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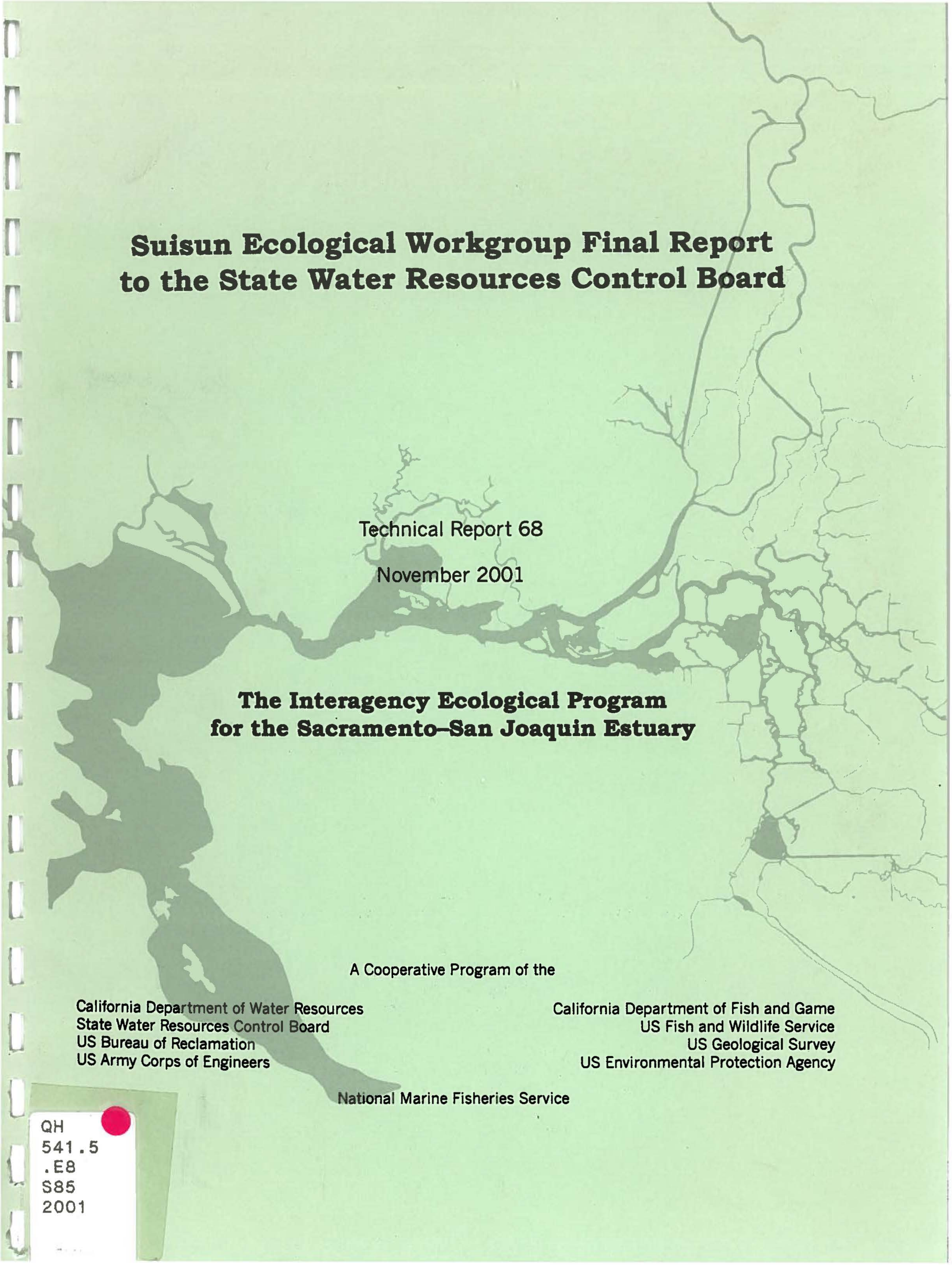

Suisun Ecological Workgroup Final Report to the State Water Resources Control Board

Technical Report 68

November 2001

The Interagency Ecological Program for the Sacramento–San Joaquin Estuary

A Cooperative Program of the

California Department of Water Resources
State Water Resources Control Board
US Bureau of Reclamation
US Army Corps of Engineers

California Department of Fish and Game
US Fish and Wildlife Service
US Geological Survey
US Environmental Protection Agency

National Marine Fisheries Service

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Suisun Ecological Workgroup
final report to the State
Water Resources Control
Board

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National Marine Fisheries Service

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Summary of Recommendations

Introduction

In the 1995 Bay-Delta Plan Water Quality Control Plan, the State Water Resources Control Board (SWRCB) directed the Department of Water Resources (DWR) to convene an interagency workgroup to evaluate the technical basis of the Suisun Marsh water quality objectives and their effects on beneficial uses. Consequently, the Suisun Ecological Workgroup (SEW) was formed in May 1995 to recommend channel water salinity objectives to protect the beneficial uses of the Suisun Marsh. SEW completed this task by forming technical subcommittees to examine the impact of various salinity regimes on the following ecosystem components of Suisun Marsh—brackish marsh vegetation, waterfowl, aquatic habitat, and wildlife. The SEW Final Report contains (1) each subcommittee's discussion of relevant scientific findings; (2) recommendations for salinity objectives, future monitoring, and special studies; and (3) a description of data analyses and model studies conducted by a hydrodynamics and water quality support team.

This summary of recommendations presents each subcommittee's final recommendations for salinity objectives and other measures they deemed protective of the beneficial uses of Suisun Marsh. A table summarizing subcommittee recommendations can be found at the end of this summary (Table S-1). Subcommittee recommendations are discussed in greater detail in chapters two through six.

Table 4-2 in Chapter 4 lists the 1995 Water Quality Control channel water salinity objectives for Suisun Marsh (SWRCB 1995). The Suisun Marsh Salinity Control Gates are operated only as needed between the months of September through May to help meet these objectives. The gates do not operate June through August.

Brackish Marsh Vegetation Subcommittee Recommendations

1. Salinity in Suisun Marsh should not be regulated independently of Delta outflows. Water quality issues in Suisun Marsh are inextricably connected to Delta hydrology (timing and volume of Delta outflows). The premise of regulating Suisun Marsh salinity independently of Delta outflows is ecologically flawed. Estuarine salinity has ecological interactions with the position of the entrapment zone, nutrient dynamics, and the trophic (food web) structure of the estuary that are not addressed by the gates. Selectively manipulating salinity independently of Delta outflows ("mitigating" diminished flows by gate operation) causes unnecessary conflicts among estuarine resources and diminishes otherwise coherent ecological benefits of meeting water quality standards.

2. SWRCB should revise the narrative standard for protection of biodiversity of brackish tidal wetlands.

3. The gates should generally not be operated in winter or springs. Winter and spring are critical periods of seed germination, seedling establishment and mortality, and early vegetative growth of tidal marsh plants. These lifehistory stages are highly responsive to salinity changes and should be allowed to respond to annual fluctuations in salinity, including extreme (non-catastrophic) events.

4. The gates may be operated in fall only in coordination with the onset of plant dormancy and senescence (dieback) in brackish tidal marsh plants, phases of the lifecycle which we presume are least

responsive to salinity changes. Monitoring of plants is essential to determining the calendar date of this threshold, which is expected to vary annually around mid-October.

5. The implementation dates for interior marsh compliance stations S-97 and S-35 should be delayed indefinitely. In addition, the objectives at other interior marsh compliance stations should not be enforced.

6. Water and salinity management in diked managed wetlands should be experimentally modified to study alternative effective methods of vegetation management which do not depend on artificially depressed salinity of applied channel water. The Brackish Marsh Vegetation Subcommittee strongly recommends specific study of microtidal ponds and lagoons (shallow "muted tidal" ponds) in northern San Pablo Bay which support submerged filamentous green algae and wigeongrass, with fringing brackish and salt marsh vegetation, and attract extremely abundant dabbling ducks and diving ducks, consistent with the objectives of many duck clubs in Suisun Marsh. These ponds are not expected to suffer progressive deterioration (e.g., subsidence, acid sulfide, and salt accumulation) and may require less intensive levee maintenance than traditionally managed diked wetlands in Suisun Marsh. More importantly, they do not depend on artificially depressed salinity in tidal sources. It is presumed that microtidal ponds could be designed to be more "fish-friendly" than flood-and-leach cycles of managed seasonal wetlands. They may serve as models for alternative marsh vegetation management for waterfowl in Suisun Marsh.

7. The western parts of the estuary should be examined for "duck food" plant success and duck habitat quality. The regional variation in soil salinity tolerance in duck food plant species should be investigated not only in Suisun Marsh, but in other parts of the estuary as well, to include the fullest range of natural soil salinity. The purpose of such investigation would be to determine whether alternative methods of vegetation management under more variable tidal salinity conditions may allow equal or better waterfowl abundance and diversity than is typically found in traditional or average modern Suisun Marsh conditions. Studies should include duck foraging based on invertebrates rather than plants.

8. A comprehensive monitoring and management plan should be implemented (see Recommendations from SEW to CALFED for inclusion in the Comprehensive Monitoring and Research Program (CMARP)).

Waterfowl Subcommittee Recommendations

It is the opinion of the Waterfowl Subcommittee that current salinity standards in Suisun Marsh are adequate for maintenance of existing habitat for the waterfowl resource. Although vegetation in the managed wetlands did show signs of salt stress during the recent 6-year drought, the habitat continued to attract and sustain waterfowl, and the vegetation in the managed wetlands has rebounded during the last few years of above-normal precipitation. If landowners can continue to upgrade their management capabilities, maintenance of waterfowl habitat does not seem to be critically impacted by the current channel water salinity, even in periods of drought. It would be advantageous for wetland managers if channel water salinity were lower in September and October so that initial flood-up could remove more soil salts that accumulate over the summer. It would also be beneficial to duckling survival if channel water salinity from March to July were lower. These changes, though not imperative, could provide benefits to waterfowl and their habitats in Suisun Marsh.

Aquatic Habitat Subcommittee Recommendations

1. The Aquatice Habitat subcommittee recommends a relaxation of the current salinity standard at interior marsh stations to 20 mS/cm in October and November of all water years. Gate operations would be triggered once salinity reaches 20 mS/cm.

   The subcommittee does not believe that current WQCP operations in the fall provide any particular benefit for native fish populations. In fact, there is information that suggests low salinities during the fall period may support the establishment of introduced fish species (Moyle and Herbold 1983, Moyle and Herbold 1986). Thus, the subcommittee favors an increase in variability and overall range of the salinity regime during this time of the year.

   This recommendation introduces an increase in variability of the salinity regime during certain months not considered critical to native fish spawning and rearing. (The recommendation increases the salinity standard by 1 mS/cm in October and 3.5 mS/cm in November.) Such an increase in range and potential variability could provide some advantage to native fish over introduced fish in the marsh (Moyle and Herbold 1983, Moyle and Herbold 1986). An adaptive management approach should be employed so that the action could be modified as needed, depending on impacts.

2. The subcommittee recommends maintaining the current salinity standards for December and January for all water year types.

3. The subcommittee recommends no operation of the gates in wet water years (as defined in SWRCB WR 98-9) from February through June.

   During wet water years, channel water salinities between February through June are optimal for spawning and rearing of larval fish. An analysis of salinity data collected during fish sampling at nine sloughs in the marsh during 6 wet years (1982, 1983, 1984, 1986, 1995, and 1996) indicated that salinity was below 8 mS/cm 100 percent of the time during February, March, and April sampling events, 99 percent of the time during May sampling events, and 92 percent of the time during June events. These low salinities were not the result of gate operations, as the gates were not constructed until 1988, and were not operated from February 1995 through November 1996 due to low salinities. Thus, gate operations are not necessary to support fish abundance in the Marsh from February through June.

4. The subcommittee recommends maintaining low salinities during all other water year types from February through June, using gate operations if necessary. The subcommittee offers two alternatives:

   a) *Current standards*:
   February-March—8 mS/cm
   April-May—11 mS/cm

   b) *Temperature dependent standards*:
   February-March—8 mS/cm
   April-June—8-11mS/cm (depending on channel water temperature)

   The first alternative (a), is based on the "optimal" salinity ranges for various native fish (See Chapter 4, Table 9). Maintaining low salinity during these months would ensure that channel water salinity is optimized for spawning and rearing of native fish, which is of critical importance to the protection of native fish populations. The second alternative (b) makes the standard dependent on temperature, since spawning is temperature dependent. This alternative extends the April-May standard into June so that these salinity levels are maintained later in the season when water temperature may be more conducive for spawning. As data become available, the impacts of this action should be evaluated and the action modified as needed.

The subcommittee strongly recommends that these salinity objectives be tested over a period of at least 10 years, and that fish surveys be conducted in the marsh to monitor the potential effects of these salinity objectives on the fish community. Further, it may be important to decrease the amount of time gates are operated in the spring occasionally and allow salinity to increase beyond the levels indicated above, for example in May or April. This would help prevent spring conditions from becoming too predictable, which could result in the migration of non-native freshwater predators.

Further Recommendations

The subcommittee recommends that SWRCB establish an IEP workgroup of biologists, statisticians, and hydrologists to continue analysis of the Suisun Marsh ecology. Key questions and suggestions for future research are listed below.

The subcommittee recommends that future research should:

- Address whether aquatic ecosystem functions in sloughs proximate to tidal wetlands are different than ecosystem functions in sloughs proximate to managed wetland or wastewater treatment plants.
- Study the potential acute and chronic toxic effects of drainage water from managed wetlands on marsh fishes, in particular special status species and those which reside in backwater sloughs, such as Delta smelt, splittail, chinook salmon, and tule perch. Develop a list of "best management practices" aimed at decreasing any such impacts.
- Investigate the relative quality of Suisun Marsh aquatic habitat compared to other shallow water habitat elsewhere in the estuary.
- Investigate whether abundances of particular fish species in the marsh increase when the species' observed salinity tolerance range coincides geographically with the entrances to the marsh.
- Investigate the role of salinities in fall for potential establishment of introduced fish and other aquatic species.
- Investigate whether fish spawning and rearing success in the marsh is measurably affected by salinity levels.
- Develop conceptual models of fish populations which use the marsh for part of their life cycle.
- Consider whether the current configuration and focus of the U.C. Davis sampling program are adequate to answer the questions listed above. If not, additions to the existing program should be made accordingly.

Wildlife Subcommittee Recommendations

General Channel Water Salinity Recommendations

1. Establish a flow-based salinity standard to reflect the basin-wide natural hydrograph of the marsh. These standards should reflect the spatial and temporal changes that would have occurred historically in the marsh as a result of Central Valley Basin hydrology and unimpaired flows, thus reflecting natural viability throughout the year. This would be similar to the current X2 flow requirements for Delta outflows which only exist from February through July, but would occur year round.

2. Existing interior marsh salinity standards should not be implemented as compliance standards at stations S-35 and S-97, but should be maintained with other existing stations as salinity monitoring stations. This action would allow salinities to exceed existing standards for the western marsh and would increase the existing salinity gradient in Suisun Marsh, especially during dry and drought periods.

3. Establish habitat and wildlife monitoring programs using salinity-sensitive species as biological indicators. Establish quantifiable criteria that will trigger the operation of the gates during prolonged drought periods. Operate the gates as needed during prolonged drought periods to prevent irreversible population declines of vulnerable wildlife species and loss of habitat diversity within the marsh.

4. Operate the gates in dry and critical water years and suspend gate operations after the date when most of the managed wetland habitats have been flooded for initial floodup in the fall. Investigate the potential for additional operation protocols that may minimize the effects to tidal habitats from freshening early in the fall. This action will minimize soil salinities in diked habitats and prevent the loss of managed wetland diversity, while allowing for variability above current standards.

5. Flood diked wetland areas managed for higher soil salinities and pickleweed habitat prior to the operation of the gates or after operations have ceased. This activity would assist in the effective management of harvest mouse habitat, even during periods of low salinity.

6. Improve infrastructure and water management on managed wetlands to protect habitat quality and diversity from increased channel water salinities caused by drought or changed salinity standards.

7. Develop new water management strategies and opportunities on managed wetlands to compensate for increased salinities, if salinity standards are increased or gate operation is limited.

8. Improve infrastructure and water management on managed wetlands to ensure long-term protection of wildlife habitat quality and diversity.

Alternative Recommendation from Frank Wernette, CDFG

Internal Suisun Marsh Channel Water Salinity Standards

Internal Suisun Marsh channel water salinity standards would be those described in the 1995 Water Quality Control Plan and contained in WR 95-6 and 98-9, with the exception that S-35 and S-97 would be eliminated as compliance stations; the trigger for defining a deficiency period at stations S-21 and S-42 would be changed to the Sacramento Valley Water Year Hydrologic Classification system index, and the previous month's Eight River Index would be used to define the channel salinity criteria that applies on a sliding scale basis between the normal standard to deficiency standard for S-21 and S-42.

Suisun Marsh Salinity Control Gate Operation Strategy

Suisun Marsh Salinity Control Gate operation will be allowed between September and the end of May, whenever needed to sustain the internal Suisun Marsh channel water salinity criteria described above.

Table S-1 Summary of Subcommittee Recommendations. **(See subcommittee reports for detailed discussion.)**

Subcommittee	Maintain SM Salinity Standards as written in 1995 WQCP?	Establish new flow based salinity standards?	Enforce a set of Interior Marsh Standards?	SMSCG Operations in Fall?	SMSCG Operations in Winter?	SMSCG Operations in Spring?	Revise the Narrative Standard?	Change S97 and S35 from Compliance to Monitoring Stations?
Brackish Marsh Vegetation	No	Regulate SM salinity in connection to Delta outflows.	No	Yes, if coordinated with onset of plant dormancy and senescence.	No. SMSCG should generally not be operated in winter	No. SMSCG should generally not be operated in spring.	Yes	Yes
Waterfowl	Yes	———	Yes	Yes. Would prefer lower standard.	———	Yes. Would prefer lower standard.	———	———
Aquatic Habitat	No	———	Yes	Gate operations not triggered until salinity reaches 20 mS/cm^2.	Current standard	No gate operations Feb-Jun of wet years. 8 11 mS/cm^2 during all other water types.	———	———
Wildlife	No	Yes	Yes	Operate SMSCG in dry and critical years; suspend gate operations after managed wetlands have been flooded in the fall. Establish criteria that trigger SMSCG operations during prolonged			———	Yes
Alternative Rec. from DFG	Yes, with some modifications	———	Yes.	Yes. SMSCG operations allowed between September through May when needed to meet channel water salinity standards.			———	Yes.

Notes: "SM" refers to Suisun Marsh. Dashed lines indicate that the subcommittee did not comment on the particular issue.

Chapter 1: Introduction

The Suisun Ecological Workgroup (SEW) completed its Final Report in response to the directives in the State Water Resources Control Board (SWRCB) 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (1995 Bay-Delta Plan). The SEW Final Report includes recommendations for water quality objectives (narrative and numerical) to improve conditions for the beneficial uses (wildlife habitat, rare, threatened and endangered species, estuarine habitat, etc.) in Suisun Marsh. In addition, the workgroup prepared a set of recommendations for future research and monitoring in Suisun Marsh.

SEW focused primarily on the impact of channel water salinity on the beneficial uses based on SWRCB's request for recommendations. Consideration of certain topics, such as changes to the landscape or land use, toxins in the soil or water, or water quality parameters other than salinity, were beyond the scope of SWRCB directives and beyond what the group could accomplish within the time frame allotted.

Background

Suisun Marsh Standards

Salinity standards for Suisun Marsh, adopted by SWRCB in 1978 in Decision 1485, were based principally on the Department of Fish and Game's (DFG) recommendations. In Water Rights Order 7 of D-1485, SWRCB deferred the compliance dates for the salinity standards in the western Suisun Marsh and required the Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR) to develop and fully implement a plan to meet the standards.

DFG's recommendations to SWRCB were based primarily on ecological studies conducted by Mall (1969) and Rollins (1973). These two studies examined: (1) the relative value of marsh plants as duck food; (2) the influence of soil salinity and other factors on distribution and growth of marsh plants; and (3) the relationships between channel water salinity and soil salinity.

Results from the study by Mall (1969) identified alkali bulrush, brass buttons, fat hen, and cultivated barley as the foods eaten most frequently by wintering waterfowl. However, DFG recently noted that the methods used in this study, while state of the art at the time, may not accurately reflect which foods are most frequently consumed by waterfowl. For example, the study likely underestimates waterfowl consumption of invertebrates. The study by Rollins (1973) revealed that the most significant soil and water factors influencing plant distribution and competitive ability are length of soil submergence, soil salinity, depth of flooding, soil moisture, salinity of applied water, and soil organic matter. DFG concluded from these studies that improved management practices, improved drainage, water control facilities, and adequate water quality were needed to achieve desired soil salinity conditions for waterfowl food plants.

DWR and USBR developed and began implementing the Plan of Protection (1984) in accordance with D-1485. However, in 1994, wildlife and fishery agencies and urban water users expressed concerns about the appropriateness of western Suisun Marsh channel water salinity standards. There was also concern that the physical solutions necessary to meet the standards in Cordelia and Goodyear sloughs would adversely impact habitat and sensitive species in the western Suisun Marsh.

Formation of Suisun Ecological Workgroup

SWRCB's 1995 Bay-Delta Plan modified the Suisun Marsh salinity objectives (Table 1-1). In the Plan's Program of Implementation, the agency called for the convening of an ecological work group to reassess the water quality objectives in Suisun Marsh, as well as a number of other items. SWRCB recommended that DWR convene SEW to accomplish the following tasks:

> "The work group will: (1) evaluate the beneficial uses and water quality objectives for the Suisun Bay and Suisun Marsh ecosystem; (2) assess the effects on Suisun Bay and Suisun Marsh of the water quality objectives in this plan and the federal Endangered Species Act biological opinions; (3) identify specific measures to implement the narrative objectives for tidal brackish marshes of Suisun Bay and make recommendations to the SWRCB regarding achievement of the objective and development of numeric objectives to replace it; (4) identify and analyze specific public interest values and water quality needs to preserve and protect the Suisun Bay/Suisun Marsh ecosystem; (5) identify studies to be conducted that will help determine the types of actions necessary to protect the Suisun Bay area, including Suisun Marsh; (6) perform studies to evaluate the effect of deep water channel dredging on Suisun Marsh channel water salinity; (7) perform studies to evaluate the impacts of urbanization in the Suisun Marsh on the marsh ecosystem; and (8) develop a sliding scale between the normal and deficiency objectives for the western Suisun Marsh" (1995 Bay-Delta Plan).

Table 1-1 1995 Water Quality Control Plan Objectives and Suisun Marsh Preservation Agreement Channel Water Salinity Standards for Suisun Marsh

	1995 Water Quality Control Plan Objectives		*Suisun Marsh Preservation Agreement*		
	Location in Marsh		*Marshwide*		
	Values are Specific Conductance in mmhos		*Values are Specific Conductance in mmhos*		
Month	Eastern	Western Normal	Western Deficiency	Normal Standards	Deficiency Standards
October	19.0	19.0	19.0	19.0	19.0
November	15.5	16.5	16.5	16.5	16.5
December	15.5	15.5	15.6	15.5	15.6
January	12.5	12.5	15.6	12.5	15.6
February	8.0	8.0	15.6	8.0	15.6
March	8.0	8.0	15.6	8.0	15.6
April	11.0	11.0	14.0	11.0	14.0
May	11.0	11.0	12.5	11.0	12.5

The SEW Process

DWR invited the interested parties on SWRCB's Bay-Delta mailing list to participate in SEW. The workgroup, beginning in May 1995, was composed of representatives from DWR, DFG, USBR, U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), U.S. Environmental Protection Agency (EPA), California Native Plant Society, Suisun Resource Conservation District, San Francisco Estuary Institute, Metropolitan Water District of Southern California, Ducks Unlimited, and The Bay Institute. Staff from SWRCB, SRCD, DWR, DFG, USBR, and USFWS became the active-working participants. The workgroup's first steps were to review the history of land use, DFG's recommendations to SWRCB for Suisun Marsh salinity standards, and identify the beneficial uses.

Of the list of tasks requested by SWRCB, SEW identified and prioritized the primary goals and created a list of tasks and a timeline for completion for the work.

SEW formed five technical subcommittees: (1) Brackish Marsh Vegetation; (2) Waterfowl; (3) Wildlife; (4) Aquatic Habitat; and (5) Hydrology and Water Quality. The Hydrology and Water Quality Subcommittee provided technical and modeling support for the other subcommittees. The subcommittees met individually beginning in mid-October 1995, and the subcommittee chairs reported on their committees' progress at the SEW meetings.

In December 1995, each subcommittee submitted a draft work plan and timeline subject to review by all SEW participants. After this review period, revised subcommittee work plans were finalized and adopted in February 1996 and the technical subcommittees began their resource-specific analyses. It was initially envisioned that, after completing their tasks, the subcommittees would merge and the workgroup as a whole would address the issues associated with the water quality objectives for Suisun Marsh.

Each subcommittee grappled with difficult issues such as focusing the scope of their topic, choosing representative species to examine, identifying necessary assumptions, and searching for relevant literature on salinity tolerance levels of various species. The subcommittees documented their assumptions and decisions as they progressed.

The subcommittees' members undertook their tasks differently depending on their expertise and interests and the available technical information. The Brackish Marsh Vegetation Subcommittee investigated the scientific literature on brackish marsh ecology and historical conditions in the marsh, and conducted a limited field investigation. The Waterfowl Subcommittee examined literature on historical salinity conditions in Suisun Marsh and effects of salinity on waterfowl, and analyzed monitoring data from Suisun Marsh. The Aquatic Habitat Subcommittee initially examined the literature on salinity tolerance of key species in Suisun Marsh and then analyzed data on channel water salinity and fish abundance from the UC Davis Suisun Marsh Fish Sampling Program. The Wildlife Subcommittee was somewhat overwhelmed by the scope of their task and the paucity of pertinent data. They concluded that effects on wildlife would occur from changes in both the terrestrial and aquatic ecosystems.

SEW's first product was a summary of each subcommittee's tasks, the research and literature available, and their conclusions on how salinity was important to their beneficial use(s). Their reports were compiled in the SEW Interim Report (1997) submitted to SWRCB in September 1997.

SEW's next step was to recommend salinity objectives based on scientific literature, subcommittee expertise, and the input of peer reviewers. Peer review input was sought by some of the subcommittees on the

Interim Report and prior to the release of the Final SEW Report. Peer reviewers of the Final Report are listed at the beginning of the report.

In May 1998, SEW held a workshop in which the subcommittees presented conceptual models detailing the ecological relationships between the physical, chemical, and biological factors affecting the health of the resource being examined. The purpose was to determine pathways (e.g., salinity level, habitat availability, etc.) critical to the health of each resource. The subcommittees also presented their preferred recommendation regarding salinity standards, Suisun Marsh Salinity Control Gates operations, and management actions in Suisun Marsh. It became clear during the workshop that the subcommittees had disparate recommendations.

SEW's goal was to make a single recommendation or set of recommendations to SWRCB by July 1998, but the diversity of the beneficial uses required a different approach. Recommendations for salinity objectives differed greatly between the subcommittees due to different environmental requirements of the beneficial uses in the Suisun Marsh ecosystem. Therefore, SEW did not develop a single workgroup recommendation. Instead, each subcommittee prepared its own set of recommendations. It should be noted that these recommendations reflect the professional opinions of the subcommittee members, and not necessarily those of their agency or organization.

In addition to the subcommittee recommendations, each group discussed areas of agreement and disagreement with the other subcommittees' recommendations. This was the most thorough way to document the full range of issues discussed at the SEW meetings and to document common ground. The subcommittee discussions included, but were not limited to, issues such as critical periods during the year, triggers for management actions, critiques of current objectives, and the narrative objective, etc. Short- and long-term recommendations were made.

As part of the SEW effort, the subcommittees compiled a list of comprehensive monitoring and research needs for Suisun Marsh to help answer technical questions that could not be addressed with the available information. The list was submitted to the CALFED Comprehensive Monitoring Assessment and Research Program and is included in this report.

SEW's Final Report is a compilation of nearly 4 years of technical research and discussions. The report reflects the different ecological perspectives, goals, and views regarding ecosystem protection of the technical experts who comprised the workgroup.

SEW as Interagency Ecological Program Project Work Team

In 1996, SEW became a Project Work Team under the Interagency Ecological Program (IEP). The purpose was to encourage other technical experts working on related topics in the estuary to provide input to SEW and to facilitate meaningful interagency review of SEW's work. Updates on SEW's progress were published quarterly in the IEP Newsletter and peer review of the technical work products became an integral part of the SEW documentation process. In addition, an e-mail reflector was set up to notify interested parties of SEW business between meeting dates.

In January 1996, SEW established a Web site to post meeting summaries, work plans, and products through the IEP Home Page. This Final Report will also be posted on the web page at http://iep.water.ca.gov/suisun_eco_workgroup/.

Contents of the SEW Final Report

Of the eight tasks itemized by SWRCB, SEW addressed tasks one through five. SEW was not able to undertake tasks six through eight. These tasks were either too broad in scope, beyond the expertise of the workgroup, or would require considerably longer than the time allotted.

The Final Report includes the following:

- **Summary of Recommendations.** A compilation of the subcommittees' recommendations
- **List of Preparers by Subcommittees and Peer Reviewers.**
- **Introduction**
- **Subcommittee chapters that include:**

Subcommittee Recommendations. This section includes recommendations for water quality objectives for long and short-term protection of managed and tidal marshes, aquatic habitat and wildlife, and listed species. It identifies sensitive time periods, and biological triggers for salinity objectives.

Areas of Agreement and Disagreement. This section is an attempt to document all the issues raised in SEW meetings and workshops by the subcommittees about the recommendations.

Recommendations for Additional Research and Monitoring. SEW submitted this material to the CALFED Comprehensive Monitoring and Research Program. It is a summary of the research needs and monitoring necessary to answer the technical questions that arose as the subcommittees progressed.

References. This section follows at the end of each chapter and includes scientific and other literature used by SEW members to develop and support their recommendations. Hard copies will be provided to SWRCB by the subcommittees.

For additional copies of the SEW Final Report or questions about SEW, please contact Heidi Rooks at (916) 227-2557 (e-mail: hrooks@water.ca.gov) or Nick Wilcox at (916) 657-0446 (e-mail: nwilcox@waterrights.swrcb.ca.gov).

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Chapter 2: Brackish Marsh Vegetation Subcommittee

Introduction

The State Water Resources Control Board in the 1995 Bay-Delta Plan recommended that the Department of Water Resources (DWR) convene the Suisun Ecological Workgroup to accomplish specific tasks. SEW, as a technical workgroup, was directed to, in part, identify the specific measures to implement the Suisun Marsh narrative objective, evaluate the water quality objectives for the Suisun Marsh, and identify and analyze specific public interest values and water quality needs to preserve and protect the Suisun Marsh ecosystem. SEW divided itself into five subcommittees, each focusing on a specific resource area within Suisun Marsh. The Brackish Marsh Vegetation Subcommittee (BMV) set as its goal an evaluation of salinity standards necessary to protect and maintain the undiked tidal wetland plant communities of Suisun Marsh.

SEW was established as a technical advisory committee, with members from both public and private sectors. The role of individual members was to present recommendations based on their technical expertise for the benefit of the resources addressed by their subcommittees. Recommendations presented here represent the professional judgement of individual subcommittee members and do not necessarily represent the views of the subcommittee members' respective agencies.

Summary of Recommendations

1. Salinity in Suisun Marsh should not be regulated independently of Delta outflows. Water quality issues in Suisun Marsh are inextricably connected to Delta hydrology (timing and volume of Delta outflows). The premise of regulating Suisun Marsh salinity independently of Delta outflows is ecologically flawed. Estuarine salinity has ecological interactions with the position of the entrapment zone, nutrient dynamics, and the trophic (food web) structure of the estuary that are not addressed by the Suisun Marsh Salinity Control Gates. Selectively manipulating salinity independently of Delta outflows ("mitigating" diminished flows by gate operation) causes unnecessary conflicts among estuarine resources and diminishes otherwise coherent ecological benefits of meeting water quality standards.

2. SWRCB should revise the narrative standard for protection of biodiversity of brackish tidal wetlands (see Conclusions section for proposed revisions).

3. The gates should generally not be operated in winter or spring. Winter and spring are critical periods of seed germination, seedling establishment and mortality, and early vegetative growth of tidal marsh plants. These life history stages are highly responsive to salinity changes and should be allowed to respond to annual fluctuations in salinity, including extreme (non-catastrophic) events.

4. The gates should be operated in fall only in coordination with the onset of plant dormancy and senescence (dieback) in brackish tidal marsh plants, phases of the life cycle which are presumed least responsive to salinity changes. Monitoring of plants is essential to determining the calendar date of this threshold, which is expected to vary annually around mid-October.

5. The implementation dates for interior marsh compliance stations S-97 and S-35 should be delayed indefinitely. In addition, the objectives at other interior marsh compliance stations should not be enforced.

6. Water management of salinity in diked managed wetlands should be experimentally modified to study alternative effective methods of vegetation management which do not depend on artificially depressed salinity of applied channel water. The subcommittee strongly recommends specific study of microtidal ponds and lagoons (shallow "muted tidal" ponds) in northern San Pablo Bay that support submerged filamentous green algae and widgeongrass with fringing brackish and salt marsh vegetation; these ponds attract extremely abundant dabbling ducks and diving ducks, consistent with the objectives of many duck clubs in Suisun Marsh. These ponds are not expected to suffer progressive deterioration (e.g., subsidence, acid sulfide, and salt accumulation) and may require less intensive levee maintenance than traditionally managed diked wetlands in Suisun Marsh. More importantly, they do not depend on artificially depressed salinity in tidal sources. It is presumed that microtidal ponds could be designed to be more "fish-friendly" than flood-and-leach cycles of managed seasonal wetlands. They may serve as models for alternative marsh vegetation management for waterfowl in Suisun Marsh.

7. The western parts of the estuary should be examined for "duck food" plant success and duck habitat quality. The regional variation in soil salinity tolerance in duck food plant species should be investigated not only in Suisun Marsh, but in other parts of the estuary as well, so as to include the fullest range of natural soil salinity. The purpose of such investigation would be to determine whether alternative methods of vegetation management under more variable tidal salinity conditions may allow equal or better waterfowl abundance and diversity than is typically found in traditional or average modern Suisun Marsh conditions. Studies should include duck foraging based on invertebrates rather than plants.

8. A comprehensive monitoring and management plan should be implemented (see Recommendations from SEW to CALFED for inclusion in the Comprehensive Monitoring and Research Program (CMARP)).

Factors Considered by the Brackish Marsh Vegetation Subcommittee

The scope of the subcommittee's recommendations is focused primarily on tidal brackish marshes, but also considers vegetation in diked marshes, because recommendations of other subcommittees (Waterfowl and Wildlife) depend in part on assumptions about vegetation and soil conditions.

The subcommittee based its recommendations on the following sources of information and theory:

- Local field observations in tidal marshes of Suisun Marsh throughout precipitation cycle (drought and wet years);
- Field observations of other brackish marsh systems in the estuary with minimal water diversions compared with the Delta (e.g., Napa, Petaluma marshes) and elsewhere on the central coast. Comparison of geographic variation in brackish marsh vegetation was used to corroborate local observations;
- Paleoecological data from studies of Suisun Marsh and San Pablo Bay marshes, representing changes over thousands of years. These studies indicate climate cycles causing long-term shifts between fresher and brackish-saline conditions.

- Recent scientific literature in tidal marsh plant ecology worldwide, especially research on dynamic marsh processes that enable relatively weak competitors to persist in fluctuating conditions;
- Scientific literature on the ecophysiology of salt tolerance in tidal marsh plants and seasonal variations in salt sensitivity at different life-history stages;
- Complex biotic interactions (parasitism, competition, facilitation) indirectly affected by physical factors such as salinity, considered qualitatively;
- Qualitative observations of exotic invasive brackish marsh vegetation during dry and wet phases of the precipitation cycle; and
- Foreseeable implementation of Bay-Delta outflows based on X2 standards, acknowledging the uncertainty of the ecological effects associated with X2. The use of X2 as a management tool should be continuously reviewed.

