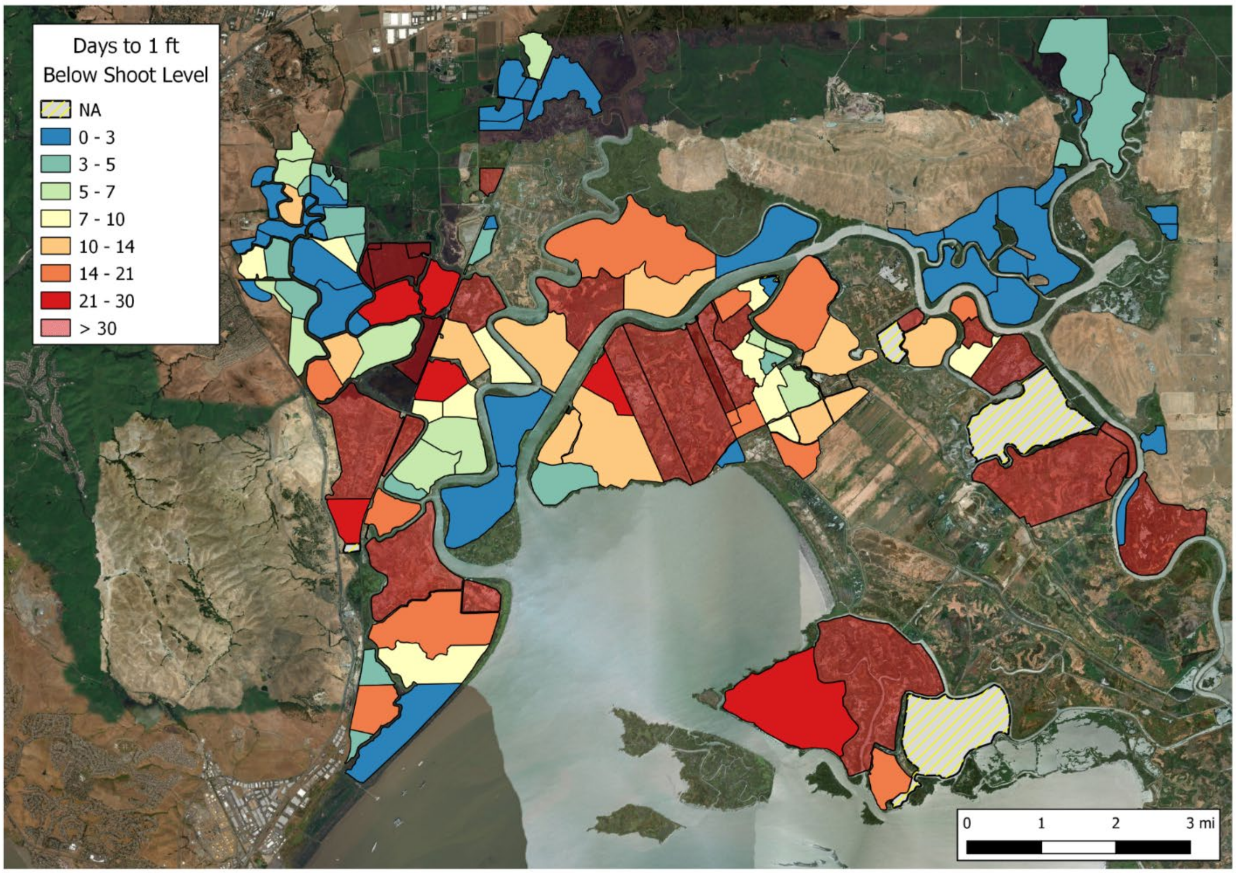
Suisun Marsh Improvement Assessment

Final Report
31 October 2018



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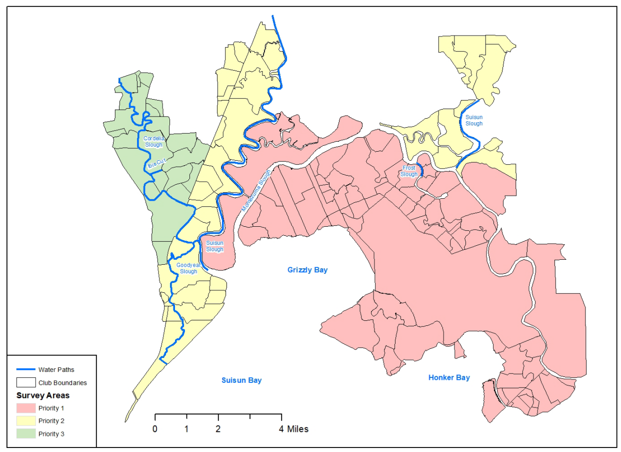
Executive Summary

- We conducted an assessment of Suisun Marsh managed wetland water control structures. Our goal was to develop a list of priority projects in the Suisun region that could improve managed wetland drainage capacity to provide the greatest benefit to managed wetland habitats and functions for a range of fish and wildlife species.
- The improvement assessment was supported by a planning grant from the Sacramento-San Joaquin Delta Conservancy and by the Department of Water Resources through the Delta Smelt Resiliency strategy. The work was led by the Suisun Resource Conservation District partnering with the California Waterfowl Association contributing survey expertise and RMA Associates leading the hydrologic modeling.
- The 3 primary objectives of this study were to: 1) enlist landowner-managers in the assessment and obtain written permission for their involvement, 2) conduct a survey to obtain highly accurate elevations for exterior water control structures, and 3) develop a simulation model and prioritization tool to assess which wetlands would most benefit Marsh habitats with infrastructure improvements.
- We invited landowners to participate through the SRCD website, via mail and email, and in presentations about the project at the SRCD Landowner Workshops on 18 April and 5 September 2018. SRCD staff also made personal contacts to obtain permission and coordinate access for fieldwork. The Marsh was divided into 3 priority areas grouping the managed wetlands from most to least likely to benefit from infrastructure improvements. A total of 91 of 102 landowners (89%) in the priority areas participated, 8 landowners declined to participate, and 3 failed to respond.
- From April through September 2018, surveys were completed on 409 managed wetland water control structures by CWA and SRCD staff with RTK GPS survey units tied to NAVD88 elevation benchmarks. We photographed each structure and recorded information on pipe diameters (12-48”), materials, gate types, and invert elevations (inside bottom of the pipes). In addition, target water levels were obtained from staff gauges or other marks.
- These data were used in a U. S. Army Corps of Engineers Hydrologic Engineering Center River Assessment System model (HEC-RAS) applied to assess individual pond draining rates (in days) and water volume exchange (in acre-feet). The model was calibrated with water level data available for 5 wetlands, and simulations were developed for 130 wetland units. Model predictions suggested that 42% drained to 1 foot below target water elevations relatively quickly (<5 days), 17% moderately (5-10 days), 22% slowly (10-30 days), while 19% failed to drain in 30 days.
- An Excel prioritization tool was developed from the RAS model to compare and rank the best projects to improve drainage capacity among wetlands and to compare different drainage scenarios within wetlands. This tool was written as a user-friendly program that SRCD water managers could operate to show landowners how infrastructure improvements may benefit their management.
- Application of the HEC-RAS model allowed us to objectively assess which projects would be best to benefit Suisun Marsh habitats. Continued development of the model will allow us to examine which management alternatives may most benefit zooplankton production and foraging Delta smelt. It also will allow us to assess how future climate change effects including sea-level rise will affect tidal flooding and draining of Suisun Marsh managed wetlands.

Introduction

Suisun Marsh is a 116,000-acre complex of brackish managed wetlands, tidal wetlands, and transitional upland habitats located downstream of the confluence of the Sacramento and San Joaquin Rivers and upstream of the San Francisco Bay (Figure 1). Management and ownership of this land is by a combination of public, non-profit organizations, and private organizations (duck clubs). The objective of the SMP (2014) is to enhance 40,000 to 50,000 acres of managed wetlands, restore 5,000 to 7,000 acres of tidal wetlands, and to generally improve water quality for beneficial uses in the Marsh including estuarine, spawning, and migrating habitat uses for fish species. The primary objective of the DSRS is to improve the status of Delta Smelt through improving habitat conditions and food resources in the Delta and Suisun Marsh regions. The 50,000 acres of managed wetlands that exist in Suisun Marsh provide numerous ecosystem benefits including food resources and habitat for a variety of species including waterfowl and species of special concern.

