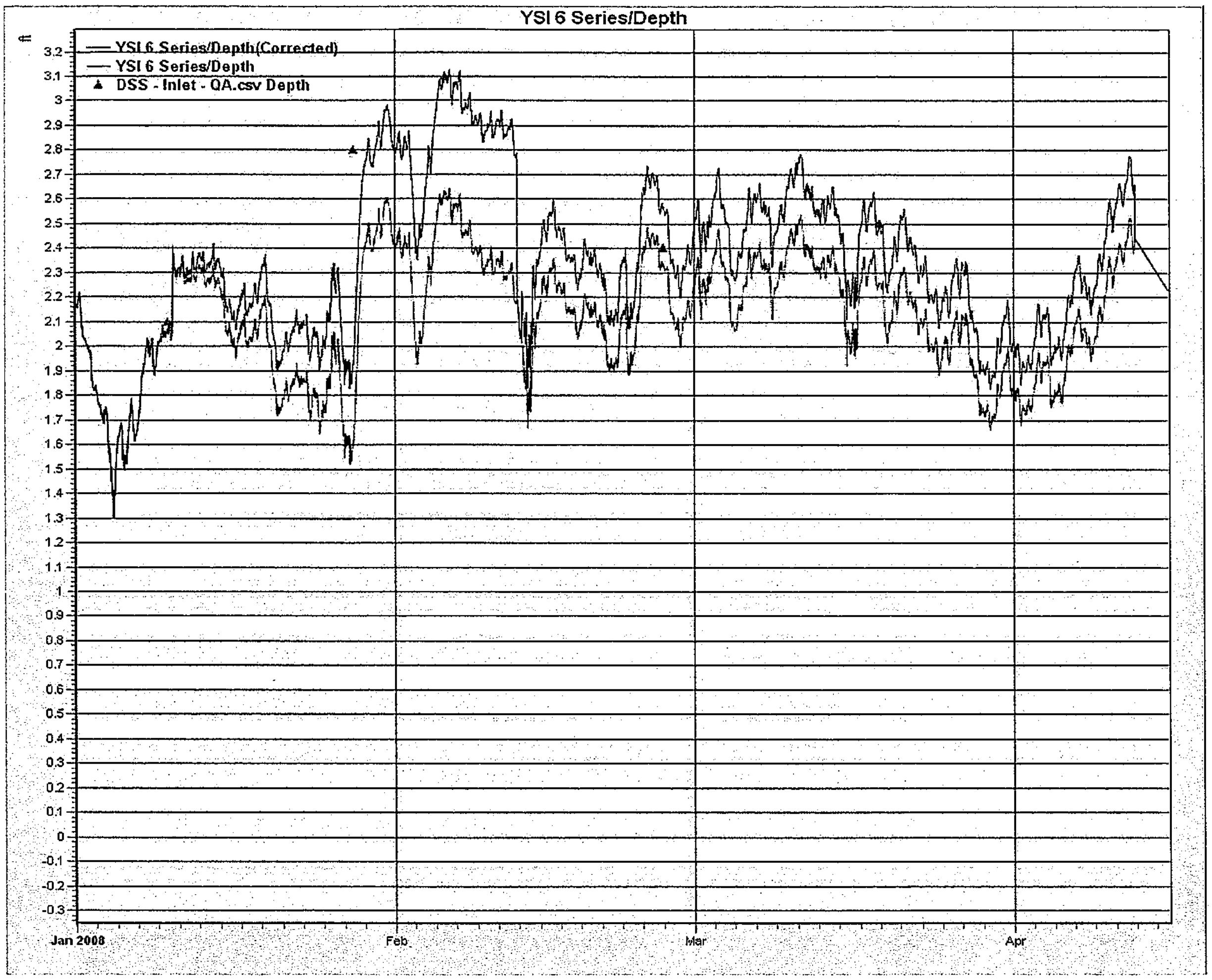


Figure 3.9. Aquarius allows the raw data to be plotted with the corrected data after QA analysis. The software also allows the data manipulations to be annotated and associated with the data trace. Plot is for YSI sensor depth at the Ducky Strike South pond.

The advantages of this system were that it resided in the public domain and was free of charge. In addition the system tools are frequently updated and improved and there is a substantial user community around the US that utilizes the system – though the system was primarily designed to serve the academic community. Training in the CUAHSI-HIS basic system was offered through the University of Texas. The downside of this system was the lack of local technical support and the lack of integration with data quality assurance tools to screen the station data and perform automated data correction. CUAHSI-HIS is an excellent concept but the lack of application - even on University campuses such as UC Merced which serve as CUAHSI-HIS hubs – suggested that the system would not be a good candidate for long-term application in the Grassland Water District and the Federal and State refuges. The ideal hydrologic data management system should have advocates and customers in local water districts and water management agencies to be viable over the long term.

The database module for the hydrologic data management system "Aquarius" - developed by Aquatic Informatics of Vancouver, Canada – was implemented during 2010 for processing of real-time flow and salinity data from the twelve pond monitoring locations on the Los Banos Wildlife Management Area complex and on the Ducky Strike Duck Club. Aquarius is an object-oriented signal processing toolbox developed using the MATLAB development toolbox. Users of the software develop workflows for the sensors at each monitoring location – these workflow architectures are developed on a project "white-board" which allows them to be saved for batch processing of data after a subsequent monitoring site download. Once the output data stream from each sensor has been characterized and recognized by Aquarius the data processing steps can be automated. Discrete data quality assurance (QA) checks performed in the field and recorded in a separate QA data file can be plotted on the time series plot of the raw data. Algorithms can be chosen within the Aquarius signal processing and trimming toolboxes to condition the raw time-series data to fit the discrete quality assurance data. Separate data processing is performed for the flow and electrical conductivity data. One of the important attributes of the Aquarius software is that the original raw time series data streams are never erased – the processed and error-corrected data can be superimposed directly on the raw data plots. A narrative of data processing steps can be annotated directly on the time-series graphs for each sensor parameter to guide later users of the data and data analysts on the attempts undertaken to improve data accuracy.

A separate database module was purchased and installed which allowed data migration between database and data processing software. The Aquarius platform and Aquarius database module each cost about $6,000 with annual maintenance fees of approximately 20% of the initial software cost. Although this cost was justified in the previous application owing to the significant time saving and ease of use over Excel spreadsheets – this high initial cost and maintenance cost may not be affordable given the need for additional software to download data from data collection platforms and to web post data after data QA has been accomplished.

The KISTERS WISKI hydrological data management system has been investigated for the current application since mid – 2010. WISKI is currently used by a number of California water districts and water agencies including the Merced and Turlock Irrigation Districts and the California Department of Water Resources. A variant of the WISKI software (originally a separate company that was acquired by KISTERS Inc.) marketed under the name HYDSTRA is still used by water agencies in California, including the California Department of Water Resources. KISTERS Inc. has been migrating many of these installations to the new WISKI software platform. A number of meetings were arranged with KISTERS staff at their Regional office in Citrus Heights California to receive initial training using the software. A meeting was organized in Merced Irrigation District to obtain direct feedback from a current user of the software.

The WISKI software was loaded onto the cuahsi.lbl.gov server in mid 2010 and data has been migrated from the NIVIS server to WISKI for the past year. Initial data migration involved setting up custom templates for each site since the sensor and parameter list is not always consistent between sites. In addition there has been movement of telemetry equipment since the end of the SWRCB-funded real-time salinity management project – requiring careful matching of time-series data.

The WISKI software meets the specifications of an affordable distributed database that is well integrated with data acquisition and information dissemination. Although not in the public domain like CUAHSI-HIS – the fact that use of the software is widespread and technical support is readily available locally – will create significant cost savings over time. Reclamation's obligation to support basin-level real-time water quality management is made easier when local entities manage and control their own databases and have common tools for sharing the data between stakeholders, resource agencies and regulatory agencies.

3.3 Wetland pond stage-surface area and stage-volume relationships

3.2.1 GIS-based wetland pond stage-surface area and stage-volume relationships

In order to develop accurate evapotranspiration estimates the effective surface area of the pond needs to be determined over time during the critical flood-up and drawdown periods. When ponds are filled to capacity – the wetland footprint is typically less than the total surface area of the pond due to islands within the pond and areas of upland that intersect the impounded area. Failure to recognize the changing wetland footprint can lead to over-estimation of wetland evapotranspiration.

Each of the wetlands that were included in the project had YSI 650XL sondes installed at the pond outlets. These sondes have pressure transducers that provided water level elevations within each pond. The sonde depth measurement was calibrated to the staff gauge elevation in each pond. The staff gauges were installed so that the zero reading on the staff gauge corresponded with the concrete lip of each culvert. This was almost always the low point of each pond.

During 2007 the California Waterfowl Association helped to fund detailed motorized GPS surveys of each of the ponds included in the study. These were performed by an ATV that was equipped with Trimble GPS surveyor grade instrumentation that provided excellent control and vertical accuracy within 1/10 ft. These data were analyzed using ArcGIS Spatial Analyst software to create 3-D volume models of each wetland impoundment. A "robot" was created using Visual Basic software within ArcGIS that sliced each 3-D volume rendering of the pond at 0.1 ft vertical intervals to allow relationships to be developed between pond surface area (measured in acres) and pond depth (ft) and between pond volume (measured in acre-ft) and pond depth (ft). These relationships are shown as two-dimensional bar plots within ArcGIS with surface area and volume on the ordinate of each graph and pond stage on the abscissa. An Excel look-up table was created to enable pond surface area to be assigned for each increment of pond stage for each of the wetland impoundments surveyed as part of the project.

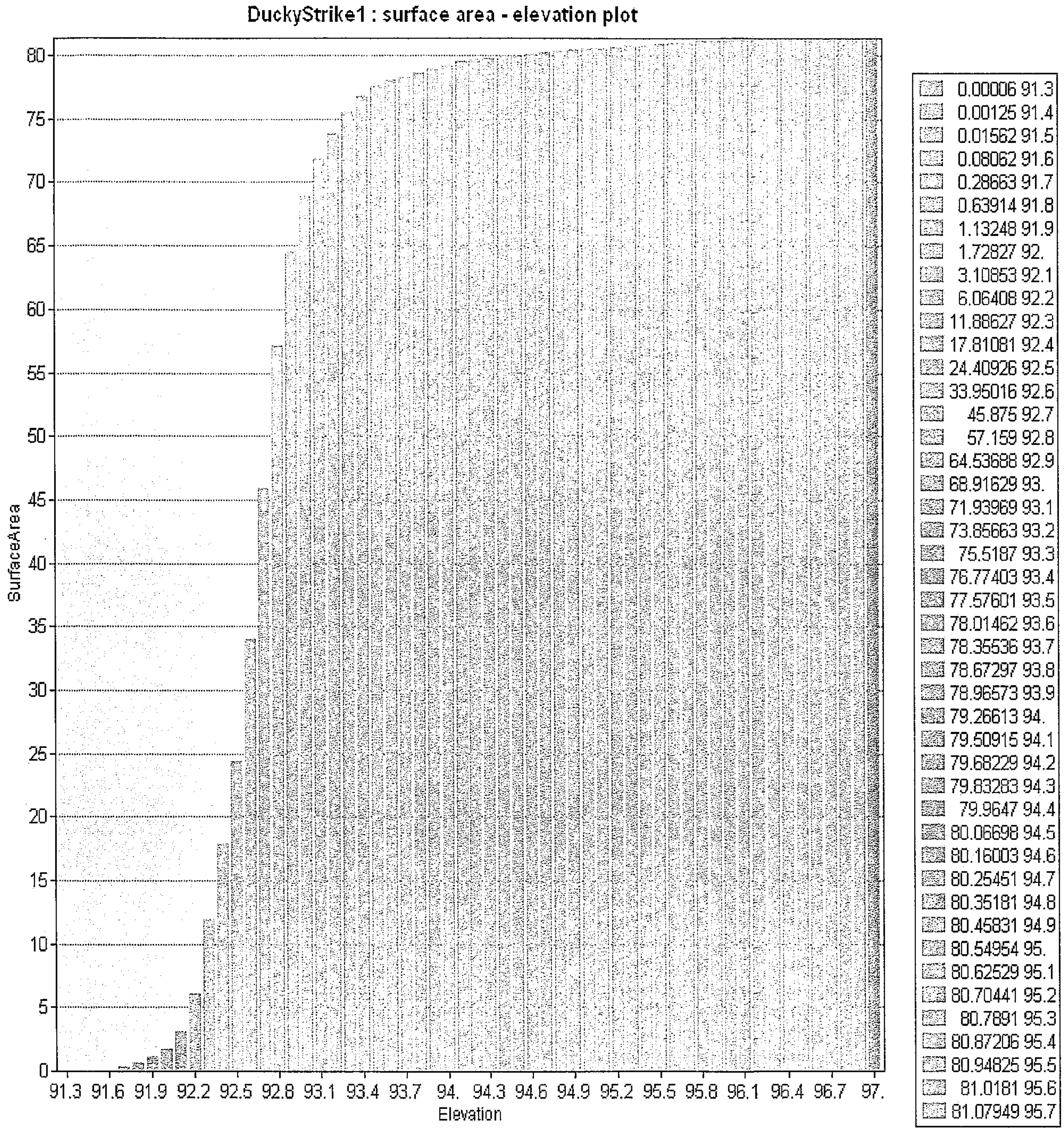


Figure 3.10. Surface-area –elevation plot for Ducky Strike Duck Club (North pond) obtained from a motorized GPS survey during 2007 .

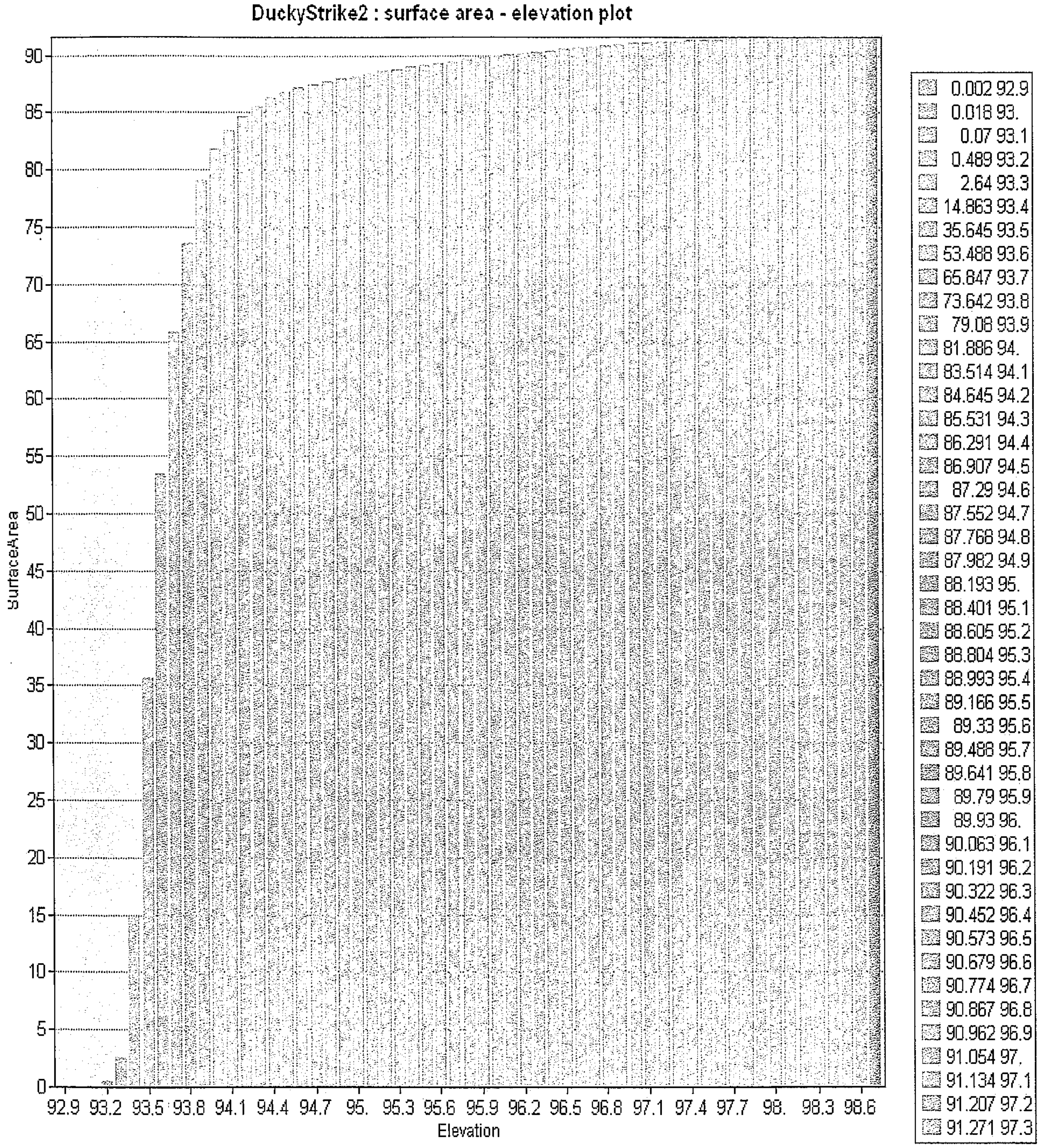


Figure 3.11. Surface-area –elevation plot for Ducky Strike Duck Club (South pond)) obtained from a motorized GPS survey during 2007 .

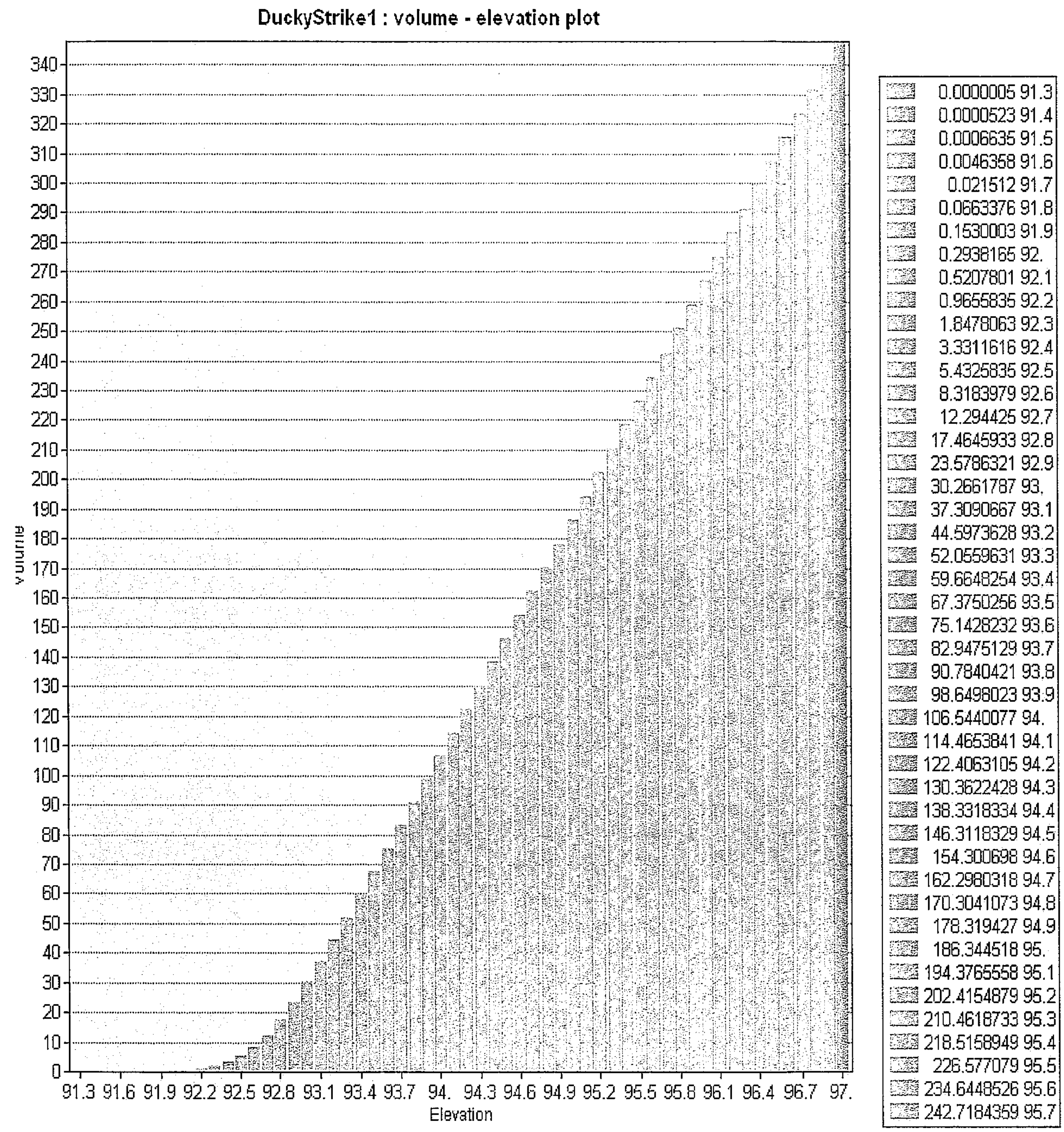


Figure 3.12. Volume – elevation plot for Ducky Strike Duck Club (North pond) obtained from a motorized GPS survey during 2007 .

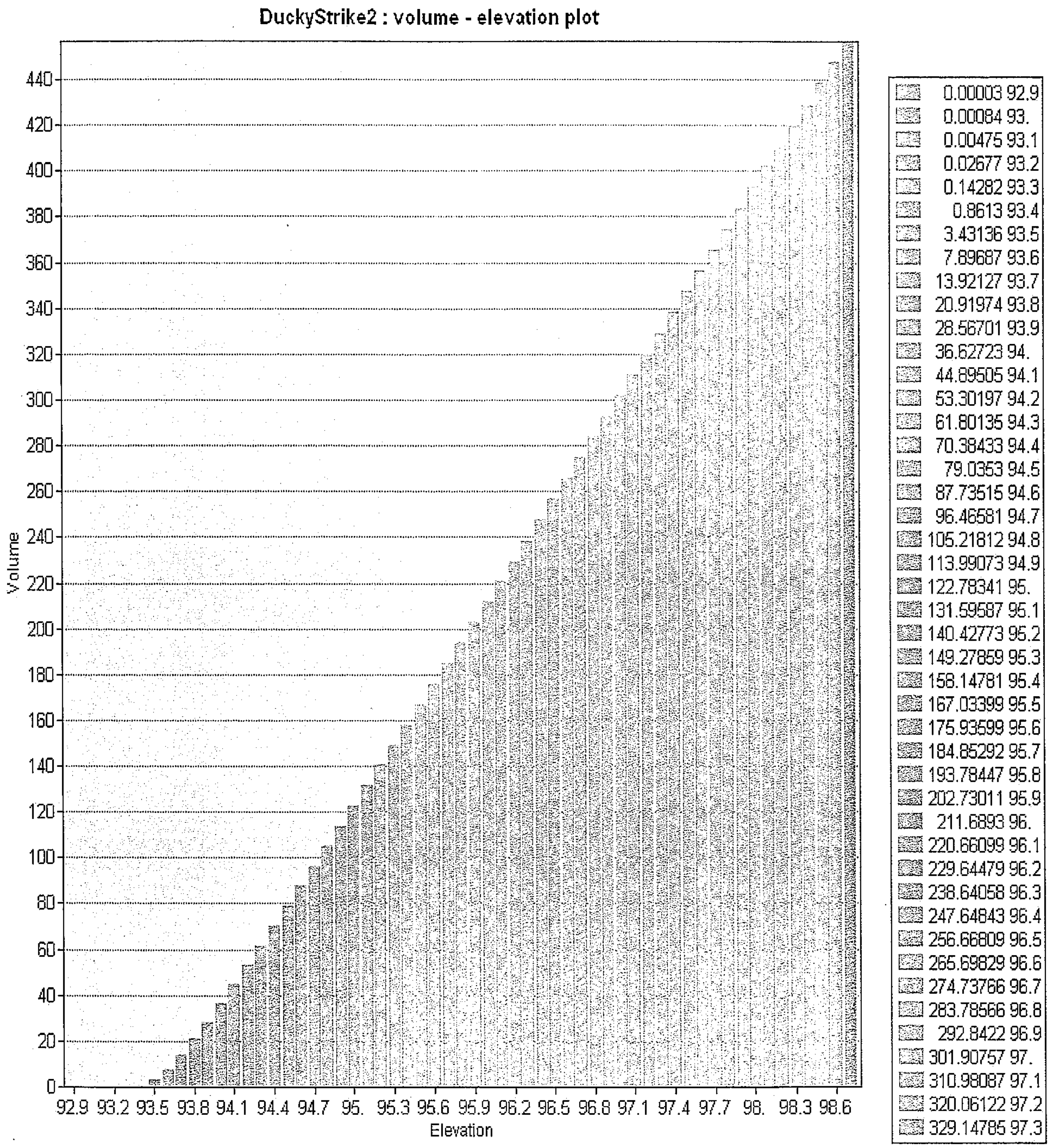


Figure 3.13. Volume – elevation plot for Ducky Strike Duck Club (South pond) obtained from a motorized GPS survey during 2007.

CHAPTER 4: DEVELOPMENT OF SALINITY BUDGETS

4.1 Sensor data acquisition

Sensor data acquired by the YSI EcoNet datalogger at each monitoring location (data node) was transmitted via cellular modem located at one of seven access nodes to the NIVIS internet server (the data repository for continuous data). Each access node in the network also functioned as a data node. Project data for each sensor parameter at each data node has been available for query via the public YSI-EcoNet website at : http://www.ysieconet.com/public/WebUI/Default.aspx?hidCustomerID=99 and for sensor data download at the username and password-protected, private YSI-Econet website at :

http://www.ysieconet.com/private/WebUI/Default.aspx?hidCustomerID=99 . The private website can be configured to automatically download data every week from the NIVIS data server.

The flow and electrical conductivity data for the twelve experimental wetland ponds were downloaded from the NIVIS website as .csv files and processed using an Excel spreadsheet for the 2006-2007 data and using the Aquatic Informatics Inc. Aquarius software for the 2007-2008 and 2008-2009 data. The 2009-2010 data are being analyzed using the Kisters Inc. hydrologic data management system WISKI as previously described in Chapter 2. After initial data screening using both the Excel spreadsheet approach and Aquarius - the results of the analysis imported into an Excel spreadsheet template containing macros designed to produce individual water and salt balances for each wetland pond. In both the Excel data screening procedures and the more streamlined Aquarius data screening routines - the data was first analyzed for gaps in in data time series and the data manually or automatically populated with interpolated readings. Sensor readings that showed drift or produced readings outside the normal expected range were adjusted based on weekly quality assurance data. In Excel missing data was interpolated using a standard linear curve between the two data points. Aquarius allowed more complex functions to be utilized including non-linear and polynomial interpolations and cubic splines. In cases where sensors were found to be malfunctioning for an extended length of time (from a few days to weeks) - sensor readings for the same time period for the paired wetland inlet or outlet monitoring site were utilized to provide guidance for the interpolation process.

4.2 Data quality assurance

Real-time monitoring station data quality assurance (QA) for stage (depth), flow and electrical conductivity was performed, as previously described in Chapter 2, by comparing real-time sensor data with manual field measurements of the same parameters. For electrical conductivity and stage – the sensors were affected by biological growths, accumulation of sediment around the sensors (in the stilling well), floating debris and by inadequate flow past the sensor in the case of electrical conductivity. Blockages and biological growth was removed manually by extracting the sonde from the stilling well and cleaning the EC sensor with a small cylindrical bristle brush and the depth sensor by poking a wire probe into the cap covering the pressure sensor. A pre-calibrated, hand-held YSI-sonde was used to take readings of EC and temperature. The EC reading from the hand-held sensor would then be compared to the reading from the field sensor after cleaning (the reading before cleaning was also recorded) - the two EC readings and the resulting error percentage recorded. If the EC field sensor was off more than 5% from the calibrated reading, the EC field sensor would be adjusted in the field and the date and time of adjustment noted. Sonde stage measurements were compared to the staff gauge and a manual adjustment was made any time there was a discrepancy. All of the QA information

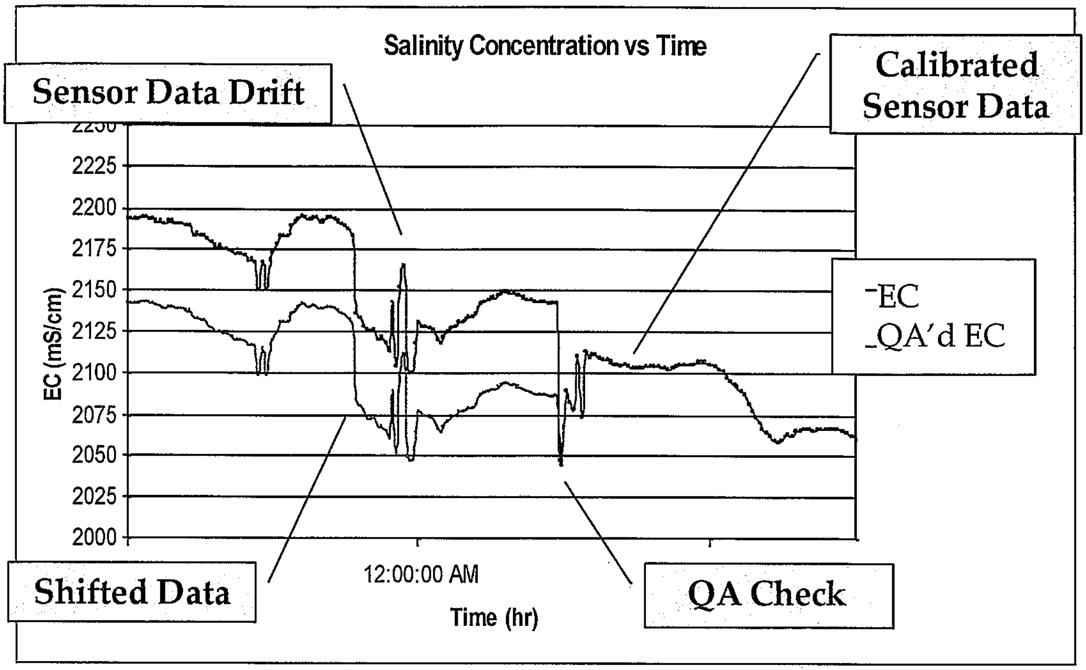


Figure 4.1. Example of adjustments made to YSI Sonde EC data to correct for sensor drift and match monitoring site QA data.

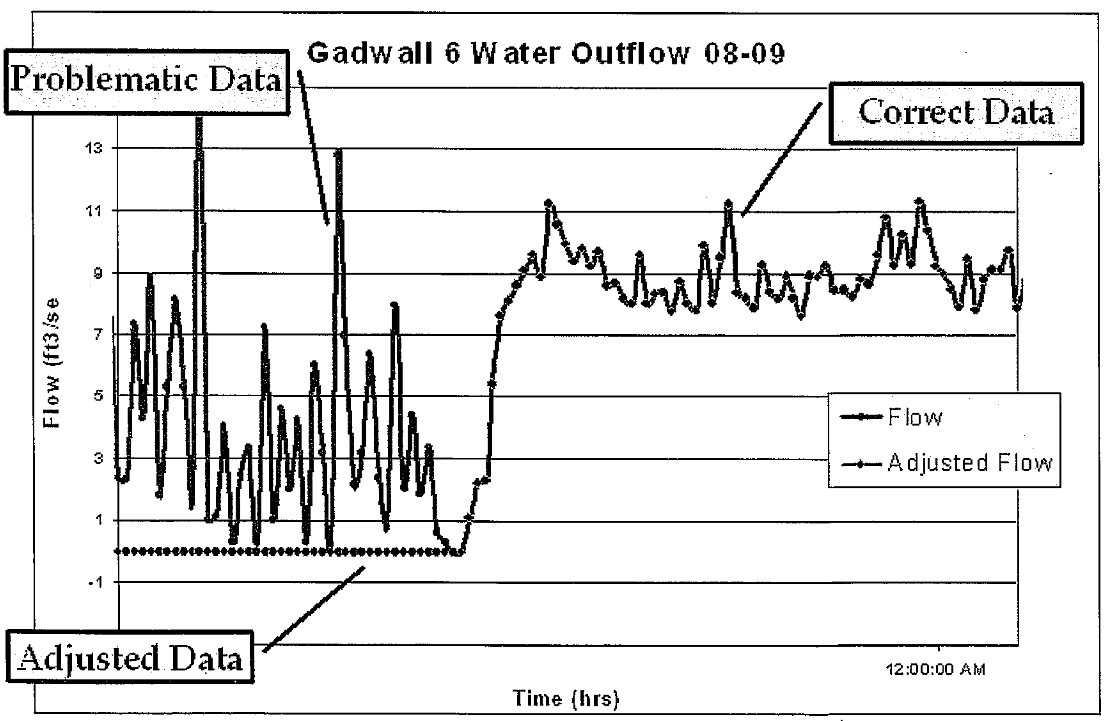


Figure 4.2. Example of adjustments made to MACE flow data to correct for sensor noise and match monitoring site QA data.

was recorded on standardized QA datasheets.

Flow is estimated by combining velocity data, measured by the MACE or SONTEK acoustic Doppler transducers, with MACE or SONTEK stage data that is used to estimate the cross-sectional area of the flow. Under pipe-full conditions in culverts – the cross sectional area is the cross-section of the pipe culvert. In pipe culverts that experienced a wide range of flow conditions such that pipe-full conditions could not be assumed – stage was frequently measured by both the MACE depth sensor (embedded in ceramic on the underside of the Doppler transducer) and a MACE EchoFlo downward-looking sonar sensor deployed at the top of the pipe culvert. The EcoFlo sensor readings would overwrite MACE Doppler sensor stage values at low flow when there was only a small depth of water flowing over the Doppler sensor.

Making accurate measurements of culvert pipe flow to validate flow estimates made using the MACE Doppler (and MACE EchoFlo) is more difficult than in open channels given the problem establishing a true mean velocity. These measurements were made with a Marsh-McBirney Flo-Mate 2000 flow meter and a measuring rod, bent at right angles to allow approximately 30 inches of the rod – with the electromagnetic velocity sensor attached at its end – to be inserted into the culvert. The rod was inserted at a depth equivalent to 6/10th of the flow depth measured from the bottom of the culvert in order to obtain a mean pipe velocity (difficult to perform reliably). Open channel flow estimation is easier using the standardized flow-area method – whereby the flow is assessed incrementally across the channel at both 2/10^{ths} and 8/10^{ths} depths (the average providing a mean channel velocity for each flow segment). Multiplying the velocity of each flow segment by its cross-sectional area and summing across the channel produces an accurate estimate of open channel flow with which to compare the SONTEK transducer readings. The SONTEK readings were multiplied by a calibration factor - the ratio of the sensor data to the QA measurement at the same data and time to obtain QA-adjusted flow data.

4.3 Water and salinity balance spreadsheets

The conceptual water and salinity mass balance for each wetland pond is illustrated in Figure 4.3. A customized Excel spreadsheet was developed (Figure 4.4) to develop water and salinity mass balances for the individual wetland ponds based on sensor data from the pond inlets and outlets together with information on evapotranspiration, precipitation and estimated ground water seepage. The analysis was performed for both 2007-2008 and 2008-2009 wetland seasons – however the completeness of the analysis was compromised by poor and missing data at several of the stations in the 2007-2008 season. Hence only those wetland ponds with complete results for both years are discussed.

Evaporation, transpiration and groundwater seepage from each pond were estimated based on local weather station data (for evapotranspiration) and shallow well elevation data (for seepage). In the modified Penman-Monteith equation (used to calculate evapotranspiration) - evaporation rates are based on ambient air temperature and wind speed, whereas transpiration rates are based on plant species and extent of plant coverage (determined by hyper-spectral aerial photo analysis). Due to the heterogeneous nature of wetland soils and the wide distribution of plant species in any given wetland pond, accurate estimation of both direct evaporation and plant transpiration is difficult. There are no well-proven field techniques for making reliable evapotranspiration estimates from wetland moist soil plants. Likewise groundwater seepage rates are difficult to determine due to temporal variation in soil hydraulic conductivity. At the time of flood-up the clay-dominated wetland soils are highly desiccated and cracked to depths greater than 1 foot – leading to high initial seepage rates. However as cracks fill and the clays absorb moisture – they swell, closing the surface and

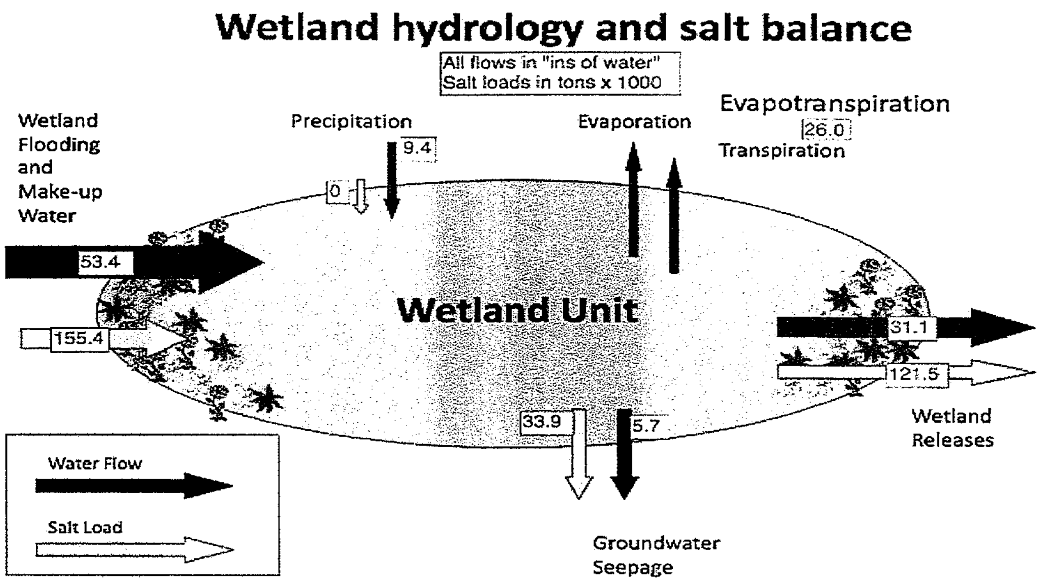


Figure 4.3 Graphical schematic of conceptual water and salinity mass balance (budget).

Site: Los Banos 33
Date: 9/30/07

		Inflow Values							Outflow Values							Difference		
Week	Day	Inflow (acre-feet)	Precipitation	Groundwater	Total Daily Water In (acre-feet)	Cumulative Water In (acre-feet)	Daily Average EC (µS/cm)	Total Daily Dissolved Solids In (tons)	Outflow (acre-feet)	Evaporation	Evapotranspiration	Total Daily Water Out (acre-feet)	Cumulative Water Out (acre-feet)	Daily Average EC (µS/cm)	Total Daily Dissolved Solids Out (tons)	Daily Water (acre-feet)	Cumulative Water Difference (acre-feet)	Total Daily Dissolved Solids (tons)
1	1	0.3			0.29	0.29	770.4	#VALUE!	0.0			0.00	0.00	1071.4	0.0	0.3	0.29	#VALUE!
	2	0.1			0.05	0.34	899.5	#VALUE!	0.0			0.00	0.00	1072.6	#VALUE!	0.1	0.34	#VALUE!
	3	0.0			0.00	0.34	917.4	0.0	0.0			0.00	0.00	1066.8	0.0	0.0	0.34	0.0
	4	0.2			0.16	0.51	897.5	0.0	0.0			0.00	0.00	1068.3	0.0	0.2	0.51	0.0
	5	0.3			0.26	0.77	854.1	0.0	0.0			0.00	0.00	1066.4	0.0	0.3	0.77	0.0
	6	0.2			0.25	1.02	804.5	0.0	0.0			0.00	0.00	1070.4	0.0	0.2	1.02	0.0
	7	0.3			0.32	1.34	835.1	0.0	0.0			0.00	0.00	1076.6	0.0	0.3	1.34	0.0
Weekly Totals		1.3			1.34			#VALUE!	0.0			0.00			#VALUE!	1.3		#VALUE!
2	1	0.3			0.34	1.68	863.8	0.0	0.0			0.00	0.00	1081.6	0.0	0.3	1.7	0.0
	2	1.1			1.10	2.79	846.3	0.0	0.0			0.00	0.00	1084.4	0.0	1.1	2.6	0.0
	3	0.6			0.58	3.37	833.2	#VALUE!	0.0			0.00	0.00	1084.8	0.0	0.6	3.4	#VALUE!
	4	0.0			0.00	3.37	688.3	0.0	0.0			0.00	0.00	1083.5	0.0	0.0	3.4	0.0
	5	0.1			0.13	3.50	617.9	0.0	0.1			0.10	0.10	1074.7	0.0	0.0	3.4	0.0
	6	0.5			0.46	3.96	630.7	0.0	0.2			0.24	0.33	1068.6	0.0	0.2	3.6	0.0
	7	0.0			0.00	3.96	612.9	0.0	0.4			0.36	0.69	1063.7	0.0	-0.4	3.3	0.0
Weekly Totals		2.6			2.62			#VALUE!	0.7			0.69			0.0	1.9		#VALUE!
3	1	0.0			0.00	3.96	581.9	0.0	0.1			0.11	0.80	1061.5	#VALUE!	-0.1	3.2	#VALUE!
	2	0.0			0.00	3.96	579.4	0.0	0.0			0.01	0.81	1055.8	#VALUE!	0.0	3.1	#VALUE!
	3	0.0			0.00	3.96	603.8	0.0	0.0			0.01	0.82	1028.0	#VALUE!	0.0	3.1	#VALUE!
	4	0.0			0.00	3.96	587.5	0.0	0.0			0.02	0.85	1038.5	#VALUE!	0.0	3.1	#VALUE!
	5	0.0			0.00	3.96	583.6	#VALUE!	0.1			0.14	0.99	1013.2	#VALUE!	-0.1	3.0	#VALUE!
	6	0.0			0.00	3.96	593.3	#VALUE!	0.1			0.10	1.09	1014.5	#VALUE!	-0.1	2.9	#VALUE!
	7	0.0			0.00	3.96	596.2	0.0	0.2			0.17	1.27	985.5	#VALUE!	-0.2	2.7	#VALUE!
Weekly Totals		0.0			0.00			#VALUE!	0.6			0.57			#VALUE!	-0.6		#VALUE!
4	1	0.0			0.00	3.96	649.0	0.0	0.3			0.27	1.53	930.7	0.0	-0.3	2.4	0.0
	2	0.0			0.00	3.96	643.8	0.0	0.3			0.26	1.79	957.3	0.0	-0.3	2.2	0.0
	3	0.2			0.19	4.15	652.4	#VALUE!	0.2			0.21	1.99	960.7	0.0	0.0	2.2	#VALUE!
	4	0.2			0.20	4.35	671.5	0.0	0.3			0.26	2.25	962.5	0.0	-0.1	2.1	0.0
	5	0.1			0.13	4.48	711.0	#VALUE!	0.1			0.14	2.39	1034.1	#VALUE!	0.0	2.1	#VALUE!
	6	0.0			0.00	4.48	751.5	0.0	0.2			0.18	2.58	1115.3	0.0	-0.2	1.9	0.0
	7	0.0			0.00	4.48	759.4	0.0	0.2			0.15	2.73	1102.8	0.0	-0.2	1.8	0.0
Weekly Totals		0.5			0.52			#VALUE!	1.5			1.46			#VALUE!	-0.9		#VALUE!
5	1	0.0			0.00	4.48	730.2	0.0	0.1			0.10	2.82	1102.7	0.0	-0.1	1.7	0.0
	2	0.0			0.00	4.48	718.5	0.0	0.1			0.11	2.93	1094.6	0.0	-0.1	1.6	0.0
	3	0.0			0.00	4.48	717.3	0.0	0.1			0.09	3.02	1073.4	0.0	-0.1	1.5	0.0
	4	0.0			0.00	4.48	681.9	0.0	0.1			0.06	3.08	1075.7	0.0	-0.1	1.4	0.0
	5	0.0			0.00	4.48	591.5	#VALUE!	0.1			0.07	3.15	1008.7	#VALUE!	-0.1	1.3	#VALUE!
	6	0.0			0.00	4.48	545.0	0.0	0.1			0.09	3.23	946.7	0.0	-0.1	1.2	0.0
	7	0.0			0.00	4.48	544.8	0.0	0.1			0.09	3.33	950.8	#VALUE!	-0.1	1.2	#VALUE!
Weekly Totals		0.0			0.00			#VALUE!	0.6			0.60			#VALUE!	-0.6		#VALUE!
Monthly Totals		4.5	0	0	4.48			#VALUE!	3.3	0	0	3.33			#VALUE!	1.2		#VALUE!

Figure 4.4 Water and salinity budget spreadsheet template in Excel. Weekly inflow and outflow data are pasted into the columns on the left. Precipitation and estimated groundwater losses in the next two columns to the right. Spreadsheet produces monthly and annual water and salinity mass balances as well as cumulative import and export.

subsurface cracks – leading to a rapidly declining rate of seepage. By the time the vadose zone is fully saturated and the clay soils at saturation groundwater seepage below the ponds is negligible.

Four wells were instrumented within the Los Banos Wildlife Management Area to obtain better estimates of wetland groundwater losses during flood-up and to more accurately track the rate of fall of groundwater levels after the start of wetland drawdown. Data from one of these instrumented sites in the Los Banos Wildlife Management Area is presented in Figure 4.5. This data has been corrected using the pressure data obtained from a barometric sensor in order to provide the true groundwater level elevation during the wetland drawdown period in the vicinity of the instrumented well.

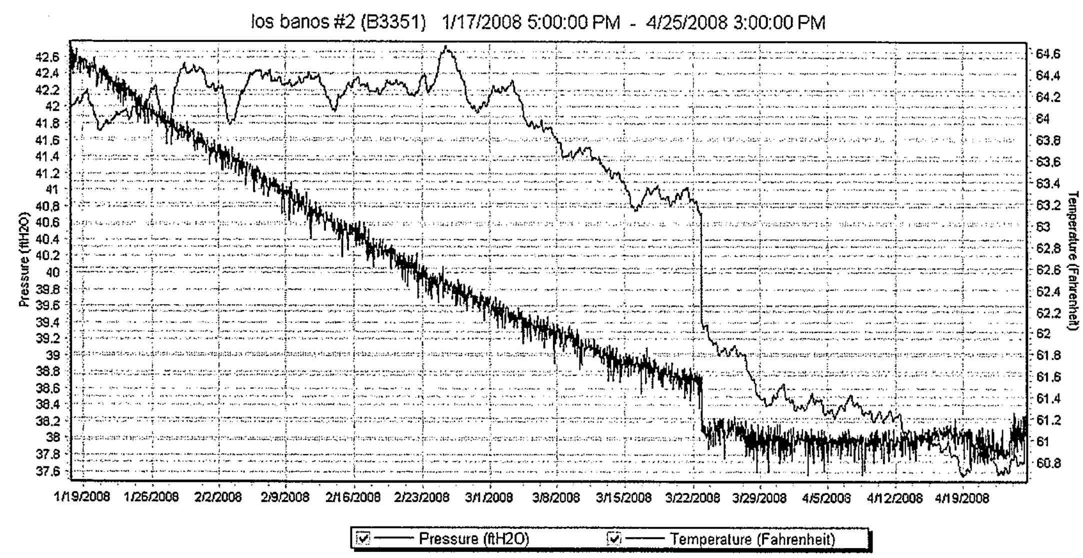
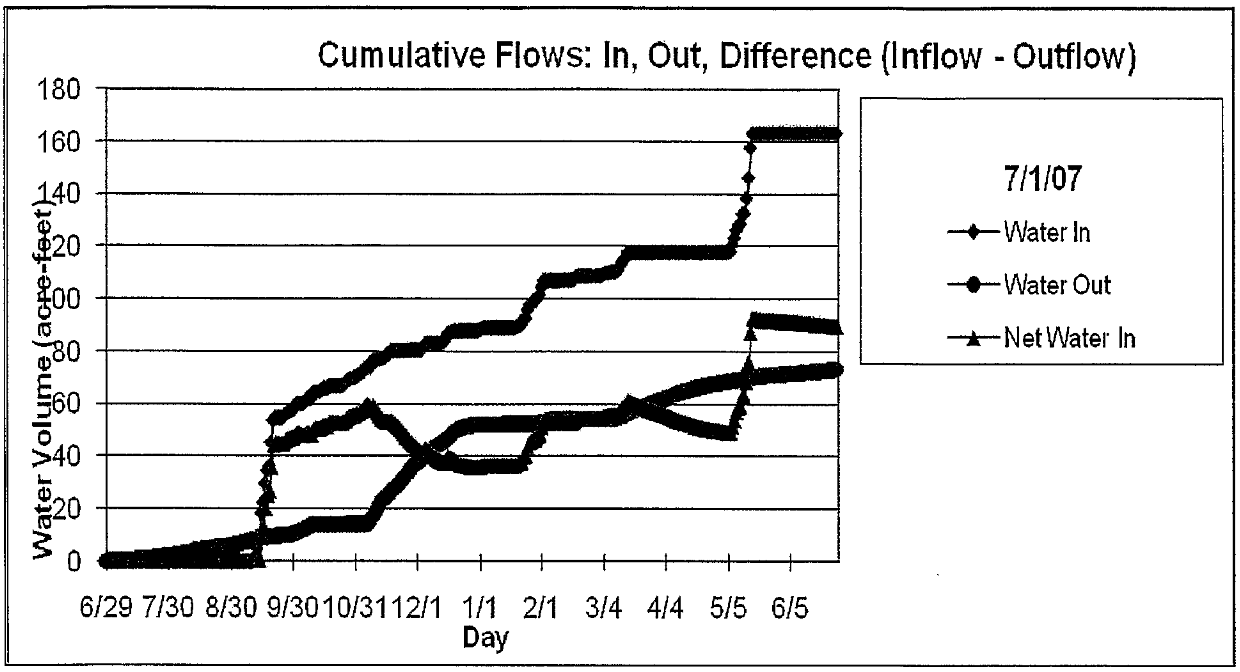


Figure 4.5. Groundwater elevations (not corrected for barometric pressure) within the Los Banos Wildlife Management Area. Well elevations drop rapidly immediately after ponded water is drained and then decline gradually over the remainder of the summer until fall flood-up.

Daily seepage estimates were taken directly from the monthly output of the WETMANSIM model (Quinn, 2001) that was described in Chapter 2. The average depth to groundwater at the beginning of the fall flood-up for all sites were based on the average of the four well sites in the Los Banos Widlife Management Area. WETMANSIM assumes that the vadose zone is filled first before water begins to pond in the wetland impoundment. A porosity characteristic of wetland soils high in clay content is used to estimate the fillable porosity. A low vertical deep groundwater flow (equivalent to flow across the Corcoran Clay layer in the vicinity of the Valley trough) equivalent to 0.1 ft/year was assumed to provide a steady-state groundwater loss (equivalent to a reduction in water table elevation of 1 ft/year assuming an aquifer porosity of 10%). Groundwater loss to drainage ditches, sloughs and stream channels constitute the minor component of the annual water budget – these losses are responsible for the slow decline in water table between wetland drawdown and the following season flood-up.