Baseline Hydrologic Considerations. The current and foreseeable circumstances of State and federal water management are relevant to recommendations about salinity standards in Suisun Marsh. When the original salinity standards were made, regulators presumed that progressive increases in water diversions would cause progressive increases in water salinity in the Suisun Marsh region. The Bay-Delta Accord alters this premise; outflows based on X2 standards constitute the foreseeable baseline condition indirectly controlling maximum marsh salinity and variability. This alone is sufficient to warrant re-examination of the salinity standards.

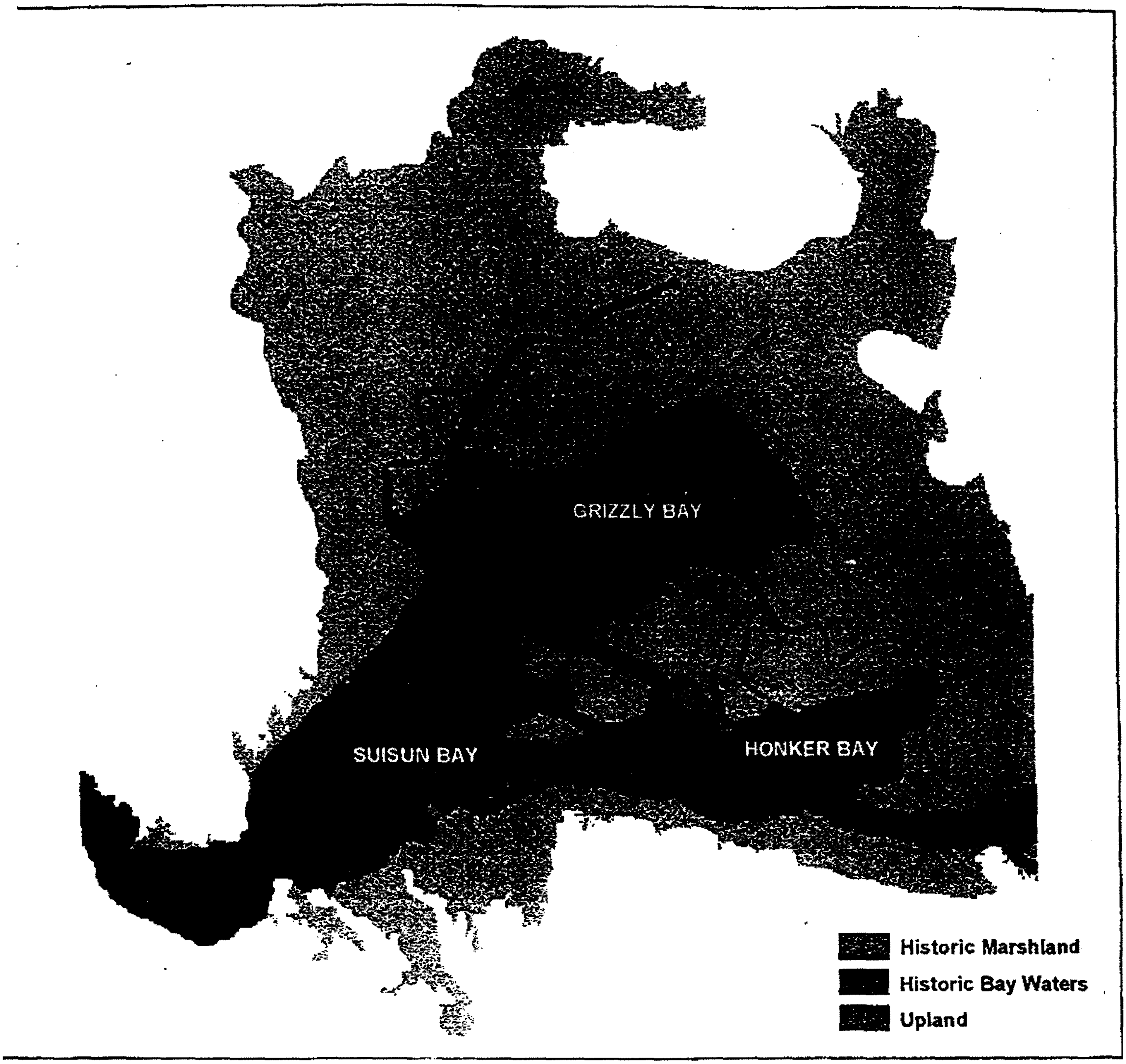
Ecological Baseline Considerations. The historic and modern Suisun Marsh tidal brackish marsh evolved during the last 6,000 years under conditions of higher base flows from the Delta, greater natural Delta marsh water storage and evapotranspiration, and much greater tidal prism in both the Delta and Suisun Marsh. Suisun Marsh also evolved over a period of significant climate fluctuation, including periods significantly drier (more saline) and wetter (less saline) than are currently considered "normal" based on recent history. The complex salinity conditions associated with post-reclamation (levee) reduction of tidal prism, dams and diversions, and this century's relatively wet conditions are not an adequate ecological baseline for this subcommittee's purposes.

Background

Historical Patterns of Suisun Tidal Wetlands—Chronology of Change

The history of Suisun tidal wetlands is one of change—change in the natural habitat as it evolved, coupled with an accelerated progression of anthropogenic changes over the past 200 years. Seawater intrusion through the Golden Gate began to fill San Francisco Bay some 10,000 years ago as the glaciers melted at the end of the last ice age (SFEP 1990). Some 550,000 acres of tidal wetlands evolved over approximately 6,000 years into the landscape in dynamic balance between sedimentation and sea level variability (Wells 1995). The historic distribution of tidal wetlands is shown in Figure 2-1.

Studies of the quaternary history of Suisun Marsh and the San Francisco Estuary indicate that these wetlands have been subject to a cycle of environmental variability over a broad range of frequencies including millennial-and centennial-scale, climatically-driven changes in mean fresh water flux and decadal and interannual cycles of flood and drought (Wells 1995). A long historical record of variability is recorded in the sediments of Suisun. Historical variability in river discharge, sedimentation rates, and estuarine salinity was much higher than it is today. In wet years such as the great flood years of 1861-1862, the tidal range at



Source: Nichols and Wright Historic Shoreline Map taken from GRASSLinks Map Display at http://www.regis.berkeley.edu

Figure 2-1 Historic Distribution of Tidal Wetlands in the Suisun Marsh

Golden Gate dropped to zero and fresh water was detected as far offshore as the Farallon Islands (Dana 1939). In drought years such as the early 1840s, tidal influence was measured as far upstream as the Sacramento-Feather River confluence, and brackish water conditions existed throughout the Sacramento-San Joaquin Delta, precluding agricultural irrigation and human consumption of Delta water as beneficial uses during these times (Thompson 1957, Wells 1995). Suisun Marsh plant communities evolved with these dynamic conditions and records of plant remains in the sediment profile substantiate these human records of environmental conditions (Wells and Goman 1995, Byrne 1997). Today, the natural variability of these systems is highly muted and modified due to the extensive development and control of water resources throughout the State.

Transformation of the landscape began in the 1700s as the Spanish and native American estuary inhabitants introduced both non-native plants and fire to the system as agents of vegetation change. Early explorers reported that fire was used by native peoples in every habitat type (including wetlands) around the estuary. The most dramatic influence of man on the estuary began in the mid to late 1800s as hydraulic mining discharged tremendous sediment loads into the estuary, which provided additional substrate for tidal marsh development. However, at this same time diking and "reclamation" of lands intensified for agricultural purposes. By the mid 1880s, nearly all of the Delta islands had been leveed and many people became wealthy as crop production was successful (Thompson and Dutra 1983). In the late 1870s and 1880s, the reclamation effort extended into Suisun as Grizzly Island was leveed. Agricultural production in Suisun actually started when market for vegetation native to Suisun was discovered. Saltgrass (*Distichlis spicata*) was baled, loaded on three masted schooners, and shipped out as hay for cattle, and "three corner tules" (*Scirpus americanus*) were also baled and loaded on schooners for delivery upstream where the Gladdin McBean Pottery Works in Lincoln used it as packing material for pottery (Frost 1970s, Arnold 1996). The pottery works also purchased salt grass hay from the Vennick family on Grizzly Island. Diking of historic tidal marsh in Suisun Marsh proceeded over time from the late 1870s through the 1970s, though nearly 90 percent of Suisun Marsh was diked by the 1930s. The last tidal marshes to be converted were leveed in the 1960s and 1970s. Since 1850, tidal wetlands have been reduced throughout the entire estuary to only 5 to 10 percent of their historic acreage (Atwater and Belknap 1979).

The vegetation of tidal marsh communities throughout Suisun Marsh prior to this landscape change was recorded by early botanists. For example, Willis Lynn Jepson (1867-1946) was a professor of botany at the University of California, Berkeley, born and raised near Vacaville, who lived most of his life in Solano County. Jepson was the first to describe many species endemic to the estuary; he wrote the first taxonomy of the California flora and explored Suisun tidal marshes before they were leveed (Jepson 1925). Herbert Mason, another professor of botany at U.C. Berkeley, wrote the first early flora specific to the marshes of California (Mason 1957). Mason conducted extensive surveys of plant communities in Suisun and throughout the estuary. Mason (1972) and George and others (1963) reported that prior to attempted reclamation of Suisun marshes for agriculture, there were extensive tidal marshes where water stood on the land and tall tules as seen today lined the margins near deep water. This vegetation was also observed and recorded by De Anza when he first explored Suisun by water in 1776. Mason (1972) and George and others (1963) also noted that the high marsh plains on Grizzly Island were covered with saltgrass (*Distichlis spicata*) which was also associated with other salt tolerant herbaceous plants such as pickleweed (*Salicornia virginica*) in poorly drained places. Saltgrass and pickleweed are still co-dominant in the high marsh plains of relict undiked tidal marshes in Suisun Marsh. The focus on waterfowl management in the diked lands of Suisun Marsh deemed this native vegetation of Suisun "undesirable" for waterfowl, and attempts to manage these lands for production of wetland plants which were never historically dominant in Suisun marshes (including several non-native species) continue to this day (Rollins 1981). For well over 5,000 years, wintering waterfowl of the Pacific Flyway visited a very different Suisun Marsh than today. The wetlands of the Suisun basin were entirely undiked marshes with the vegetation patterns described above. Modern management of seasonal wetlands has been plagued with problems promulgated by management, including subsidence and acidification and salinization of soils. It is the opinion of this subcommittee that an ecosystem approach to long-term sustainable management of all lands in Suisun Marsh should take into account the species assemblages that these marshes supported historically and, to the extent feasible, should emulate the natural processes that shaped this dynamic ecosystem over the past several millennia.

Man's desire to change the historic habitat in Suisun Marsh has a long record. Arnold (1996) reports that agricultural development of the Suisun marshes brought prosperity to some, but the success was not long lasting. A series of drought years returned to Suisun Marsh, and saline intrusion (prior to State and federal water project development) had largely shut down the short lived industry by 1930 when the remaining diked lands had converted to waterfowl hunting clubs (Arnold 1996). The waterfowl hunting community in Suisun saw the failure of agriculture due to land subsidence and soil salinization as a positive step towards providing more lands for wintering waterfowl (Arnold 1996). As the federal water project started to develop in the 1930s, further upstream withdrawals of water exacerbated the salinity intrusion problem in Suisun. Salinity intrusion in dry years intensified as Delta withdrawals began with the completion of the State Water Project in the 1960s.

The extensive diking of lands in Suisun Marsh has not been without profound consequences for the region's indigenous tidal wetland system. These human activities have not only resulted in the severe loss and fragmentation of marsh habitat, they have also changed the tidal prism and altered hydrologic regimes in the historic marshes. Of equal impact has been the loss of natural variability which once defined this unique natural resource. This loss of variability has occurred at multiple scales, from regional muting and loss of watershed flows to local site-specific activities, such as levee-building and mosquito abatement activities. Consequently, the historic processes which once nourished and sustained the Suisun's rich marshlands have been disrupted and the opportunities for recovery of these systems are now limited due to the relatively small amount of scattered tidal marsh remnants.

Contemporary Patterns of Suisun Marsh Tidal Wetlands

Tidal brackish marshes occur where the tidal salt water of the bay has been diluted by freshwater runoff. A delicate and highly fluctuating interaction exists between saline and freshwater conditions on a seasonal, diurnal, and interannual cycle. This produces a mix of species typical of fresh and saline areas that varies locally due to soil salinity, moisture, organic content, inundation, evaporation, plant competition, and historic conditions (Fiedler and Zebell 1995, Malamud-Roam and others 1995, Atwater 1979, Mason 1972). Biodiversity is high within the brackish reaches of the San Francisco Estuary as a result of the convergence of freshwater and salt tolerant species. Suisun Marsh includes the largest area of brackish tidal marsh within this estuary, although extensive brackish tidal zones are present along the Napa and Petaluma Rivers of the North Bay, and Alviso Creek of the South Bay (Meiorin and others 1991).

Brackish tidal wetlands are characterized by three major transition zones—low marsh, middle marsh, and high marsh. Upland from high marsh are flat, unvegetated salt pannes and ecotonal transitions to upland (Mason 1972, Josselyn 1983). Extensive diking of historic tidal marsh has greatly impacted the high marsh and ecotonal transitions by creating sharp boundaries between tidal marshes and uplands (Fiedler and Zebell 1995, Josselyn 1983). The consequence has been an overall decline in species diversity because the greatest floristic diversity in the brackish tidal wetlands occurs in the halophytic high marsh zone and adjacent transition lands.

The high marsh can be defined as the area from approximately mean higher high water (MHHW) to extreme high water (EHW) (at or above MHHW, Josselyn 1983). Pickleweed (*Salicornia virginica*) and saltgrass (*Distichlis spicata*) dominate a varied group of halophytes. Also common locally are the native fathen (*Atriplex triangularis*), saltmarsh dodder (*Cuscuta salina var. major*), fleshy jaumea (*Jaumea carnosa*), seaside arrowgrass (*Triglochin maritima*), and alkali heath (*Frankenia salina*); and the introduced brass buttons (*Cotula coronopifolia*) and rabbitsfoot grass (*Polypogon monspeliensis*). Plants in this zone must tolerate high salinity, as salt is deposited during intermittent inundation and accumulates during long periods of soil water evaporation. Species diversity is higher here than in the lower two vegetation zones.

Middle marsh is defined as the region from approximately mean high water (MHW) to MHHW (MTL to MHHW, Josselyn 1983). Codominants are pickleweed (*Salicornia virginica*), American bulrush (*Scirpus americanus* formerly described as *S. olneyi*), and saltgrass (*Distichlis spicata*). Middle marsh plant associates include fleshy jaumea (*Jaumea carnosa*), sea milkwort (*Glaux maritima*), baltic rush (*Juncus balticus*) and Mexican rush (*Juncus mexicanus*), alkali bulrush (*Scirpus maritimus*), and narrow leaf cattail (*Typha angustifolia*). Also found in this zone are sneezeweed (*Helenium bigelovii*) and marsh gumplant (*Grindelia stricta spp. angustifolia*). Plants in this zone receive inundating tides at least once per 24-hour period and are not subject to the extremes in soil salinity found in the high marsh. Pickleweed often reaches its most robust form in this zone.

Management of seasonal wetlands for alkali bulrush (*Scirpus maritimus*) production has been an objective of many Suisun Marsh waterfowl habitat managers. Alkali bulrush is not dominant in the historic tidal wetlands of the eastern Suisun Marsh region. This species becomes subdominant to codominant in middle marsh zones near the southwestern reach of Suisun Marsh, and is also prevalent in middle marsh zones of Napa Marsh, areas of the South Bay, and in coastal salt marshes. Seasonally wet depressions within Suisun tidal marshes which collect water on poorly drained sites and retain water through the spring and into the summer months historically supported the densest stands of alkali bulrush encountered anywhere in California (Mason 1972). Examples of this historic habitat for alkali bulrush exist in the Peytonia Slough Ecological Reserve, Rush Ranch, Roe Island, and Hill Slough tidal marshes of Suisun Marsh. Pickleweed and marsh smartweeds (*Polygonum lapathifolium* and *P. persicaria*) are associated with alkali bulrush in these depressions (Fiedler and Zebell 1995).

The low marsh occurs from approximately the mean lower high water (MLHW) to MHW (Josselyn 1983). Low brackish tidal marsh vegetation typically is dominated by perennial emergent herbaceous monocots up to 2 meters tall which are tolerant of extended periods of tidal submergence. The dominant plant species here are hardstem bulrush (*Scirpus acutus*) and California bulrush (*Scirpus californicus*). Low club rush (*Scirpus cernuus*), pickleweed (*Triglochin striata*) and common reed (*Phragmites australis*), and common cattail (*Typha latifolia*) may also be found in this low zone at the margin of channels and bayshores. Plants in this zone are subjected to inundation once or twice a day. Soil salinity does not fluctuate as much as in the high and middle marsh zones. The clonal dominants in this zone tend to occur in large, monospecific stands, with narrow strips of the less common species.

Fringing tidal wetlands are found along the channel and bayward sides of levees throughout Suisun Marsh. These fringing wetlands do not maintain the full ecological functions and food web support as the historic tidal marshes, but they do support wetland plant communities, some rare plant and avian species, and function as an element of protection to levees as buffers from wave erosion. The dense tule stands absorb tidal and wave energy, reducing the impact of these forces along the shoreline. The upper zones of levees are typically weedy in nature and support a variety of introduced and invasive species. Along depositional shorelines, these fringing tidal wetlands also support a diverse low marsh community including species such as California bulrush, hardstem bulrush, common cattail, and common reed. Protective salinity standards for Suisun Marsh plant communities will need to consider maintenance of these fringing wetlands.

Preliminary evidence suggests that low marsh fringing emergent macrophyte plant communities are tolerant of the wide range of channel water salinity that has been observed throughout Suisun Marsh in recent years. For example, the wetland vegetation along the banks of lower Goodyear Slough downstream of the S-35 salinity monitoring station has remained constant through the recent drought period. Salinities in this region would have exceeded the original D-1485 standards in critical water years, had these standards been in place. There has been no observable change in the occurrence or stature of dominant *Scirpus californicus* stands along this channel as monitored from 1992 through 1997 at the Morrow Lane overcrossing and at the very south end of Goodyear Slough at Lake Herman Road.

Brackish marsh habitat represents a very significant natural resource, which is characterized by a high diversity of halophytic plants adapted to life in this extremely dynamic environment. While salinity compliance standards are essential to protect Suisun Marsh plant communities from excessive anthropogenic reductions in Delta outflow, management of this system must also recognize aqueous salinity as a positive and necessary component that in part defines the natural communities of Suisun. Salinity standard development in past evaluations of Suisun Marsh focused on soil salinity levels required to germinate *Scirpus maritimus* for maximum seed production. Germination of most halophytes, including those in coastal marshes flooded directly with seawater, often takes place when salinity levels are reduced from precipitation under field conditions (Ungar 1991). Pre-treatment with water with salinity levels of seawater followed by fresh water has actually been found to enhance germination in some halophytes such as *Limonium spp.* (Boorman 1968 and Ranwell 1972). It is believed that water of such salinities pre-conditions the embryo for germination and has an osmotic shock effect that weakens the seedcoat and stimulates subsequent germination in fresh water. The seeds of halophytes have developed a number of adaptations that allow them to avoid salt stress and to time germination for successful establishment and reproduction of plants.

Perennial species predominate in most saltmarsh and brackish plant communities, including Suisun Marsh. In many cases, flowering is intermittent and sexual reproduction through seed production is only favored in times of lowered salinity. Annual reproduction of these plants from seeds is not essential for their long-term survival. The spread of *Scirpus* by underground vegetative rhizomes produces extensive clones and the natural history strategy of these plants does not include high seed production (Adams 1990). Clonal plants such as tules and bulrushes typically have a low rate of establishment from seed, but persist for many years through the maintenance of the survival and extensive spread of underground rhizomes (Adam 1990, Cook 1985). Underground biomass of these species far exceeds above ground shoot growth. Management schemes for growth of these species in Suisun Marsh have often been counter to the natural life history strategies of the species, and have only monitored the growth and response of above ground shoots rather than whole plant response to environmental conditions.

Suisun Tidal Wetlands Plant Community Characterization

Staff from DWR and Department of Fish and Game (DFG) conducted detailed field surveys in 1992 to locate and map the distribution of existing undiked brackish tidal wetlands (Figure 2-2). The largest remnant historic brackish tidal wetland is at the Solano Farmlands and Open Space Foundation's Rush Ranch tidal wetlands associated with Cutoff Slough. Other locations with significant brackish emergent tidal wetlands exist at the eastern terminus of the Hill Slough Wildlife Area, Browns Island, Ryer Island, Roe Island, Peytonia Slough Ecological Reserve, and at selected DFG and Concord Naval Weapons Station properties along the southern shoreline of Suisun Bay in Contra Costa County. The remaining smaller tidal wetlands are located along a broad estuarine salinity gradient from the upstream boundary of Suisun Marsh at the mouth of the Sacramento River near Collinsville, to the northern reaches of the interior Suisun marshes along Hill Slough and Peytonia Slough, and downstream to the Carquinez Straits at Benicia.

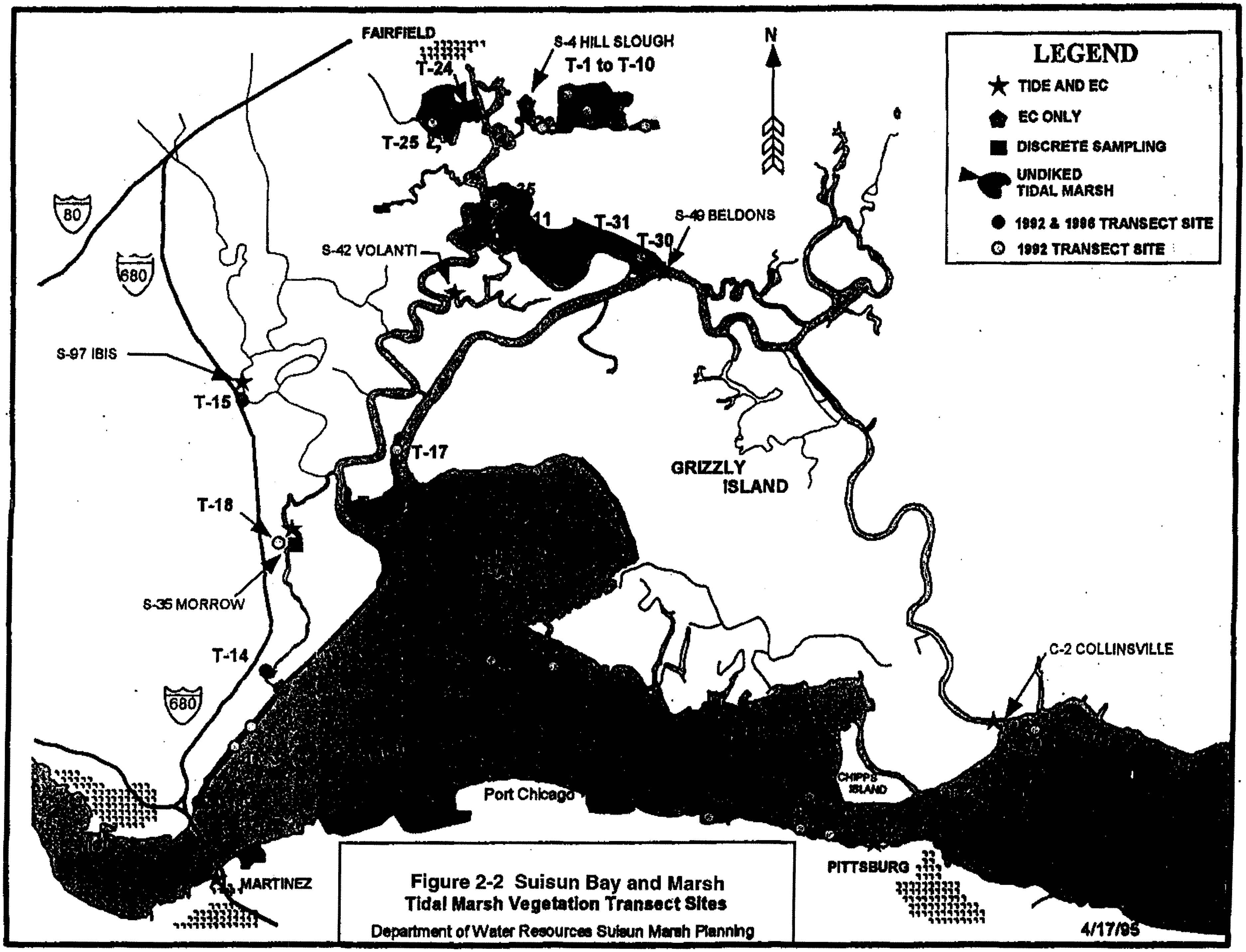


Figure 2-2 Suisun Bay and Marsh
Tidal Marsh Vegetation Transect Sites

Department of Water Resources Suisun Marsh Planning

4/17/95

In an effort to characterize contemporary patterns of tidally influenced vegetation throughout the Suisun Marsh tidal wetlands region, 36 tidal marsh vegetation transects were established in 1992 as a component of a Suisun Marsh Biological Assessment (Figure 2). These monitoring stations were not established to evaluate salinity standards, but were to provide a descriptive characterization of the plant community composition of the relict tidal marshes. Vegetation composition and structure were measured along direct environmental gradient strip quadrats at each transect site. Each quadrate was oriented perpendicular to the tidal water source (tidal creek, slough, or bay) and extended upslope towards the upland ecotone through wetland elevational zones. Data collected in 1992 represented vegetation composition in these marshes in drought conditions. A dedicated monitoring program was not supported to continue this effort, though data have been collected at a few sites annually.

Factors Influencing Tidal Wetlands Plant Community Composition

While the focus of this effort is on the influence of aqueous salinity on brackish plant communities, it is important to recognize the complex suite of environmental and biological variables that influence wetland plant community composition and structure. In the broadest model, the distribution of plants in the San Francisco Estuary and other temperate zone tidal wetlands is influenced by physical gradients of inundation frequency and salinity regime resulting in plant distributions that correlate with landform. Brackish marsh plains and ecotonal high marsh zones are dominated by saltgrass and pickleweed, salt tolerant halophytes which are also common in estuarine and coastal saltmarshes. Tall tules, cattails, and reeds, which are tolerant of greater depth and duration of flooding, dominate the edges of bayshores and tidal creek channels. These glycophyte/mesophytes are also common to freshwater marshes of the Sacramento-San Joaquin Delta. The character of vegetation assemblages changes, progressing from the more saline reaches of Suisun Marsh at the upstream end of the Carquinez Strait some 55 kilometers from the Golden Gate tidal source. The tidal marsh vegetation assemblages remain fairly similar until Brown' s Island, 80 kilometers upstream of the Golden Gate at the mouth of the Sacramento River. Freshwater inflow at this point results in tidal marsh plant communities with closer affinity to Delta freshwater wetlands.

The use of the phrase "brackish" to describe water salinity thresholds for Suisun Marsh plant communities is problematic, as Suisun Marsh is characterized by wide annual and seasonal swings in salinity and occupies a vast land area over some 30 kilometers of estuarine salinity gradient (Malamud-Roam and others 1995). Thus it is difficult to clearly characterize brackish marshes or brackish marsh plants (Faber 1982). Collins and Foin (1993) acknowledge that major vascular plant species of the tidal marshlands are ordered along the estuarine axial salinity gradient. However, they caution that the functional role of salinity as a causative agent for the distribution and abundance of plant species may differ within and between marshlands and that salinity has not been identified as a direct causative factor of plant distribution. Mall (1969) postulated that depth and duration of flooding are the factors most influential in Suisun Marsh plant community composition. Josselyn and others (1990) confirmed that the controlling factor supporting wetland plant communities along moisture gradients from tidal marsh channels to upland ecotones is the duration of saturation and anaerobic soil conditions. At Elkhorn Slough, California, Oliver and Mayer (1987) found that salt marsh plant species mosaics reflect the effects of interspecific competition rather than responses to physical gradients of salinity and inundation. Zedler (1986) found increases in Spartina density and biomass following removal of other species from the upper part of its range, confirming that interspecific competition plays a dominant role in salt marsh plant distributions. Mahall and Park (1976) correlated northern San Pablo Bay salt marsh plant zonation between pickleweed (*Salicornia virginica*) and cordgrass (*Spartina foliosa*) with interspecific differences in tolerance to salinity. Subsequently, Brenchley-Jackson (1992) conducted intensive monitoring of edaphic characteristics and plant zonation in San Francisco estuary and coastal marshes. They found interspecific interactions to play a large role in determining *Spartina foliosa* and *Salicornia virginica* dominance, and rejected the traditional view that California salt marsh vegetation pattern is generated primarily by salinity. Pennings and Callaway (1992) demonstrate through experimental manipulations that biotic interactions, including competition between species, are important in determining marsh plant zonation patterns, and explain why boundaries between marsh vegetation are often abrupt, whereas edaphic factors change gradually across the marsh. Bertness and Hacker (1994) show how New England salt marsh plant communities are structured by positive plant interactions that buffer interspecific neighbors from physical stress.

Tidal wetlands are highly dynamic environments. Semi-diurnal tidal phenomena are predictable, but interactions between meteorological and tidal events can produce extreme conditions which are unpredictable in occurrence and which may impose severe perturbations. Major episodes of flooding (low salinity gap) or prolonged drought (soil hypersalinity) are part of the normal variability experienced by these systems which can substantially alter marsh plant species competition and community structure (Zedler and others 1986). Tidal wetland plant communities undergo long-term successional processes but appear to be stable over many years and for longer than the lifespan of their individual components (Adams 1990). The complexities of vegetation pattern and structure will be an important consideration as this effort progresses. While salinity is an important variable to consider, aqueous salinity does not stand alone in its influence on these wetlands, and a growing body of scientific literature suggests salinity is often not the controlling factor in brackish and salt marsh plant community structure. Future estuarine water management and wetland protection programs must look beyond salinity and also consider the consequences of water management-influenced depth and duration of flooding, which is imposed on estuarine tidal marsh plant communities across the full elevational gradient from the bayshores and tidal sloughs to the upland ecotone.

The prehistoric and modern salinity regime in brackish tidal marshes of Suisun Marshh is known to be naturally highly variable throughout the evolution of the marshes. Tidal sediment cores from Brown's Island (Wells and Goman 1994) provide evidence from trace metal concentrations, fossil plant pollen and vegetative structures, and foraminifera that indicate marked long-term fluctuations from relatively freshwater marsh to brackish conditions, punctuated with extreme flood and drought events. Similar patterns of variable paleosalinity have been inferred for San Pablo Bay, based on stable isotopic composition of mollusk fossils (Ingram and others 1996); these independent data suggest prolonged periods of relatively high and low salinity, deviating from long-term averages for periods of 40 to 160 years. Most variation of salinity in San Francisco Bay is explained by Delta outflows (about 87 percent; Peterson and others 1989). Estimates of Delta outflows derived from tree-ring analyses since 1560 (Earle and Fritts 1986) also corroborate the long-term pattern of high magnitude variation of Delta outflows (markedly wet and dry periods on a scale of about 10 to 20 years or more). Historic ecological accounts of Suisun Marsh also indicate considerable seasonal and interannual variation in salinity (George, Anderson and McKinney 1965). There is no evidence which suggests that tidal marshes of Suisun Marsh evolved under a regime of relatively stable or predictable low salinity within a relatively narrow range of variation, as it is currently managed.

Because vegetation and plant populations of Suisun tidal marshes have not been systematically monitored to detect changes associated with salinity variations, there is no direct documentary evidence to demonstrate effects of salinity management on long-term vegetation change. The general effects of salinity management on Suisun Marsh plant communities can be reasonably estimated, however, based on (1) studies of tidal marshes elsewhere, particularly Pacific coast marshes experiencing artificial or strong salinity changes; (2) qualitative observations of Suisun tidal marshes over precipitation cycles and comparison with other parts of the San Francisco Bay Estuary; and (3) interpretation of mechanisms of tidal marsh plant community composition based on studies within and outside the region.

Shifts in tidal marsh salinity due to changes in freshwater inputs are associated with major and long-term or rapid vegetation changes (Beare and Zedler 1987; Clark 1986; Clark and Patterson 1985). Artificial reduction of tidal marsh salinity, particularly during the season of seedling establishment, can enable exotic invasive plant species to spread and increase in dominance (Callaway, Jones and Ferren 1990; Kuhn and Zedler 1997). This effect is most apparent when freshwater influence is amplified or prolonged beyond the natural winter-spring seasonal peak (Kuhn and Zedler 1997). Some of these invasions have been inelastic; once invasive species are well-established during artificial low salinity conditions, they can persist through less favorable high salinity periods (Zedler 1983). Similarly, rarer plants may be slow to re-invade "freshened" marshes because of seed bank depletion, or competition with invaded vegetation (Allison 1992). Salinity variation in California tidal marshes has been shown to affect the interactions between dominant perennial plants and less common annual and short-lived perennial plants (Callaway, Jones & Ferren 1990; Allison 1992). Variation in rainfall and tidal marsh soil salinity promotes dynamic community composition among years and increases overall plant species diversity in California marshes; some species are favored in wetter, less saline years, while others are favored in drier, more saline years (Allison 1992, Callaway and Sabraw 1994, Ferren 1985). Elimination or reduction of natural seasonal or interannual marsh salinity peaks are likely to favor increased dominance of exotic plants with relatively low salinity tolerance and reduce dynamic community composition.

The underlying mechanisms which relate salinity variation to plant species diversity and patterning are not completely understood, but one important mechanism relates indirectly to effects of salinity on competition, positive plant interactions, and vegetation gaps (Pearcy and Ustin 1982; Bertness and Ming Yeh 1994). Many marsh plants in salt marshes are considered to be "fugitives" of competition either throughout their life cycles or during seedling/juvenile phases, and require either bare or relatively sparse patches in which they regenerate (Bertness, Gough and Shumway 1992). Rare tidal marsh species of the genus *Cordylanthus* in California, for example, are negatively correlated with abundant growth of dominant species and are positively correlated with vegetation gaps or sparse vegetation needed for seedling regeneration (Parsons and Zedler 1997, Kelley & Fletcher 1994). Episodes of high salinity are one factor which has been shown to be an important factor in the development of tidal marsh vegetation gaps (Callaway and others 1990; Bertness and others 1992; Zedler and Nordby 1986). Relatively rare salt marsh species in some systems are also known to increase in abundance following release from salinity stress, in years of high rainfall following drought years (Allison 1992). Although salinity stress physiologically inhibits growth of individual salt marsh plants (Pearcy and Ustin 1984, Mahall and Park 1976), alternation between salt-stressed and low-salinity years appears to establish community conditions which enable higher species coexistence and higher dynamic diversity than less stressful conditions of low salinity, which may favor dominance of fewer species.

These conclusions correspond well with direct qualitative field observations of vegetation change in brackish tidal marshes of the northern San Francisco Bay Estuary (San Pablo and Suisun Bay area) in the 1990s. Most brackish tidal marsh plains dominated by low grasses, subshrubs, and perennial herbs during drought years of the early 1990s exhibited rapid increases in abundance of tall, dense, "wetter" preference species during subsequent years of high rainfall and freshwater outflows: expansion of native Olney's bulrush (*Scirpus americanus*), alkali-bulrush (*S. maritimus*) and cattail (*Typha spp.*), rapid expansion of exotic invasive peppergrass (slough mustard, *Lepidium latifolium*) was widespread. Even otherwise minor exotic species such as wild celery (Apium graveolens) became conspicuously invasive after several above-average wet years. Although some uncommon to rare plants thrived in the wetter years in some parts of the estuary (e.g., Delta tule pea, *Lathyrus jepsonii* var. *jepsonii* in Napa-Sonoma marshes), others were more abundant in drier years and declined after several wet years in most populations (e.g., endangered Suisun Thistle, *Cirsium hydrophilum* var. *hydrophilum*, and soft bird's-beak, *Cordlyanthus mollis ssp. mollis*). Some rare tidal marsh plants expanded in the initial wet post-drought years and declined after wet years persisted (e.g., Point Reyes bird's-beak, *Cordylanthus maritimus ssp. palustris*). These observations generally agree with the hypothesis that fluctuation between relatively high and low salinity conditions dynamically maintains a diverse native plant community, permitting species to coexist in the long-term, as indicated in other tidal marsh systems.