Figure 1. Suisun Marsh and the three priority regions with similar hydrology used to assess and prioritize the managed wetlands that would benefit from additional water control structures.



Wetland management in Suisun Marsh involves diversion and draining of tidal waters in and out of managed wetlands (Barthman-Thompson et al. 2005). External levees separate managed wetlands from bays and tidal sloughs, while internal levees separate adjacent units. Landowners use levees, ditches, water control facilities, grading, pumps, and fish screens to manipulate the timing, duration, and depth of flooding. The operations schedule is driven by water year, location, and water control facilities, but most managers begin flooding in late September to mid-October as most migrating waterfowl arrive.

Since most wetlands are at or below mean tide level, gravity flow may be used to fill and drain through water control structures. Inflows occurs during the flood tides, and drainage occurs during ebb tides. During initial flood-up, managed wetlands are filled to 8-12 inches (20-30 cm) when inlet gates are opened and drain gates are closed as diversions may operate <12h/day during the two daily high tide cycles. The volume and velocity of diversions vary with location, intake diameter, and head pressure created by the high-tide stage.

From mid-October to late January, relatively small amounts of water are circulated from adjacent sloughs to maintain water quality and depth. Managed wetlands are drained in February as spring flood-up begins. typically undergo 1-2 leach cycles which consist of rapid draining and flooding to remove salts from wetland soils, but re-flooding rates depend on Delta outflows, spring weather, and drainage. Thereafter, smaller volumes are used for circulation, and remaining water is drained in June and July to allow for vegetative growth and maintenance activities. Water diverted from July-September is used to maintain water levels and water quality in permanent wetlands.

We conducted an assessment to document existing water management infrastructure in the Suisun Marsh to develop a prioritized list of actions for improvements on individually-managed private and public wetlands. The Marsh-wide assessment determined the quantity, quality, location, and resiliency of the existing marsh drain infrastructure. The assessment of existing managed wetland water management infrastructure in the Marsh is vitally important to maximize the ecological benefits of the managed wetland habitats and functions for a range of resident and migratory fish and wildlife species. By identifying priority sites for water management improvements, we were supporting several actions of the Department of Water Resources' Delta Smelt Resiliency Strategy
(DSRS), and the Suisun Marsh Habitat Management, Preservation, and Restoration Plan (SMP; 2014). This assessment will further the objectives of the Water Quality, Supply, and Infrastructure Improvement Act of 2014 (Proposition 1) by resulting in a prioritized list of actions that may be considered for future funding.

The cyclic seasonal flood and drain cycle of these managed wetlands provide an opportunity for the robust primary and secondary productivity produced on these wetlands to be exported to the surrounding tidal sloughs augmenting aquatic food resources for native and listed fish species (e.g. Delta Smelt). Two recent and ongoing studies by Win Kimmerer (San Francisco State University), Peter Moyle (U.C. Davis), and John Durand (U.C. Davis) on two managed wetlands in different regions of the Marsh (west-central and north-east regions of the Marsh) have shown higher primary and secondary productivity in effluent water from the managed wetland study sites as compared with background productivity in the receiving tidal sloughs. Two relevant DSRS actions are coordinating the effective and efficient drainage of managed wetlands throughout the Suisun Marsh at key times of year and installing and operating the drain gates on Roaring River. These actions have the potential to provide a regional boost in food supply and maximize export of productivity to adjacent open water habitat used by Delta Smelt.

In order to maximize the benefits of improved managed wetland operations for the aforementioned species, meet several of the elements of the DSRS, and to minimize negative impacts of managed wetlands operations (e.g. reduce low dissolved oxygen discharges), the drainage infrastructure of the individual wetlands needs to be in optimal working order. Optimal working order of managed wetlands includes flooding and draining within a 30-day period, reducing soil salinities through leaching cycles and irrigating desirable wetland plant communities, and improving water quality conditions to reduce low dissolved oxygen discharge events and decrease mosquito vector production for public health and safety. The first step towards achieving these goals is this Marsh-wide infrastructure assessment to determine the quantity, quality, location, and resiliency of the existing marsh drain infrastructure.

This assessment consisted of physically surveying the water management infrastructure on nearly every managed wetland in the Suisun Marsh and developing a simplified hydrodynamic model to determine the length of time each managed wetland takes to drain. Specifically, surveying and identifying physical elements would include: the geographic location, invert elevation, diameter, material, and qualitative condition of each drain pipe; the type and condition of gate on each drain pipe; and an estimate of the managed wetland acreage flooded served by the structures, water level in the managed wetlands, and average pond bottom elevation in comparison to the tidal datums.

A modified U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS) model was used to determine the length of time each managed wetland takes to drain (RMA 2018). This modeling approach was simplified to a format readily usable by individual landowners and SRCD biologists and water managers. To facilitate this assessment, the total area of the Suisun Marsh was divided into three geographic areas (**Figure 1**). These areas were stratified based on hydrological connectivity and the aquatic habitats adjacent to the managed wetland discharge locations and were surveyed in priority order.

Objectives

This project is a collaboration between the Suisun Resource Conservation District, the California Waterfowl Association (CWA), Resource Management Associates (RMA), the Department of Water Resources (DWR), and the Sacramento-San Joaquin Delta Conservancy (DC) to lead the development and implementation of the assessment; obtain the costs to complete the work; and use the assessment to support the stakeholders and landowners. The three study objectives were to:

1. Identify and contact the landowners in each survey area to explain the need for the infrastructure assessment and obtain permission for access to conduct the work.

2. Assess the managed wetland drainage infrastructure and water elevations relative to established regional elevation benchmarks.

3. Calibrate and run a hydrologic model to determine flooding and draining times for all managed wetlands and develop a spreadsheet tool to allow prioritization of the managed wetlands where infrastructure improvements would most provide a benefit to Suisun Marsh habitats.

Methods

Procedures for Obj. 1: Identify and contact the landowners in each survey area to explain the need for the infrastructure assessment and obtain permission for access to conduct the work.

SRCD staff contacted and informed each landowner about the project through presentations at two Landowner Workshops (18 April 2018, 5 September 2018), and a request form was distributed at the meetings, through the SRCD website (www.suisunrcd.org), by mail, email, and in person to obtain written permission. In addition, SRCD staff conducted for individual meetings, calls, and emails to contact nearly all of the landowners in the Marsh and explain the project. SRCD then made a formal request for permission to survey the managed wetland properties.

Where permission was granted, the survey crew worked with the landowner-managers to schedule the survey fieldwork for recording the winter-flooded water surface elevation target for each management unit and the size, material, elevation and water control structure arrangement for each exterior structure that had drainage capacity. Photos were taken at every water control structure and where water surface elevations were recorded.

<u>Procedures for Obj. 2: Assess the managed wetland drainage infrastructure and water elevations relative to established regional elevation benchmarks.</u>

<u>Elevation Surveys</u>

CWA and SRCD staff collected field elevation data (<5 cm accuracy) with a Real Time Kinematic (RTK) GPS system following standardized survey procedures (**Figure 2**). A base station consisting of a Trimble 542 receiver with a Trimble Zephyr Geodetic Model 2GPS antenna (Trimble, Inc., Sunnyvale, CA) mounted on top of a 2m fixed-height tripod was used to link the elevation data to regional benchmarks. These benchmarks were either those found at DWR monitoring and compliance stations or obtained from National Geodetic Survey (NGS) recorded benchmarks. The rover unit used to take the infrastructure elevations consisted of a Trimble 342 receiver with integrated GPS receiver and antenna paired with a Trimble Kenai Tablet running Carlson SurvPC survey software (Carlson Software, Inc., Maysville, KY).

Figure 2. Survey equipment including a Trimble RTK GPS rover survey unit, base station, and measuring pole.

Existing benchmarks were located throughout the project area as reference points (**Table 1**). A network of temporary field benchmarks was established from these benchmarks to reduce the distance between base station and rover unit during data collection (**Figure 3**). Survey crews attempted to keep the distance between the base station and rover to < 1.5 miles. During the localization process, the benchmark was occupied, and readings were averaged for a minimum of 30 seconds. Once localized, the survey crew would travel to all sites within the range of the base station to record infrastructure elevations. Once the area within the physical or logistical range of the base station was surveyed, the base station would be relocated and the rover re-localized to a previously established benchmark. This process was repeated for all collected data. Elevation was reported relative to the NAVD88 vertical datum.