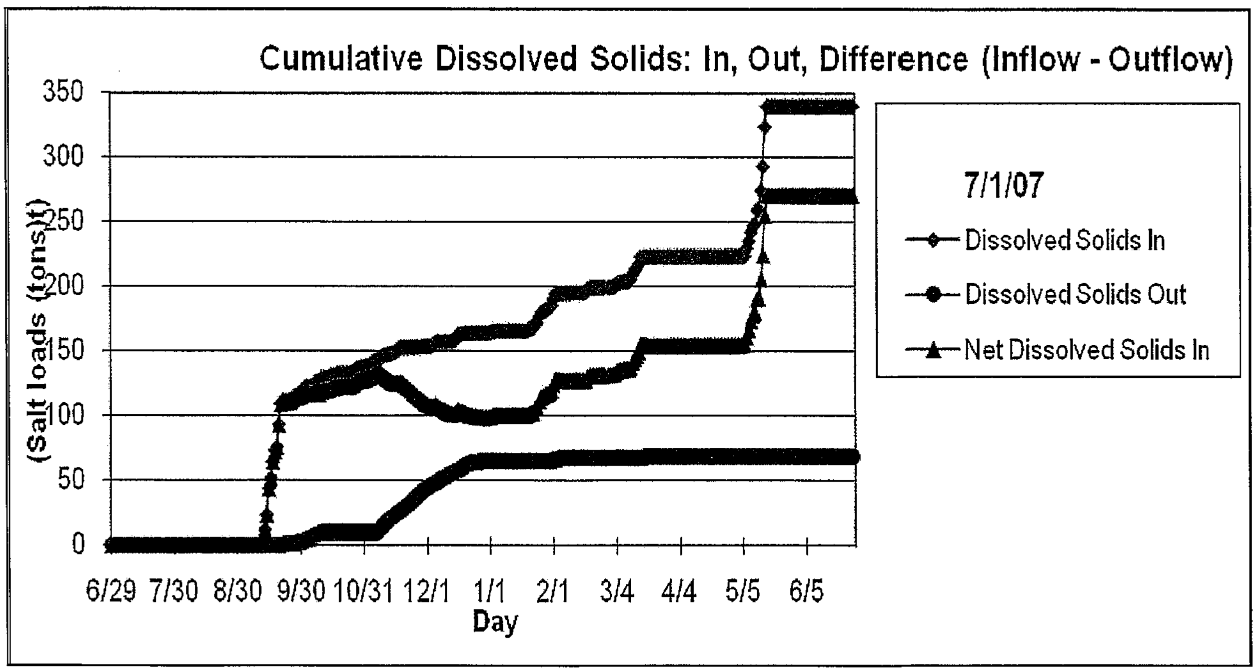


Figure 4.6. Spreadsheet model output showing cumulative flow and salt loading into and out of individual ponds over the 2006/2007 season. The outflow data was compromised at several of the pond sites owing to lack of consistent record keeping by ditch tenders. This problem was resolved by the installation of acoustic flow sensors at the inflow sites during 2007/2008 and 2008/2009 wetland flooded seasons.

4.4 Comparison of wetland budgets for paired wetland sites

The results of the spreadsheet hydrology model for all 24 stations and the 6 paired monitoring locations within the following State Wildlife Management Areas: (Gadwall, Mud Slough, Salt Slough, Volta, Los Banos and the Ducky Strike duck club are presented in Figures 4.7 and 4.8. The hydrology balance summary is presented for the 2007/2008 flooded season. Modem and sensor failures that took time to resolve were responsible for incomplete data sets at several sites which prevented the development of a complete water balance. Most of these issues were resolved in 2008/2009.

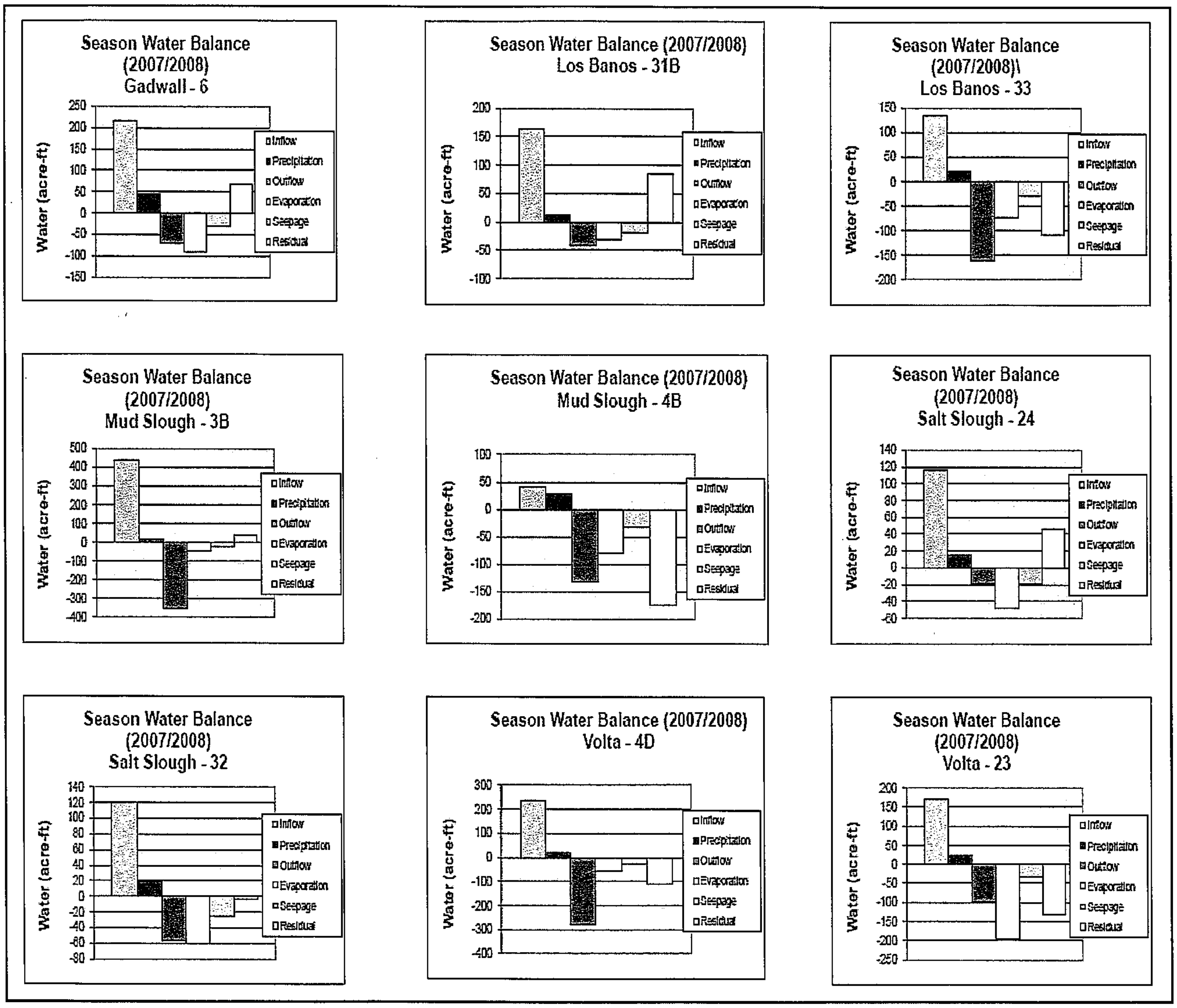


Figure 4.7. Summary water balances for all sites for the 2007/2008 flood-up season. Complete hydrologic balances were not possible at all twelve sites owing to sensor failure at certain pond sites which compromised the completeness of the hydrology and salinity mass balances.

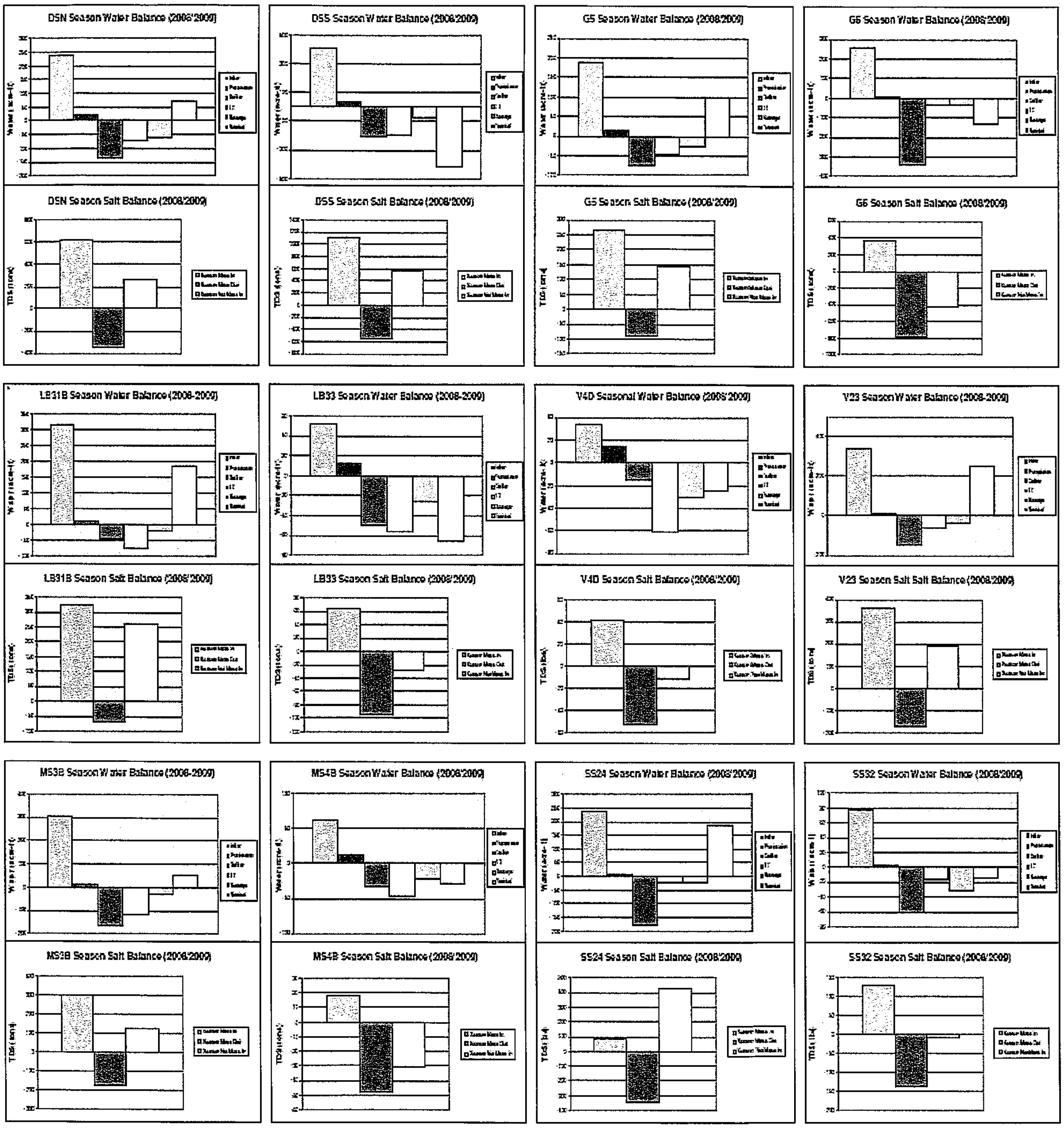


Figure 4.8. Summary water and salt balances for all sites for the 2008/2009 flood-up season. By 2008/2009 the majority of the sensor problems had been solved and the water and salt balances were completed for all sites.

Preliminary analysis of the data shows much improved control of sensor variability during 2008-2009 with far fewer instances of sensor and modem failure. Quality assurance protocols were better established – which resulted in only short periods of monitoring station down-time when sensors fell out of calibration or modems failed to transmit. The most significant source of error in the hydrology and salinity mass balance analysis continues to be wetland evaporation and emergent plant evapotranspiration. Wetland seepage is another poorly controlled source of error. Despite these limitations the project has allowed the first credible water and salinity balances of these areas to be produced.

4.5 Interannual comparison of water and salinity mass balances at selected sites

Five ponds with sufficient data sets were compared in detail. Water and mass balances for the 2007-08 and 2008-09 seasons were calculated using the Excel spreadsheet model and contrasted. Any differences between the following results and those in Figures 4.7.and 4.8 are the result of additional refinement of seepage and evapotranspiration estimates. The inflow and outflow data remained the same.

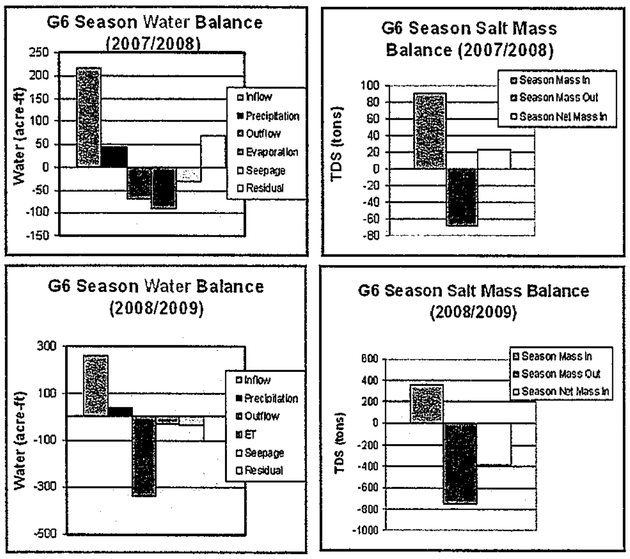


Figure 4.9. Water and salt balance for the Gadwall 6 wetland.

Gadwall 6. The water budget for the 2007-2008 season showed a positive residual error whereas the water budget for 2008/2009 was negative suggesting a lack of bias in the result. Water outflow was larger than inflow and precipitation combined in 2008-2009 suggesting error in the monitoring of either inflow or outflow to the site. Errors in the water budget are perpetuated in the salt budget. The error residuals are relatively small for both years – in 2007-2008 the results suggest more salt entered the wetland than left. This result is reversed in 2008-2009. Salt accumulation can occur in the soil or shallow groundwater (not deep percolated). However in the case of the Gadwall 6 pond the availability of a relatively secure, good quality water supply – suggests that the wetland may be close to equilibrium salt balance.

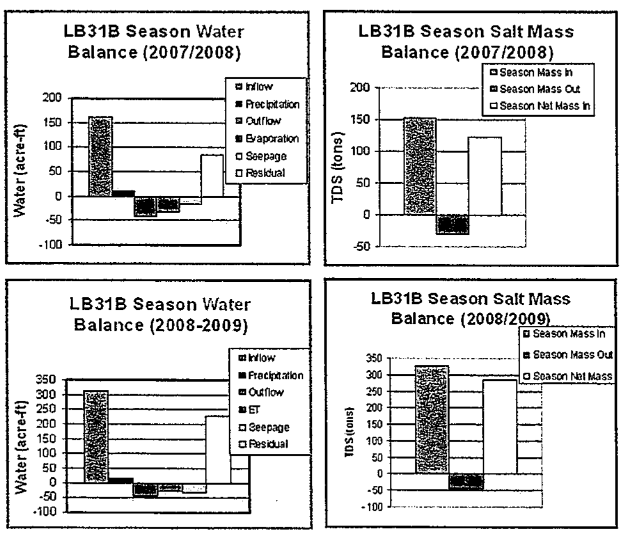


Figure 4.10. Water and salt balance for the Los Banos 31B wetland.

Los Baños 31B: This wetland shows significant residual error for both 2007-2008 and 2008-2009. The result suggests that pond inflow has been over-estimated in both years – given the relative magnitude of the inflows compared to the other hydrologic components. This could have been caused by a poorly calibrated MACE stage or acoustic Doppler velocity sensor which produced unreasonably high readings. Given the extreme range of pipe velocity experienced at the inlets and the difficulty of verifying pipe discharge with accuracy – this result is to be expected. The salinity budgets mirror the error in the water budgets.

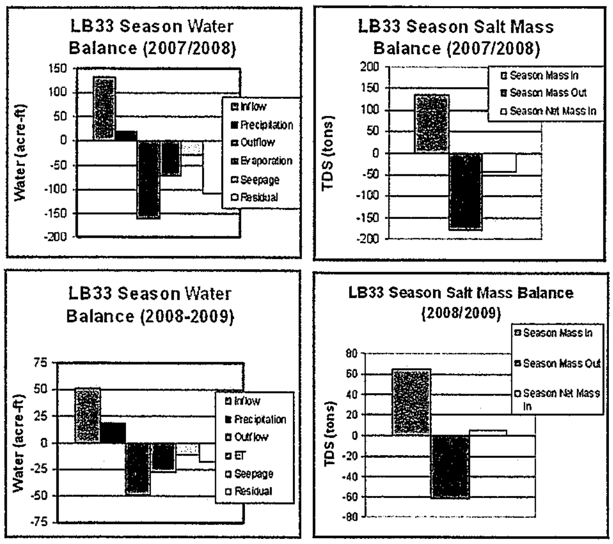


Figure 4.11. Water and salt balance for the Los Banos 33 wetland.

Los Baños 33: The residual error in the water budget is more significant in the case of the 2007-2008 season than during 2008-2009. Both residual water budgets are negative suggesting that there is a bias in the water budget that produces outflow. This could be associated with an underestimate of annual pond inflow or to errors in outflow measurement or the estimation of seepage or evapotranspiration. The residual error in 2008-2209 is small – suggesting that the water balance presented may be reasonable. If so – then the salt budget suggests approximately as much salt entering the wetland as leaving the wetland. Under these circumstances significant salt accumulation in the soil would not be expected.

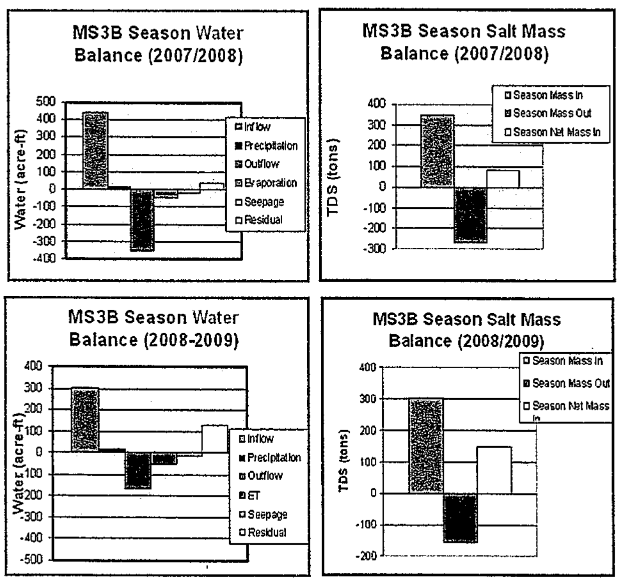


Figure 4.12. Water and salt balance for Mud Slough 3B wetland.

Mud Slough 3B. The small residual error in 2007-2008 and the larger, but still relatively small, residual error in 2008-2008 suggests that the water budget may provide a reasonable depiction of wetland hydrology. In 2007-2008 inflows and outflows to and from the Mud Slough 3B wetland appear to be in balance producing a salinity budget that shows slightly more salt entering the wetland than leaving. This might suggest some accumulation in wetland soils. The salinity imbalance is greater in 2008-2009 – though this result may be the result of an imperfect water budget.

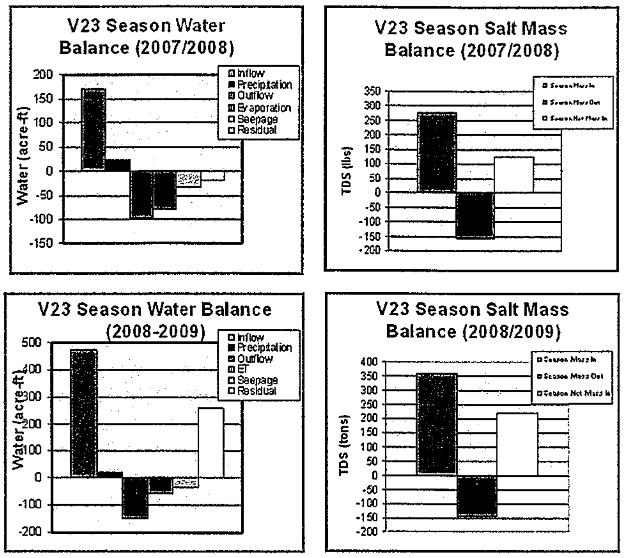


Figure 4.13. Water and salt balance for the Volta 23 wetland.

Volta 23: The water and salt balances for Volta pond 23 are similar to those for Mud Slough 3B. The small residual error in the 2007-2008 water balance suggests that the wetland hydrology may be reasonably represented. The residual error in the 2008-2009 season is much greater – the pond inflow appears to be disproportionately large compared to the other inflows and outflows suggesting a possible problem with the measurement of pond inflow. More water enters the wetland than can be accounted for in the measured and estimated outflow. Salinity budgets for both 2007-2008 and 2008-2009 seasons show more salt entering the wetland than leaving. This could indicate accumulation in wetland soils

The analysis of water and salinity budgets for all wetland sites and for the 2007 and 2008 seasons suggests that, although significant improvements have been made in improving the monitoring of inflow, outflow and salinity in managed wetlands within the Grassland Ecological Area – these budgets are imperfect and some further improvement may still be needed in the monitoring of flow and EC. There was missing or problematic data for some of these sites – although, as previously noted – most of the sensor problems were resolved ahead of the 2008-2009 season. As part of the data QA process, missing stage and salinity data would be interpolated – however this was insufficiently pervasive to compromise the integrity of the datasets. Certain pond inlets and outlets occasionally provided noisy and erratic data. This problematic data was observed during times when there was no gain or loss of stage depth in the pond and zero or close to zero velocity data recorded by the acoustic Doppler sensor. In these cases, the flow data would be set to zero.

The hydrologic components of seepage and evapotranspiration are still inadequately understood and poorly quantified. However the estimates made of these factors seem reasonable from a visual inspection of the water and salinity budget results. Neither seepage or evapotranspiration can be measured directly – even if they could there is significant heterogeneity in the soils and vegetation to complicate their accurate estimation over the study area.

Comparison of the graphs for the two consecutive years for all sites suggest that salt loads were accumulating in the wetland to a greater degree in the second year of the study (2008-2009). All of the ponds except the Gadwall 6 pond have a higher positive residual salt loading in the pond the 2008-2009 year than the prior year. (Note that this may be due to error – however less likely if all ponds show the same result). Also, weather data from CIMIS show that the temperature was an average of one degree higher the second year of the study. The higher temperatures during 2008-2009 could have contributed to greater evapotranspiration in the ponds, possibly causing a higher concentration of salt settling into the fissures in the wetland soils over the maintenance period. A longer period of record is necessary to be able to draw conclusions on these issues with any confidence.

The development of water and salinity budgets has been compromised in the past by the lack of data. The current project and prior investigations, starting in 2001, have helped to develop a robust sensor network of flow and salinity monitoring stations. These stations have been of two types : (a) monitoring stations deployed to improve understanding of the hydrology of managed wetlands and service channels in the study area; (b) monitoring stations that are used to assist Water District-level operations and maintenance decisions and improve water management within the study area. Until relatively recently the high cost of environmental monitoring instrumentation and the lack of accuracy and robustness of the sensors stymied investment in this technology by agencies, wetland and agricultural and water districts. However the past 5 years there has been an explosion in the deployment of environmental sensors and the commercial release of products such as YSI-EcoNet which have allowed the development of sensor networks and provided web access to the telemetered monitoring station data. Despite these advances in technology flow monitoring of wetland channels remains difficult and taxes the capabilities of even the most sensitive instrument – given the wide range of flows encountered in water delivery systems serving these wetlands and the difficult access to closed pipes and culverts – often the only available control structures where flow can be measured.

CHAPTER 5: MEASURING IMPACTS OF DELAYED WETLAND DRAWDOWN PRACTICES

5.1 Real-time wetland drainage management

Real-time water quality management will only be successful if actions such as delaying seasonal wetland drawdown can be shown to have no long-term impact on the habitat value, biological health and diversity of the seasonal wetland resource for migratory waterfowl and shorebirds. Potential long-term impacts of making changes to the traditional scheduling of seasonal wetland drawdown must be assessed both biological and vegetative survey techniques. The basic premise of the assessment is that quantitative longitudinal (over time) surveys of wetland moist soil plant succession, combined with surveys of soil salinity, continuous monitoring of salts in and out of these wetlands, and biological monitoring of waterfowl and their food sources, provide a realistic picture of potential long-term impacts to these wetlands from salinity management practices (which include delayed drawdown). If impacts are recognized – improved and salinity techniques may need to be developed to help limit long-term damage due to modified hydrology. Vegetation and soils mapping may be used to provide a quantitative record that can be used by wetland managers to document changes to the biological resource over time and to assess the effectiveness of improved water and salinity management practices.

5.2 Habitat quantification and assessment using remote sensing

The water regime in managed seasonal wetlands is largely artificial, with surface water inflows and outflows designed to emulate a natural wetland cycle. Water management practices include the timing of irrigations and draw-downs to maximize desirable food production plants and to minimize undesirable weeds. Outflow events, such as seasonal wetland draw-down, can influence water quality in the San Joaquin River – wetland managers have been exploring ways of improving the scheduling of wetland drainage to improve compliance with State water quality objectives. This was the motivation behind the current project. Changes to wetland water management practices can impact the wetland ecological health and the areal extent of desirable habitat. High resolution satellite imagery and remote sensing technologies are being used to assess these potential impacts as well as improve the quantification of the wetland habitat resource.

There is urgency within the San Joaquin Valley to quantify wetland water usage and water requirements. In addition to surface drainage and loss of the groundwater system (where it can travel vertically into the deeper groundwater or horizontally into drainage ditches, sloughs and eventually into the San Joaquin River) a large portion of annual outflow occurs through wetland evaporation and transpiration. Land managers' understanding of how local vegetation influences water usage is rudimentary. One way to improve water use estimates is to develop an understanding of the evapotranspiration characteristics of the existing plant communities (Norman, et al 1993) With an understanding of the distribution of plant communities and their evapotranspiration characteristics, scientists can provide improved estimates of water needs and water usage for managed wetland resources. To address the need for understanding the distribution of plant communities, this study evaluated the feasibility of mapping vegetation using remote sensing and established a methodology for this analysis.

Remotely sensed digital imagery captures the spectral reflectance values of different landcover classes. By combining high resolution satellite images and image processing tools with industry standard environmental survey methods, the abundance of different species of wetland vegetation over large regions can be accurately and efficiently estimated. Analysis of satellite imagery to quantify land cover in managed wetlands has multiple benefits. Compared to traditional vegetation survey techniques, satellite imagery requires significantly less time and labor, while covering a larger area. Rather than the exhaustive on-going field effort that would be required to survey a large area such as Grasslands Ecological Area (GEA), field work was limited to the time necessary to provide necessary calibration for the image. While satellite imagery can be used effectively to map large or small areas, it becomes increasingly cost effective for larger study sites. Satellite imagery is also a flexible technology; depending on the variables of interest, image collection can be timed to capture different features throughout the growing season. Through tracking the changes in multi-temporal imagery and correlating changes with previously made management decisions, impacts may be assigned to various land use activities (Fredrickson, 1991.)

Satellite imagery is also an unbiased and consistent data source, reducing concerns of consistency between teams of surveyors, or drifts in field methodology and nomenclature during the field season. As an added benefit, the availability of satellite imagery as an unbiased and standardized data source creates the potential for study sites to be viewed in a broader context, both regionally and worldwide. Finally, the imagery provides an archival data source, which after its initial use, continues to be available as a historical reference, and can be used in later studies, the requirements of which may not have been foreseen at the time.

5.2.1 Background

Management decisions such as scheduling drawdowns and irrigations are made routinely, and the timing of these events changes from year to year. Habitat assessment is needed to optimize the timing of these changes. Traditional means of habitat assessment such as random sampling or transects for large areas (>1000 acres) are extremely labor intensive (Tatu et al., 1999.) It can also be difficult to acquire timely data at a sufficiently high resolution. Moreover, although impact assessment using a fine scale sampling program at the individual pond level could be accomplished, the spatial variations found in larger areas may be missed completely (Link et al., 1994.) What is means to rapidly assess and quantify the various habitat communities at the regional scale, and readily track changes in those communities from year to year (Wiens and Parker, 1995, Shuford et al., 1998; Shuford et al., 1999.)

A remote sensing analysis methodology was implemented for mapping seasonal wetland vegetation in the GEA based on techniques developed during a previous research study that focused on the San Luis Unit of the San Luis National Wildlife Refuge SLNWR and the northern division of Grasslands Water District (NGWD) (Quinn et al., 2005). Whereas the previous study was regional in scope - the current study focuses on individual wetland impoundments, focusing on wetland pairs that have similar climate, soils, and topology and management goals. Vegetation mapping performs two major functions useful to landscape managers; firstly to identify the composition and aerial extent of existing wetland moist-soil plant communities; and secondly to assess changes in these communities over time.

5.2.2 High resolution multispectral imagery acquisition

Various vendors have been used to supply imagery for wetland vegetation mapping. This project used high-resolution, multi-spectral QuickBird imagery purchased from Digital Globe (Longmont, Colorado) for imagery acquired during 2006 and 2007. Flown imagery at an even higher resolution (6 inch) was acquired during 2008. High-resolution satellite imagery refers to the recent generation of satellite sensors that have a spatial resolution of less than five meters. A high spatial resolution is necessary to capture the spatial variability of the small and irregularly shaped vegetation communities that are typical of wetlands in the GEA. Multispectral imagery denotes imagery with a small number of broad spectral bands (generally three to seven). In this project, the imagery provided bands in the blue, green, red and near-infrared (NIR) ranges of light. Multiple vendors provide an acceptable digital image product meeting these requirements. QuickBird and IKONOS data (Space Imaging - Thornton, Colorado) are both widely used to satisfy these requirements. Sensors flown on an aircraft platform can also produce high-resolution, multispectral data. Detail of the spectral and spatial characteristics of QuickBird data is given in Table 5.1.

Table 5.1 – Specifications of project imagery.

Color/ Band	QuickBird
Blue	450 – 520 nm
Green	520 – 600 nm
Red	630 – 690 nm
NIR	760 – 900 nm
Panchromatic	450 – 900 nm
Spatial resolution	2.4 m 60 cm panchromatic

The imagery was delivered in the form of orthorectified GeoTiff raster files. Orthorectification of imagery results in a more spatially accurate product. The orthorectification was based on precisely located ground control points collected by project personnel and on a publicly available digital elevation model (DEM.) DigitalGlobe performed the orthorectification, and the root mean square error (RMSE) for the imagery orthorectification process was 2.1 pixels.

In previous studies in 2004 and 2005 imagery was collected for three dates in April, May and June. Image collection was timed to represent different stages of growth throughout the growing season. Late April images capture seedlings and perennials in wetland basins, and verdant uplands vegetation. May imagery was timed to coincide with the maximum growth period for wetland basins, following the first summer irrigation, usually late May to early June (Lower, 2003; Poole, 2003.) The May imagery would therefore capture a mix of inflorescence and mature growth in the wetland basins, and a mix of inflorescence, verdant growth, and seeding in the uplands vegetation. June imagery was designed to capture inflorescence, mature growth, and seeding in the wetlands basin, and seeding and senescence in the uplands vegetation. For the current project imagery was collected in May and June each year for 2006, 2007 and 2008 owing to budget constraints and the fact that crown closure was often poor for swamp timothy in April.

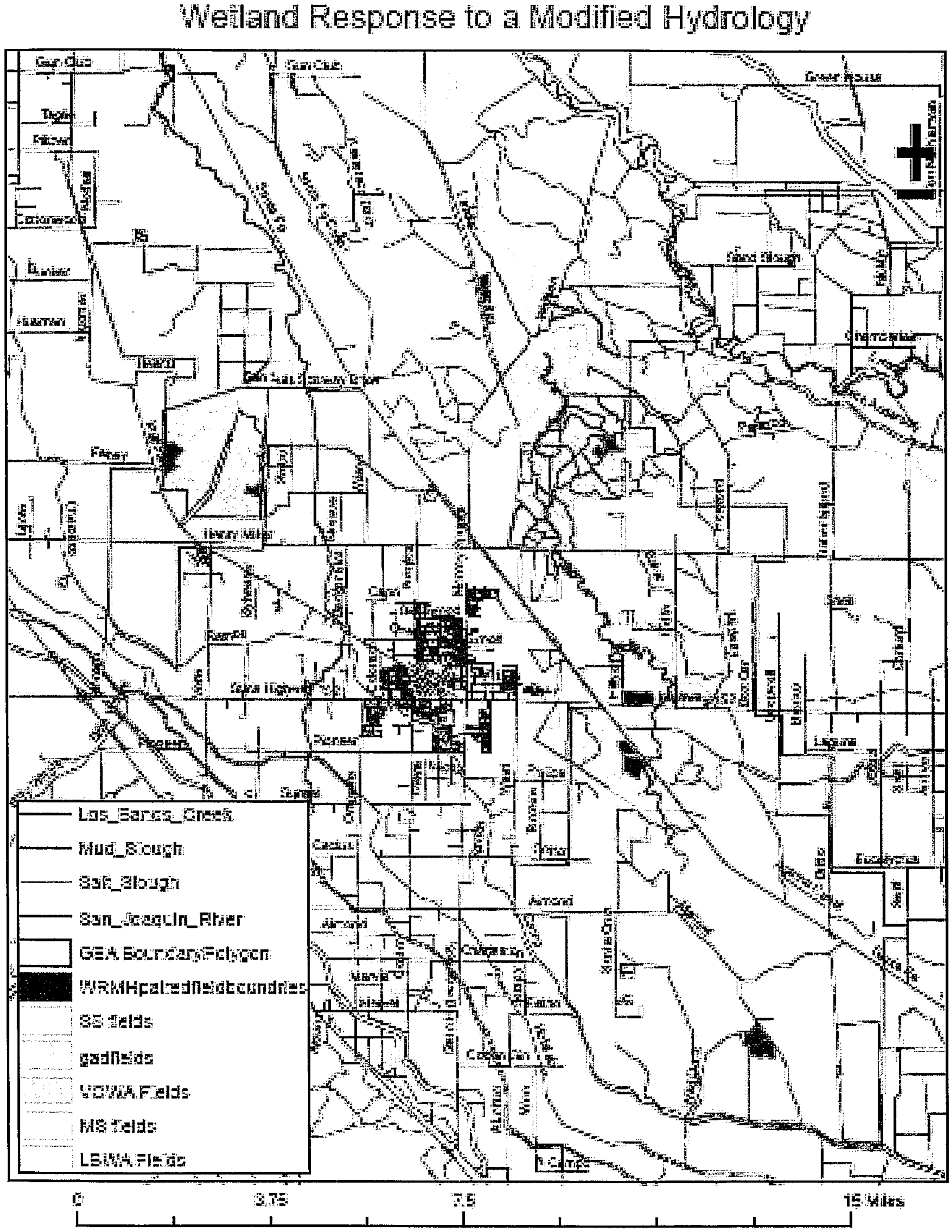


Figure 5.1. Grasslands Ecological Area showing the wetland areas targeted during the last remote sensing data acquisition campaign. During this survey performed by aircraft by the University of Utah image resolution was 6 inches. The following graphics show more details of the imagery acquisition campaign.

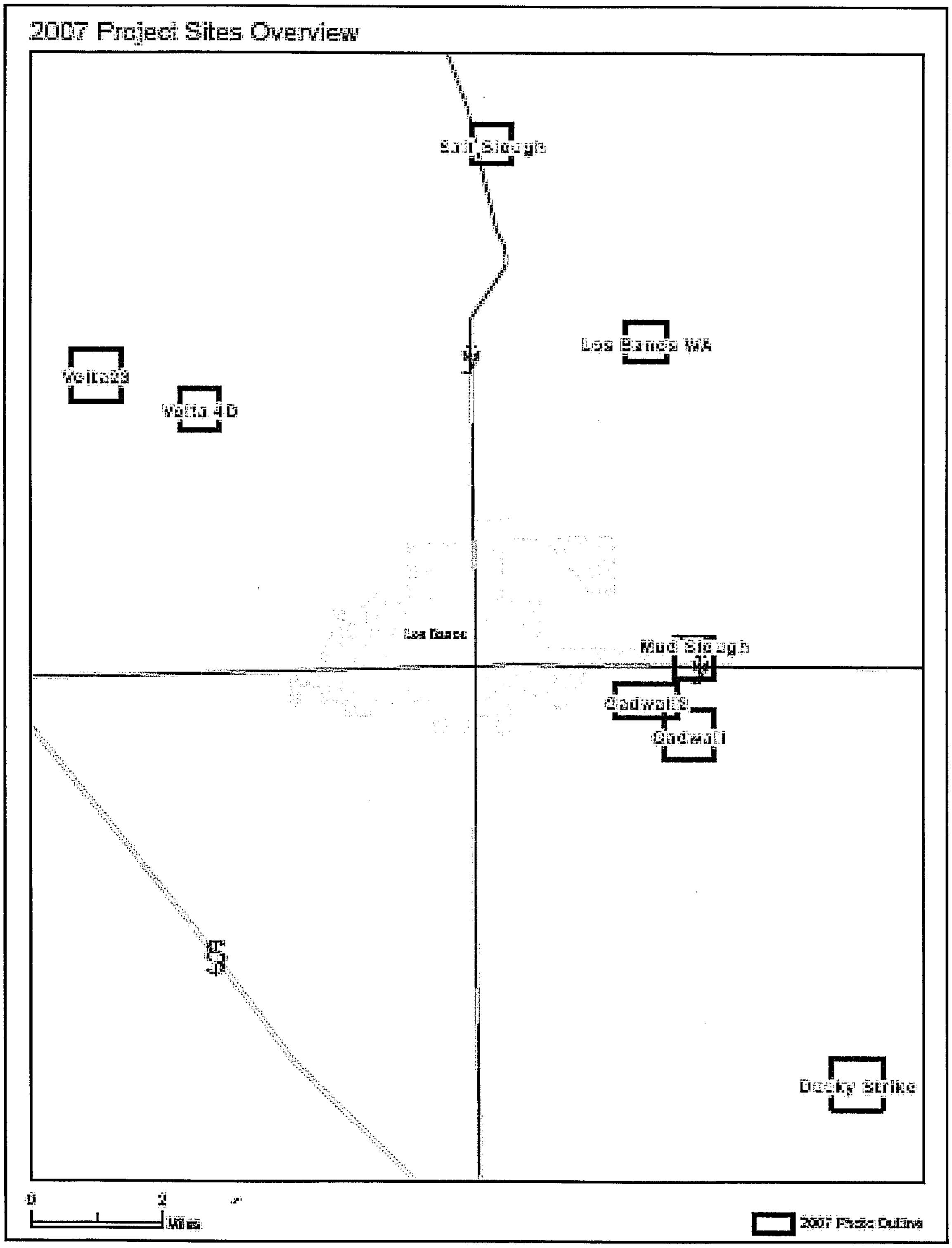


Figure 5.2. Remote sensing imagery flight campaign in 2008 based on 2007 flown imagery.

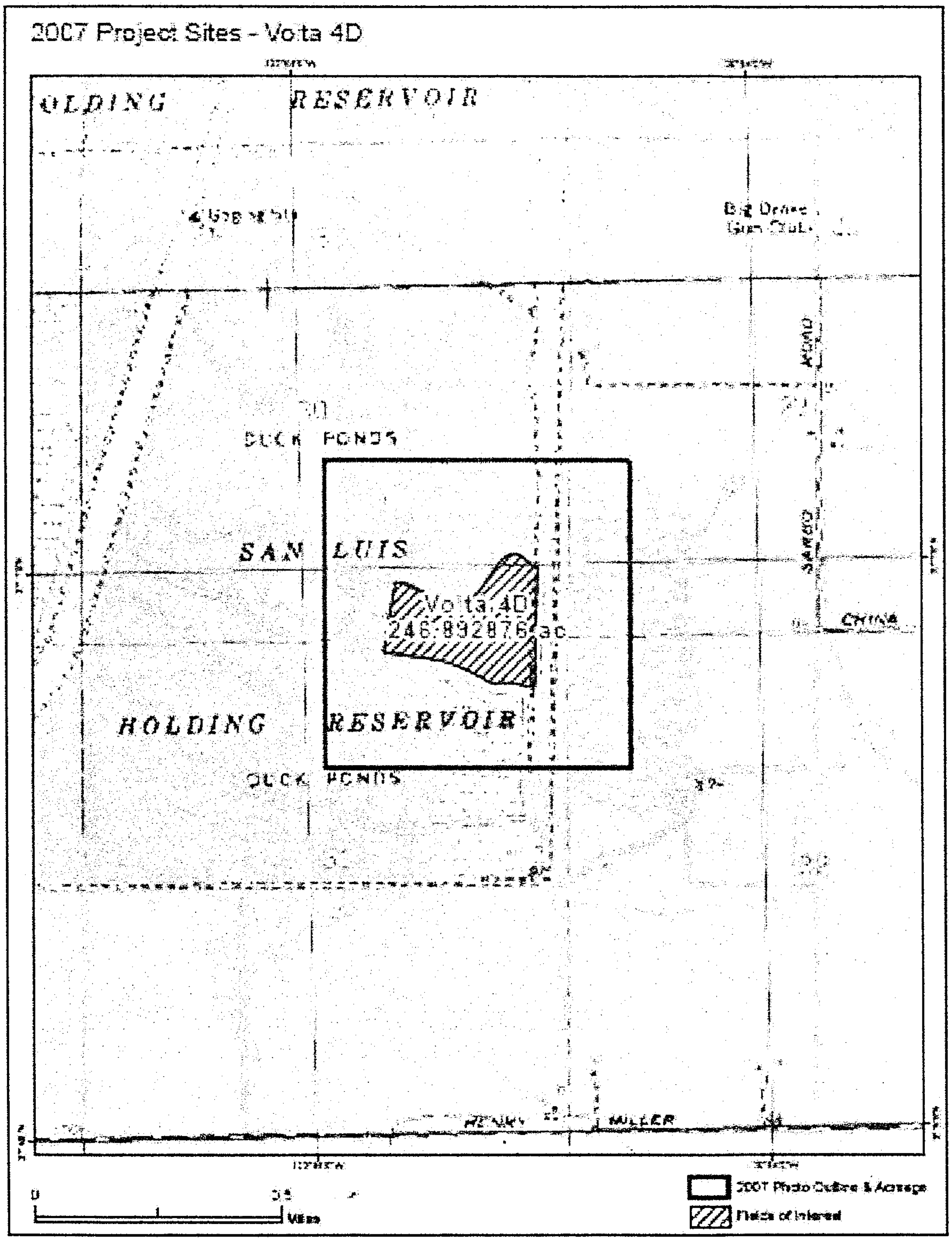


Figure 5.3. Remote sensing imagery flight campaign for Volta pond 4D within the Volta WMA.

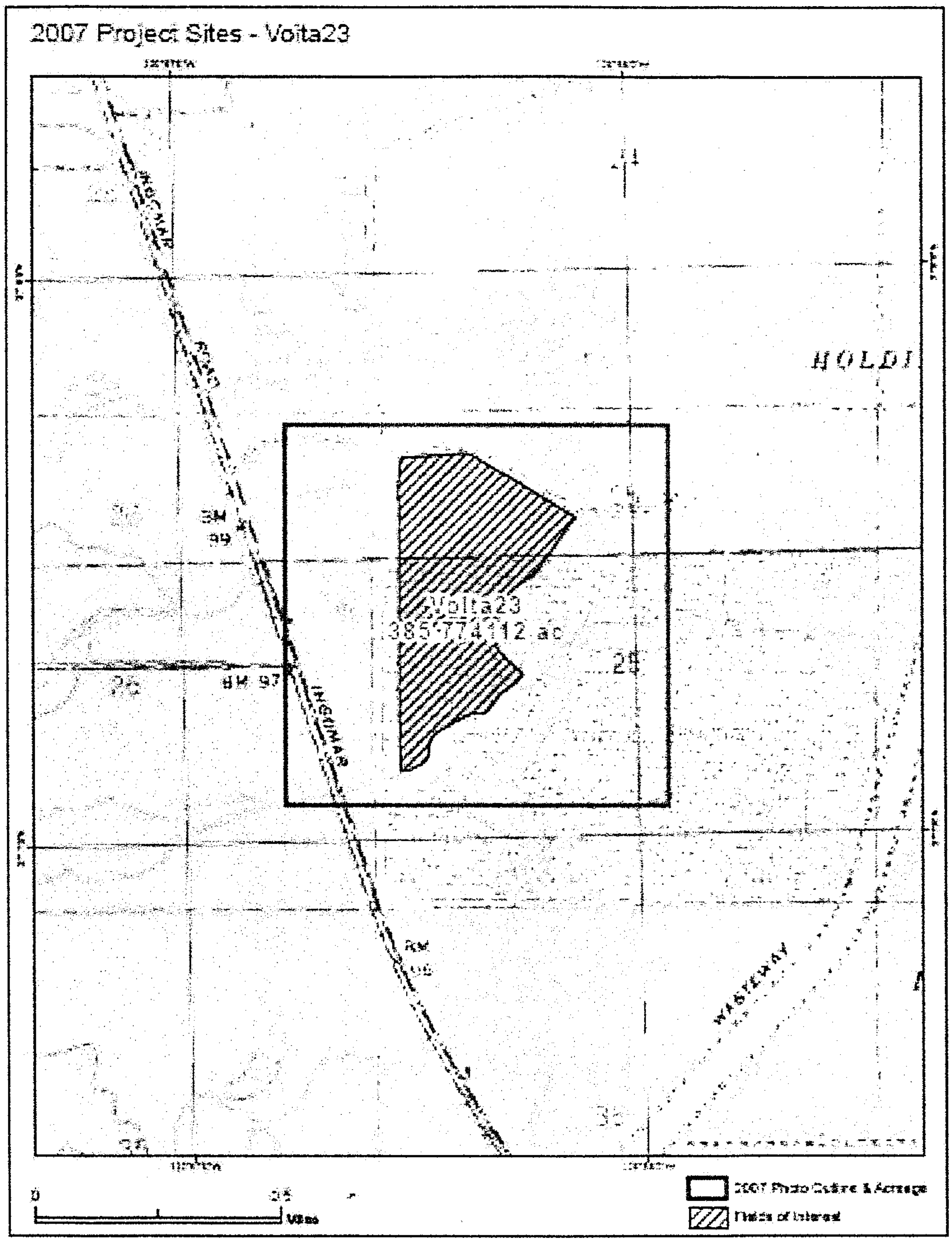


Figure 5.4. Remote sensing imagery flight campaign for Volta pond 23 within the Volta WMA.

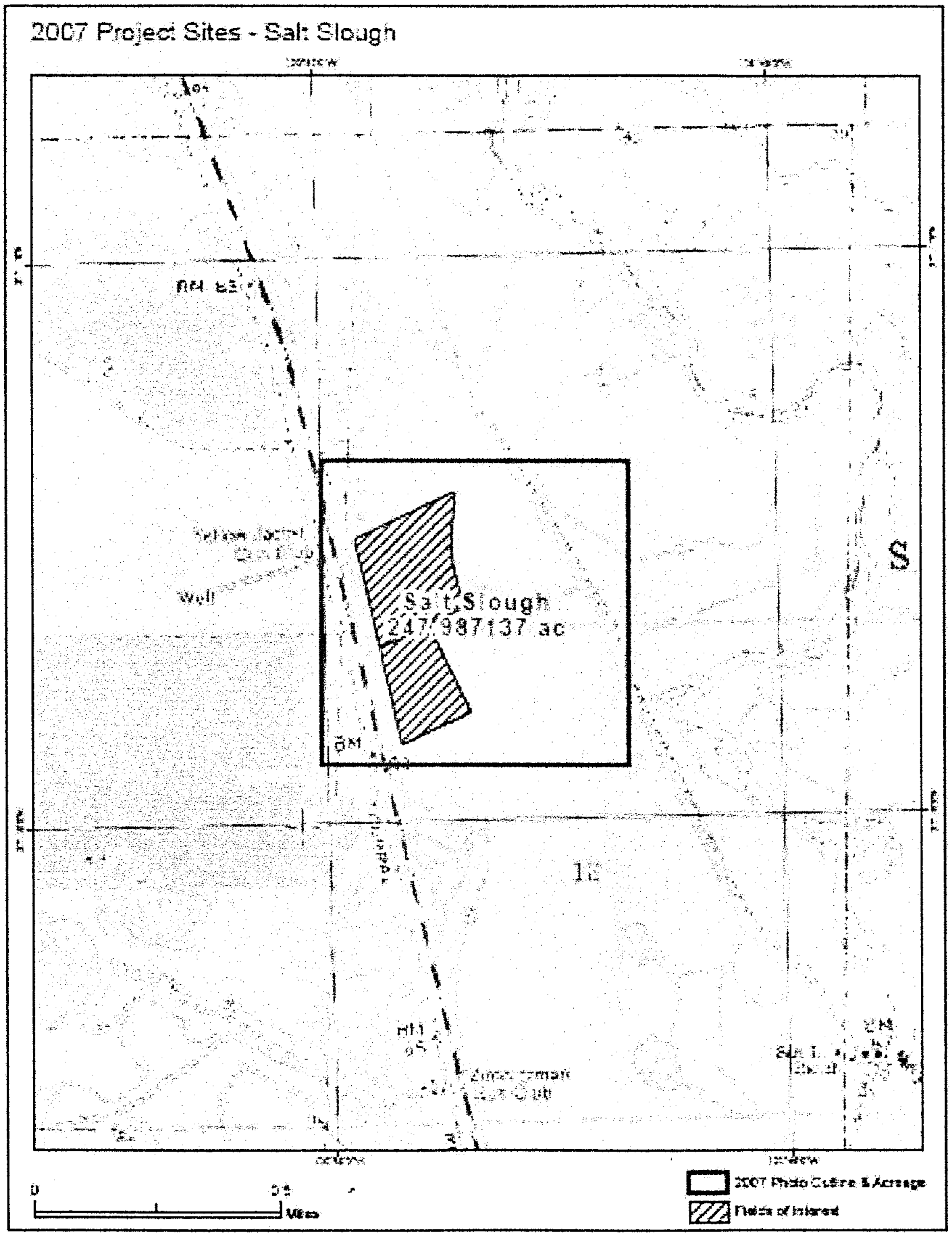


Figure 5.5. Remote sensing imagery flight campaign for Salt Slough Unit ponds 32 and 24 within the Los Banos Wildlife Management Area.