Plant Species of Special Significance in Suisun Marsh

Seven special status plant species occur within the brackish marsh and salt marsh vegetation of Suisun Marsh; these are discussed in Appendix A. Maps of the distribution of sensitive plants species in Suisun Marsh and the San Francisco Estuary were included in a previous report to SWRCB (DWR 1994).

Conclusions

1. Suisun Marsh was once a broad plain dominated by saltgrass associations with a diverse assemblage of brackish tidal marsh plant species.

   Prior to European influence, the historic Suisun tidal brackish marsh consisted of extensive broad plains dominated by saltgrass associations with diverse brackish marsh plant species. Channel margins were dominated by tall grass-like vegetation (bulrushes, tules, cattails) or erosional banks. It is likely that relative dominance of plant species changed significantly with short-term climate cycles; rushes, bulrushes, and cattails probably increased in abundance during wet year series, while saltgrass and pickleweed increased relative abundance during dry year series. Plants now uncommon to rare in Suisun Marsh were more widespread, and it is very likely that they also underwent large fluctuations in abundance and distribution in relation to climate cycles and indirect changes in the marsh vegetation. Marsh pannes (ponds, unvegetated flats, and wet depressions), scarce in modern fringing tidal marshes, were larger and relatively more abundant. Deeper pannes probably supported great abundance of widgeon-grass, algae, and other submersed aquatic vegetation, particularly in wet year series.

2. Historic Delta outflow data alone is insufficient to draw conclusions about the range of salinities under which Suisun Marsh vegetation evolved.

   Recommendations regarding salinity standards for Suisun Marsh must be made on the basis of limited information and analysis regarding factors considered above. It not realistic to hindcast salinity regimes affecting tidal marsh vegetation based on historic Delta outflows alone. The integrated effects of prehistoric tidal prism and tidal circulation (before diking and hydraulic mining sedimentation), Delta marsh storage of outflows, and undeveloped local watersheds have not been realistically modeled or quantitatively estimated; these would be essential to realistic estimates of prehistoric vegetation conditions. Similarly, there are currently no realistic quantitative predictive models which relate static or dynamic salinity with brackish tidal marsh plant communities. No such models are currently foreseeable. It is possible that such models may be very difficult or impossible to achieve because of constraints of historic data. In the absence of accurate models and historic data, qualitative or rank quantitative estimates of past and future salinity regimes affecting prehistoric Suisun marshes are appropriate. Practical recommendations must be informed by best professional judgement, reliant on available current quantitative and qualitative scientific data and theory.

3. Artificial reduction of channel water salinity through gate operation can cause some plant species to dominate at the expense of others.

   The subcommittee concludes that reducing salinity variation in Suisun Marsh by artificially "freshening" the marsh in all dry years, preventing periodic high salinity events, is likely to cause progressive shifts towards dominance by some marsh plant species (especially invasive exotic plants), and progressive declines in other species, including rare and endangered native plants. The subcommittee believes that the dieback caused by high salinity stress is likely to promote thinning or gaps in dominant vegetation, which allows transient increases in less common plants when salinity stress is relaxed initially in wet years immediately following droughts. Prolonged series of wet years probably caused transient shifts in dominance which are unfavorable for many populations of rare plants. The subcommittee believes that the dynamic shifts in vegetation between extreme water year types are essential to the long-term persistence of some rare marsh plants, as well as common marsh plants which are critical habitat for wildlife species. The subcommittee agrees that progressive increases in marsh salinity due to upstream diversions in the Delta, expected in the 1970s, would also reduce natural salinity variation and would probably have comparable (though different) detrimental effects on native plant diversity.

4. The plant species used by waterfowl as food are found in abundance in tidal and diked wetlands in other more saline parts of the estuary.

   The principal "duck food species" which are traditionally the greatest concern of waterfowl managers (fat-hen or spearscale; brass-buttons; alkali-bulrush; and pickleweed) all occur abundantly in more saline parts (compared with Suisun Marsh) of the estuary under both tidal and diked wetlands. Channel water salinities in Suisun Marsh even in dry years would not preclude robust growth of these plant species under tidal conditions. The subcommittee strongly doubts that the current salinity standards are necessary for productive growth of brass-buttons, fat-hen, and pickleweed in diked managed wetlands, muted tidal wetlands, or tidal wetlands. Poor performance of these purported duck food species in diked managed wetlands is most likely related to water management deficiencies which cause adverse soil conditions related to poor drainage and circulation. The adverse soil conditions not caused by tidal source water salinity are due to interactions involving accumulation of salts and toxic sulfides in subsided, undrained diked marsh soils. These plant growth factors can be fully addressed by water management in ponds and do not require manipulation of tidal source water salinity. Striving to achieve objectives of diked marsh management by enforcing arbitrary channel salinity standards which affect the entire estuarine ecosystem, instead of improving water management of diked managed wetlands, is an inefficient and ecologically unsound approach to wetland management. Furthermore, the subcommittee finds that seed germination requirements of alkali-bulrush are effectively irrelevant to salinity standards, since this species reproduces primarily by vegetative growth and its seedling establishment is naturally limited to infrequent wet years.

5. Operation of the gates may contribute to the spread of invasive tidal marsh plants.

   The subcommittee believes that the spread of exotic invasive plants, such as perennial pepperweed (*Lepidium latifolium*) and rabbitsfoot grass (*Polypogon monspeliensis*) which are naturally favored in series of wet years and tend to decline or stabilize in dry years, is probably facilitated in the long term by continued operation of the gates. Periodic years of high salinity stress is probably an important factor in checking or slowing the spread of invasive exotics in Suisun Marsh. Perennial pepperweed, in particular, threatens the continued existence of rare native marsh plants and rabbitsfoot grass displaces pickleweed in Suisun Marsh (B. Grewell, personal observation) and other estuaries (Callaway and Zedler 1998).

6. Significant increases in the area of brackish tidal marsh in the Suisun Marsh subregion could offset some long-term impacts of the reduced salinity variation under gate operation.

   The subcommittee believes that significant increases in the area and structural diversity (including transitions to upland and lowland soils) of brackish tidal marsh in the Suisun Marsh subregion could offset some long-term impacts of the reduced salinity variation under gate operation. Rare plants would more likely find suitable microhabitats if more marsh with high natural diversity were available. Optimal structural diversity takes decades to develop in restored tidal marshes.

7. Past studies of vegetation-waterfowl relationships in Suisun Marsh are in urgent need of re-evaluation.

   The subcommittee believes that the methodology and conclusions of past studies of vegetation-waterfowl relationships in Suisun Marsh are partly erroneous and in urgent need of re-evaluation (see Appendix B). In particular, the conclusions of Rollins (1973) and Mall (1969) should be re-investigated with broader ecological and geographic scope, using both autecological (study of individual plant ecophysiology) and realistic mesocosm (experiments performed on controlled field conditions, at larger scales and with multiple species) experimental methods. The conclusions of earlier studies should be interpreted cautiously when applied to management considerations.

8. The subcommittee believes the narrative standard should be revised to read:

   - Prevent the loss of species diversity.
   - Prevent the conversion of brackish marsh to salt marsh or freshwater marsh. Maintain the historic variability in interannual salinity regimes as closely as possible.
   - Prevent a decrease in animal and plant populations as a result of reduced salinity variance.
   - The portion of the narrative objective that discusses plant stature and cover should be deleted, since these are expected to change in response to variability in salinity and many other factors.

9. Further evaluation of scientific data should be funded.

   The subcommittee advises that further evaluation of quantitative and qualitative scientific data relative to the issue of salinity be conducted and resources provided to ensure such a comprehensive review.

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Appendix A: Special Status Plants in Suisun Marsh

Aster lentus Greene, Suisun aster:

Status. Federal "species of concern" (formerly referred to as a candidate for listing); California Native Plant Society (CNPS) List 1B, a list of species that are rare, threatened and endangered in California and elsewhere (CNPS 1994).

Habitat. Middle marsh. Regularly flooded estuarine wetlands and intertidal banks (Fiedler and Zebell 1995). Associated species: *Scirpus californicus, S. cernuus, S. acutus, S. americanus, Agrostis exarata, Euthamia occidentalis, Epilobium spp. Calystegia sepium, Hydrocotyle verticillata, Juncus balticus, J. oxymeris, Potentilla anserina ssp. pacifica, Rubus spp., Rosa californica, Triglochin striata, and Typha ssp.* (Fiedler and Zebell 1995), plus *Phragmites australis, Plantago sp., Lilaeopsis masonii, Eryngium articulatum, Helenium bigelovii* (NDDB 1997).

Species Range. Sacramento-San Joaquin Delta and Napa River marshes (NDDB 1997).

Distribution within Suisun Marsh Study Area. DWR and DFG staff mapped the distribution of Suisun aster (*Aster chilensis var. lentus*) throughout Suisun Marsh in 1992. However, recent taxonomic changes splitting *A. chilensis* and *A. lentus* as separate species (Hickman 1993) require a new look at the distribution of the sensitive *A. lentus*, as both species occur throughout the Bay-Delta system.

Salinity Tolerance and Requirements. Restricted to brackish marshes; no known studies of salinity requirements/tolerance.

Cirsium hydrophilum (Greene) Jeps. var. hydrophilum, Suisun thistle:

Status. Federal endangered, CNPS List 1B (rare, threatened and endangered in California and elsewhere)

Habitat. Irregularly flooded estuarine wetlands. Middle marsh to high marsh along tidal creek channels (Fiedler and Zebell 1995).

Associated Species. *Typha angustifolia, Scirpus americanus, Juncus balticus* and *Distichlis spicata* (USFWS 1995), plus *Sonchus sp., Frankenia salina,* and *Lepidium latifolium* (NDDB 1997).

Species Range. Known only from Suisun Marsh.

Distribution within Suisun Marsh Study Area. Two populations are known. The first is within DFG's Peytonia Slough Ecological Preserve; in 1992-1994, 18-30 plants were observed here, but only one plant was found in 1996 (Grewell, personal observation). The other consists of four distinct patches associated with the Cutoff Slough tidal marshes; most plants on the Rush Ranch property of the Solano County Farmlands and Open Space Foundation, but a portion occur on DFG's Joice Island Unit of the Grizzly Island Wildlife Management Area (DWR 1996).

Salinity Tolerance and Requirements. Annual observations of the Rush Ranch population beginning in 1991 revealed a significant decline in both the number and vigor of plants, with some recovery in 1996. The Peytonia Slough population declined dramatically in 1995 and 1996, while an increase in the density of the surrounding marsh species was observed. It is possible that Suisun thistle does better in years with lower water elevations or higher channel salinities, when competing herbaceous species do less well (DWR 1996). There are no known studies of salinity requirements/tolerance for *Cirsium hydrophilum var. hydrophilum.*

Comments. Competition from introduced species, including perennial pepperweed *(Lepidium latifolium)*, is a threat (DWR 1996). Possible threats include an introduced biocontrol agent, a weevil (*Rhinocyllus conicus)* that may be lowering reproduction rates, in addition to *Phyciodes myllita* caterpillars, which caused "significant" damage to rosettes at the Rush Ranch population in 1996 (DWR 1996.)

Cordylanthus mollis Gray ssp. mollis, Soft bird's-beak

Status. Federal endangered, State listed as rare, CNPS List 1B (rare, threatened and endangered in California and elsewhere)

Habitat. High marsh and ecotonal transition zone. Seasonally flooded palustrine wetlands including hypersaline or eurysaline areas within the wetland - upland ecotone (Fiedler and Zebell 1995).

Associated Species. *Salicornia virginica, Distichlis spicata, Jaumea carnosa, Frankenia salina, Triglochin maritima* (USFWS 1995), plus *Cuscuta salina var. major, Scirpus americanus* (Ruygt 1994).

Species Range. Historically, *Cordylanthus mollis ssp. mollis* was known from near the Antioch Bridge, on the north side of the San Joaquin River (last seen in 1972), Martinez (1881), Mare Island (1885, the type locality), Napa Marsh (1952), the confluence of Dutchman and South sloughs associated with the Napa River (1982), and Petaluma Marsh (1978) (NDDB 1997). The plant was also reported from near Peytonia Slough in Suisun Marsh (1892). These historical sites were searched in 1993 by J. Ruygt (1994).

Distributions within the Suisun Marsh Study Area. The plant is now limited to seven locations within the Suisun Marsh area including McAvoy Marsh, Middle Point, Hastings Slough, and Point Edith Marsh along the Contra Costa shoreline; and Rush Ranch, Joice Island Bridge area, and Hill Slough tidal marsh with Suisun Marsh (Ruygt 1994; NDDB 1997; Grewell, personal communication). This species is also known to exist in Southampton Marsh at Benicia State Park, Pt. Pinole Regional Shoreline, and Fagan Slough Marsh along the Napa River (Ruygt 1994; NDDB 1997). The Hill Slough tidal marsh in Suisun Marsh supports the largest extant population of the species throughout its range. An additional nine historic populations have been extirpated.

Inundation and Salinity Tolerance and Requirements. *Cordylanthus mollis ssp. mollis* is known only from tidally-influenced marshes, and occurs in a narrow elevational range above MHW (Ruygt 1994). Observations suggest that the species requires fresher soil conditions for germination, which occurs when soil water salinity is at a minimum after winter rains and runoff. Observations suggest that peak germination may occur when tidal inundation is most frequent (Ruygt 1994). However, this hemi-parasite can tolerate high soil salinity for the rest of its growing cycle: it is most commonly associated with the halophytes pickleweed (*Salicornia virginica*) and saltgrass (*Distichlis spicata)*, which are also its likely host plants, and it occurs as far downstream as Pinole Point and was known historically from Mare Island and Petaluma Marsh (DWR 1996, NDDB 1997).

Comments. Threats include oil spills, drainage changes, development of habitat.

Grindelia stricta DC. ssp. angustifolia (Gray) M.A. Lane, marsh gumplant

Status. CNPS List 4 (a watch list of plants of limited distribution)

Habitat. Middle marsh, high marsh, outboard sides of levees, natural high ground along tidal creeks. Regularly flooded estuarine wetlands and intertidal banks (Fiedler and Zebell 1995).

Associated Species. *Scirpus americanus, Senecio hydrophilum, Salicornia virginica, Distichlis spicata, Jaumea carnosa* (B. Grewell and D. Hickson, personal observation).

Species Range. Salt and brackish marshes from lower Sacramento-San Joaquin Delta to south San Francisco Bay and Monterey County (CNPS 1994)

Distribution within Suisun Marsh Study Area. Relict tidal marsh habitat and outboard sides of levees throughout the marsh.

Salinity Tolerance and Requirements. Wayne (1995) investigated recruitment response to salinity in this species in a salt marsh occurring in southern San Pablo Bay (China Camp State Park). She conducted both field and lab reproductive experiments on a population that occurs both in the upland transition zone and along channel margins. In general, Wayne found that marsh gumplant is highly sensitive to salinity in its germination requirements. It has almost 100 percent germination in 0 ppt salinity and decreases in percent germination in a linear manner until ceasing at approximately 25 ppt salinity. In field germination experiments, Wayne found a marked difference in germination success between the 92-93 season (a wet winter) and the 93-94 season (a dry winter). Interestingly, the upland transition zone germination varied little during these 2 seasons (28 percent for 1993 versus 22 percent for 1994) whereas it varied dramatically for the channel sample (20 percent for 1993 versus 4 percent for 1994). Wayne (1995) suggests that marsh gumplant reproduction is so sensitive to seasonal salinity regimes that it could act as an effective biological indicator for ecosystem monitoring.

Lathyrus jepsonii Greene var. jepsonii, Delta tule pea

Status. Federal "species of concern" (formerly referred to as a candidate for listing); CNPS List 1B (rare, threatened and endangered in California and elsewhere).

Habitat. Middle marsh and high marsh, tidally influenced banks along sloughs, channels and outboard sides of levees (DWR 1994). Regularly flooded estuarine wetlands and intertidal banks (Fiedler and Zebell 1995).

Associated Species. *Distichlis spicata, Salicornia virginica, Typha spp., Rosa californica, Baccharis douglasii, Rubus discolor, Phragmites australis, Lilaeopsis masonii, Scirpus spp., Hydrocotyle verticillata, Jaumea carnosa* (NDDB 1997).

Species Range. Sacramento-San Joaquin Delta from Tule Island in Middle River, and from Snodgrass Slough, to Carquinez Strait (Southampton Marsh), Napa River marshes (NDDB 1997), and south San Francisco Bay (DWR 1994), Fresno and San Benito counties (CNPS 1994).

Distribution within Suisun Marsh. Throughout the Suisun Marsh, from the Suisun Bay shoreline, Montezuma Slough and Nurse Slough to Hill Slough, westward to Cordelia and Goodyear sloughs, Brown' s

Island, the southern shore of Van Sickle and Chipps Islands, New York Point, Mallard Island, Seal Islands, and near Belloma Slough (DWR 1994).

Salinity Tolerance and Requirements. *Lathyrus jepsonii var. jepsonii* occurs in freshwater habitats of the Delta and the brackish marshes of Suisun Marsh and the Napa River Marsh. There are no known studies of salinity requirements/tolerance for this species.

Lilaeopsis masonii Math. & Const., Mason's lilaeopsis

Status. Federal "species of concern" (formerly referred to as a candidate for listing), state listed as Rare, CNPS List 1B (rare, threatened and endangered in California and elsewhere).

Habitat. Regularly flooded estuarine wetlands and intertidal banks (Fiedler and Zebell 1995). Low marsh zone, especially eroding shores or earthen levees.

The habitat is frequently transient due to erosion; *Lilaeopsis masonii* may not compete well with other species that eventually invade substrates that are stabilized (Fiedler and Zebell 1993, Golden and Fiedler 1991). Within the Delta, *L. masonii* is not found upstream of the extent of active tidal fluctuation (B. Grewell, personal observation).

Associated Species. *Primarily Scirpus californicus, Hydrocotyle verticillata* and *Scirpus cernuus* (Golden and Fiedler 1991) in the Delta; however, in Suisun Marsh, the primary associates are *Scirpus californicus, Scirpus cernuus,* and *Triglochin striata* (B. Grewell, personal observation)

Species Range. Sacramento-San Joaquin Delta from southern shore of Union Tract and from Hass Slough, downstream to mouth of Pacheco Creek near Martinez; Napa River marshes from near the town of Napa downstream to Mare Island in the San Pablo Bay; also, a 1936 collection from Tomales Bay in Marin County (NDDB 1997). This Tomales Bay location has not been rediscovered although it was intensively resurveyed in 1990 (Golden and Fiedler 1991).

Distribution within Suisun Marsh Study Area. *Lilaeopsis masonii* occurs along tidal sloughs and channels throughout most of Suisun Marsh and along Honker, Suisun, and Grizzly bays and along the opposing Contra Costa shoreline. Interestingly, *L. masonii* does not occur in Goodyear and Cordelia sloughs in western Suisun, except for a small colony near the their confluence with Suisun Slough. The lack of plants on these channels is unlikely due to a difference in salinity, as a wide salinity gradient is present from the fresh inflow of Green Valley Creek to upper Cordelia Slough to the more saline reaches of the southern terminus of Goodyear Slough near Benicia. The reason for the complete absence of *L. masonii* along Cordelia and Goodyear Sloughs is unknown. *L. masonii,* like many other tidal marsh plants, does not appear to be substrate specific as it is found in organic mucks, silty clays, and even pure sand throughout its range (Golden and Fiedler 1991).

Salinity Tolerance and Requirements. Plants occur in freshwater tidal habitats of the Delta (Golden and Fiedler 1991). Additional populations of *L. masonii* have been found downstream as far west as the southern tip of Mare Island since the work by Golden and Fielder, suggesting that *L. masonii* occurs in habitats inundated by water of higher salinity than is observed within Suisun Marsh. Golden (1992) found that growth was not significantly reduced up to 6.1 ppt NaCl, and increased mortality rates for individuals were seen only at 32 ppt NaCl. In the same study, seeds germinated at a 95 percent rate in freshwater but did not germinate in 4 ppt NaCl. Two possibilities for this seeming discrepancy were postulated—the seeds used were collected from a freshwater population, or the seasonality of water salinity was important.

Fiedler and Zebell (1993) found that seeds of *Lilaeopsis masonii* germinated in salinities of up to 12 ppt, unlike the results of Golden (1992), suggesting that increased water salinity levels in the Sacramento-San Joaquin Delta would probably adversely affect growth and establishment of *L. masonii.* Optimum seed germination requirements may not be essential in all years, however, as the plant may also reproduce by vegetative lateral spread of its rhizomes. Clonal tufts of *L. masonii* were observed floating in the Delta region by Golden and Fiedler (1991), and have been photographed by Grewell (1992) in Suisun Marsh.

Comments. Although small patches of *L. masonii* have been observed on silt deposits on rotting wood pilings (Golden and Fiedler 1991), these small populations could not sustain the species as a whole; the plant requires natural, eroding mud banks or levees to persist. Threats include the rip-rapping of levees combined with the lack of siltation compared with historical conditions; excessive erosion from boating and jet-skiing; herbicide spraying for levee maintenance; and competition from exotic species such as *Eichornia crassipes* (DFG 1997; Zebell and Fiedler 1996). Transplantation of populations as mitigation may be problematic; recent observations of sites to which *Lilaeopsis masonii* was translocated about 10 years ago as mitigation for levee work revealed that most of the habitat has eroded away. This is in contrast to the results of the 5-year monitoring report, which indicated that the transplants were still largely thriving. Mitigation must somehow provide a continuing supply of "new" habitat, through a continuous cycle of deposition, to which *Lilaeopsis* will naturally spread.

Limosella subulata Ives, delta mudwort

Status. CNPS List 2 (rare, threatened or endangered in California, but more common elsewhere)

Habitat. Regularly flooded estuarine wetlands and intertidal banks (Fiedler and Zebell 1995). Low marsh, on intertidal mud banks.

Associated Species. *Helenium bigelovii, Hydrocotyle verticillata, Lilaeopsis masonii, Mimulus guttatus, Pluchea odorata, Polypogon persicaria, Scirpus acutus, Scirpus cernuus, Triglochin striata* (NDDB 1997, reports from J. Ruygt 5/10/91 and B. Grewell 7/24/96).

Species Range. Native to the Sacramento-San Joaquin Delta, downstream to Montezuma Slough and on the eastern coast of the United States, where it is threatened by habitat destruction (CNPS 1994). A reported occurrence at Point Reyes, Marin County needs confirmation.

Distribution within Suisun Marsh Study Area. Reported from two occurrences in Suisun Bay: Montezuma Slough, approximately 0.45 mile southeast of Dutton, and at Brown's Island, toward the west end of an intertidal slough (possibly New York Slough) (NDDB 1997).

Salinity Tolerance and Requirements. "*Limosella* is more sensitive to high salinity values than is *Lilaeopsis* (Zebell and Fiedler 1996).

Appendix B: Limitations on Historical Salinity Standards Development, Areas of Agreement and Disagreement with Other Subcommittees, Response to Comments

1. Limitations on Development of Previous Salinity Standards

The BMV questions the wisdom of continued reliance on the numeric salinity standards established in D-1485 for the Suisun Marsh. There are significant technical concerns relative to the historic development and recommendation of these standards. The institutional acceptance of these management targets, coupled with the multi-million dollar salinity control program that followed, should be reexamined.

The internal numeric standards for Suisun Marsh were proposed by the Department of Fish and Game and the California Waterfowl Association as recommendations to the SWRCB based on limited field observations in Suisun Marsh (Mall 1969, Rollins 1973, SWRCB Phase II DFG Delta Hearing Exhibit 25 1977). The stated purpose of these field investigations was to determine the effect of future upstream water development upon the ecology of Suisun Marsh (Rollins 1973).

Studies designed to achieve this goal were observational in nature, and much more limited in scope than the stated objective. Mall (1969) addressed two questions: (1) What are the relative values of various marsh plants as duck foods; and (2) what influences do soil salinity and other factors have on the distribution and growth of marsh plants. Rollins (1973) addressed a third question—what is the relationship between channel water and soil salinity? An extensive technical review of these studies is not provided, but a summary of problems with this historic approach are provided to explain why we should consider moving away from the specific numeric targets established in previous water rights decisions.

The most obvious limitation of the historic development of the Suisun Marsh standards is that the overall ecology of this ecosystem was not considered. The numerical objectives addressed the managed production of a single waterfowl food plant.

The technical merit of the gizzard analysis approach to the first question has been dismissed by modern waterfowl ecologists as methodologies utilized in the Suisun Marsh studies were inadequate to answer the question of waterfowl food preference (Harvey & Miller 1992, Swanson and Bartonek 1970). The identification of alkali bulrush as the key waterfowl food plant became the foundation of a marshwide salinity control program, and numeric objectives recommended to SWRCB focused on perceived growth requirements of this single species.

The second question investigated the relationship between marsh plants and environmental factors. Wetland ecologists universally acknowledge that a variety of factors including hydroperiod, soil redox potential, soil nutrient status, soil salinity, soil texture, disturbance factors, herbivory, dispersal, competition, facilitation, and other factors may all play a significant role in marsh plant occurrence, growth, and reproduction. The Suisun Marsh study yielded important observations regarding plant response to managed length of soil submergence and soil salt concentrations. However, controlled and replicated experiments to determine the actual mechanisms responsible for the observed vegetation parameters were not conducted. Field and/or mesocosm experiments essential to the determination of salinity tolerances of these species were not conducted. The soil-water-salt relationships reported (Mall 1969) were important observations, but the later use of these observations to determine salinity standards is problematic.

The third field study intended to examine the relationship between soil salinity and salinity of applied water (Rollins 1973). Study sites were limited to five managed wetlands in northwestern Suisun Marsh. Soil salinity observations were recorded through time on four private duck hunting clubs, and a small experimental diked wetland was used to observe soil and channel water salinity relationships. The experimental wetland study was reported as a "controlled" study, as hydrology was controlled in the field. However, the study was not controlled or replicated in accordance with experimental design protocols. The results of this study were observational correlations, and were not designed to determine the relative role of channel salinity as an explanatory factor for observed soil salinity regimes. Other factors including plant ecophysiology, herbivory, level of ground disturbance, positive plant interactions, and many other physical factors are known to influence in situ soil salt concentrations in brackish and salt marshes. The channel water and soil salinity relationships observed in this study provided management insight, but the use of these results to develop salinity criteria are problematic.

Details of the extension of the observational correlations yielded in these early studies to recommended salinity standards for Suisun Marsh are not available in SWRCB testimony or agency reports. Methods of analysis used to determine recommended standards are not reported in historic SWRCB testimony or DFG reports. However, tables were submitted to SWRCB indicating the salinity of applied water required to achieve an average of 60 percent and 90 percent of maximum alkali bulrush seed production and 60 percent seed germination (Table VI-3 SWRCB Phase I DFG Delta Hearing Exhibit 3, 197x, SWRCB Phase II DFG Delta Hearing Exhibit 25, 1977).The basis of these standards were projections of applied water needed to achieve specific germination and seed production levels. Germination requirements of alkali bulrush were not determined by studies supporting this recommendation, and this particular species *(Scirpus maritimus)* has a life history strategy characterized by clonal spread of underground plant parts rather than reproduction by seed. Numeric criteria were projected to achieve 90 percent maximum of alkali bulrush seed production, while maximum seed production for this species was not determined or reported.

In summary, the early field observations of Mall (1969) and Rollins (1973) were important contributions to our understanding of diked wetland management. The application of the results of these studies to development of channel salinity standards in Suisun Marsh is extremely problematic as the scope, design, and results of the studies do not support the historic salinity standard recommendations.

2. Areas of Agreement and Disagreement with Waterfowl Subcommittee

On October 10, 1998, the BMV met with the Waterfowl Subcommittee to discuss areas of agreement and disagreement. The following summary of that meeting was agreed to by both committees:

Nick Wilcox reported that he and Heidi Rooks met to discuss the mission of SEW. Two directions are possible: (1) SEW could make a common recommendation to the Board for all resources, or (2) the SEW subcommittees could identify common ground and clearly discuss the areas in which there is disagreement, because it's not up to SEW to negotiate a political compromise. Rather, that will be up to the board.

The BMV subcommittee members clarified that X2 is not necessarily their recommendation for salinity variation, but that they see X2 as a controlled factor, and that they'd like to see the maximum variability possible, if it is under X2 or any other standard (that is, no gate operations) with concurrent monitoring and adaptive management.

We discussed that the lack of data—on all sides—does not allow us to make a firm recommendation on salinity. For example, the BMV cannot say what channel water salinity, or the number of years of high salinity, that will occur under the variability scenario. The Waterfowl group cannot say what level of management would be needed for each managed wetland to maintain acceptable soil salinity, because of the variability between managed wetlands. Thus, the first point of agreement is that a comprehensive monitoring program is needed, both for the managed and tidal wetlands in Suisun.

Peter Baye stated that it is unlikely that the saltier years under an extremely variable regime would result in the extirpation of the most endangered species or create a monotype of vegetation to the detriment of the rare species, but, rather, the lack of variation that would cause harm. Mike Vasey stated allowing such variability should be approached cautiously and accompanied by good monitoring, since conditions in the marsh today are much more constrained and there may not be opportunities for species to find appropriate refugia during highly stressful times as there once were in the historical marsh. These constraints may pose added risks to certain species under extreme conditions.

We discussed identifying needs for the waterfowl resource versus needs for hunting. The Waterfowl Subcommittee has not differentiated between the two and sees no reason to.

The second point of agreement was that management is critical to reducing soil salinity in managed wetlands. Increased channel water salinity would presumably require better methods for moving water on and off the managed wetlands. This might require added infrastructure or perhaps an investment in portable pumping systems that could be shared by wetland managers.

Management and the use of channel water of low salinity helps to determine habitat quality in the managed wetlands based on the Waterfowl Subcommittee's data presented at an earlier full SEW meeting. However, the ability to increase management is currently limited by costs and regulations.

We discussed the possibility of other types of management (e.g., moist soil management). However, Dennis Becker pointed out the many constraints to such management (e.g., mosquito abatement, fish screen requirements—a list follows this text). We discussed how influential SEW or the board could be in changing the requirements set by NMFS or USFWS which could allow different management. We seemed to agree that all of this process is incremental, and is worth putting ideas before the board and other regulatory agencies.

A third point of only partial agreement is that October is (although not in all years) less important in terms of allowing variability. This is because plants are mostly dormant in late fall/early winter. At this time, fresher water on a consistent basis may not be detrimental. We discussed the possibility of a "senescence" trigger, but this may be impractical, as wetland managers begin flooding to provide habitat for early migrating waterfowl beginning in early August. The Waterfowl group expressed the desire to flood up with less saline water even earlier, such as in early September as this year, some of the private lands started flooding up on September 1 and State lands started flooding as early as mid-August. BMV would likely object to this on a consistent basis.

A point of disagreement is decreasing channels water salinity in spring. The BMV would like to see more variability in channel water salinity in spring than would the Waterfowl Subcommittee.

The Waterfowl group stated that they would want a monitoring and adaptive management program in place prior to changing salinity standards; BMV stated the change and monitoring program should at least be concurrent. Neither subcommittee wants change without monitoring and adaptive management. In this regard, a "Suisun Ops" group—similar to CALFED Ops, could actually assess the monitoring data and recommend management changes. Presumably, the Suisun Ops group would be composed of representatives of the SMPA agencies (DFG, DWR, SRCD, USBR) with the addition to members of the recently formed SMPA Environmental Coordination Advisory Team (ECAT) which would also include USFWS and NMFS representation. Such a group could possibly recommend input on management changes more frequently than would happen under the Triennial Review.

A concern was expressed that, if endangered species were to expand their ranges during drier years under a variable regime, USFWS may not allow normal operations to resume in the managed wetlands. Also, landowners need to have standards on which they can rely.

Mike Vasey at the end of the meeting offered that the monitoring plan have actual biological triggers, rather than salinity or other non-biological standards. Time limited further discussion on this topic.

It was clear that some areas will not have agreement and should be stated as such. For this reason it is likely that the full SEW committee will need to choose path number two as stated in paragraph one in advising the board on Suisun Marsh salinity standards.

Peter Baye felt that there was little utility in meeting further as there seemed to be diminishing returns each time the needs of BMV and Waterfowl were discussed. He suggest that we bring forth what we have for the board and wrap things up.

Flooding constraints to managed wetlands

The following list of constraints was added by the Waterfowl Committee after the meeting for informational purposes. These constraints are independent of salinity control gate operations.

Delta Smelt and Chinook Salmon diversion restrictions are causing wetland managers to have to screen their intakes or face closures in Spring and Fall

Wetlands flooding during warm months (April to October) may be charged by the mosquito abatement district for treatments to their wetlands. Thus summer irrigations can be expensive if treatment is required.

California Clapper rail nesting season currently runs February through the end of August each year restricting any disturbance within 500 feet of tidal sloughs in many areas of the marsh.

Related to flooding managed wetlands is the periodic need to set back plant succession. One of the tools used to set back plant succession is fire (burning) and is failing under increased scrutiny of the Sacramento and San Francisco area air quality management districts. Daily allowable acreage that can be burned is currently regulated.

3. Areas of Agreement and Disagreement with the Aquatic Habitat Subcommittee

The BMV and the Aquatic Habitat subcommittee (SEWAH) both recognize the ecological significance of low channel salinity in spring for their respective plant and fish species, but differ in their interpretation and recommendations for spring salinity. BMV and SEWAH's perspectives are aligned on an autecological grounds—ecology at a physiological, individualistic level. For seedlings that emerge in the marsh during the late fall-winter-spring period, and for juvenile fish, mortality and physiological stress are expected to increase with increasing salinity. During the sensitive juvenile life-history stages, it would appear that managing for lower spring salinity would benefit both fish and plants. SEWAH adopts this protective view, but BMV concludes that chronic depression of spring salinity in the marsh may cause long-term population decline in sensitive plant species, and long-term shifts in tidal marsh vegetation. The BMV's perspective is based on assessment of complex community-level factors that may override simple autecological relationships between growth, mortality, and salinity in plants.

The BMV gives much weight to observations that during periods of low salinity, invasive non-native plants, and some abundant native species in tidal marshes, increase significantly in abundance. This has been particularly evident in brackish marshes in northern San Pablo Bay and Suisun Marsh in the last several years of above-normal precipitation, when brackish tidal marsh vegetation has generally exhibited rapid and dramatic increases in the abundance and vigor of tules, cattails, bulrushes, and invasive pepperweed, *Lepidium latifolium.* The abundance of these species in marshes which become wetter and relatively fresher in "wet" years has corresponded with declines in many populations of rare plants and many independent localities. We are particularly concerned that in years when marsh soils are relatively fresh and wet in spring, new colonies of invasive peppercress appear to establish more frequently and grow faster. We have also observed that some species, like the endangered soft bird's-beak (*Cordylanthus mollis ssp. mollis*), which can grow better at low salinities, but do not tolerate crowded, dense vegetation in waterlogged soil, and can be displaced by spreading pepperweed. Since pepperweed establishment appears to be slower during years of higher salinity, it is likely that occasional dry years of higher salinity may be important in checking the spread of this competitor. Similarly, consistent low salinity may be physiologically "too much of a good thing" for diverse marsh vegetation, because it may give too much advantage to a few larger dominants. Occasional "extreme" years of high marsh salinity may be important in establishing non-equilibrium or "disturbed" conditions in which a more diverse range of plant species can co-exist. Long-term, chronic high salinity, however, would probably be detrimental for plant diversity in naturally brackish marsh systems. A dynamic, fluctuating salinity regime, we believe, would be more likely to preserve the natural diversity of brackish tidal marshes, and would aid the marsh's resistance against invasion by non-natives.

The apparent differences between the BMV's and SEWAH's views of spring salinity management, however, may depend on the current environmental setting. Although we were asked to comment on the appropriateness of seasonal salinity standards under prevailing conditions, in isolation from other factors such as habitat, we think BMV and SEWAH's differences might be resolved by habitat factors. Because the brackish tidal marsh systems of Suisun Marsh are reduced in both area and complexity by the prevailing dike systems, their responses to variations in channel salinity are very different from what we would expect from the original tidal marshes. The current tidal marsh remnants have few small tidal creeks, and are mostly isolated from surface and subsurface flows of fresh water from adjacent uplands, which are captured and drained off by diked areas. If complex, large tidal marshes offered more habitat, particularly low-salinity "refugia" associated with local freshwater streams and groundwater influences during droughts, the impacts of high-salinity events on fish might be less incompatible with long-term vegetation management needs.