Figure 3. Examples of a fixed NGS monument and temporary field benchmark tacs.

<u>Data Collection</u>

Figure 4. Photograph of a water control structure and staff gauge where target "shoot levels" were measured.

In some cases, the landowner provided a staff gauge reading or another known mark for the winter-flooded water level that was directly measured (**Figure 4**). Where known water marks were not provided, the target water surface elevation was estimated by taking measurements at hard water marks at multiple locations such as water control structures, boat docks and pilings.

Survey crews employed a variety of methods to record information at each exterior water control structure. The elevation of the pipe was measured by either directly occupying the top or bottom of the pipe (whichever was exposed) or by occupying a location on the support structure above the pipe then measuring the distance to the top or bottom of the pipe using a tape measure or graduated survey pole. Pipe diameters were estimated by either measuring the width of the control gates or measuring the diameter of the pipe using a tape measure or pipe calipers. Precise measurements were not possible in most instances, so pipe diameters were assumed to be standard sizes (i.e. 12", 18", 24", 30", 36", 48", etc.). Wherever possible, we asked the landowner or manager for the actual pipe size if they knew it.

Table 1. Suisun Marsh benchmark label, elevation (NAVD88), latitude, and longitudes used to reference the elevation data for managed wetland infrastructure.

BM	Elevation (NAVD 88)	Latitude	Longitude
DH6896	6.7′	38˚ 7′ 14.50310″	-121 ˚ 57′ 17.44253″
JS2021	39.7′	38˚ 12′ 20.84635″	-121˚ 53′ 20.43355″
AE7864	9.2′	38˚ 14′ 11.51321″	-122˚ 1′ 47.69756″
DH6910	7.3′	38˚ 12′ 20.26190″	-122˚ 3′ 42.0912″
DH6908	7.8′	38˚ 9′ 24.19225″	-122˚ 6′ 49.53754″
JS2011	17′	38˚ 8′ 12.71792″	-121˚ 54′ 21.17343″
AE7865	10.6′	38˚ 11′ 17.72218″	-121˚ 58′ 36.81399″
Blacklock NE-1	9.6′	38.180278	-121.906667
Belden's Landing S-49A	10.3′	38.187778	-121.96972
Goodyear Slough S35	2.61′	38.119167	-122.095833
Sunrise Club S21D	10.3′	38.184444	-121.083056

Invert elevations for the interior and exterior pipes were calculated using the elevation of the top of the pipe and subtracting its diameter and wall thickness to obtain the elevation of the inside bottom edge of the pipe. Many control gates were not visible except at low tides, so control gate arrangement was based on a combination of local knowledge by SRCD or CWA staff, landowners, and field observation. After submitting preliminary data to RMA for analysis, in some cases it was necessary to collect additional information on interior water control structures. For the level of modeling planned for this effort, only location and pipe diameter were collected for interior water control structures.

<u>Procedures for Obj. 3: Calibrate and run a hydrologic model to determine flooding and draining times for all managed wetlands and develop a spreadsheet tool to allow prioritization of the managed wetlands where infrastructure improvements would most provide a benefit to Suisun Marsh habitats.</u>

The objective of the modeling was to evaluate the capacity for individual managed wetlands within Suisun Marsh to drain within a reasonable amount of time given their current drainage infrastructure. Flooded wetland extents and water control structure specifications were used with a digital elevation model (DEM) and stage data available from the network of DWR compliance and monitoring stations to create models for all wetland units. The DEM used in the modeling was a composite created by merging aerial LiDAR data for pond topography with slough bathymetry obtained from DWR.

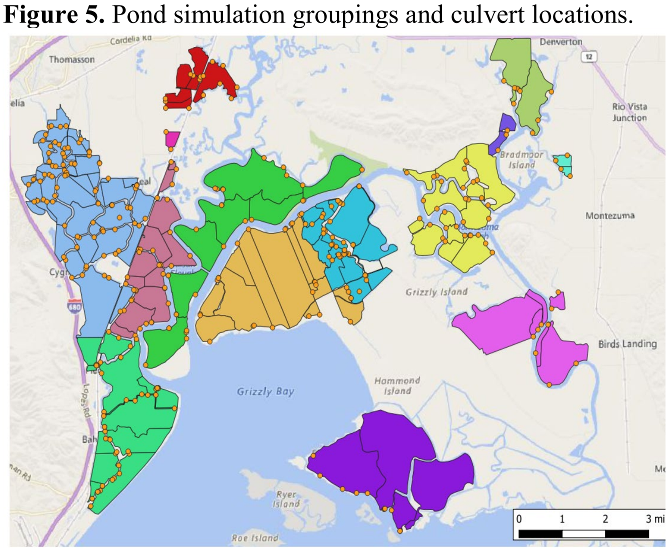
The River Analysis System model (RAS), developed and distributed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC), was chosen for this study because of its ability to efficiently and accurately simulate flows through culverts and its ability to model individual ponds as zero-dimensional storage areas (HEC 2016). The model uses water surface elevation timeseries data in adjacent sloughs, culvert specifications, and a hypsographic curve of the wetland to predict pond water levels and volumes during drainage. Model results can be queried to determine the length of time each managed wetland takes to drain.

The user interface allows users to quickly add and remove culverts and enter detailed culvert specifications, including inlet and outlet elevations, culvert shape, pipe material, gate specifications, and friction coefficients. The interface also calculates pond storage-elevation curves from an input digital elevation model (DEM). RAS has been tested on a wide range of analytical, laboratory, and real-world datasets to validate its computed results (HEC 2018).

Managed wetlands in Suisun Marsh were modeled as zero-dimensional storage areas in RAS. It was assumed that any internal flows in the wetland, including flows through networks of swales and drainage ditches or through internal culverts, do not limit the availability of water to flow out of culverts on the boundaries. In other words, flows through external culverts were assumed to be the limiting factor controlling drainage. One-dimensional channels were used to represent large reaches such as Suisun Slough, Montezuma Slough, Nurse Slough, and Cordelia Slough. Smaller connecting streams, such as Goodyear Slough, Frost Slough, and Ibis Cut were also modeled using one-dimension channels, as needed in the model. Larger water bodies such as Grizzly Bay and Honker Bay were only partially modeled as necessary.

Instead of one large model grid set up to simultaneously model all 134 properties, the managed wetlands were divided into 14 groups (**Figure 5**). The separation of these properties depended on shared usage of connecting waterways, drainage ditches, and receiving bodies of water. Some properties did not drain into adjacent sloughs, but directly into other wetlands. This required properties to also be included in the same groupings. Proximity to DWR monitoring stations with tidal stage height data available on the California Data Exchange Center (CDEC) also

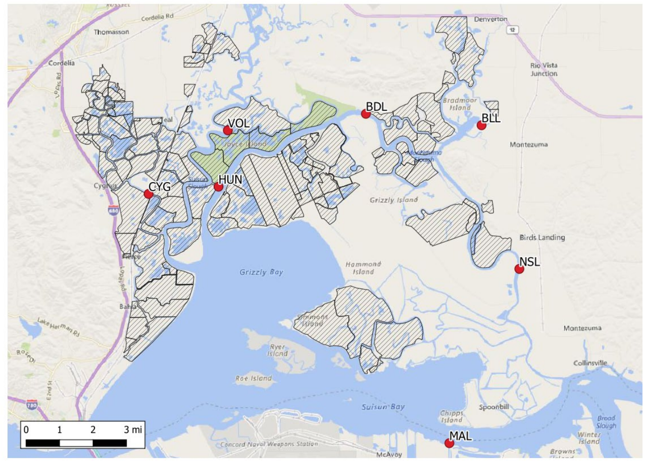
Figure 5. Pond simulation groupings and culvert locations.



influenced grouping of properties (**Figure 6**).