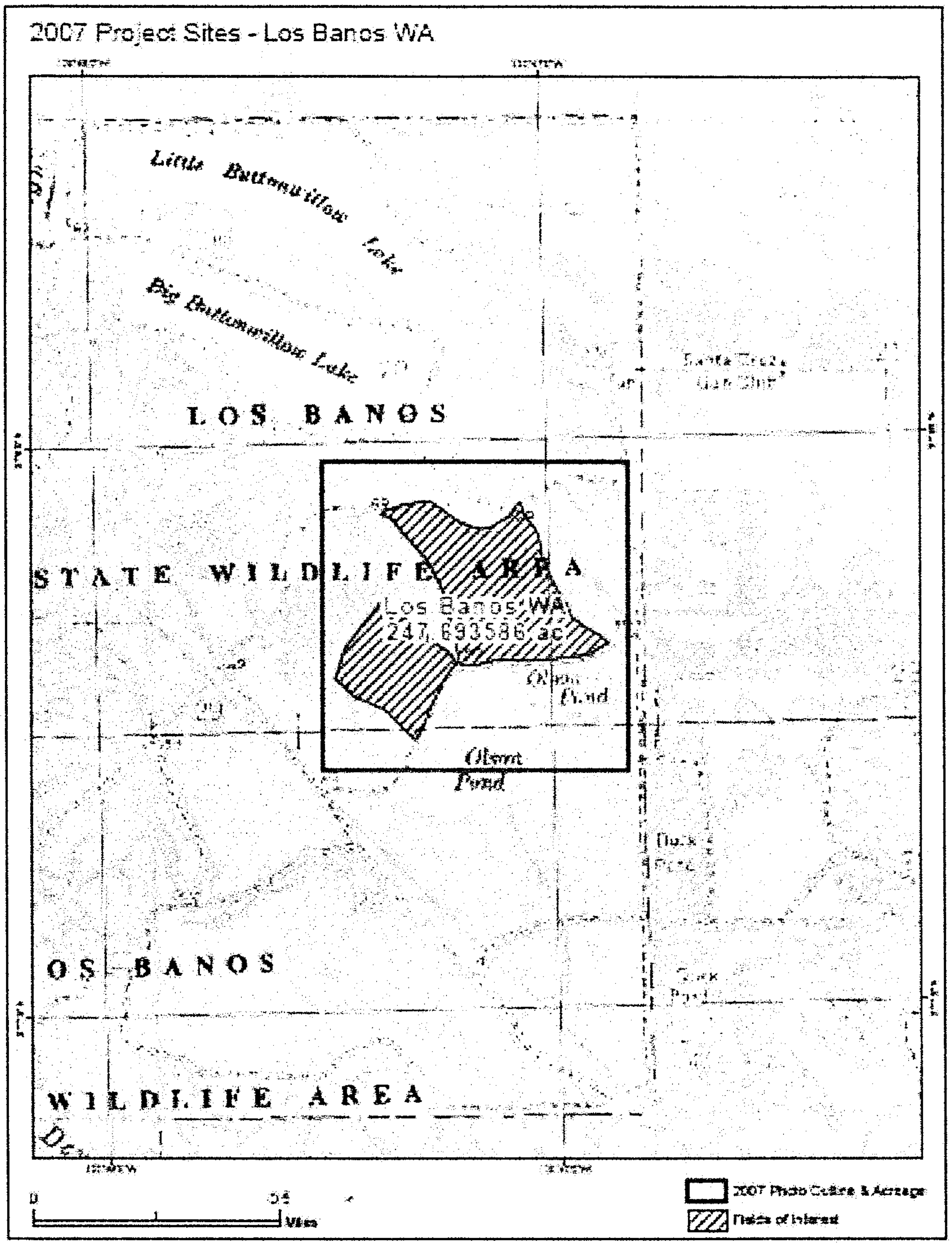


Figure 5.6. Remote sensing imagery flight campaign for ponds 31B and 32 within the Los Banos Wildlife Management Area.

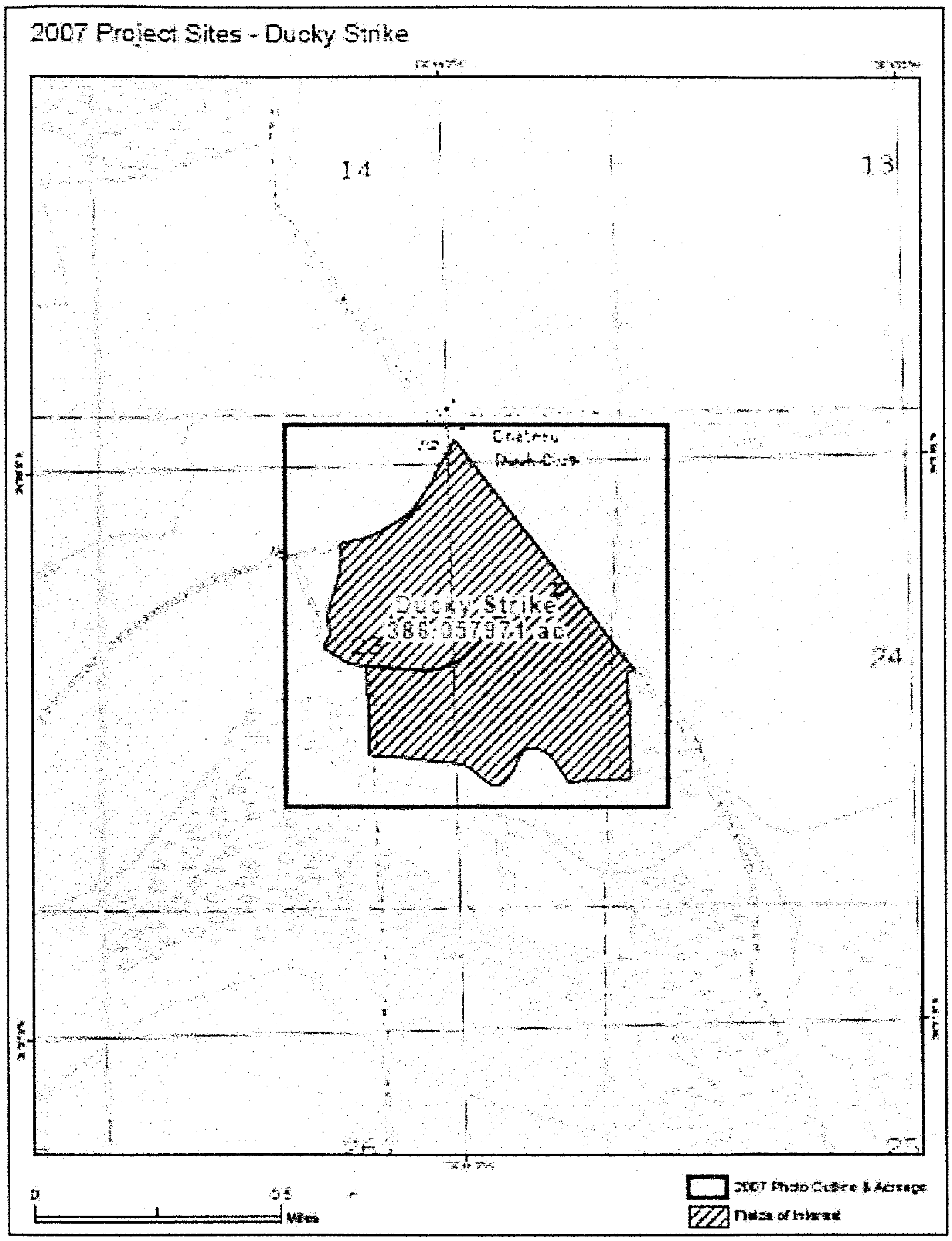


Figure 5.7. Remote sensing imagery flight campaign for the Ducky Strike Duck Club – north and south ponds within the South Grassland Water District.

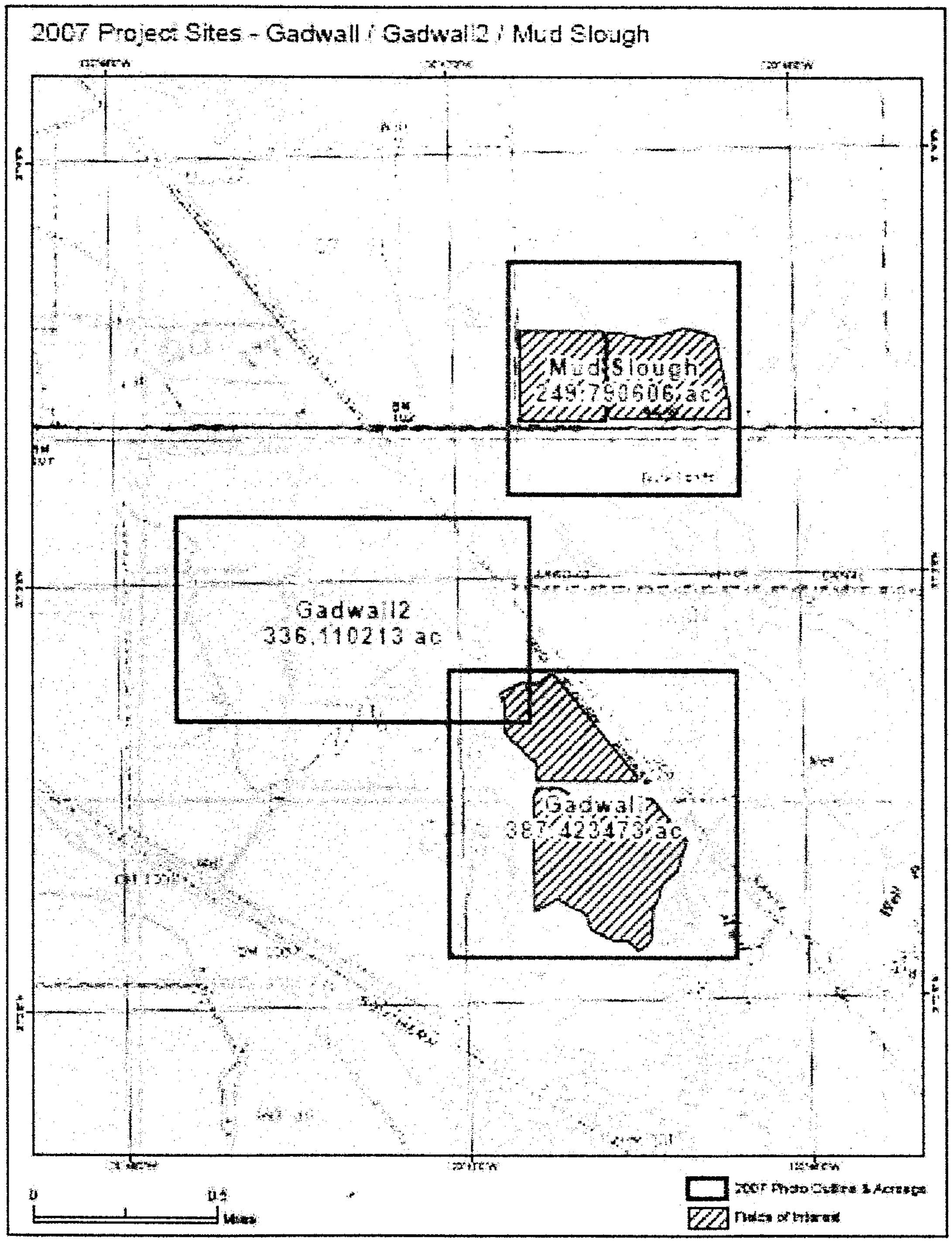


Figure 5.6. Remote sensing imagery flight campaign for ponds 5 and 6 within the Gadwall Unit and for ponds 3B and 4B within the Mud Slough Unit. The Bowen weather station is located to the north and west of the Gadwall pond 6.

5.2.3 Data acquisition – ground-truth surveys

A detailed description of the use of high resolution remote sensing data for wetland moist soil plant vegetation mapping is provided in the report, previously described by Quinn et al. (Quinn et. al., (2006), based on three years of experiments using the E-Cognition and ERDAS Imagine software. The report provides results of the analysis performed to compare remote-sensing based interpretation of high resolution imagery with ground truth data, collected a two different times post-drawdown for a period of three years. One of the more significant findings made during this study was that the initial hypothesis that unique spectral signature files could be developed and used continuously to classify wetland moist soil plant associations was shown to be invalid. Had it been possible to develop these unique spectral signatures - this could have led to easy automation of remote sensing analysis to produce accurate maps of wetland moist soil plant associations – supporting change detection analysis for problems such as the invasion of non-native plant species and allowing it to be performed at relatively low cost. In reality the study found that moist soil associations could change radically in composition from year to year as a function of seasonal weather patterns that affect soil temperature, moisture and salinity. Hence extensive ground-truthing is most likely necessary every year to ensure accurate classification and mapping of moist soil plant vegetation.

For the current project a modification of the California Native Plant Society's (CNPS) Rapid Assessment Protocol (RAP), co-developed by the California Department of Fish and Game (CNPS, 2003) was used to perform ground-truth surveys of moist soil plant associations. The RAP is accepted widely for similar applications throughout California. The California Native Plant Society, the California Department of Fish and Game, California State Parks, National Parks, other State and Federal agencies, and consulting firms all use this methodology to quickly and quantitatively inventory and map vegetation types for projects throughout California. For example, it is being used in conjunction with a Wildlife Habitat Relationships (WHR) Validation study at Point Reyes National Seashore. It is also being used to inventory and map vegetation for prioritization of conservation sites in the Los Angeles and San Gabriel River watersheds, Napa and Riverside Counties (CNPS, 2003).

The CNPS RAP employs a community-based approach to surveying. In its original format, the CNPS RAP uses a one-page worksheet to rapidly assess large landscapes for a number of important parameters. These parameters include location and distribution of vegetation types and communities, composition and abundance information on the member plant species, and general site environmental factors. The RAP also provides guidance for identifying characteristics such level of community disturbance (CNPS, 2003). The RAP is useful for collecting basic quantitative information sufficient for identification and verification of habitats. It can be used for rapid inventory of habitats in any natural or other management area. Thus, this method can provide wetland managers with efficient tools for natural resource inventorying and planning (CNPS, 2003).

Modifications were made to the CNPS protocol that reflected the needs and particular focus of this study. For example, in this project's field surveys, field protocols ignored the CNPS's emphasis on native species and placed equal weight on cataloging important non-native species. Because of the availability of detailed soils maps for the area, the time-consuming soil classification technique used by the RAP was replaced by existing soil survey data. Other minor modifications included the addition of new data fields, such as annotating the presence of visible salts, as it was perceived that this could have an effect on the spectral response of the landcover. The traditional RAP vegetation worksheet was programmed into a hand-held GPS computer. A Trimble GeoExplorer 3 GPS was programmed with the data fields necessary to define a community, so that the collection of GPS positions would be automatically tied to attribute data for each data point. The vegetation database was programmed with comprehensive, predefined pull-down menus wherever possible in order to standardize and streamline the entry of field data. The development of this computer-based data collection system made it possible to collect considerably more field data in comparison with previous projects.

5.2.4 Ground truthing surveys and imagery classification

Ground truthing of remotely sensed imagery is the process of collecting *in situ* data that tie the spectral values in the imagery to land cover on the earth's surface. Ground truth data may be used both as input to the classification process and, once classification is complete, to check the accuracy of interpretation. Ground truth data was collected during the days shortly before, during, and after the satellite fly-overs to ensure maximum correlation between field data and the recorded image. Ground truth data was collected primarily on the San Luis unit of the SLNWR. Because of a related project ongoing at NGWD, additional ground truth data was collected from the Salinas Land and Cattle Club (Salinas Club), a privately owned area of approximately 1,600 acres, during the same time period.

Ground truth data were post-processed for improved accuracy and utility. GPS feature positions were post-processed via differential correction to improve the accuracy of feature locations. Differential correction utilizes data from a regional base station with a known, fixed location to correct for GPS errors that may be introduced via satellite error, transmission error, or atmospheric effects. Differential correction was performed using Trimble Pathfinder Office software and using cotemporaneous base station data from the National Geodetic Survey Continuously Operating Reference Stations (NGS CORS.) Following differential correction, the data was exported to ESRI (Redlands, CA) shapefile format. The feature attribute data was then analyzed using ESRI's ArcGIS software to identify the two dominant species in each vegetation community. The field data could then be applied to classification of the images.

In a few cases, ground truth points were selected after the fact based on analyst interpretation of the images. Data points were selected this way for the land cover classes of trees, water, and buildings. Each of these land cover types is easily identifiable through visual analysis of the image, and difficult to obtain values for in the field. (For example, to obtain a ground truth point for open water, you either have to find a boat, or go stand in the middle of a pond.) Collecting points in this way involves a negligible risk of error on the part of the analyst and ensures adequate data to compile a robust spectral signature for these classes.

5.2.5 Pixel-based image processing

Pixel-based image processing and data analysis was performed using software routines provided by ERDAS Imagine. Other off-the-shelf commercial image processing packages are available that perform comparable analyses. A supervised classification technique – whereby data input by an analyst is used to determine seed values for classes – was selected for classification of the images. Maximum likelihood classification is a standard industry algorithm for projects where adequate ground truth data has been collected. This technique requires the input of "training" data, with which software algorithms define statistically-based spectral bounds for each class. Training data is derived from ground truth points; in this case, the analyst has defined an area around each ground truth point representative of that community of vegetation, and the image processing software compiles statistics that uniquely describe the spectral values for that community. Multiple ground truth points are combined into a robust spectral signature for a single land cover class, and this process is repeated until the analyst has created a signature for all desired land cover classes. After all training data has been entered into the spectral signature file, the classification algorithm is implemented. The maximum likelihood algorithm uses the defined spectral signatures to extrapolate from the training pixels to all the pixels in the image. This is an efficient process, resulting in the use of data from a few thousand pixels to classify an entire image comprised of tens of millions of pixels. Every pixel is assigned to a class – the class it is "most likely" to belong to, even if the pixel's spectral values fall outside the initial seed values.

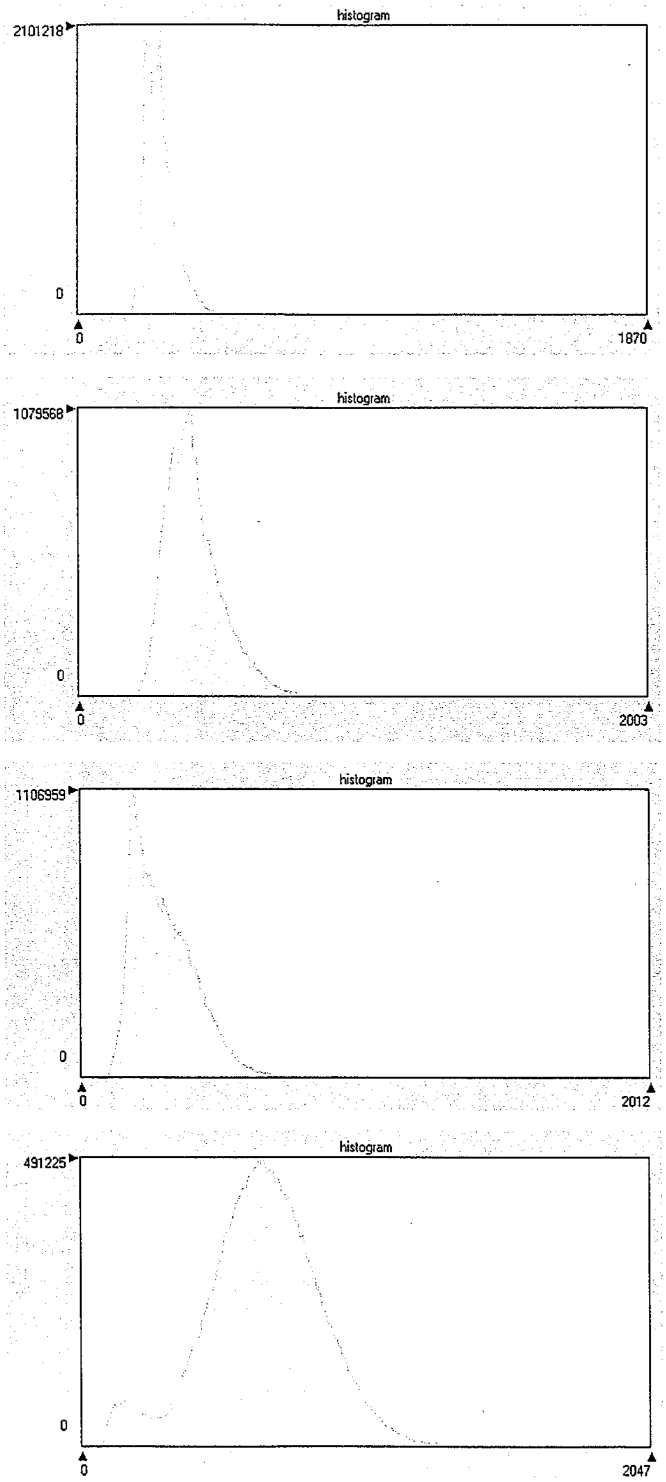


Figure 5.7. Histograms for Bands 1, 2, 3, and 4 (top to bottom) for project multispectral imagery. The X-axis displays the spectral value, and the Y-axis displays the number of pixels exhibiting the value in that band. The histograms show the range of spectral values present in the satellite imagery.

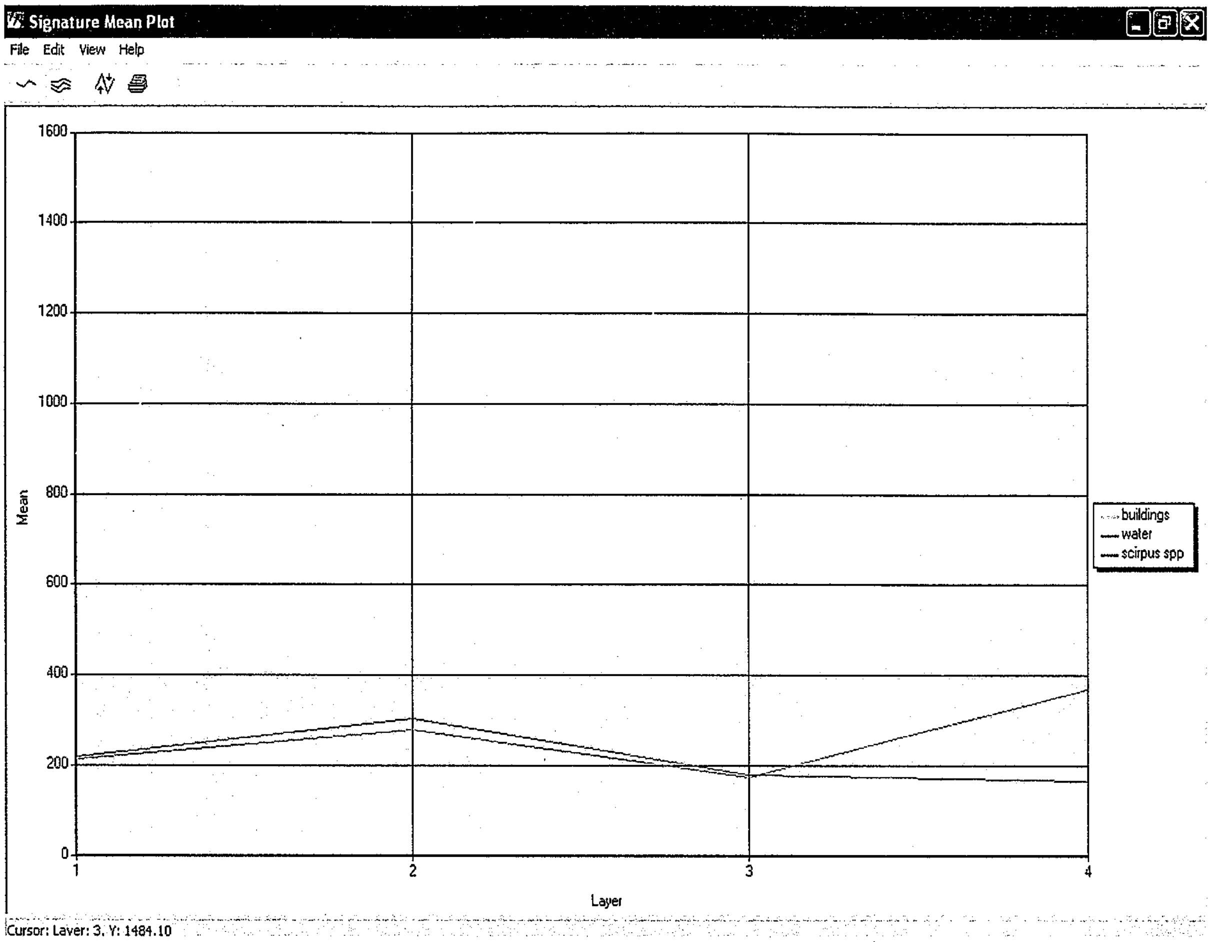
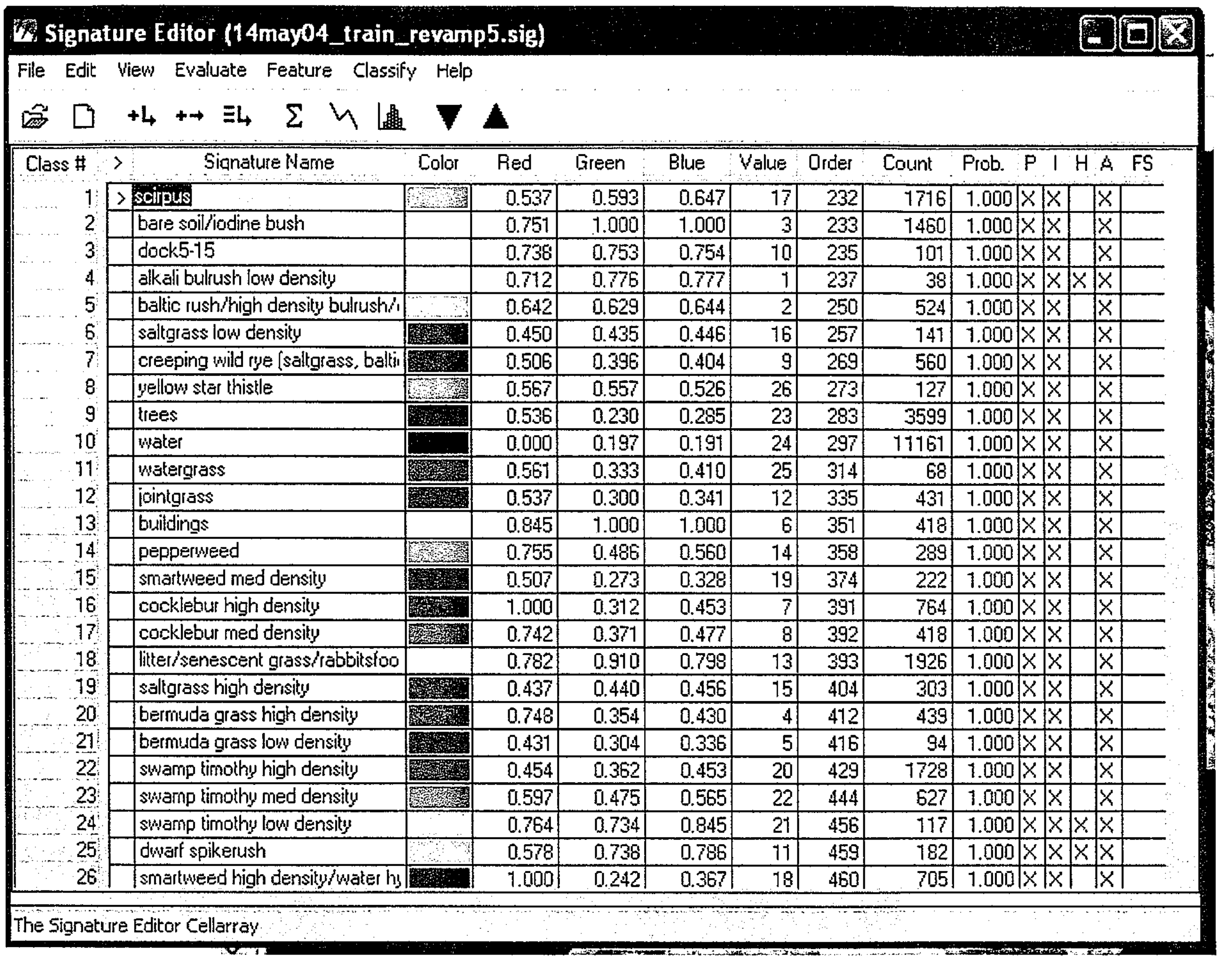


Figure 5.8. Mean values of the training signatures of three land cover classes for May imagery. Buildings are considerably brighter in all four bands. Water and scirpus spp take on similar mean values in bands 1, 2, and 3 (blue, green, and red), however scirpus spp is brighter in band 4 (near-infrared.)

The start point for classification - a statistical representation of the raw imagery data - is shown in Figure 5.7. This figure shows four histograms, one for each spectral band in the imagery for May. The histogram shows the statistical distribution of spectral values. For each band, the spectral values (or digital number, DN) are given on the X-axis, and the number of pixels exhibiting that value is graphed on the Y-axis. Spectral values near the peak of the curve will be most common in the imagery. The histogram describes the statistical distribution of values within a band, but says nothing about the relationships between bands. Pixels that are bright (high spectral value) in one band may be dark in another.

An introduction to the relationship between bands is shown in Figure B11. Here, the mean values for the training signatures of three land cover classes – buildings, water, and scirpus spp – are shown for the four multispectral bands. Maximum likelihood classification also accounts for the range and co-variance of spectral signatures, however, it can be seen in this figure that these three classes may be separable based solely on the mean. Scirpus spp and water have similar means in bands 1, 2, and 3. However, scirpus is significantly brighter in band 4, due to the response of chlorophyll in this band. These three land cover classes were chosen for ease of illustration. As a general rule, land cover classes comprised of individual plant species will appear more similar and will be more challenging to separate.



Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	scirpus		0.537	0.593	0.647	17	232	1716	1.000	X	X		X	
2		bare soil/iodine bush		0.751	1.000	1.000	3	233	1460	1.000	X	X		X	
3		dock5-15		0.738	0.753	0.754	10	235	101	1.000	X	X		X	
4		alkali bulrush low density		0.712	0.776	0.777	1	237	38	1.000	X	X	X	X	
5		baltic rush/high density bulrush/		0.642	0.629	0.644	2	250	524	1.000	X	X		X	
6		saltgrass low density		0.450	0.435	0.446	16	257	141	1.000	X	X		X	
7		creeping wild rye (saltgrass, balti		0.506	0.396	0.404	9	269	560	1.000	X	X		X	
8		yellow star thistle		0.567	0.557	0.526	26	273	127	1.000	X	X		X	
9		trees		0.536	0.230	0.285	23	283	3599	1.000	X	X		X	
10		water		0.000	0.197	0.191	24	297	11161	1.000	X	X		X	
11		watergrass		0.561	0.333	0.410	25	314	68	1.000	X	X		X	
12		jointgrass		0.537	0.300	0.341	12	335	431	1.000	X	X		X	
13		buildings		0.845	1.000	1.000	6	351	418	1.000	X	X		X	
14		pepperweed		0.755	0.486	0.560	14	358	289	1.000	X	X		X	
15		smartweed med density		0.507	0.273	0.328	19	374	222	1.000	X	X		X	
16		cocklebur high density		1.000	0.312	0.453	7	391	764	1.000	X	X		X	
17		cocklebur med density		0.742	0.371	0.477	8	392	418	1.000	X	X		X	
18		litter/senescent grass/rabbitsfoo		0.782	0.910	0.798	13	393	1926	1.000	X	X		X	
19		saltgrass high density		0.437	0.440	0.456	15	404	303	1.000	X	X		X	
20		bermuda grass high density		0.748	0.354	0.430	4	412	439	1.000	X	X		X	
21		bermuda grass low density		0.431	0.304	0.336	5	416	94	1.000	X	X		X	
22		swamp timothy high density		0.454	0.362	0.453	20	429	1728	1.000	X	X		X	
23		swamp timothy med density		0.597	0.475	0.565	22	444	627	1.000	X	X		X	
24		swamp timothy low density		0.764	0.734	0.845	21	456	117	1.000	X	X	X	X	
25		dwarf spikerush		0.578	0.738	0.786	11	459	182	1.000	X	X	X	X	
26		smartweed high density/water hy		1.000	0.242	0.367	18	460	705	1.000	X	X		X	

Figure 5.9. Spectral signature file. Each class is the result of compositing training data for numerous ground truth points. The total number of pixels included in each class is displayed in the "Count" column. The color swatch, used for visualization only, is derived from the average values of all pixels comprising that class, based on the color mapping used in the display window. Since near-infrared is mapped to red in the display window vegetation tends to appear red.

The final spectral signature file used for the May imagery is shown in Figure 5.9. Note that this figure shows only display values for the different land cover classes; the statistical description of each class is too complex to display in a single view. The color patches and RGB values shown in the signature file correspond to the average tone of that land cover type, as it is displayed in the working window.

Through a complex process of signature refinement, individual training signatures (Figure 5.9) evolve into the final class signature file that is used to classify the image. The class signatures are based on multiple single signatures added together in proportion to the number of pixels each represents. After signatures are compiled for each class, they may be evaluated for separability. There are several tools that may be used for this evaluation. Separability here is calculated in all four image bands, using a measure of the spectral distance between classes known as transformed divergence. Transformed divergence ranges in value from 0 to 2000, and values over 1500 are considered to be separable. If classes are insufficiently separable, the analyst may choose to combine classes, to add more training data, or to cull some training data before repeating the evaluation of signature separability.

5.2.6 Object-based image processing

Definiens e-Cognition software is an advanced, object-based image processing package providing specialized algorithms not currently available in traditional (pixel-based) image processing packages. For the purposes of this project, e-Cognition was used in conjunction with ERDAS Imagine Professional software to apply a maximum likelihood classification to landscape objects in the form of polygons. E-Cognition uses spectral and shape characteristics of the raw imagery to separate pixels into self-similar landscape objects. This correlates well with viewing the landscape in terms of vegetation communities, or in terms of homogenous landcover classes such as roads or water. Polygon objects created using eCognition were used later in the study to compare a landscape-object based approach to a pixel-based approach in using the maximum likelihood classifier. A close up of the raw imagery divided into landscape object polygons is shown below in Figure 5.10.

5.2.7 Image processing accuracy assessment

Accuracy assessment was performed through standard calculations using randomly selected ground truth points that had been set aside especially for this purpose. Check points, as this type of ground truth points are typically called, are not used in creating training signatures. Therefore, they form a reliable, independent dataset for classification verification. The number of checkpoints ranged from 79 to 131 for the first and second fly dates – typically late April or early May and early June.

Accuracy assessment was evaluated using two industry-standard metrics: producer's accuracy and user's accuracy. Producer's accuracy is the ratio of the number of correctly classified check points in a class to the total number of reference check points in that class. User's accuracy is the ratio of the number of correctly classified check points in a class to the total number of reference check points that were classified as the target class. This metric is a measure of commission error and represents how likely it is that an imagery pixel assigned to that class is actually a member of that class.

5.2.8 Vegetation identification

Over fifty species of wetlands and uplands vegetation were identified during the three years of conducting wetland moist-soil plant surveys. Of these, only species with sufficient presence to dominate numerous communities were included in the classification schema. Species that were present only at a low density in observed communities, or were dominant only in small, rare pockets of the landscape, were not included in the classification. Table 5.3 provides a listing of dominant species, their scientific names, and the common names. Separate training signatures were created for and applied to the May and June imagery as a result of the analysis described earlier. The April imagery was determined to have captured growth too early in the season to provide adequate differentiation of many species, especially moist soil plants, and was not used to create vegetation maps. (It was, however, used in the process of creating landscape object polygons in e-Cognition.)

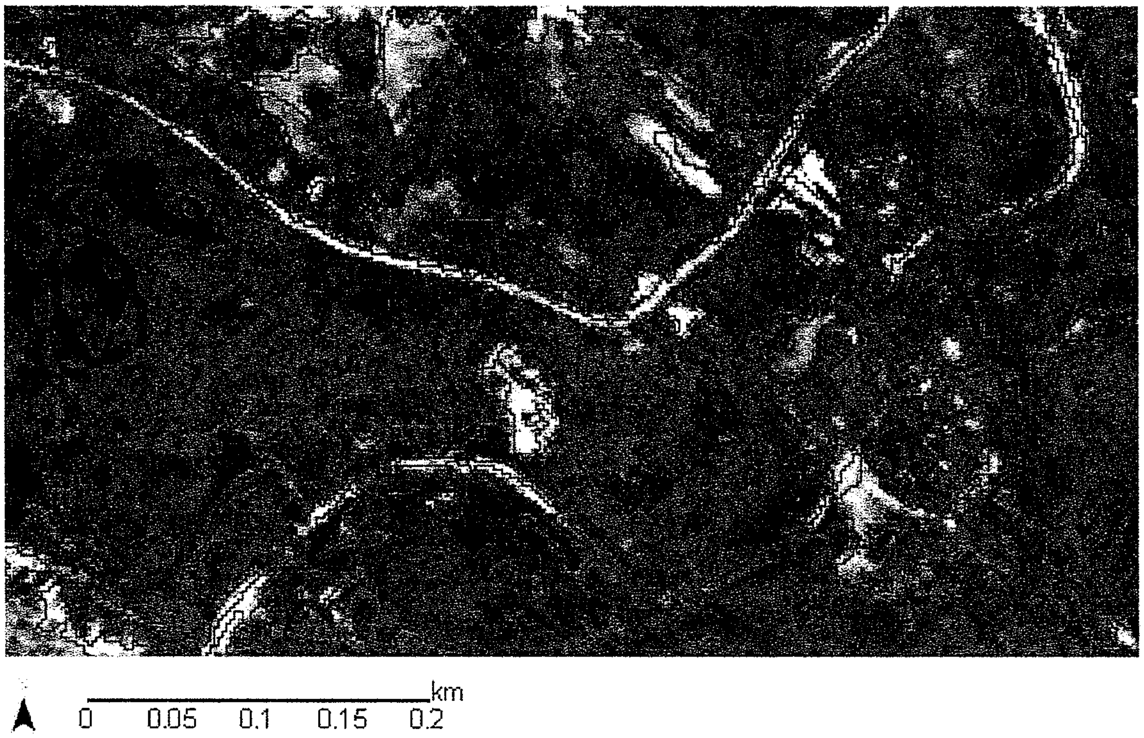


Figure 5.10. Close-up image showing eCognition's automated segmentation of the landscape into polygon objects. Polygons are limited to a maximum heterogeneity based on spectral characteristics, object compactness, and smoothness of their borders. Polygons were created using data from the April, May, and June images, reflecting that vegetation communities develop over the growing season. The May imagery is used as the backdrop for this figure.

Table 5.2. Classified vegetation species

Allenrolfea occidentalis	Iodinebush
Bromus diandrus	Ripgut brome
Bromus hordeaceus	Soft brome
Centaurea solstitialis	Yellow starthistle
Cressa truxillensis	Alkali weed
Crypsis schoenoides	Swamp timothy
Cynodon dactylon	Bermuda grass
Cyperus esculentus	Chufa
Distichlis spicata	Saltgrass
Echinochloa crusgalli	Watergrass
Eleocharis spp.	Spikerush

Frankenia salina	Alkali heath
Hordeum jubatum	Foxtail barley
Hordeum murinum	Hare barley
Juncus balticus	Baltic rush
Leymus triticoides	Creeping wildrye
Lotus corniculatus	Trefoil
Paspalum distichum	Jointgrass
Polygonum lapathifolium	Pale smartweed
Polypogon monspeliensis	Rabbitsfoot grass
Rumex spp.	Dock
Scirpus maritimus	Alkali bulrush
Scirpus spp.	Scirpus
Sporobolus airoides	Alkali sacaton
Typha spp.	Cattail
Xanthium strumarium	Cocklebur

Training signatures primarily were developed using ground truth data collected in close temporal association with each satellite fly-over. However, in some cases it was recognized that data from the adjoining months could be used to increase the amount of data used in signature development, and therefore to improve the robustness of the spectral signatures. In most cases, vegetation communities have some stability from month to month. When data from an adjoining time period was used, the point was individually inspected in both months to ensure that the vegetation community appeared stable. When a large degree of change was apparent, the point was not used for that month's analysis.

Land cover classes developed for May and June were similar but not identical. New land cover classes were added to June and old ones removed based on their observed presence or absence in the field data. Both time periods offer an opportunity to optimally observe certain vegetation communities. There is no one perfect time of year to collect data on all land cover classes.

5.3 Results of habitat quantification and assessment analysis

The following section provides a qualitative and quantitative comparison of remotely sensed imagery flown in 2007. Charlotte Peters, GIS and Remote Sensing Specialist with the California Department of Fish and Game, Fresno provided considerable assistance in the analysis and interpretation of the 2007 multi-spectral imagery data and the following vegetation maps.

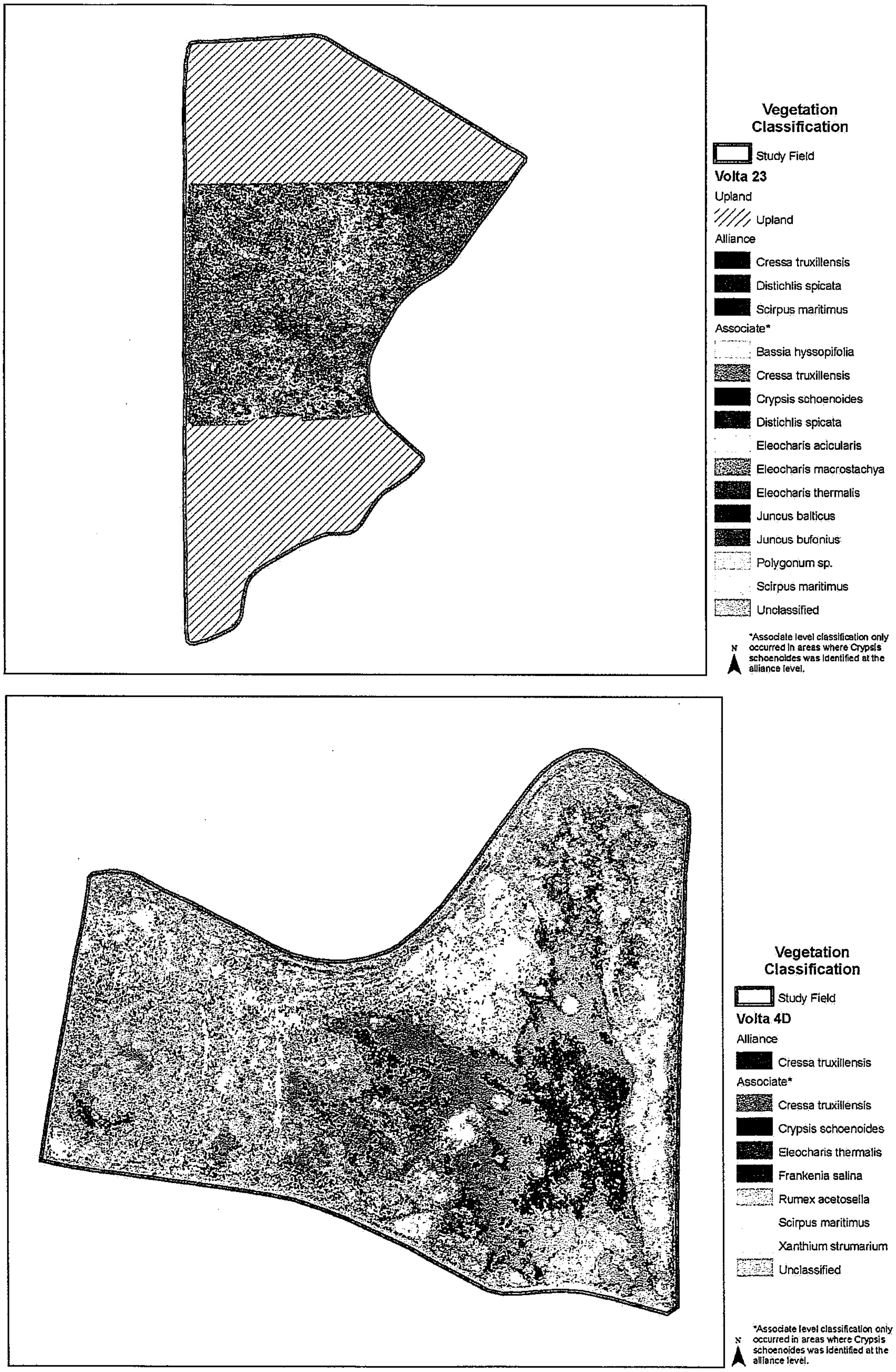


Figure 5.11. Vegetation classification for Volta ponds 23 and 4D during 2007.

Figure 5.12. Vegetation classification for Salt Slough ponds 32 and 24 during 2007.

Figure 5.13. Vegetation classification for Los Banos ponds 33 and 31B during 2007.

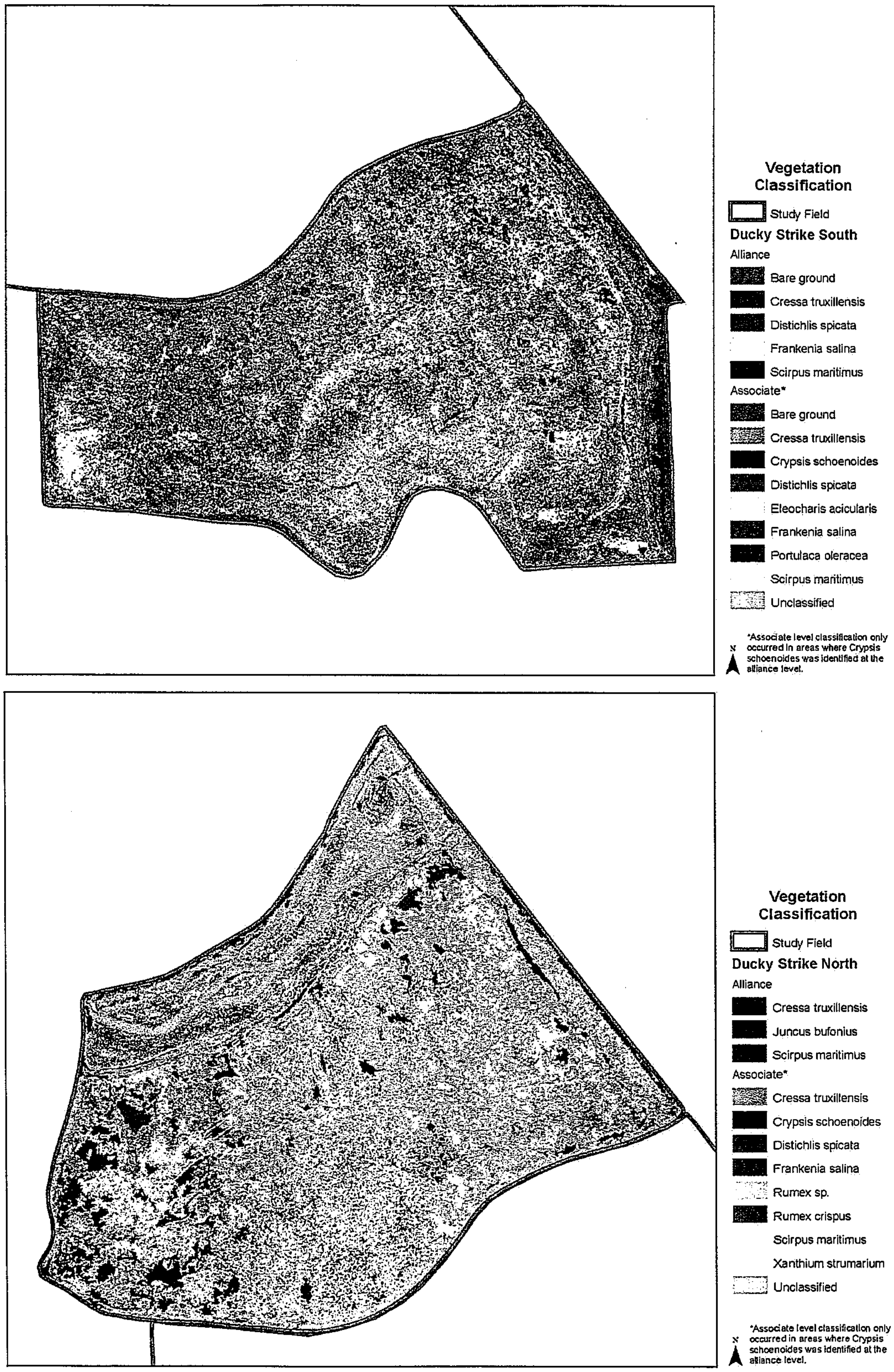


Figure 5.14. Vegetation classification for Ducky Strike south and north ponds during 2007.

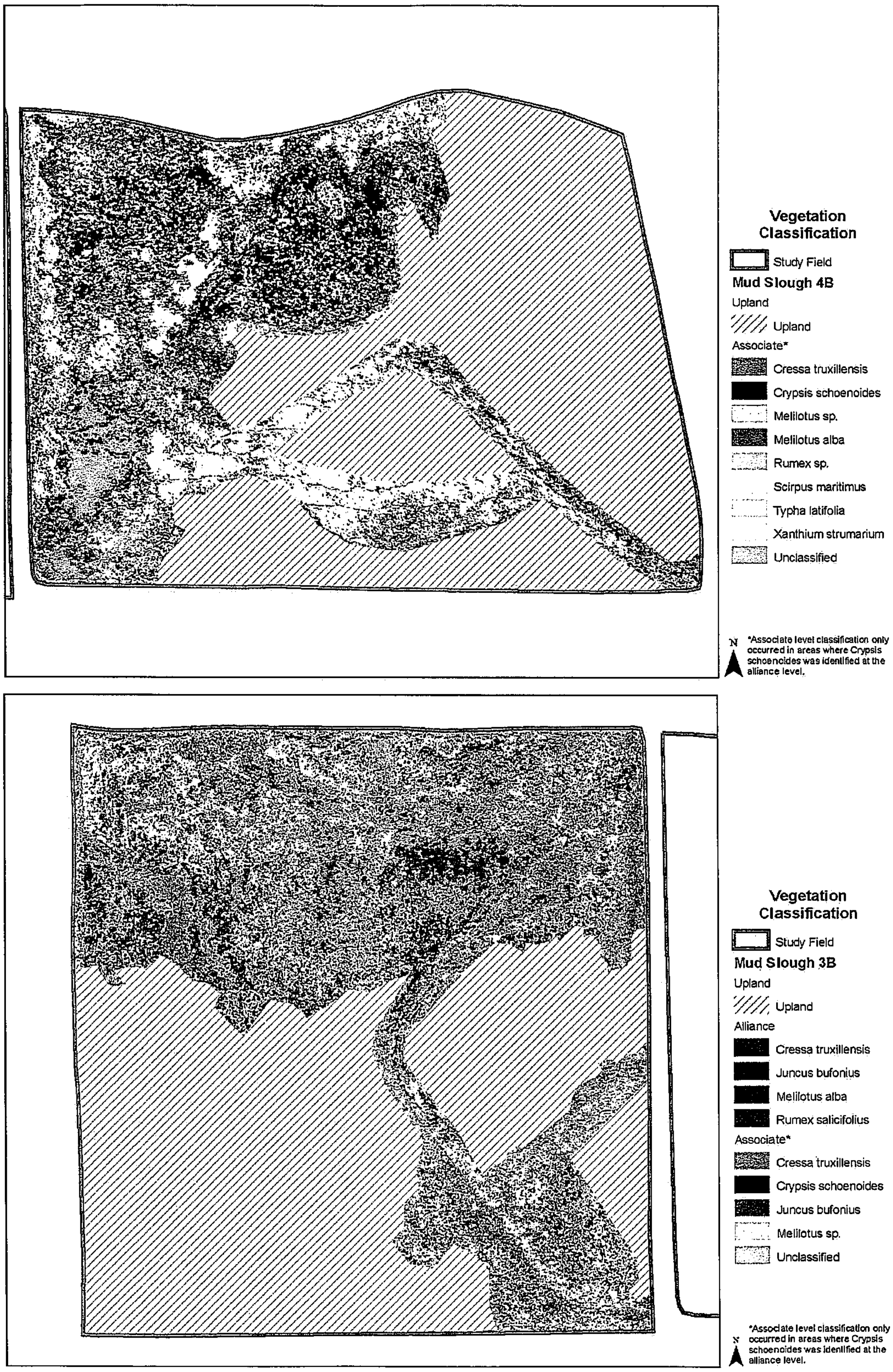


Figure 5.15. Vegetation classification for Mud Slough ponds 4B and 3B during 2007.

5.4 Summary and discussion

From the error matrices it appeared that the May imagery provided the most accurate assessment of land cover classes. The difference is not large, however, and both May and June provide considerable improvement over the preliminary results for analysis of imagery collected earlier in the year in April. An optimal date will also depend on yearly weather patterns, and on the timing of irrigations. (Ideally, imagery should be collected at a time when minimal land is flooded.) Mid-May through early June is recommended for future image data collections.

The error matrices showed that the compilation of individual pixels into landscape objects improved the accuracy for some classes and decreased it for others. The overall effect, for the parameters chosen, was a small decrease in accuracy. The size of the landscape objects is determined by an abstract parameter which sets the maximum allowable heterogeneity for a polygon, in terms of both spectral and shape characteristics. The scale parameter used in this study was 50. After visual review of the landscape objects created using this scale parameter, and completion of the formal accuracy assessment, it is suggested that a smaller scale parameter – and therefore smaller landscape objects - would yield improved results.