Unfortunately, no one has tried to model the potential salinity interactions between fresh groundwater and surface water systems integrated with tidal marshes and their tidal creeks. The current SEW forum bypasses the most basic question of what part of the marsh ecosystem should be re-engineered to maximize public benefits and compatibility of ecosystem needs; it proceeds directly to the factor immediately in the SWRCB's jurisdiction, channel salinity standards. While this is administratively practical in the short term, the BMV thinks that this narrow approach may cause artifacts of subcommittee conflict (such as between appropriate spring salinity standards for fish and plants). It would be useful to revisit the recommendations of the subcommittees in a broader context of water resources, including what kinds of habitat amounts and configurations in the landscape would minimize resource conflicts in the future. This is what regional wetland plans have attempted to do, but at a more programmatic level. BMV believes that it would have much less likely disagreement with SEWAH on both salinity and habitat issues if a broader aquatic habitat management question were posed by the SWRCB, and we would welcome such an opportunity.

4. Response to Comments on BMV's Draft Recommendations (dated December 15, 1998)

Comments by Paul Crapuchettes, December 16, 1998. "I am having a great deal of difficulty getting into the frame resulted in this above presentation. It is my understanding of salinity in the Delta arises from farming and fisheries concerns. Are the persons who are preparing this recommendation aware of the salinity distributions of past times and the present? Their proposals don't speak to the issues they seem to want to address.

"The SMSCG restores salinity variations in the managed wetlands to a poor replica of what was historical, to a greater or lesser degree depending on water releases. The usual 12 month full range of salinities with gates in operation is greater than the historic values. Operation of the SMSCG does not increase channel salinities by more than a few percent when in operation and changes them not at all when not operating.

"Thus none of the recommendations regarding marsh salinity should be acted upon.

"The suggestion that work be done to determine alternate methods of leaching to expand and verify the work of Moll and Rollins to various geographic sites may provide useful data for incorporation in future site related management plans but should in no way influence major changes in management plans until proven.

"I think this group should direct their attention to determine scientific level just what salinity variations are tolerable and/or necessary for the vegetation they want to protect."

Response to Comments of Paul Crapuchettes:

a. The BMV is aware of the current scientific literature of inferred pre-historic distribution of salinity patterns in the estuary and lower Delta. We understand that the prehistory of salinity patterns was complex, and its interpretation is subject to considerable uncertainty. BMV gave full consideration to contemporary stratigraphic studies of estuarine marshes and reconstructed precipitation records of the late Holocene epoch. BMV also considered the uncertainties and controversy regarding the relative effects on salinity and outflow interactions caused by Delta evapotranspiration, and the radical loss of tidal prism caused by widespread diking of the estuary and Delta, and changes in watershed storage/detention of runoff. BMV did not consider early historic salinity and outflow conditions to represent the long-term ecological "norm" of the estuary. Our recommendations considered conditions that were pre-historic, not merely historic.

b. We disagree that operation of the SMSCG creates salinity conditions "greater than historic values," and are reasonably confident that existing salinity standards significantly dampen variability in salinity well below natural ranges.

c. BMV finds the Rollins and Mall conclusions to be sufficiently unreliable and misinterpreted to justify major changes in management approaches. The scope of the Rollins and Mall studies did not address whether salinity itself, and not other variables circumstantially linked with them in diked Suisun marshes, was a limiting factor for good waterfowl habitat and food plants. There is existing waterfowl habitat information from San Pablo and San Francisco Bays which can be immediately utilized and applied to Suisun Marsh, and we recommend this.

d. The BMV does not accept an engineering approach to ecology which presumes that a particular environmental variable such as salinity can or should be optimized or stabilized within narrow limits of tolerance. We understand that marsh ecology is dynamic, and species exploit fluctuating habitats. Accordingly, it is not possible to simultaneously optimize stable habitats for co-existing species which have different environmental requirements. Such species are compatible only in dynamic habitat conditions. Moreover, we understand that many species occupy ecological niches which are far from optimum in terms of physical environment. We agree, however, that we need to better understand how species exploit environmental variability, and how much and what patterns of variability affect different species.

Chapter 3: Waterfowl Subcommittee

Background

Waterfowl are the most conspicuous component of the Suisun Marsh fauna. In the last ten years, 1-day counts commonly tally more than 125,000 waterfowl. Because of the large number of waterfowl, the marsh is popular with waterfowl hunters, and the primary land use in the marsh today is private duck clubs. These clubs are almost all diked marshes managed to provide habitat for wintering waterfowl.

The historic tidal marshes of Suisun Marsh were diked beginning in the 1860s to reclaim the land for agricultural uses. Starting in the early 1900s agriculture became less productive due to upstream water diversions, large scale water projects, and increasing salinity in the marsh soils. As agricultural uses declined in the marsh, these diked lands were converted to duck clubs and flooded on a seasonal basis. In both the historic tidal marshes and today's seasonal ponds, waterfowl have found wintering habitat that meets their needs for water, food, and cover. In addition, in recent years large numbers of waterfowl have been found to nest in the marsh. Mallards in Suisun Marsh nest in higher densities (up to 23 times higher) than in many of their traditional nesting areas.

An observed decline in the number of waterfowl wintering in Suisun Marsh is commonly attributed to increased acreage of seasonal wetlands and flooded agricultural fields in the Sacramento Valley. It is important to note that the wetlands of the Sacramento Valley are not protected like the Suisun Marsh. Currently, there are many thousands of acres of flooded rice and corn in fall and winter in the Sacramento Valley; however, agricultural and economic factors may dictate that these seasonal wetlands be converted to other types of agriculture (grapes or cotton, for instance), or other uses (such as urban or industrial). If these types of conversions do occur, many waterfowl will seek other habitats such as the Suisun Marsh. Therefore, it is very important that the marsh maintain large tracts of high quality waterfowl habitat.

The three main components of waterfowl habitat are water, food, and cover. Water in the managed wetlands is provided by opening the water control structure on a slough and allowing water to enter the pond. There is no evidence to suggest that the salinity of this “flood-up” water affects the use of the pond by waterfowl. However, it has been shown to have a long term effect on the salinity of the soil in the pond. When a diked pond is repeatedly flooded with high salinity water, salts accumulate in the soil, and soil water salinity can increase to levels where no plants can survive. Thus, management actions, like circulation or leaching with low salinity water, become necessary to decrease soil water salinity and maintain vegetation that provide waterfowl with food and cover. Despite applied and soil water salinity increases during the 1987-1992 drought, most wetland managers were able to use effective water management to maintain vegetation in their ponds. This has led the Waterfowl Subcommittee to conclude that the existing salinity standards were adequate to prevent a widespread and potentially harmful increase in soil water salinity during the 1987-1992 drought.

When low salinity water is available in Suisun Marsh channels, there are many advantages to waterfowl, diked wetland management, and some waterfowl food plants. When channel water salinity is low, pond and soil water are much less likely to rise to levels that become limiting to ducklings or vegetation. During these times, managers are able to leave water in their ponds longer, providing habitat for breeding birds, or to conduct effective leach cycles with low salinity water. Some plants may produce more seed during times of low salinity, providing more food for wintering waterfowl.

To protect ducklings in the marsh, the Waterfowl Subcommittee recommends that the channel water salinity standards be decreased from March through July. Mallard ducklings exposed to brackish water of 4 mS/cm have been shown to have impaired growth rates, while water of 20 mS/cm was lethal. The Waterfowl Subcommittee would like the March to July standard to be 4 mS/cm, but does not believe that current standards during that time period have been overly restrictive to the waterfowl resource. These salinity standards would mimic the historic conditions present when Sierra snow melt could decrease channel water salinity in the marsh to almost zero.

Currently a majority of water control structures and pipes in the marsh are steel. Increasing channel water salinity levels may make these structures rust out more rapidly and thus be in need of replacement more often. This directly translates to higher management costs to the landowner. Decreasing channel water salinity levels may slow down the decomposition of pipes and water controls.

Recommendations for Channel Water Salinity Standards

It is the opinion of this subcommittee that current salinity standards in Suisun Marsh are adequate for maintenance of existing habitat for the waterfowl resource. Although vegetation in the managed wetlands did show signs of salt stress during the recent 6-year drought, the habitat continued to attract and sustain waterfowl, and the vegetation in the managed wetlands has rebounded during the last few years of above-normal precipitation. If landowners can continue to upgrade their management capabilities, maintenance of waterfowl habitat does not seem to be critically impacted by the current channel water salinity, even in periods of drought. It would be advantageous for wetland managers if channel water salinity were lower in September and October so that initial flood-up could remove more soil salts that accumulate over the summer. It would also be beneficial to duckling survival if channel water salinity from March to July were lower. These changes, though not imperative, could provide benefits to waterfowl and their habitats in Suisun Marsh.

Introduction

Overview of Waterfowl Chapter

Suisun Marsh is an important habitat for wintering waterfowl and breeding ducks. To determine the effects of channel water salinity standards on waterfowl populations, the following factors were examined by this subcommittee:

- waterfowl census data 1953-1995;
- water requirements of waterfowl and how salinity of the water affects waterfowl use;
- food and cover requirements of waterfowl and waterfowl use of vegetation to meet those requirements;
- species of vegetation used by waterfowl and how salinity affects these plants;
- effects of water management on wetland plant communities;
- relationships between channel, pond, and soil water salinity; and
- necessary management structures and cost of structure maintenance.

The Waterfowl Subcommittee has operated under the following assumptions:

- The majority of waterfowl habitat in Suisun Marsh is in the diked, managed wetlands.
- The hydrology of diked wetlands (constant inundation for several months followed by several months with no surface water) has changed from their natural state (daily or periodic tidal action). Because of changes in hydrology, soil structure, and soil chemistry in the diked wetlands, plant communities are different and may consist of fewer species than those in tidal wetlands.
- Certain plant species provide the nutritional and/or physiological requirements of waterfowl and are critical for their survival.
- The factors primarily responsible for determining what plants are likely to grow in the diked wetlands are water management, applied and soil water salinity, and competition with other plant species.
- The results of studies on Suisun Marsh vegetation and waterfowl food habits conducted in the 1960s and 1970s (George and others 1965, Mall 1969, Rollins 1973, 1981) have shaped subsequent water management, water right rulings, and data collection and monitoring in Suisun Marsh.
- Soil water salinity can be high in the diked wetlands and tends to increase over time unless water management is used to keep it in check.

To facilitate making a recommendation on salinity standards, the Waterfowl Subcommittee examined three potential scenarios for salinity in Suisun Marsh:

1. no change from present channel water salinity levels;
2. decreasing channel water salinity levels from present; and
3. increasing channel water salinity levels.

Lastly, the subcommittee explored an area coined "the cost of doing business." These are the costs associated with the management of diked wetlands. The maintenance of levees and water conveyance systems requires constant work by landowners and managers, sometimes at great expense. Maintenance is necessary to maintain high quality managed wetlands in the marsh.

Historic Conditions for Waterfowl in Suisun Marsh

Suisun Marsh has long been an important wintering area for waterfowl of the Pacific Flyway. In 1853 a Pacific Railroad report referred to great flocks of geese in the Suisun Valley where "as far as the eye could reach the sky was filled with flock after flock" (Stoner 1937).

Market hunters began harvesting the waterfowl of the western Suisun Marsh about 1859 and monopolized these shooting grounds for the next 20 years. Under good conditions, a market hunter could shoot between 100 and 200 birds per hunt day (Arnold 1996), often shooting roosting birds at night. In 1879, the first private club was formed in the marsh, and from that time on private duck clubs were the primary use of the western marsh. Many of these lands were not diked until 1919. Beginning in 1870, most of the rest of Suisun Marsh (Grizzly Island, the islands south of Grizzly Island, and the northeast area of the marsh) was diked and developed as agricultural land. Starting in the early 1900s, agriculture became less productive due to upstream water diversions, large scale water projects, and increasing salinity in the marsh soils. As agricultural uses declined in the marsh, these lands became private duck clubs (Arnold 1996).

Recent counts and observations substantiate the marked decline of waterfowl numbers in the last 150 years. There are no waterfowl survey records until the 1950s, but Arnold (1996) cites some early hunt records that give a very rough sense of waterfowl abundance. One season in the 1880s was well documented at Tule Belle Club in the western marsh. Over a period of 166 hunter days, 2,324 birds were killed, an average of 14 birds/hunter/day. Arnold points out that these are not spectacular numbers given that there was no bag limit at that time. He adds that many of the birds shot that year would not be shot today, given their unpalatability, unpopularity, or legal protection (such as goldeneye, merganser, curlew, and shoveler). Deleting these species from the count lowers the average to about 9 birds/hunter/day. For the period 1882-1907, Ibis Club in the western marsh shot an average of 20 waterfowl/hunter/day (ducks, geese and swans, only) (Stoner 1937). Admittedly, many factors have changed in the ensuing years, but Department of Fish and Game lands in Suisun Marsh have recorded daily averages per hunter at 1.1 birds for the 1996 and 1997 seasons. Averages for Suisun Marsh duck clubs were 2.2 birds per hunter for 1996 and 1997.

The composition of species wintering in the marsh has also changed in the last 150 years. Again, these are not quantified changes, but both observation and kill records show that geese and canvasbacks are much less common in the marsh today (Arnold 1996). The decline in canvasbacks may be due to a flyway-wide phenomenon, but the decline in geese is attributed to changes in local conditions. In the past the Suisun valley was open lands and agricultural fields, which offered feeding opportunities for geese. Today, these open lands are greatly diminished, and what remains is no longer ideal foraging habitat for geese. In addition, many local waterfowl hunters noted a significant decline of geese in the marsh after large military transports from Travis Air Force began flying frequently over the marsh.

Historic Salinity Conditions in Suisun Bay

There is little empirical data on salinity conditions in Suisun Bay prior to the 1920s, when salinity intrusion into Delta channels became a threat to agricultural developments. In 1931, the California Department of Public Works published two reports (Bulletin 27, *Variation and Control of Salinity*, and Bulletin 28, *Economic Aspects of a Salt Water Barrier*) addressing this threat to the economic development of the State. The findings below are from these two documents except where otherwise cited.

The earliest known record of the salinity in Suisun Bay is from the summer of 1775 when a Spanish explorer reported non-potable brackish water in the upper part of Suisun Bay. Beginning in the 1840s, local residents found that during times of low outflow, saline water invaded the lower channels of the Delta to such a degree that the water at Antioch was unsuitable for domestic consumption (Thompson 1957). It is not known what salinity level early inhabitants considered unpalatable, but the current California Code of Regulations (Title 22, Sect. 64449) sets the secondary (taste, odor) maximum contaminant levels for drinking water salinity at 1.6 mS/cm.

Probably the earliest long-term record of salinity is from the California-Hawaiian (C&H) Sugar Refinery in Crockett. From 1905 to the 1930s, C&H obtained most of its water supply by filling barges with fresh water from points upstream of Crockett. Beginning in 1908, daily records were kept of the number of miles of upstream travel needed to encounter fresh water. Salinity measurements were made as parts of chlorine per 100,000 parts of water. Figure 3-1 shows that the fresh water collected was usually about 4 parts chlorine. It is apparent from the data in Figure 3-1 that much of Suisun Bay was fresh for at least 6 months in most years, and that during summer and fall salinity usually extended several miles upstream from the confluence of the San Joaquin and Sacramento Rivers.

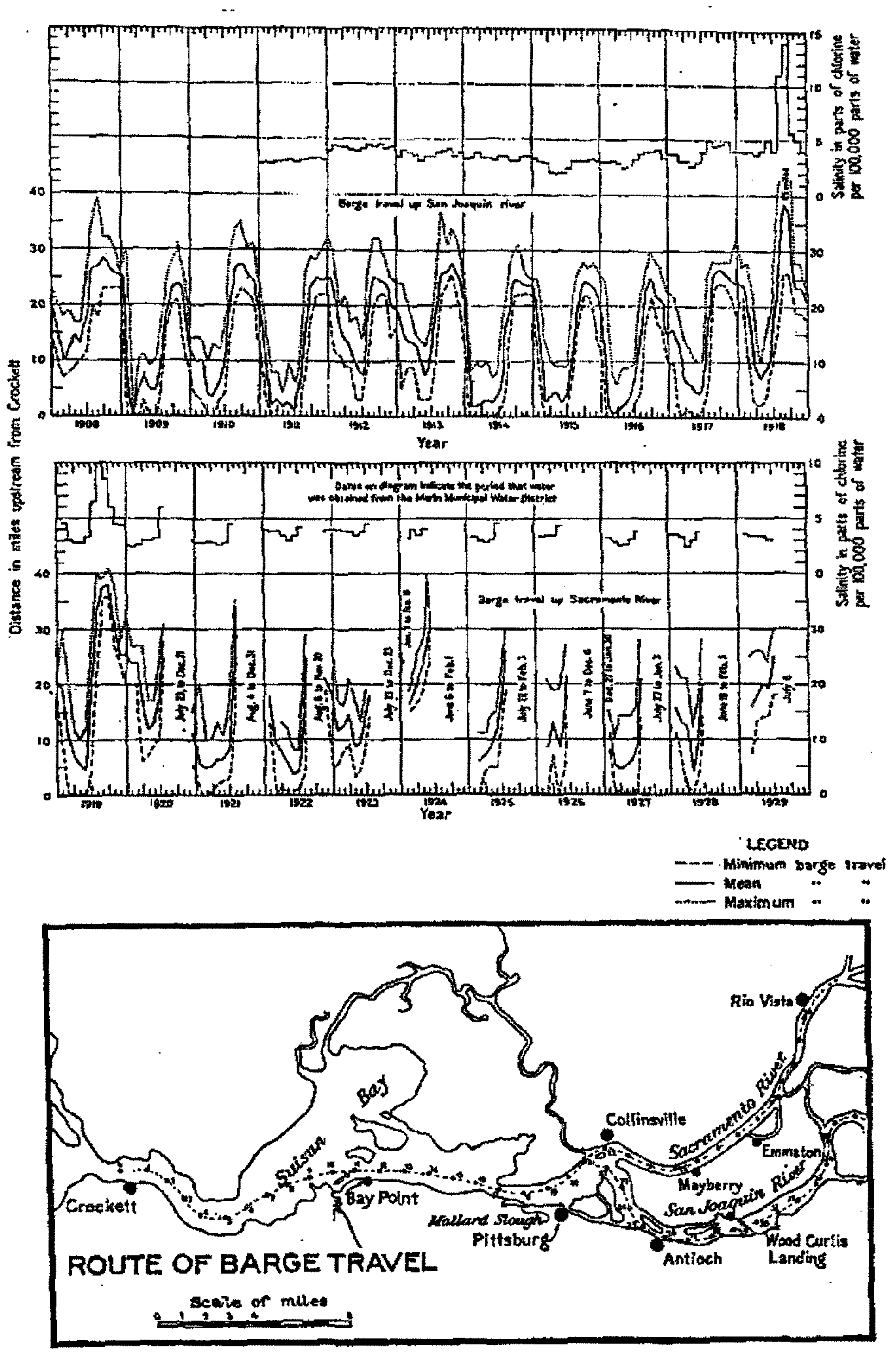

Figure 3-1 Records of C&H Sugar Refinery of Distance Travelled to Obtain Fresh Water, and Salinity of Water Taken, 1908-1929

From 1920 to 1931 salinity intrusion was more severe than in previous years, due to a combination of subnormal precipitation and increased upstream diversions. In years of low precipitation and outflow, such as 1920, 1924, 1926, 1931, 1934, and 1939, salinity increased in 20-70 percent of Delta channels, and late-season agricultural irrigations were curtailed (Thompson 1957).

For comparison with recent conditions, salinity at Collinsville was examined. To assist in interpreting this data, the 4 parts chlorine measurement from the C&H data set was translated to mS/cm using the Salinity Unit Conversion Equations in a DWR Memorandum (DWR 1986). The conversions are variable by station and by water year (increasing to the west and as outflow decreases), and for station C2 at Collinsville, 4 parts chlorine per 100,000 parts water is about 0.4 mS/cm. The C&H data show that in most years the salinity at Collinsville (22 miles upstream of Crockett) was usually greater than 0.4 mS/cm from August to January. There was some variability based on water year, but salinity always fell below 0.4 mS/cm in the winter months. More recent data from C2 show that patterns of salinity are much more variable. In wet years, salinity may exceed 0.4 mS/cm for only a month or two, and in critically dry years salinity may exceed 0.4 mS/cm for the entire year. However, the magnitude of annual changes in salinity was much greater in the C&H data set than in recent times, when water releases are used to prevent salinity intrusion into the Delta. The C&H records show that saline water extended into the lower channels of the Delta in varying degrees during a period of 3 to 9 months in almost every year from 1908 to 1920 (Figure 3-1, previous page).

There are even fewer records from the interior channels of Suisun Marsh, but the available historic information states that fresh water was not available throughout the irrigation season, and that fresh water was available for shorter periods of the year as upstream diversions increased. One record gives some indication of channel salinity in early years. Shortly after 1900, a tract of land on the southeastern portion of Grizzly Island was reclaimed by the construction of drains and the leaching out of soil salts by diversion of water from Montezuma Slough at a point about 3 miles below its confluence with the Sacramento River. Leaching was conducted over 5 or 6 years whenever water testing determined that fresh water was available in Montezuma Slough. Fresh water was usually available for 8 months per year (usually December through July). There is no indication what salinity level was considered “fresh,” but UC Cooperative Extension (UC and DWR 1984) cites a maximum salinity of 8 mS/cm for 75 percent yield of the most salinity-tolerant crops (cotton and barley), and less than 4 mS/cm for 75 percent yield of most vegetable crops such as the asparagus grown on Grizzly Island. It is also difficult to compare the historic record to current records, because there is no long term data set for salinity in Montezuma Slough. The monitoring station closest to the historic diversion point is S64, which collected almost no data prior to the installation of the Suisun Marsh Salinity Control Gates in 1988. At S64, with gate operations during the drought period between October 1988 and September 1992, channel water was under 4 mS/cm for only 7 months and under 8 mS/cm for 21 months. During the wet years 1993 and 1995, channel water at S64 exceeded 4 mS/cm only during October, November, and December.

Suisun Marsh Today

Suisun Marsh is a key waterfowl wintering area in the Pacific Flyway. Waterfowl commonly wintering in the marsh include northern pintail (*Anas acuta*), mallard (*Anas platyrhynchos*), American wigeon (*Anas americana*), green-winged teal (*Anas crecca*), northern shoveler (*Anas clypeata*), gadwall (*Anas strepera*), cinnamon teal (*Anas cyanoptera*), ruddy duck (*Oxyura jamaicensis*), canvasback (*Aythya valisineria*), ring-necked duck (*Aythya collaris*), greater scaup (*Aythya marila mariloides*), lesser scaup (*Aythya affinis*), bufflehead (*Bucephala albeola*), common goldeneye (*Bucephala clangula*), white-fronted goose (*Anser albifrons*), and Canada goose (*Branta canadensis*).

The Suisun Marsh is known to have high levels of waterfowl production (McLandress and others 1996). Data collected annually since 1985 show that nesting densities of mallards in the Suisun Marsh are higher than in most of their traditional production areas. McLandress and others found that mallard nest density in Suisun Marsh, at 190 nests/km2, was 4 to 23 times the density at other nesting areas in California and the prairie pothole region. Because of the significant nesting efforts by mallards, the Suisun Marsh is now valued as habitat for both resident and migratory waterfowl.

A primary management goal in Suisun Marsh is to create habitat that is attractive to waterfowl. This is accomplished by flooding diked wetlands in the fall and managing the water throughout the year to provide favorable conditions for the growth of waterfowl food plants. Therefore, this report focuses on these managed wetlands. Waterfowl come to Suisun Marsh to fulfill biological needs (breeding, nesting, and feeding). This report includes a discussion of these needs and how salinity can affect them.

Waterfowl Use of Tidal Wetlands and Managed Wetlands

Prior to the construction of dikes to "reclaim" the tidal wetlands of Suisun, waterfowl utilized the tidal marshes and ponds. The acreage of tidal wetland is now just over 6,000 acres, and there are few tidal ponds for waterfowl to utilize. Today, the majority of waterfowl in the Suisun Marsh occupy the diked wetlands, primarily because these are the areas that provide the open, shallow water preferred by waterfowl for feeding and resting.

The Waterfowl Subcommittee acknowledges that the historic configuration of tidal wetlands in Suisun Marsh provided habitat for wintering waterfowl. However, the majority of the wetlands in the marsh are currently diked and managed as waterfowl habitat. To restore these lands to their historic tidal nature would take a great deal of planning, expense, and effort. It is doubtful that restored tidal wetlands would be as beneficial to waterfowl as the existing diked wetlands. Although large scale tidal restoration may be the vision of some for Suisun Marsh, it is many, many years into the future. Because the habitats that waterfowl use today are managed wetlands, this is the habitat and management addressed in this chapter.

Waterfowl Numbers

Waterfowl Data Collected from California

Waterfowl have been identified as an important component of the fauna of Suisun Marsh. The primary reason for the establishment of salinity standards in the Suisun Marsh was to maintain high quality waterfowl habitat. DFG has been collecting waterfowl abundance data in Suisun Marsh since the 1950s. These data were analyzed to document how waterfowl abundance has changed in the marsh over time. Data prior to the 1950s was not collected systematically and is not considered valid for these analyses.

Waterfowl numbers throughout the Pacific Flyway declined from the mid-1980s through the early 1990s. This decline has been attributed to loss of breeding habitat due to an extended drought in the north central United States and south central Canada and to widespread conversion of shortgrass prairie to agriculture (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1995). Within California, fall and winter waterfowl numbers from 1987-1996 averaged 3.2 million. In 1996, due to excellent conditions on the primary breeding grounds, numbers reached 4.3 million, the highest number since 1984 (Figure 3-2).

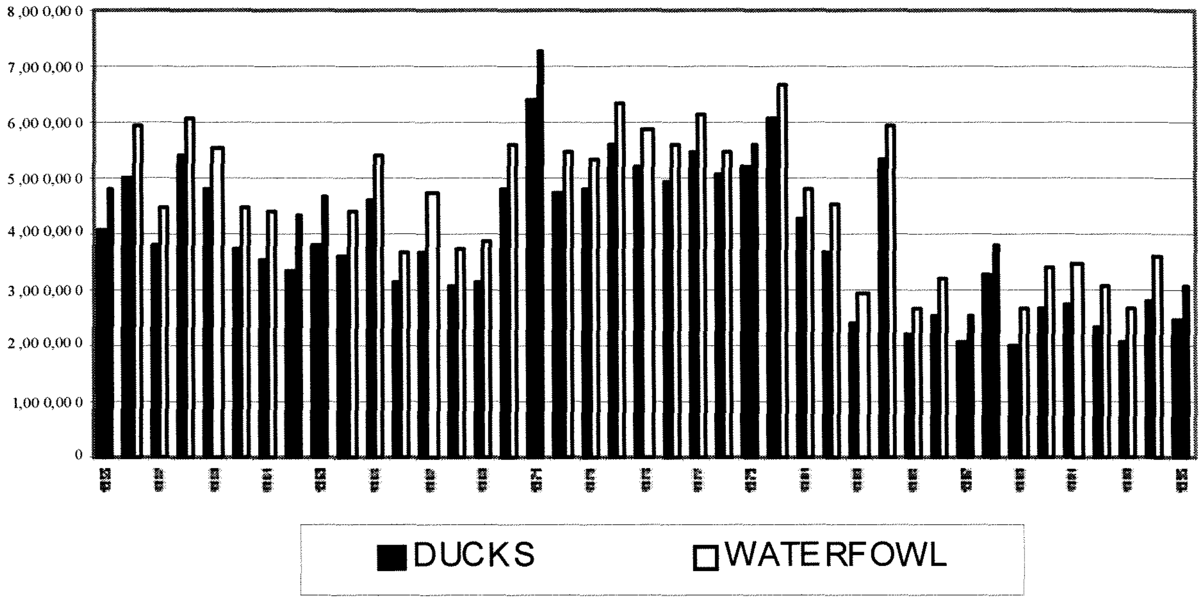

Figure 3-2 Number of Ducks and Waterfowl in California During January Counts, 1955-1995

Waterfowl distribution in California is not uniform, with most of the waterfowl wintering in the Sacramento and San Joaquin Valleys (Central Valley). Analysis of waterfowl count data compiled from 1953 through 1995 by the U.S. Fish and Wildlife Service documents that the Central Valley supports an average of 3.8 million birds, or 75 percent of all the birds counted in California (unpublished DFG data, DFG 1996a). In some years more than 90 percent of all the birds counted in California are found in the Central Valley.

Suisun Marsh also supports a large number of waterfowl throughout the winter. On average (1953-1995) Suisun Marsh winters slightly more than 215,000 waterfowl in January. The bulk of these ducks are pintails, which account for nearly 50 percent of all the waterfowl recorded. Because Suisun Marsh is protected as a wetland, the habitat is much more reliable for waterfowl than the flooded agricultural fields of the Central Valley, which are vulnerable to changes in cropping patterns, economics, and zoning.

Comparing total waterfowl numbers from Suisun Marsh and the Central Valley is problematic because wetlands are scattered over a very large area and flooded agricultural acreage changes from year to year. The National Biological Service estimated the quantity of suitable waterfowl habitat in the Sacramento Valley to be just over 1.1 million acres (Orthmeyer and others 1989), which supports an average of 2.75 million waterfowl in January (DFG 1996a). This translates to 2.5 birds per acre in the Sacramento Valley (Figure 3-3). The San Joaquin Valley (Grassland Ecological Unit plus the Mendota Wildlife Area) is approximately 165,000 acres (John Beam, pers. comm.) and supports slightly more than a million birds for an average of 6.1 birds per acre. The Suisun Marsh managed wetlands comprise approximately 52,000 acres and support approximately 215,000 waterfowl for an average of 4.1 birds per acre (DWR 1984 and DFG 1996a). While the long-term average is 4.1 birds per acre in Suisun Marsh, that trend is decreasing and over the last 20 years the marsh has supported about 2.7 birds per acre. It is suspected that these declines are due in part to increasing acreage of winter-flooded agricultural fields which draw ducks from traditional areas like Suisun Marsh.

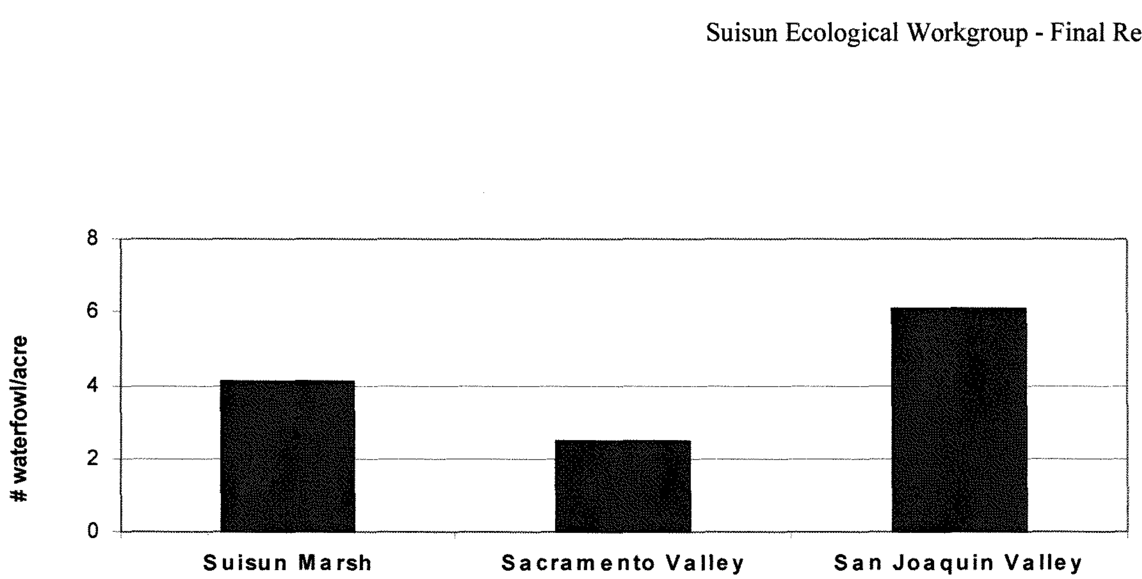

Figure 3-3 1953-1995 Average Results of Waterfowl Counts in Three Areas of California Translated to Waterfowl/Acres

Waterfowl Data Collected from Suisun Marsh

Beginning in 1953, DFG counted waterfowl numbers in Suisun Marsh in September only; however, in 1958, the survey effort was expanded to include September through January. These counts are done from an aircraft flown 100 to 150 feet above the ground at 90 to 105 miles per hour (USFWS 1987). Observers estimate the number and species composition of all waterfowl species within 1/8 of a mile on either side of the plane (1/4 mile total width).

Initially the Waterfowl Subcommittee ran statistical analyses (ANOVA) of rainfall and waterfowl survey numbers in an attempt to draw correlations between water year types and numbers of waterfowl in the marsh. Due to the variability in weather conditions and survey locations, the data sets could not yield significant correlations. For this reason the ANOVAs provided in the interim report have been removed. The population numbers below have been included without analysis to provide an index of the numbers of pintails, mallards, and total waterfowl that occur in Suisun Marsh.

Over the period of record, 1958 through 1995, waterfowl counts within Suisun Marsh have been highly variable (DFG 1996a). Since the mid-1960s the general trend for total waterfowl (ducks, coots, geese, and swans) abundance has been decreasing. Numbers of ducks and waterfowl counted in Suisun Marsh during midwinter (January) count from 1958 to 1995 are shown in Figure 3-4. Despite factors such as weather, timing of the counts, numbers of observers, and flight lines, which can affect the counts, the data document a marked decline in waterfowl abundance. Data ranges and averages for pintails, mallards, and total waterfowl from 1958 to 1995 are shown in Table 3-1.

Waterfowl Ecology at Varied Channel Water Salinity Levels

Life requisites of watefowl considered to be resident and/or migratory are addresssed below. Efforts to examine the effects of varied channel water salinity levels on waterfowl ecology will be addressed. The following text on waterfowl ecology is written from the perspective of what critical habitat elements are currently available under existing standards. Possible outcomes of decreasing or increasing channel water salinity beyond existing standards are discussed.

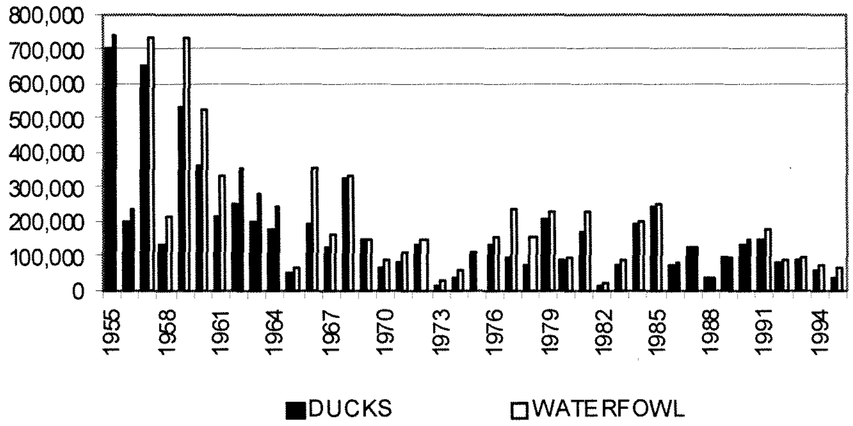

Figure 3-4 Number of Ducks and Waterfowl in Suisun Marsh During January Counts, 1955-1995

Table 3-1 Range and Average of Waterfowl Counted in Suisun Marsh Surveys, 1958-1995

	Pintails			*Mallards*			*Total Waterfowl*		
	High	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Average*
September	128,800	635	26,998	16,330	315	3,804	159,175	5,170	36,594
October	995,985	11,186	182,501	61,415	238	13,776	1,151,950	33,165	241,523
November	730,770	17,303	210,875	112,000	2,425	16,439	828,330	53,057	299,536
December	1,027,050	15,476	206,941	49,765	140	14,396	1,497,943	52,440	329,069
January	537,639	1,675	101,636	53,400	95	13,507	741,575	15,905	215,480

Food Requirements of Waterfowl

Dabbling Ducks. Dabbling ducks (ducks that tip to feed—mallards, pintail, green-winged teal, and gadwall) utilize a variety of seed, vegetation, and invertebrate foods to satisfy their nutritional needs. The use and availability of these foods often vary seasonally. Dabbling ducks prefer to use areas where average water depth is 6-8 inches (15-20 centimeters). Dabbling ducks rely heavily on seeds as food in fall and winter and shift to more invertebrate and some vegetation foods in spring and summer.