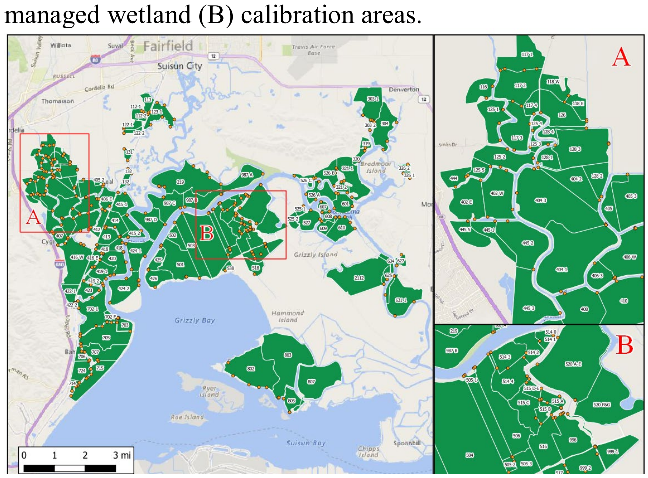
The RAS model developed for this work consisted of collections of storage areas split into several spatial groups. Each storage area represented a single wetland management unit. The culverts attached to each storage area were given specifications corresponding to collected field data on: barrel number, diameter, invert elevation, pipe material, and inlet and outlet control structure. Culverts were joined directly to one-dimensional river reaches in the model. Each reach was connected to a network of adjacent sloughs, and a single water surface elevation boundary condition was applied using available observed stage timeseries data. River cross sections were added along the length of each channel as needed to describe the bathymetry of the channel. Where DEM data in small sloughs was poor, some cross sections were lowered manually to ensure sufficient flow and prevent model crashes resulting from water depths approaching zero.

Figure 6. DWR compliance and monitoring stations used to determine tidal stage.



Model calibration was carried out by varying culvert roughness coefficients to best match observed water surface elevations within wetlands during draining periods. Two sets of observed data were available for calibration (**Figure 7**): the first using two wetland units on Grizzly Ranch #520, and the second involving data collected on Suisun Farms #112, Tule Farms #113, Gray Goose #122, and Walnut Creek #123 (SRCD, unpubl. water quality data).

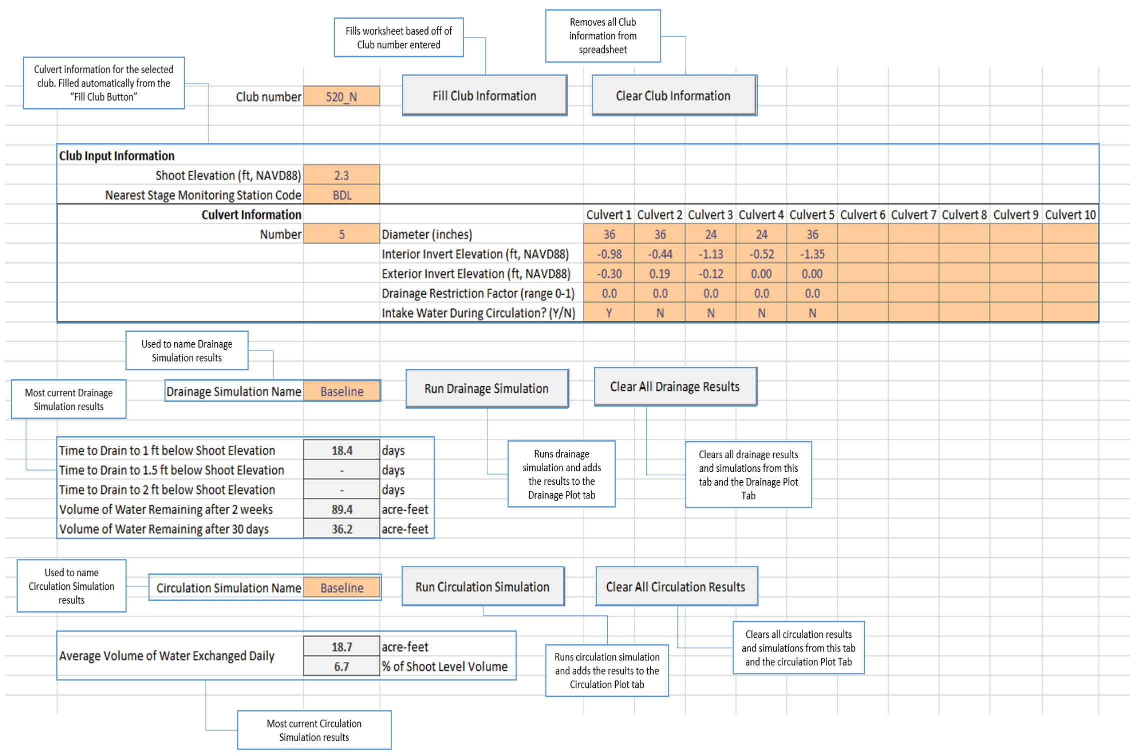
Figure 7. Managed wetland identification numbers and culvert locations with Grizzly Ranch (A) and northwest managed wetland (B) calibration areas.



Draining simulations were performed over a typical spring-neap period using observed stage records from February–March 2018. Pond drainage capacity was assessed by post-processing the drainage time series to calculate times to drain to 1, 1.5, and 2 feet below the manager's preferred water surface elevation or "shoot level." Volumes of water remaining in the wetlands after 14 and 30 days were also calculated.

An Excel-based “rapid assessment” tool was also developed to help SRCD staff in assisting wetland landowners in estimating how specific infrastructure changes (e.g. adding a culvert) could improvement drainage time. The spreadsheet (**Figure 8, Appendix D-E**) allowed users to quickly retrieve information on any specific property, add or modify culverts, and then compare drainage and circulation rates with different parameters. It allows fast comparisons of model simulations and culvert alternatives without major reworking of hydrodynamic model geometries. Summary metrics were calculated and presented on the main spreadsheet, and graphs showing comparisons of alternatives to baseline conditions were generated.

Figure 8. Excel calculator to examine projected changes with water control structure changes in managed wetlands of Suisun Marsh.



Results

<u>Landowner Permission</u>

In the three areas included in the infrastructure survey (**Figure 1**), a total of 91 landowners (89%) contacted agreed to participate in the survey, 8 landowners (7.8%) declined, and 3 landowners (2.9%) were non-responsive (for list of individual parcels and written permission forms, see **Appendices A, B).** Of the 91 managed wetlands surveyed, 42 were in Area 1, 30 were in Area 2, and 19 were in Area 3. Some of the parcels had more than one wetland unit. The total estimated managed wetland flooded area was 33,405 acres including 17,535 acres in Area 1, 10,390 acres in Area 2, and 5,481 acres in Area 3.

Infrastructure Surveys

The drainage infrastructure surveys included measuring and visually inspecting locations, invert elevations, diameters, materials, gate types, and target water elevation levels (**Table 2**). Water surface elevations were summarized and included with the water control structure information (**Appendix C**). All data was reviewed by CWA and SRCD staff for accuracy and when possible, confirmed with area managers. Pipe invert elevations were calculated based on recorded elevations, derived pipe diameters and estimated wall thickness (based on typical pipe construction). A total of 134 wetland units and 409 pipes were surveyed.

Table 2. Example of water control infrastructure data including wetland, structure, diameter, exterior invert, interior invert, pipe material, interior and exterior structure type, and unit.

Wetland	Structure Number	Diameter (Inches)	Exterior Invert	Interior Invert	Pipe Material	Interior Control	Exterior Control	Unit
520	1	42	-1.24	-1.21	HDPE	flap	combo	F-G
520	2	36	-0.30	-0.98	HDPE	combo	combo	A-E
520	3	36	0.19	-0.44	HDPE	combo	combo	A-E
520	4	24	-0.12	-1.13	HDPE	combo	combo	A-E
520	5	24	0.00	-0.52	CPP	riser	flap	A-E
520	6	36	0.00	-1.35	CPP	riser	flap	A-E
520	7	48	-1.32	-1.72	HDPE	open	flap	F-G

Typical pipe diameters included 48’’, 36”, 24”, 18”, and 12” pipes, and a small number of pipes were in metric sizes. The most commonly used drainage pipe diameter was 36’’ (46%) followed by 24’’ pipes (32.3%). Materials used for infrastructure pipes included high-density polyethylene (HDPE), corrugated plastic pipe (CPP), and corrugated metal pipe (CMP). HDPE was the dominant pipe material used in the managed wetlands (88%), followed by CPP (8.3%), and CMP (3.3%). Some of the CMP and CPP structures were older and had damage due to corrosion.