In considering the error matrix for the pixel-based May classification result, it was apparent that the classification performed well for a number of important species, among them alkali bulrush, cocklebur, scirpus, and swamp timothy. However, other important species were less accurately mapped, including bermuda grass, jointgrass, smartweed, and watergrass. Future work should emphasize ground data collection for these species, so that a robust spectral signature can be developed, and so that any mapping limitations are well understood. It should also be noted that open water was classified with a high degree of accuracy in all three maps. Accurately mapped water bodies could be used to improve calculations of open water evaporation for these wetland areas, thereby contributing to a quantitative understanding of water needs and water usage for wetland regions.

In this methodology, an industry standard maximum likelihood classification methodology was used, combining multiple spectral signatures into a single spectral signature per landcover class, which is then used in the classification algorithm. Combining signatures in this way ensures that the full range of values exhibited by a species are included in the final signature. However, an alternative method is to run the classification algorithm using one spectral signature per ground truth point, and to manually recode the classification after the algorithm has run (Milliken, 2005.) This method reduces overlap between classes that have similar locations in feature space, as most vegetation does, and may result in a more accurately classified final product.One of the image processing packages used in this study, e-Cognition, provided a large number of advanced, object-based, scale-dependent feature extraction methods. Examples of these include neighborhood attributes (such as nearness to open water), ratios (dividing one spectral band by another), and texture characteristics (such as spectral heterogeneity.) Some of the more intractable land cover classes may have characteristics that would make them readily distinguishable. E-Cognition contains a suite of data-mining tools that makes possible the exploration and utilization of complex object-based land cover characteristics.

This methodology for using remotely sensed imagery to map land cover can have an immediate impact on resource management programs in the Central Valley of California. Salinity TMDL's and other actions to control salt and nutrient loading from managed wetlands may influence the wetlands' hydroperiod, as basin drawdown is adjusted to match the San Joaquin River's assimilative capacity. This broadly-applicable mapping technique provides a tool to assess the long-term impact of these adaptive management strategies on the wetland resource. Results from this methodology can also help provide a scientific basis for estimation of water needs of the moist-soil vegetation in managed seasonal wetlands. This research promotes better use of existing water resources to maximize wetland benefit with the possibility of long-term water savings.

CHAPTER 6: WETLAND SOIL SALINITY MAPPING USING ELECTROMAGNETIC SURVEYS

6.1 Electromagnetic survey techniques and background

This section describes the use of an electromagnetic (EM) device to map soil salinity of the study sites immediately after wetland drawdown. The surveys were conducted over a period of three years with the most recent complete surveys of the wetland ponds sites completed in 2008. The current chapter is derived from Patrick Rahilly's MS thesis at the University of California, Merced - who was engaged with the project between 2006 and 2008.

The EM-38 ®, developed by Geonics Ltd, together with analytical software, based on the DPPC (Dual Pathway Parallel Conductance) model developed by James Rhoades et al. (1989), has been proven to be effective and accurate in the prediction of soil salinity across vast landscapes in agricultural settings (Corwin and Lesch 2003, 2005a, and 2005b, Isla *et al.* 2003, Lesch and Corwin 2003, Lesch *et al.* 2005, Cassel 2007). However, its use in wildland settings has largely been unexplored. Wildland settings lack the uniformity and the homogenous nature of soils in agricultural fields, and therefore may require additional or different interpretative schemes. Readings obtained by the EM-38 instrument can be affected by factors such as soil texture and taxonomy, soil moisture, topography, vegetation and litter cover which all affect electromagnetic response (Hanson and Kaita 1997, Suddeth *et al.* 2005, Brevic *et al.* 2006). The most significant factors determined by Corwin *et al.* (2003b) in a west-side San Joaquin Valley cotton field (Broadview Water District, Fresno County) were ECe, gravimetric water content, and texture.

The EM-38® utilizes dual coil electromagnetic induction in order to obtain soil salinity measurements employing non-invasive methods where the strength of the magnetic flux is proportional to the bulk conductance of the soil. Data from the EM-38 and a Trimble backpack GPS system are recorded on a Juniper Systems Allegro Cx, a rugged, hand-held PC, well suited for fieldwork. The data logging software designed for this application is TrackMaker ® which plots the person conducting the survey's current GPS location on the Allegro Cx while retaining the previous survey locations as a continuous line of closely spaced sample points. After some practice field personnel can use the screen tracks to make evenly spaced passes across the field.

The EM-38 MK1, which was used for the first salinity survey in 2007, can be used in two different orientations; vertically or horizontally. Figures 6.1 (a) and (b) (McNeill 1980) illustrate the nature of the EM38 MK1 response in both the vertical and horizontal orientations. Figure 6.1 (a), displays the cumulative signal response and illustrates that the maximum depth of the horizontal and vertical orientations, representing 75% of the response signal, are roughly 1m and 2m respectively. The 75/25 response pattern was considered to be the maximum reading depth by McNeill *et al.* (1980) based on their theory and field trials. In Figure 6.1 (b), the relative signal response, or the integrated depth-weighting pattern, exhibits the effective depth of response. Figure 6.1(b) suggests the peak signal strength for the horizontal and vertical orientations are between 0-0.3m (1 ft) and 0.3-0.6m (1 ft – 2 ft) respectively. The EM-38 MK2®, which was used for the 2008 field surveys, is a relatively new instrument developed by Geonics. The EM-38 MK2® utilizes the same technology as the MK1® yet contains two sets of coils at both a 1.0 meter and 0.5 meter separation which represent, comparatively, the vertical and horizontal orientations of the EM-38 MK1 respectively. The dual coils allow both the near surface and subsurface soil averaging measurements simultaneously.

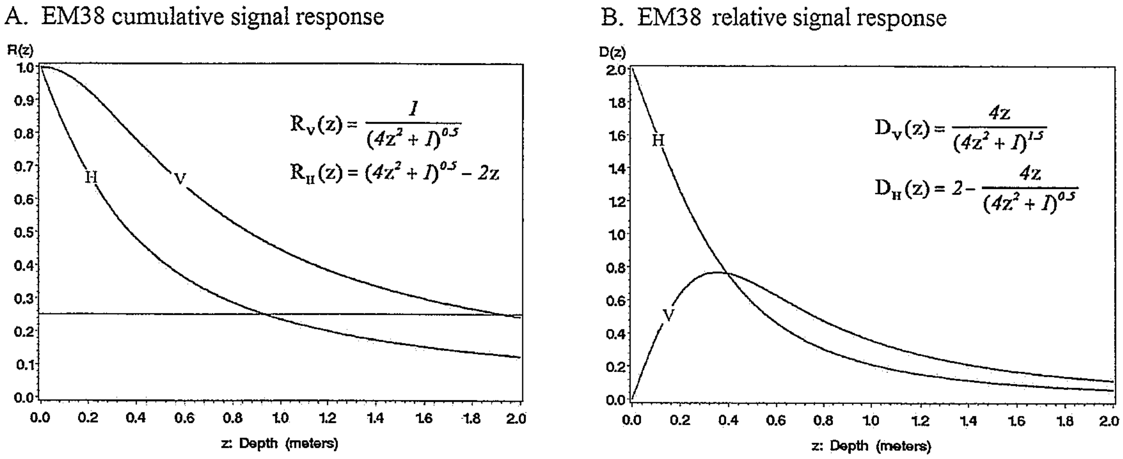


Figure 6.1. EM38 (a) cumulative and (b) relative signal responses where H is horizontal orientation and V is vertical orientation (McNeill 1980).

6.2 Electromagnetic survey protocols

The goal of the electromagnetic survey campaign was to develop a practical and cost-effective method of quantitatively assessing changes in soil salinity within the affective rooting zone of swamp timothy, as a result of future salinity management practices within the Grassland Ecological Area. One of the most important project tasks was to develop an accurate baseline of soil salinity conditions within a range of wetland pond sites that could be used for comparison if changed practices such as wetland delayed drawdown, drainage reuse and other water conservation and salinity management techniques are adopted. The central premise is that seasonally managed wetlands on the west-side of the San Joaquin Basin require annual drainage if they are to be sustained and the quality of the wetland habitat will be a direct function of salinity in the rooting zone of the more important moist soil plants relied upon for over-wintering habitat.

6.2.1 Instrument orientation

In order to receive an accurate response in the horizontal orientation, the device must be in direct contact with the soil surface. After consideration of the acreage of our study sites as well as the dense vegetation likely to be encountered, the project team concluded that horizontal deployment was infeasible for the study sites – hence the 2007 surveys were conducted in the vertical orientation with the assumption that in dense clay soils, such as the ones found in the project study sites, allowed minimal downward migration of salts in the profile. Ideally the measured EC should be uniform throughout the penetration depth of the instrument. Because of the tight 2:1 clays present in the profile - the EM-38 signal was not expected to penetrate as deeply as suggested in Figure 6.1 (Williams 1987, Brus *et al.* 1992, Doolittle *et al.* 1994, Kitchen *et al.* 1999) - those figures were developed in agricultural soils. The 2008 surveys were conducted using the EM38 MK2 which has the ability to gather both vertical and horizontal measurements simultaneously. The horizontal mode results were directly comparable to the 2007 surveys conducted with the Geonics MK 1.

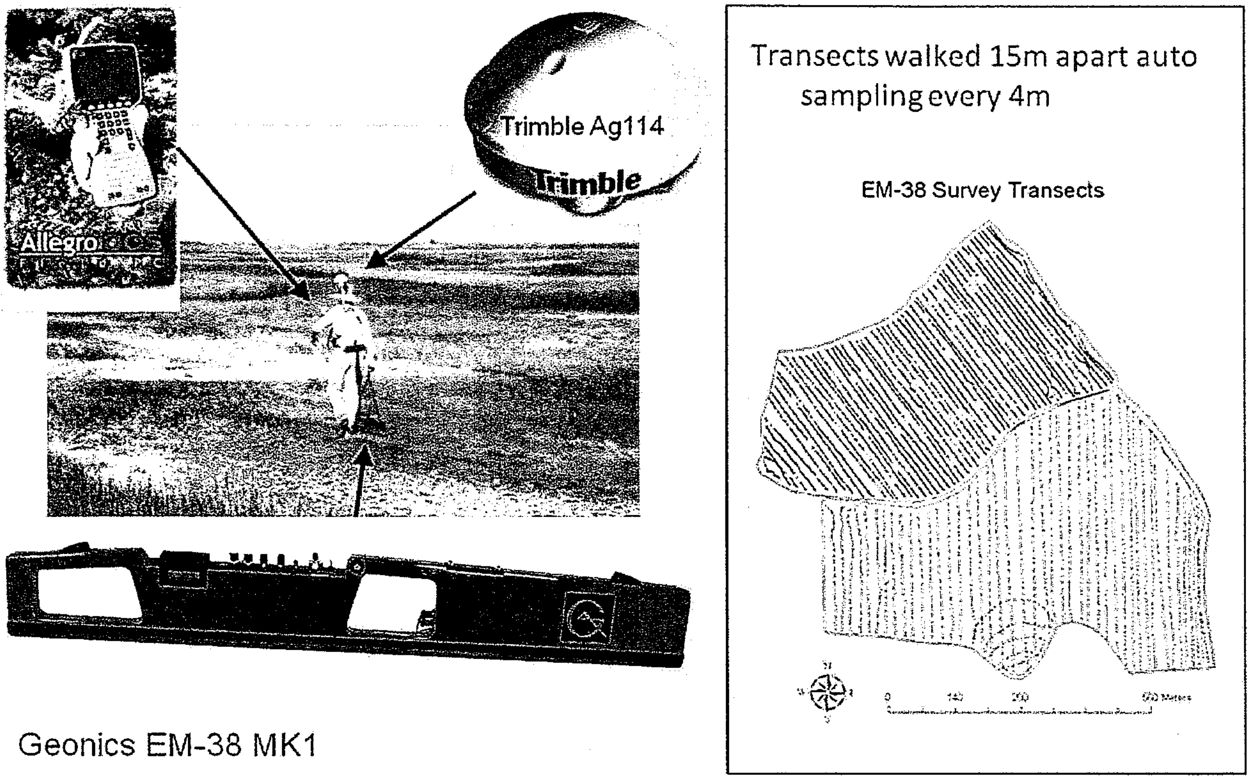


Figure 6.2. Mapping wetland soils using the Geonics EM-38 Mrk 1 and Mrk II instruments, Trimble GPS and Allegro logging unit.

6.3 Study site descriptions

The soil series associated with each pond and general profile description and chemical constituents are generally described below. Table 6.1 lists the soil classification and parent material of each soil series. Table 6.2 lists the chemical constituents of each soil series.

6.3.1 Ducky Strike Club

Ducky Strike (North and South, DSN & DSS) is located 6 miles east of Dos Palos. The north pond covers nearly 80 acres and the south pond covers just over 90 acres. The soil series that this site resides on is Britto clay loam, ponded. The Britto series is a Fine, smectitic, thermic Typic Natraqualfs and is characterized by deep, very poorly drained soils with high concentrations of salt and alkali in the lower horizons. Typical profile is 0 to 22 inches as a clay loam and 22 to 62 inches as a sandy clay loam. Some of the chemical elements of this series include 5% maximum calcium carbonate, 10% gypsum, electric conductivity of 1.0 to 11.0 dS/m, sodium adsorption ratio (SAR) maximum of 30.0 (NRCS 2007), and pH's ranging from 6.0 to 8.5. This area was historically above the flood zone but was frequently inundated from ponding rain water. The water table is near surface.

6.3.2 Gadwall Wildlife Management Area

Gadwall (Gadwall ponds 5 & 6), located 4 miles to the east, south east of Los Banos, is the most southern publicly owned complex of the Grasslands Ecological Area (GEA). The northern most pond, field 5, is 39 acres, and the field adjacent to the south, field 6, is 82 acres. Three soil series' are contained within the two fields, Triangle clay (alkali), Dos Palos clay (hummocky), and Britto clay loam. Field 5 is nearly entirely Triangle clay. Field 6 is dominantly Triangle clay, Dos Palos clay occupies the western 25% of the field, and the Britto clay the southern 10%. The Triangle series is poorly drained wide cracking soils with high percentage of exchangeable sodium formed of predominantly granitic mixed alluvium. Typical pedon is vertic clay to 34 inches, and clay loam below. The Dos Palos clay is poorly drained soils formed on valley rims or flood plains of dominantly granitic mixed alluvium. Typical pedon is clay to 24 inches and clay loam below. A description of the Britto clay loam can be found below.

6.3.3 Mud Slough Wildlife Management Area

Mud Slough (MS3b & MS4b) is located 4 miles directly east of Los Banos and just north of the Gadwall complex. The two adjacent fields are 3b and 4b, 36 acres and 46 acres respectively. The soil series contained within the borders of these two fields are Dos Palos clay and Triangle clay (alkali). The Dos Palos clay is dominant in both fields with a large inclusion of Triangle running down the center of the two ponds, the east side of field 3b and the west side of field 4b.

6.3.4 Los Banos Wildlife Management Area

Los Banos (LB31b & LB33) is located 5 miles to the northeast of Los Banos city, south of the confluence of Mud and Salt Sloughs. The western field, LB 31b, is 23 acres in size and the eastern field, LB 33, is 49 acres. This is the only pair of ponds that have willows within the field boundaries, which is a likely result of its proximity to the sloughs and ground water at or near the surface. The soils are predominantly Dos Palos clay with Bolfar clay loam (hummocky) and Edminster – Kesterson complex around the periphery. A description of the Dos Palos clay can be found in 2.2. The Bolfar clay loam and Edminster – Kesterson make up less than 5% of the total pond area and will not be described.

6.3.5 Salt Slough Wildlife Management Area

Salt Slough (SS24 & SS32) is located 7.5 miles directly north of Los Banos City. The north pond, field 24, is 33 acres, and the south pond, field 32, is 19 acres. The soils in field 32 are almost entirely Alros clay loam with the western 10% as Kesterson sandy loam. The Alros series only makes up about 30% of the soils in field 24, which are on the western side of the field. The eastern side of field 24 is El Nido sandy loam. These soils, specifically the soil textures and high Ksat (El Nido series), are quite in contrast to every other field in our study. The Alros series is characterized by deep, poorly drained soils with high percentages of exchangeable sodium. The typical pedon description 0 – 12 inches of clay loam, 12 – 39 inches of loam, and 39 – 60 inches of stratified sandy loam to clay loam. The El Nido series is characterized by very deep poorly drained soils derived from granitic alluvium. Typical pedon is 60 inches of sandy loam. The Kesterson series is characterized by deep, poorly drained soils with a high percentage of exchangeable sodium and a thick layer of lime in the subsoil and derived from granitic alluvium. Typical pedon is 0 – 6 inches sandy loam, 6 – 43 inches sandy clay loam, and 43 – 60 inches stratified fine sandy loam to clay loam.

Table 6.1 Site Soil origin and classification

Soil Series Name	Soil Classification	Parent Material
Alros clay loam	Fine-loamy, mixed, superactive, thermic Typic Epiaqualf	
Britto clay loam, ponded	Fine, smectitic, thermic Typic Natraqualfs	Coast Range alluvium, alluvial fan
Dos Palos clay (hummocky)	Fine, smectitic,calcareous, thermic Vertic Endoaquoll	Granitic mixed alluvium
El Nido sandy loam	Coarse-loamy, mixed, superactive, thermic Typic Endoaquoll	Granitic mixed alluvium
Kesterson sandy loam	Fine-loamy, mixed, superactive, thermic Glossic Natraqualfs	Granitic mixed alluvium
Pedcat loam	Fine, mixed superactive, thermic Aquic Natrixeralfs	Coast Range alluvium, alluvial fan
Santa Nela loam	Fine-loamy, mixed, superactive, thermic Typic Natraqualf	mixed sedimentary rock alluvium
Triangle clay (alkali)	Fine, smectitic, thermic Sodic Epiaquert	Granitic mixed alluvium

6.3.6 Volta Wildlife Management Area

Volta (Volta ponds 4D & 23) is located 7.5 miles to the northwest of Los Banos City. The west field, 23, is 88.3 acres and 4d, 1.4 miles km to the east, is 33 acres. A large portion of field 23 is upland, roughly 30%, and is not flooded. Historically both of these sites were above river flood plains. The soils in field 23 are predominately Pedcat loam, with 10% of the north west corner as Santa Nella loam. The soils in field 4d are predominately Triangle clay, with the western 10% as Santa Nella loam. The Pedcat series is characterized by very deep, poorly drained soils formed on remnants of alluvial fans from sedimentary rock. Typical profile is 0 – 5 inches loam, 5 – 29 inches clay, and 29 – 60 inches stratified sandy clay loam to clay. The Santa Nela series is characterized as deep, very poorly drained soils with high percentages of sodium formed from mixed sedimentary rock alluvium.

Table 6.2 Site soil chemical constituents

Soil Series Name	$CaCO^3$ (max)	Gypsum (max)	ECe	SAR (max)	pH
Alros clay loam	50%	na	1 - 6 dS/m	40	7.1 - 8.5
Britto clay loam, ponded	5%	10%	1 - 11 dS/m	30	6 - 8.5
Dos Palos clay (hummocky)	10%	na	1 - 7 dS/m		
El Nido sandy loam		na	0.8 - 2 dS/m		7.1 - 9.6
Kesterson sandy loam	45%	na	1.1 dS/m	60	7.5
Pedcat loam	3%	na	0.7 - 5 dS/m	60	6.9 - 9.1
Santa Nela loam		na	0.5 - 4 dS/m	30	6.0 - 7.0
Triangle clay (alkali)	10%	na	1 - 5 dS/m	30	

6.4 Survey transects and protocols

For each field, the 2007 and 2008 survey transects were paced by foot in parallel where tules and cattails allowed with a 50 ft spacing between transects. The 2010 surveys were conducted using a non-metal toboggan which cradled the EM-38 device and was towed behind an ATV (Figure 6.3). For all surveys the device was set to auto-sample every 2 seconds; at a walking/driving speed of 2.5 mph, that is roughly one sample every 15 ft along each transect.

Table 6.3. Dates and site locations of soil surveys

Site	2007	2008	2010
Ducky Strike North	13-Jan	18-Apr	5-May
Ducky Strike South	16-May	12-May	5-May
Gadwall 6	14-Jun	14-May	-
Gadwall 5	20-May	15-May	-
Los Banos 31b	25-May	1-May	-
Los Banos 33	14-May	20-May	-
Mud Slough 3b	19-Jun	11-Apr	-
Mud Slough 4b	18-Jun	7-May	-
Salt Slough 32	31-May	15-May	-
Salt Slough 24	15-Jun	23-Apr	-
Volta 4d	11-Jun	2-Jun	-
Volta 23	11-Jun	13-May	-

The device was kept at a consistent 4 inch height above ground. The 2010 surveys using the toboggan also carried the EM-38 at a height of 4 inches above the ground. The dates of the 2007, 2008 and 2010 surveys are shown in Table 6.3. The output from the GPS and EM-38 was in *xyz* format.

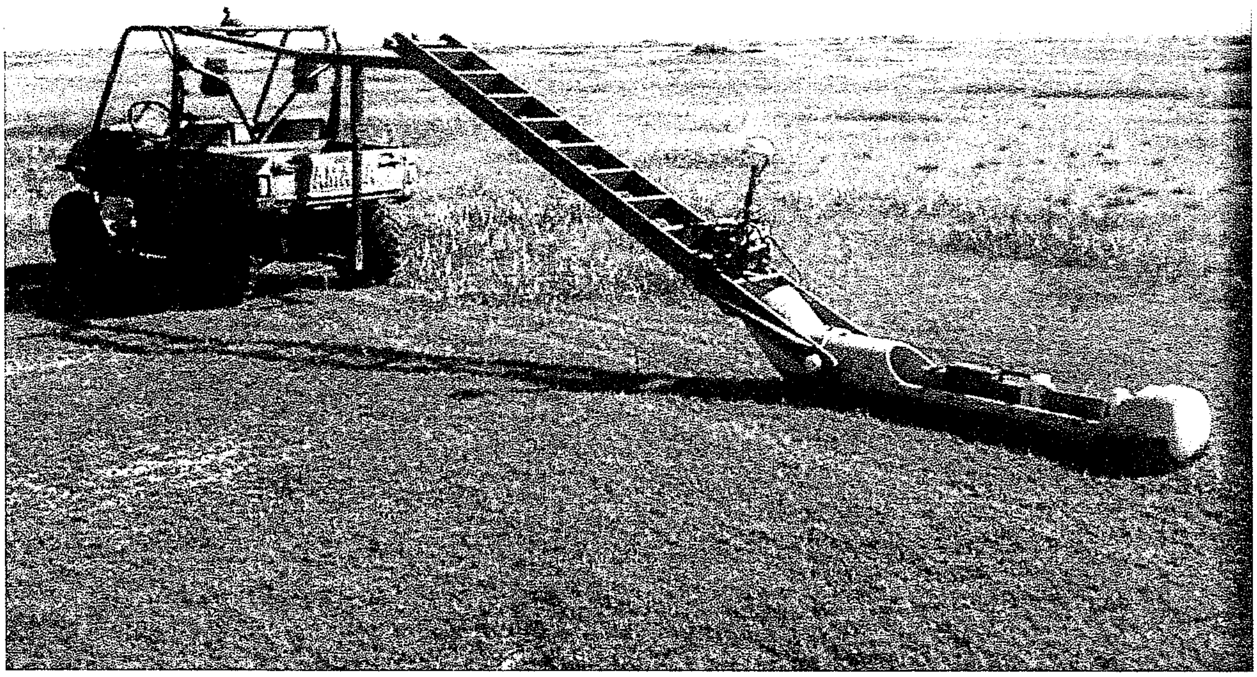


Figure 6.3. Soil survey conducted in 2010 using the ATV and toboggan designed for EM-38 surveys. Note; toboggan is entirely non-metallic. Use of the ATV and toboggan would have compromised the vegetation sampling being conducted by the Department of Fish and Game during the 2007 and 2008 surveys.

6.5 ESAP software program and sampling protocol

The ESAP software package was created by USDA Salinity Laboratory (Riverside, California) to correlate EM-38 *xyz* (apparent EC) data to actual electrical conductivity (EC). The program includes a Response Surface Sampling Design (RSSD) routine that uses the raw EC_a *xyz* data to design a sampling strategy to calibrate the EM-38 instrument against actual soil EC values. For each field, the RSSD software selects 12 sample locations based on even-increment sampling of a frequency distribution of values from which to collect soil samples for analysis. An example of the ESAP RSSD sample design out put and sample locations is given in Table 6.4 and Figure 6.4.

Table 6.4. Example of the ESAP RSSD sample design for Ducky Strike North 2010.

Date & Time: 5/6/2010 10:17:30AM
Field Desc: DSN-10

Sample Size: 12 (Total Survey Size = 2369 Active Survey Size = 2327)
D-Factor Val: 1
Opt-Criteria: 1.6
Loop Count: 11

Target Information for SRS Sampling Design # 1

Site ID	Design	Levels	Ds1-STD	Ds2-STD	X-Coordinate	Y-Coordinate
1043	0.75	0	0.75	0.04	701734.61	4093294.9
2204	1.75	1.75	1.82	1.84	701678.44	4092932.48
19	-1.75	-1.75	-1.77	-1.44	702084.36	4093215.66
2070	1.75	-1.75	1.71	-1.77	701568.08	4093102.99
218	-1.75	1.75	-0.72	0.71	701947.14	4093322.9
1502	2.5	0	2.09	0.04	701635.36	4093220.18
716	-2.5	0	-1.55	-0.51	701942.85	4093155.15
1315	0	2.5	-0.05	1.77	701733.87	4093173.85
2369	0	-2.5	0.11	-2.67	701547.32	4092953
1285	-0.75	0	-0.78	0.02	701811.39	4093078.77
1696	support site		-0.19	0.2	701706.29	4093072.59
1614	support site		0.01	-0.14	701803.09	4092980.77

Given that the primary objectives of the project were to : (1) create baseline soil salinity maps to document changes in soil salinity over time; and (2) to investigate relationships between soil salinity and vegetative productivity - a depth of 8 inches was selected for soil sample collection. The 8in depth of sampling was chosen to ensure that sample was mineral soil, within the effective rooting zone of swamp timothy, but also at depth shallow enough that changes in salt concentration due to variations in hydrologic management could be quantified. For the 2007 surveys, these samples were taken one month after the EM-38 survey had taken place, but before the next flood-up event. For the 2008 surveys, the samples were taken within one day of the EM-38 survey. The scheduling of the 2008 soil samples allowed sufficient time for the soil moisture of each sample to be measured.

6.5.1 Soil sample processing protocol

For each sample, gravimetric water content was measured by calculating difference in soil mass before and after baking samples at 105°C for 24 hours. Dried samples were left in ambient air for one hour to cool before the soil dry mass was measured. Dried samples were crushed with a wood rolling pin to break up aggregates and then passed through a 2mm sieve. None of the pebble fraction was crushed during processing. Qualitative notes of percentages of pebbles to soil, as well as the parent rocks were taken.

For each sample, a fixed ratio of 15 grams of soil and 30 mL of deionized water were added to 50 mL vials; a 1:2 ratio. The vials were mixed by hand to ensure that all of the soil was wet. Vials were then placed in a shaker for one hour. After shaking, samples were left upright overnight to allow suspended soil to settle. The following day, samples were placed in centrifuge at 3,000 rpm for 30 minutes. After 30 minutes, if supernatant was not clear, samples were re-spun. The conductivity ($EC_{1:2}$) and pH of the supernatant was measured using a Myron Ultrameter II and values recorded.

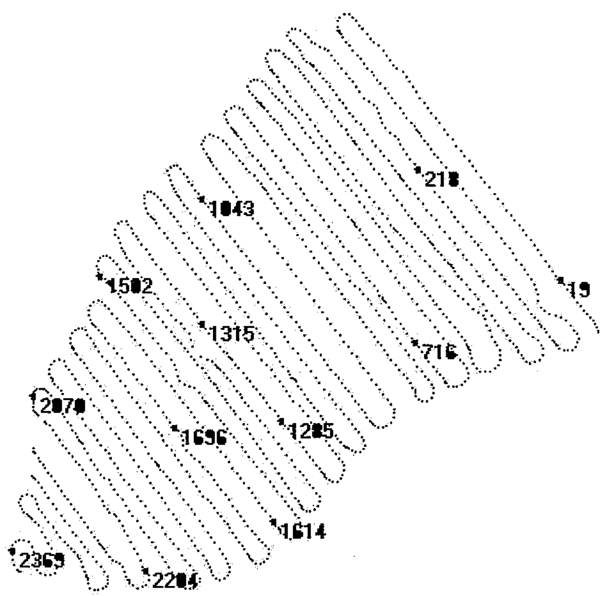


Figure 6.4. Sample locations on survey transects, Ducky Strike North 2010

6.5.2 ESAP model calibration

The USDA Salinity Lab's ESAP-Calibration software was used to convert the EM-38 response distribution (apparent bulk EC: ECa) to an actual EC (ECe) across the pond areas. The program utilizes a stochastic calibration using an empirically fit regression model employing the DPPC equation developed by Dr. James Rhoades (1989) at the USDA Salinity Laboratory.

6.6 EM Results and discussion – 2007 wetland soil salinity survey

The relationships between the laboratory measured EC values and the EM-38 response for the 2007 surveys were poor. Best-fit trend lines were produced where there appeared to be a reasonable relationship between laboratory results and EM-38 response. The superior correlations between variables were found in wetland soils that were mapped earlier in the season when there was more elevated soil moisture – which produced a higher quality EM-38 signal response. The poorest correlations occurred in wetland soils that were surveyed last. Soil moisture control is of great importance in the development of accurate and reliable soil salinity maps.

6.6.1 EC values and EM-38 response

Due to the lack of correlation between actual EC ($EC_{1:2}$) and EM-38 response values (ECa) for certain wetland sites - good calibration was not uniformly achievable. The problem was addressed, in part, by editing the data to remove outliers; in some cases half the points were removed. However, the results were still poor and did not represent the extremes of high and low salinity apparent in the data. For example, the 95% confidence intervals (CI) of the maps created from the edited data were, as in DSS (Figure 6.5) between 1 and 2.5 dS/m, while the mean of the EC measurements for DSS was 3.1 dS/m, a value outside the range of the 95% CI. In addition, DSS $EC_{1:2}$ values were upwards of 11dS/m, which were not always predicted based on the confidence interval.

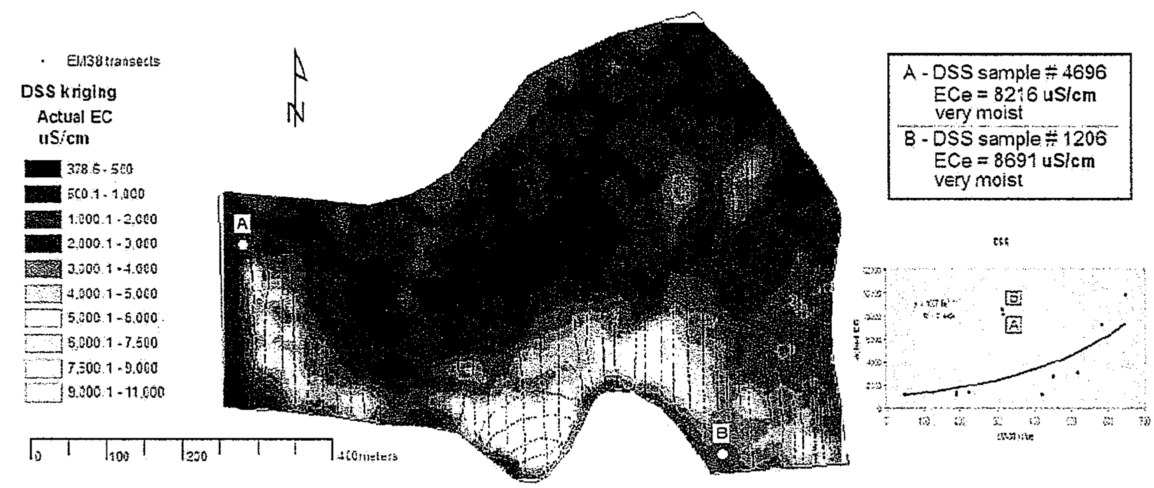


Figure 6.5. Ducky Strike South (2007) $EC_{1:2}$ as predicted by ESAP. Two outliers were removed during the process of calibration.

The initial assumption that soil salinity within the upper soil profile was uniform was subsequently found to be untrue. While sampling with an auger, a soil matrix marbled with salt was found at a depth of 24 inches at many of the wetland survey sites (Figure 6.6). Although not all of the sites were vertisols, almost all have vertic cracks and contain superactive shrink-swell clays and clay loams. As the soils crack, downwards beyond 24 inches, the soil pore water wicks off the vertic faces. As the water evaporates, the salts are left behind resulting in salt crusts on the vertic faces at a 24 inch depth. As the soils are re-flooded in fall, the vertic cracks close and the salt crusts become encapsulated at depth creating a marbled like appearance. This phenomenon was not found in the surface horizons, only at depths between 20 and 30 inches -greater depths were not investigated. This result confirms the lack of uniformity in salinity within the soil profile. Hence the surveying performed with the EM-38 in the vertical orientation was unlikely to accurately represent the surface soil salinity profile. This factor most likely contributed to the noise in the data.

In addition to the problem of signal noise created from the substantial salt accumulation at depth, the method of determining EC with the fixed water/soil ratio ($EC_{1:2}$) was also investigated. ESAP was developed based on a standardized method of EC measurement using a saturated soil paste extract (ECe) - a method that has found favor because it mimics field capacity and therefore accounts for minor textural differences between soil samples (Tanji 1990). This method is tedious and time consuming and can be difficult to perform when fine textured samples such as the heavy, 2:1, superactive clays such as those found in our study areas. It is also suggested that some conversion factor be used to convert the $EC_{1:2}$ to ECe, but as that factor varies substantially between soil textures, it is difficult to assign one without a texture analysis. A deeper investigation into this question is needed.

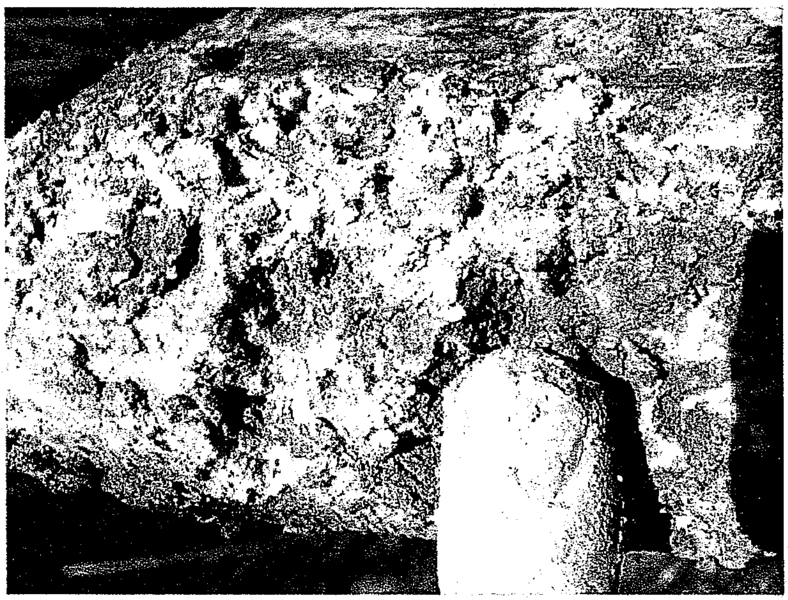


Figure 6.6. Salt crystals (white) marbled in clay loam matrix centered at 60cm depth. Image taken at Mud Slough 3b, 2008.

6.6.2 Relationship between soil texture and EM-38 signal response

Soil texture greatly influences the reliability of data not only in the calibration process but also during the EM-38 survey. As illustrated by the NRCS Soil Survey soil series polygons delineated in the apparent soil salinity maps the soils vary substantially across the landscape. In some fields the textural differences between soil series' are not substantial but may alter the EM-38 signal response just enough to distort the values. The depth to restrictive layers, bulk density, and horizontal textural differences also play a roll in the EM-38 signal response. A case in point, Salt Slough 24 (Figure D6a) has apparent soil salinity values that appear to follow the soil series delineation between the Alros clay loam to the west and the El Nido sandy loam to the east, where the signal values are much higher over the Alros than the signals over the El Nido. In such instances, it is advised that two surveys are conducted, one for each soil type. The survey of SS 24 did not take this consideration. However, since the survey was conducted early in the season the soil moisture was such that a good correlation between ECa and $EC_{1:2}$ was obtained. Figure D6b illustrates the calibrated SS24 calibrated soil salinity map. Notice the inverse of soil salinity estimations from the EM-38 signal response and the predicted EC post calibration.

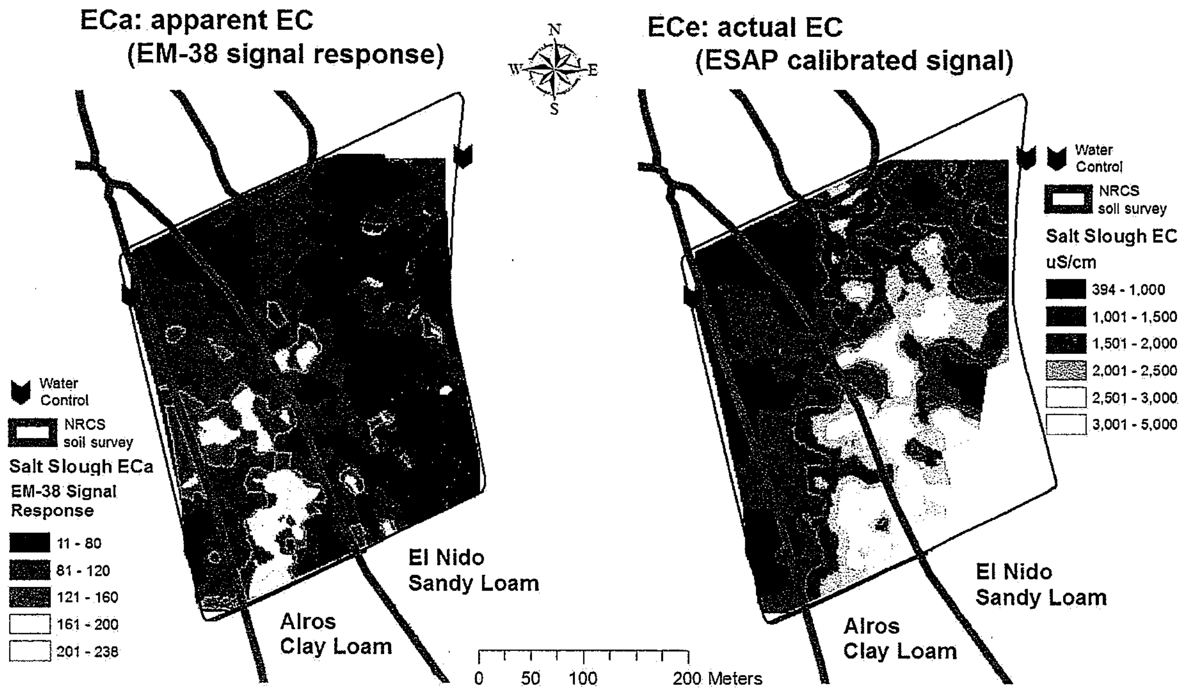


Figure 6.7 a,b Salt Slough 24 2008 apparent EC (EM-38 signal response) left, and calibrated actual $EC_{1:2}$ on right, illustrating the effect of spatial textural differences on EM-38 signal response.

6.6.3 Relationship between soil moisture and EM-38 signal response

More significant than the effect of soil texture on the quality of EM-38 signal response is that of soil moisture content. Adequate moisture content is important when measuring electrical conductance. Without adequate soil moisture the inductive signal response of the EM-38 deteriorates. The EM-38 literature suggests a soil moisture contents at or near field capacity (FC)- typically the greater the soil moisture up to field capacity, the better the signal. The wetland sites were surveyed through the month of June - soil moisture content was well below FC at this time of the year. This factor may explain much of the noise in the field data. In addition- since the samples where collected at a depth of 6 inches it most likely did not represent the soil moisture content at a depth of 24 inches – given the lack of salinity profile uniformity. The ideal EM-38 depth of observation in the vertical orientation was 24 inches.

During 2008, the effects of soil moisture on EM-38 signal response was investigated using the EM-38 MK2. The investigation was conducted at MS 3b with weekly surveys that followed the same transects. The effects of soil desiccation on EM-38 signal response are quite dramatic. Figure 6.8 shows the dramatic weakening of the EM-38 signal strength over the six week study.

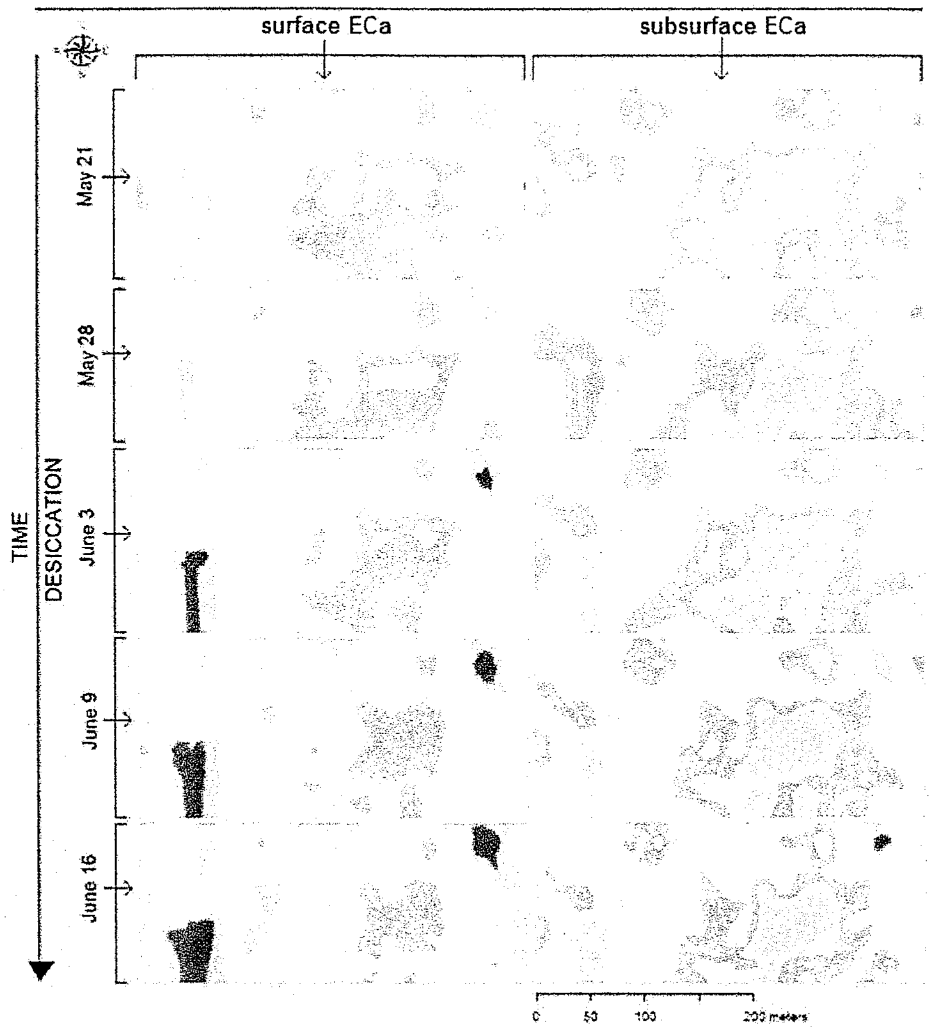


Figure 6.8 Temporal Study at MS 3b in 2008 demonstrating the effects of soil dessication on EM-38 signal response. Weekly Surveys conducted from May 21, 2008 thru June 16, 2008 following exact transects for each survey. Surface ECa (left column) represent the EM-38 Horizontal signal, subsurface ECa (right column represents the EM-38 Vertical signal.

Another capability of ESAP is the ability to create soil moisture maps, if there is a significant relationship between measured $EC_{1:2}$ and measured gravimetric soil moisture content. The May 21, 2008 survey of the desiccation study (Figure 6.8) had a good correlation between soil moisture and bulk EC which allowed the ability to create an accurate soil moisture map. This strong correlation also allowed for an accurate calibrated $EC_{1:2}$ map. The two maps are shown in Figure 6.9.

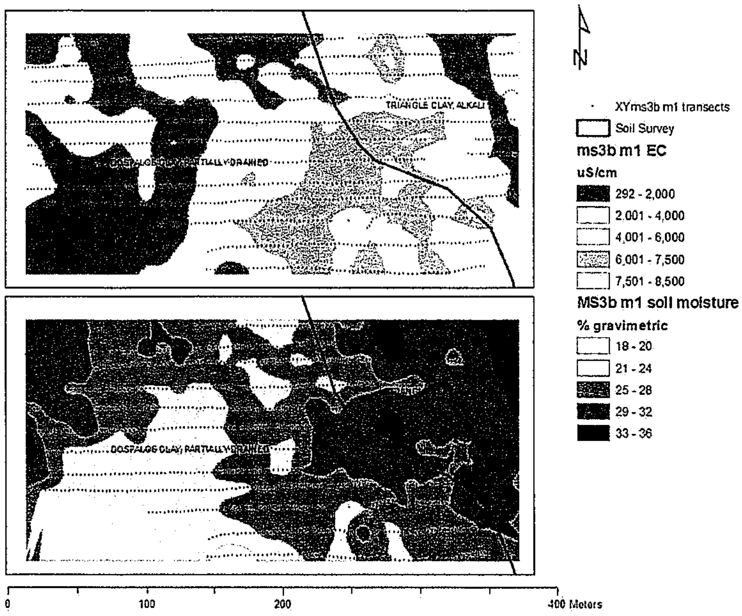


Figure 6.9. Mud Slough 3b May 21, 2008 calibrated $EC_{1:2}$ map (top) and calibrated soil moisture map (bottom) visually illustrating the relationship between soil moisture and bulk soil EC.

Another potentially important factor is that, for many soils, the upper 12 inches of the profile accounts for less that 10% of the electromagnetic signal that is received in the vertical orientation (Scott Lesch, USSL, personal comm.). Even if one were to assume that the EC is consistent throughout the entire profile, the moisture gradient between the surface and subsurface soil is steep during late spring and early summer. By the middle of May, the upper foot of soil is practically desiccated whereas the subsurface, considering these soils are upwards of 50% smectite, may still be near field capacity. There is currently no known method to account for this type of moisture gradient in analyzing EM-38 data.

In light of the effects of soil moisture on the EM-38 response, why then was the correlation between $EC_{1:2}$ and ECa decent in Ducky Strike South as well as Mud Slough 3B. When reviewing the dates of the surveys (Table D3) those two fields were the earliest surveys for the season, May 16 and May 14 respectively. This finding suggests that the majority of the surveys conducted were much too late in the season and did not have adequate soil moisture for the EM-38. For future wetland surveys, it is suggested that the surveys are conducted the moment that the soils are dry enough to be walked on. In some cases, this could take well over a week, but fortunately, these tight clay soils don't release water readily and still may be at or near FC.

6.6.4 Discussion of 2007 survey results

Though the calibration process performed using the 2007 survey data did a poor job correlating the observed soil apparent EC (ECa) values to the true $EC_{1:2}$ distributions at the study sites, the ECa maps provided an informative qualitative view of the distribution and relative concentrations of salts across the field sites. Considering the calibration of the EM-38 was consistent between surveys, the ECa values for all fields were compared on an equal basis. Maps were produced for all 12 sites for the EM-38 generated ECa distributions using ordinary kriging in an effort to evaluate the spatial distribution of salinity qualitatively in spite the failure to obtain a working calibration for the survey.

6.7 EM results and discussion – 2008 wetland soil salinity survey

Following the lessons learned from the 2007 soil salinity survey similar surveys were conducted were conducted in 2008 at all of the wetland study sites. The main difference in survey technique was that the surveys were conducted much earlier in the season, as near to wetland draw down as possible - while allowing the soil surface to be walked upon. The 2008 surveys utilized a newly developed instrument from Geonics, the EM-38 MK-2. Much improved salinity calibration with the measured salinity data was achieved in 2008 at all 12 wetland study sites. The spatial statistics and Jack-Knife predictions showed substantial accuracy at all wetland survey sites as evidenced in the wetland salinity maps derived from the calibrated wetland models. Figures 6.11 – 6.19 show the improved and more realistic wetland soil salinity maps which will be used as the new baseline to assess future wetland salinity management practices.

Table 6.4 Spatial statistics generated by ESAP program

DSN

of Survey Sites: 4642
# of Sample Sites: 11
# of free df's: 3

MLR Model Form:

ln(ECe) = b0 + b1(z1) + b2(z2) + b3(x) + b4(y) + b5(xy) + b6(x^2) + b7(y^2)

Field Average Point Estimates [ln(ECe)]

depth	mean	variance	95% Confidence Interval
0.20	6.81004	0.00241	6.654 to 6.966

Back-Transformed Field Median Point Estimates [ECe]

depth	median	95% Confidence Interval
0.20	906.911	775.82 to 1060.15

Basic Regression Summary Statistics

Depth	R-square	Root MSE	Est.%CV
0.20	0.9965	0.1371	13.77

AOV Table and Parameter Estimates for depth: 0.20

Source	DF	SS	MS	F Value	Prob >F
Model	7	15.9205	2.2744	121.04	0.0011
Error	3	0.0564	0.0188		
C-Total	10	15.9769			

model R-square = 0.9965
root MSE = 0.1371
estimated CV = 13.7726

press score = 0.699

Univariate R-student residual summary statistics

depth	n	mean	std.dev	min	max
0.20	11	-0.027	1.117	-2.032	1.692

Depth specific R-student HAT leverage [h(ii)] and residual values

Site-ID	h(ii)	Sample Depths 0.20	Site-ID	h(ii)	Sample Depths 0.20
206	0.9672	0.106	2709	0.7672	-1.449
1566	0.9586	0.165	3462	0.3910	1.692
1623	0.7015	-0.770	3557	0.8999	0.086
1666	0.5701	0.824	4043	0.8987	1.240
2644	0.3728	-0.595	4108	0.7268	-2.032
2680	0.7497	0.434			

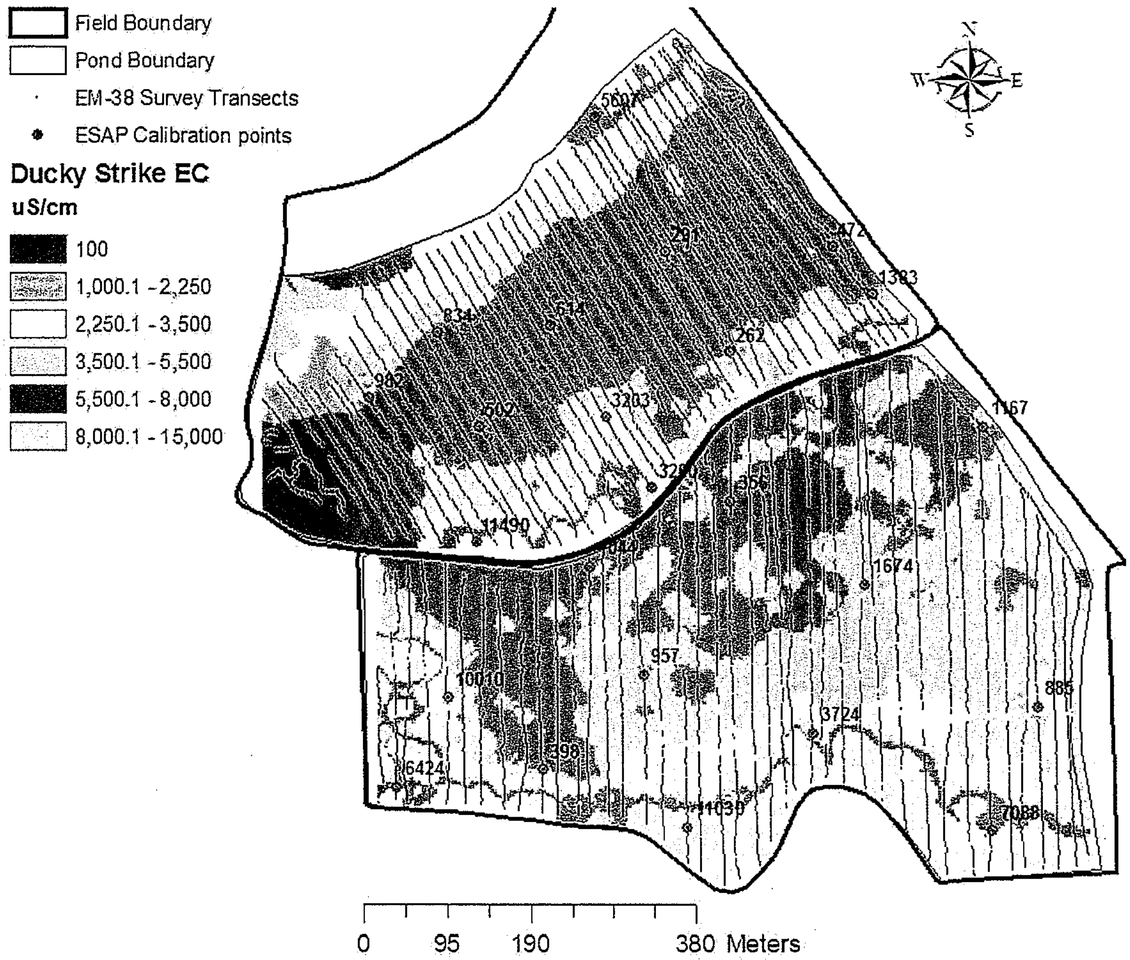


Figure 6.11. Ducky Strike North and South, 2008 calibrated EC1:2 maps of surface bulk soil salinity, 0 – 30 cm.