Increasing channel water salinity above current brackish levels reduces the diversity of plant types available as waterfowl foods in the managed wetlands (Rollins 1981, Mall 1969, Payne 1992). The resulting increase in homogeneity (dominance of pickleweed, *Salicornia virginica*, community) most likely would cause waterfowl currently using the marsh to seek their seed food requirements elsewhere. If birds have to move from place to place to find adequate food resources, their energy reserves necessary for winter survival, spring migrations, and nesting needs may be seriously depleted. It is likely that increasing salinity would affect dabbling ducks more than diving ducks as divers eat more invertebrates rather than the seed producing plants preferred by dabblers. The application of water of existing or decreasing salinity levels would maintain a diversity of plant species. A diversity of plant species in turn would help to provide a wide variety of food types, each becoming available at a different time during fall and winter. Plant diversity also provides a more varied invertebrate assemblage.

Invertebrate foods provide an important source of protein needed by waterfowl for egg laying and for feather growth of both ducklings and adult birds. The Suisun Marsh studies done by Batzer and others (1993) identified *Chironomid* midges (specifically *Chironomus stigmaterus*) and seed shrimp (*Ostracoda*) as the preferred invertebrate food items consumed by mallards and green-winged teal on the Grizzly Island Wildlife Area. Also consumed were water beetles (*Coleoptera*), water bugs (*Hemiptera*), and amphipods (*Amphipoda*). Batzer and others (1993) reported that the dominant species of invertebrates found in the brackish habitats of Suisun Marsh and the diets of local mallards were similar to those species found in freshwater habitats of California's Central Valley. There is very little data on invertebrates and their salinity tolerance levels, but there are data on the habitats that invertebrates occupy and the salinity levels of those habitats.

Generally, it appears that the makeup of invertebrate species found in Suisun Marsh would not change significantly with decreasing salinity levels. It is not known what effect decreasing salinity levels would have on the number of invertebrates produced per unit area. It does appear that increasing salinity levels would decrease the species diversity first and eventually the species abundance of Suisun Marsh invertebrates. Studies in South San Francisco Bay salt ponds indicated that the abundance of invertebrates in these same ponds exhibited an inverse relationship to salinity levels (SF Estuary Project 1991). It was found that as the salt content increased, the number of species decreased.

Reducing the abundance and/or diversity of invertebrates available to Suisun Marsh waterfowl could slow the development of feathers on ducklings produced in the area, rendering them flightless for longer than the traditional 60 days documented by Gollop and Marshall (1954) as the time period necessary for mallard ducklings to attain flight stage. Ducklings potentially would have to forage over a greater area to find enough invertebrates to satisfy protein demands and could then be exposed to a greater likelihood of being predated. Molting adults could be similarly affected. As dabbling ducks constitute the majority of Suisun Marsh nesting waterfowl, it is believed that they would be most affected by a reduction in numbers or diversity of invertebrates. However, fall and winter migrants, especially cinnamon teal and shoveler, and spring migrants of all species would be adversely affected by a lack of protein food sources.

Diving Ducks. Diving ducks (canvasback, redhead (*Aythya americana*), common goldeneye, ring-necked duck, greater scaup, lesser scaup, bufflehead, and ruddy duck) eat mostly snails, clams, and assorted invertebrates, but also utilize plant root materials (tubers), vegetation, and seed foods made available preferably in deeper water habitats (approximately 3-10 feet/1-3 meters in depth). Most diving ducks use Suisun Marsh only during fall and winter. A decrease in channel water salinity would not cause significant changes in diver habitat.

Increasing salinity in a deeper water habitat would most likely reduce the diversity of plant types available as waterfowl food. Submerged aquatic plants like sago pondweed (*Potamegeton pectinatus*) and wigeongrass (*Ruppia maritima*) can withstand higher salinity levels (14.0-19 mS/cm, soil water salinity for sago, and 14.0-19 mS/cm, pond water salinity for wigeongrass) and still produce nutletts (Rollins 1981, Neely 1962). Sago pondweed provides a host site for midge larvae (Euliss and Grodhaus 1987). Invertebrates are also an important source of protein as described in the section on dabbling duck foods. The primary change in deeper water habitats with increasing salinity may be in habitat structure. Over time, emergent vegetation like cattails (*Typha* spp.) and tules (*Scirpus* spp.) may decrease. Flooding a marsh during most of the growing season with water of 10 ppt (15.5 mS/cm) salinity kills cattails (Sojda and Solberg 1993). This may reduce the attractiveness of impounded deep water habitats to divers.

Geese. Several species of geese frequent Suisun Marsh. A majority of the geese use the marsh during fall and winter, but Canada geese use the marsh year round, reaching peak population in late winter. Much of the habitat available for geese in fall and winter is grown during spring and summer. The most common geese observed on the marsh are Canada geese and Pacific greater white-fronted geese (PGWFG, *Anser albifrons frontalis*). The Tule white-fronted goose (tule goose, *Anser albifrons gambelli*) is a subspecies of the PGWFG that winters only in a few select areas of California, Suisun Marsh being one of those areas. The Tule goose population is believed to be 5,980 geese (range of 4,332-7,628 in USFWS yearly surveys, September 1995). At times Suisun Marsh held a significant portion of this population (1,500 to 2,000 geese).

Geese are grazers and granivorous. Canada geese browse on the young shoots of salt grass (*Distichlis spicata*) around the margins of pond units and in planted grain fields of managed uplands. Although grain crops are the preferred foods for Canada geese in other flyways, they are known to forage on various roots, stems, and seeds of spike rush (*Eleocharis* spp.) and the roots, rhizomes, and seeds of bulrush (*Scirpus* spp.) (Bellrose 1980). A study in Missouri (Bellrose 1980) found the following in Canada geese diets: wild millet (36 percent), smartweed seeds (10.1 percent), cut grasses (10.2 percent), spike rushes (8.3 percent), winter wheat (6.1 percent), corn (5.5 percent), nutgrasses (4.8 percent), and soybeans (3.2 percent). Some of these plants are found in Suisun Marsh.

Increasing salinity in the marsh would most quickly affect species like smartweed (*Polygonum* spp.), watergrass (*Echinochloa* spp.), and swamp timothy (*Heleochloa shoenoides*). This would most likely be witnessed first as a lower seed yield, and then the disappearance of these species altogether. As salinity continues to increase, the next plant species likely to be affected would be alkali bulrush (*Scirpus maritimus*), fat hen (*Atriplex triangularis*), and brass buttons (*Cotula coronopifolia*). Eventually pickleweed/sea purslane (*Sesuvium verrucosum*)/saltgrass communities would dominate, resulting in less natural seed and shoot foods available for Canada geese. Barley and wheat are planted in late fall and rely on rainfall for moisture. These crops are generally not flood irrigated in Suisun Marsh because the application of channel water with elevated salinity can increase surface soil salinity in the fields, reducing both the rates of seed germination and seed production. Thus the availability of these cereal grains should not vary much with increasing channel water salinity. How well saltgrass and pickleweed can fill the green feed browse needs of Canada geese is not known. The studies of Korschgen indicated that grasses made up 10 to 11 percent of

Canada goose diets (Bellrose 1980). Again as with dabbling ducks, the Canada geese will probably be most affected by the loss of seed foods caused by increased salinity.

PGWFG and Tule geese are not identical in their food preferences despite the fact that the Tule goose is a subspecies of PGWFG. PGWFG feed extensively on seed foods and less on green foods (Bellrose 1980). Tule geese eat seed foods as well as the starchy roots of alkali bulrush. It is a common sight in Suisun Marsh to see bulrush plants uprooted and floating on the pond surface in the areas where Tule geese have been feeding (Cann, pers. comm.). Longhurst (1955) recorded that "Tule geese were feeding primarily on the tubers and rhizomes of *Scirpus* which they pulled up from the mud beneath water that was as much as one and one half feet (30-46 cm.) in depth. At one spot almost all the rushes over an area of approximately one hundred and fifty square feet had been uprooted." The roots of alkali bulrush are reported to make up as much as 5-10 percent of Tule goose diets (Martin and others 1961). Increasing salinity could decrease seed production and abundance of seed bearing plants that PGWFG and Tule geese wintering in Suisun Marsh depend upon. Decreasing salinity would help to maintain and eventually increase the abundance and diversity of these seed producing plants. Since 1992 wintering numbers of PGWFG and Tule geese in the Grizzly Island Wildlife Area have declined, as has the harvest of these species (Cann, pers. comm.). It is not known if changes in habitat conditions in the Suisun Marsh are responsible for this decline or the population is responding to improved habitat conditions in the Central Valley.

Swans. Tundra swan (*Cygnus columbianus*) winter in limited numbers (peak of 500-1,000 individuals) in Suisun Marsh. Areas frequented by swans include Joice Island and the Garibaldi properties along highway 680. Joice Island provides more than 400 acres (162 hectares) of deep water habitat with a plentiful crop of sago pondweed. Tundra swans in the Chesapeake Bay feed on wigeongrass, sago, and clasping leaf pondweeds (Bellrose 1980, Stewart 1962). In the Great Salt Lake marshes the tubers and seeds of sago pondweed were almost exclusively consumed by swans (Bellrose 1980). Another 1,400 acres (566 hectares) of shallow to mid level wetlands exist on Joice Island providing bulrush, sea purslane, and some cattails. The Garibaldi properties support primarily pickleweed with a limited amount of bulrush and cattails. The current owner farms and feeds grain to wintering Canada geese on the upland portion of his property which is attractive to the swans.

Wigeongrass is more salt tolerant than most marsh plants. Increasing salinity would probably not affect this plant in the short term. Sago pondweed is documented to exist at low to moderate salinity levels; thus, lowering salinity levels in the marsh would not adversely affect sago pondweed production. Increasing salinity levels could cause this plant to decrease in abundance over time. It is difficult to say how swan use of Suisun Marsh would change with varied salinity levels. If swan use of Suisun Marsh is directly tied to the availability of sago pondweed, swans would be expected to continue to use Suisun Marsh until salinity levels exceeded the tolerance level of sago pondweed.

Water Requirements

Salt Content of Free Water for Drinking. Ducklings (1-14 days old) are most vulnerable to increasing salinity levels. Mallard ducklings subjected to a water salinity level as low as 4 mS/cm have impaired growth rates (Mitcham and Wobeser 1988). Water with conductivity of 20 mS/cm is lethal to mallard ducklings. It was also noted that saline wetlands able to provide free water below 4 mS/cm would not adversely affect duckling development.

Waterfowl brood data available for Suisun Marsh is being examined in relation to known channel water salinity. Data from the long term cooperative project (1985-present) between DFG and the California Waterfowl Association conducted in the Grizzly Island Wildlife Area (GIWA) is presented in Table 3-2. Channel water salinity in the form of the progressive daily mean (PDM) was used from the S-71 site on

Montezuma Slough near the intake to the Roaring River Distribution System. The PDM data was averaged for the period most critical to waterfowl ducklings (March-July) and the range given as well to more clearly depict variability in channel water salinity. Station S-71 had the most complete data set for the time period 1985 to present and is fairly close geographically to the Grizzly Ditch intakes that supply much of the water utilized in the GIWA. Plans were to statistically analyze these data to see if correlations exist between average brood size and channel water salinity. There appear to be some weak relationships between average number of nests per acre and channel water salinity. The surveys assembled in Table 3-2 were not designed to examine brood survival in relation to channel water salinity. The Waterfowl Subcommittee believes that the data merit further examination. The subcommittee also recommends a study to relate Suisun Marsh brood survival to channel water salinity.

Table 3-2 Grizzly Island Wildlife Area Mallard, Rainfall and Channel Water Salinity Data 1985-1996

Year	*Fairfield Cumulative Annual Rainfall (inches)*	*S-71 Salinity March - July mS/cm*	*Salinity Range mS/cm*	*Overall Mayfield Nest Success (%)*	*Average # of Nests Per Acre*	*Average # of Nests Per sq. Km.*	*Average Brood Size Class I (1-18 days)[1]*	*Sample Size of Class I Broods [1]*
1985	15.85	No Data	No Data	58	0.72	179	5.53	110
1986	27.82	0.89*	0.24 -2.05	39	0.92	227	5.26	105
1987	10.10	4.08	1.61 - 8.90	50	0.81	200	4.99	192
1988	16.30	9.55	6.62 - 12.40	25	0.75	184	5.15	162
1989	13.81	3.08*	1.28 - 5.25	08	0.64	158	5.66	95
1990	13.44	6.38*	5.14 - 8.51	35	0.41	101	5.51	222
1991	14.11	5.36*	2.29 - 9.99	48	0.60	148	5.41	112
1992	17.37	6.90	1.28 - 12.50	48	0.75	185	5.75	73
1993	29.64	0.50	0.20 - 1.30	31	1.29	319	6.32	38
1994	11.90	4.38	0.40 - 9.90	29	2.03	501	6.31	32
1995	31.18	0.13*	0.10 - 0.20	38	2.02	499	6.03	34
1996	-	0.57	0.10 - 2.10	33	1.78	440	6.68	56
Average	18.32							

15 percent Mayfield nest success needed to sustain mallard population.

* Indicates Less than 5 monthly PDM's in sample.

[1] Age classes as in Gollop and Marshall 1954.

Functional Use of Water

Brood Water. See water requirements of mallard ducklings, above. Functionally, any deep water would provide protection from terrestrial predators. However, emergent escape cover is also required as part of good brood habitat to hide ducklings from predators and increasing salinity levels would most likely negatively impact emergent vegetation growth. Decreasing salinity levels would be conducive to producing the emergent vegetation required for good brood habitat.

Pair Water. Pair water is used by waterfowl during the breeding season to formulate and cement social status (pair bonding). Pair water can take many shapes but ditches that have many turns in them and emergent vegetation that help to separate pairs of ducks from each other's sight seem especially suited for this purpose. In the GIWA pair water is provided in spring in and around upland fields. In years of elevated applied water salinity, fewer ditches and ponds are flooded and therefore less pair water is provided because it can increase soil water salinity. Usually water quality in early spring under current standards is good enough to use for pair water without adversely affecting soil salinity. There are no data to indicate if saline water is physically good or bad as pair water. It is known that less pair water is made available by managers if it would elevate existing soil water salinity. Increasing salinity of available water in spring would therefore reduce the amount of pair water provided on the marsh. Decreasing salinity levels would probably increase the amount of pair water made available by managers in the marsh, thereby benefitting waterfowl and a host of other water-associated wildlife.

Sheet Water and Puddled Habitats. These habitats serve various purposes for waterfowl. Sheet water refers to large expanses of very shallow flooded areas available as waterfowl foraging areas or pair water. Puddled habitats, as the name implies, are areas usually created by abundant rainfall that provide fresh water feeding opportunities for waterfowl such as invertebrate or waste grain areas. Since these habitats are usually the result of abundant rainfall and are seldom created by wetland managers on the marsh, changing channel water salinity levels would not really affect this habitat type.

Functional Uses of Cover

Vegetation, particularly in the form of aquatic emergents, provides shelter against the elements. Thermoregulatory costs are high in winter and waterfowl seek refuge from high wind and low temperatures in emergent vegetation. During the molting phase waterfowl experience a flightless period lasting approximately 3-5 weeks and depend on large patches of robust emergent vegetation to avoid predators (Ringelman 1990). Young ducklings in particular are vulnerable to predation and use wetland vegetation as a means of escaping predators (Sedinger 1992).

Mallard Molting Habitat. Waterfowl choose large expanses of relatively deep water interspersed with thick cover to remain safe from predators during the flightless period when they are molting their wing feathers. Joice Island pond A, owned and managed by DFG, is a cooperative project with Ducks Unlimited (DU) and has been managed as a deep water habitat since 1991. The unit has sprouted emergent vegetation and supports a good summer crop of sago pondweed. This unit has become a productive brood pond and serves as a molting habitat for waterfowl, mallards, and gadwall in particular. Preferred cover to open water ratios for waterfowl molting habitat are between 50:50 and 70:30 (Ringelman 1990). Trapping and banding programs run cooperatively by DFG and the California Waterfowl Association (CWA) have captured large numbers of adult mallards on pond A (CWA 1995). Decreasing salinity levels would help to maintain and perhaps improve plant diversity in these habitats. Increased channel water salinity in these areas may eventually reduce the amount of emergent vegetation thus decreasing their attractiveness as a molting habitat.

Mallard hens have been radio marked in Suisun Marsh and tracked in a post-breeding molt migration to the large lakes of northeastern California and southern Oregon (Yarris and others 1994). The energy necessary to complete a post breeding molt migration is greater than remaining in the marsh and this most likely affects mallard winter survival. Existing channel water salinity or decreased channel water salinity would provide the water quality necessary to create the deeper water/emergent vegetation habitats preferred by molting hen mallards.

Nesting Habitat. Nesting habitat is available in large upland parcels at GIWA (1200 contiguous acres/485 hectares) and around pond margins in a majority of Suisun Marsh. Nesting cover for overwater nesters (cattails and tules) is available in limited quantity in the marsh. Increasing salinity eventually may reduce emergent vegetation for overwater nesters. Over water nesters make up a minority of waterfowl successfully producing young in the marsh.

As previously mentioned, mallards are the majority nester in the marsh. Gadwall, northern shoveler, northern pintail, cinnamon teal, wood ducks (*Aix sponsa*), ruddy ducks, and Canada geese are known to produce young locally. Only Canada geese are documented as having demonstrated a preference for habitats that are more open than the majority of nesting habitat available in Suisun Marsh. Ringelman (1990) reported that an openwater to vegetation ratio of 90:10 or higher was attractive to Canada geese.

Upland nesting sites are most often irrigated only by precipitation; they would not be directly affected by increasing channel water salinity. Those areas immediately adjacent to ponded areas and over water nesting habitats would be directly affected by increasing salinity. Increasing salinity in pond margins would discourage nesting cover like rye grass (*Lolium* spp.), vetch (*Vicia* spp.), and bromegrass (*Bromus* spp.) and encourage more pickleweed and saltgrass to grow. Pickleweed is not considered to be good nesting habitat. Decreasing salinity would allow for grasses and legumes to spread to pond margins and eventually increase available nesting cover in the marsh. Grasses and legumes like rye, brome, and vetch (*Vicia* spp.) are considered to be good waterfowl nesting cover when present together (Bellrose 1980).

Vegetation

The success of waterfowl life cycle events such as reproduction, molt, and migration are dependent on the availability and quality of food and cover. Plants provide both nutritional and physiological requirements of waterfowl and are critical for their survival. Waterfowl have diverse needs for recruitment and survival that vary from species to species and throughout the annual cycle. Wetland complexes that offer a variety of wetland types and plant assemblages have the best chances of meeting all of these requirements (Fredrickson and Laubhan 1994).

The Importance of Plants in the Diked Managed Wetlands to Waterfowl in Suisun Marsh

The distribution of vegetation in the diked managed wetlands of the Suisun Marsh is influenced primarily by three factors—the length, depth of soil submergence, and the salinity of soil water in the root zone (Mall 1969). Hydrologic regime probably has the greatest influence on plant distribution, while soil salinity can limit the relative shoot density (and survival) of a given plant species. Rollins (1973) determined that soil salinity is largely dependent on the salinity of the water applied on wetlands for management but is also influenced by water management capability (i.e., flood/drain structures, ditch capacity) and activity (i.e., timing, length, duration of flooding).

At present, waterfowl management on privately-owned wetlands in Suisun Marsh is extremely variable. Management ranges from properties that are intensively managed by a year-round resident keeper to properties that are simply drained following the waterfowl hunting season in late January and not reflooded until the following waterfowl season (the beginning of October). Some landowners drain their wetlands after the waterfowl hunting season and then re-flood and drain at least once from February until June because this leaching process can reduce the soil salinity in the root zone.

Suisun Marsh varies both spatially and temporally in salinities of channel water used to flood managed wetlands. Most landowners/managers manipulate the length and depth of soil submergence to encourage the production of target plant species that provide food for wintering and staging waterfowl such as alkali bulrush, fat hen, and brass buttons. Other Suisun Marsh plants important in the diets of waterfowl include lamb's quarters (*Chenopodium album*), sea purslane, wigeongrass, and watergrass. The leaves of pickleweed are thought to be consumed by wigeon and gadwall; however, recent research has revealed that the importance of pickleweed in the feeding ecology of waterfowl wintering in Suisun Marsh may lie in its ability to harbor high numbers of aquatic invertebrates in its complex branching system (De Szalay and Resh 1996).

Robust emergent plants that offer waterfowl good cover from predators and inclement weather include alkali bulrush, hard-stem bulrush (*Scirpus acutus*), narrow-leaved cattail (*Typha angustifolia*), broad-leaved cattail (*T. latifolia*), American bulrush (*Scirpus americanus*), and baltic rush (*Juncus balticus*).

Alkali Bulrush *(Scirpus maritimus).* Alkali bulrush has been the focus of management in Suisun Marsh for the last 30 years. Mall (1969) first documented alkali bulrush as having the highest overall use by Suisun Marsh pintail and mallard, although pintail in the nearby Sacramento Valley were found to rely little on alkali bulrush (*Scirpus palodosus*) (Miller 1987). (There are several *Scirpus* species with the common name alkali bulrush including *S. palodosus, S. maritimus,* and *S. robustus.*) Saltmarsh bulrush (*S. robustus*) growing in diked brackish marshes in South Carolina is the most important food plant for wintering pintail, mallard, and black duck (*Anas rubripes*) (Prevost and others 1978).

Brackish marsh impoundments along the Atlantic Coast are managed intensively for the closely related *S. robustus*. Tidal impoundments include stands of saltmarsh bulrush on higher flats and wigeongrass and dwarf spikerush (*Eleocharis parvula*) at lower elevations (Neely 1962, Landers and others 1976, Prevost and others 1978, Gordon and others 1989, Loesch and others 1989).

Alkali bulrush is able to tolerate large seasonal salinity changes; however, monitoring results in Suisun Marsh show that when soil water salinity rises above 25 mS/cm, alkali bulrush occurrence is very low. Low spring salinities are important for the successful germination and seed-set of alkali bulrush. Dietert and Shontz (1978) reported that the germination of *S. robustus*, a close relative of *S. maritimus*, was most successful when water salinities were close to 0 mS/cm. A 50 percent reduction in seed germination occurred when water salinities were between 8-15 mS/cm while no seed germination was observed at salinities of 35 mS/cm. Prevost and Gresham (1981) found similar results for *S. robustus* in which experimental blocks with the lowest water salinities (14 mS/cm) had the most seedlings compared to blocks with salinities of 33 mS/cm. Although excessive salinity concentrations reduce seed germination, salt tolerance during seed germination may be correlated with tolerances during later stages of plant development (Bolen 1964). In natural brackish conditions, alkali bulrush is found in areas of moderate salinity (7-14 mS/cm) because, although it germinates best at very low salinities, it cannot become dominant since other plants such as cattails have a competitive advantage there.

High salinity concentrations have been found to limit not only bulrush seed germination but plant growth as well. Occurrence of *S. robustus*, for example, was found to be limited where salt impaired both growth and photosynthetic rates (Pearcy and Ustin 1984, Ustin and others 1982). Toxic salinity levels, however, are difficult to determine because preconditioning of the plant and environmental physiological factors may alter levels of tolerance (Haller and others 1974). A literature search revealed that *S. maritimus* tolerates a wide range of applied water salinities (Table 3-3).

Fat Hen *(Atriplex triangularis).* Fat hen, a member of the goosefoot family, is also a significant waterfowl food in Suisun Marsh (Rollins 1981). It is a prolific seed producer that tolerates only short periods of inundation. Fat hen typically thrives in highly saline soils and is a management target for only a few clubs, although it often grows on edges of ponds drained later in the summer.

Mall (1969) indicated that fat hen was dominant in annual soil salinities ranging from 13-49 ppt TDS (approximately 20-77 mS/cm), and that seeds germinated in soils with a salinity of about 14 ppt TDS (approximately 22 mS/cm).

Table 3-3 Salinity Ranges of *Scirpus maritimus* Where Cl is the Dominant Anion*

Salinity range (mS/cm)	*Reference*
4.3-4.5	Lundegardh-Ericson 1972
5	Flowers 1973
4.45-5.34	Mercado et al. 1971
0.18-5.96	Van Wijk 1988
7	Barnes et al. 1971
8	Vestergaard 1985
8.2	Lieffers 1984
9.0	Shubert 1982
2.56-9.08	Smeins 1967
3.9-9.3	Grillas and Duncan 1986
3.2-9.6	Ferren 1985
10.0	Harshberger 1911
1.5-13.5	Kruger and Kirst 1991
7.5-14.0	Olsen 1945
2.6-14.2	Kadlec 1982
16.0	Gillham 1957
19.6	Christiansen and Low 1970
3.0-20.0	Zenkevitch 1963
21.7	Podlejski 1981
4.3-23.5	Verhoeven and van Vierssen 1978
2.4-25.9	Wright et al. 1949
31.95	Tansley 1922
5-55.0	Richardson 1980
67.5	Millar 1976

*Table adapted from Kantrud 1996

Brass Buttons ***(Cotula coronopifolia).*** Brass buttons, an exotic plant naturalized from South Africa, is a low-lying perennial herb common in Suisun Marsh particularly in mechanically disturbed sites. In a feeding ecology study conducted by DFG (Mall 1969), brass buttons was identified as the second most prevalent food item found in the gizzards of waterfowl. Recent research in Suisun Marsh revealed that pintail made heavy nocturnal use of wetlands dominated by brass buttons suggesting that pintail may be foraging on this plant (Casazza 1995).

Brass buttons are dominant in soils with annual salinities ranging from 9-30 TDS (approximately 14-48 mS/cm) (Mall 1969).

Sea Purslane ***(Sesuvium verrucosum).*** Sea purslane is a low-growing, fleshy plant that produces an abundance of tiny seeds. It typically thrives on highly saline soils and stands often develop on coastal areas under severe drought conditions. Sea purslane is common in Suisun Marsh, particularly in the late summer when it fills in areas of bare ground. In South Carolina, the high-protein seeds were found to be a preferred food of blue-winged teal (*Anas discors*), green-winged teal, and pintail (Swiderek and others 1988).

Sea purslane can withstand relatively high soil salinities and is abundant where soil salinities exceed 10 ppt (approximately 24 mS/cm). Swiderek and others (1988) propose that this plant is suitable for culture in brackish impoundments for waterfowl food because of its tolerance to high soil salinities and its nutritional importance.

Wigeongrass ***(Ruppia maritima).*** Wigeongrass is a submerged aquatic plant which grows under permanently flooded conditions. The drupelets and vegetation are consumed by waterfowl (Swiderek and others 1988). Wigeongrass also supports high densities of aquatic invertebrates, an important food consumed by ruddy ducks and northern shovelers (Euliss and Grodhaus 1987) and most other waterfowl and ducklings during the breeding, post-hatch, and molting seasons. In brackish impoundments in South Carolina, wigeongrass was the principal waterfowl food in fall (Landers and others 1976).

The best growth for wigeongrass is achieved with water of salinities between 5-23 g/L (5-23 mS/cm) (Kantrud 1991), although researchers have found wigeongrass inhabiting waters with salinities reaching up to 390 g/L. For a full review on the salinities of waters supporting wigeongrass see Kantrud (1991).

Sago Pondweed ***(Potamageton pectanatus).*** Sago pondweed is a submerged aquatic plant which could resemble wigeongrass. It can grow in permanently flooded ditches, channels, and ponds in the marsh. The seeds and vegetative parts are consumed by mallard, pintail, and gadwall. Tubers are consumed by canavasback (Rollins 1981) and swans. The plants also provide a good substrate for invertebrates, crucial for hens in need of protein during egg laying and for developing ducklings. Sago can grow in shallow water 1-6 feet deep and tolerate water of 9-12 ppt. TDS (14.0-18.7 mS/cm) (Rollins 1981).

Watergrass ***(Echinochloa crusgalli).*** Watergrass, a member of the Grass family and an exotic to California, is an important waterfowl food that produces an abundance of seed. Watergrass seeds were an important food item found in the diet of pintail wintering in the Sacramento Valley (Miller 1987) and in the diets of pintail and green-winged teal in the San Joaquin Valley (Euliss and Harris 1987). *Echinochloa* seeds formed a major portion of the diet of cinnamon teal in the fall in New Mexico (Thorn and Zwank 1993).

Wetland habitat managers in Suisun Marsh report that for best germination of watergrass, irrigation water should be no more than approximately 5 mS/cm (Cann, pers. comm). Soil samples collected in the marsh that supported dense stands of watergrass ranged from 4-6 mS/cm in salinity.

Swamp Timothy ***(Heleochloa schoenoides).*** Swamp timothy is a low growing (2-10", 5 cm-25 cm), high seed yielding, grass-like marsh plant that grows in select areas within Suisun Marsh. More common in fresher water years, this plant is suspected to be mildly salt tolerant. Swamp timothy was found to be an important food item in the diets of pintails and green-winged teal in the Sacramento and San Joaquin Valleys (Euliss and Harris 1987). As seed supplies diminish in flooded habitats during winter, invertebrate populations can become available in shallowly flooded swamp timothy stands. No salinity tolerance data was found for this plant.

Smartweed ***(Polygonum spp.).*** The seeds of smartweed are also a heavily relied upon food item for California pintail (Miller 1987). Smartweed seeds were also common in the digestive tracts of cinnamon teal (Thorn and Zwank 1993). Landers and others (1976) found smartweed to be a principal food in the diets of waterfowl in South Carolina. Smartweed often grows in association with watergrass on seasonally managed wetlands in Suisun Marsh.

Soil salinities often did not exceed 5 mS/cm from samples supporting moderately dense stands of smartweed. Irrigation water salinities are generally similar to those used for growing watergrass.

Pickleweed ***(Salicornia virginica).*** Pickleweed is a common plant in Suisun Marsh, typically inhabiting high marsh zones on undiked wetlands and areas of moderate to high salinity in diked wetlands. The importance of pickleweed in the diet of waterfowl wintering in Suisun Marsh is unclear. Although De Szalay and Resh (1996) report that pickleweed-dominated habitats in Suisun Marsh support high numbers of invertebrates, particularly members of the Corixidae family, Batzer (and others 1993) found that Chironomid midge larvae, and not corixids, predominated in the diets of mallard and green-winged teal.

According to Mall (1969), pickleweed grew well on soils where mean annual soil water salinities exceeded 31 TDS (approximately 48 mS/cm), although it was observed on soils reaching 67 TDS (approximately 105 mS/cm) in September. Recent monitoring in Suisun Marsh found pickleweed growing in areas of a wide range of soil water salinities. It appears that once established, pickleweed is very resistant to changes in soil salinity.

DFG has conducted marsh-wide vegetation surveys during 1981, 1988, 1991, and 1994 (DFG 1996b). The results of these surveys are summarized in Table 3-4. Generally, the more salt-tolerant species, such as pickleweed, fat hen, and sea purslane, increased from 1981 to 1994. This is not surprising given the drought conditions of 1987-1992, which contributed to increased soil water salinity that salt tolerant species could take advantage of.

Table 3-4 General Trends in Suisun Marsh Vegetation as Reported in *Suisun Marsh Aerial Vegetation Survey, April 1996.*

Species	*Trend from 1981 to 1988*	*Trend from 1988 to 1991*	*Trend from 1991 to 1994*	*Change from 1981 to 1994*
Pickleweed	No Change	Decreasing	Increasing	Increased
Alkali bulrush	Decreasing	Decreasing	Decreasing	Decreased
Salt grass	Increasing	No Change	Decreasing	No Change
Cattail	Decreasing	No Change	No Change	Decreased
Brass buttons	Decreasing	Increasing	Decreasing	Decreased
Fat hen	Decreasing	Increasing	Increasing	Increased
Sea purslane	Increasing	Decreasing	Increasing	Increased
Bare ground	Increasing	Increasing	Decreasing	Decrease

The Importance of Management in Determining Wetland Plant Communities

The timing, duration, and depth of flooding (i.e., hydroperiod), together with the concentration of soil salt in the root zone, influence the characteristics of plant communities found in impounded wetlands in Suisun Marsh. Each plant species in a brackish marsh grows best within a range of salinity and hydroperiod conditions. Hydroperiod appears to be the most important variable influencing plant growth when soil salts stay within the broad range characteristic of brackish marshes. However, when soil salt concentrations approach and exceed sea water strength (35 ppt) or approach zero, salinity appears to be more important than hydroperiod in influencing the plant community makeup. The salinity in most diked wetland soils in the marsh lie within the natural brackish soil range suggesting that hydroperiod, which can be manipulated by marsh managers, plays an important role in determining what plant species occur in the managed wetlands.

Marsh management and the management facilities (e.g., flood gates, drain gates, ditches, levees, pumps) that manipulate water depth and duration of flooding play a significant role in Suisun Marsh wetland plant communities. For example, if two adjacent ownerships divert channel water (the terms channel water and slough water are used interchangeably) from intake gates located within 50 yards from each other; thus, channel water salinities that flood these wetlands are assumed to be identical. Meridian #612, has poor flood and drain capability due to highly permeable levees, shallow ditches, and an insufficient number of flood and drain gates. Conversely, Pintail Ranch #625 has high volume ditches capable of carrying large volumes of water at a fast rate, impermeable levees that allow for more accurate depth control, and drain gates that are properly placed relative to mean pond bottom elevation. In other words, Pintail Ranch can flood and drain at a faster rate where depth of flooding can be controlled. Increased flood and drain rates are important because this will allow for more pond-slough water exchanges, thereby minimizing pond and soil salinity. High rates will also prevent water from being trapped and depositing salts into the soil due to evaporation. Control of the depth of flooding is critical to ensure that seedling are not submerged by too much water for too long.

Table 3-5 summarizes the results, collected on Meridian #612 and Pintail Ranch #625, of soil salinity analysis using the soil saturation paste extraction and the number of vegetative shoots in a 1-meter square quadrat. Although both ownerships flooded with identical slough water salinities, soil salinities on Meridian were higher, suggesting that salts were deposited in the soil due to a lack of efficient drainage. More importantly, sites with similar soil salinities supported alkali bulrush and salt grass on Pintail Ranch but supported no vegetation on Meridian, suggesting that water may have been too deep during the germination period because of a lack of water depth control.

Table 3-5 Comparison of Soil Salinity in the Root Zone and Plant Growth During March and April 1997, on Two Adjacent, Privately Owned Wetlands in Suisun Marsh Flooded with Identical Slough Water Salinities

Sample Site	*Soil salinity (mS/cm) in the 12" root zone*	*Number of vegetative shoots/m^2*
Meridian #612		
1	26.2	0
2	26.8	5 pw
3	21.0	8 pw
4	18.2	0
5	18.5	0
6	23.9	14 sg; 5 pw
7	22.4	0
8	19.5	6 pw
9	16.7	0
Pintail Ranch #625		
1	9.3	senescent sg
2	17.0	20 ab
3	18.5	senescent ab
4	20.2	60 ab
5	12.8	50 pw; 2 ab
6	15.8	30 ab
7	14.0	50 ab; 5 pw
8	13.7	6 ab
9	19.2	30 sg
10	14.3	70 ab

pw, pickleweed (*Salicornia virginica*); sg, saltgrass (*Distichlis spicata*); ab, alkali bulrush (*Scirpus maritimus*)

A second example compared the same variables between ownerships located on opposite sides of the natural east-west slough water salinity gradient. Spoonbill #927, lying at the southeastern tip of the marsh, diverts water from Montezuma Slough near the confluence of the Sacramento and San Joaquin rivers. Typical slough water salinities during the water diversion period in the spring are generally 0-4 mS/cm. Goodyear Land Company #707, located on the southwestern side of the marsh, floods with water diverted from Goodyear Slough which can be 5 times greater than the salinity of the slough water available to Spoonbill. Spoonbill has few ditches to distribute and drain water quickly in large volumes, resulting in stagnant water that remains ponded in the center of the ownership. Water is diverted from a single drain structure located 0.5 miles from the ownership and drains from a structure located at the northwestern tip of the wetland. This results in fewer (or none) pond-slough water exchanges and a poorer ability to maintain shallow depths to encourage seed germination. This is particularly difficult on Spoonbill because of low, subsided pond bottoms where water becomes ponded at depths too high for seedling growth and survival. Goodyear Land Company has a complex ditch system where flooding and draining can be accomplished within several days. This allows for a high number of pond-slough water exchanges, thus precluding soil salt accumulation and better control of water depth. Flood and drain structures are strategically placed so that water runs evenly throughout the wetland, resulting in better water control.