The invert elevation or inside edge of the bottom of a pipe was estimated by subtracting the pipe diameter and wall thickness from the elevation at the top of the pipe. The invert elevations for 65-67% of the interior and exterior pipes was in the range of zero to -8.0 feet (**Appendix C**). When comparing the interior side of the pipe with the exterior side of the pipe, we recorded differences in the elevation that can affect drainage capacity (**Table 3**). For each area, about 25% of the pipes were level, but the exterior was higher for 6-38%, and the interior was higher for 18-32%.

Table 3. Difference from interior (managed wetland) to exterior (slough) side of drainage pipes, where invert elevations are measured as the inside edge of the bottom of the pipe.

Priority area	Int < Ext by 3 feet	Int < Ext by 1 foot	Int = Ext	Int > Ext by 3 feet
1	17%	38%	27%	18%
2	6%	38%	28%	28%
3	14%	31%	23%	32%

Exterior and interior water control structures (**Figure 9**) included combination drainage and canal gates (combo), canal gates, flap gates, winch flaps (hand crank setup to manually open or close a flap), flashboard risers, and open pipes. Combination gates and flap gates were the main structure observed (~37%) on the exterior pipes to control draining. Other exterior structures included open pipes (10.8%), canal gates (8.3%), flashboard risers (4.8%), and winch flaps (2.3%). Flashboard risers were the main structure (35.8%) on interior pipes followed by open pipes (21.6%), combination gates (20.8%), flap gates (10.2%), canal gates (8.4%), and winch flap gates (3.3%).

Figure 9. Water control structures including A) combo gates, B) canal gates, C) flap gates, D) winch flaps, and E) flashboard risers.

Water Elevation Levels

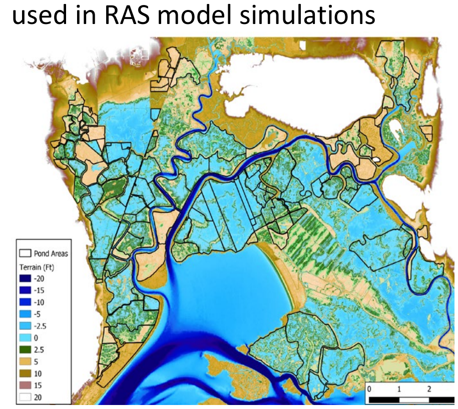
Target pond levels were most often measured by reading staff gauges established by the managers or by measuring hardwater marks on interior water control structures. A total of 199 water levels were measured (**Appendix C**). Depending on the size and interior levee design, managed wetlands had 1 to 7 different water levels or units. The average target pond level was 1.0-3.0 feet for 46.7% of the managed wetlands surveyed, while 39.7% held their wetlands at 3.0-5.0 feet, 11.1% at 5.0-8.0 feet, and 2.5% at 0-1.0 feet.

Suisun Marsh Elevation Data

The DEM used for the RAS modeling was a composite developed using six bathymetry sources. These source DEMs were layered on top of each other in a preferred order and combined within the RAS-Mapper interface. Layers were ordered based on their resolution and presumed accuracy. Source DEM extents (**Figure 10**) included:

- DWR San Francisco and Sacramento-San Joaquin Delta DEM 10m bathymetry (Wang and Ateljevich 2012), available at: http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/modelingdata/DEM.cfm
- National Oceanic and Atmospheric Administration (NOAA) California Coastal Conservancy DEM 2m LiDAR bathymetry layer (NOAA, 2011), available at: https://coast.noaa.gov/dataviewer/index.html#/
- U.S. Geological Survey (USGS) San Francisco Coastal 1m LiDAR (Dewberry, 2011) provided by NOAA, available at: https://coast.noaa.gov/dataviewer/index.html#/
- DEMs generated from real-time kinematic (RTK) survey data for club numbers 112, 122, and 123 (SRCD, Gillenwater Consulting; unpubl. data).

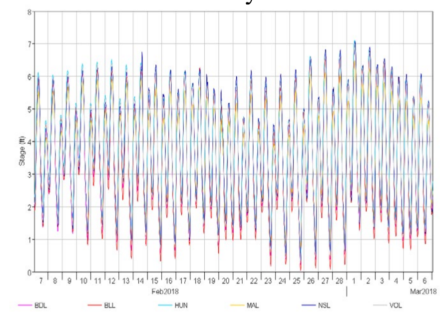
Figure 10. Final composite DEM used to develop storage elevation tables used in RAS model simulations



<u>Modeling Simulations</u>

Data was provided for 134 ponds with 340 culverts, but four ponds had no drainage infrastructure (525-West, 618, and 807) or had topography characteristics which made draining difficult or impossible (pond 422-South) and were not simulated. The remaining 130 ponds were simulated with the RAS model from an initial target water elevation (or "shoot level") provided for each pond. Stage elevations were taken from monitoring stations between February and March (**Figure 11**). Calibration was compared to water level data from Grizzly Ranch and 4 northwest wetlands (**Figure 12,13**). The individual RAS models are provided elsewhere (**Appendix G**).

Figure 11. Stage data for the simulations used as model boundary conditions.



The modeled draining time series were post-processed to calculate: 1) time to drain from shoot elevation to 1-foot below, 1.5-feet below, and 2-feet below, and volume of water after 14 d and 30 d. Drainage time ranged from 1 day for small managed wetlands with high elevation bottoms to >30 days for drainage-limited parcels. <u>*A summary of model results indicated that nearly 42% of the wetlands were estimated to drain to 1 foot below their target water elevation in <5 days, 17% drained in 5 to 10 days, 22% in 10 to 30 days, and 19% took >30 days to drain*</u> (**Table 4**). The overall results (**Table 5**) are shown with a color gradient from green to orange indicating those wetlands that drained rapidly or were unable to drain within 30 days (see **Appendix F** for example animation).

Figure 12. Calibration results for Grizzly Ranch #520 Ponds A-E and F-G comparing observed data (circles) with RAS model results (lines).

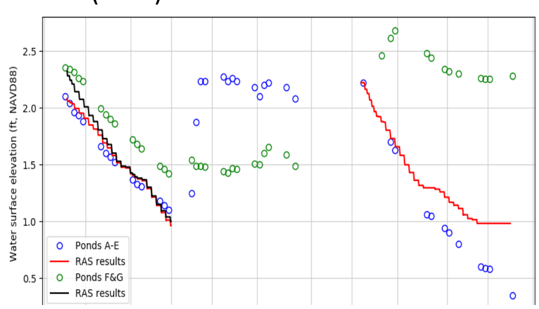


Figure 13. Calibration results for northwest managed wetlands (112, 113, 122, 123).

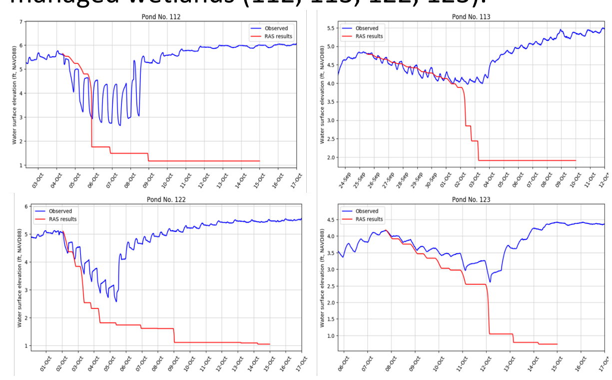


Table 5. Summary of modeling results for managed wetlands to drain to one foot below target water levels.