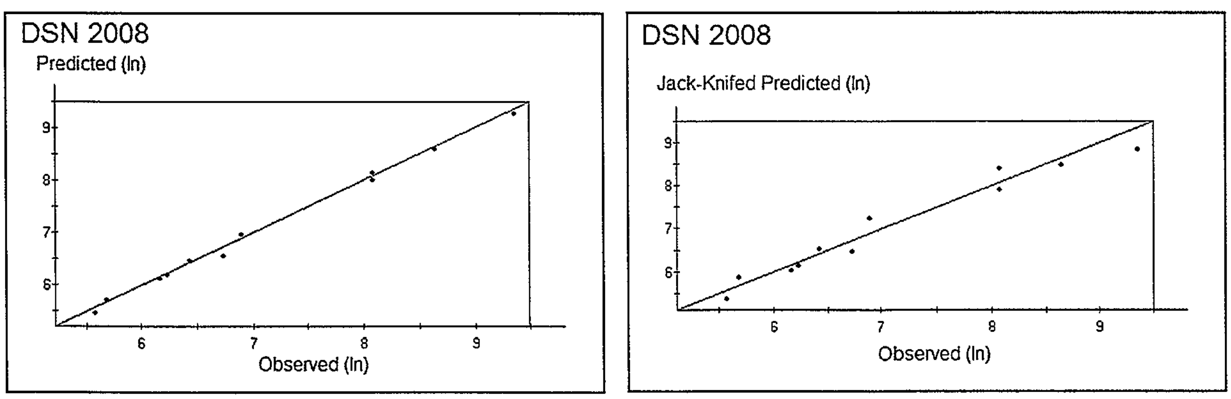


Figure 6.12. Ducky Strike North – model results comparing observed data to model predictions.

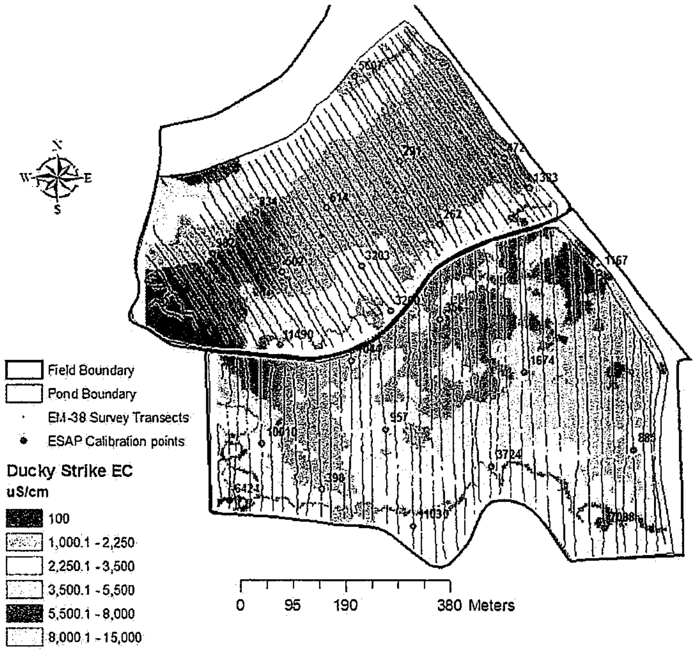


Figure 6.13. Ducky Strike North and South, 2008 calibrated EC1:2 maps of surface bulk soil salinity, 0 – 30 cm.

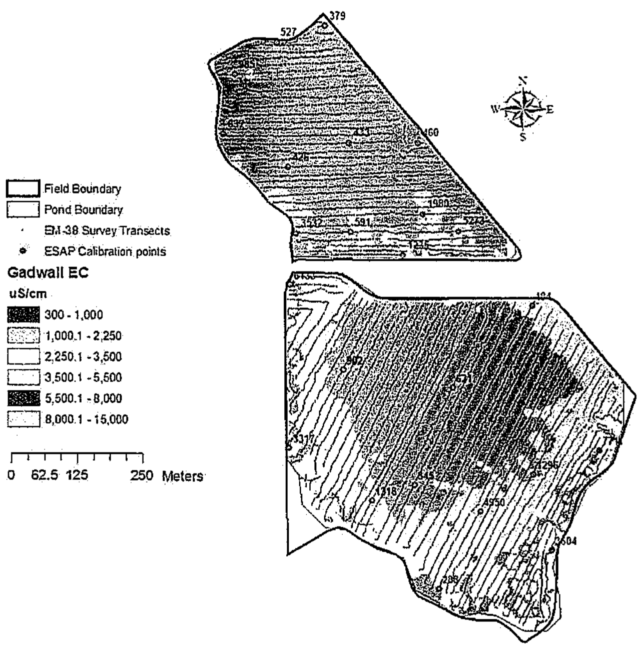


Figure 6.14. Gadwall ponds 5 and 6, 2008 calibrated EC1:2 maps of surface bulk soil salinity, 0 – 30 cm.

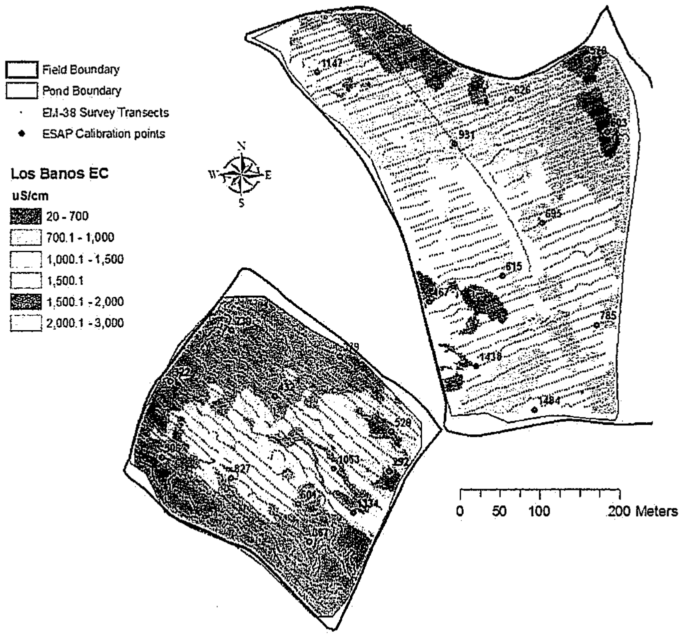


Figure 6.15.. Los Banos, 2008 calibrated EC1:2 maps of surface bulk soil salinity, 0 – 30 cm.

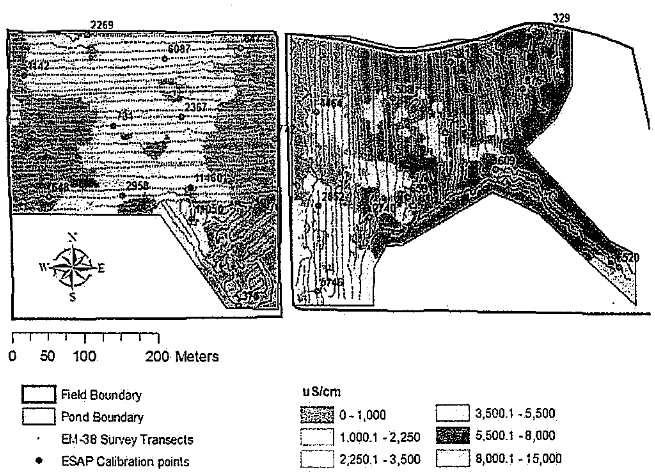


Figure 6.16. Mud Slough, 2008 calibrated EC1:2 maps of surface bulk soil salinity, 0 – 30 cm.

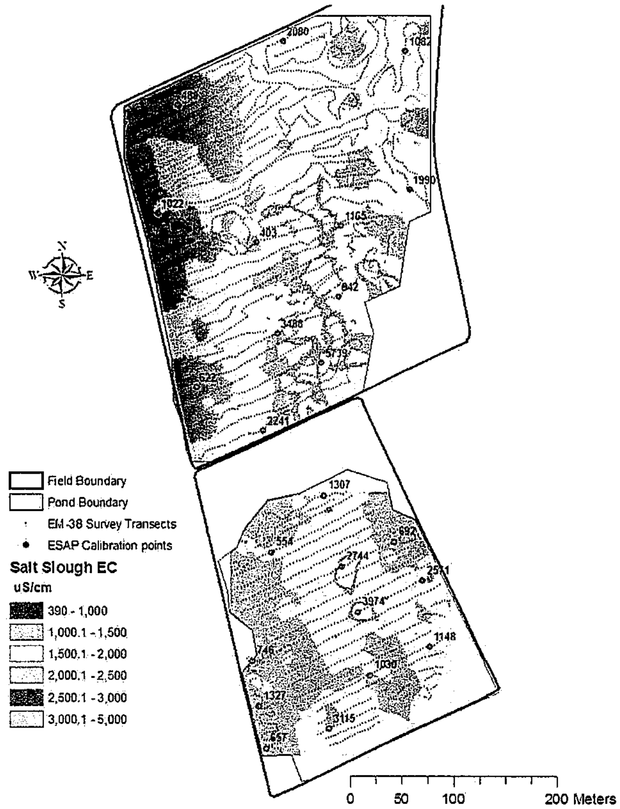


Figure 6.17. Salt Slough, 2008 calibrated EC1:2 maps of surface bulk soil salinity, 0 – 30 cm.

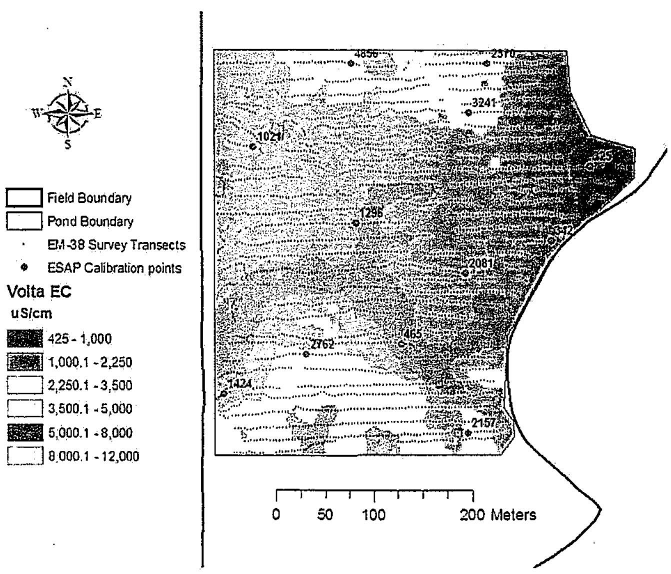


Figure 6.18. Volta 23 calibrated EC1:2 maps of surface bulk soil salinity, 0 – 30 cm.

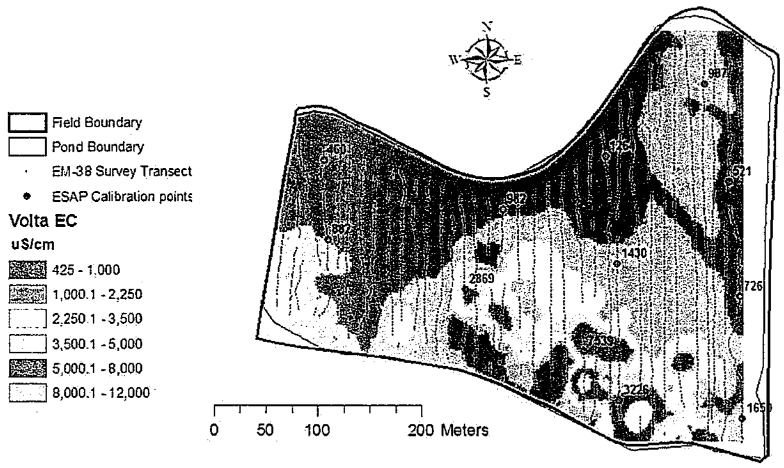


Figure 6.19. Volta 4d calibrated EC1:2 maps of surface bulk soil salinity, 0 – 30 cm.

6.8 Anthropogenic landscape alternations and effect on wetland soil salinity

An interesting observation was made in Volta 23. An historic channel, now level, was identified. When the ECa map was overlaid with the 2007 NRCS soil survey map suggested a channeled Fluvaquent to the east, outside the field, coinciding with the low salinity band though the middle of the field. Three soil samples that were taken from within the revealed historic channel, all had significantly lower EC1:2, lower pH, and a pebble fraction that was nearly 50% volumetrically. Three other samples had pebble fractions <10%, two being in

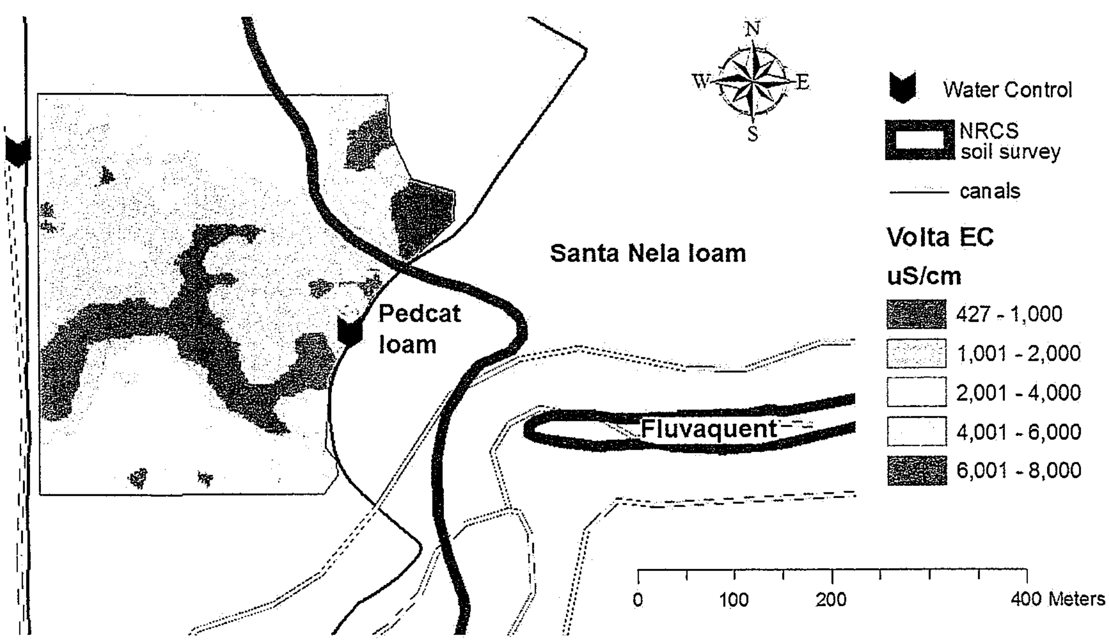


Figure 6.20. Location of anthropogenic landscape alterations

proximity of the historic channel, and the other being in an isolated pool to the south of the managed portion of the field. This finding suggests that the soil used to fill and level this channel was from a different source, resulting in inherently lower salinity levels and/or that the lower apparent bulk density and coarse particle fraction allow a greater capability for leaching, removing the high salts and alkalinity from the upper 2 meters.

6.9 Recommendations for future work

According to Lesch and Corwin (2003), the primary objective prior to EM surveying is to minimize soil variability across the landscape as much as possible, whether it be spatially (minimizing texture variations) or temporally (minimizing soil moisture variability). As discussed previously soil moisture content and textural variations across the landscape seem to be the most dominant variables controlling the quality of EM-38 survey data in seasonal wetlands. For the most part, the study sites offer similar soil parameters, outside of the sandy loam of the Salt Slough sites; therefore, minimization of variability temporally is recommended as a means of producing the desired results.

The best time to conduct soil salinity surveys is directly after the initial draw-down allowing for uniform soil moisture content both vertically in the soil profile and also spatially across the landscape. Unfortunately, due to the topographic and spatial variations between the fields, some drain much faster and some areas within the fields don't drain entirely. Surveys should take place as soon as the majority (>90%) of the field has been drained and as soon as the soils are dry enough to walk on without sinking. It is ideal to survey on the initial draw-down cycle and not to rely on the summer irrigations for adequate soil moisture content. The summer irrigations are only held for a week at most and it is uncertain that with the heavy clay soils that moisture infiltrates very deep. As well, the temperatures during the irrigations are much higher and upon draw-down the fields dry out differently. In some of our sites, not all of the field was inundated by the irrigation resulting in a large dry spot surrounded by soils with 40% moisture content. Careful considerations should be made reflecting on the circumstances and condition of the fields before the time to survey takes place.

The observation of massive salt marbling in the soil profile is evidence of a need to rethink the survey techniques. A new strategy may be possible with the help of a new EM instrument that Geonics has recently developed, EM-38 MK2. The MK2 device has two lengths of dipole separation; the traditional 1m separation and now a 0.5m separation. The 0.5m separation is the equivalent to the 1m device operating in the horizontal orientation. With the MK2, both surface and sub-surface soil salinity can be measured simultaneously in the vertical orientation. This capability should help with both the timing as well as the quality of data collected.

CHAPTER 7: SUMMARY AND CONCLUSIONS

The main goals of the "adaptive, coordinated real-time management of wetland drainage" project have been to take the first steps toward real-time management of wetland drawdown so as to limit salt loading to the San Joaquin River during times of limited assimilative capacity. During the term of this project to date we have compiled historic monitoring data, utilized data from on-going TMDL and water quality surveys, installed new monitoring stations and collected data from these stations over a period of three years. This is the first comprehensive flow and water quality dataset that has been collected on seasonal wetland management practices in the region. Better understanding the complete water quality impacts of their management practices will allow wetland managers to evaluate the potential benefits and hazards of modifying management practices to help improve water quality conditions in the San Joaquin River.

Technology transfer, which is part of the outreach and education effort, is more challenging in the private wetland sector than for the State or Federal Refuges. Grassland Water District (an entity formed under the California Water Code to purchase Federal water supply and convey this water supply to its customers) this aspect will be particularly challenging contains 160 separate duck clubs, land and cattle clubs and private land holdings – each with their own boards and management structure. The District faces significant challenges in developing a system that is equitable, easy to understand and that addresses the concerns of their constituency.

During the last year of the project attention will be paid to the development of decision support tools and computer software to help coordinate data gathering and dissemination among the three wetland entities and to automate, where possible, the data downloading, error checking, and data sharing tasks. This will be done in a distributed manner initially, allowing those entities that may be reluctant to share data widely to develop a level of comfort with the new technology before making the data more generally available. The process of developing real-time water quality management capability will be both incremental and adaptive – nothing like this has been attempted in the past – yet it is essential that, where technology choices are available, that an optimal path be chosen that maintains system flexibility and ensures system coherence.

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APPENDIX : A

Real-time flow and water quality monitoring stations

1.0 Flow monitoring

Measuring flow is the most difficult and costly aspect of real-time monitoring. The amount of effort required to obtain reliable flow records is often significantly underestimated. Measuring diversions into and drainage return flows from seasonal wetlands is especially difficult on account of the following :

(a) There is a large variation in flow between deliveries and end of season drainage – where flow can approach 10 cfs and maintenance drainage flows which may be a fraction of 1 cfs. Because the smaller maintenance flows are continuous – they can accumulate to a large volume during the season. Finding sensors that can provide reliable flow measurements for this large value range is challenging.

(b) Channels are irregular and control structures are crude and not designed for accurate flow measurement – especially at low flow rates. The fact that the control structures are used to control pond drainage constrains technology selection for flow measurement. If stage is used to compute flow over a control structure, detailed records of weir board removal and addition are needed, otherwise flows will be significantly under or over – reported.

(c) There is considerable debris in the flow including sediment, algal biomass and vegetation. Sediment is a problem at the beginning of the season, especially after wetland rehabilitation, which can cause mud to accumulate around the YSI sensors, affecting both EC and stage measurements. Loose vegetation can get trapped at the weir – distorting readings and, in some instances, can impede drainage through the culverts. Daily maintenance is required at some sites to remove accumulated debris.

(d) Inlet structures employ radial screw gates whereas outlet structures typically utilize weir boards. Inlet structures therefore require that velocity and stage be recorded within each culvert to measure flow.

The technology for flow measurement has improved radically in performance as well as cost effectiveness in the past 5 years. Previous monitoring studies, performed in the Grassland Water District and the Salinas Duck Club between 1999 and 2004 used SONTEK-SL transducers to measure flow in canals and large channels and autosampler integrated acoustic Doppler/pressure sensors to measure inflow and outflow from individual ponds.

Acoustic Doppler velocity transducers utilize the Doppler principle whereby during operation each transducer produces short pulses of sound at a known frequency along two different axes. Sound from the outgoing pulses is reflected ("scattered") in all directions by particulate matter in the water. Some portion of the scattered energy travels back along the beam axes to the transducer. These return signals have a frequency shift proportional to the velocity of the scattering material. This frequency change (Doppler shift), as measured by the circuitry within the transducer, is proportional to the projection of the water velocity onto the axis of each acoustic beam. By combining data from both beams, and knowing the relative orientation of those beams, the device measures velocity in the two-dimensional plane defined by its two acoustic beams.

When mounted on an underwater structure, these devices measure velocity in a user-programmable sampling volume located several meters in front of the transducer (the transducer can be mounted to look downstream (with the flow) or upstrea m (opposing the flow). A major advantage of this technology is that the transducer never requires calibration because measurements are made in a remote sampling volume free from flow distortion and the velocity data are free from drift. Additionally, Doppler technology has no inherent minimum detectable velocity, performing well at low flows ranging from 0.01 ft/s to approximately 30 ft/s (0.003 m/s to 9.2 m/s) – the low range of velocities is suitable for wetland monitoring.

2.0 Technology used in previous studies

The SONTEK-SL transducers cost $7,500 each and were only suitable for canals and channels with a width of 20 ft or more – a smaller, equally priced transducer was deployed on a 5 ft wide channel (Fremont Canal). The SONTEK-SL provides accurate flow data provided there is sufficient head above the sensor. In canals of varying depths the mean computed velocity may underestimate or overestimate flow – depending on the placement of the transducer . The SONTEK-SL is better suited to canals and channels with relatively small changes in stage – although the transducer depth can be adjusted seasonally to cope with different stage conditions. This is both time-consuming and awkward.

The acoustic velocity transducers manufactured for American Sigma (now Hach Inc.) did not feature an integrated pressure (depth) sensor and were of insufficient sensitivity at the low range required for the wetland pond outlets to provide usable data for mass balance computations. The lack of an integrated pressure sensor made it difficult to match the stage readings (determined by an independent pressure sensor) to the exact position of the acoustic velocity sensor in the pipe culverts. This technology has been improved in recent years.

A follow-on project in the federal San Luis National Wildlife Refuge used Unidata Starflow acoustic velocity transducers with integrated pressure sensors to measure flow in major wetland drainage outlets. The Starflow pressure sensor is vented to the atmosphere and provides accurate readings of stage at the exact location of the acoustic velocity transducer. However our experience with this technology was that several of the pressure sensor failed after about 6 months of deployment requiring complete replacement of the transducer at a cost of about $2,500. We also experienced transducer damage when the vented tubing was inadvertently damaged by mechanical equipment used to remove debris from the large drainage culverts.

3.0 Flow measurement technology selection for current project

Flow measurements for the current project were initially made using a pressure (stage) sensor and custom-made V-notch weir at each of the drainage outlets. The V-notch was designed to match the size of an average weir board – to allow water managers to achieve the same outflow rate control as before. Flow measurements at the inflow diversion structures necessitated the use of an acoustic Doppler sensor since flow is controlled using radial screw gates rather than weir boards. The acoustic sensor is pushed into the culvert pipe, pointing either upstream or downstream, a sufficient distance to encounter mostly laminar flow conditions. The rule of thumb used was to have the sensor mounted a distance greater than 3 pipe culvert diameters into the pipe. At the entry and exit of each pipe eddies and water turbulence can cause significant noise in the velocity measurements. The sensors were initially mounted using hose clamps to a 6 ft length of 2 inch channel iron on to which a "T" (made of the same material) was bolted. This "T" piece was dropped into the first of the board slots in the outlet concrete structures and served as a stay – preventing the sensor assembly from being washed out of the pipe culvert. In the case of the inlet structures, which had no weir slots, sensors were installed with anchored channel iron, strap mounts or expandable straps, pointed up stream near the tail end of the pipe to minimize inaccurate velocity and depth measurements caused by undershot flows from screw gates. At sites where there is low to no sediment buildup in the pipe, the higher the sensor is mounted the more maintenance flow goes unmeasured. At sites without sediment issues sensors should be mounted as close to the bottom of the culvert as possible.

The failure of several sensors after approximately 6 months was due to the use of a bad epoxy sealant by the manufacturer which caused the sensor to leak and fail when the internal circuit board short-circuited or became corroded. All sensors were replaced and the manufacturer provided an additional 11 sensors to address the problem. Further sensor issues were attributed to overtightening the hose clamp which it was suggested might crack the delicate ceramic onto which the strain gauge of each pressure sensor is mounted. The hose clamps were replaced with zip ties which worked well – rigidly fixing the acoustic sensor to the top of the channel iron without causing damage to the ceramic.

Another technical problem encountered was the replacement of replacement sensors after initial flood-up. Once the pond was filled and the boards were put in place it became impossible to enter the culvert without scuba equipment to remove the problem sensor. Several damaged sensors were

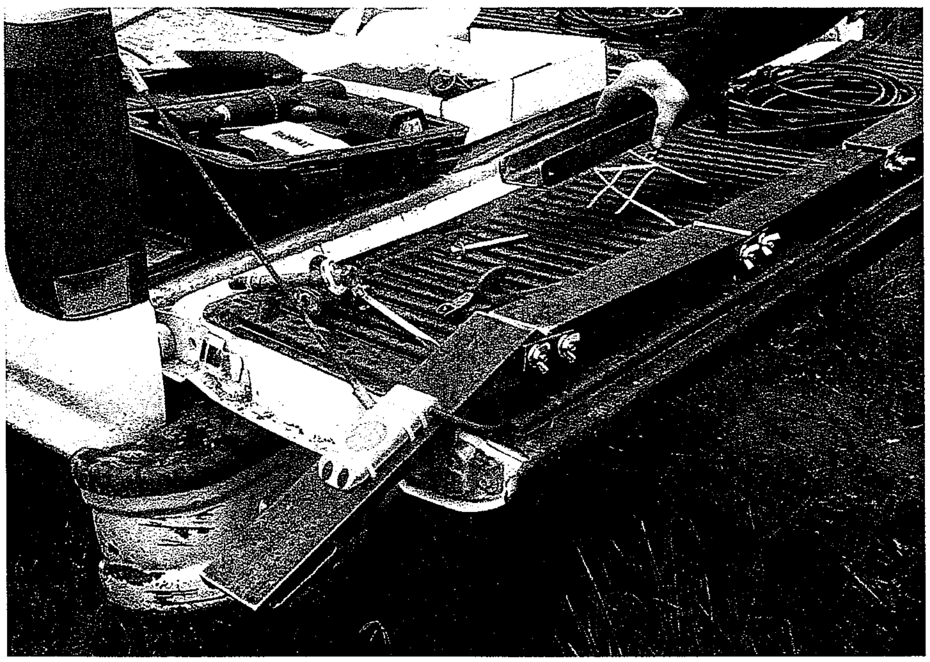


Figure 1. Articulated channel iron platform used to deploy MACE acoustic sensors in pipe culverts once wetland ponds have been filled – providing easy access or removal of problem units.

retrieved by this manner. The manufacturers recommended strap mount or expandable strap mount, which can help to maximize low flow measurement, are impossible to retrieve under flooded conditions if placed at the recommended distance inside the pipe culvert .A new design of mounting platform was developed in 2007 – an articulated channel iron platform that could be folded and unfolded and pushed length-by-length into the pipe culvert. Figure 1 shows one of these units being made ready for deployment. At some sites sensor retrieval from weirs was performed by a crew of two people by sliding the 6 ft channel iron mount between the weir boards – however this operation was difficult and invoked some safety concerns.

Analysis of the flow data from 2006 demonstrated that the QA data sheets that had been prepared in advance to record board changes at the drain outlets were not being filled out consistently. A board change that is not recorded can drastically effect the accuracy of the flow record i.e. a board removed will produce significant flow though the pressure transducer would suggest a stage lower than top of the apparent weir board elevation – and thus record no flow. Conversely a board replaced would cause a rise in head above the apparent weir board elevation and suggest significant flow when in fact there might be none. The limited accuracy of the unvented sonde depth pressure sensors, which appeared to require frequent calibration, suggested that these not be used as a primary means of measuring flow. Board adjustments at the outlet weirs are made on a routine basis by management staff, occurring multiple times between QA data checks, to maintain optimal pond depths for maximum waterbird usage. Board height data measured at the time of QA monitoring would provide little insight to sometimes daily adjustments made by water managers.

To improve the accuracy of flow measurement and to eliminate the tedium of recording these paper records and the end of the season analysis to estimate flow, a decision was made to add MACE acoustic velocity sensors at each drainage outlet in a similar configuration to the inflow diversion monitoring sites. The US Bureau of Reclamation provided the financing for the purchase of twelve Series III MACE Agriflo units which were subsequently installed – these were married with the additional acoustic Doppler transducers that had been supplied by MACE. This decision has eliminated considerable staff time devoted to data processing and is delivering a more accurate flow record at the drainage sites. The description of individual monitoring sites, that appears later in this document, shows both the existing V-notch weirs and MACE series III Agriflo units at each monitoring site. The V-notch weirs now act as a secondary flow recorder at each site - useful in the case of MACE flow sensor failure.

4.0 Salts and salinity measurement

Salinity content is measured by sampling the electrical conductivity of the water. Electrical conductivity (EC), measured in micro-Siemens per centimeter [uS/cm], is a measure of the ions present in the water. The ions consist mainly of Calcium (Ca^+), Magnesium (Mg^+), Sodium (Na^+), and Potassium (K^+) cations and Bicarbonate (HCO_3^-), Sulfate (SO_4^-) and Chloride (Cl^-) anions. There is a direct relationship between TDS in mg/L and EC in uS/cm – this ratio has been determined to be in the vicinity of 0.74 for the Grasslands drainage basin. Flow and EC data can be combined to estimate salt loading in to and out of each wetland impoundment. The computation to convert the flow (cfs) and EC (uS/cm) to total salt load (tons of salt per day – tpd) is as follows:

Equation 1

$$SaltLoad = M \times Q \times EC$$

Where : Q = flow [cfs]

EC = electrical conductivity [uS/cm]

M = ratio of TDS [mg/L] to EC [uS/cm] = 0.74 in the Grassland Basin (California Environmental Protection Agency, 2002).

Converting salt load into tons per day [tpd] Equation 1 becomes :

Equation 2

$$SaltLoad.[tpd] = \frac{M\left[\frac{mg/L}{uS/cm}\right] \times Q\left[\frac{cu.ft.}{\text{sec}}\right] \times EC\left[\frac{uS}{cm}\right] \times 28.32\left[\frac{L}{cu.ft.}\right] \times 2.2046\left[\frac{lb.}{kg}\right] \times 86{,}400\left[\frac{\text{sec}}{day}\right]}{1{,}000{,}000\left[\frac{mg}{kg}\right] \times 2{,}000\left[\frac{lb}{ton}\right]}$$

This can be simplified as follows :

Equation 3

$$SaltLoad[tpd] = Q[cfs] \times EC\left[\frac{uS}{cm}\right] \times 0.002023$$

5.0 Salinity Monitoring

The technology chosen for electrical conductivity (EC) measurement was the YSI 600 XL sonde. Although all of the previous monitoring within the Basin had been performed with Campbell Scientific Inc. probes, with some success, the decision was made to use a SDI-12 capable sensor which would be adaptable to any data collection platform that supported the SDI-12 protocol. Campbell Scientific probes have the advantage of being simple and inexpensive but they require a Campbell Datalogger to make measurements from them – unlike the solid-state YSI sondes which contain the circuitry within the body of the sonde, the Campbell Scientific probes are merely one branch in a Wheatstone network – the probe is merely an epoxy covered electrode. The YSI 650 XL contains three sensor ports – one of which is used for the EC/temperature sensor. There is a built-in non-vented pressure transducer in the body of the sonde which is used to estimate water stage. The lack of venting reduces the accuracy of the probe in changing weather conditions since the probe is not able to compensate for atmospheric pressure conditions. However the accuracy is sufficient for measuring changes in stage over the V-notch weir and for estimating flow within 5%.

A stilling well with a lockable cap was designed for each monitoring site to protect the $2500 sonde from theft or vandalism. The stilling well tube was perforated at the depth of the EC/temperature sensor to allow sufficient circulation to ensure good readings, the dark environment the stilling well provides also prevents the build-up of algal biomass. However, at some sites where there was a lot of sediment in suspension, sediment would accumulate around the open base of the stilling well impeding circulation and in some instances restricting exchange between the inside of the stilling well and the pond - causing significant error in the EC readings. This problem was solved by elevating the stilling well above the accumulated sediment and re-setting the stage offset. In one or two cases, accumulated sediment had to be removed with a backhoe. The experience of two years of monitoring suggests that the YSI EC sondes be visited at least twice-weekly during the initial flood-up period and for 1 month afterwards until the majority of the flood-up has been completed, in order to obtain good quality data.

6.0 Site Quality Assurance

Flow quality assurance is performed weekly with a Marsh McBirney Flowmate flow sensor with a long L-shaped mounting arm that allows the sensor head to be inserted approximately 3 feet into the pipe culvert. A comparison is made between the velocity measured by the Marsh McBirney after the reading has stabilized and the velocity recorded by the MACE acoustic velocity transducer. Any discrepancy between the readings would require that a calibration curve be developed between actual and measured velocity. The 2006 and

2007 monitoring have shown good agreement between MACE and Marsh McBirney Flowmate values. Stage over the acoustic velocity transducer is difficult to estimate – a check is made using the bottom of the pipe culvert as the reference point and this is compared with the MACE pressure sensor value. If the MACE pressure sensor is working properly these values are typically in close agreement. Failure of the MACE pressure sensor results in data value drift which is readily apparent. Replacement of the sensor and resetting sensor values using the MACE data acquisition user interface is the remedy to pressure sensor failure.

Salinity quality assurance was initially performed with a Myron Ultrameter 6P handheld meter. The 6P Ultrameter has proved both robust and reliable in the field. However the differences in electrodes resulted in some systematic discrepancies between Myron field reference and recorded YSI 650 XL data. A portable YSI 650 XL instrument was substituted for the Myron meter in early 2007. This has allowed much better correlation between reference and measured values. In instances where reference and measured values are greater than 5% different – the field sonde is recalibrated using the YSI 650 handheld instrument and the beginning and ending EC values noted on the QA sheet. If the discrepancy is less than 5% the field value is noted along with the reference value on the QA sheet. During data processing interpolation of other curve fitting techniques are used to adjust the field recorded data to better approximate the weekly reference data.

The most significant finding from the past two years of monitoring is that we feel that real-time monitoring with web-based reporting of data is essential for proper data quality assurance. These wetland field sites are very different from stream and river monitoring stations operated by the USGS and DWR or agricultural canals monitored by local water districts in that they require more sophisticated measurement technology to acquire good data, they see significant changes in flow conditions within short periods of time, some due to water manager manipulation and they are in a very biologically diverse environment with a host of invasive insects and rodents that can ruin sensitive equipment. These sites are located in an environment with high humidity which can cause circuit board corrosion if the interior of the instrument cases are not properly desiccated. The latter issue an ongoing concern with the MACE Series II and Series III instrument boxes which were developed originally for the Australia market and have a wide 2 inch opening at their base. Originally designed to prevent the MACE acoustic Doppler sensor from being disconnected – this opening is very difficult to seal properly. We have had several instances of invasion by yellow jackets and most recently by ants – which is the last instance completely ruined the circuit board. It is difficult to desiccate the circuit boards properly using putty or fiberglass wool as a sealant. Real-time access to these sites has allowed issues to be recognized and field parties dispatched to the monitoring sites within a day or two of a problem occurring. This has resulted in a minimal loss of data, reduced time spent trying to understand problem data and has helped to develop a rapid response system by the equipment manufacturer to replace bad sensors within a week of the sensors being removed from the site. We have kept a minimum of one spare sensor for each monitoring network component which can be used immediately in the field to replace a problem unit, in the case of equipment failure.

Unlike the MACE Agriflo Series II, The Agriflo series III does not report a depth parameter through its SDI 12 interface. From a real-time QA perspective, without the depth parameter, it is difficult to remotely assess flow measurement accuracy. We have been assured by MACE Inc. that the next generation FloPro meter (which is an upgrade of the Agriflo III will report depth through the SDI-12 interface The circuit boards from these new units will be supplied to our project by the manufacturer in time for the 2009 drawdown season.

Telemetry and Communications

The backbone of network of continuously reporting monitoring stations that currently report stage, velocity, instantaneous flow, cumulative flow, temperature, and electrical conductivity every 15 minutes is a system called YSI ECONET (YSI Inc., 2005). YSI ECONET eliminates many of the operational constraints of the previous EDSS monitoring station platform design. YSI ECONET is a remote monitoring and control platform that provides wireless (or wired) data acquisition, remote monitoring and control over the Internet (Figure 2). The system is comprised of Data Nodes that monitor water quality and flow measuring sensors. The mesh of multiple Data Nodes connects to a Access Nodes through a low power radio interface. The Access Nodes , in turn, connect to a remote DataCenter through the Internet via CDMA cellular phone or satellite modem. The Communication Server performs the communication with the Access Node, receiving data and any possible alarm messages and sending back commands and functioning parameters. The Data Node can compare the acquired data against predefined alarm thresholds (minimum and maximum) and immediately notify the Access Node when the input values are outside the defined range. This feature may be used in the future to control drainage salt loading from automated gate outlets in a follow-on project.

The wireless mesh network topology allows "point-to-point" or "peer-to-peer" connectivity and creates an ad hoc, multi-hop network. The mesh network is self-organizing and self-healing – hence loss of one or more nodes does not necessarily affect its operation. This increases the overall reliability of the system by allowing a fast local response to critical events in the rare event of a communication problem. Elimination of tedious data acquisition and processing procedures through adoption of YSI-ECONET is freeing up time in our current monitoring system deployments. The system allows point and click access to current monitoring data at a particular Data or Access Node within the network. Maintenance of the monitoring network can now focus on monthly sensor quality assurance checks including cleaning of sensors and checking the accuracy of gauge stage data from which flow is determined.

Perhaps the greatest virtue of the YSI-ECONET system is that software running on the Data Node is intuitive and the units are programmable by technical staff in the Grassland Water District and the Department of Fish and Game. The object-interface consists of a series of pre-built routines that implement the data acquisition, control functions and communication protocols. A configuration file defines parameters such as the device ID, sampling rates, reporting frequencies, alarm thresholds and actions to be taken in case of alarms and can be readily changed through the project password protected website. The Access Node runs a small Linux Program that is independent of the application and handles the communication with the supervised Data Nodes, the Data Center and the digital input/outputs.

Deployment of YSI ECONET within the Grassland Water District and the various wetland units managed by the Department of Fish and Game has not been problem-free. During initial deployment we needed to replace more than 6 modem cards in the YSI ECONET boxes. This was initially highly disruptive since it required fedexing these units back to Massachusetts and waiting for a replacement unit to be repaired and fedexed back – in the meantime replacing the missing node with the spare. Since each node has a unique registry – website corrections were needed to have the replacement box recognized by the system. This took time and coordination with YSI ECONET technicians. The company eventually agreed to supply us with a small stock of spare modems which we were able to replace ourselves in the field – eliminating a lot of wasted time. Ongoing issues are related to YSI ECONET Master Nodes with poor CDMA reception. There are a number of cellular dead zones within the Refuge Complex. In the case of the Salt Slough Master Node site, we have difficulty obtaining regular real time data feeds and have had to install a secondary battery in parallel with the original battery to facilitate multiple calling attempts.

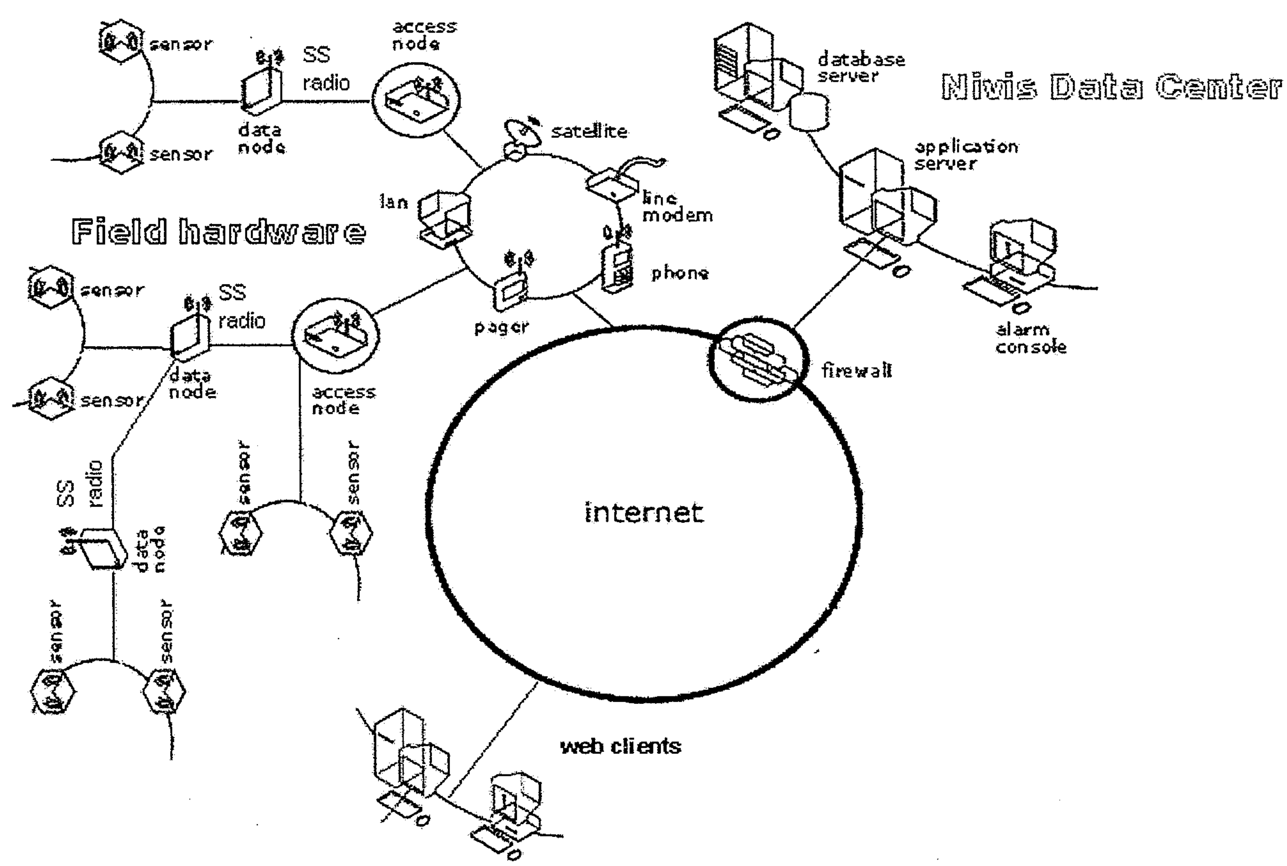


Figure 2. System architecture linking field monitoring stations with external NIVIS Data Center which stores, maintains and serves real-time flow and water quality data on public and private websites

From a user perspective one disadvantage with the YSI ECONET system is the inability to access the data through a SDI-12 or serial direct connection to the box. The system has been designed to be a "black box" with radio, CDMA or satellite telemetry through an internal modem or direct network access through and Ethernet cable as the only means of interacting with the data collection platform. This may be a strategic design decision on the part of the manufacturer but it comes at a cost to the end user at times where access to data is critical and there is insufficient time to remove the unit and either sent it back to the manufacturer or configure it into an Ethernet network.