Table 3-6 summarizes soil salinities and plant growth on these two ownerships. Spoonbill recorded soil salinities that were 10-100 times the salinity of water used to flood the ownership, whereas Goodyear Land Company recorded soil salinities only 2-3 times greater than available slough water salinity. Lower soil salinities were achieved through an increase in pond-slough water exchanges, made possible only by efficient management facilities. The difference between soil salinity and slough water salinity is decreased as the number of pond-slough water exchanges increases. Several sites on Spoonbill could have supported vegetation, particularly more halophytic plants; however, water depths were too high for too long, precluding their germination and growth.

In conclusion, it appears that increased hydroperiod control, is the precise manipulation of water depth and duration of flooding and draining, results in greater wetland plant abundance and diversity. Management facilities function to hold water depths to levels suitable for plant germination and serve to maintain soil salinities within the wide range suitable for supporting brackish marsh plants. Under current salinity standards and with present management facilities in Suisun Marsh today, many of the ownerships are able to grow plants typical of the Suisun Marsh brackish environment; however, a significant number support only sparse growth with large acreages of barren areas.

Table 3-6 Comparison of Soil Salinity in the Root Zone and Plant Growth in April 1977 on Two Privately Owned Wetlands Located on Either Side of the East-West Salinity Gradient in Suisun Marsh

Sample Site	*Soil salinity (mS/cm) in the 12" root zone*	*Number of vegetative shoots/m^2*
Spoonbill #927		
1	17.6	0
2	33.2	0
3	29.0	0
4	12.2	9 ab
5	23.5	0
6	23.4	0
7	21.4	0
8	11.9	5 ab
9	10.1	0
10	36.0	0
11	45.3	0
12	95.1	0
Goodyear Land Co. #707		
1	15.6	45 ab w. bb understory
2	13.0	11 bb
3	6.6	30 ab
4	8.9	12 pw

pw, pickleweed (*Salicornia virginica*); ab, alkali bulrush (*Scirpus maritimus*)

If channel water salinities increase and remain increased over subsequent years, management facilities would have to be improved in order to maintain soil salinities within the range characteristic of brackish marshes. This suggests that in order to maintain the current biomass and diversity of plants on diked wetlands under increased channel water salinities, greater pond-slough water exchanges would be necessary. This could only be achieved with a greater number of drain/flood structures, less permeable levees, more pumps, and greater ditch lengths and volumes. This would undoubtedly be cost prohibitive for most landowners and agencies that fund Suisun Marsh management facility cost-share programs. Because most landowners can not afford a substantial improvement in management facilities, a decrease in overall biomass and plant diversity and productivity would result from an increase in channel water salinities.

During the drought of 1987-1992, landowners in Suisun Marsh experienced an increase in salt-tolerant plants, such as pickleweed, and a decrease in plants such as alkali bulrush that are popular management targets. The Waterfowl Subcommittee believes that if channel water salinity standards had been at higher levels during this drought, there would have been severe increases in soil water salinity. If soil salinities begin to exceed sea strength, salinity will become the primary variable driving wetland processes. Salinity tolerances of even halophytic plants, such as pickleweed, may be exceeded and bare ground acreage increased, and the soil may become toxic to vegetation. We believe that an increase in channel water salinity with the current level of water management activity could lead to a degradation of Suisun Marsh diked wetlands.

Plant Communities in the Diked Managed Wetlands under Present Salinity Standards

Under the existing salinity standards, and if late drawdown management (i.e., 1-2 pond-slough water exchanges with final drain in June) is practiced, plant communities would be dominated by alkali bulrush, cattail, and tule (*Scirpus acutus*), with pickleweed, fat hen, and brass buttons established on areas of higher elevation. This plant association appears to be replaced by the watergrass/*Polygonum* associations in the fresher areas of the marsh, particularly in the northeast corner and along Roaring River. Pickleweed/alkali bulrush associations generally dominate the more saline areas such as the southwest corner.

Early drawdown management under present salinity standards appears to encourage the plant association dominated by pickleweed and with an understory of brass buttons. Other plants occurring under this water regime include fat hen and sea purslane.

Plant Communities in the Diked Managed Wetlands under Increased Salinity Standards

If channel water salinity standards were to increase during the plant growing season, and late drawdown water management was practiced, the watergrass/*Polygonum* association would likely be reduced even in the fresher areas of the marsh. This loss would be more pronounced if channel water salinities remained elevated during consecutive years. The pickleweed acreage would likely increase, with fat hen and brass buttons established on areas of higher elevation. Tall emergents such as cattail and tule may become less predominant especially during drought years. Drainage ability would be critical in preventing barren pond bottoms due to salt build-up.

If early drawdown management was practiced, the higher soil salinities would likely result in an increase in plant communities dominated by pickleweed. The pickleweed/alkali bulrush association may be replaced with homogeneous stands of pickleweed, while fat hen and brass buttons would likely still be present on levee slopes and other high areas. Sea purslane and bare ground acreages may increase while cattail and tule acreages would likely decrease. Under higher salinity standards, especially during periods of drought, areas of bare ground may increase significantly, particularly in parts of the marsh where channel water salinities are already naturally higher because of the natural gradients in the marsh (e.g., southwest, wetlands on Grizzly Island that divert bay water).

Plant Communities in the Diked Managed Wetlands under Decreased Salinity Standards

A decrease in salinity standards under late drawdown management may result in an increase in acreage of watergrass and *Polygonum* and a decrease in pickleweed, sea purslane, and bare ground. However, because of the north-south and east-west channel water salinity gradients, watergrass and *Polygonum* would likely not establish in the southwest portion of the marsh. Alkali bulrush communities may increase in certain areas, particularly where competition from grasses and smartweed is low.

Early drawdown management under lowered channel water salinities may result in an increase in the abundance of grasses such as *Polypogon* and saltgrass into the diked ponds. It is also expected that cattails, tules, and brass buttons would increase. Pickleweed would likely still be represented, especially in the southwest region of the marsh where diverted channel water is slightly higher in salinity.

Results of On-Site Monitoring

This section presents the results of monitoring conducted from 1984 to 1995 at 49 sites in managed ponds in Suisun Marsh. This monitoring, part of a program required by D-1485, collected data on pond water salinity, soil water salinity, water management, and vegetation occurrence in an attempt to discover the relationships between applied water salinity, pond water salinity, soil water salinity, and vegetation occurrence. Unfortunately, the effects of these factors on waterfowl can only be speculated upon, since the monitoring program did not collect any data on waterfowl numbers in the monitored ponds.

In the past, wetland management in Suisun Marsh was primarily directed by the management schedules in *A Guide to Waterfowl Habitat Management in Suisun Marsh* (Rollins 1981). These schedules were based on food habit studies (George 1965) that determined that seeds from alkali bulrush, fat hen, and brass buttons provided the bulk of the winter waterfowl food supply in Suisun Marsh. Rollins (1981) used this information to formulate the late drawdown management schedule to produce large stands of alkali bulrush and the early drawdown schedule to produce conditions favorable to the growth of fat hen. These studies and the findings related to alkali bulrush seed production were also used in establishing D-1485 Suisun Marsh channel water salinity standards.

During the 1970s, the Suisun Resource Conservation District prepared water management plans for each of the privately managed wetlands in the marsh. At that time, it was recommended that most clubs follow either the late or early drawdown management schedule. More recently, the district recommended that the clubs periodically change their water management regimes to discourage the production of monocultures and increase diversity of vegetation in wetland habitats. The district is currently updating its management plans to include more variable management schedules that can respond to changing environmental and regulatory conditions. DFG has prepared its own management plans for State-owned land in the marsh.

The monitoring program took into account that the late and early drawdown schedules were widely used in Suisun Marsh, and vegetation monitoring was centered around the occurrence and productivity of alkali bulrush and fat hen. Since 1984, when the monitoring program was initiated, management in the marsh has moved away from these limited schedules, but analysis of the monitoring data continued to focus on alkali bulrush and fat hen.

Applied Water Salinity

Upstream water diversions and storage have had an impact on the salinity of channel water in Suisun Marsh. Water diversions and storage have decreased annual Delta outflow to about 60 percent of pre-diversion amounts (Ingram and others 1996) and releases of stored water have completely changed the annual pattern of outflow, decreasing seasonal and annual variability.

Data from Collinsville, beginning in 1967, does not show significant increases in specific conductance after completion of the State Water Project in 1973. From 1967 to 1995 salinities are remarkably similar within water year types. Specific conductance data from internal marsh stations from 1985 to 1995 do not indicate an increasing trend despite 7 of those years being classified as dry or critical. The Suisun Marsh Salinity Control Gates were effective at keeping channel salinity in check during the 1987-1992 drought (DWR 1997). Salinities were significantly lower during the wet years 1986, 1993, and 1995.

Pond Water Salinity

There is a strong correlation between the salinity of the water applied to the ponds and the water in the pond. In general, pond water SC is about 2-10 mS/cm higher than the applied water and follows the same annual trend as applied water salinity. However, despite the relative stability of applied water salinity from 1985 to 1995, pond water salinity has shown an increase at some sites. This is probably due to salts accumulating in the soil over time and being released into the pond water each year.

Soil Water Salinity

In general, the soil water salinity (January to June average) recorded on most ownerships increased from 1985 to 1990 and remained somewhat stable until the end of the monitoring period. A linear regression of the data from each site showed that 13 of the 49 monitored sites (about 25 percent) increased each year, for a significant increasing trend (R2 value equal to or greater than 0.8). The other sites were fluctuating significantly and no linear correlation could be made. The increasing trend seen at many sites was probably due in part to effects of the 1987-1992 drought. Almost all the sites recorded the lowest soil water salinities in 1985, which is not surprising given the wet hydrologic conditions before 1985, and the subsequent 6-year drought. Only six sites continued to be monitored during wet years 1993 and 1995. None of these six sites decreased in soil salinity during 1993, but decreases were seen in both 1994 and 1995. It would seem, therefore, that the marked increases in soil salinity observed at most of the monitored sites can be attributed to low Delta outflow and below normal precipitation during the drought years of the monitoring period. It would also seem that soil water salinity does not respond immediately to changes in applied water salinity or precipitation amounts.

Based on the data collected in the monitoring program, there appears to be a direct relationship between the salinity of applied water in October-November and soil water salinity for the entire water year. Analyses showed that soil water salinity followed the trend in fall applied water salinity rather than the trend in applied water salinity from December-May. With the available data, 48 complete year-to-year comparisons can be made. Of the 48 comparisons, soil water salinity changes followed October and/or November applied water salinity changes 38 times, or 79 percent of the time. Thus it appears that the salinity of applied water at flood-up exerts a significant effect on soil water salinity.

Water Management and Seasonal Wetland Monitoring

When marsh lands are diked and isolated from tidal action, salts tend to accumulate in the soil. Wetland managers have several water management tools to alleviate this problem. Salinity increases markedly when the pond is dry, so duration of flooding is an important tool in controlling soil salinity. Over the 10 years of the monitoring program, average flood duration was about 200 days (range 77-365 days). Circulation was a common practice where pond water was exchanged with channel water, which acted to flush salts from the soil into the pond water, and out into the slough or bay. Leaching (a quick drain and re-flood) the pond in the spring can decrease soil water salinity during crucial periods for plant growth and seed development (Rollins 1973). Of the 12 clubs whose water management practices were monitored, only 6 conducted leach cycles during 3 or more years of the 8-10 year monitoring program.

It appeared that quick leach cycles were the most effective at reducing soil salinity. At 15 sites where a leach cycle took 30 days or less, soil salinity never increased in the month following the leach cycle (salinity stayed the same at three and decreased at least 1 mS/cm at 12, for an average salinity decrease of 3.7 mS/cm). At 19 sites where a leach cycle took 40 days or more, soil salinity increased at 8, stayed the same at 4, and decreased at least 3 mS/cm at 7 (average salinity decrease was 1.2 mS/cm). The average soil salinity change at all sites (leached and unleached) during these same time periods was a decrease of 1.4 mS/cm, indicating that a 30-day leach can result in a measurable decrease in soil water salinity immediately afterwards. However, in the month following completion of the leach cycle, about half the leached sites had soil water salinities equal to or greater than the salinity before initiation of the leach.

Data collected by the monitoring program show that water management has a significant effect on soil water salinity. During times of high applied water salinity (as in drought periods or in the western marsh), water management techniques must be used to successfully maintain soil water salinities that promote a diversity of wetland plants.

From recommendations made in the 1960s and 1970s, some wetland managers in Suisun Marsh attempt to create conditions favorable to three plant species believed to be preferred waterfowl food plants—alkali bulrush, fat hen, and brass buttons (Mall 1969, Rollins 1973). Each plant thrives under different environmental conditions. Data from the monitoring program indicate that alkali bulrush tends to be most abundant when spring soil water salinities are less than 25 mS/cm, whereas brass buttons and fat hen can tolerate higher soil water salinities. Rollins (1981) found that fat hen and brass buttons prefer a flood duration of about 150 days, while that for alkali bulrush is about 210 days. Brass buttons is often found in disturbed soils, fat hen in the higher margins of the pond, and alkali bulrush in the bottom of the pond.

There are many factors (flood duration, circulation, leaching, precipitation, depth of flooding, discing, burning) that affect the vegetation in the managed wetlands, so it is impossible to draw unequivocal conclusions from the monitoring results. In general, however, ponds that were circulated and leached tended to have low to moderate spring soil water salinities (<20 mS/cm) and a diversity of plants, with alkali bulrush, brass buttons, and fat hen often making up about 50 percent of the vegetation. Pickleweed, sea purslane, and bare ground, all indicative of high (>40 mS/cm) soil water salinity, were not usually well-represented in these ponds. Conversely, ponds that were not circulated or leached generally had increasing soil water salinity and increasing abundance of pickleweed, sea purslane, and bare ground. Although some consider pickleweed and sea purslane as undesirable, waterfowl do consume invertebrates in pickleweed (Batzer and others 1993) and the leaves, stems, and seeds of sea purslane (Swiderek and others 1988). These plants are, however, indicative of high soil water salinity, and can serve as a warning to wetland managers that some water management may be necessary to prevent salinities from rising to higher levels. When salinities continue to rise to levels toxic to pickleweed and sea purslane, large patches of bare ground begin appearing and the pond offers fewer feeding opportunities for waterfowl.

Draft results of marshwide vegetation surveys by DFG found that acreage of pickleweed and bare ground increased from 1973 to 1994. These preliminary findings support the on-site monitoring results that soil water salinities are increasing.

The studies by George (1965) and Mall (1969) focused on waterfowl foods found in the gizzard. Generally, hard seeds are the primary foodstuffs that make it into the gizzard because foods like soft leaves, stems, or invertebrates are quickly digested and are difficult or impossible to identify. There are many ponds in the marsh that contain little or no alkali bulrush, fat hen, or brass buttons, yet ducks are there year after year. Thus, the past studies potentially overlooked other valuable food sources in Suisun Marsh. A new food habits study, which examines esophageal contents, began in fall 1997. It is hoped that this study will give us a more accurate picture of what ducks are eating in Suisun Marsh.

Acid Sulfate Reactions in Wetland Soils

Certain soil types in Suisun Marsh can be prone to acid buildup if not managed properly. Soils high in iron combined with organic matter and bacterial action can become acid enough to be toxic to plants. The bacteria consume plant detritus ladened with ferrites from the soil and excrete sulfuric acid as a by-product. Paul Crappuchettes (long-time club owner and manager of the West Family Club #422) spent many years attempting to understand this complex cycle and how to avoid acid buildup in the soil.

Soil scientists interested in such problems have visited the marsh twice in the last 10 years and have commented that these acid reactions are exacerbated by alternately wetting and drying ponds, causing oxidation and reduction of the soil. Drying a pond is often necessary to grow desired wetland plants and to allow land managers to work pond bottoms (discing, ditching, etc.). These scientists have recommended that wetland soils not be allowed to completely dry out. This is a management challenge that not many are equipped to handle. Mr. Crappuchettes has recommended the well-timed use of flooding to help leach acids from the soils. These leaching cycles are carried out differently than those needed for salinity control. He also feels that rapid circulation with winter flooding could help wetland managers freshen acid soils. Research into a related phenomenon called "Red Water" has been conducted by the Suisun Resource Conservation District and the USGS-Biological Resources Division (BRD). Red water is a condition where acidity of the pond water becomes high and causes a reddish flocculent to be deposited on the vegetation. Mr. Crappuchettes believes that this condition is undesirable to ducks.

Results of a cooperative SRCD and BRD project indicate that while the red water phenomenon can be common in the marsh during certain times of the year, that there is no evidence to indicate that ducks are avoiding these areas. It is entirely possible that some other factor in the wetlands is responsible for the avoidance behavior reported by Mr. Crappuchettes. Regardless of waterfowl use of red water habitats, acid soil reactions should be included in areas of future study as they relate to impacting plant growth and because wetlands in other parts of the nation and world have reported similar conditions.

Suisun Marsh Infrastructure

A discussion of infrastructure is included on managed wetlands, levees, and water control structures because it is essential to facilitate the creation of quality waterfowl habitat. Changing salinity of applied water will influence the maintenance and lifespan of physical facilities. For most wetland managers in the marsh, the cost of doing business is a limiting factor in habitat management.

Exterior Levee System

Beginning in the 1850s, low sod levees were built in Suisun Marsh by individuals to reclaim wetlands for agricultural uses. During the 1860s levee construction increased, with the formation of over 20 reclamation districts in the marsh. The bulk of the reclamation activity was completed before 1920 and, by 1930, approximately 44,600 acres of wetlands had been converted to commercial agriculture purposes in Suisun Marsh (Miller and others 1975).

The standard method of levee construction was the use of dredges or draglines from floating barges. Typically a dredger cut was made through a tidal area, and the spoils were placed on the inland side of the barge to build the levee. This method of levee construction also provided future levee protection by leaving a tidal berm to protect the levee system from wind-driven wave damage. In areas of the marsh without the luxury of tidal berm protection, the placement of rip-rap, bulkheads, and even the sinking of old ships and barges were effective methods of levee protection.

In 1980, the Suisun Resource Conservation District (SRCD) Board of Directors passed a resolution adopting Public Resource Code, Section 29401(d) for enforceable standards for diking, flooding, draining, filling, and dredging of sloughs, managed wetlands, and marshes. The SRCD exterior levee standards for Suisun Marsh (DFG 1980 unpublished) are as follows:

- minimum top width of 12 feet;
- minimum design water height shall be 9 feet at zero tide;
- minimum design side slope shall be 2:1 on both sides;
- minimum freeboard shall be 2 feet; where wave action is expected, the freeboard shall be at least 3 feet;
- existing tule berms on the outboard side of the levee shall be retained; and
- outboard faces shall be rip-rapped only in areas which are exposed to major wave action and are not protected by vegetated berms.

In 1983, a Suisun Marsh Levee Evaluation Study categorized and rated 228.8 miles of exterior levees in the Suisun Marsh (Ramlit Assoc. 1983). The levees were rated as Class I, II, and III, by existing condition, vulnerability to wind and wave action, and history of repairs and problems.

Class I Levees:	High wind and wave action Islands, open bays, and major sloughs **122.6 miles of levees**
Class II Levees:	Medium wind and wave action Secondary sloughs **72.48 miles of levee**
Class III Levees:	Low wind and wave action Small inner sloughs **33.7 miles of levee**

This evaluation estimated that the total cost of rehabilitating the Suisun Marsh exterior levees to the U.S. Army Corps of Engineers (USACE) standards for a uniform level of protection was $52.7 million (September 1982 price level). Once rehabilitated, it was estimated that the annual maintenance cost would be $250,000 a year.

Suisun Marsh landowners currently maintain exterior levees throughout the marsh under the current SRCD, USACE Regional General Maintenance Permit. This permit has strict limitation on maintenance activities, the scope of work, source of material, endangered species protection, etc. Corps permit restrictions will be discussed in a later section.

Today, it is not uncommon for a property bordering Suisun Bay or Grizzly Bay to have an annual levee maintenance cost in excess of $8,000 per mile. This figure can increase in wet years when Delta outflow is high and the tidal elevations may be enhanced as much as 2 feet. Combined with storm events, wave action, heavy boat traffic, levee subsidence, and rodent damage, the cost of levee maintenance in the marsh can be quite high. The following sections address typical levee maintenance problems.

Soil Types from Which Levees Are Constructed. Suisun Marsh soils are a mixture of hydrophytic plant remains and mineral sediments. As the marsh formed, plant detritus slowly accumulated, causing the underlying base material to subside. Mineral sediments were added to the organic material by tidal action and during floods. Generally, mineral deposition decreased with distance from the sloughs and channels (Miller and others 1975).

Reyes soils are usually adjacent to the sloughs and channels, resulting in a mineral soil having less than 15 percent organic matter. Tamba soils are typically adjacent to Reyes, but at lower elevations and contain 15 to 30 percent organic matter. Joice soils contain 30 to 50 percent organic matter and are found between Tamba and Joice soils in the marsh. Suisun soils occur furthest from the sloughs, at the lowest elevations, and contain the highest organic content, usually over 50 percent. The Valdez soils, which formed on alluvial fans and contain very little organic material, are usually located at the fringe of the marsh near the surrounding hillsides. Valdez is also the primary soil type on Grizzly Island.

Levee Subsidence and Consolidation of Peat Material. The health and stability of Suisun Marsh exterior levees is dependent on the type of material the levee was originally constructed from as well as the underlying substrate the levee was built upon. Due to the varying amount of organic content of the peat soils, levees have a tendency to weather through oxidation and reduction, consolidate when placed under pressure, and shrink, crack, and blow away when dried.

Historically, levee maintenance was completed through the use of a dredge on a barge, by removing bay mud from the sloughs and channels. This material was prized as levee maintenance material due to its clay content and durability to weathering and wave action. With the recent restriction on dredging activities associated with environmental and endangered species concerns, landowners now have few options. Alternative methods are inefficient and less cost effective.

Importation of fill material by barge or truck is one option for levee maintenance. The hauling and placement of dry material, by barge and dragline, on the crown of the levee is cost prohibitive. The placement of wet material removed from shipping channel dredging would be acceptable, but presents several environmental concerns such as contaminants, water quality, and protection of both the tidal and nontidal wetlands at the base of the levee.

Importing material by truck for levee maintenance is a viable option for certain areas of the marsh. In other areas, issues such as distance of hauling, vehicle access, and levee stability prevent use of this method. Some levees in the marsh can actually be compacted and destroyed by truck traffic faster than they are built-up by the fill material carried by those trucks.

Currently, the most common method of levee maintenance is removal of accumulated silt from water circulation ditches within the managed wetlands and placement on the crown of the levee. Another option available to landowners is the removal of high ground within the managed wetlands as a source for levee maintenance material. Both of these activities are permitted under the USACE Suisun Marsh General Permit and provide the most cost effective methods.

Wind, Wave, and Boat Wake Levee Erosion. Historically, in areas of the marsh where vegetated tidal berms did not protect exterior levees from wave damage, the placement of riprap was the common practice of levee protection. With the recent restriction on placement of riprap, associated with environmental and endangered species concerns in tidal areas, landowners now have fewer options for levee protection. Under the USACE Suisun Marsh General Maintenance Permit, the placement of riprap may only occur in the minimum amount to stabilize existing, previously authorized, levees, dikes, and banks.

Levee Overtopping and Back Slope Erosion During Extreme Tides and/or High Runoff. Suisun Marsh is located on the western edge of the Delta at the confluence of the Sacramento and San Joaquin Rivers and upstream of the Carquinez Straits in the San Francisco Bay. Due to the geographic location of the marsh, the effects of spring tides compounded with the runoff of the entire Central Valley, levee overtopping is inevitable.

Water Control Structures

In the DFG database dated June 30, 1995, it was estimated that 417 diversions existed in the Suisun Marsh. (This included all flood and drain structures on exterior levees as diversions.) The average cost of replacing a gate in Suisun Marsh is variable depending on the location, mobilization of equipment, and availability of fill material. The estimated costs of control structures in Suisun Marsh are listed in Table 3-7.

Table 3-7 Estimated Costs of Control Structures

Structure	*Estimated Cost*
24-inch flap gate	$ 800
24-inch screw gate	2,100
24-inch combination screw/flap	2,700
24-inch flashboard riser (plastic/metal)	800
24-inch corrugated metal pipe	1,000
24-inch plastic pipe	2,000
36-inch flap gate	1,700
36-inch screw gate	3,000
36-inch combination screw/flap	4,500
36-inch flashboard riser (plastic metal)	1,500
36-inch corrugated metal pipe	1,500
36-inch plastic pipe	3,000

The average cost of replacing a gate in Suisun Marsh is about $15,000, but depending on the location, mobilization of equipment, and availability of fill material, it can range from $8,000 to $25,000. The average cost of equipment mobilization is $750, with construction costs ranging from $5,000 to $15,000.

Recently there has been experimental use of plastic water control structures in the marsh. The advantage of their use is the possibility of a 20 to 30 year life expectancy of these structures. The current life of a corrugated steel pipe is only 8 to 12 years. The negative impacts of plastic structures is the initial additional expense and the threat of damage or complete loss from peat fires which can burn out of control.

Increasing channel water salinity would have little effect on plastic and stainless steel water controls and plastic pipes outside of the increased expense of these products. Currently a majority of water control structures and pipes in the marsh are steel, and increasing channel water salinity levels will make these structures rust out more rapidly. Decreasing channel water salinity levels may slow down the decomposition of pipes and water controls.

Discussion

The subcommittee has based its recommendations for channel water salinity standards on (1) the needs of ducklings in the early stages of post hatch development; and (2) experience with current standards.

Ducklings 1 to 14 days old are subject to impaired growth rates when conductivity levels exceed 4 mS/cm. Cooperative research conducted by DFG and the California Waterfowl Association since 1985 documents GIWA as having high levels of mallard production. Ducklings have been observed marshwide but extensive research has focused on Grizzly Island. Nesting takes place late March to early June each year and ducklings can be present in the marsh from March to July. During this time it is important to provide safe water for ducklings.

Water in excess of 20,000 micro mho/cm (20 mS/cm) is lethal to mallard ducklings and should not be considered as an acceptable extreme upper limit of their tolerance. Therefore we recommend a March-July salinity standard that should not exceed an average of 4 mS/cm March-July annually. Under current standards this goal was attained 7 of the 11 years at S-71 (Table 3-1).

Experience has demonstrated that current salinity standards are adequate to protect the managed wetlands from toxic levels of soil water salinity, even during drought periods. This protection is strengthened by active water management, which utilizes effective water delivery systems and actions such as circulation and leaching to control soil water salinity. Current efforts to amend the Suisun Marsh Preservation Agreement will support further management efforts to mitigate for negative effects (such as loss of preferred waterfowl food plants, decline in seed production, increased importance of leaching) of drought periods.

Waterfowl Resources in the Ecosystem

Today, the management of habitat for waterfowl is the primary land use in Suisun Marsh and has a great impact on the habitats in the marsh. In addition to waterfowl, managed wetlands provide habitat for shorebirds, wading birds, and some passerines; there is also use by mammals such as river otter, beaver, raccoon, muskrat, striped skunk, and mink. Northern harrier, short eared owls, and pheasants also nest in the areas. The endangered salt marsh harvest mouse can occur in the managed wetlands when pickleweed habitat is available. The diversion of water onto the wetlands is known to entrain fish, so screens are being applied to marsh diversions as funds become available and, until screened, many areas of the marsh are subject to intake closures during times of potential impact to salmonids and Delta smelt.

Suisun Marsh provides brood-rearing, molting, wintering, or staging habitat for 18 species of waterfowl. In general, a single vegetation type will not provide all of the habitat requirements for this diverse group of birds. As a result, it is important to bear in mind a complex of wetland types when considering the quality of habitat for waterfowl.

Critical findings related to channel water salinity are as follows:

- Soil salinity tends to increase in diked managed wetlands that are flooded with brackish water.
- Water management has a significant effect on soil water salinity and vegetation.
- Circulation decreases soil water salinity.

- Leaching can decrease soil water salinity.
- Soil water salinity increased in the marsh from 1985 to 1993, probably due to the drought from 1987 to 1992. When the drought ended, soil water salinity decreased the following year.
- Mallard ducklings subjected to a water salinity level as low as 4 mS/cm have impaired growth rates; water with conductivity of 20 mS/cm is lethal to mallard ducklings.
- When channel water salinity increases, metal water control fixtures corrode more quickly.

Data Gaps

Waterfowl Foods

One of the most significant gaps in our knowledge of waterfowl feeding ecology in the diked wetlands of Suisun Marsh involves determining what plants and invertebrates waterfowl are feeding on today. Earlier studies based on examination of gizzard contents may have exaggerated the importance of hard seeds.

Research needs on waterfowl feeding ecology include:

- identifying plants and plant parts eaten by the different waterfowl species in the marsh; and
- determining whether these plants are selected or used in proportion to availability.

The current Waterfowl Food Habits Study is collecting data on these issues. Also needed are studies to determine:

- distribution and abundance of plants used as food by wintering waterfowl; and
- nutritional value of plants used as food by wintering waterfowl.

By identifying plants important in the diet of waterfowl wintering in Suisun Marsh, marsh managers may meet the needs of waterfowl by improving water management techniques that promote the growth of nutritious, preferred food plants.

There is also a lack of information on the influence of hydroperiod and soil salinity tolerances of plants occurring in the diked managed wetlands of Suisun Marsh. Research needs include determining the depth and duration of flooding that affect the germination and growth of plants in the managed wetlands. Research should also include determining the salinity tolerances of these plants at different life stages, and how soil water salinity affects seed production. This information could then be used by marsh managers to emulate environmental conditions that promote the growth of plants to produce habitat that meets the life requisites of waterfowl.

Monitoring may include recording, at frequent intervals, soil water salinity in response to water management activity, such as depth and duration of flooding and associated plant associations. This could involve sampling soil salinity and soil moisture along transects in ponds undergoing different water management schedules.

If acid soils or red water become significant problems in Suisun Marsh, research into these phenomena and ways to prevent or mitigate negative effects will be necessary.

Invertebrates

Information is still needed on aquatic invertebrates and their water salinity tolerance ranges, especially data on salinity tolerances of invertebrates used as food by waterfowl. This information may exist but to date has not been found. An intensive literature search is likely required; however, some answers may be revealed by commissioning work with existing data sets (e.g., DFG Bay-Delta Salt Slough system in the San Joaquin Valley).

Waterfowl Brood Survival and Channel Water Salinity

Grizzly Island has some of the highest mallard nesting densities in North America. What happens to broods post-hatch in Suisun Marsh needs further study. Knowing how many ducklings survive that critical 14-day period when they are most sensitive to channel water salinity (possible pen bird study with wild stock) and how many broods survive to fledging would help to better estimate Suisun's contribution to the Pacific Flyway.

Waterfowl Population Survey

Currently, waterfowl population surveys are conducted September through January in Suisun Marsh. Survey teams fly the marsh in a fixed-wing aircraft. Areas of the marsh known to concentrate waterfowl (such as closed zones) are flown on hunt days to facilitate census of the population as waterfowl quickly learn to utilize closed zones. This strategy works well for total numbers of waterfowl but does not provide insight into spatially specific data.

Ideally, transects would be established in the marsh and flown monthly. If transects could be established it would no longer be necessary to target hunt days as survey days. By surveying on non-shoot days waterfowl in the marsh would more accurately reflect habitat choice or preference. Through examination of these preferred habitats, it should be possible to determine what desirable salinity levels should be.

Water Salinity Relationships

The following studies are recommended to determine channel water salinity standards for producing desired vegetation in managed wetlands.

1. Studies to verify relationships of channel water, pond water, and soil water salinity, a study of smaller geographic scope but more intensive data collection. For example, in a single pond a line of soil water collection tubes every (approximately) 30 meters across the pond, with pond and soil water collected weekly or in relation to water management activities, would serve to more closely track these salinity relationships.

2. Controlled studies that attempt to separate the effects of applied water salinity and management. Factors to consider include applied water salinity, length of flooding, depth of flooding, circulation, leaching, ditches, drainage efficiency, and soil type.

3. Studies to determine salinity and other environmental tolerances of wetland plants in Suisun Marsh.

4. Much of the past regulatory history of Suisun standards has related to waterfowl, yet past monitoring has stopped short of relating habitat and vegetation to duck use. To really measure the effectiveness of channel water salinity standards on waterfowl, a study is needed on the effects of water salinity on waterfowl and their habitat by relating environmental factors (vegetation types, ratio and layout of vegetation and open areas, water depth, hunting pressure) to duck use.

5. Current water management in the marsh, where ponds are dry for several months, can lead to soil chemistry and soil structure problems. A study could use test plots comparing standard (dry summer) management to moist soil management.

Other areas for potential studies are:

- Would moist soil management alleviate problems of soil chemistry and soil structure?
- Could habitats in the marsh be "improved" by using different water management?
- Can soil water salinity be decreased with moist soil management? How would it affect other management activities like mowing? How would it affect duck use and mosquito abatement?

The available data on waterfowl and salinity clearly indicate a need for future studies in other areas. The current Suisun Marsh waterfowl food habits study is essential. Further research on brackish wetland management techniques will probably be necessary after the results of the food habits study are tabulated. More comprehensive sampling of soil/pond/channel water salinity is necessary if the equation of the relationship of applied water to soil water salinity is to be solved.

Areas of Agreement and Disagreement with Other Subcommittees

Waterfowl and Brackish Marsh Vegetation Subcommittees

Areas of Agreement:

- A comprehensive monitoring program is needed in the tidal and managed wetlands of Suisun Marsh.
- Water management is critical to reducing soil water salinity in the managed wetlands.

Areas of Disagreement:

- Decreasing channel water salinity in spring. The Waterfowl Subcommittee would like to see lower channel water salinity standards from March through July. The Brackish Marsh Vegetation Subcommittee is opposed to decreasing channel water salinity in spring.
- Operation of the gates. The Brackish Marsh Vegetation Subcommittee is opposed to winter and spring operation of the gates, and the Waterfowl Subcommittee is in favor of gate operations during these times. The Brackish Marsh Vegetation Subcommittee has less objection to gate operations in October than in other months.
- Existing channel water salinity standards. The Brackish Marsh Vegetation Subcommittee is opposed to enforcing any standards, and the Waterfowl Subcommittee is in favor of enforcement of the existing standards.

Waterfowl and Aquatic Habitat Subcommittees

Areas of Agreement:

- Gate operations are not needed during wet water years.
- It would be beneficial to have lower salinity standards from March to May and that the gates could be operated during these months.

Areas of Disagreement:

- The degree of the actual numerical standard to be met from March to May. The Aquatic Habitat Subcommittee would like the standard to be 8 mS/cm in March and 11 mS/cm in April and May. The Waterfowl Subcommittee would like the March to June standard to be 4 mS/cm, but does not believe that current standards during that time period have been overly restrictive to the waterfowl resource.
- Gate operations during October and November. The Aquatic Habitat Subcommittee recommends that there be no gate operations until channel water salinity reaches 20 mS/cm. The Waterfowl Subcommittee would like to see gate operations used to maintain channel water salinity at no more than the October standard of 19 mS/cm and the November standard of 15.5 mS/cm.

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Chapter 4: Aquatic Habitat Subcommittee

Introduction

As part of the work of the Suisun Ecological Workgroup, the Aquatic Habitat Subcommittee (SEWAH) was given the task of recommending salinity objectives protective of aquatic species in Suisun Marsh. The following report presents the recommendations prepared by the subcommittee and explains their scientific basis. Also included is a discussion of the subcommittee's perspective on the recommendations proposed by the other SEW subcommittees.

The subcommittee's recommendations are based on examinations of the relationships of salinity, outflow, and habitat to fish abundance in Suisun Marsh. These three areas were chosen because review of the scientific literature and discussions with fish biologists indicated that two key factors impacting the relative abundance of native and introduced fish in the Bay-Delta estuary are *outflow* and *habitat*. These factors became the main focus of the subcommittee's exploration; the role of *channel water salinity* (a function of outflow and other factors) in regulating fish abundance and distribution was also examined, since SEW's primary task was evaluating the impact of salinity standards on the beneficial resources (fish, wildlife, and plants) of Suisun Marsh.