Managed Wetland	Too Low for Gravity Drains	Benefit from Added Drains	Already Drain Quickly
Priority 1	10	25	14
Priority 2	2	14	24
Priority 3	5	10	25
Total	**17**	**49**	**63**

Table 5. Modeling results showing shoot level (in feet), volume (in acre-feet), time to drain to -1, -1.5, and -2 feet, and volume remaining at 14d and 30d. Drainage ranged from fast (green),

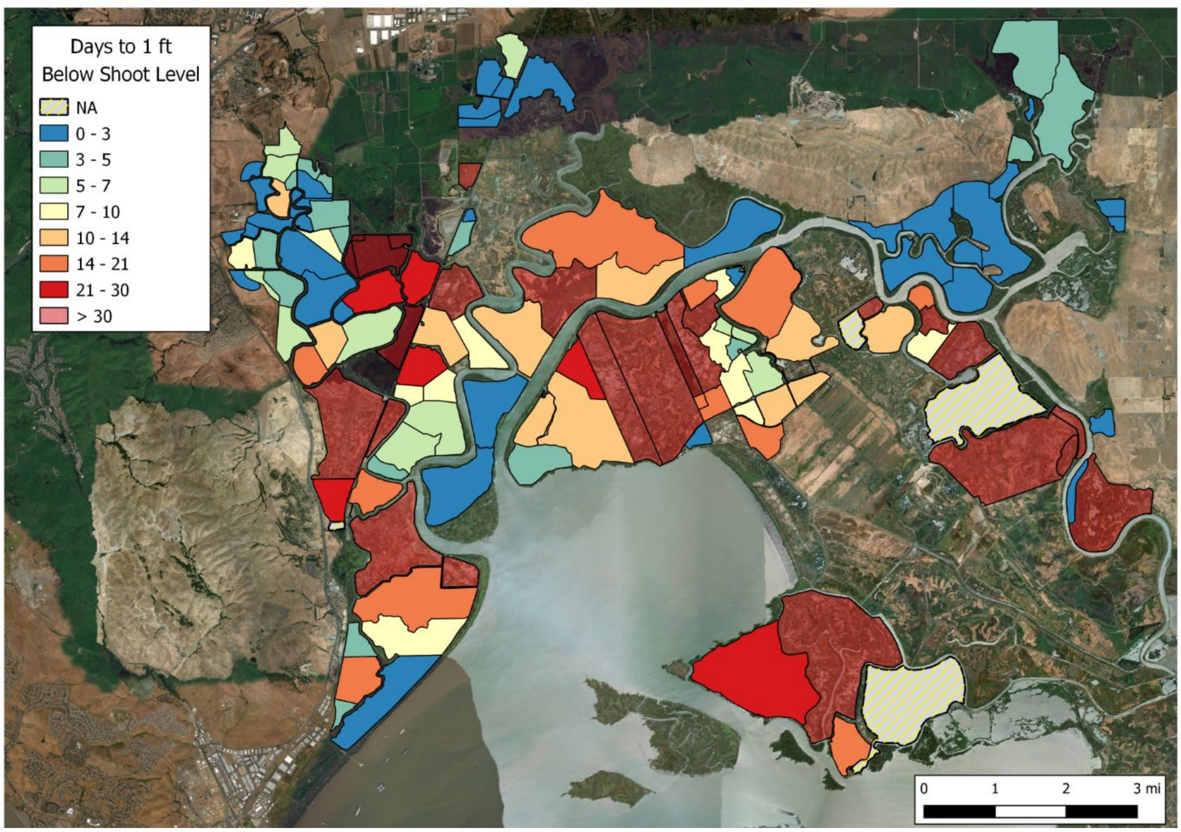
Club	Initial Shoot Level (feet)	Initial Shoot Volume (acre-feet)	Time to Drain to 1 ft below shoot level (days)	Time to Drain to 1.5 ft below shoot level (days)	Time to Drain to 2 ft below shoot level (days)	Volume remaining after 14 days (acre-feet)	Volume remaining after 30 days (acre-feet)
112_E	5.78	49.16	1.67	2.43	3.28	0	0
112_W	6.52	119.09	1.33	1.81	2.3	0	0
113	5.04	81.28	5.9	6.61	6.94	0	0
116	6.17	14.75	0.59	0.59	0.6	0	0
117_1	4.4	35.59	6.5	10.64	13.25	0.38	0
117_2	4.4	131.35	6.51	10.62	13.24	3.01	0
117_3	3.51	54.69	12.61	14.69	16.28	6.77	0
117_4	4.79	15.71	4.52	5.36	N/A	0	0
118_E	5.42	22.62	3.9	6.56	8.53	0.01	0.01
118_W	5.42	47.6	3.96	6.55	8.56	0	0
122_N	5.23	46.41	1.28	1.41	1.78	0.04	0.02
122_S	5.23	45.07	0.67	0.82	1.3	0	0
123	4.18	264.49	2.36	3.44	4.43	0	0
125_1	5.76	117.43	0.7	1.31	2.25	0	0
125_2	4.53	129.49	1.44	3.38	5.45	0.13	0
125_3	6.07	25.22	0.24	0.31	0.36	0	0
125_4	6.08	24.49	0.7	1.28	1.78	0.01	0.01
125_5	5.46	17.26	0.34	0.39	0.41	0	0
126	5.42	191.86	1.7	3.38	5.54	9.88	0
128_1	4.7	7.73	0.81	0.81	1.26	0	0
128_2	4.5	30.75	4.39	4.39	4.39	0	0
128_3	4.6	74.8	4.91	4.91	5.39	0	0
128_4	4.7	5.9	0.23	0.23	0.23	0.01	0
131	1.7	65.79	N/A	N/A	N/A	51.41	42.44
132_N	4.36	1.74	0.18	0.18	0.23	0	0
132_S	3.79	80.61	3.36	5.52	7.55	0	0
2112	1.25	322.21	N/A	N/A	N/A	316.55	306.03
219	2.97	952.96	14.16	21.5	N/A	359.95	167.46
303_N	4.58	555.11	4.4	6.45	7.62	0	0
303_S	5.11	15.92	0.42	0.72	0.75	0	0
304	3.7	401.51	4.47	6.59	9.54	0.19	0.04
319	4	33.29	4.53	5.35	5.4	0	0
320	4	4.12	0.25	0.25	0.25	0	0
321_N	4.73	0.15	0.14	0.18	0.23	0	0
321_W	3.22	27.72	2.4	3.45	6.54	0.07	0.01
326_N	5.2	25.89	0.42	0.43	0.67	0	0
326_S	5	3.76	0.16	0.16	0.16	0	0
402_E	4.76	167.63	4.43	8.99	15.78	33.46	8.35
402_W	3.86	170.9	9.04	14.19	19.44	47.56	20.77
404_1	4.4	122.41	2.43	3.54	6.42	4.6	0
404_2	4.06	189.96	8	13.11	20.52	81.99	45.63
404_3	4.5	55.09	1.44	2.34	2.46	0	0
405_1	1	8.61	N/A	N/A	N/A	8.21	6.1
405_2	0.9	31.05	N/A	N/A	N/A	30.7	25.72
405_3	0.9	106.15	N/A	N/A	N/A	105.64	96.39
406_E	2.66	224.47	21.49	N/A	N/A	128.7	82.27
406_SW	3.63	38.49	1.98	7.55	16.38	2.55	0.38
406_W	2.62	202.37	25.67	N/A	N/A	109.52	60.75
407	2.98	140.15	15.22	N/A	N/A	47.13	16.77
408	2.88	202.85	12.68	20.47	N/A	63.76	23.56
410	2.78	72.37	5.46	5.5	16.33	0	0
412	1.9	87.56	N/A	N/A	N/A	49.83	27.66
413	2.6	247.1	21.52	N/A	N/A	145.07	81.8
414	2.74	308.06	10.65	19.45	N/A	97.86	40.62
415_N	2.71	264.15	N/A	N/A	N/A	176.43	114.27
415_S	3.45	225.27	7.5	10.66	16.28	23.56	1.9
416_E	1.93	24.25	N/A	N/A	N/A	24.24	24.24
416_W	1.34	169.9	N/A	N/A	N/A	165.07	155.44
418_E	2.3	42.78	9.59	17.33	N/A	4.73	1.39
516	2.45	54.38	8.53	8.59	18.42	0.04	0.03
517	2.59	9.33	7.54	8.58	17.38	0	0
518	4.6	159.2	15.32	21.6	26.18	53.85	0.17
520_A-E	2.3	277.87	19.48	N/A	N/A	100.08	43.91
520_F-G	2.35	269.99	13.68	N/A	N/A	88.38	39.81
525_E	1.55	27.34	N/A	N/A	N/A	17.23	11.8
526_A	3.88	22.23	0.25	0.25	0.25	0	0
526_B	3.91	112.28	1.35	2.34	2.41	0.07	0.02
526_C	5.8	162.67	0.71	1.3	1.79	0	0
527	2.6	157.39	13.7	18.38	19.5	26.8	0.65
538	3.42	9.52	1.25	1.3	1.34	0	0
601	4.2	12.32	0.23	0.23	0.23	0	0
607	1.5	0.01	16.31	N/A	N/A	0	0
608	1.5	1.06	N/A	N/A	N/A	0.07	0.05
609	2	55.48	8.58	17.39	N/A	7.33	4.06
610	1.45	351.16	N/A	N/A	N/A	309.73	275.85
625	2.6	35.45	N/A	N/A	N/A	17.02	11.53
627	3.74	2.62	0.21	0.26	0.3	0	0
631_E	1.11	210.18	N/A	N/A	N/A	199.81	166.49
631_W	2.44	0.29	1.36	6.53	18.42	0	0
634	2.5	20.95	N/A	N/A	N/A	11.94	9.19
702	1.77	138.41	N/A	N/A	N/A	68.41	6.22
703	2.46	108.61	N/A	N/A	N/A	51.86	21.85
705	3.22	615.65	15.24	21.56	N/A	193.62	30.36
706	4.79	88.14	3.42	5.41	5.57	0.05	0.04
707	3.59	292.96	9.62	17.45	N/A	40.05	13.43
714	3.9	8.61	3.45	10.66	N/A	0.02	0.01
715	5.9	40.51	0.24	0.25	0.25	0.05	0.03
724	3.51	131.01	19.49	N/A	N/A	43.41	10.5
516	2.45	54.38	8.53	8.59	18.42	0.04	0.03
517	2.59	9.33	7.54	8.58	17.38	0	0
518	4.6	159.2	15.32	21.6	26.18	53.85	0.17
520_A-E	2.3	277.87	19.48	N/A	N/A	100.08	43.91
520_F-G	2.35	269.99	13.68	N/A	N/A	88.38	39.81
525_E	1.55	27.34	N/A	N/A	N/A	17.23	11.8
526_A	3.88	22.23	0.25	0.25	0.25	0	0
526_B	3.91	112.28	1.35	2.34	2.41	0.07	0.02
526_C	5.8	162.67	0.71	1.3	1.79	0	0
527	2.6	157.39	13.7	18.38	19.5	26.8	0.65
538	3.42	9.52	1.25	1.3	1.34	0	0
601	4.2	12.32	0.23	0.23	0.23	0	0
607	1.5	0.01	16.31	N/A	N/A	0	0
608	1.5	1.06	N/A	N/A	N/A	0.07	0.05
609	2	55.48	8.58	17.39	N/A	7.33	4.06
610	1.45	351.16	N/A	N/A	N/A	309.73	275.85
625	2.6	35.45	N/A	N/A	N/A	17.02	11.53
627	3.74	2.62	0.21	0.26	0.3	0	0
631_E	1.11	210.18	N/A	N/A	N/A	199.81	166.49
631_W	2.44	0.29	1.36	6.53	18.42	0	0
634	2.5	20.95	N/A	N/A	N/A	11.94	9.19
702	1.77	138.41	N/A	N/A	N/A	68.41	6.22
703	2.46	108.61	N/A	N/A	N/A	51.86	21.85
705	3.22	615.65	15.24	21.56	N/A	193.62	30.36
706	4.79	88.14	3.42	5.41	5.57	0.05	0.04
707	3.59	292.96	9.62	17.45	N/A	40.05	13.43
714	3.9	8.61	3.45	10.66	N/A	0.02	0.01
715	5.9	40.51	0.24	0.25	0.25	0.05	0.03
724	3.51	131.01	19.49	N/A	N/A	43.41	10.5
802	2.62	679.54	21.53	N/A	N/A	330.68	175.97
419_N	1.92	8.38	6.5	17.36	N/A	0.05	0.01
419_S	3.72	18	4.46	4.48	4.48	0	0
420	2.59	121.17	5.52	6.52	8.57	0.03	0
422_N	3.12	137.27	21.5	N/A	N/A	61.94	20.51
423	2.25	45.59	16.27	16.32	N/A	0.48	0
424_N	4.34	163.75	2.45	3.38	3.41	0.02	0.01
424_S	3.98	87.33	1.43	1.44	2.44	0	0
425	2.19	91.3	10.59	18.44	N/A	16.16	2.47
426	3.4	154.93	4.47	6.46	7.55	0.05	0.02
444	7.1	30.13	0.24	0.29	0.3	0	0
445_1	4.02	26.16	5.4	6.43	6.46	0	0
445_2	4.1	251	4.43	8.48	13.62	36.84	2.15
445_3	3.3	96.45	5.49	6.55	7.54	0	0
445_5	6.47	25.94	0.45	0.57	0.59	0	0
501	2.4	651.94	12.6	19.44	N/A	169.52	34.6
502	2.58	203.12	21.55	N/A	N/A	105	49.65
503	2.08	454.73	N/A	N/A	N/A	313.55	209.89
504	1.02	726.79	N/A	N/A	N/A	724.47	719.65
505_1	1.7	161.09	N/A	N/A	N/A	123.91	85.55
505_2	2.3	24.44	17.38	N/A	N/A	10.34	6.46
505_3	2.3	55.8	17.38	N/A	N/A	14.2	7.15
506	1.79	228.02	N/A	N/A	N/A	165.89	121.95
514_1	3.3	21.82	1.33	9.54	20.54	2.78	2.04
514_2	2.9	52.44	7.59	18.48	N/A	13.93	8.6
514_3	2.4	68.57	18.49	N/A	N/A	33.06	19.61
514_4	2	139.32	N/A	N/A	N/A	100.24	67.9
515_A	2.7	10.45	5.53	9.58	18.41	0.12	0.06
515_B	2.7	19.44	3.46	8.55	17.39	0.56	0.29
515_C	2.5	101.23	7.51	16.3	N/A	14.36	9.07
515_D-E	2.7	19.27	5.5	9.57	18.41	0.67	0.13