DUCKY STRIKE NORTH POND - INLET

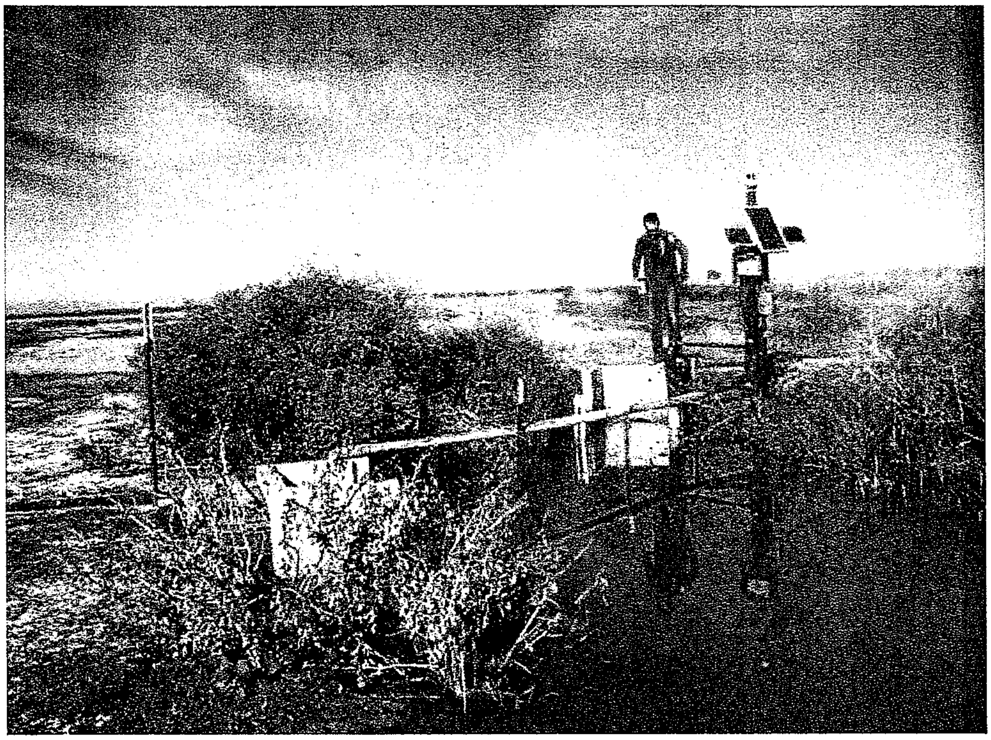


Table 1 – Ducky Strike North Pond Inlet Monitoring Station Specifications

Site Summary	Ducky Strike North - Inlet This is a compound monitoring site which also monitors flow through berm into Ducky Strike South
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger with telemetry
EC Sensor	YSI sondes with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Agriflo Series II data collection platforms using acoustic Doppler velocity sensors and vented pressure (stage) sensors. Inlet V-notch weirs provide a secondary flow measurement
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

DUCKY STRIKE NORTH POND - OUTLET

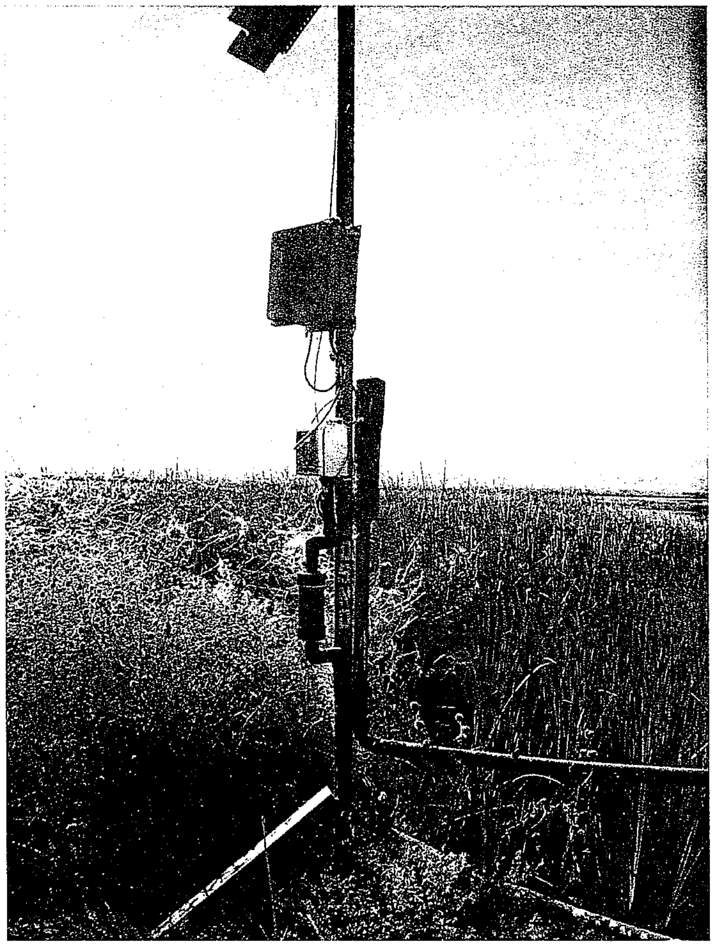


Table 2 – Ducky Strike North Pond Outlet Monitoring Station Specifications

Site Summary	Ducky Strike North Pond - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger with telemetry
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

DUCKY STRIKE SOUTH POND - COMMON INLET

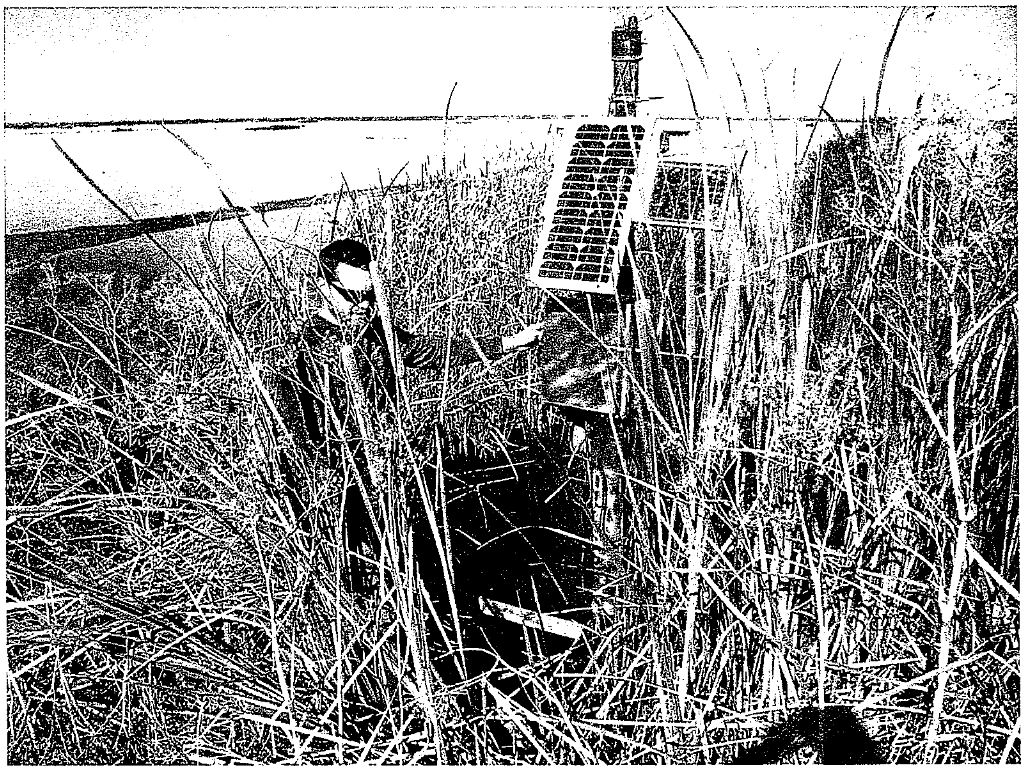


Table 3 – Ducky Strike South Pond Common Inlet Monitoring Station Specifications

Site Summary	Ducky Strike South Pond – Common Inlet Pond inlet through duck club to the south
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger with telemetry
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Agriflo Series II data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

DUCKY STRIKE SOUTH POND - OUTLET

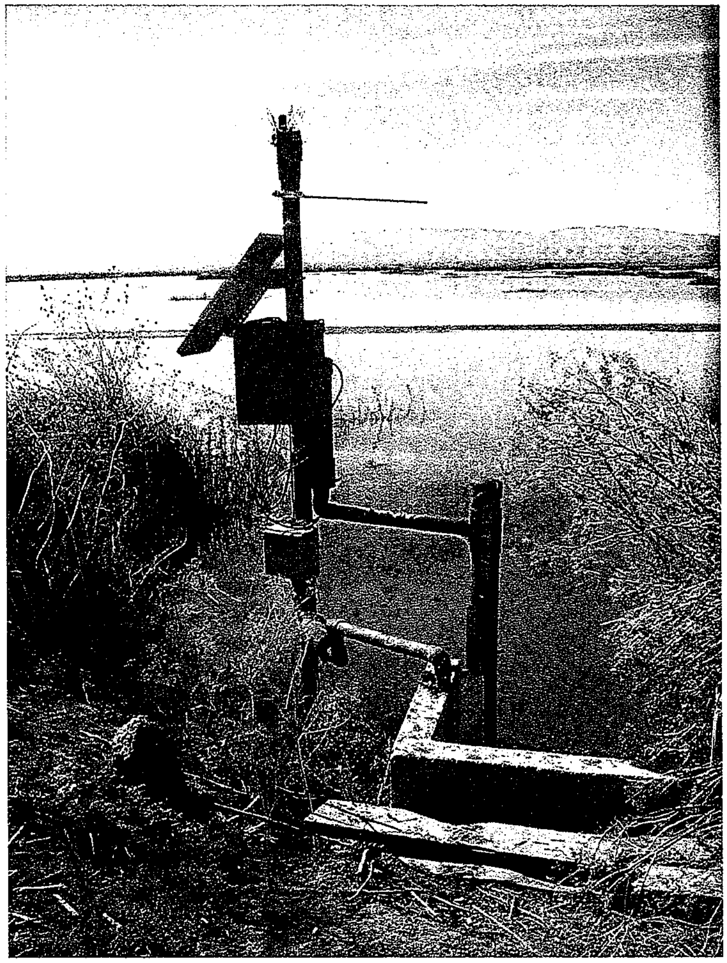


Table 4 – Ducky Strike South Pond Outlet Monitoring Station Specifications

Site Summary	Ducky Strike South Pond – Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger with telemetry
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

DUCKY STRIKE SOUTH POND - BERM INLET

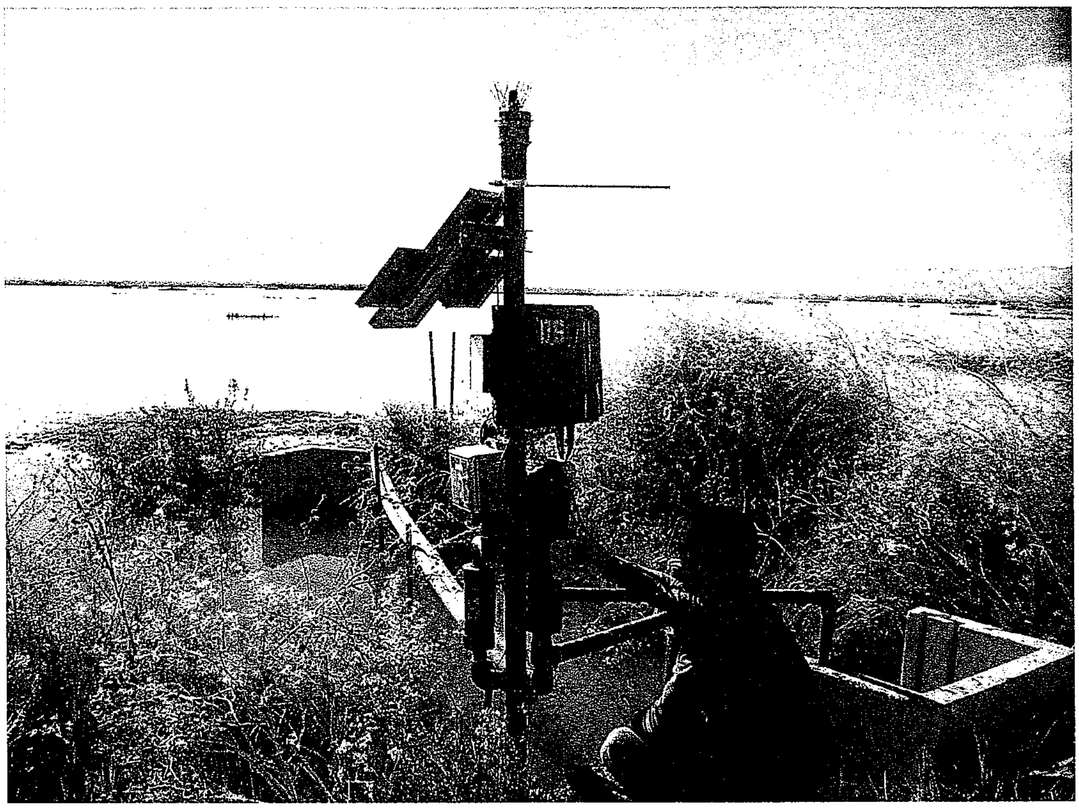


Table 5 – Ducky Strike South Pond Berm Inlet Monitoring Station Specifications

Site Summary	Ducky Strike South Pond – Berm Inlet This is a compound monitoring site – water flows in two directions through the berm into south pond
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

GADWALL POND 5 - INLET

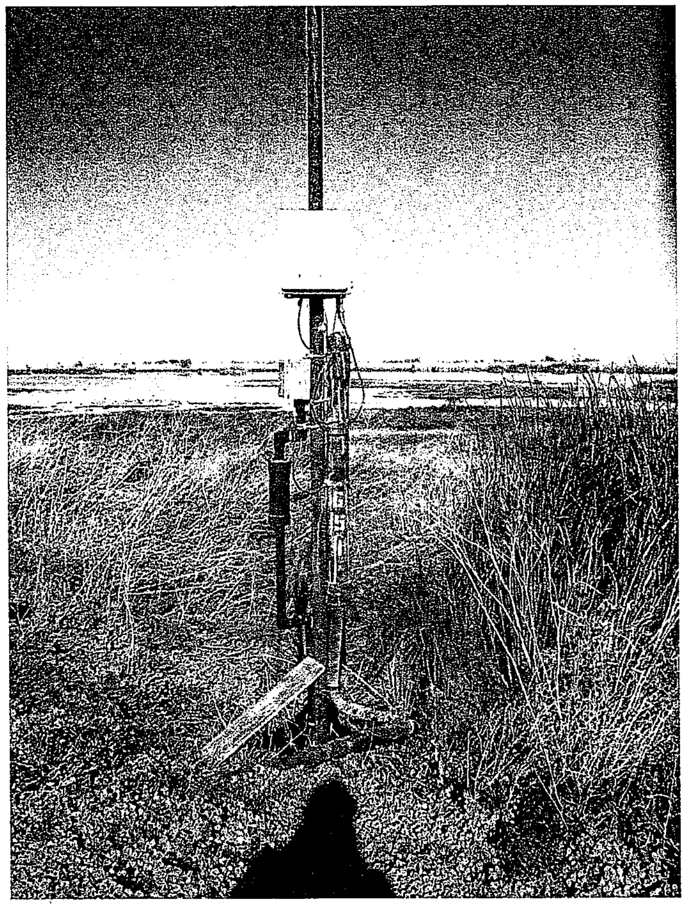


Table 6 – Gadwall Pond 5 Inlet Monitoring Station Specifications

Site Summary	Gadwall Pond 5 - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

GADWALL POND 5 - OUTLET

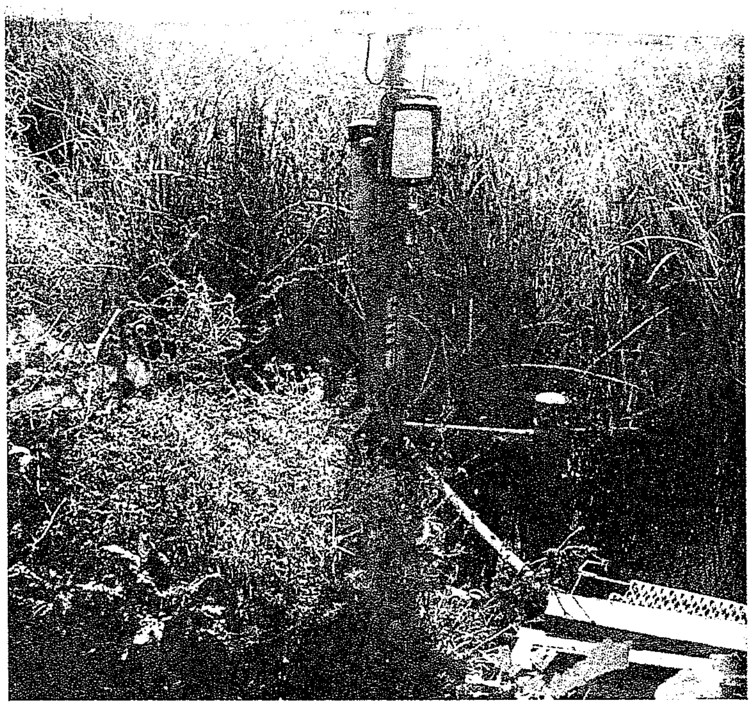


Table 7 – Gadwall Pond 5 Outlet Monitoring Station Specifications

Site Summary	Gadwall Pond 5 - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

GADWALL POND 6 - INLET

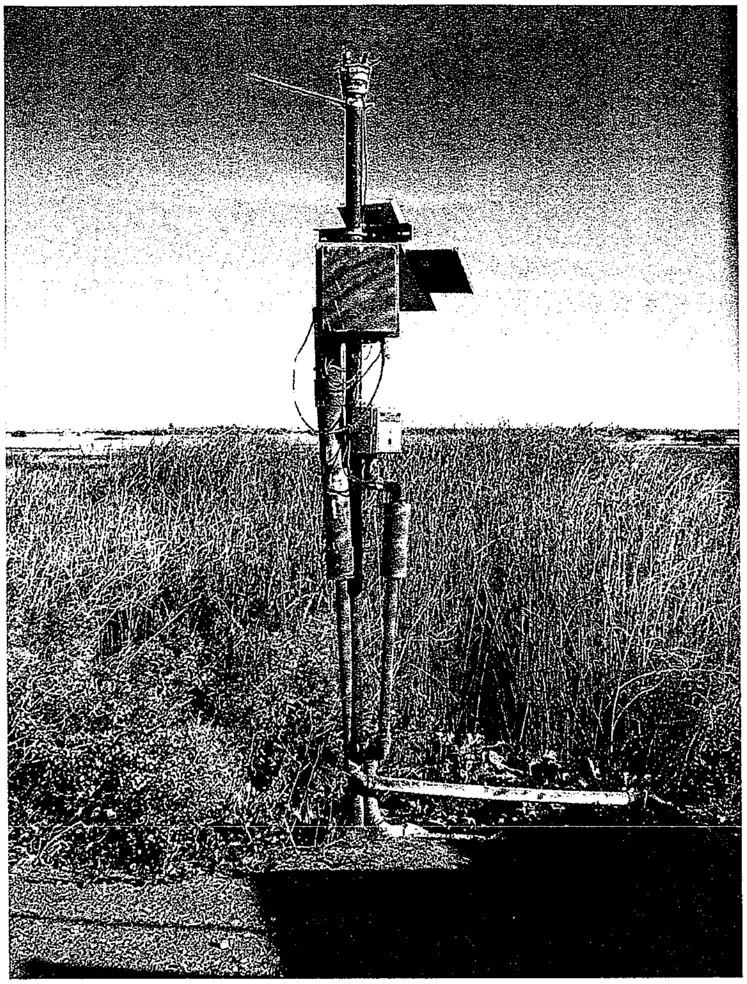


Table 8 – Gadwall Pond 6 Inlet Monitoring Station Specifications

Site Summary	Gadwall Pond 6 - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II AgriFlo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

GADWALL POND 6 - OUTLET

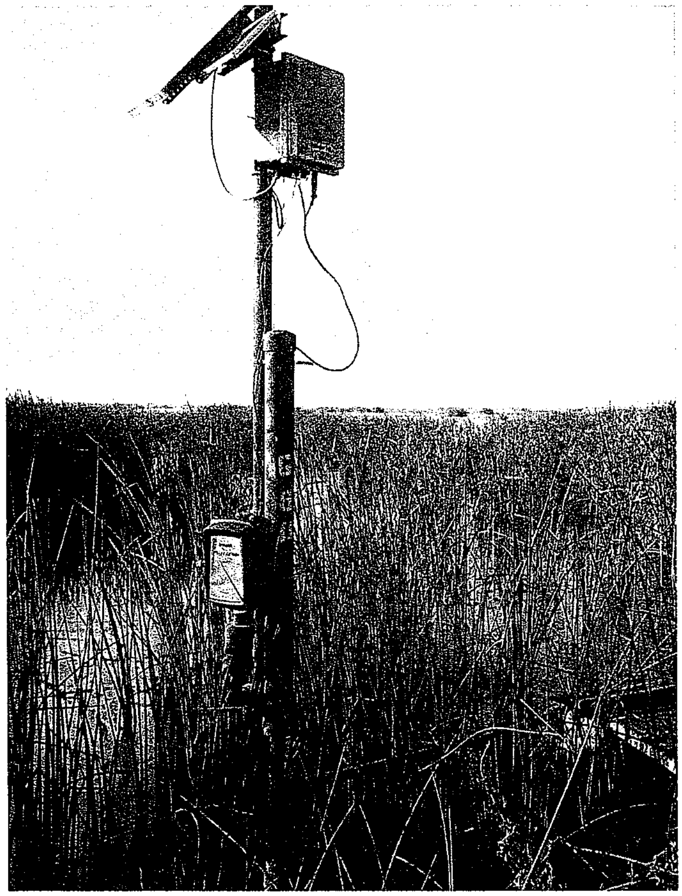


Table 9 – Gadwall Pond 6 Outlet Monitoring Station Specifications

Site Summary	Gadwall Pond 6 - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

LOS BANOS POND 31B - INLET

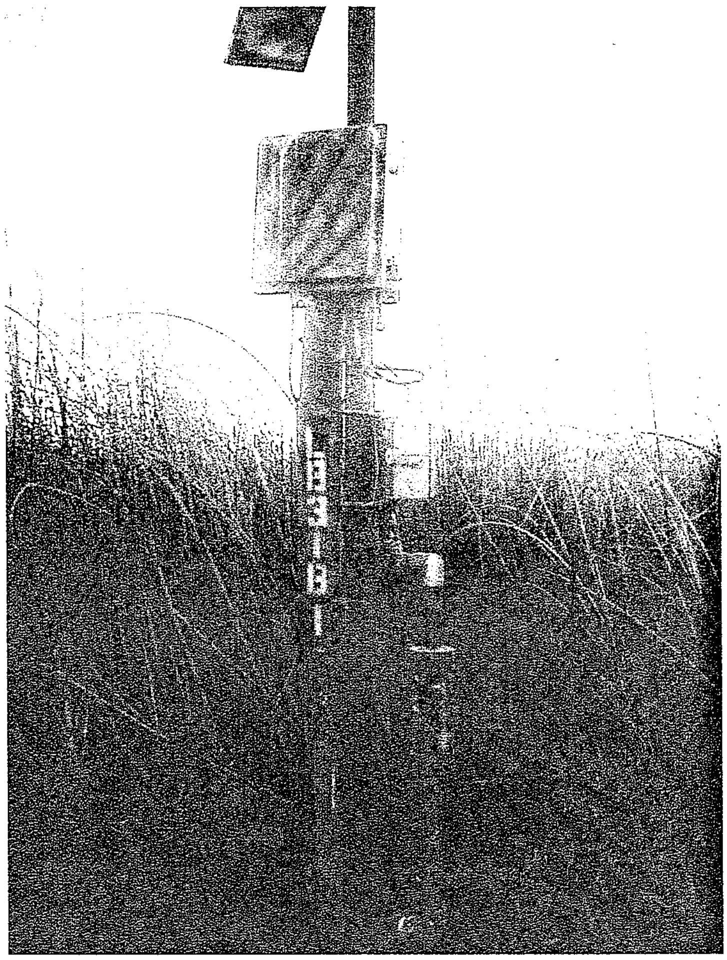


Table 10 – Los Banos Pond 31B Inlet Monitoring Station Specifications

Site Summary	Los Banos Pond 31B - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

LOS BANOS POND 31B - OUTLET

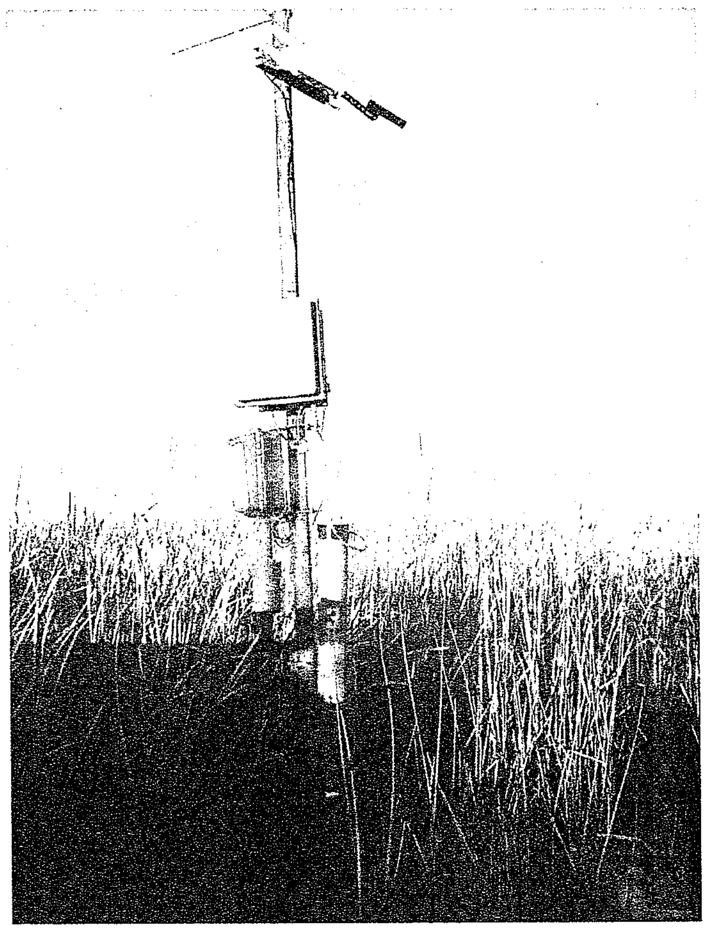


Table 11 – Los Banos Pond 31B Outlet Monitoring Station Specifications

Site Summary	Los Banos Pond 31B - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

LOS BANOS POND 33 - INLET

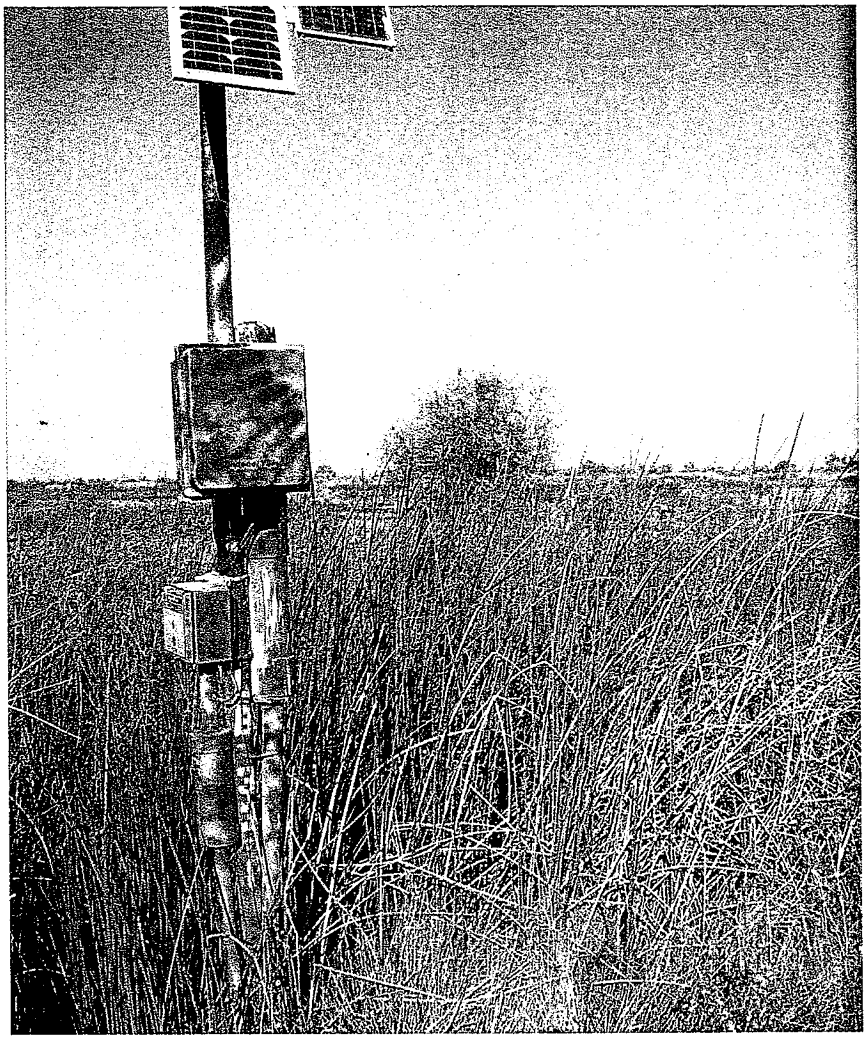


Table 12 – Los Banos Pond 33 Inlet Monitoring Station Specifications

Site Summary	Los Banos Pond 33 - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

LOS BANOS POND 33 - OUTLET

Table 13 – Los Banos Pond 33 Outlet Monitoring Station Specifications

Site Summary	Los Banos Pond 33 - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

MUD SLOUGH POND 3B - INLET

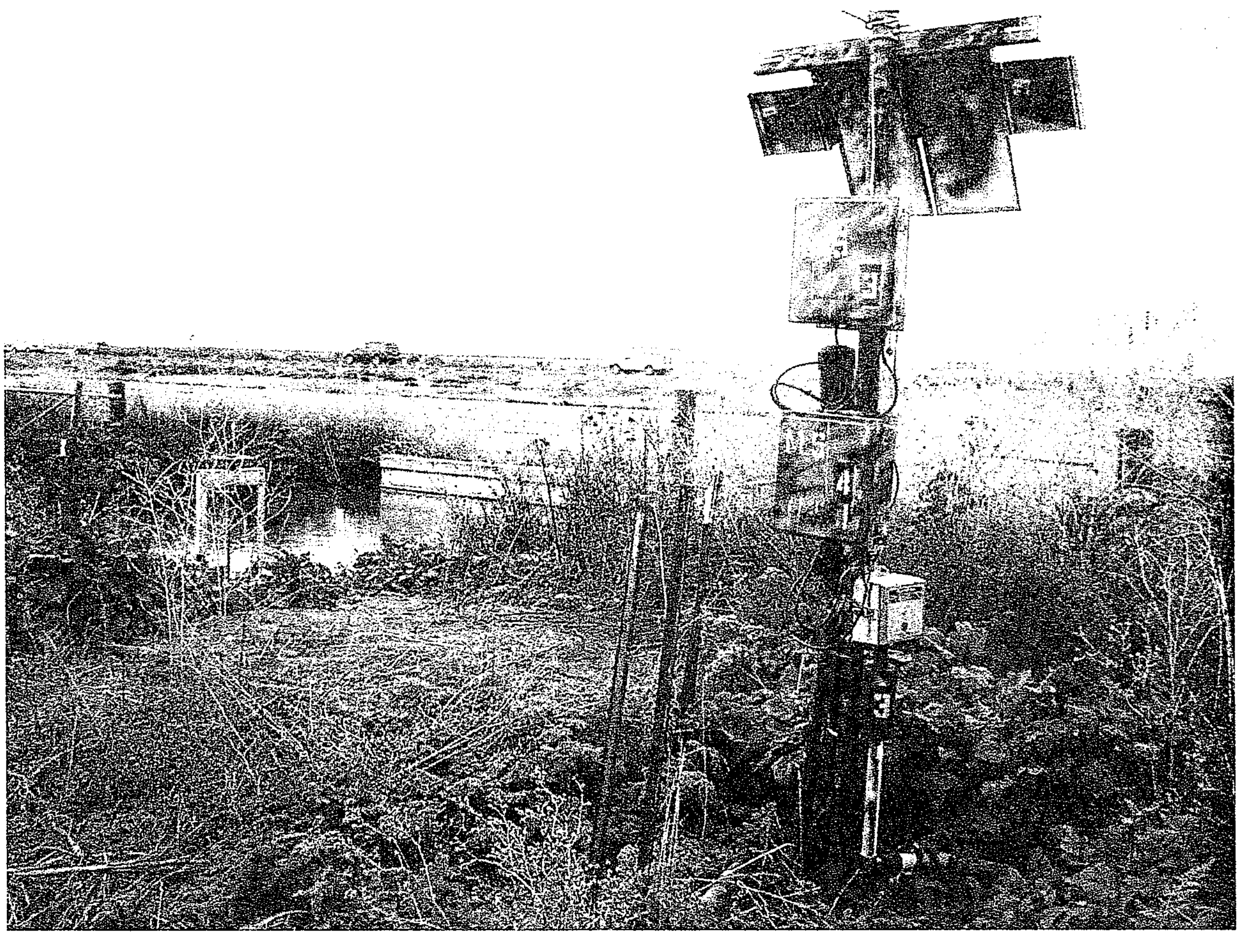


Table 14 –Mud Slough Pond 3B Inlet Monitoring Station Specifications

Site Summary	Mud Slough Pond 3B - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

MUD SLOUGH POND 3B - OUTLET

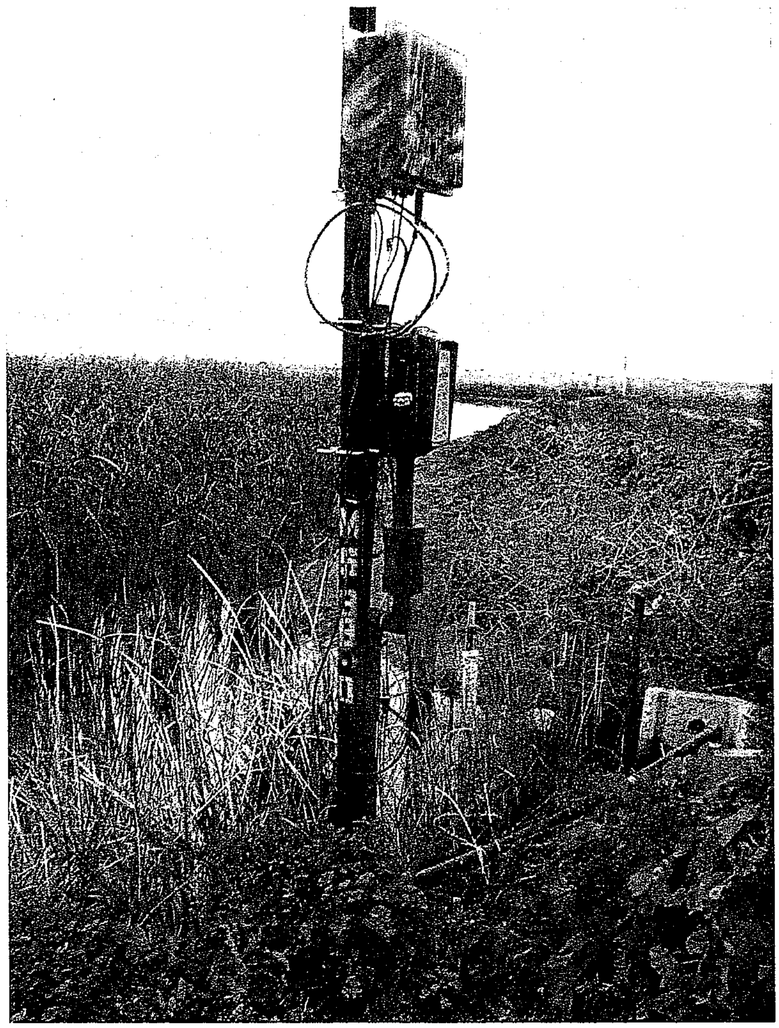


Table 15 – Mud Slough Pond 3B Outlet Monitoring Station Specifications

Site Summary	Mud Slough Pond 3B - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

MUD SLOUGH POND 4B - INLET

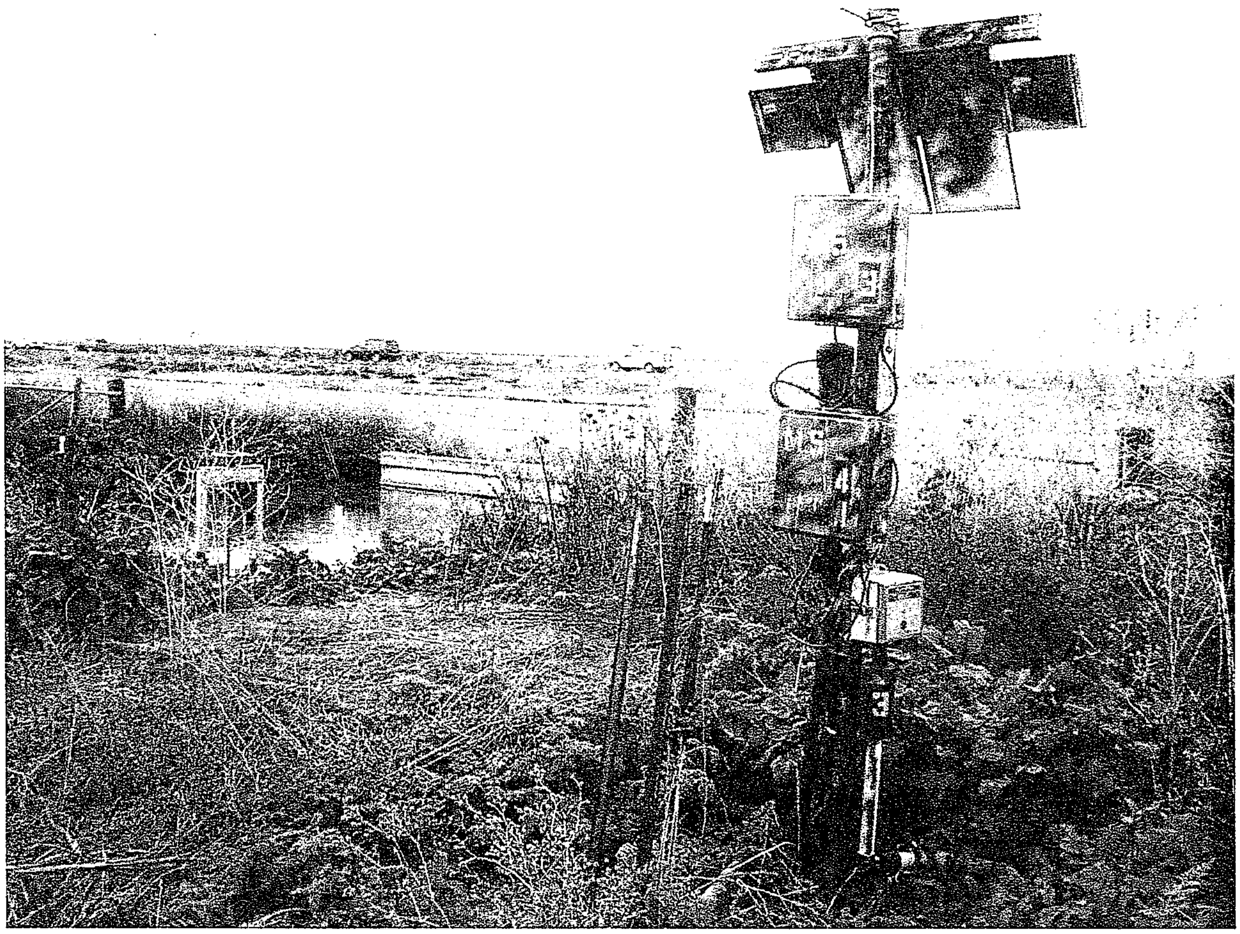


Table 16 – Mud Slough Pond 4B Inlet Monitoring Station Specifications

Site Summary	Mud Slough Pond 4B - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

MUD SLOUGH POND 4B - OUTLET

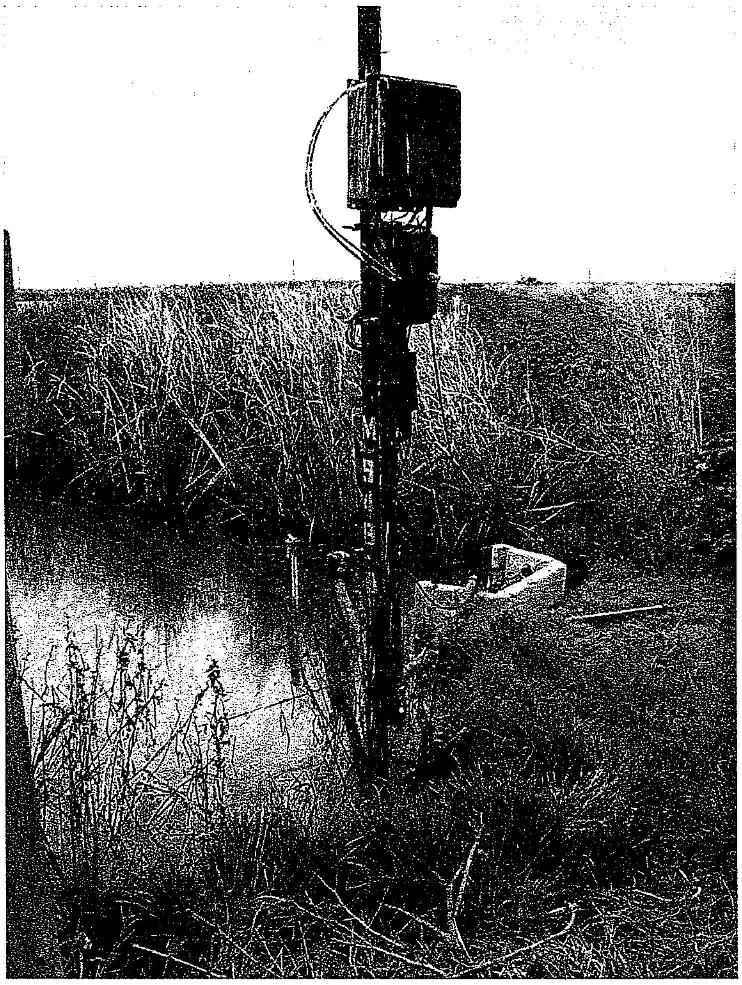


Table 17 – Mud Slough Pond 4B Outlet Monitoring Station Specifications

Site Summary	Mud Slough Pond 4B - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

SALT SLOUGH POND 24 - INLET

Table 18 – Salt Slough Pond 24 Inlet Monitoring Station Specifications

Site Summary	Salt Slough Pond 24 - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

SALT SLOUGH POND 24 - OUTLET

Table 19 – Salt Slough Pond 24 Outlet Monitoring Station Specifications

Site Summary	Salt Slough Pond 24 - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

SALT SLOUGH POND 32 - INLET

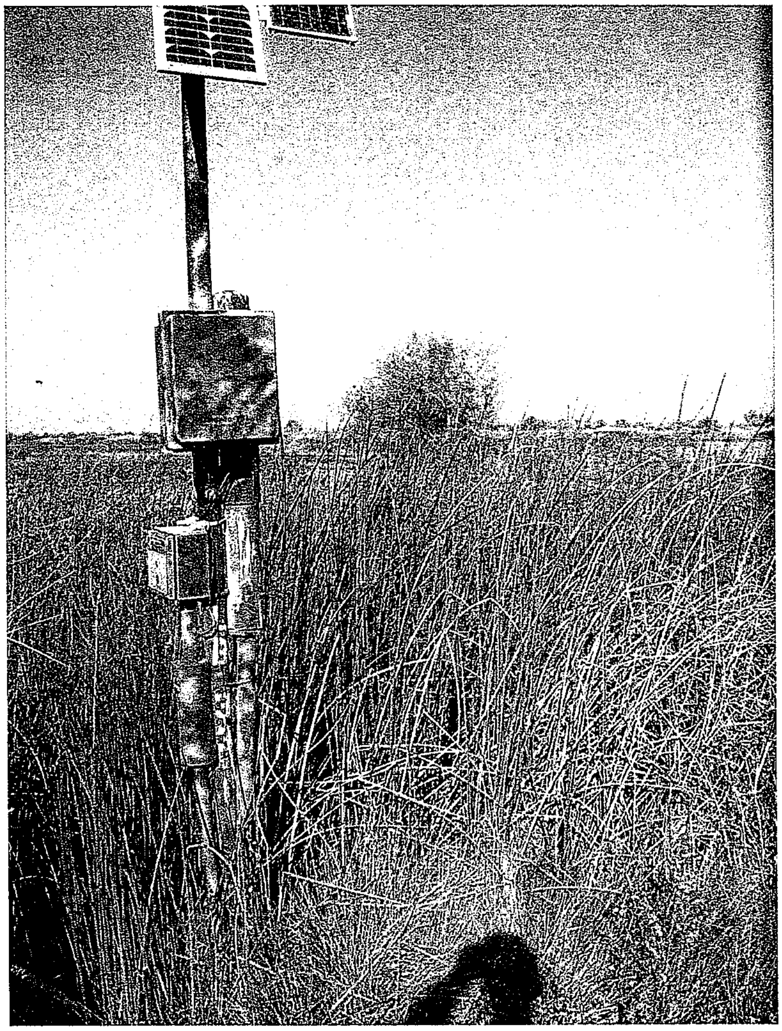


Table 20 – Salt Slough Pond 32 Inlet Monitoring Station Specifications

Site Summary	Salt Slough Pond 32 - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

SALT SLOUGH POND 32 - OUTLET

Table 21 – Salt Slough Pond 32 Outlet Monitoring Station Specifications

Site Summary	Salt Slough Pond 32 - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

VOLTA POND 23 - INLET

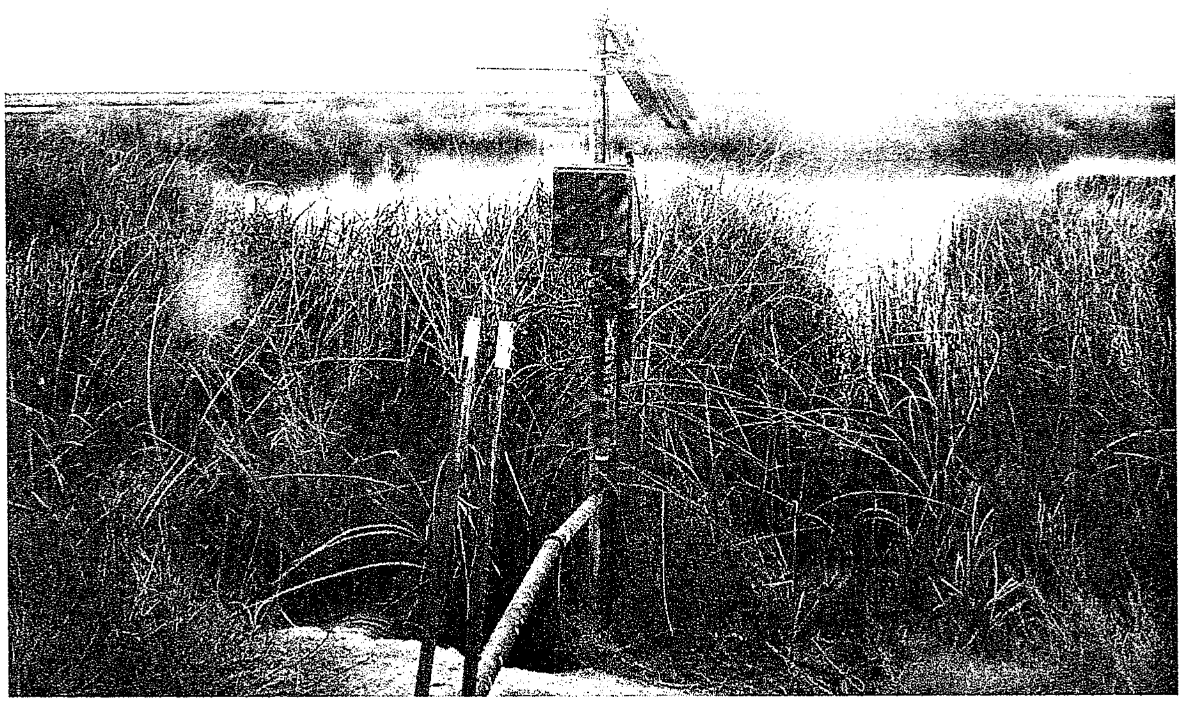


Table 22 –Volta Pond 23 Inlet Monitoring Station Specifications

Site Summary	Volta Pond 23 - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

VOLTA POND 23 - OUTLET

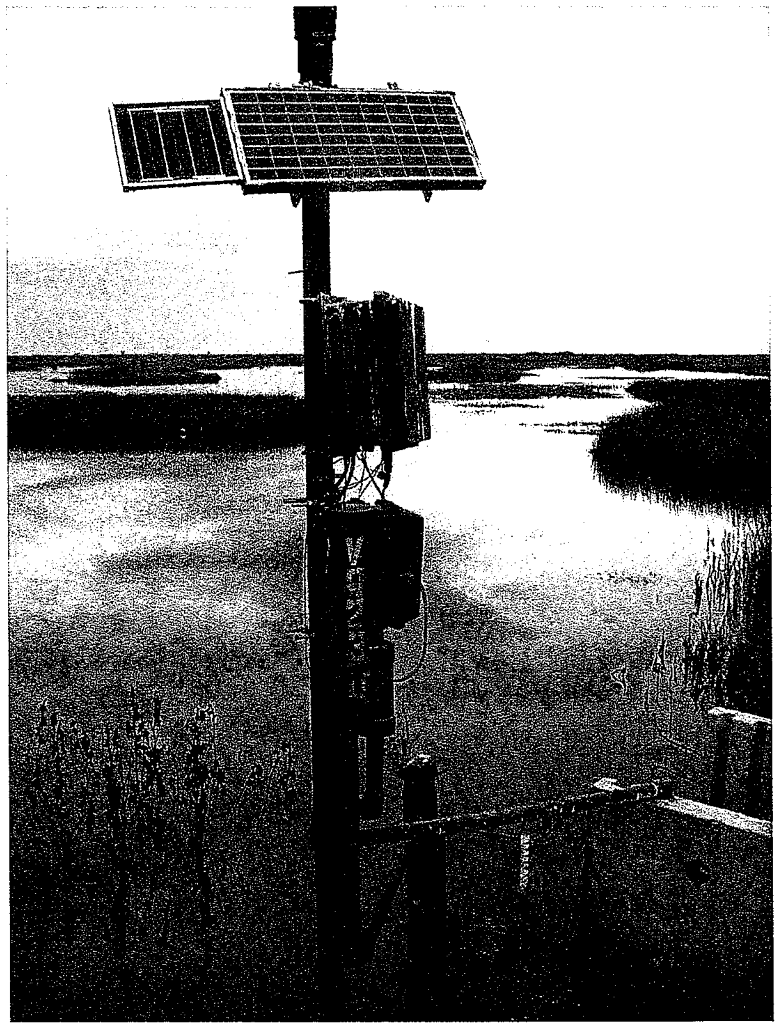


Table 23 – Volta Pond 23 Outlet Monitoring Station Specifications

Site Summary	Volta Pond 23 - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

VOLTA POND 4D - INLET

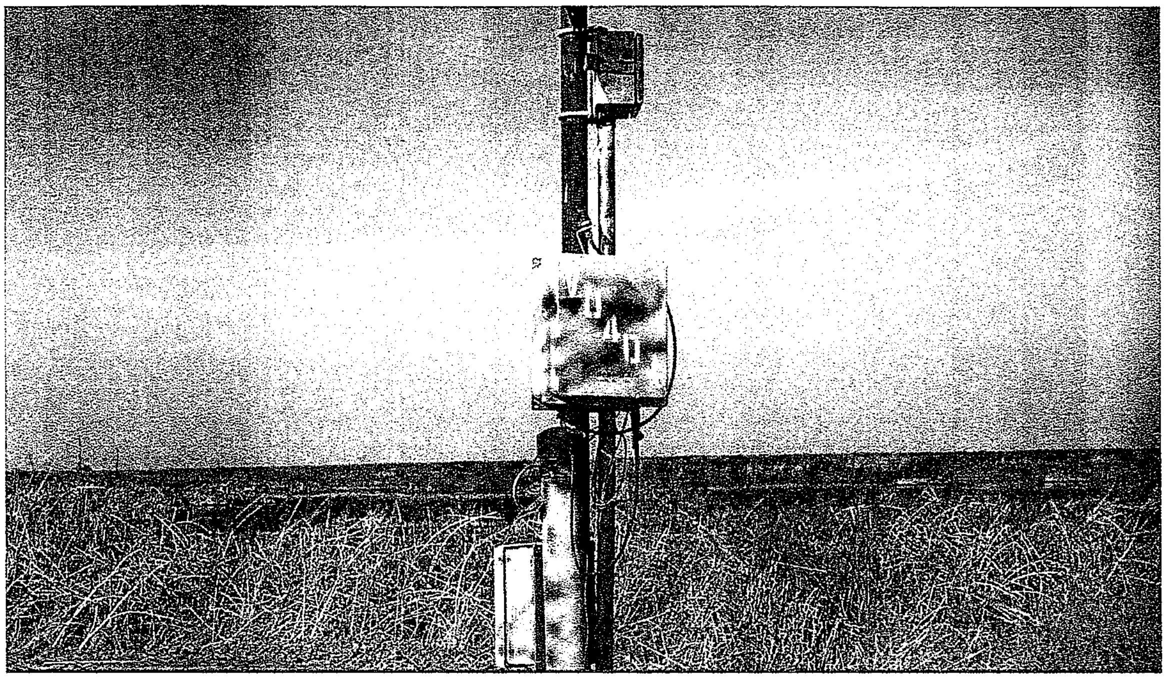


Table 24 – Volta Pond 4D Inlet Monitoring Station Specifications

Site Summary	Volta Pond 4D - Inlet Radial gate inlet control structure – YSI sonde in supply ditch
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series II Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

VOLTA POND 4D - OUTLET

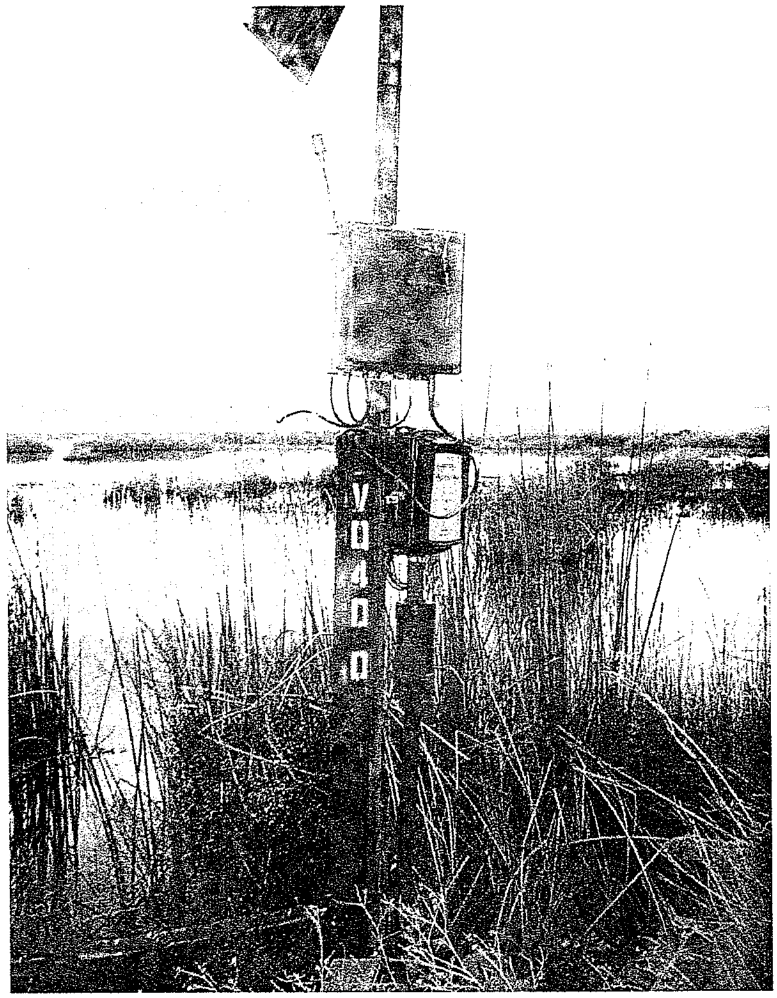
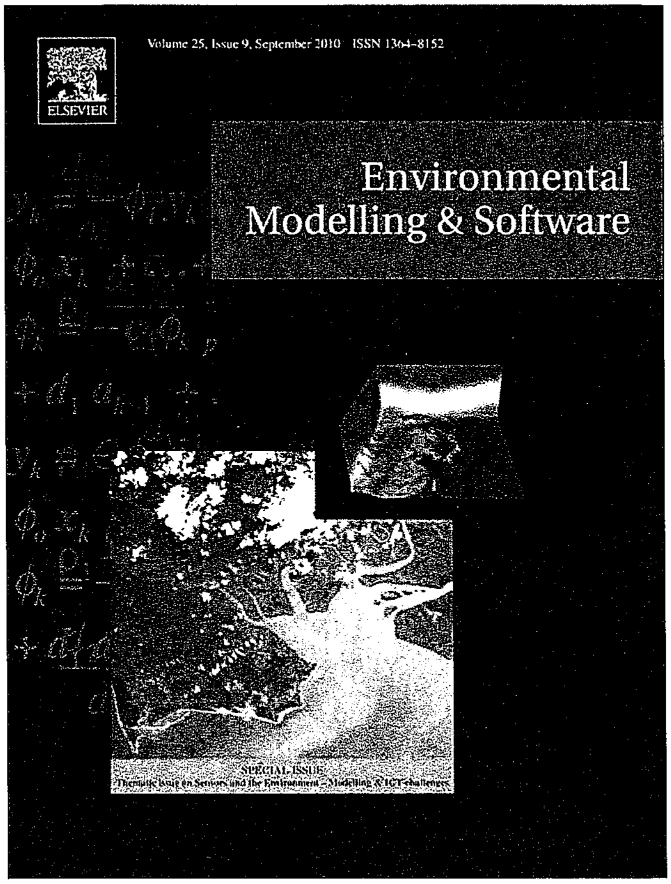


Table 25 – Volta Pond 4D Outlet Monitoring Station Specifications

Site Summary	Volta Pond 4D - Outlet Weir board control structure with V notch weir controls discharge to the east to a common drain
Power	Solar Panels with 12-volt batteries
Datalogger	EcoNet datalogger
EC Sensor	YSI sonde with temperature compensation
Stage Sensor	YSI non-vented pressure transducer (no barometric compensation)
Flow Measurement	MACE Series III Agriflo data collection platform using acoustic Doppler velocity sensor and vented pressure (stage) sensor. Outlet V-notch weir provides a secondary flow measurement.
• Depth	MACE pressure transducer in pipe
• Velocity	MACE acoustic velocity transducer in pipe
Telecommunications	EcoNet radio telemetry and CDMA phone telemetry through ACCESS node to NIVIS dataserver

APPENDIX : B

COMPILATION OF PROJECT-RELATED JOURNAL PAPERS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Use of environmental sensors and sensor networks to develop water and salinity budgets for seasonal wetland real-time water quality management

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ABSTRACT

Management of river salt loads in a complex and highly regulated river basin such as the San Joaquin River Basin of California presents significant challenges for current Information Technology. Computer-based numerical models are used as a means of simulating hydrologic processes and water quality within the basin and can be useful tools for organizing Basin data in a structured and readily accessible manner. These models can also be used to extend information derived from environmental sensors within existing monitoring networks to areas outside these systems based on similarity factors – since it would be cost prohibitive to collect data for every channel or pollutant source within the Basin. A common feature of all hydrologic and water quality models is the ability to perform mass balances. This paper describes the use of a number of state-of-the-art sensor technologies that have been deployed to obtain water and salinity mass balances for a 60,000 ha tract of seasonally managed wetlands in the San Joaquin River Basin of California. These sensor technologies are being combined with more traditional environmental monitoring techniques to support real-time salinity management (RTSM) in the River Basin. Two of these new technology applications: *YSI-Econet* (which supports continuous flow and salinity monitoring of surface water deliveries and seasonal wetland drainage); and *electromagnetic salinity mapping* (a remote sensing technology for mapping soil salinity in the surface soils) – have not previously been reported in the literature. Continuous sensor deployments that experience more widespread use include: *weather station sensor arrays* – used to estimate wetland pond evaporation and moist soil plant evapotranspiration; *high resolution multi-spectral imagery* – used to discriminate between and estimate the area of wetland moist soil plant vegetation; and *groundwater level sensors* – used primarily to estimate seepage losses beneath a wetland pond during flood-up. Important issues associated with quality assurance of continuous data are discussed and the application of a state-of-the-art software product AQUARIUS, which streamlines the process of data error correction and dissemination, is described as an essential element of ensuring successful RTSM implementation in the San Joaquin River Basin.