Previous drafts of this report included studies that focused on the three different areas mentioned above. However, prior to publishing this report, discrepancies were discovered in the database used to produce these studies. Thus, the studies were eliminated from this report. These studies may or may not be repeated once errors in the database are corrected, depending on the need for such analyses. However, since the subcommittee's recommendations are based primarily on findings from the scientific literature, these recommendations still stand.

This report does not evaluate the impact of several factors known to impact the aquatic environment, such as pesticide and herbicide runoff, urban growth, etc. Examination of these factors was beyond the scope of the task assigned to the subcommittee.

Though the original Aquatic Habitat Subcommittee was composed of biologists from the Department of Water Resources, Department of Fish and Game, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, National Marine Fisheries Service, and Metropolitan Water District, many participants were unable to participate on a regular basis. However, representatives from many of these agencies continued to contribute by reviewing the subcommittee's documents, such as a draft of the Interim Report, produced in 1997. (A revised version of the report is included in Appendix 1.) The subcommittee also consulted with fish biologists from University of California at Davis who are actively involved in ecological studies of Suisun Marsh. Six technical experts outside of the subcommittee provided comments on this final report—two from DWR, two from DFG, one from NMFS, and two from U.C. Davis.

Recommendations for Salinity Objectives

Channel Water Salinity and Fish Abundance

The subcommittee's literature reviews, data analyses and discussions with fish biologists indicate that channel water salinity does not limit the abundance and distribution of juvenile and adult fish in Suisun Marsh, although it may impact the physiological processes involved in spawning and larval rearing.

Adult and Juvenile Fish

The literature indicates that adult and juvenile native fish found in the marsh have broad salinity tolerance ranges, suggesting that adult and juvenile fish would not be impacted by changes in salinity during most of the year (Wang 1986, Moyle 1976, Unger 1994, CUWA 1994, Table 1). The subcommittee's initial analysis also suggests that, in general, channel water salinities in Suisun Marsh (as affected by current water quality standards and Suisun Marsh Salinity Control Gate operations) do not limit the abundance and distribution of juvenile and adult fish in Suisun Marsh (Moyle 1976, CUWA 1994, Unger 1994, Wetland Goals 1997).

Spawning and Juvenile Rearing. The literature on physiological salinity tolerance levels indicates that fish species native to Suisun Marsh require low salinities during the spawning and rearing period, generally from February through June (Moyle 1976, CUWA 1994, Unger 1994, Wetland Goals 1997, Table 1). Suisun Marsh channel water salinity may be limiting to spawning and rearing of native fish if salinities exceed approximately 8 mS/cm (5 ppt) during this critical spawning and rearing period. Thus, it is important to maintain low salinity conditions for spawning and larval rearing from February through June to support native fish species in the marsh.

Native fish populations have declined dramatically in Suisun Marsh in the past 20 years. Matern et al. (1999) have documented an overall trend in the marsh toward a less numerous, less diverse assemblage of fish, which is increasingly dominated by introduced species. This decline could be hastened if high salinities, such as those known to occur during dry and critical years, occurred during the spawning/rearing period, as spawning and larval rearing success might be decreased. The subcommittee's initial analysis indicated that optimal salinity conditions for spawning and larval rearing occur much less frequently during dry and critical years than during wet years (see Table 4-1).

Further, the literature indicates that exposure to extreme events such as droughts can be devastating to populations of native fish and aquatic invertebrates in the San Francisco Bay Estuary (Bennett et al. 1996) and Suisun Marsh (Meng et al. 1994). This may make it easier for non-native species to invade the marsh, since invasions tend to be more successful when native fish populations are stressed or depleted (Bennett et al. 1996). Allowing extreme variability in Suisun Marsh salinity during the critical spawning/rearing period could potentially be detrimental to recruitment, which could in turn make Suisun Marsh vulnerable to establishment of non-native fish species if low recruitment seriously impacted native fish populations.

Table 4-1 Optimal Salinity Ranges for Different Native Fish Species at Various Life Stages

Species, Life Stage	*Optimal Salinity Range mS/cm*	*Source*
Delta smelt		
rearing, pre-spawning	0 – 3; 0 - 28	(Goals Project 1997; DFG 1992)
larvae, early juvenile	0.5 - 3	(Unger 1994)
juvenile	0.8 – 16	(CUWA 1994)
adult	0 – 16	(CUWA 1994)
Longfin smelt		
spawning	0 - 0.8	(CUWA 1994)
larvae, early juvenile	2 – 29	(Unger 1994)
adult	>= 0	(CUWA 1994)
Tule perch		
breeding, juveniles	0 - 0.8	(CUWA 1994)
adults	0 - 8	(CUWA 1994)
Splittail		
spawning, eggs, larvae	0 – 8	(CUWA 1994)
adults	0 - 16; 0-28	(Sommer et al, in press)
Prickly sculpin		
juveniles, adults	0 – 16	(Goals Project 1997)
Chinook salmon		
juvenile, adult	>= 0	(CUWA 1994)
Starry flounder		
young of year	0.2 – 31	(Unger 1994)

Hypotheses Regarding Salinity Variability, Spawning/Rearing Conditions, and Native Fish Abundance

Moyle and Herbold (1983, 1986) hypothesized that decreases in the abundance of native fish in the marsh may be linked to the frequency with which freshwater conditions prevail in the marsh. Matern et al. (1998) note that overall, salinities in the marsh have been lower than in previous years with similar amounts of rainfall, especially from October through March. This decrease in salinity is likely due to gate operations, which began in 1988. Moyle and Herbold (1983) hypothesize that maintenance of an annual fluctuating regime, plus an occasional high salinity year, may be necessary to maintain the native fish of the marsh.

However, Moyle (pers. comm.; see Notes) and Baxter (pers. comm.; see Notes), suggest that maintenance of low salinity conditions in the marsh during spring is still considered critical to the protection of native fish populations in the marsh. Likewise, increasing the variability of the salinity regime during summer, fall, and winter, which would generally result in higher salinities, is also seen as important. Moyle advised the subcommittee to recommend maintaining "low salinities in the spring when larval native fish are present, and higher salinities in the fall to prevent establishment of freshwater introduced residents" (pers. comm.; see Notes). Likewise, Baxter recommended maintenance of low salinities from February through

June, during the critical spawning and rearing period, and suggested that management of salinity levels be suspended during the remainder of the year (July through January) (pers. comm.; see Notes).

Consequently, the subcommittee's recommendations relative to salinity levels reflect the position that low salinity (0-11 mS/cm) from approximately February through June is important to spawning and rearing of native fish populations, and an increase in salinity variability and overall salinity range from approximately July through January (which would generally result in an increase in salinity over current levels) may deter the further establishment of introduced fish. The subcommittee recommends that future research investigate (1) the relationship between variability of the salinity regime and establishment of introduced species; (2) the relationship between extent and success of spawning and rearing and subsequent abundance and distribution; (3) the proportion of juvenile fish rearing in the marsh resulting from local spawning and that from transport to the marsh as planktonic larvae; and (4) the relationship between gate operations and transport of planktonic larvae into the marsh.

X2 and Suisun Marsh Fish Abundance

Initial analysis by the subcommittee indicated that there is no relationship between fish abundance in Suisun Marsh and the position of X2. Future research should evaluate whether abundances of particular fish species in the marsh increase when the species' observed salinity tolerance range coincides geographically with the entrances to the marsh. This "spatial coincidence" could be especially important during critical life stages of certain species, which may have greater spawning and rearing success in the marsh than in the Delta.

Habitat Quality and Quantity and Fish Abundance

Habitat quality and quantity have been identified as key factors influencing fish abundance and distribution in Suisun Marsh and San Francisco Bay Estuary (Unger 1994, Bennett and Moyle 1996, Goals Project 1997). Habitat types important to the native fishes of Suisun Marsh and the bay estuary include shallow bays and channels, tidal flats, and low, mid, and high tidal marshes (Goals Project 1999).

Previous analyses of U.C. Davis Suisun Marsh Fish Sampling Program data indicate that spatial differences exist in the abundance of fishes in the marsh (Moyle and Herbold 1983, Moyle et al 1986, Meng et al 1994, Matern et al 1997, Matern et al 1998). Moyle and Herbold (1983) identified two distinct associations of fish in the marsh—a native fish association that existed in the dead-end sloughs and an association of introduced and seasonal species that existed in the main channels. Meng et al. (1994) found the fish assemblage structure less predictable than in the earlier study of the marsh, but confirmed that native species were found more often in small dead-end sloughs, while seasonal species were found in larger sloughs and introduced species were found in both habitats.

Matern et al. (1997) evaluated catch on a slough by slough basis using data from 1995-1996, and found that species diversity was highest in Spring Branch Slough and lowest in Nurse Slough. Their findings indicated that species diversity was lower in all large and medium-sized sloughs than in small sloughs, with the exception of Boynton Slough. Matern et al. (1998) conducted a similar analysis using data from 1995 through 1997, which indicated that the highest catch per trawl occurred in Spring Branch, while the lowest occurred in Boynton Slough. Boynton Slough receives outflow from the Fairfield Sewage Treatment Plant, while Spring Branch occurs within one of the few remaining areas of undiked tidal wetlands in Suisun Marsh (the Solano Farmlands and Open Space Foundation's Rush Ranch). Matern et al. (1998) note that their results reflect, to some extent, decreases in gear efficiency in the larger sloughs.

Results from the habitat studies described above differ somewhat. However, overall they indicate that species diversity and native fish abundance tends to be higher in smaller sloughs than in medium and large sloughs. Since habitat complexity tends to be higher in smaller sloughs, these studies indicate that habitat complexity is important to native fish abundance and distribution (Matern et al. 1997).

The subcommittee agrees that habitat complexity may be an important determinant affecting fish abundance and distribution in the marsh. The subcommittee believes that efforts to increase acreage of and rehabilitate certain habitat types in the marsh, particularly edge habitat (e.g., shallow water, tidal), could lead to increases in the abundance of native fish populations in the marsh. Thus, most subcommittee participants endorse the recommendations of the Goals Project (1999) regarding potential restoration/rehabilitation sites for the Suisun Bay subregion. The subcommittee believes that rehabilitation should not necessarily preclude use of the gates to maintain low salinity habitat in the spring to restore and maintain stable populations of native fish species.

Current Salinity Standards

Table 4-2 lists the 1995 Water Quality Control channel water salinity standards for Suisun Marsh (SWRCB 1995). The gates are operated only as needed during October through May to meet these standards. The gates do not operate June through September.

Table 4-2 1995 Water Quality Control Plan Channel Water Salinity Standards (Values are in Specific Conductance in mmhos (Mmhos are equivalent to mS/cm))

Month	*Eastern Stations*	*Western Stations - Normal*	*Western Stations - Deficiency*
October	19.0	19.0	19.0
November	15.5	16.5	16.5
December	15.5	15.5	15.6
January	12.5	12.5	15.6
February	8.0	8.0	15.6
March	8.0	8.0	15.6
April	11.0	11.0	14.0
May	11.0	11.0	12.5

Channel Water Salinity Objectives

The subcommittee's recommendations for Suisun Marsh channel water salinity objectives are as follows:

1. A relaxation of the current salinity standards to 20 mS/cm in October and November of all water years. Gate operations would be triggered once salinity reaches 20 mS/cm.

   The subcommittee does not believe that current WQCP operations in fall provide any particular benefit for native fish populations. In fact, information suggests low salinities during fall may support the establishment of introduced fish species (Moyle and Herbold 1983, Moyle and Herbold 1986). The subcommittee favors an increase in variability and overall range of the salinity regime during this time of the year.

This recommendation introduces an increase in variability of the salinity regime during certain months not considered critical to native fish spawning and rearing. (The recommendation increases the salinity standard by 1 mS/cm in October and 3.5 mS/cm in November.) Such an increase in range and potential variability could provide some advantage to native fish over introduced fish in the marsh (Moyle and Herbold 1983, Moyle and Herbold 1986). An adaptive management approach should be employed so that the action could be modified as needed depending on impacts.

2. Maintaining the current salinity standards for December and January for all water year types.

3. No operation of the gates in wet years (as defined in SWRCB WR 98-9) from February through June.

   During wet years, channel water salinities from February through June are optimal for spawning and rearing of larval fish. An analysis of salinity data collected during fish sampling at nine sloughs in the marsh during 6 wet years (1982, 1983, 1984, 1986, 1995, and 1996) indicated that salinity was below 8 mS/cm 100 percent of the time during February, March, and April sampling events, 99 percent of the time during May sampling events, and 92 percent of the time during June events. These low salinities were not the result of gate operations, as the gates were not constructed until 1988, and were not operated from February 1995 through November 1996 due to low salinities. Thus, gate operations are not necessary to support fish abundance in the marsh from February through June.

4. Maintaining low salinities during all other water year types from February through June, using gate operations if necessary. The subcommittee offers two alternatives:

   a) *Current standards*:
      February-March—8 mS/cm
      April-May—11 mS/cm

   b) *Temperature dependent standards*:
      February-March—8 mS/cm
      April-June—8-11mS/cm (depending on channel water temperature)

   The first alternative (a), is based on the "optimal" salinity ranges for various native fish shown in Table 9. Maintaining low salinity during these months would ensure that channel water salinity is optimized for spawning and rearing of native fish, which is critical for the protection of native fish populations. The second alternative (b), makes the standard dependent on temperature, since spawning is temperature dependent. This alternative extends the April-May standard into June so that these salinity levels are maintained later in the season when water temperature may be more conducive for spawning. As data become available, the impacts of this action should be evaluated and the action modified as needed.

The subcommittee strongly recommends that these salinity objectives be tested over a period of at least 10 years, and that fish surveys be conducted in the marsh to monitor the potential effects of these salinity objectives on the fish community. Further, it may be important to occasionally decrease the amount of time gates are operated in spring and allow salinity to increase beyond the levels indicated above, for example in May or April. This would help prevent the possibility that spring conditions could become too predictable, which could result in the migration of non-native freshwater predators.

Further Recommendations

The subcommittee recommends that SWRCB establish an IEP workgroup of biologists, statisticians, and hydrologists to continue analysis of the Suisun Marsh ecology. Key questions and suggestions for future research are listed below. (Additional recommendations are included.)

Recommendations for Future Research

1. Address whether aquatic ecosystem functions in sloughs proximate to tidal wetlands are different than ecosystem functions in sloughs proximate to managed wetlands or the wastewater treatment plant.

2. Study the potential acute and chronic toxic effects of drainage water from managed wetlands on marsh fishes, in particular special status species and those which reside in backwater sloughs, such as Delta smelt, splittail, chinook salmon and tule perch. Develop a list of "best management practices" aimed at minimizing any such impacts.

3. Investigate the relative quality of Suisun Marsh aquatic habitat compared to other shallow water habitat elsewhere in the estuary.

4. Investigate whether fish abundance in Suisun Marsh is related to geographical/salinity access to Suisun Marsh.

5. Investigate whether abundances of particular fish species in the marsh increase when the species' observed salinity tolerance range coincides geographically with the entrances to the marsh.

6. Investigate the role of salinities in fall for potential establishment of introduced fish and other aquatic species.

7. Investigate whether fish spawning and rearing success in the marsh is measurably affected by salinity levels.

8. Develop conceptual models of fish populations which use the marsh for part of their life cycle.

9. Consider whether the current configuration and focus of the U.C. Davis sampling program are adequate to answer the questions listed above. If not, additions to the existing program should be made accordingly.

Areas of Agreement and Disagreement With Other Subcommittees

The following summarizes the Aquatic Habitat Subcommittee's evaluation of the recommendations by the Brackish Marsh Vegetation, Waterfowl, and Wildlife subcommittees. Tthe Aquatic Habitat Subcommittee evaluated these recommendations in terms of how their implementation may affect adult, juvenile, and larval native fishes in Suisun Marsh.

Brackish Marsh Vegetation Subcommittee

Areas of Agreement and Disagreement:

1. The Brackish Marsh Vegetation Subcommittee bases its recommendations on the assumption that "minimizing artificial reduction of long-term variability in salinity of tidal water of the Suisun Marsh system would benefit brackish marsh vegetation and rare plant species of the marsh." The Brackish Marsh Vegetation Subcommittee recommends eliminating operation of the gates in winter and spring months of all years. The Aquatic Habitat Subcommittee believes that elimination of gate operations during the late winter and spring months (February through June) could adversely affect native fish in the marsh (except during wet years, at which time there is no operation of the gates anyway).

   Plants and fish differ fundamentally in their modes and strategies for reproduction. The viability of a given plant species does not often depend on optimizing juvenile recruitment in all years. This is due to the fact that plants can often rely on asexual reproduction or a seed bank for recruitment. Therefore, the Brackish Marsh Vegetation Subcommittee's recommendation of eliminating operation of the gates in winter and spring months may not adversely affect the plant community of Suisun Marsh.

   However, this recommendation could adversely impact the native fish community in Suisun Marsh. Bennett and Moyle (1996) assert that the majority of the fish species in the Sacramento-San Joaquin estuary appears to be recruitment limited, which they define as having poor survival through the first year of life. Maximizing recruitment (survival to age 1) on a yearly basis could be essential to the viability of certain fish species, especially those that are short-lived such as Delta smelt. One way to help preserve the native fish communities in the marsh may be to maintain low salinity conditions in spring to maximize survival to age 1. The importance of providing low salinity conditions during spring for spawning and rearing is supported by Moyle (1976), CUWA (1994), Unger (1994), and Wetland Goals (1997), and biologists who study fish populations in the marsh (Moyle, pers. comm. see Notes; and Baxter, pers. comm. see Notes).

   Additional research on variability of the salinity regime and suspension of gate operations during spring months indicates that for an ecological system not highly disturbed by habitat alteration and exotic species invasions, re-establishment of historical variability might help to restore ecosystem health (e.g., increase populations of native species, etc.). However, for a system such as Suisun Marsh, which has experienced dramatic changes in the physical, chemical, and biological habitat parameters and in species composition, due to invasion of exotics and much more, such an increase in variability could negatively impact native species by exposing them to extreme events. Extreme events, such as droughts (which could offset some of the impacts of a drought) and floods, often have a negative impact on native aquatic species in the marsh, many of whose populations are already depauperate (Meng et al. 1994, Bennett and Moyle 1996). Further, when these extreme events decrease population abundance of native species, non-native species may have greater success at establishment. Herbold et al. (1992) found that high salinities in the estuary due to low outflow decreased the reproductive success of native species and allowed several exotic species to gain a foothold in the more saline habitat.

   In a discussion of the invasion of exotic fish species in the nineteenth century, Bennett and Moyle (1996) assert that introductions of exotic species are often successful when native populations are ecologically weakened:

   > "These introductions, and many others that have taken place since the 19th century, suggest that invasions of the estuary have a higher potential for success when the establish assemblages are

> stressed or depleted from habitat alteration and/or reduced outflow (Moyle 1986; Baltz & Moyle 1993).
>
> "Further evidence for this 'rule' is the number of major invasions that occurred between 1985 and 1993, a period of severe drought whose effects were exacerbated by increasing water diversions (Nichols et al. 1990; Moyle et al. 1992; Kimmerer et al. 1995; Matern & Fleming in 1995). Following the extreme flood event of February, 1986, populations of many estuarine organisms (particularly benthic organisms) were greatly diminished and a number of new species invaded. The most spectacular invasion was that of the Asiatic clam, *Potamocorbula amurensis* which quickly became the dominant filter-feeding organism in the [northern] estuary, with drastic effects on the plankton (Kimmerer et al. 1995; Kimmerer & Orsi, this volume). Other post-1986 invaders include a number of crustacean species (Carlton & Geller 1993; Hedgpeth 1993; Kimmerer & Orsi, this volume). The most recent fish invader is the shimofuri goby (*Tridentiger bifasciatus*) which arrived around 1986 (Matern and Fleming, 1995), and is now one of the most abundant fish in the system (Meng et al. 1994)...Therefore the rate at which exotic species have become established in the estuary has increased dramatically in recent years, concurrent with and perhaps facilitated by, the maintenance of low outflow conditions by drought and diversion."

Native species account for slightly more than half the fish species in the marsh (28 of 54 total species). In the 1997 Annual Report on the U.C. Davis Suisun Marsh Fisheries Sampling Program, Matern et al., report that "native fishes have declined while introduced fishes have fluctuated with high interannual variance at relatively higher population levels, resulting in increasing dominance by exotics." Native aquatic species tend to have low population numbers in the marsh relative to exotic species. Eliminating gate operations in late winter and spring—the most critical times of the year for fish spawning and larval rearing—could increase stress on native fish populations in below normal, critical, and dry years. While a modest increase in variability of the salinity regime during non-critical months could possibly be beneficial to the native fish fauna of the marsh (Moyle and Herbold 1983, Moyle and Herbold 1986), allowing unmanaged increases in variability may not be.

The timing and magnitude of salinity variation in the marsh has changed from historical conditions. The gates are mitigation for the upstream and Delta diversions. Compared to historical conditions, current diversions have reduced outflows in late winter and spring months. In contrast, historical (pre-diversion) fall salinities were almost always higher than under current conditions. With gate operations in fall, the marsh salinities are considerably fresher than historically. Moreover, the possibility exists that additional diversions will occur upstream in the future and in the Delta, further reducing outflow in the spring months. Gate operations serve to decrease the salinities in the marsh in spring so they are more similar to historical conditions.

The Aquatic Habitat Subcommittee believes that long-term, interannual salinity variability is a key physical feature of the system that resulted in the suite of native fish species these recommendations are seeking to protect. The Aquatic Habitat Subcommittee would concur with re-establishment of long-term salinity variability (as recommended by the Brackish Marsh Vegetation Subcommittee) minus all other physical and biological changes that have occurred recently. However, the effect of extreme salinity conditions has changed from a long-term selective advantage for native fishes to one that threatens their existence in the presence of habitat changes and exotic species. The Aquatic Habitat Subcommittee believes that, under current and future levels of water diversions, the re-establishment of long-term interannual variability (through the elimination of gate operations during spring) could negatively impact native fish and aquatic invertebrates in Suisun Marsh.

2. The Brackish Marsh Vegetation Subcommittee does not object to the operation of the gates during late fall/early winter. While the Aquatic Habitat Subcommittee also does not object to operation of the gates during this period, the subcommittee does not believe that such operation will be of much benefit to native fish populations. Operation of the gates in early winter may help to freshen the marsh during the critical spawning period of February through June, during dry and critical years. However, low salinities during the fall period may support the establishment of introduced species (Moyle and Herbold 1983, Moyle and Herbold 1986). Thus, the Aquatic Habitat Subcommittee favors an increase in the variability of the salinity regime during this time of the year, which might deter the establishment of introduced fish. The Aquatic Habitat Subcommittee also believes that with substantial improvements to landowners' management capabilities, flooding with low salinity water could be achieved without fall operation of the gates. Thus, the Aquatic Habitat Subcommittee recommends a relaxation of the current salinity standard at interior marsh stations to 20 mS/cm in October and November of all water years.

3. The Brackish Marsh Vegetation Subcommittee recommends delaying the implementation dates for interior marsh compliance stations S-97 and S-35 indefinitely and suspending enforcement of interior marsh compliance stations. The Aquatic Habitat Subcommittee does not object to delaying the implementation dates of compliance stations S-97 and S-35 and maintaining them as monitoring stations. However, the Aquatic Habitat Subcommittee believes that suspension of interior marsh standards would be detrimental to native fishes for reasons discussed in Number 1 above. Enforcement of interior marsh salinity standards during the months of February through May could be important to the maintenance of healthy native fish populations in the marsh.

4. The Brackish Marsh Vegetation Subcommittee recommends that leach management of salinity should be experimentally modified to determine alternative effective methods of vegetation management which do not depend on artificially depressed salinity of applied channel water. The Aquatic Habitat Subcommittee supports the scientific investigation of such alternative methods.

5. The Brackish Marsh Vegetation Subcommittee recommends investigation of regional variation in soil salinity tolerance of duck food plant species throughout the estuary to determine whether combination of alternative types of water management would support higher waterfowl abundances. The Aquatic Habitat Subcommittee supports such an investigation.

Waterfowl Subcommittee

Areas of Agreement and Disagreement:

1. The Waterfowl Subcommittee believes that current salinity standards in Suisun Marsh are adequate for maintenance of existing habitat for waterfowl. Therefore this subcommittee recommends maintaining current salinity standards in the marsh. The Aquatic Habitat Subcommittee supports certain aspects of this recommendation.

   The current salinity standards maintain salinity concentrations in the marsh that do not appear to adversely affect fish and their habitat in the marsh. As our investigations suggest, channel water salinity in the marsh does not appear to be limiting to juvenile and adult fish from July through January. Further, the current normal salinity standards (as opposed to deficiency standards) maintain relatively low salinity from February through May, which is beneficial for spawning and larval rearing of native fish. The Aquatic Habitat Subcommittee supports the maintenance of these or similarly low salinity standards in the marsh from February through May during all years except those classified as wet.

The Aquatic Habitat Subcommittee recognizes the importance to marsh landowners of flooding with low salinity water during fall in order to maintain waterfowl habitat in the managed wetlands. However, the subcommittee believes that with substantial improvements to landowners' management capabilities, flooding with low salinity water could be achieved without fall operation of the gates. The subcommittee suggests revising the salinity standards to include gate operations in October and November only when channel water salinity reaches 20 mS/cm. Eliminating operation of the gates in October and November (except during dry years) would return a small measure of variability to an ecosystem that historically experienced substantial variability. A modest increase in variability of the salinity regime during the January through July period could be beneficial to the native fish fauna of the marsh (Moyle and Herbold 1983, Moyle and Herbold 1986).

2. The Waterfowl Subcommittee also tentatively recommended lowering channel water salinity from March through July. As discussed earlier, the Aquatic Habitat Subcommittee would support somewhat lower salinity standards from February through June.

Wildlife Subcommittee

Areas of Agreement and Disagreement:

1. The Wildlife Subcommittee supports the establishment of year-round, flow-based standards. The subcommittee calls for standards that would reflect the spatial and temporal changes that have occurred historically in the marsh, but the subcommittee does not elaborate on what this would mean on a month-by-month basis. The Wildlife Subcommittee also proposes that the gates be operated only during dry and critical water years throughout the October through May control season. The Aquatic Habitat Subcommittee agrees with certain aspects of this recommendation.

   The Aquatic Habitat Subcommittee supports the maintenance of flow-based standards similar to X2 during certain times of the year. Likewise, the subcommittee supports the position that gates should not be operated in wet years. However, as detailed above, the subcommittee does not support operation of the salinity control gates during October and November unless salinities reach 20 mS/cm. Further, the subcommittee does support the maintenance of low salinities between February through June using gate operations if necessary. These positions differ from that of the Wildlife Subcommittee discussed above.

2. The Wildlife Subcommittee recommends additional scientific studies and improvements to infrastructure on managed wetlands to assist wetland managers in effective control and maintenance of soil salinities and acid production. The Aquatic Habitat Subcommittee also supports this recommendation.

3. The Wildlife Subcommittee recommends increased monitoring and research of Suisun Marsh wildlife populations. The Aquatic Habitat Subcommittee supports this recommendation.

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Appendix 1

Aquatic Habitat Subcommittee's Revised Interim Report

Purpose

This report is part of the work of the Suisun Ecological Workgroup (SEW). One of the many tasks being undertaken by this group is to review salinity standards in Suisun Marsh and recommend salinity objectives for it. This paper, which represents one phase of this process, focuses on the status of invertebrates and fish and water quality of the marsh. Its purpose is to compile and review scientific literature on the habitat needs, and physical tolerance (specifically temperature and salinity) levels of selected fish and invertebrates that reside in or migrate through the marsh. The next phase of this process, which will be completed by the SEW Aquatic Habitat Subcommittee during 1997-99, will be to analyze data collected on fish species in the marsh. Ultimately, the findings of this and other SEW subcommittees (Waterfowl, Wildlife, Brackish Marsh Vegetation, and Hydrology) will be used to recommend salinity objectives that would protect all the beneficial uses of the marsh. This process will be completed when SEW presents its final report to the State Water Resources Control Board in fall 1999.

Fish and Invertebrate Species Considered in this Study

In order to best evaluate the status and needs of fish and invertebrates in the marsh, the SEW Aquatic Habitat Subcommittee decided to focus on a limited number of species that would be most representative of the marsh community. Species selected could be resident, non-resident, or migratory, and were representative of a particular fish or invertebrate community or habitat; or are special status species (threatened, endangered, or candidate). Although we wanted to focus primarily on native species, we included several introduced species in this list. Striped bass was included on our list because it is an important sport fish. Yellowfin and shimofuri goby were included because we wanted to know more about the population dynamics of these non-native species, which have occasionally reached relatively high abundances in the Marsh, and try to determine whether these peaks affect the abundance of native fish in the marsh.

The following fish species were chosen for inclusion in all or specific aspects of our study:

1. Chinook salmon (*Oncorhynchus tshawytscha*)—Native
2. Steelhead (*Oncorhynchus mykiss*)—Native
3. Delta smelt (*Hypomesus transpacificus*)—Native
4. Longfin smelt (*Spirinchus thaleichthys*)—Native
5. Prickly sculpin (*Cottus asper*)—Native
6. Splittail (*Pogonichthys macrolepidotus*)—Native
7. Starry flounder (*Platichthys stellatus*)—Native
8. Striped bass (*Morone saxatilis*)—Introduced
9. Tule perch (*Hysterocarpus traski*)—Native
10. Yellowfin goby (*Acanthogobius flavimanus*)—Introduced
11. Shimofuri goby (*Tridentiger bifasciatus*)—Introduced

The following invertebrate species were chosen for study:

1. Opossum shrimp (*Neomysis mercedis*)—Native
2. Bay shrimp (*Crangon spp.* and *Palaemon macrodactylus*)—Native

Information on habitat requirements and potential times of occurrence in the Suisun Marsh is summarized in tables 4A-1 and 4A-2 and in Figure 4A-1.

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Table 4A-1 Aquatic Habitats in Suisun Marsh

Sampling Locations	*Habitat Types*	*Species*
Peytonia Slough	narrow and shallow	splittail and tule perch[1]
Cutoff Slough	narrow and shallow	juvenile salmon[2]
Boynton Slough	narrow and shallow	some juvenile salmon
Goodyear Slough	narrow and shallow	**some juvenile salmon**, low catches overall but larger SB, sculpins
Suisun Slough	wide and often deep	**most salmon, juvenile SB**, sculpins
Montezuma Slough	wide and often deep	**most salmon, juvenile SB**, sculpins
Nurse Slough		**juvenile salmon**, highest catches of splittail and delta smelt[3]
Denverton Slough		**juvenile salmon**, highest catches of splittail and delta smelt
Cordelia Slough		highest catches of longfin smelt
Spring Branch	narrow and shallow, bordered by unmanaged tidal marsh	**juvenile salmon**, striped bass and sculpins

[1] Text in italics is from Moyle and Daniels 1980.

[2] Text in bold is from National Marine Fisheries Service 1994.

[3] Plain text is from Matern and others 1995.