Drainage times ranged from <1 day for small ponds with relatively high elevation pond bottoms to >30 days for drainage-limited and low elevation ponds (**Table 6**). In the tables, a value of "N/A" indicates that the pond never reached that benchmark. The distribution of the managed wetlands and their drainage times (days) to reach 1 foot below their target elevation was derived (**Figure 14**). Individual pond drainage timeseries, pond volume-elevation data, and a map showing pond and culvert location are given for each pond in **Appendix G**.

Table 6. Drain time (days) to 1-foot below target water levels.

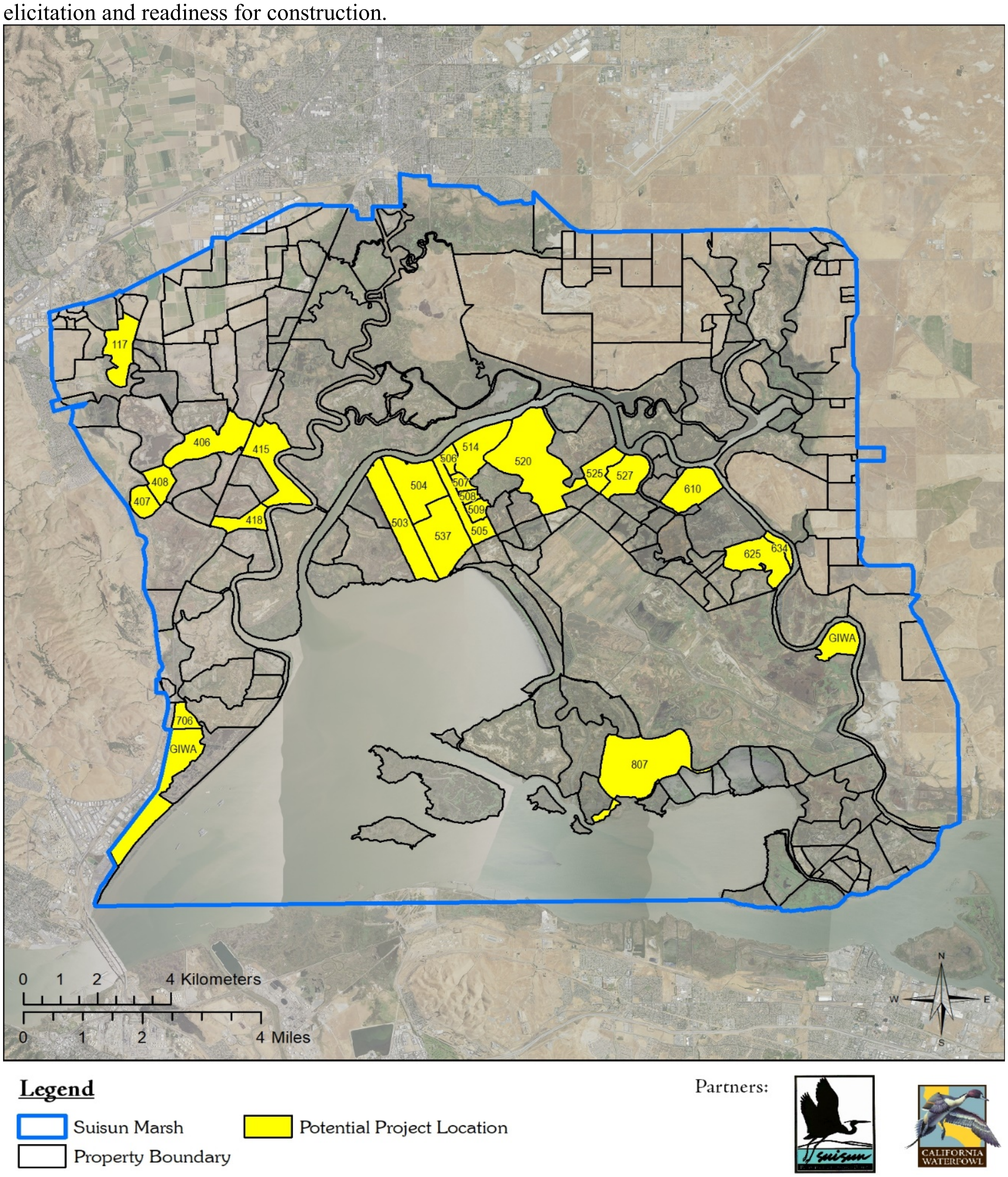
Time to Drain to 1 ft below shoot level (days)	Number of Clubs	Percent of Total Clubs
0 - 3	38	29.5
3 - 5	16	12.4
5 - 7	11	8.5
7 - 10	11	8.5
10 - 14	11	8.5
14 -21	12	9.3
21 - 30	6	4.7
> 30	24	18.6