1. Introduction

Real-time water quality management (RTWQM) is a strategy for meeting downstream water quality objectives by making use of river assimilative capacity and improving coordination of upstream contaminant loading from point and non-point sources with dilution flows. In California and other western States (within the United States) as well as other arid river basins around the world (such as the Murray Darling River Basin in Australia) – salinity is treated as a pollutant and its concentration in rivers used for agricultural, municipal and industrial water supply regulated (Murray Darling Basin Commission, 2005). The assimilative capacity for a pollutant such as salinity in a water body is defined as the maximum loading of that contaminant that can be accommodated by the water body without exceeding water quality objectives (or standards). These objectives are typically defined at a downstream compliance monitoring location. In the case of California's San Joaquin Basin – reservoir releases from tributaries on the East-Side of the River Basin (mostly snow-melt from the granitic Sierra Nevada mountains) and return flows from east-side irrigation districts provide dilution for west-side San Joaquin Basin drainage flows, derived mostly from west-side San Joaquin Valley irrigated agricultural

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crop land, municipalities and seasonally managed wetlands. West-side soils derive from eroded sediments from an uplifted marine and are high in naturally occurring salts. Water supplies for irrigation of west-side agriculture, some urban areas and for seasonally managed wetlands (Fig. 1) derive from the Sacramento–San Joaquin River Delta and contain salt – most often in the range of 300–600 ppm TDS. West-side agricultural return flows are at their highest during the summer irrigation season. Seasonal wetland salt loads are highest during the months of March and April when the majority of the seasonal wetland ponds are drawn down to promote establishment of moist soil plants and other native grasses that provide a protein source to overwintering waterfowl.

Salt export from agricultural, wetland and municipalities is regulated as part of a comprehensive Total Maximum Daily Load (TMDL) for the San Joaquin River Basin (CEPA, 2002; CRWQCB, 2004; Quinn and Karkoski, 1998). The TMDL is intended to identify, quantify and control sources of pollution that affect attainment of water quality objectives and full protection of identified beneficial uses of water. The TMDL includes both point and non-point sources of salt loading. Point sources of salinity, such as discharges from wastewater treatment systems, are regulated using Waste Load Allocations (WLA). These WLAs are usually concentration based and allow the entities regulated to enter into a marketplace with other regulated entities to trade their allocations. Non-point sources of salinity (LA) are not typically amenable to the establishment of fixed monthly or seasonal salt load allocations because of the diffuse nature of these non-point source loads in the watershed (which makes it difficult to assign responsibility), the technical challenges of monitoring individual discharge points, and the high seasonal variation in export flows and salt loads.

The loading capacity for a TMDL is determined by multiplying the water quality objective (WQO) at the downstream compliance monitoring location by the available flow in the river or stream, Q (CRWQCB, 2004):

$$\mathrm{TMDL} = Q^{*}\mathrm{WQO} \tag{1}$$

This total loading capacity (TMDL) equals the sum of the waste load allocations from point sources (WLA) and non-point sources (LA) and includes an appropriate margin of safety (MOS) (CRWQCB, 2004).

$$\mathrm{TMDL} = \mathrm{LC} = \sum \mathrm{WLA} + \sum \mathrm{LA} + \mathrm{MOS} \tag{2}$$

where LC = salt load capacity, WLA = point-source salt load allocation, LA = non-point source salt load allocation, MOS = margin of safety (%).

These allocations are calculated based on the lowest anticipated flow condition in the River and the River's assimilative capacity during these periods. Point-source salt loads (WLAs), are subtracted from the total assimilative capacity of the River to determine the salt load allocation to all non-point sources. These non-point source loads of salt include both background salt loads (salt loads imported with surface water supply and not controllable by landowners) and salt loads contributed by groundwater return flows (CRWQCB, 2004).

$$\mathrm{TMDL} = \sum \mathrm{WLA} + \sum \mathrm{LA} + \sum \mathrm{BG} + \sum \mathrm{GW} + \mathrm{MOS} \tag{3}$$

where GW = groundwater salt loading, BG = background salt loading.

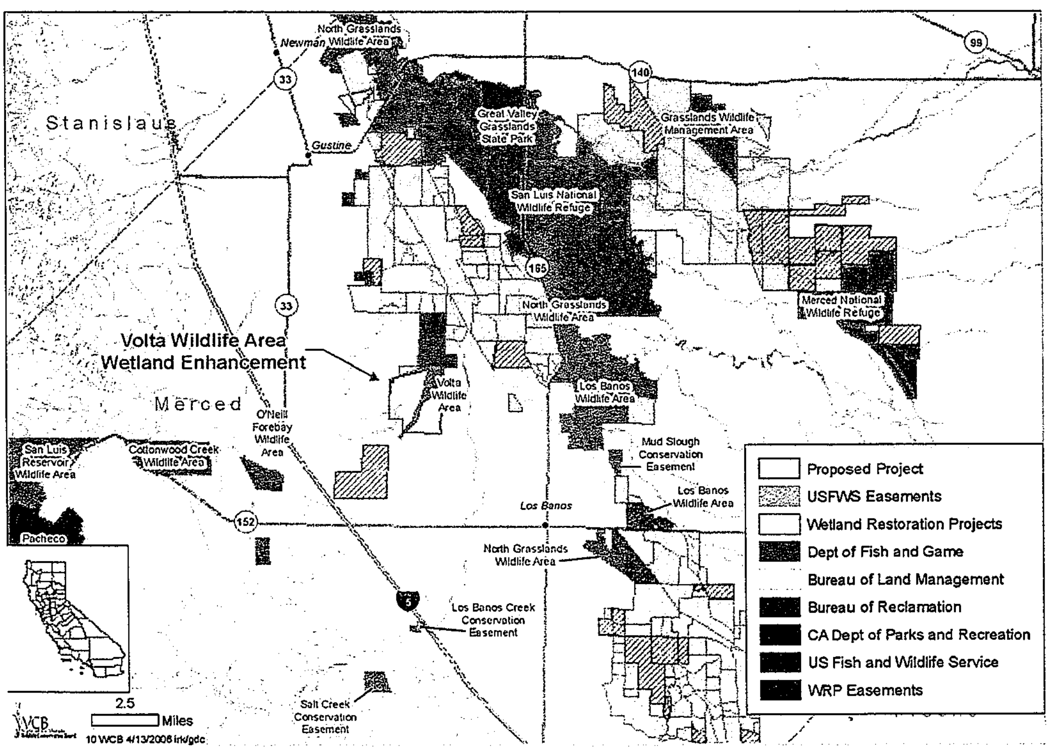

Fig. 1. Project area which contains approximately 60,000 has of seasonal wetland habitat collectively known as the Grasslands Ecological Area (GEA). It comprises Federal, State and private wetlands and conservation easements to form the largest contiguous area of waterfowl habitat in the western United States. The GEA is subject to EPA mandated salinity regulation which is best met through an innovative salt management technique, now under development, known as real-time salinity management (RTSM).

For a successful TMDL, the actual sum of loads from tones all point and non-point sources, background loads, groundwater loads, and margin of safety must be less than or equal to the TMDL. The margin of safety is typically set at 15–20% of the total salt load and takes account of the hydrologic variability of the system and the technical inability to use 100% of the assimilative capacity of the River, even under near-perfect management.

The salinity TMDL limits both agricultural and wetland discharges of salt loads to the San Joaquin River. During dry and critically dry years the salinity TMDL is especially restrictive curtailing salt load from irrigated agricultural land during the summer months when drainage return flows are highest. Under these hydrologic conditions the total volume of dilution flow from Sierran tributaries to the San Joaquin River diminish – River assimilative capacity is likewise reduced, resulting in more frequent violation of the CRWQCB water quality objectives for salinity.

Real-time salinity management has been advocated as a means of improving compliance with San Joaquin River salinity objectives by improving the coordination of west-side agricultural and wetland dischargers of salt with reservoir releases flows made along east-side tributaries (Quinn and Hanna; 2002, 2003; Quinn et al., 2005). RTSM is a concept that relies upon access to real-time flow and electrical conductivity data from networks of sensors located along the San Joaquin River and its major tributaries (Quinn and Karkoski, 1998). RTSM provides timely decision support to agricultural water districts and seasonal wetland managers – allowing them to improve the coordination of salt load export with the available assimilative capacity of the San Joaquin River (Quinn and Hanna; 2002, 2003). An Environmental Decision Support System (EDSS) is under development which combines watershed flow and water quality monitoring, modeling, salt assimilative capacity forecasting and web-based information dissemination and sharing. The published literature contains examples of similar, although less ambitious, EDSS projects for adaptive management of salinity and other water quality contaminants (Zhu and Dale, 2001; Janssen et al., 2005; Garcia and Lange, 1993).

1.1. Wetland salinity management

Seasonally managed wetlands in the western San Joaquin Basin of California's Central Valley provide overwintering habitat for migratory waterfowl and hunting opportunities during the annual duck hunting season. Wetland water supply from the Sacramento–San Joaquin River Delta contains inorganic salts which evapoconcentrate in the man-made, seasonally managed ponds, before being drained into channels that discharge into the San Joaquin River. This seasonal wetland drainage, produced within a 60,000 ha wetland Grasslands Ecological Area (GEA) of the San Joaquin Basin (Fig. 1), must be eliminated to preserve salt balance and sustain habitat conditions that make these wetlands the most important migratory bird resource in the western United States. Unfortunately wetland drainage schedules often coincide with periods of low assimilative capacity in the San Joaquin River as well as the germination period of salt sensitive agricultural crops in the southern Delta. These southern Delta crops are irrigated with water pumped from the River – the area in which they are grown is located approximately 100 km downstream of the major salt-load bearing tributaries to the River. Assimilative capacity, expressed in tonnes (tons) of salt, is the numerical difference between the product of the current flow and numerical water quality objective and the current salt load measured at the compliance monitoring station. A negative River assimilative capacity (Fig. 2) occurs any time the numeric water quality objective is exceeded.

Application of RTSM to seasonal wetlands in the San Joaquin Basin will likely require more intensive management of wetland hydrology which might include modification of traditional wetland drawdown schedules to better match wetland salt loads with the assimilative capacity of the San Joaquin River. Wetland drawdown schedules have been established over several decades to promote the establishment of moist soil plant habitat that provides the optimal food resource for overwintering waterfowl (Mushet et. al.,1992; Reinecke and Hartke, 2005; USFWS, 1986). Changes to this traditional schedule may come at a potential cost to the sustainability of the moist soil plant habitat resource (Fredrickson and Taylor, 1982; Quinn et al., 2005; Taft et al.,

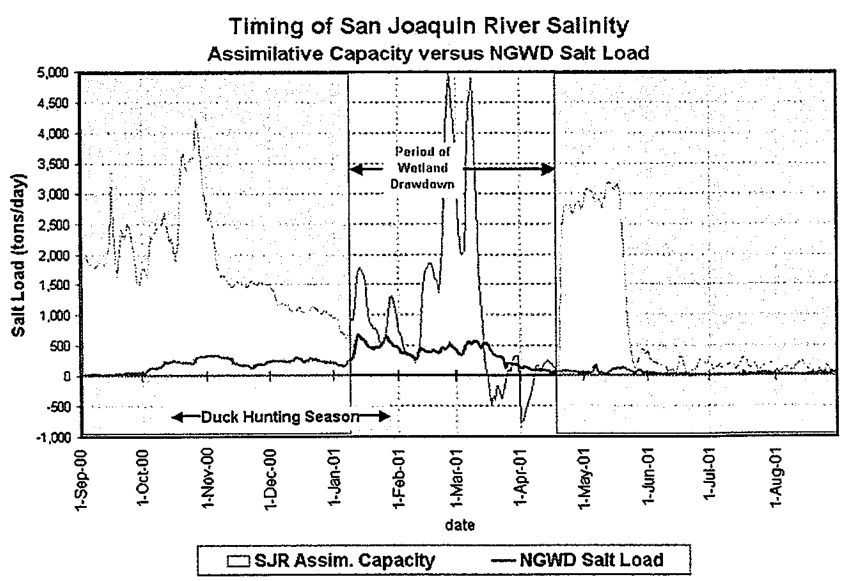

Fig. 2. Illustration of the concept of RTSM. Salt assimilative capacity (shown by the shaded grey area – tons/day) is typically high during winter months when a combination of a higher salinity river objective (1,000 μS/cm) and rainfall runoff produce high diluting flows from east-side San Joaquin River tributaries. Wetland drainage salt loads from private wetlands in the Grasslands Ecological Area are sufficient to produce negative assimilative capacity during periods in late March and early April when river salt concentrations exceed State-mandated water quality objectives. Under an RTSM scenario delaying wetland drainage drawdown until mid-April would re-schedule this salt loading to a period of high River assimilative capacity preventing exceedence of river salinity objectives.

2002). However there exists is a dearth of field data or published studies upon which to base wetland seasonal salinity management strategies. A primary objective of the study described in this paper is to develop a quantitative approach to improve the understanding of wetland hydrology and salinity and to guide RTSM.

2. Methods

The concept of water and salt balance is fundamental to all water quality simulation models. Wetland water and salinity balances are performed by summing fluxes of water and salt entering a leaving a defined control volume, such as a single pond, resulting in an estimated rate of change in wetland water storage or salt content (Fig. 3). Implementation of wetland RTSM requires continuous updating of water and salinity balances using sensors to: measure water and salt inflow to and outflow from each pond; seepage and salt flux exchange with groundwater; surface water storage gain due to precipitation and surface water storage loss due to the sum of direct pond evaporation and moist soil plant evapotranspiration.

Sensors selected to take these measurements should have the following capabilities:

1. Provide accurate flow measurements within the range of 0.1–10 cfs – typical of wetland flow hydrology
2. Have a common data communication interface such as SDI-12 providing sensor compatibility with a number of data collection platforms
3. Fast response and capable of being telemetered in combination with other sensors through the data collection platform
4. Robust and resilient – capable of performing accurately under a wide range of environmental conditions (i.e. cold, moist winter conditions and hot, desiccating summer conditions)
5. Inexpensive and easy to deploy

The environmental monitoring systems described in this paper fall into three categories :

1. Sensors that are part of a environmental sensor network that contains master (access) nodes that directly communicate with the data storage service center and slave (data) nodes that report to the master nodes. The YSI-EcoNet environmental monitoring and web-based data dissemination system is state-of-the-art example of this type of sensor network.
2. Sensors that are not normally part of a telemetered sensor network that are interrogated at irregular intervals and data are accessed manually. The Bowen weather station and in situ groundwater elevation sensors are examples of this type of sensor deployment.
3. Sensors that are typically deployed only once at a single location as part of a system characterization procedure or experiment. Soil salinity maps based on surveys conducted using a portable electromagnetic (EM-38) instrument and wetland vegetation maps developed from high resolution, multi-spectral remote sensing imagery and spectral analysis software are examples of this mode of sensor deployment.

2.1. Monitoring system design

For the seasonal wetland application an integrated suite of environmental sensors were deployed to develop accurate water and salinity balances for individual

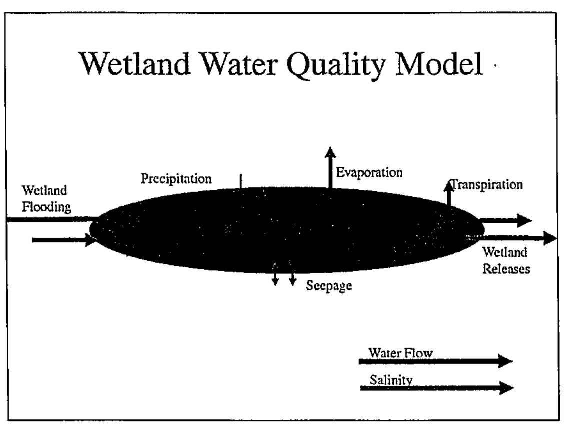

Fig. 3. Conceptual wetland hydrology and salinity model showing component processes.

wetland ponds and extrapolate these results over the GEA. With over 300 wetland ponds, ranging in size from a few hectares to several hundred hectares, the annual cost of providing telemetry to each inlet and outlet of every pond within the entire 60,000 ha GEA would be in excess of $270,000 (assuming an average of $450 per site per year and no scale-up cost offsets). This figure would exceed the annual salinity monitoring budgets of the wetland entities combined. Hence the environmental monitoring system was designed to provide characterization at both individual pond and sub-watershed scale. At the scale of the individual wetland pond – inlets and outlets were continuously monitored for flow and salinity during the period of flooding. High resolution imagery was analysed of each of the wetland pond sites and the resulting classification used to determine the relative proportion of each pond area vegetated with desirable moist soil crops that provide superior wetland habitat such as swamp timothy (*Crypsis schoenoides*), watergrass (*Hydrochloa caroliniensis*) and smartweed (*Polygonum lapathifolium*).

Sub-basin scale characterization was accomplished by subdividing the entire Basin into subareas that shared a common water supply (i.e. were flooded up together and hence were provided similar quality water) and subareas that drained through common drainage outlets (drainage water quality expected to be similar). Flow and salinity monitoring stations were installed at these major inlets and outlets, within several of the major wetland supply and drainage canals and also at the inlets and outlets of carefully selected individual ponds. In the GEA it was fortunate that the footprint of the larger flooded sub-basins and the drainage sub-basins were most often closely matched. A certain amount of redundancy was built into the monitoring system to act as checks when extrapolating the data derived from individual ponds to the larger drainage subareas. This also assisted in validation of model hydrologic and water quality assumptions.

3. Results

Implementation of the monitoring system design and the data reporting and visualization system began in 2005 and the system continues to evolve and expand in coverage and capability. The timing of the project was fortuitous in one aspect that it coincided with the commercial release to market of a suite of innovative sensor technologies some of which have been exploited in the project application. The downside of being the first in line to apply new technology was that our project became the de-facto alpha test platform for several of the technologies that still contained software bugs and hardware components that had not been adequately tested.

3.1. Data collection, dissemination and visualization

The technology for telemetry of environmental monitoring data has been available for several decades. Supervisory Control and Data Acquisition (SCADA) systems provide not only continuous monitoring of flow and water quality for their client municipalities and water districts but also have the ability to adjust control settings of pumps and other flow devices according to preset logic or specific control-feedback algorithms. These systems typically utilize radio or cellular telemetry to transmit data to a central base station, are complicated to program and are rarely accessible to outside monitoring networks. Skilled technicians are often required to install, re-program and administer these systems – although new SCADA software is now available, such as Control Microsystem's ClearSCADA product (http://www.clearscada.com/), which makes this technology more accessible. Commercial vendors such as Campbell Scientific Inc. (http://www.campbellsci.com), Vaisala Inc. (http://www.Vaisala.com), Design Analysis Associates Inc. (http://www.daa-utah.com) manufacture open-architecture data logging systems that are somewhat easier to program but which rely on custom software to communicate with the datalogger and download data. Campbell Scientific Inc., in particular, developed complementary software known as (RTDM – Real-Time Data Management) as an add-on to their popular LoggerNet datalogger programming software, which allows post-processed data to be posted on a web-server as image files. Experience with this software was positive although frequent hiccups in the batch processing system did not eliminate the need for human system oversight. Water district personnel were reluctant to take time away from their busy field activities to keep the system current leading to sensor malfunctions going unreported until the next quality assurance check of the instruments. The Water District was not able to justify hiring a full-time staff member whose time was devoted to monitoring system administration and data quality assurance. A system design that eliminated all manual data downloading and processing while and providing reliable web access to both downloaded and quality-assured data was sought for the GEA wetlands application.

The advent of YSI-EcoNet (YSI, 2007, https://www.ysi.com/ysi) in 2004 provided the capability to provide web delivery of the wetland flow and water quality monitoring data. YSI-EcoNet integrates sensor hardware (acoustic flow probes, pressure and water quality sondes), dataloggers and software that perform local data storage, telemetry and visualization (Fig. 4). The YSI-EcoNet architecture comprises a mixed mesh of Data Nodes (that collect data from flow and water quality measuring sensors) and Access Nodes (that have the added capability of collecting data, via a low power radio interface, from surrounding Data Nodes) (Fig. 4). The Access Node transmits logged data to a remote Data Center (NIVIS) via CDMA cellular phone or satellite modem – the data is made accessible to the world-wide web through the NIVIS Data Center. The NIVIS Data Center is a remote data storage and processing facility, located on the east coast of the US, that initiates each call to the Access Node network at 15 min intervals through a service contract with YSI Inc, maintains all data collected by the monitoring network and allows customized web access and downloading of the data.

The wireless mesh network topology of YSI-EcoNet allows "point-to-point" or "peer-to-peer" connectivity within an ad hoc, multi-hop network. The mesh network is self-organizing and self-healing – hence loss of one or more nodes does not necessarily affect its operation. This has helped to increase the overall reliability of the system by allowing a fast local response to critical events in the rare event of communication problems. Elimination of tedious data acquisition and processing procedures through adoption of YSI-EcoNet has worked well with our wetland manager client base by eliminating the tedium of downloading and processing environmental data. It has also allowed wetland managers to perform daily oversight of the system and to devote more time to perform bi-weekly sensor quality assurance checks including cleaning of sensors and checking the accuracy of staff gauge data (used in the computation of flow) and to prepare for contingencies such as sensor failure prior to travelling to the site. Project monitoring sites were up to 30 km apart.

3.2. Precipitation and evapotranspiration process sensors

A Bowen weather station (Radiation & Energy Balance Systems, Inc. model CR10-3C) with a continuously recording datalogger was installed centrally within the GEA in the State Wildlife Management Complex (Fig. 5). The Bowen ratio-energy balance method indirectly estimates evapotranspiration (ET) (combination of direct evaporation and emergent moist soil plant transpiration) using micrometeorological sensors (Radiation and Energy Balance Systems, 2004)– it does not directly measure actual ET. Nevertheless, it is considered to be an accurate method for obtaining ET values if net radiation, soil heat flux, and vertical gradients of temperature and humidity can be accurately measured (ASCE, 1996).

The Bowen ratio method derives from the basic surface energy balance equation:

$$R_n = G + H + \lambda E + W + M + S \quad (4)$$

where R_n is the net radiation (incoming–outgoing), G is the surface soil heat flux, H is the sensible heat flux, λE is the latent heat flux, W is the surface water heat flux, M is the energy flux used for photosynthesis and respiration (metabolism), and S is the energy flux into and out of plant tissue, with each term expressed in W/m^2 (Radiation and Energy Balance Systems, 2004). When no standing water is present, the water heat flux term can be removed. In their review of numerous ET estimation methods, Drexler et al. (2004) concluded that the method can produce good results in wetlands that are relatively smooth and uniform (i.e. aerodynamic resistance over the surface is not highly variable) as well as large in area allowing for adequate "fetch" distances. The sensors are powered by two 6 V deep-cycle batteries, connected in series, which are

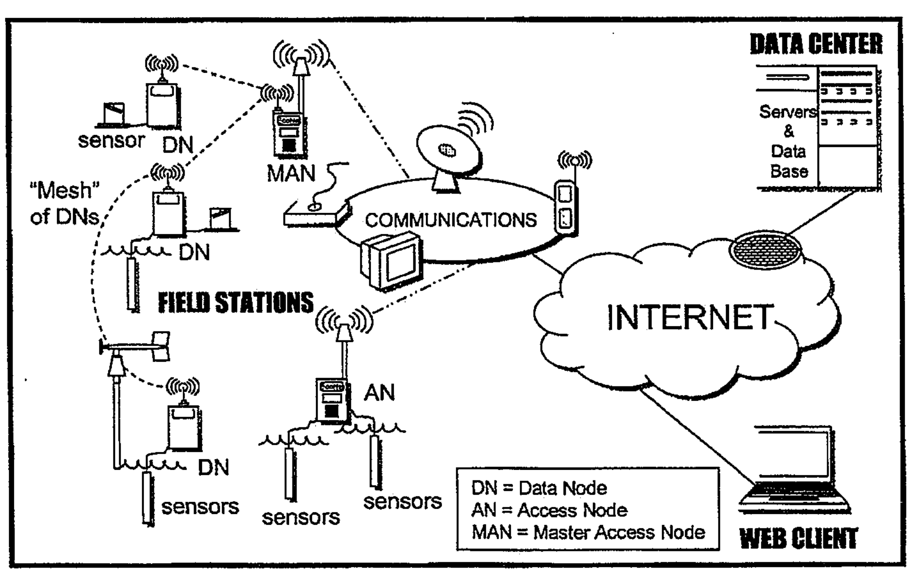

Fig. 4. Environmental sensor network showing how individual sensors at each monitoring site report to local data nodes and communicate to each other through radio frequency telemetry. Master (access) nodes poll each data node and report data from multiple data nodes to the NIVIS data center. The NIVIS Data Center posts sensor data every 15 min to the web – allowing near real-time retrieval of preliminary data. Continuous data processing is required to produce data suitable for public access and retrieval (YSI Inc., 2007).

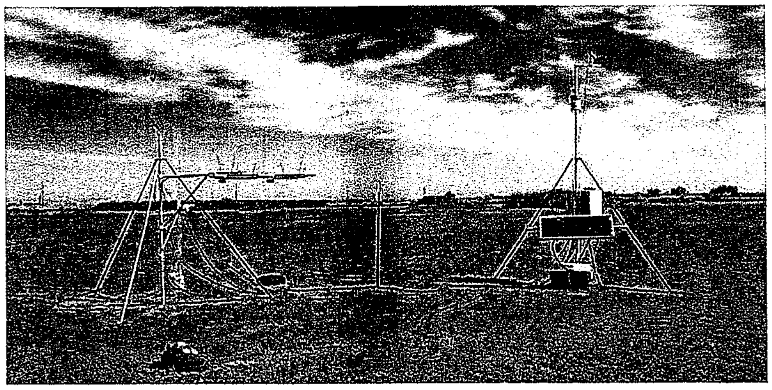

Fig. 5. Bowen weather station showing the solar panel, 6 V batteries (inside the cooler below to prevent contact with moisture), cable box with datalogger, rain gauge, and anemometer. Two net radiometers (left side of photo) are held at approx. 1.5 m over the surface. The air exchangers (right side of photo) face the prevailing winds and are spaced 1 m apart, with the lower exchanger positioned approximately 25 cm above the surface.

continually recharged by a 53-W solar panel. The station includes (Fig. 5):

- two double-sided total hemispherical radiometers, two vertically-separated air exchangers (automatic exchange mechanism) with temperature and humidity probes, three soil heat flux measurement disk, soil moisture plate, and soil temperature probes, one anemometer, a barometer and a rain gauge.

The net radiometers, placed at approximately 1.5 m above the vegetation, record both incoming and outgoing radiation to produce a single net radiation value at each time step. The air exchangers were separated vertically by a distance of 1.0 m and the lower radiometer was mounted about 1.5 m above the vegetation – these instruments measure vertical gradients of temperature and vapor pressure within the equilibrium boundary layer that forms over the swamp timothy. Ground sensors were inserted into the soil at shallow depths to record heat flux, moisture, and temperature. In order to capture the "average" soil environment, sensor groups were placed in locations with slightly varying microscale moisture conditions and topography, as assessed from field observation. The Bowen weather station was positioned so that at least 100 m of upwind fetch existed for the 1 m of separation between the air exchangers as suggested by protocol (ASCE, 1996). This helped to ensure that flux measurements represented the underlying surface and that the measured boundary layer were not contaminated by fluxes from distant surfaces (Drexler et al., 2004). A number of factors affect the rate of evapotranspiration from a given surface, including solar energy, humidity, soil moisture, extent of open water, solar albedo, vegetation density, species composition, growth stage, heat advection, wind speed and salinity.

Data from the Bowen weather station was reported at 15 min intervals to a Campbell Scientific Inc. datalogger housed in the white, air-tight, metal enclosure (Fig. 5). Data was downloaded daily to the remote project computer workstation by means of a cellular modem located within the enclosure. Upon download termination a number software programs were initiated in batch mode to error check the data, flag out-of-range or potentially erroneous values and parse the data into hourly and daily data reports. The daily mean values of wetland evapotranspiration were used in the wetland water balance.

During wetland annual flood-up and drawdown pond surface area varies over time as the pond floods or is drawn down. Hence evapotranspiration rates are a function of pond surface area – the surface area needs to be determined continuously to measure the daily volume of evapotranspiration loss from the pond surface of each wetland. Detailed pond bathymetric surveys were made using an ATV-mounted differential GPS instrument and relationships developed using ESRI's Arc-GIS (3-D analyst – http://www.esri.com) to develop functional relationships between pond stage and pond surface area. Slices of a three dimensional volume rendering of each pond were made at 1/10th ft (0.03 m) increments and the surface area and cumulative volume were recorded at each depth increment. Polynomial curves were fitted to the data to allow pond surface area to be calculated from the continuous stage data recorded at each pond outlet. Pond elevations were referenced to the deepest point in the pond which was typically the bottom of each culvert at the outlet weir box for each pond. As each wetland pond was drawn down – evapotranspiration losses were determined as the sum of direct water evaporation, evapotranspiration from emergent moist soil plants and grasses (such as cattail and skirpus – these losses can exceed potential evapotranspiration), direct soil evaporation and evapotranspiration from germinating grasses (such as swamp timothy and watergrass). Germinating grasses provide increasing soil cover as they spread and mature.

Development of ET estimates for the entire GEA required maps of wetland ponded area and emergent wetland vegetation during the flooded season and maps of the area of moist soil plant habitat post wetland drawdown. Evapotranspiration rates exhibit significant variation for various wetland moist soil plant types – ET was calculated by applying specific crop coefficients, representative of the wetland moist soil plant vegetation, by potential wetland evaporation (California Irrigation Management Information System, 2009).

3.3. *Remote sensing of wetland moist soil vegetation*

Estimation of the area of moist soil plant habitat was made using high resolution remote sensing imagery, supported by field surveys of wetland moist soil habitat plant associations. The QuickBird satellite (Digital Globe, Longmont, Colorado) was tasked to provide high resolution, multi-spectral imagery to capture the spatial variability of the patchy and irregularly shaped vegetation communities typical of these wetlands. The imagery provided bands in the blue, green, red and near-infrared (NIR) spectra. Image collection was timed to record the different stages of growth of the dominant wetland moist soil plants throughout the growing season. A late April image typically captures seedlings and perennials in wetland basins, and verdant uplands vegetation. May imagery usually coincides with the maximum growth period for the wetland basins, following the first summer irrigation, usually late May to early June. For field data collection and ground-truthing of the imagery, a modified version of the California Native Plant Society's Rapid Assessment Protocol (CNPS RAP) was used. The CNPS RAP employed a community-based approach to surveying, and provided a methodology for collecting basic quantitative information sufficient for identification and verification of habitats. Parameters collected included composition and abundance information on the sampling locations' plant species, their state of health and growth stage. General site environmental factors were also tabulated, including litter cover, anthropogenic disturbances, the presence of visible salts, and soil cracking. A Trimble GeoExplorer 3 GPS was programmed to include sufficient of these factors as data fields to define a vegetation community. Data was post-processed via differential correction to increase on-ground accuracy to less than 2 m. Data was collected with a single point representing a community of vegetation. Field personnel worked in teams, defining the boundaries of a homogenous area, visually estimating the size and shape of the area, and then characterizing it according to the field protocol.

Pixels and ground truth points were assigned to one of twenty land cover classes. Vegetation land cover classes were developed from observations of the dominant species in each vegetation assemblage at ground sample points. The decision to combine two or more dominant land cover classes into a single class was based on the similarity of their habitat, the frequency of their co-occurrence on the landscape, and the amount of spectral confusion between the classes that was observed in the check point dataset. The complexity of the seasonal wetland landscape intensified the difficulty inherent in developing a representative classification schema – given that the twenty land cover classes in this schema did not represent the entire diversity of plant species that exists in these wetlands. Rather, it represents the most commonly observed dominant plant species.

Pixel-based image processing was performed on the high resolution imagery using ERDAS (Leica Geosystems, Norcross, Georgia) Imagine Professional. A maximum likelihood classifier, which has been found to give superior results in mapping wetlands (Ozesmi and Bauer, 2002), was selected for analysis of the images. This technique required the input of the training data, used by algorithms to define statistically based spectral bounds for each class. After the training area was defined, the image processing software compiled statistics that described the spectral values for those pixels. This process was repeated until a signature for each ground truth point was determined. The final result was a compilation of 262 spectral signatures used by the classification algorithm. A pixel-based land cover map for the North Grassland Water District and San Luis National Wildlife Refuge (approximately 50% of the land area of the GEA) is shown in Fig. 6. The legend shows the sixteen wetland moist plant associations that were used to classify the vegetation and that were also used to assign wetland crop coefficients to calculate wetland ET for the flow and salinity mass balance model.

3.4. Groundwater water table sensors

Monitoring of the depth to the water table below each pond is important to the estimation of water loss through seepage, especially during initial pond flood-up when the underlying clay soils are desiccated and fissured with deep cracks – causing high initial seepage losses. During early September, when wetland flood-up typically begins, seepage losses to groundwater have been estimated to be as high as 30% of applied surface water. Wetland pond soils desiccate during the summer months in the San Joaquin Valley when temperatures can exceed 40 °C and fissure to depths of up to 1 m owing to the high clay content of the soils. Water fills the cracks in the soil and the soil swells – closing the fissures and slowing down infiltration. Infiltrating water fills pore spaces causing a rise in the water table. For many ponds that are not subjected to regional drainage gradients (which relieve groundwater mounding below the pond) the vadose zone can become completely saturated. Pond seepage can be estimated by the rate of rise of the water table using estimates of shallow aquifer porosity.

Schlumberger Diver pressure sensors (http://www.swstechnology.com/equipment_product.php?ID=5) were attached to 4 m lengths of plastic-coated cable and fixed to the well cap of each monitoring well (Fig. 7). Although technology exists to telemeter the pressure and temperature data that are produced by each sensor – the fact that groundwater levels change slowly and incrementally over time – made it more cost effective to make periodic downloads of the data during each field site visit. Inexpensive Bluetooth and radio telemetry options are being considered to improve the efficiency of data collection from remote groundwater monitoring locations. RTSM, which is concerned with wetland drawdown and drainage volumes, is not impacted by changes in water table – however these data are critical for estimates of annual water and salt balances.

3.5. Remote electromagnetic sensing of wetland soil salinity

Remote sensing of wetland soil salinity content was used as an indirect check on wetland salt balance – and to assess the distribution of salts within each wetland pond. Ponds managed for swamp timothy production (the most productive of the moist soil plants used to provide waterfowl habitat) are typically drawn down in mid-March – a schedule that appears to favour swamp timothy dominance. RTSM solutions would suggest that wetlands be drained later, in mid-April, since San Joaquin River assimilative capacity is higher during this period when major releases are made from east-side reservoirs to aid fish migration. The impact of a delayed drainage hydrology on the ecological health and productivity of these wetlands as a food source for migratory waterfowl are not well-established although experience suggests a vegetation shift from swamp timothy dominance to watergrass dominance as the most likely long-term outcome (Mushet et al., 1992). The warmer temperatures in April result in increased pond evaporation which produce higher concentrations of salts in those ponds still inundated. Higher concentrations of salt in the water column will affect soil salinity as saline water infiltrates or diffuses into the wetland soil.

An electromagnetic sensing instrument (EM-38 Geonics Ltd. – http://www.geonics.com) was used to estimate bulk soil salinity in the wetland ponds (Fig. 8). The EM-38 instrument utilizes dual coil electromagnetic induction to obtain a signal response which is a function of both bulk soil salinity and soil moisture content. When water content is controlled – the instrument can be used (McNeill, 1980) to map near-surface soil salinity (Suddeth et al., 2005; Williams and Hoey, 1987). The EM-38 can be used in two different orientations; vertically or horizontally. The peak signal strength for the horizontal and vertical orientations are between 0–0.3 m and 0.3–0.6 m respectively. Software has been developed by the US Department of Agriculture Salinity Laboratory (ESAP – http://www.ars.usda.gov/Services/docs.htm?docid=8918) to convert the raw EM-38 signal to electrical conductivity (EC) after soil cores have been drawn and the saturated soil extract salinity determined at sample sites chosen by the program to conform to a normal distribution within each pond (Cassel, 2007; Corwin et al, 2003; Rhoades et al., 1989). The EM-38, along with a backpack GPS system (Trimble Inc. – www.trimble.com) was deployed with a hand-held PC (Juniper Systems, Allegro Cx – http://www.junipersys.com/products/products.cfm?id=99). Data logging was performed with

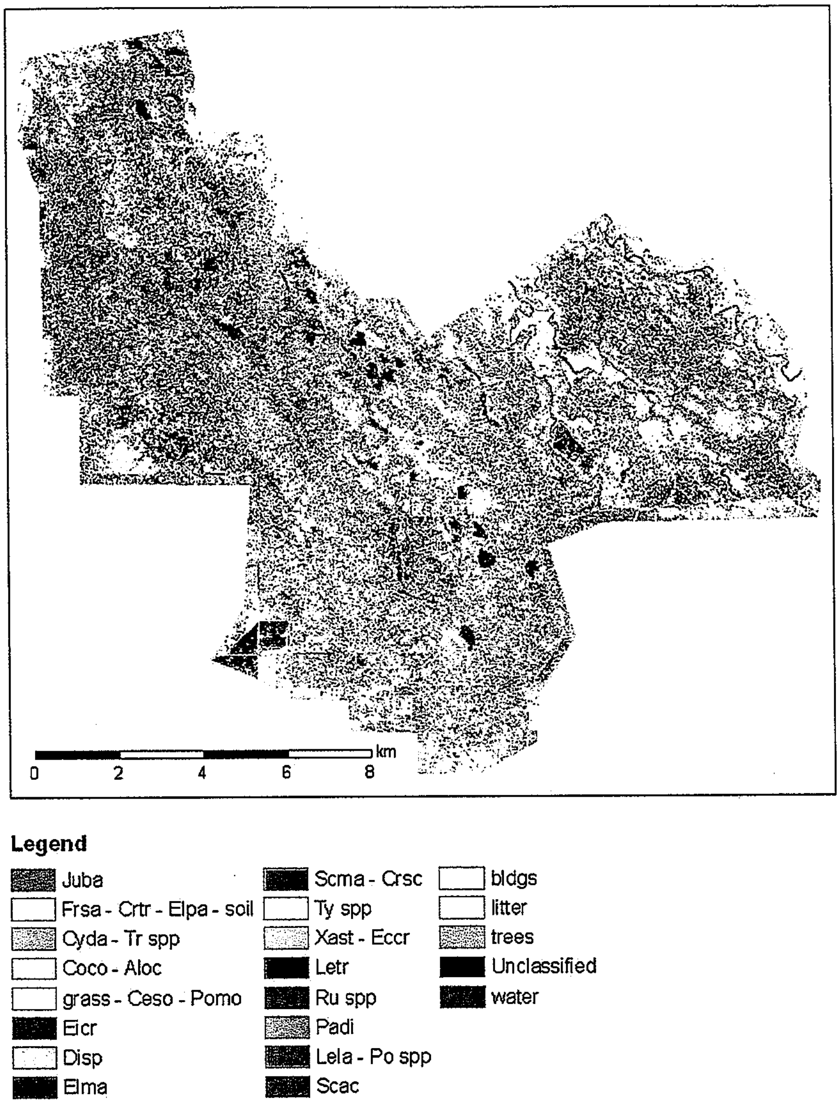

Fig. 6. Moist soil vegetation map derived from high resolution remote sensing imagery and analysis using ERDAS-Imagine software. Ground-truthing provided the spectral signatures associating spectral data and specific wetland moist soil plant associations (shown in legend).

the aid of TrackMaker software (http://www.kdjonesinstruments.com/uploads/files/pdfs/TrackMaker31.pdf) which helps the field analyst visualize each transect of the field survey while being performed by foot or GPS-enabled ATV. The EM-38 instrument has been widely used to assess soil salinity in agricultural areas (Corwin and Lesch, 2003, 2005a,b; Isla et al., 2003; Lesch and Corwin, 2003; Lesch et al., 2005; Cassel, 2007) though its use in wetland soil applications has not been previously reported. Factors to be considered in wetland soil salinity remote sensing include variations in soil texture and taxonomy, soil moisture, topography, vegetation and litter cover which all affect electromagnetic response (Hanson and Kaita, 1997; Suddeth et al., 2005; Brevik et al., 2006).

The instrumentation used in the field survey and its deployment is shown in Fig. 8. The right-hand panel in Fig. 8 shows the individual survey points along each transect for two adjacent wetland ponds. Readings were taken every 2 s and the transects were spaced approximately 5 m apart. The results of the survey of the Ducky Strike Duck Club south pond (one of twenty four ponds surveyed) are shown in Fig. 9. Fig. 9 shows the raw and model-derived (based on the regression model between laboratory saturated extract soil salinity and field EM readings) sensor data from the EM-38 instrument. Fig. 9 also shows the frequency distribution of salinity measurements over the wetland area and the control measurements made at selected sample sites to represent the full range of wetland soils salinity readings.

Data collected over a period of 3 years for ponds subjected to late wetland drawdown has shown a statistically significant increase in soil salinity due to the practice of delayed wetland drawdown in those ponds subjected to the highest influent salinity concentration. Water delivery to ponds in the south of the Grassland Water District is typically higher in EC than those Northern Division owing to the fact that the Northern Division receives

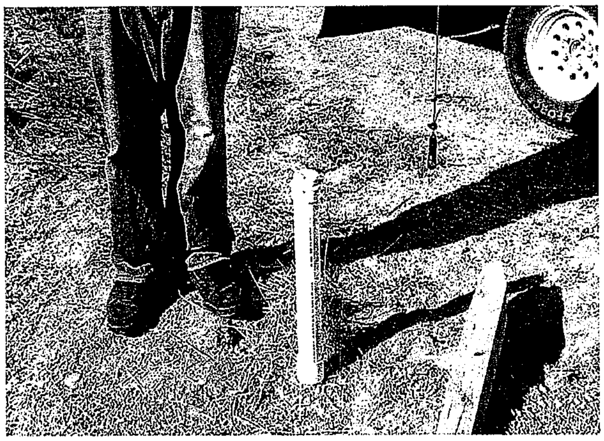

Fig. 7. Deployment of pressure sensors in shallow groundwater monitoring wells to measure changes in water table depth and to estimate pond seepage losses during fall flood-up.

a better quality water supply than the Southern Division. Evapoconcentration of salts leads to higher soil concentrations in those areas where influent salinity is highest. This also suggests that adoption of RTSM should require rotating a particular wetland back to a more traditional hydrology after two seasons of delayed drainage drawdown or in instances where the salinity of influent water supply becomes elevated.

4. Discussion

Integration of the sensor technologies described in section 3 into a fully functional EDSS is work in progress, although in reality, successful EDSS projects are rarely finished if they continue to innovate. New sensor technologies and improvements to data management and visualization software are embraced when trained personnel can be assigned to take on new tasks and fiscal budgets allow this expansion. Budgets need to be justified in terms of long-term resource management efficiency and economies of innovation. Institutional changes will also be required over the longer term to accommodate the reality of Basin-wide RTSM.

4.1. Data quality control and assurance of continuous data

A common weakness of many environmental decision support projects that rely on the telemetry of continuously monitored data is data quality assurance. Data quality assurance is easier to provide for discrete or periodic monitoring where adequate time exists between sample collection events to analyze data and make corrections to the instrument software, in the case of sensor drift, or replace a sensor in the case of irreversible sensor failure. Data quality assurance protocols established for discrete environmental sampling are well-established and data quality control plans are integral components of most environmental monitoring projects. However in the case of continuously recorded and reported data – the logistics of monitoring site visitation, data management, processing and error correction become more onerous. Until recently, few software tools existed to facilitate and guide these tasks – even the task of migrating preliminary data from one internet-accessible location to another (after data quality assurance tasks have been performed) has not been routinely practiced. Inaccurate or absurd data posted to a project website can do irreparable harm to a project and can quickly lead to a loss of confidence in the stakeholder community. In our wetland salinity management project cumulative flow calculations, which were performed by our acoustic Doppler instrument, were accurate when downloaded directly from the data collection platform through the output data processor but were 100 times too high when intercepted prior to output processing using an SDI-12 device (these readings should be identical). The issue was eventually resolved and turnedout to be a programming error in the firmware – a decimal point was omitted in the program and re-inserted during output processing. This error was caught by one of our project cooperators, who had become a routine user of project real-time data. Our close working relationship prompted early feedback from this cooperator and relatively quick recognition and resolution of the problem. This is not typical – problems such as these often fester within the stakeholder community before coming to light – by which

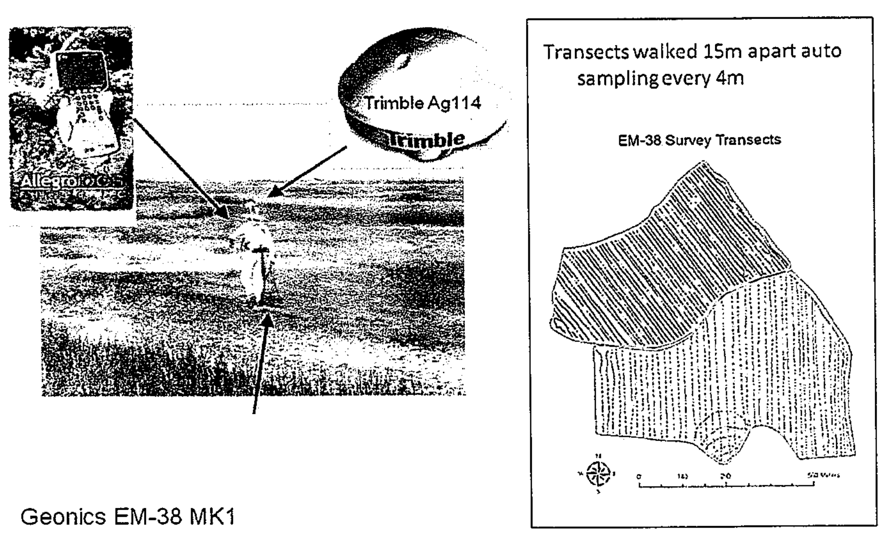

Fig. 8. Instruments used to perform soil salinity mapping of wetland soils in the Grasslands Ecological Area. Image shows the field analyst traversing a large area of swamp timothy, a non-native grass that is nevertheless regarded as highly desirable as waterfowl habitat. A patch of salt efflorescence appears in front of the field analyst – high soil salinity limits moist soil plant growth in these areas.