Figure 14. Project site map of Suisun Marsh managed wetlands with results from hydrologic prioritization model (developed from a HEC-RAS circulation model) indicating the top 20 sites that would benefit most from water control structure improvements. The 20 sites include: #117 Mallard Inn, #406 Teal, #407 Ibis, #408 Franciscan Marshview, #415 Arnold Ranch, #418 Cygnus, #503 Montezuma, #504 Gum Tree Farms, #505 DuxRUS, #506 Four Winds, #507 Grizz/Fizz, #508 Little West Wind, #509 Garben Ranch, #514 Tree Slough Farms, #520 Grizzly Ranch, #525 Balboa Farms, #527 Delta King Ranch, #537 Westwind, #610 San Francisco, #625 Pintail Ranch, #634 Grizzly Hilton, #706 Mallard Haven, #807 Wheeler Island, CDFW Goodyear Slough Unit, CDFW Pond 3.



We used the model results and expert elicitation to identify the top 20 managed wetlands where flooding and draining cycles could be improved immediately with added drainage (**Figure 14, 15**). Most of the identified wetlands were located in Priority Area 1 where many of the land areas are at lower elevation and have difficulty draining quickly. Thus, the prioritization tool allowed us to suggest which improvement projects may be undertaken first to allow us to best improve the Marsh habitats.

Figure 15. Project site map of Suisun Marsh managed wetlands with results from hydrologic prioritization model (developed from a HEC-RAS circulation model) that indicate the top 20 sites that would benefit most from water control structure improvements. These 20 sites include: #117 Mallard Inn, #406 Teal, #407 Ibis, #408 Franciscan Marshview, #415 Arnold Ranch, #418 Cygnus, #503 Montezuma, #504 Gum Tree Farms, #505 DuxRUS, #506 Four Winds, #507 Grizz/Fizz, #508 Little West Wind, #509 Garben Ranch, #514 Tree Slough Farms, #520 Grizzly Ranch, #525 Balboa Farms, #527 Delta King Ranch, #537 Westwind, #610 San Francisco, #625 Pintail Ranch, #634 Grizzly Hilton, #706 Mallard Haven, #807 Wheeler Island, CDFW Goodyear Slough Unit, CDFW Pond 3. The final 10 sites for implementation will be determined by expert elicitation and readiness for construction.



Discussion

The primary goals of the Suisun Marsh Plan (2014) include the tidal restoration of 5,000-7,000 acres of existing managed wetlands to tidal flows and the concurrent enhancement of habitats on the nearly 50,000 acres of remaining managed wetlands. However, while a conceptual model for managed wetlands has been developed (Barthman-Thompson et al. 2005), a detailed plan for the projects to enhance existing wetlands has not been developed. Improving the managed wetland habitats depends on the ability of managers to flood and drain the wetlands to conduct leach cycles and reduce the soil salinity (see California DWR 2001a, b; Rollins 1973, 1981) or to work the lands to benefit the preferred plant communities or reduce the spread of invasive species. Our study allows us to address this need by assessing the water control structures in the managed wetlands and determine which areas may most benefit with improved flood-and-drain capacity.

This rapid assessment tool may be particularly helpful for manager seeking to maximize their costs by determining how water control structures may improve their management. For example, model results may indicate that it is more beneficial to install two smaller pipes for drainage rather than a single larger pipe or vice versa, and managers can simulate adding more drainages to see if it will greatly improve drainage rates. In contrast, this rapid assessment tool also will determine where investment in tidal drainage facilities would be a poor investment producing limited benefit in increasing drainage and wetland management capabilities.

There are several possible improvements that could benefit the modeling approach initiated here. First, the DEM of the marsh surface is not highly accurate, because it depends on LiDAR coverages that typically provide a map of the surface of vegetation rather than the bare earth with average errors in tidal marshes of 10-40 cm (Sadro et al. 2007, Foxgrover et al. 2011, Buffington et al. 2016). Managing water levels for wildlife requires more accurate elevation information, because many species respond to much smaller changes. For example, foraging waterfowl may be affected by a -6" (15 cm) change in water depths, and for small shorebirds such as western sandpipers that roost in the water, a change of an inch (2.5 cm) may greatly change the value of the habitat.

Our model calibrations were derived from a few sites where flooding and draining was recorded, but it may be beneficial to have detailed records on most if not all of the wetlands. Installation of water level loggers may provide a continuous record of flooding and draining that could help to fine-tune their water management. In the future, it may be possible to use sensors to determine the best time for flooding and draining, especially if there is an improved understanding of how and when soil salinities are limiting development of the habitats (author's unpublished proposal). Also, it may be possible to included real-time data from tidal cycles, allowing managers to better plan their flooding and draining cycles. This would include maximizing wetland circulation to improve water quality (SRCD and Tetra Tech, EPA unpubl. grant data) and potentially, increasing production of zooplankton as fish food (Kimmerer 2002, Slaughter et al., 2018).

We hope to apply results from a recent aerial LiDAR survey flown in the September 2018 (DWR, unpubl. data). Ground surveys (SRCD, DWR, and USGS; unpubl. data) were conducted in coordination with that aerial survey, and we plan to adjust for the height of the vegetation (Buffington et al. 2016). A more accurate DEM of the surface should improve estimates of the volume of water in flooded wetlands and provide more accurate estimates of drainage times. Also, it may be worthwhile to consider developing a 2-D version of the model to examine within wetland variation. However, this will require changing the base model which will require extensive programming.

Finally, the RAS model may be useful as the basis for examining climate change and to help managers prepare for adaptive management. For example, by including sea-level rise projections (Dettinger and Cayan 2005, Parker et al. 2011), the model results may be useful in predicting when gravity drains may become ineffective as the water levels increase in the adjacent slough. Future management options may include the need for more pumping capacity to drain the wetlands or for increased numbers of water control structures to keep pace.

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Appendices

The large supplemental files in the Appendices have been submitted digitally on Google Drive to the Sacramento-San Joaquin Delta Conservancy with the final report and may be requested from the Conservancy or SRCD**.**

Appendix A: Summary of managed wetland permission

Appendix B: Written permission forms

Appendix C: Water control structure and surface elevation dataset

Appendix D: Directions for the managed wetland excel calculator

Appendix E: Managed wetland drainage calculator (in Excel)

Appendix F: Animation from a sequence of modeling results

Appendix G: Individual managed wetland model results