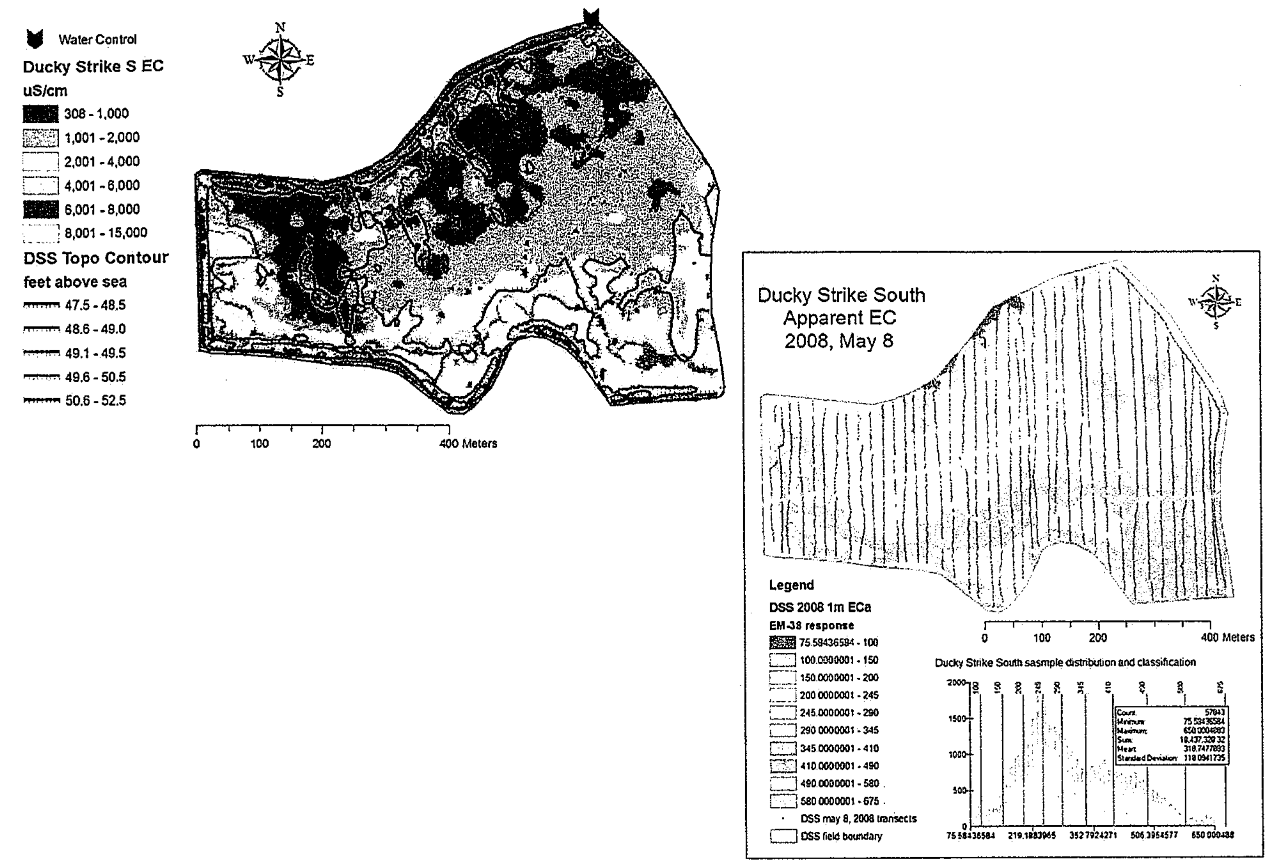

Fig. 9. Map of EM-38 response developed from a soil salinity survey of a wetland pond. These readings are converted into soil salinity estimates based on a regression model developed between instrument readings and saturated extract soil salinity from field samples. The sample locations are chosen using software which ensures that the sample values fall across a normal distribution.

time enthusiasm for the project and trust between project proponents and the stakeholder community has been eroded.

4.2. Software tools for continuous data quality assurance

The Aquarius Environment Toolbox (Aquatic Informatics Inc., 2009) is a suite of software object modules used to manage the entire data processing workflow from the project flow and water quality monitoring stations. The software object modules relevant to the wetland salinity management project include those responsible for: *Data Pre-Processing; Data Correction; Modeling;* and *Output Visualization and Reporting.* The Aquarius Whiteboard environment is used to assemble the sequence of object modules that comprise the data processing workflow (Fig. 10).

The *Data Pre-Processing* module comprises software objects for *Signal Joining* and *Signal Trimming*. The *Signal Joining* object is used to append multiple time series data files during each data download so that a complete data record can be compiled within a local database. Storing the data in a local database after performing data quality assurance allows the certified data to be uploaded routinely to the NIVIS Data Center, which previously provided access to uncensored real-time data. The *Signal Trimming* object is used to trim outliers and periods of incomplete data records from the data record before being stored in the database. At the beginning of the project technical problems such as bad circuit boards and poorly sealed acoustic Doppler sensors produced periods of incomplete or suspect records which had to be removed from the data record.

The *Data Correction* object is used to apply manual adjustments to time series datasets. Autonomous collection of data results in anomalies such as biases, drifts, outliers, and non-physical data. Hence, the *Data Correction* object is used to apply corrections for sensor drift (not typically a problem with the water quality (YSI) or acoustic Doppler (MACE) instruments) or sensor fouling (a significant problem in the wetland environment of the project). For example a *Fouling Drift* correction is used routinely to compensate for biological fouling or scaling of the water quality sensor that tend to skew readings in a progressive fashion as the biological film or scale develops. Standard practice for quality assurance is to take a single measurement from a sensor immersed in a control solution both before and after cleaning. A more time and cost effective protocol, practiced in the current project, was to calibrate a portable YSI sonde (comprising EC, temperature and pressure sensors) in the laboratory before and after each day in the field. The sonde at each monitoring station was calibrated against the ambient portable sonde sensor reading. The sonde EC sensor was recalibrated if the readings differed from the value of the standard solution by 5% or greater. Pressure transducers in both the water quality sonde and acoustic Doppler instrument remained stable requiring little adjustment. Monthly removal of biological growth surrounding the pressure transducers was sufficient to keep the transducers from drifting – except in the

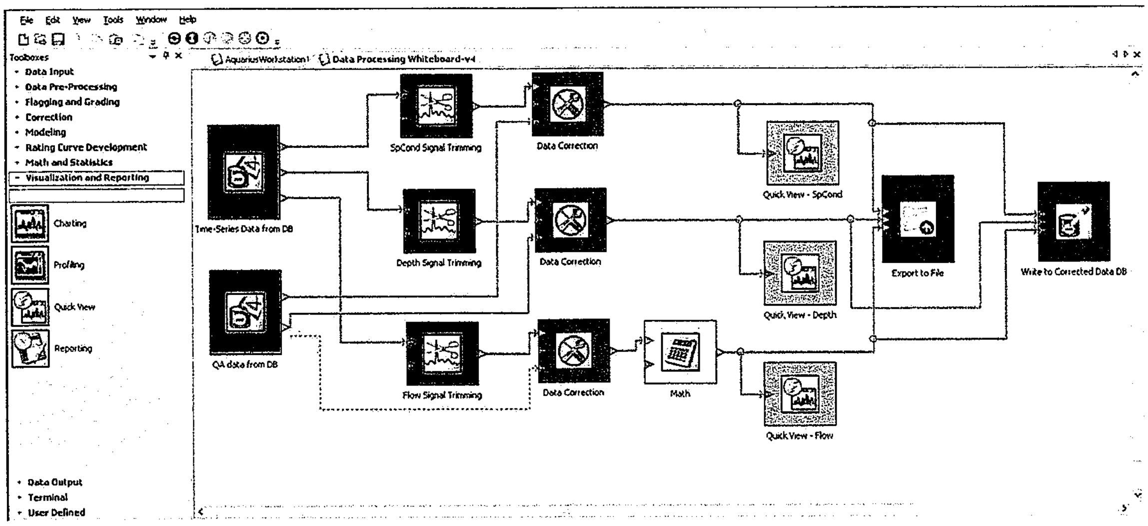

Fig. 10. Data processing whiteboard within the Aquatic Informatics Aquarius software. Continuous environmental monitoring data is merged with weekly quality assurance data collected at each monitoring station to allow continuous error checking and data corrections to take place. RTSM requires continuous data processing to allow daily salinity assimilative capacity forecasts to be made.

instances of catastrophic failure where improper sealing with epoxy allowed moisture migration into the sensor housing.

When using the Aquarius software each correction made to the time series data was recorded in the Correction History Manager which logs information about the correction and makes an entry in the correction history (Aquatic Informatics Inc., 2009). Comments describing the correction appeared in small text that is auto generated and can be modified, if necessary, to increase the amount of information for a subsequent correction audit. Offset adjustments were made to correct for any constant (throughout time) bias in the target time series data. Offset adjustments were necessary when a sonde had to be replaced or a sonde moved higher within the stilling well as a result of sediment accumulation around the base of the stilling well. This accumulation of sediment affected water circulation around the electrical conductivity and temperature sensors. Within the Aquarius software the *Mark Region* tool was used to select a section of the target time series where the *offset correction* could be used to adjust readings upwards or downward. The *percent correction* featured in the correction control pane of the software allows the user to apply a calculated known percentage correction to the signal at either the beginning of the data sequence or at the end. Data outliers were be removed using these tools and short data gaps were interpolated without resorting to a model based correction approach. Data gap interpolation controls provided options that include the application of a *linear spine*, which simply draws a straight line in between the endpoints of the gap; or a *cubic spline*, which uses up to 5 data points outside the range of the marked gap to guess at the curvature of the time series plot using a best-fit polynomial or other non-linear expression. The automated interpolation control options within the Aquarius toolbox were a significant technical advance over existing software and were critical for the anticipated expansion of existing sensor networks necessary to fully implement RTSM. Manual as well as automated interpolation changes was all noted in the *Correction History Manager*. Each time a correction is applied to a section of target time series data the *Correction History Manager* was invoked to capture details about the user performing the correction and the rationale for performing the correction.

The *Modeling* object within the Aquarius toolbox has proved useful in the application of calibration factors to discharge data derived from acoustic Doppler velocity sensors and pressure sensors. Acoustic Doppler velocity devices sample the flow volume either approaching or moving away from the sensor. In open channels with fluctuating stage or in culverts which can flow partially full – it is difficult to obtain a true mean area-velocity owing to the friction along the perimeter of the conveyance structure. Flow rating relationships between reported and actual flow have been developed for each monitoring site and the rating equation built into the modeling object to transform the reported flow value to an actual flow. At a number of monitoring sites weir boards (flash board risers) provide the means of controlling wetland pond stage and pond outflow – at these sites the *modeling object* was first used to calculate discharge using the weir equation which is a function of board dimensions (width and height) and water stage over the weir boards. However the difficulty of maintaining continuous records of weir board adjustments proved too onerous for wetland managers and became a bottle-neck for real-time data reporting. Acoustic Doppler flow sensors were retrofitted at each wetland drainage site to address this issue.

The Aquarius toolbox contains a full suite of *Output Visualization and Reporting* tools that allow easy review and auditing of any data sequence within the time series database at each monitoring site. The *Quick View* object displayed time series data in a spreadsheet format which facilitated plotting and charting and was used to provide descriptive statistics of each sensor time series record. It has been used to create overlay multiple data traces within a single window in order to check the functioning of suspect sensors in the monitoring network as part of the data quality assurance program. Reporting the quality certified data back to the NIVIS website was a feature initially lacking in the commercial release of YSI-EcoNet. The NIVIS Data Center did not permit client access to the data except as served through the NIVIS EcoNet website – rather the Data Center provided a means of discriminating between public and private (password protected) access to the website. This had the unfortunate consequence of restricting public access to current data only, given our cooperators reluctance to share potentially flawed data with the general public, as discussed at the beginning of this paper. Only project personnel and cooperators were provided with private user access allowing these clients to download the time series data record. In late 2009 a solution was negotiated between YSI Inc. and

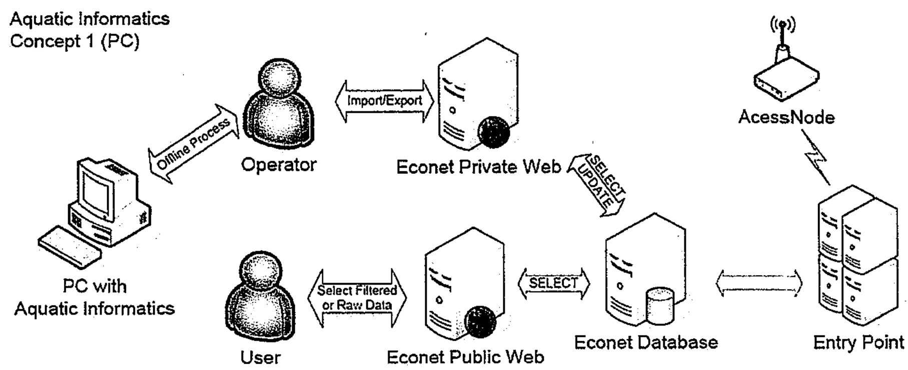

Fig. 11. Protocol for replacing preliminary data on the NIVIS public website with data after quality assurance filtering has been completed.

the NIVIS Data Center that provided a data export wizard and the ability to add a second data column paired with each of the web-reported sensor outputs. The schema for the protocol is shown in Fig. 11. Under this protocol public access clients can view all historic data once they have been migrated into the second column after having undergone data quality assurance procedures.

Private access clients were able to view both columns of data on the project website and had full access to the time series data for all monitoring sites. Automation of the data filtering and web posting process has sped-up stakeholder access time to information needed to make RTSM decisions. These actions will help develop the assurances needed for stakeholders to fully implement RTSM within the San Joaquin River Basin.

4.3. *Water quality forecasting and decision support*

Successful implementation of RTSM in the San Joaquin Basin requires that salt loads exported from managed wetlands and other west-side dischargers within the Basin never exceed the calculated assimilative capacity of the San Joaquin River. River assimilative capacity (expressed as a salt mass load) was determined by the product of river flow and the ambient water quality standard for salinity, established at the downstream compliance monitoring station. A decision support tool was developed to simulate daily river assimilative capacity and permit forecasting of allowable salt loading from managed wetlands in the Basin based on real-time flow and salinity data.

The Watershed Management Framework (WARMF) model (Chen et al., 2001; Herr et al., 2001; Herr and Chen, 2006) is comprehensive decision support tool specifically designed to facilitate TMDL development at the watershed-level (http://www.epa.gov/ATHENS/wwqtsc/html/warmf.html). The San Joaquin River Basin application of the WARMF model (WARMF-SJR), shown in Fig. 12, simulates the hydrology of San Joaquin River and performs mass balances for a broad suite of potential contaminants including total dissolved solids. The model accounts for tributary inflows from the major east-side rivers, agricultural and wetland drainage return flows, riparian and appropriative diversions and uses hydrologic routing to calculate flow and water quality at approximately 0.8 km intervals along the main stem of the San Joaquin River. Wetland drainage from the Grassland Ecological Area was partitioned into component State, Federal and private wetland contributors to San Joaquin River salt load. A GIS-based graphical user interface (GUI) facilitated the visualization of model input flow and water quality data. Data templates expedited automated data retrieval from State and Federal agency hydrology and water quality databases and the automated updating of model input files. Water managers can enter daily schedules of diversions and discharges using the spreadsheet formatted model data interface. Standardized model output graphics aided the dissemination of flow and water quality forecasts.

A wetland water quality model (WARMF-WETLAND) is under development within the WARMF modeling framework. The model simulates water and salinity balances for individual (and lumped) ponded areas and aggregates wetland discharge and salt loading from all contributing areas. The model allows comparison with (soon to be established) salt loading targets for the Grasslands Ecological Area. Monthly sub-basin, seasonally-adjusted salt load targets are one of a number of salinity management strategies that could be used to encourage cooperation and coordination of wetland drawdown by State, Federal and private wetland stakeholders. Coalition building between stakeholders with like interests and who are required to comply with similar environmental regulations has been effective in California as a means of retaining local control and management flexibility. The new model application will track the salt concentration within each ponded area based on estimated wetland evaporation, seepage and cumulative inflow and outflow and the salinity concentrations of these fluxes. Output from the WARMF-WETLAND model application will overwrite estimated values for the State, Federal and private wetland salt loads in the WARMF-SJR model – to provide a more accurate assessment of San Joaquin River assimilative capacity.

4.4. *Institutional accommodation*

Realization of the potential of RTSM will require the formation of a watershed-level salinity management entity with the authority to encourage compliance with sub-basin salt load targets and to impose penalties for violation of these established salt load limits. A local coalition of entities discharging drainage to the San Joaquin River formed a "Drainage Authority" to coordinate flow and water quality monitoring requirements imposed by the Regional Water Quality Control Board (the State institution responsible for implementation of TMDLs in the San Joaquin River Basin). This Drainage Authority is financed by stakeholder contributions and retains a staff to oversee the activities of the agricultural, wetland and municipal dischargers of salt and other contaminants into the San Joaquin River. Oversight involves maintenance of monitoring stations, responsibility for discrete sample collection and analysis and monitoring data record keeping. Implementation of RTSM will require a similar institution though with added responsibilities of coordinating both drainage return flows and reservoir releases from east-side tributaries, synthesis of real-time data and dissemination of daily salt assimilative capacity forecasts for the San

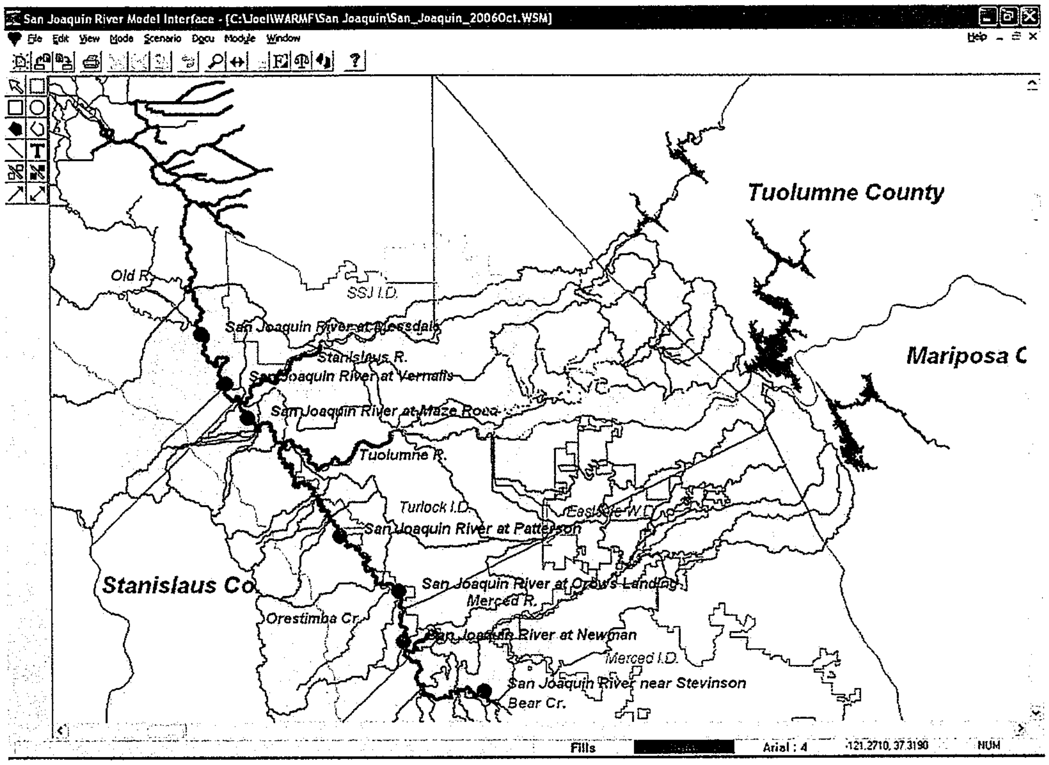

Fig. 12. The WARMF-SJR simulation model is used to develop short-term forecasts of San Joaquin River salt assimilative capacity decision support system as part of the wetland EDSS for salinity management in the GEA. Wetland drainage discharges to the River from the west between the Stevinson and Newman monitoring stations.

Joaquin River. At the present time a conceptual design of this new institution has not been formulated.

5. Summary

Technical advances in data acquisition and information dissemination technologies have made possible the implementation of an RTSM program in California's San Joaquin Basin wetlands. RTSM relies on continuously recording sensors that form the backbone of a monitoring network and simulation models that are used to forecast flow and water quality conditions in the receiving water body and the tributary watersheds that contribute flow and salt load to the river. The application discussed in this paper – RTSM of drainage from seasonal wetlands – relies on a suite of sensor technologies the data from which are used to develop water and salt mass balances. The concept of mass balance is fundamental to all flow and water quality simulation models. Models can be used to extrapolate the results of system monitoring since it is impossible to collect data for every drainage outlet and stream tributary in the Basin. Dividing the San Joaquin Basin into smaller drainage sub-basins each with a monitoring station at their outlet can provide an efficient means of characterizing salt export loading from the GEA to the River and the basis for control to meet salt loading objectives. This paper has described the use of several state-of-the-art sensor technologies that are being combined with more traditional sensor techniques to support RTSM. The paper also discussed the problems associated with continuous data quality assurance and described a new software product which streamlines the process of data error correction and dissemination that will be necessary to build stakeholder assurances key for successful implementation of the RTSM in the GEA.

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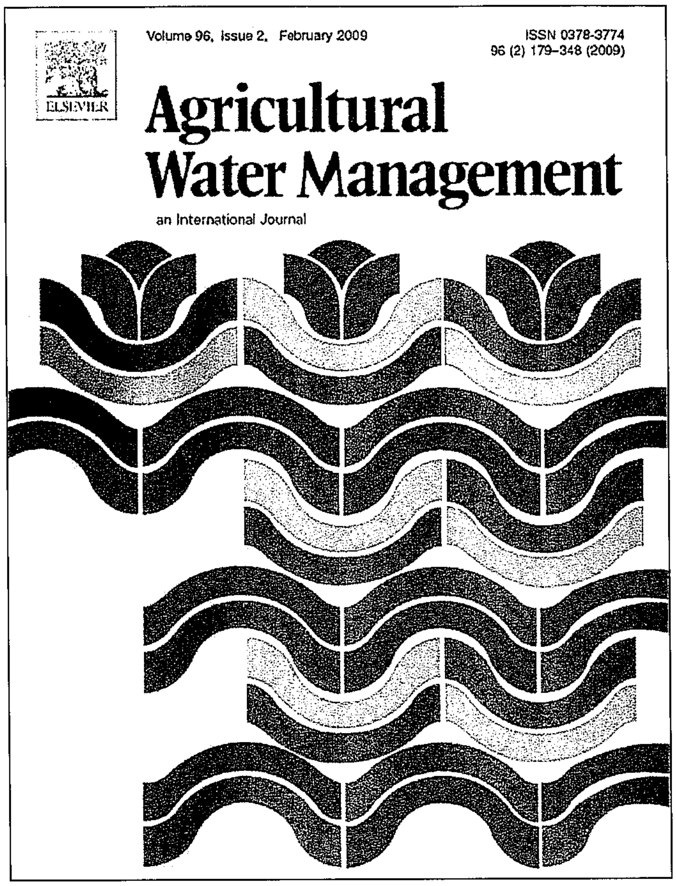
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Environmental decision support system development for seasonal wetland salt management in a river basin subjected to water quality regulation

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ABSTRACT

Seasonally managed wetlands in the Grasslands Basin on the west-side of California's San Joaquin Valley provide food and shelter for migratory wildfowl during winter months and sport for waterfowl hunters during the annual duck season. Surface water supply to these wetlands contain salt which, when drained to the San Joaquin River (SJR) during the annual drawdown period, can negatively impact water quality and cause concern to downstream agricultural riparian water diverters. Recent environmental regulation, limiting discharges salinity to the SJR and primarily targeting agricultural non-point sources, now also targets return flows from seasonally managed wetlands. Real-time water quality management has been advocated as a means of continuously matching salt loads discharged from agricultural, wetland and municipal operations to the assimilative capacity of the SJR. Past attempts to build environmental monitoring and decision support systems (EDSS's) to implement this concept have enjoyed limited success for reasons that are discussed in this paper. These reasons are discussed in the context of more general challenges facing the successful implementation of a comprehensive environmental monitoring, modelling and decision support system for the SJR Basin.

1. Introduction

Seasonally managed wetlands in the western San Joaquin Basin of California's Central Valley provide overwintering habitat for migratory waterfowl and hunting opportunities during the annual duck hunting season. Two decades ago these wetlands received agricultural drainage return flows as a means of increasing water supply until it was discovered that evapoconcentration of the saline and seleniferous drainage in open ponds caused selenium teratogenicity in waterfowl embryos. Free of harmful concentrations of selenium, wetland water supply is now supplied by canal from the Sacramento—San Joaquin River (SJR) Delta but still contains inorganic salts which evapoconcentrate in the man-made, seasonally managed ponds, before being drained (between late March and early May) into channels that flow into the SJR. The wetland drainage (drawdown) schedule often coincides with the germination period of salt sensitive agricultural crops, irrigated with water pumped from the River more than 100 km downstream in the South Delta. Seasonal wetland drainage produced within a 50,000 ha wetland ecological complex, known as the Grasslands ecological area (GEA) must be eliminated to preserve salt balance and preserve habitat conditions that make them the most important migratory bird

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resource in the western United States. During dry and critically dry years dilution flows from the Sierran tributaries to the SJR diminish and can no longer prevent frequent violations of the State water quality objectives for salinity from occurring. The compliance monitoring station for salinity on the SJR is located at a site immediately upstream of any tidal influence.

Recent environmental regulation promulgated as total maximum daily loads (TMDL's) limit agricultural discharges of salt loads to the SJR—drainage salt loads from seasonally managed wetlands are subject to the same numerical constraints (CEPA, 2002). During dry and critically dry years the salt TMDL is especially restrictive allowing no salt load export to the SJR during the summer months when drainage return flows are typically highest and the impacts due to restricted drainage most severe. Seasonally managed wetlands, which mostly drain during the months of March and April each year will also be restricted in their drainage salt load export to the River. These restrictions could have significant impacts on wetland habitat quality and their long-term resource potential as overwintering habitat for waterfowl.

Real-time water quality management (RTWQM) has been advocated as a means of improving SJR water quality by better coordinating the discharge of salt loads from west-side San Joaquin Basin agricultural, wetland and municipal dischargers with east-side San Joaquin Basin reservoir releases and irrigation return flows that provide dilution. RTWQM is a concept that relies upon access to real-time flow and water quality data from networks of flow and water quality (electrical conductivity and temperature) sensors on the SJR (Quinn and Karkoski, 1998) and which involves watershed flow and water quality modelling, salt assimilative capacity forecasting in the SJR and information dissemination as part of an environmental decision support system (EDSS).

The ultimate goal of projects underway in support of RTWQM is to develop a comprehensive monitoring and modelling system that provides timely decision support to agricultural water districts and seasonal wetland managers—allowing them to improve the coordination of salt load export with the available assimilative capacity of the SJR (Quinn and Hanna, 2003). Although salinity management has been practiced within west-side SJR Basin agricultural water districts for more than 100 years and salinity management has only become a concern to seasonally managed wetlands since the announcement of the salt TMDL—progress towards RTWQM is more advanced in the wetland areas. This is largely because of the more serious long-term consequences of restricted salt export in the seasonally managed wetlands.

Alteration of the schedule of annual wetland drawdown comes at a potential cost to the sustainability of optimal moist soil plant habitat in seasonally managed wetlands (Fredrickson and Taylor, 1982; Quinn et al., 2005). Hence any project that suggests alteration of the hydrology of these lands needs to investigate long-term soil salinity and vegetation response as a result of the intervention and to quantify the environmental impact and cost of various altered drawdown management scenarios compared to traditional practices (Prato, 2005). Current projects addressing these questions are multidisciplinary collaborations between the Grassland Water District, Lawrence Berkeley National Laboratory, the Department of Fish and Game, the US Bureau of Reclamation and the University of California, Merced.

2. Legacy environmental decision support systems

Past attempts to build integrated environmental monitoring and decision support systems to improve salinity management in the SJR Basin and, more specifically, to implement the concept of RTWQM in seasonally managed wetland, have enjoyed limited success. Water quality management in large river basins and the use of EDSS's to guide decision making is still in its infancy in the US. Janssen et al. (2005), Denzer (2005) and Poch et al. (2004) describe European efforts in EDSS development – the Janssen et al. paper focusing on a project-relevant topic of wetland decision support – albeit for drained peat meadows in polders below sea level. What is striking from the European experience is the relative ease of implementation of data sharing networks, particularly exemplified in Denzer's paper.

Our experience in California is less impressive—the nature of a less centrally planned and more institutionally fragmented approach to environmental decision making makes the provision of decision support more complicated. To develop the comprehensive datasets needed to develop the simulation models, which in turn could be used to provide reliable decision support, requires the cooperation of stakeholders with no current incentive to share information about their operations and the salt loading to the River contributed by their return flows. Central-planning concepts are viewed with scepticism in a watershed where agriculture, municipal and industrial uses and the environment all compete for scarce water supply. Our home-grown EDSS's lag those of many European nations in the area of common data management frameworks and modular simulation models (e.g. models produced by the Danish Hydrologic Institute, Wallingford and Delft Hydraulics) that can be shared among water agencies, regulators and the private sector. Few California EDSS development projects enjoy long-term institutional support such as the European Community initiative known as ORCHESTRA (Denzer, 2005), a collaboration of more than a dozen countries and research institutions that have developed a common platform for water resource management and the provision of emergency response services. Data sharing is made possible between different countries, sectors and water agencies through a database architecture that is based on a common naming ontology.

In the SJR Basin many large budget projects are led by academic institutions, private consultants or agencies with a poor track record of long-term collaboration and data sharing. Many projects have a lifespan of only 3–5 years after which the project team disbands to be replaced by another following the next round of grant announcements. This is a difficult environment within which to build the type of institutional infrastructure needed to realize RTWQM. Projects appear to fail more through an inability to provide a long-term venue for the orchestra, to use a musical analogy, than the technical competence of any one of the instruments on the podium.

The remainder of this paper is a narrative on some of the observations made by the author over the past decade as he and others have attempted to implement the concepts of RTWQM within the SJR Basin. Seasonally managed wetlands provide the most compelling example of the merits of RTWQM—given that their salt loads exports coincide with periods of relatively high SJR assimilative capacity allowing significantly greater export volumes and loads than would be allowable under a typical salinity EPA-mandated salinity TMDL. For this reason the initial discussion focuses on our collective experience—success and failure in implementing RTWQM in the 50,000 ha GEA. It is likely that RTWQM applied to seasonally managed wetlands in the GEA will become the exemplar for RTWQM applied to the entire SJR Basin. Lessons learned from implementation of RTWQM in the GEA and some of the technologies that are being developed and evaluated may have direct relevance to implementation of the concept within the larger system.

2.1. *Development of an environmental decision support system should involve the end user at the conceptual and design phases of the project. Involvement should be more than mere inclusion, rather it should be an earnest effort to imagine the problem from the end-user's perspective and to extract pertinent information relevant to the design of the EDSS*

End user involvement has become a cliché within the EDSS developer community—however at every meeting of practitioners it is mentioned as the most common reason for non-achievement of project goals. Why can't we get this right? In California since many of our EDSS projects originate in the University environment – few research projects develop the level of collaboration needed, or have a sufficiently complete work product after 3–5 years, to allow a migration from conceptual to implementation phase. EDSS architectures designed to address the questions the student and the advisor or the study team think are most interesting and pertinent – are often very different questions that those relevant to the end-user who makes day-to-day decisions. Post-development adoption of an EDSS to the needs of the end-user are usually futile because the conceptual system behavior model is often fundamentally different for the developer and the practitioner – new technology take time to infiltrate current institutions and become adopted – by that time most projects have ended and the project team have moved on to new endeavors.

A relevant example of this issue was the collaborative development of an EDSS called the Natural Resources Workstation. This project was undertaken to improve understanding of wetland water balance and to assist in optimization of water use practices for federal and private wetlands within the GEA. The EDSS utilized the latest in Unix-based graphics libraries and was fully integrated with GRASS GIS software. In demonstrations to potential end-users of the software the feedback provided by wetland managers was very positive—most wetland water managers saw at least one or two features they really liked in the EDSS. The final version of the EDSS was turned over to one wetland water manager, after extensive beta-testing in the presence of his peers, together with the Unix workstation platform on which the software had been developed. Additional staff were trained in the use of the software on-site and the water manager flown to Colorado State University, where the EDSS was developed, for more intensive training.

However, the results of an informal survey of EDSS adoption, performed after the first year were disappointing. Feedback suggested that although the EDSS had been designed to accept continuous data inputs, it required certain input data that were not readily at hand or easily quantifiable. Our respondents felt the EDSS was more geared to developing a conceptual understanding of the system rather than solving problems at hand. Water managers were too busy to invest time calibrating the underlying conceptual model response to their own conceptual framework. If they could not obtain answers within minutes of posing a question they preferred to use their own best judgment. There is no recipe or universally applicable code of practice for user-involvement in EDSS development. It is in the details that many EDSS's succeed or fail.

2.2. *EDSS technology transfer and the institutional resources available to the long-term user(s) of the EDSS should be considered as part of the design and development process. These issues are typically only considered towards the end of a project after technical challenges have been addressed—leaving inadequate time to ensure continuity*

Eliciting pertinent information from the EDSS end-user should be an active not a passive activity since it often turns out to be the most critical element of EDSS design. Often the fun in EDSS design is in the interface and the integration of simulation models to describe the behavior of the system, ignoring the human element – which, in our case, is how water managers utilize environmental information. Understanding the human factors in EDSS design requires skill in fields of sociology and human psychology rather than in computer science – sadly skills that are not taught or easily acquired. Creativity is required in the development of system analogues and simulation prototypes to provide end-user early feedback on the EDSS architecture.

Stakeholder concerns within the GEA, prompted by the threat of future regulation of wetland salt export and exacerbated by a lack of watershed water quality data (to fully assess the contributions being made by managed wetlands to the salinity problem in the SJR)—created an opportunity to successfully implement one component of the EDSS design. One wetland partner, the Grassland Water District, found that web posting of flow and salt loading data from their major drainage outlets useful in improving understanding of the seasonality of their salt exports—wetland managers within the District began to develop an appreciation of the relationship between these salt exports and water quality conditions within the SJR. The Water District serves 160 individual duck clubs and used the website as a means of demonstrating to its customers as well as to State regulators its proactive response to improving water quality management. The public website for the EDSS data management system is shown in Fig. 1.

Despite the success in providing pertinent information to wetland managers and assurances to regulators—the EDSS failed to become self-sustaining after 4 years of operation.

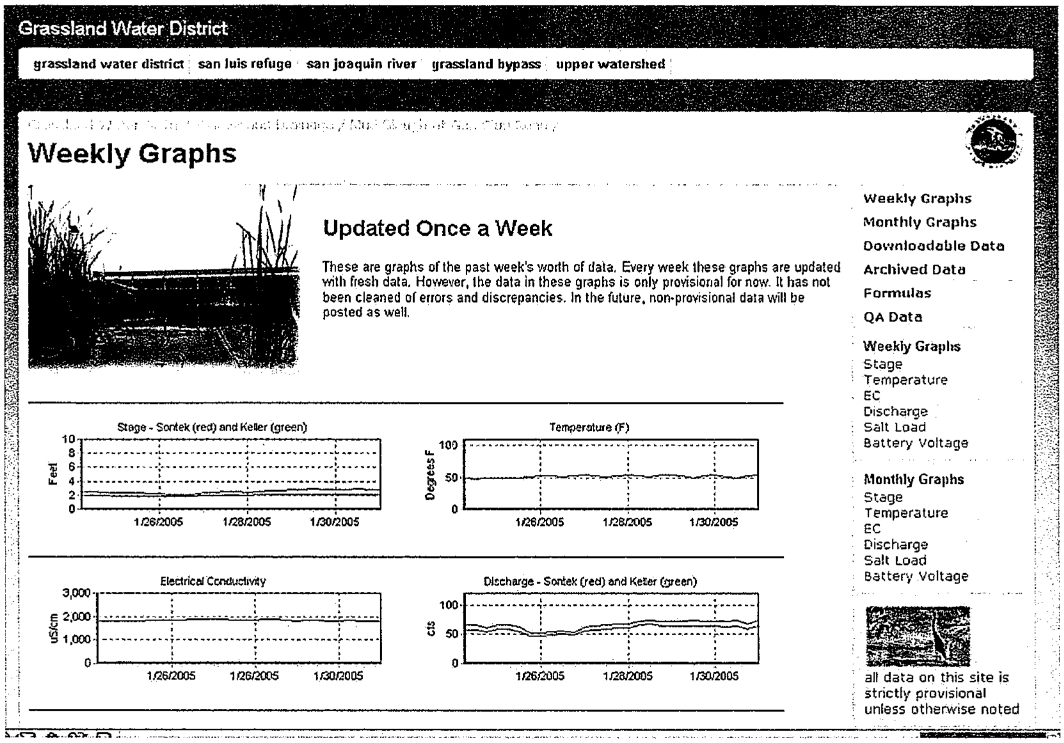

Fig. 1 – Automated web posting of wetland discharge flow and salt loading data as part of a previous EDSS development project.

Data continuously collected at each flow and water quality monitoring station was downloaded daily to a computer at Lawrence Berkeley National Laboratory (LBNL) where it was error checked and corrected where necessary, graphed and transformed to jpeg images as weekly and monthly plots. These graphical jpeg files were transmitted daily, via ftp, to a public web server based at LBNL. The project website was updated daily. However, when the student who was responsible for this work resigned after 2 years, the water district could not find the personnel who had the time or the technical skill to take over this function. Web delivery of the processed water quality data ceased for 3 years until a new product, YSI-ECONET was launched in 2005. This technology integrates sensor hardware (water quality sonde) and data-logger with software that performs the data downloading, data storage and visualization of the summarized 15 min data. This has become part of a custom service provided by the NIVIS Data Center (a remote data storage and processing facility) through a service contract with YSI Inc. Though more costly than the previous LBNL-provided system – it has conformed better to the District's existing staff resources and in-house expertise. Although we gained certain efficiencies by handling the data processing tasks at LBNL we later concluded that having the data processing tasks performed by the Water District, would have forced a closer working relationship between the water managers and those working with the data.

2.3. *Commercial environmental hardware and software products can be attractive alternatives to home-grown EDSS solutions—especially when backed by large corporations with the ability to support their technology. However innovators who are the first to implement a new technology should be cautious since system bugs are to be expected and a potentially successful EDSS project can be harmed if the system does not fully meet stakeholder expectations*

The procedures of downloading and validating monitoring station data so that it can be web posted are tedious and the volume of work can be overwhelming if large numbers of monitoring sites are involved. Wildlife biologists and wetland managers have chosen an outdoors lifestyle and are unhappy spending long hours in front of a computer. Hence automation of these processes was attempted, as previously described. However, software that was designed to automate the downloading, error-checking and parsing of data sometimes hiccupped—requiring daily checking. Visualization software designed to create gif formatted images for web posting of real-time flow and water quality data would freeze occasionally requiring system rebooting.

A commercial data telemetry and processing EDSS solution – YSI ECONET (YSI Inc., 2005) – was adopted to eliminate the operational constraints of the previous, custom-developed EDSS technology. YSI ECONET is a remote monitoring platform that provides wireless data acquisition, remote monitoring

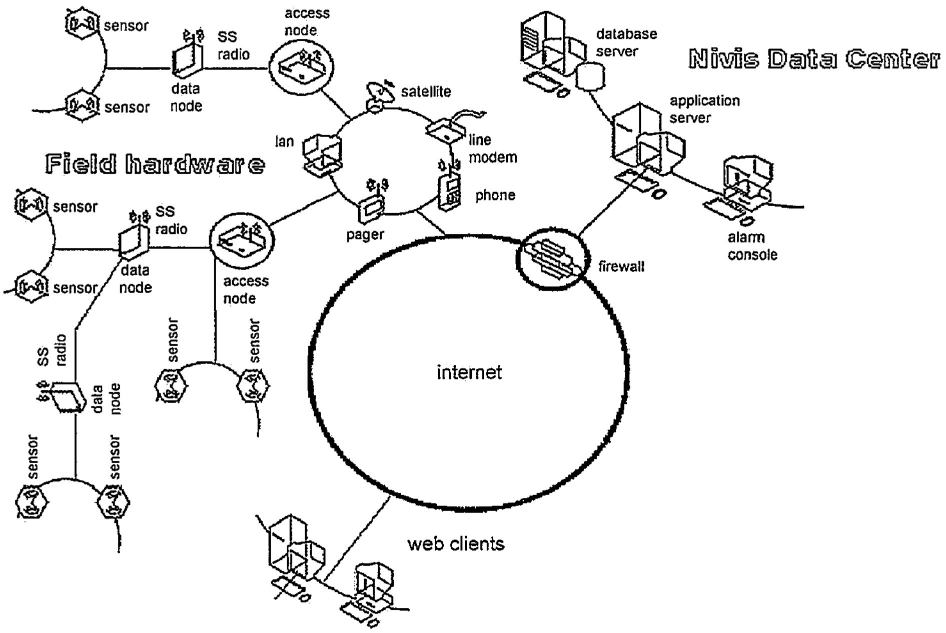

Fig. 2 – System architecture linking field monitoring stations with external NIVIS Data Center which stores, maintains and serves real-time flow and water quality data on public and private website.

and control over the Internet (Fig. 2). The system is comprised of a mesh of data nodes that collect data from water quality and flow measuring sensors at each monitoring location and access nodes that have the added capability of collecting data via a low power radio interface from surrounding data nodes. The access node transmits logged data to a remote Data Center via CDMA cellular phone or satellite modem from which the data is made accessible through the Internet. The data node can compare the acquired data against predefined alarm thresholds (minimum and maximum) and immediately notify the access node when the input values are outside the defined range. The wireless mesh network topology allows "point-to-point" or "peer-to-peer" connectivity and creates an ad hoc, multi-hop network. The mesh network is self-organizing and self-healing—hence loss of one or more nodes does not necessarily affect its operation. This increases the overall reliability of the system by allowing a fast local response to critical events in the rare event of a communication problem.

Elimination of tedious data acquisition and processing procedures through adoption of YSI-ECONET has freed up time in our current monitoring system deployments allowing more focus on bi-weekly sensor quality assurance checks including cleaning of sensors and checking the accuracy of staff gauge data from which flow is determined. Wetland biologists and wetland water managers appreciate the ability to review monitoring site data ahead of these checks which helps preparation for contingencies such as sensor failure prior to traveling to the site. In the GEA monitoring sites are as distant as 30 km apart.

Although our decision to embrace YSI-ECONET has been applauded by project advocates—it was the first major deployment of the technology on the west-coast of the United States and we suffered some of the technical issues that sometimes beset innovators. Modem failure was a problem at the beginning of the project. The software design did not allow direct communication with the dataloggers—as a result each monitoring site had to be taken off the network and the datalogger "brick" express mailed to the East Coast of the US for repair. This caused the loss of valuable data and in the case of access node modem failure data loss from more than one station. This problem was addressed by substitution with more reliable modems and with the provision of a supply of spare modems by the manufacturer which we were able to install ourselves.

Another technical issue was that the data posted on the website was preliminary data and there was no mechanism for correcting the posted data or migrating the preliminary data to another web location after quality assurance data validation had been performed. Inaccurate or absurd data posted to a project website can cause irreparable harm to a project and can quickly lead to a loss of confidence in the stakeholder community. Our MACE acoustic Doppler meters (MACE, 2008) provided very accurate measurements of water stage and velocity in culverts and small channels—however although totalized flow calculations were accurate when downloaded from the MACE data collection platform they were 100 times too high when transmitted using the SDI-12 protocol to the YSI-ECONET datalogger. This turned out to be a programming error in the firmware—a decimal point was omitted in the program and re-inserted during output processing. This error was caught by one of our project cooperators and took several months to resolve.

Environmental monitoring technology has improved significantly in the past decade—however every innovation comes with a new suite of potential problems. Adopters of new technologies need to vigilant—complacency can severely set back technology transfer and future adoption of potentially viable solutions for RTWQM.

2.4. *An ideal EDSS for RTWQM will guide the user through the sequential steps of monitoring site data acquisition, data processing and validation, simulation modelling and flow and water quality forecasting. Data acquisition and management protocols should be seamlessly linked through map-based interfaces for visualization by the stakeholder community and with simulation and forecasting models for ease of use by modelers. The EDSS needs to provide economic value to its users to ensure long-term provision of data essential for its use as a decision tool*

RTWQM involves the steps of monitoring, data acquisition, data processing and visualization, simulation modelling of basin hydrology and both flow and water quality forecasting. One of the most time consuming and onerous tasks is the conversion of raw data into information that simulation and forecasting models require to become useful as decision support tools within the EDSS. Forecasting models rely on continuous data feeds from the real-time network of flow and water quality sensors as well as information on future operations. These operations determine drainage return flows and reservoir releases to the River and its tributaries as well as pumped irrigation diversions that can affect the River's assimilative capacity. Full implementation of an EDSS for the GEA will require assessment of SJR assimilative capacity. Wetland salt load discharge from the GEA will constrained by daily salt load targets that may be formulated as a percentage of the total SJR assimilative capacity.

The first attempt at developing a forecasting EDSS for the SJR relied on a customized graphical user interface (GUI) which was developed to interact with a data-driven flow and water quality model of the main stem of the SJR—a 100 km reach between Lander Avenue and Vernalis. The San Joaquin River input–output model (SJRIO) used hydrologic routing techniques and conservative mass transport to calculate water quality at frequent (less than 1 km) intervals along the SJR and accounted for all major tributary inflows and diversions (Kratzer et al., 1987). The GUI facilitated the inspection of real-time flow and water quality data and featured internet communication and downloading capabilities that expedited the collection of agency hydrologic and water quality input data as well as the dissemination of flow and water quality forecasts. The easy-to-use features of the GUI included the point-and-click system of Windows™, on screen data entry, map-based outputs, and internet-based communication (Fig. 3). Routines were developed to upload operational schedules or to download model results. Reservoir operators were able to enter daily schedules of diversions and discharges and upload these schedules every 2 weeks to the person making the flow and water quality forecasts. Likewise, this person could also use the GUI to download operational schedules from agencies where data is routinely posted to a public ftp site. The user could scroll through a display of dates, viewing the temporal variations of water quality parameters at any map location on the screen and can display spatial color-coded changes in water quality at any given time. By clicking at a time advance button, the user

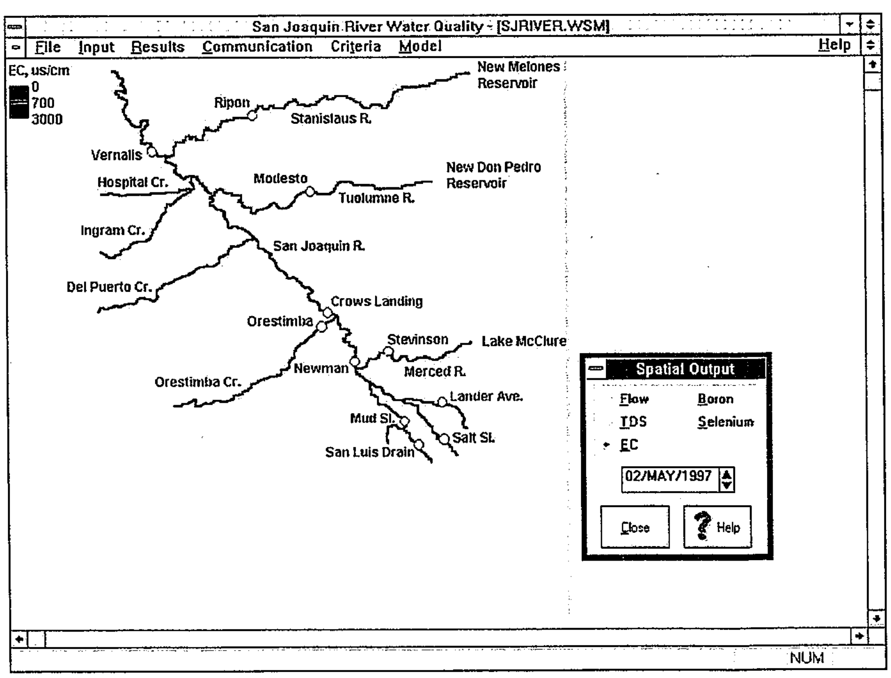

Fig. 3 – Graphical user interface for an EDSS developed to aid forecasting of SJR salt assimilative capacity and allow model users to visualize the impacts of actions to limit salt loading from west-side tributaries.

could create a near-animation of how a slug of poor quality water moves through SJR.

The GUI allowed water managers to coordinate their operational decisions on a weekly basis by providing a spreadsheet-type entry of operational schedules consisting of the past week's operation and 2 weeks projected operation. Water managers could then upload their operational schedule to the ftp site for use by the person responsible for making model runs, who would incorporate the information into simulation model input data. Water managers could download model run results from the FTP site, display the results and review the run-specific comments. Water managers who decided to change their operational schedule as a result of a review of model output could contact those responsible for making the forecast model runs by telephone or email. The model run input data could then be revised and the forecast model rerun and the revised output posted on the ftp site.

Despite the fact that the EDSS had anticipated and solved, technically, many of the essential data management issues associated with RTWQM—the institutional arrangements necessary to make sure that reservoir and drainage flow and water quality data was routinely uploaded to the ftp site were not sufficiently binding. For several months at the beginning of the project cooperating water districts and agencies were diligent at providing data weekly – however over time as staff became busy with other more pressing tasks and with changes in staff assignments – provision of data essential for developing model-based forecasts became less reliable. It became clear that unless we could demonstrate a clear economic rationale to these entities as to why they should continue to provide a service to our project, or support the effort with our own project funds that we could not rely on their long-term cooperation.

The original EDSS design relied on a dedicated computer housed in the Department of Water Resources in Fresno—EDSS user's would use the GUI, loaded on their own computer, to update the model with the latest data. This required connection to the centrally located computer. After the first 6 months of the project, noticing a significant decline in both co-operator data uploading activity and EDSS user downloading for model updates we decided to simplify information flow and EDSS system management by running the forecasting model in-house and posting weekly updates of the results. Responsibility for running the model was shared equally between the California Department of Water Resources (DWR), Berkeley National Laboratory and the California Regional Water Quality Control Board. All data compilation was assigned to the team responsible for each forecast. Automated data feeds were developed for web-served flow and water quality data from the California Data Exchange (CDEC) and the US Geological Survey. This basic EDSS design has been continued by DWR to the present although funding has limited the scope of the program and DWR has become the sole operator.

More recent development in the forecasting EDSS for RTWQM has been the replacement of the SJRIO model with the more comprehensive watershed model WARMF (Herr and Chen, 2006). WARMF-SJR simulates the hydrology of the watershed contribution to the SJR and tracks a broad suite of agricultural nutrients and contaminants in addition to river tributary inflow and salt loading. In WARMF-SJR wetland drainage from the GEA is partitioned by area according to component State, Federal and private wetland contributors as well as by Mud Slough, Salt Slough and Los Banos Creek which are the major tributary contributors of salt load to the SJR.

WARMF-SJR has been used for a number of studies during the past 18 months including studies of SJR flow recirculation, algal loading to the Stockton Deep Water Ship Canal and SJR restoration hydrology and water quality and has been independently peer reviewed by east-side Basin agricultural stakeholders. It is anticipated that the initial goal of the EDSS design will be realized with the advent of the WARMF-SJR model—given widespread financial support for WARMF-SJR modelling studies, the regulatory requirements of the salinity TMDL for dischargers of salt load and major agency backing for the concept of RTWQM.

2.5. *EDSS design should strive to include uncertainty in the conceptual, simulation and forecasting models that provide the decision support engine. This should be accomplished without confusing the end-user or causing the stakeholders to lose confidence in the EDSS*

The move away from deterministic models and EDSS's that incorporate them has been a goal of water resource systems professionals for more than a decade. There is a fear that without adequate recognition of uncertainty policy makers will make poor decisions and formulate water and water-related policies that may be unwise or potentially hazardous to sound water resources management. One of the prevalent fears among land owners in both the agricultural and wetland communities is the tendency among policy analysts to extrapolate limited data and formulate policies that work against Basin stakeholder interests. Given the dearth of reliable watershed water quality and pollutant loading data this is sadly a legitimate fear. Presentation of relevant information in a clear manner that describes the limitations of the data while keeping the EDSS simple, penetrable and non-intimidating is good practice to accommodate professionals charged with making decisions and advising those formulating policy.

The approach taken in the current RTWQM projects has been to address system heterogeneity and data uncertainty by standardizing technology to the extent possible. This objective has been applied to environmental monitoring and the types of sensors deployed and their manufacturer for flow and electrical conductivity measurements. Also to data collection platforms and telemetry systems which relay the data to agency or water district databases or in the case of YSI-ECONET to a commercial data storage facility where data is archived and made available through the company web server. Centralized storage of environmental data facilitates the development of software for automation of data feeds to simulation and forecasting models that form the basis of EDSS's used to provide decision support for RTWQM. Centralized data storage also makes it easier to take advantage of powerful data visualization software tools that can be used to explore trends and relationships within the dataset as well as provide information in a form that Basin stakeholders might more readily comprehend. Basin stakeholders are more