Table 4A-2 Habitat Requirements of Selected Aquatic Species in Suisun Marsh

Species	Description	Spawning	Larvae	Juveniles
Chinook salmon	anadromous	gravel streambeds	fry - streambanks	streambanks/estuary, tidal marsh, juvenile migration 100-240 days
Delta Smelt	low to moderate salinities	river channels and backwater sloughs	planktonic	shallow water areas
Longfin Smelt	anadromous/euryhaline	fresh to brackish water over rocks or aquatic vegetation	planktonic	San Francisco Bay; open water
Prickly Sculpin	fresh to salt	fresh or intertidal, large flat rocks and moderate currents	planktonic 3-5 weeks	20-30 mm, settle on bottom, move generally upstream
Splittail	freshwater/brackish	submerged aquatic vegetation, sloughs	shallow weedy areas	shallow open waters, sloughs and river channels
Shimofuri Goby	limnetic and low salinity			
Starry Flounder	estuarine	near-shore shallow coastal waters	pelagic in upper water column	2 months after hatching settle to bottom; shallow, brackish habitat
Steelhead	anadromous	gravel streambeds	fry - streambanks, tidal marsh	streambanks/estuary, tidal marsh
Striped Bass	anadromous/estuarine	freshwater with moderate to swift current	lower riverine, upper estuarine	0-50 mm TL-lower riverine, upper estuarine
Tule Perch	low elevation sloughs and streams	livebearers; emergent plants or overhanging banks	(no fry)	weed beds, dense cover
Yellowfin Goby	euryhaline, shallow coastal waters	burrows in mud and coarse sand bottoms	pelagic	settle to bottom at 15-20 mm
Neomysis	planktonic, low salinity waters			
***Crangon* spp.**	estuarine, marine and brackish water; brackish, warm water (*C. franciscorum*); high salinty, cool water (*C. nigricauda*); coastal, shallow water (*C. nigromaculata*)	ocean or high salinity water; prefers lower salinities; found in wide range of salinities and temperatures	ocean or high salinity water	lower salinity area; low salinities March-May
Palaemon macrodactylus	adjacent to freshwater sources			
Corbicula fluminea	low salinity water, streams and sloughs with hard bottoms			

Table 4A-2 Habitat Requirements of Selected Aquatic Species in Suisun Marsh (continued)

Suisun Marsh	Prey Preferences	Habitat	Prey Preference
Species	**Juveniles**	**Adults**	**Adults**
Chinook salmon	freshwater: aquatic and terrestrial insects, cladocerans, amphipods and other crustceans, sometimes fish; estuaries: gammarid amphipods, chironomids, copepods, mysids, decapod larvae and fish	ocean	fish and shrimp
Delta Smelt	zooplankton	open, shallow water areas	*Eurytemora affinis, Pseudodiaptomus forbesi*
Longfin Smelt	zooplankton	San Francisco Bay, open water	zooplankton, *Neomysis*
Prickly Sculpin	chronomid larvae, small benthos	streams, lakes, salt water	benthic invertebrates, mollusks, small fish
Splittail	amphipods, etc.	slow water	benthic foragers, *Neomysis*
Shimofuri Goby		structurally complex substrates	benthic invertebrates: amphipods and mysid shrimp
Starry Flounder	planktonic algae, crustaceans; amphipods and copepods	lower parts of coastal streams, Bay/Delta and ocean	crabs, polycheate worms and mollusks
Steelhead	invertebrates and small fish	ocean	fish and invertebrates
Striped Bass	invertebrates and fish, *Neomysis*	ocean and brackish water	fish
Tule Perch	small hard-shelled invertebrates associated with bottom or aquatic plants, midwater zooplankton	slough, backwaters near deep cover	small hard-shelled invertebrates associated with bottom or aquatic plants, midwater zooplankton
Yellowfin Goby	zooplankton, especially copepods	shallow, muddy littoral areas in fresh-salt water	crustaceans and small fish
Neomysis			bottom zooplankton, rotifers, copepods
***Crangon* spp.**			zooplankton

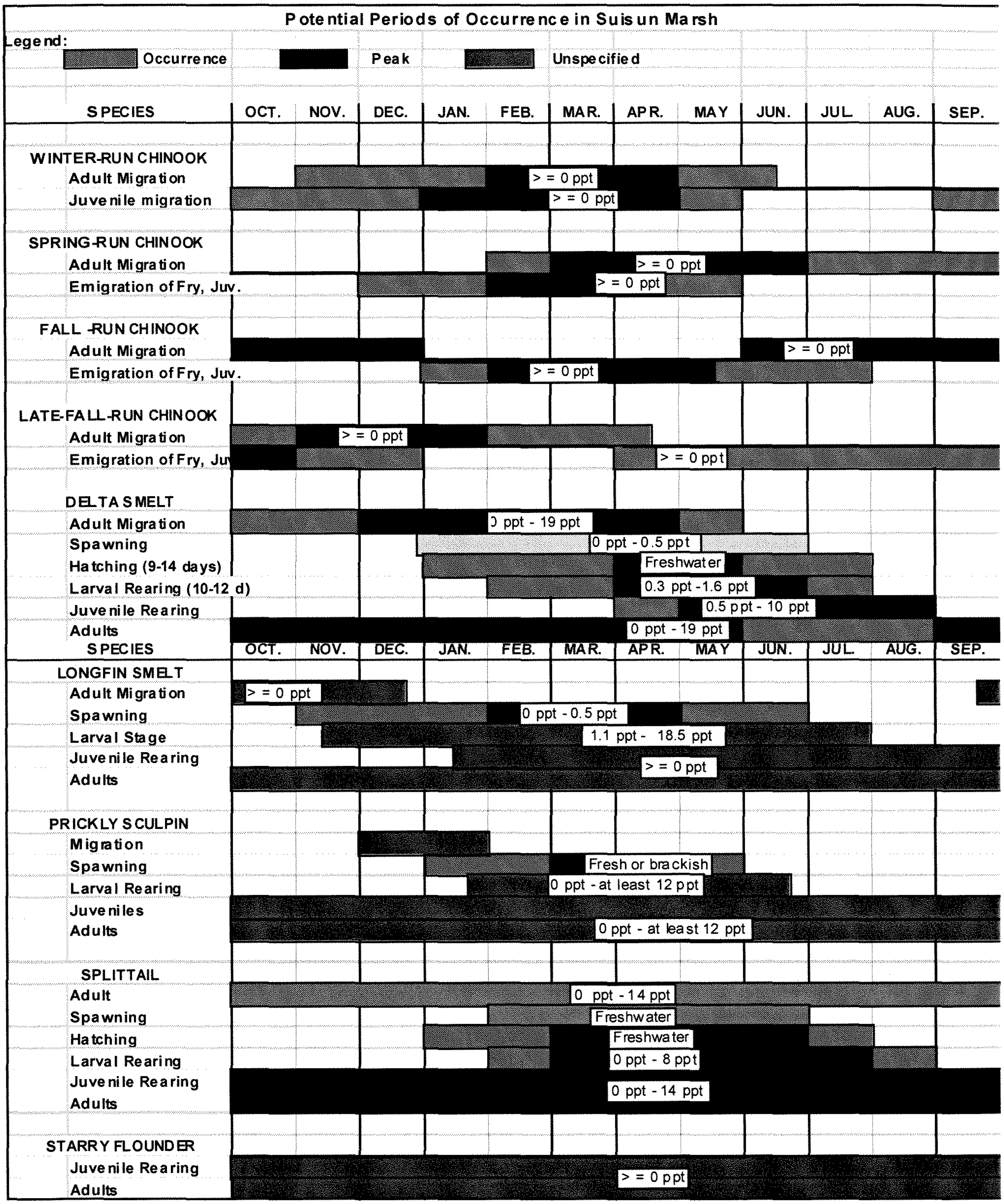
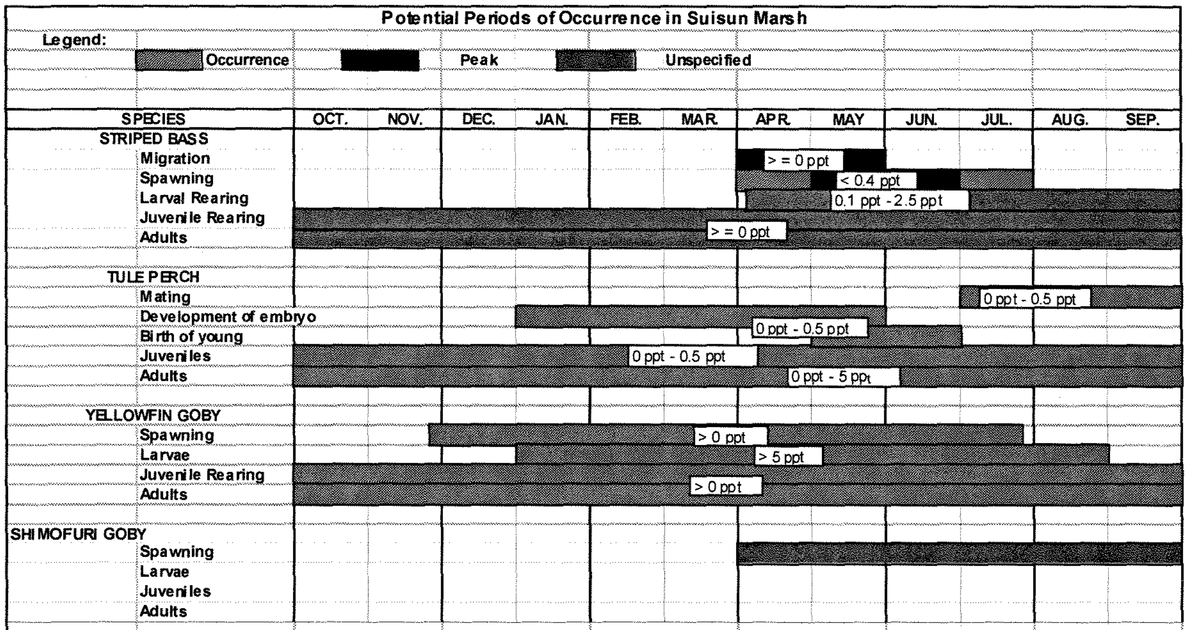


Figure 4A-1 Calendar of Life History Stages of Various Fish Species in Suisun Marsh



References:

Winter-Run Chinook salmon: Vogel and Marine 1991; info on migration timing: Holsinger 1996, pers. comm.
Spring-Run: Vogel and Marine 1991
Fall -Run: Vogel and Marine 1991
Late-Fall Run: Vogel and Marine 1991
Delta smelt: DWR and USBR 1994
Sacramento splittail: DWR and USBR 1994; Sommer, in press; Meng and Moyle 1995
Longfin smelt: McGinnis 1984; Wang 1986; Natural Heritage Institute 1992
Prickly sculpin: Wang 1986; Moyle 1976
Starry flounder: Wang 1986
Striped bass: Wang 1986; Moyle 1976; USBR 1990; Arthur 1982
Tule perch: Wang 1986; McGinnis 1984
Yellowfin goby: Wang 1986; Moyle 1976
Shimofuri goby: Matern and Fleming 1995

Figure 4A-1 Calendar of Life History Stages of Various Fish Species in Suisun Marsh (continued)

Life History and Status of Individual Species

The following species accounts were completed to assist SEWAH in evaluating the relationship between species abundance and distribution and salinity, habitat availability, outflow and other factors. Rather than write our own species life histories (which seemed unnecessary, since so much has already been written about most of these species), we primarily compiled information from relevant scientific literature. Hence, the species accounts include extensive quotations from this literature. The subsequent compilation was peer reviewed by fish biologists from DFG, U.C. Davis, and DWR and substantially revised to include more accurate information. The information included in these sections forms the basis for SEWAH's subsequent analyses.

1. CHINOOK SALMON (*Oncorhynchus tshawytscha*)

1-1. Status

There are four distinct runs of chinook salmon, distinguished by their timing of upstream migration and spawning season. The runs are named for the season during which the adults enter fresh water: winter-run, spring-run, fall-run and late fall-run. While winter- and spring-run are both State and federally listed, fall- and late fall-run are candidate species under National Marine Fisheries Service (NMFS). In 1989, the Sacramento River winter-run chinook salmon was listed as threatened under the federal ESA by NMFS (54 FR 32085). NMFS reclassified the winter-run as endangered in 1994 (59 FR 440). In 1993, NMFS designated critical habitat for the winter-run chinook from Keswick Dam (Sacramento river mile 302) to the Golden Gate Bridge (58 FR 33212). Central Valley spring-run salmon was listed as threatened in August 1998.

1-2. Distribution

The chinook salmon has the broadest geographic range of the seven Pacific salmon species. Runs of chinook salmon are found throughout the northern Pacific Ocean and tributary drainages around the Pacific Rim from northern Japan to southern California (Vogel and Marine 1991). In spite of its wide distribution, the chinook salmon is the least abundant of Pacific salmon species in North America. Numbers of this native, anadromous species, which is distinguished by its highly variable life history and multiple stocks, are maintained to a large extent by hatchery production (DWR 1993, SFEP 1992a).

The Central Valley supports the largest population of chinook salmon in the State (SFEP 1992a). The Bay-Delta estuary serves as a migratory corridor for upmigrating adults and outmigrating smolts, and serves as rearing habitat for salmon fry. All four runs of chinook salmon spawn in the upper Sacramento River.

1-3. Habitat

After maturing in the ocean, adult salmon migrate through the estuary to spawn (Monroe and Kelly, 1992). Acceptable water temperatures for the upstream migration of adults range from 57^{o} F to 67^{o} F. Spawning historically occurred in Central Valley streams that provided approximately 6,000 miles of habitat for spawning (Monroe and Kelly 1992). However, dam construction in the Central Valley has reduced the quantity of habitat available to spawning salmon: only about 300 miles of the original instream habitat remain. At present, most winter-run spawn in the upper Sacramento River from Keswick Dam southward (Wang 1986). The other runs spawn in the tributaries. Spawning generally occurs in swift, relatively shallow riffles or along the edges of fast runs where there is an abundance of loose gravel.

Spawning requires well-oxygenated cool water that percolates through the gravel and supplies oxygen to developing embryos. The ideal temperature for chinook salmon spawning is approximately 52° F, with lower and upper threshold temperatures of 42° F and 56° F. Temperatures above this range may result in reduced viability of eggs or heavy mortality of developing juveniles. Total egg mortality normally occurs at 62° F. The eggs usually hatch in 40-60 days, depending on water temperature within the appropriate temperature range. The young sac-fry remain in the gravel for an additional 4-6 weeks until the yolk sac is absorbed. After emergence, chinook salmon fry feed in low velocity slack water and back eddies. They move to higher velocity areas as they grow larger and, eventually, migrate to the ocean as smolts. Young salmon remain in the ocean from 1 to 4 years, at which time they return to their home stream to spawn.

NMFS designated critical habitat for winter-run chinook salmon from Keswick Dam (Sacramento River mile 302) to the Golden Gate Bridge (58 FR 33212).

1-4. General Ecology

Chinook salmon life history cycle involves adult migration from the ocean to freshwater streams to spawn and juvenile migration out to sea during the first year of life. Timing of adult migration differs depending on the race or run. Winter-run chinook generally move upstream between January and June and begin spawning in April. Spring-run generally move upstream between March and July and begin spawning in August. Fall-run generally enter fresh water between July and November and begin spawning in October. Late fall-run generally move upstream between October through February and begin spawning in January. After hatching, young salmon move downstream and through the Delta before passing into the San Francisco Bay system and to the ocean.

Many interacting factors are believed to be responsible for the decline in chinook salmon populations. Abundances have decreased due to human impacts, such as the construction of dams, water diversions, logging practices, pollution, and fishing, which kills 70-90 percent of the fall-run adults and a portion of the other runs as well. High mortality can occur during early life stages due to habitat destruction, redd destruction, siltation, extreme water temperatures, low dissolved oxygen, loss of cover, disease, competition, and predation.

1-5. Occurrence in Suisun Marsh

Adult chinook salmon migration in the vicinity of Suisun Marsh and Bay varies for each run of salmon. Adult winter-run migrate through Montezuma Slough and Suisun Bay from November through mid-June, with peak occurrence in the marsh from February through April (Holsinger, L., NMFS. 1996, pers. comm. See Notes). Juveniles may occur in the Marsh from October through May, with especially high numbers occurring from January through April. Adult spring-run may occur in the Montezuma Slough or Suisun Bay from February through June, with the peak migration occurring in May (Harvey, C., DFG. 1996. pers. comm. See Notes). Juveniles may be migrating through the marsh over a number of months, including the December through May period. Fall-run adults may occur in the area June through December, while juveniles may be present from January through July, with the peak occurrence from February through mid-May. Late fall-run migration may occur from October through mid-April, with the peak November through January. Juveniles may be present from April through December. It should be noted that these are only rough estimates of the timing of migration for these runs.

The presence of juvenile chinook salmon in the Marsh has varied over the past 15 years, according to the results of the U.C. Davis sampling (DWR 1997a). Chinook salmon were captured in trawls in all but 2 years between 1980 and 1989. No chinook salmon were captured subsequently until 1995, when a total of 50 individuals was collected (48 in beach seines and 2 in trawls) (Matern et al. 1995). In 1996, a total of seven chinook salmon were captured, while in 1997 only one chinook salmon was caught. All chinook salmon from 1995 and 1996 were captured between January and April and all were identified as fall run using Frank Fisher's length-at-date criteria. Most of these fish were captured at the seining beach in Denverton Slough. Since 1980 annual mean abundance of chinook salmon has ranged from 0 to 0.08 fish per trawl (DWR 1997a).

2. CENTRAL VALLEY STEELHEAD (*Oncorhynchus mykiss*)

2-1. Status

Central Valley steelhead (*Oncorhynchus mykiss*) is federally listed threatened.

2-2. Distribution

The following is quoted from the Federal Register 1996, Volume 61, Number 155:

"Central Valley steelhead Evolutionarily Sensitive Unit [ESU] occupies the Sacramento and San Joaquin Rivers and their tributaries. In the San Joaquin Basin, however, the best available information suggests that the current range of steelhead has been limited to the Stanislaus, Tuolumne, and Merced Rivers (tributaries), and the mainstem San Joaquin River to its confluence with the Merced River by human alteration of formerly available habitat. The Sacramento and San Joaquin Rivers offer the only migration route to the drainages of the Sierra Nevada and southern Cascade mountain ranges for anadromous fish. The distance from the Pacific Ocean to spawning streams can exceed 300 km, providing unique potential for reproductive isolation among steelhead. The Central Valley is much drier than the coastal regions to the west, receiving on average only 10-50 cm of rainfall annually....Steelhead within this ESU have the longest freshwater migration of any population of winter steelhead. There is essentially one continuous run of steelhead in the upper Sacramento River. River entry ranges from July through May, with peaks in September and February. Spawning begins in late December and can extend into April (McEwan & Jackson, 1996).

“Steelhead ranged throughout the tributaries and headwaters of the Sacramento and San Joaquin Rivers prior to dam construction, water development, and watershed perturbations of the 19th and 20th centuries. Present steelhead distribution in the Central valley drainages has been greatly reduced (McEwan & Jackson, 1996), particularly in the San Joaquin basin....With regard to the present distribution of steelhead, there is also only limited information. McEwan and Jackson (1996) reported that a small, remnant run of steelhead persists in the Stanislaus River, that steelhead were observed in the Tuolumne River in 1983, and that a few large rainbow trout that appear to be steelhead enter the Merced River Hatchery annually.

“Historical abundance estimates are available for some stocks within this [the Central Valley] ESU, but no overall estimates are available prior to 1961, when Hallock et al. (1961) estimated a total run size of 40,000 steelhead in the Sacramento River, including San Francisco Bay. In the mid-1960's, CDFG (1965) estimated steelhead spawning populations for the rivers in this ESU, totaling almost 27,000 fish. Limited data exist on recent abundance for this ESU. The present total run size for this ESU based on dam counts, hatchery returns, and past spawning surveys is probably less than 10,000 fish. Both natural and hatchery runs have declined since the 1960’s.

"NMFS concludes that the Central Valley steelhead ESU is presently in danger of extinction. Steelhead have already been extirpated from most of their historical range in this ESU. Habitat concerns in this ESU focus on the widespread degradation, destruction, and blockage of freshwater habitats within the region, and the potential results of continuing habitat destruction and water allocation problems."

2-3. Habitat

The following is quoted from the Wang 1986:

"Spawning habitats range from large rivers to small creeks....Newly hatched larvae initially stay in the crevices of the nesting area until their yolk sac is absorbed (about two weeks) and then move into adjacent shallow and quiet pools located below riffles .... Juvenile steelhead remain in freshwater streams from one to three years before entering the ocean (Moyle 1976)....In this study, many juvenile steelhead were observed in inshore, slough, and open waters of the estuary, in rivers, and even in some of the intermittent stream..."

2-4. General Ecology

The following is quoted from the Federal Register 1996, Volume 61, Number 155:

"Steelhead may exhibit anadromy (meaning that they migrate as juveniles from fresh water to the ocean, and then return to spawn in fresh water) or freshwater residency (meaning that they reside their entire life in fresh water). Resident forms are usually referred to as "rainbow" or "redband" trout, while anadromous life forms are termed -"steelhead". Few detailed studies have been conducted regarding the relationship between resident and anadromous 0. mykiss and as a result, the relationship between these two life forms is poorly understood.

"Steelhead typically migrate to marine waters after spending 2 years in fresh water. They then reside in marine waters for typically 2 or 3 years prior to returning to their natal stream to spawn as 4- or 5 year-olds. Unlike Pacific salmon, steelhead are iteroparous, meaning that they are capable of spawning more than once before they die. However, it is rare for steelhead to spawn more than twice before dying; most that do so are females. Steelhead adults typically spawn between December and June (Bell, 1990). Depending on water temperature, steelhead eggs may incubate in "redds" (nesting gravels) for 1.5 to 4 months before hatching as "alevins" (a larval life stage dependent on food stored in a yolk sac). Following yolk sac absorption, alevins emerge from the gravel as young juveniles or "fry" and begin actively feeding. Juveniles rear in fresh water from 1 to 4 years, then migrate to the ocean as "smolts."

"Biologically, steelhead can be divided into two reproductive ecotypes, based on their state of sexual maturity at the time of river entry and the duration of their spawning migration. These two ecotypes are termed "stream maturing" and "ocean maturing." Stream maturing steelhead enter fresh water in a sexually immature condition and require several months to mature and spawn. Ocean maturing steelhead enter fresh water with well-developed gonads and spawn shortly after river entry. These two reproductive ecotypes are more commonly referred to by their season of freshwater entry (e.g., summer and winter steelhead)."

2-5. Occurrence in the Suisun Marsh

Central Valley steelhead have been captured intermittently in Suisun Marsh by the U.C. Davis Fisheries Monitoring Program (Matern et al. 1997). In 1982, two steelhead were captured, while only one steelhead was caught in 1985, 1988, 1996, and 1997. The U.C. Davis study does not report any other catches of steelhead in the Suisun Marsh.

3. DELTA SMELT (*Hypomesus transpacificus*)

3-1. Status

Delta smelt (*Hypomesus transpacificus*) was listed as threatened by both DFG and USFWS in 1993. Critical habitat was designated for the delta smelt in 1995. Critical habitat includes the following areas: Suisun Bay (including the contiguous Grizzly and Honker bays); the length of Goodyear, Suisun, Cutoff, First Mallard, and Montezuma sloughs; and the existing continuous waters within the Delta.

3-2. Distribution

This species inhabits open surface and shoal waters of main river channels and Suisun Bay (DWR 1992, SFEP 1992a). Juvenile and adult delta smelt commonly occur in the surface and shoal waters of the lower reaches of the Sacramento River below Mossdale, through the Delta, and into Suisun Bay (Moyle 1976, Moyle et al 1992). Their normal downstream limit appears to be western Suisun Bay. During periods of high outflow they can be washed into San Pablo and San Francisco bays, but they do not establish permanent populations there (SFEP 1992a).

3-3. Habitat

The following is quoted from San Francisco Bay Area Wetlands Ecosystem Goals Project (Goals Project 1997):

“Spawning habitat has been as widely dispersed as the Napa River to Stockton in 1996. The predominate feature appears to be shallow, freshwater conditions with some sort of solid substrate for the attachment of eggs. Spawning has been reported to occur at about 45-59° F (7-15° C) in tidally influenced rivers and sloughs including dead-end sloughs and shallow edge waters of the upper Delta.

“Rearing and pre-spawning delta smelt generally inhabit a salinity range of less than 2 ppt (parts per thousand), although they have been collected at salinities as high as 10 to 14 ppt (DFG 1992d). Analysis of the salinity preferences using mid-water trawl data indicate that delta smelt distribution peaks upstream of the entrapment zone (Obrebski 1993). It should be noted, however, that the distribution of delta smelt is fairly broad, particularly in years when abundance levels are high (DWR and USBR 1994). Evidence from the 1993 year-class also demonstrates that salt field position does not necessarily regulate delta smelt distribution in all years. In late 1993 and early 1994, delta smelt were found in Suisun Bay region despite the fact that X2 was located upstream. Samples collected in this area demonstrated that high levels of copepod Eurytemora were present, suggesting that food availability may also influence smelt distribution (DWR and USBR 1994).

“Although these results show that the delta smelt is not an entrapment zone specialist, there is evidence that their abundance is correlated with X2. Herbold (1994) found a significant relationship between the number of days X2 was in Suisun Bay during February through June versus midwater trawl abundance. Furthermore, when the entrapment zone is in Suisun Bay and both deep and shallow water exists, delta smelt are caught most frequently in shallow water (Moyle et al 1992).

“Results from UC Davis provide an indication of environmental tolerances of delta smelt (Cech and Swanson 1993). The study found that although delta smelt tolerate a wide range of water temperatures (8° C to >25° C), warmer temperatures apparently restrict their distribution more than colder temperatures.”

3-4. General Ecology

The delta smelt is a small, short-lived native fish that is found only in the Bay-Delta Estuary. Delta smelt usually inhabit the upper portion of the water column and at salinities ranging from 0-10 ppt (DFG 1992d). Overall, delta smelt concentrate near or immediately upstream of the entrapment zone. The delta smelt has low fecundity and is primarily an annual species, although a few individuals may survive a second year (SFEP 1992a). The location and season of delta smelt spawning vary from year to year. Spawning, which occurs in shallow fresh or slightly brackish water in or above the entrapment zone (DFG 1992d, USFWS 1994), has been known to occur at various sites within the Delta, including the lower Sacramento and San Joaquin rivers and Georgiana Slough, and in sloughs of the Suisun Marsh (USFWS 1994). It appears that few delta smelt spawn in the southern Delta. Based on egg and larval trawls over the last few years, it appears that, at least in low-flow years, a significant portion of delta smelt spawning now takes place in the northern and western Delta (DWR and USBR 1994).

Spawning may occur from late winter (December) to early summer (July). In 1989 and 1990, peak spawning occurred in late April and early May (USFWS 1994). The adhesive eggs descend through the water column and likely attach to submerged substrates such as tree roots, vegetation, and gravel (DFG 1992d). After hatching, the planktonic larvae are transported or gradually migrate downstream where they feed on zooplankton (USFWS 1994).

The following is quoted from San Francisco Bay Area Wetlands Ecosystem Goals Project (Goals Project 1997) and provides information on the abundance of delta smelt in the estuary:

"Seven surveys, although not specifically designed to gather data on delta smelt populations in the Estuary, have charted the abundance of delta smelt. The summer tow-net survey, which began in 1959 and was primarily designed to measure striped bass abundance, is considered one of the best measures of delta smelt abundance because it covers much of the species' habitat and represents the longest historical record. Although the abundance indices vary considerably, they generally remained low between 1983 and 1993. In recent years moderately wet conditions have produced relatively high abundances in the summer tow net survey. The reduced population levels during 1980's appear to have been consistent throughout the Delta and Suisun Bay, but declines may have occurred as early as the mid-1920's in the eastern and southern portions of the Delta (DWR and USBR 1994).

"The midwater trawl survey provides one of the best indexes of smelt abundance because it covers most of the range of delta smelt (USBR and DWR 1994). From 1967 through 1975, fall catches were generally greater than 10 smelt per trawl per month (in 6 of 8 years); from 1976 through 1989, catches were generally less than 10 smelt per trawl per month (in 13 of 14 years). Since 1986, catches have averaged considerably less than one smelt per trawl per month. The frequency of occurrences of delta smelt in the trawls has also declined. Prior to 1983, delta smelt were found in 30 percent of more of the fall trawl catches. In 1983-1985, they occurred in less than 30 percent of the catches, and since 1986, they have been caught in less than 10 percent of the trawls (Herbold et al. 1992). In 1993, the midwater trawl index was the sixth highest of the 25 years of record. In 1994, the index dropped to a 28 year low, but it rebounded again in 1995. Unlike the summer townet survey indices, the mean catches of delta smelt have not declined in the mid-water trawl survey. The smelt population is more dispersed in the summer than in the fall. The summer populations have decreased in average densities while the fall populations have decreased numbers of schools (DFG 1992d). Data from the Bay Study and the Suisun Marsh study show sharp declines in delta smelt at about the same time. The exact timing of the decline is different in most of the sampling programs, but falls between 1982 and 1985 (Herbold et al. 1992).

"No single factor appears to be the sole cause of the delta smelt decline; however declines have been attributed primarily to restricted habitat and increased losses though entrainment by Delta diversions (DWR 1992, Herbold et al 1992, USFWS 1994). Reduced water flow may intensify entrainment at pumping facilities as well as reduce the quantity and quality of nursery habitat. Outflow also controls the location of the entrapment zone, an important part of the habitat of delta smelt. A weak, positive correlation exists between fall abundance of delta smelt and the number of days during the spring that the entrapment zone remained in Suisun Bay (Herbold 1994). The number of days when the entrapment zone has been in Suisun Bay during the February through June period is one of the only two parameters found so far described that predicts delta smelt abundance (Herbold 1994). Reduced suitable habitat and increased entrainment occurs when the entrapment zone moves out of the shallows of Suisun Bay and into the channels of the lower Sacramento and San Joaquin rivers as a result of low Delta outflow. The movement of the entrapment zone to the river channels not only decreases the amount of area that can be occupied by smelt, but decreases food supply (Herbold et al. 1992a). Their location in this part of the Estuary makes Delta smelt vulnerable to entrainment by the pumps of the SWP and CVP, as well as local agricultural diversions (DWR 1992, NHI 1992a, Herbold et al. 1992). Diversions in the northern and central Delta, where smelt are most abundant, are likely the greatest source of entrainment (USFWS 1994). Larvae and juveniles appear to be particularly vulnerable to pumping because screens are not effective for these life stages (DWR and USBR 1994). Whether entrainment, as estimated by salvage, affects abundance remains to be demonstrated statistically. However, the relative effects of entrainment are higher in dry years, when the abundance of delta smelt is typically lowest and the distribution of the species shifts closer to the pumps in the interior Delta. Water diversions such as Contra Costa Canal, PG&E's power plants, and in-Delta agricultural diversions, potentially entrain delta smelt in numbers comparable to or greater than at the CVP and SWP pumps. However, initial results from IEP studies have found few Delta smelt in agricultural diversions.

Although the effects of the recent high diversions of fresh water, coupled with drought conditions since 1987, are the most likely causes of the decline in the delta smelt population, other contributing factors may include: the presence of toxic compounds in the water, competition and predation, food supply, disease, very high outflows, and low spawning stock."

Pond smelt (*wakasagi*) are also occasionally collected in the Suisun Marsh. Hybridization between the *wakasagi* and delta smelt has occurred and is considered a threat to delta smelt (Sweetnam 1999).

3-5. Occurrence in the Suisun Marsh

Data from the U.C. Davis Fisheries Monitoring Program indicate that delta smelt may be found in Suisun Marsh throughout the year. Results from the 1995 Larval Sampling indicate that Delta smelt do use the marsh for spawning and rearing. In 1994, delta smelt larvae were found primarily in Nurse and Suisun sloughs (Matern et al. 1995). In 1995 and 1996 delta smelt larvae were found in all five of the sloughs sampled (Cordelia, Denverton, Nurse, Spring Branch, and Suisun), with the highest numbers occurring in Nurse Slough. During these years, larval fish were generally found March through June. Spawning also occurs in shallow fresh waters of Suisun Bay (Wang 1986).

U.C. Davis Fisheries monitoring reports indicate that Delta smelt abundance in the Marsh has been declining since at least the early 1980s (Matern et al. 1997). Of the 472 delta smelt captured in otter trawls since 1980, only 49 have been collected since 1983. The annual mean catch per trawl of Delta smelt peaked at 0.60 in the early 1980s. In 1983-1996, it was 0.05 or less, except in1994 when it measured 0.07. The 1996 mean catch per trawl was 0.05. Total otter trawl catch rose from 2 in 1995 to 12 in 1996.

4. LONGFIN SMELT (*Spirinchus thaleichthys*)

4-1. Status

Longfin smelt is designated as a Species of Concern. Longfin smelt was a federal candidate for listing in 1994; however, the USFWS declined to list the species. No critical habitat or special protection has been granted to this species.

4-1. Distribution

The longfin smelt is a small, planktivorous fish that is found in several Pacific coast estuaries from San Francisco Bay to Prince William Sound, Alaska. Until 1963, the population in San Francisco Bay was thought to be a distinct species. In California, the largest longfin smelt reproductive population inhabits the Bay-Delta Estuary (DFG 1992c). This 4-5 inch long (adult), pelagic anadromous species spawns in the fresh waters of the Delta and lower rivers, rears throughout the estuary and matures in brackish and marine waters (SFEP 1997).

4-2. Habitat

Longfin smelt can tolerate salinities ranging from fresh water to sea water. Spawning occurs in fresh to brackish water over sandy-gravel substrates, rocks, or aquatic vegetation (Meng 1993). Optimal salinity for spawning is 0 - 0.5 (CUWA 1994).

4-3. General Ecology

In the Bay-Delta Estuary, the longfin smelt life cycle begins with spawning in the lower Sacramento and San Joaquin rivers, the Delta, and freshwater portions of Suisun Bay (SFEP 1992a). Spawning may take place as early as November and extend into June, with the peak spawning period occurring from February to April (Meng 1993). The eggs are adhesive and, after hatching, the larvae are carried downstream by freshwater outflow to nursery areas in the lower Delta and Suisun and San Pablo bays (SFEP 1992a). The principal nursery habitat for larvae is the productive waters of Suisun and San Pablo bays. Age 1 fish are broadly distributed regardless of outflow, but become uncommon in the estuary during the late summer and fall. It is possible that they use the open coast as habitat during this period (Randall Baxter, CDFG Stockton, pers. comm.)

Longfin mature at age 1 and spawn at age 2 (Dryfoos 1965, Moulton 1974). During the second year of life, they inhabit San Francisco Bay and, occasionally, the Gulf of the Farallones; thus, longfin smelt are often considered anadromous. Longfin smelt are also more broadly distributed throughout the estuary, and are found at higher salinities than delta smelt (Sommer et al, in press). Because longfin smelt seldom occur in fresh water except to spawn, but are widely dispersed in brackish waters of the bay, it seems likely that their range formerly extended as far up into the Delta as salt water intruded. The easternmost catch of longfin smelt in the fall mid-water trawl was at Medford Island in the Central Delta. They have been caught at all stations of the bay study. The two species differ substantially in terms of the depth they each inhabit in the water column: longfin smelt are caught more abundantly at deep stations (10 m), whereas delta smelt are more abundant at shallow stations (<3 m) (SFEP 1992a).

The longest index of longfin smelt abundance in the estuary comes from the DFG's fall mid-water trawl survey that began in 1967. The index represents at least 2 years' classes; however, young-of-the-year are usually predominant. Age 0 will dominate in the index in the fall of high outflow years, but may not necessarily dominate in low outflow years. Longfin abundance alternates between strong and weak year classes that are related, in part to flow and to spawner abundance. For these reasons abundance will lag (i.e., be higher than estimated by flow alone) in its decline over successive low outflow year. Once at low levels, indices will lag again over successive high outflow years (Randall Baxter, CDFG Stockton, pers. comm.).

The following is quoted from SFEP (1997):

"Longfin smelt abundance in the Estuary reached an all-time low in 1992 (fall-midwater trawl survey index=73) following 6 years of drought...There is a strong relationship between freshwater outflow during the spawning and larval periods and the subsequent abundance of longfin smelt. Outflow disperses buoyant larvae--increasing the likelihood that some will find food. By reducing salinities in Suisun and San Pablo bays, outflow may also provide habitat with few marine or freshwater competitors and predators (marine species often do not tolerate lower salinities, and freshwater species have mechanisms to avoid being washed downstream). Moderate outflow in 1993 resulted in a modest population rebound (abundance index=797). In 1994, some early spawning (at age 1) of the 1993 year class augmented the 1992 year class spawning so that the fall index was moderate for a low outflow year (index=523). Both the 1993 (age 1, returning to spawn) and the 1994 (age 0-1, rearing in the Estuary) year classes contributed to the 1994 index. In 1995, sufficient spawning stock and high outflow led to very good survival (age 0-1) and returned the population to pre-drought abundance levels (index=8632). A smaller spawning stock and moderately high outflow in 1996 resulted in a substantial increase in abundance above the parent stock, but did not quite reach pre-drought levels (index=1356). Stock size and water conditions in 1997 appear sufficient to produce another large jump in population (Baxter, SOE, 1996)."

Water project entrainment may also affect abundance. Analysis of salvage data shows that entrainment is highest in dry years, when the population is already reduced as a result of low abundance (Sommer et al. in Press). This dry year effect appear to be caused by a shift in the distribution of smelt toward the export facilities.

4-4. Occurrence in the Suisun Marsh

Data from the U.C. Davis Suisun Marsh Fisheries Monitoring Program indicate that longfin smelt can occur in the marsh year round. Spawning occurs from November through June throughout the marsh and in Suisun Bay. Each year of the U.C. Davis larval fish survey, longfin smelt larval fish were captured in all five slough sampled (Suisun, Spring Branch, Nurse, Denverton, and Cordelia) (Matern et al. 1995, 1996, 1997). However in 1996, the greatest portion of larval longfin smelt were captured in Cordelia Slough, which probably reflects that species preference for more marine conditions (Matern et al. 1997).

Longfin smelt abundance in the Marsh declined sharply in the early 1980s and has remained low since then (Matern et al. 1997). Annual mean catches between 1980 and 1985 were above 1.0 smelt per trawl, with a peak of 7.16 smelt per trawl in 1980. Since 1985, values have remained below 1.3; after 1990, values decreased to less than 0.35 smelt per trawl (DWR 1997a). Interestingly, the prolific 1990 spawn (1.29 smelt per trawl) did not alter the general decline in abundance, as low numbers of fry were caught in subsequent years.

5. PRICKLY SCULPIN (*Cottus asper*)

5-1. Status

There is no special status designated for prickly sculpin.

5-2. Distribution

The following is quoted from Moyle 1976:

"Prickly sculpins are found in coastal streams from the Kenai Peninsula, Alaska, down to the Ventura River, southern California. In California they are widespread throughout streams of the Central Valley, mostly at low elevations. They are absent from the upper Pit River."

5-3. Habitat

The following is from Moyle 1976:

"Few fishes occupy the wide range of bottom habitats occupied by prickly sculpin populations. They live in waters ranging from fresh to salt, in streams ranging from small, cold, and clear to large, warm, and turbid, and in lakes and reservoirs ranging from small to large, eutrophic to oligotrophic....Most typically, however, they are found in pools and quiet water of moderate-sized, clear, low-elevation streams, with bottoms of sand, silt, and scattered rocks. They are also the most abundant sculpin in many coastal streams."

5-4. General Ecology

The following is from Moyle 1976:

"As their body shape and cryptic coloration indicate, [prickly sculpin] spend most of their time quietly lying on the bottom. During the day they hide underneath or in submerged objects, such as rocks, logs, beer cans, and other pieces of trash. At night they come out to actively forage for food. Cook (1964) noted that prickly sculpins were commonly taken in night plankton tows in Clear Lake, Lake County.

"Prickly sculpins are usually not gregarious, but neither do they appear to be territorial outside the breeding season, a behavior pattern that might be expected of sedentary bottom fish. Apparent schooling behavior, however, was observed among large numbers of prickly sculpins moving along the shore of a British Columbia lake (Northcote and Hartman, 1959). Downstream migration of adults and upstream migration of young-of-the-year sculpins is typical of many (but not all) populations. Shapovalov and Taft (1954) noted a pronounced downstream movement of adult prickly sculpins in Waddell Creek, Santa Cruz County, during the winter months, especially January and February. The function of the downstream movement is not clear, but it seems to be related to spawning.

"As might be expected, prickly sculpins feed mostly on large benthic invertebrates, particularly blackfly, midge, mayfly, stonefly, and caddisfly larvae. Other aquatic insects, molluscs, isopods, amphipods, and small fish are also eaten. In Clear Lake, Lake County, 74 percent of their summer diet is chironomid midge larvae and pupae (Cook, 1964). Their food, however, varies with the size of the fish. Thus, those less than 30 mm TL feed to a great extent on planktonic crustaceans while those greater than 70 mm TL often take small fish, including other sculpins. While trout and salmon are spawning, sculpins may feed on their eggs (Reed, 1967). Most of those eaten are presumably loose eggs that did not get buried during spawning. Several studies have also indicated that sculpins prey heavily on salmon and trout fry (Munro and Clemens, 1937; Shapovalov and Taft, 1954). However, these studies are based on stomach analyses of sculpins caught in traps set for salmonid fry, where the fry are very easy for sculpins to catch. Under normal stream conditions, it seems unlikely that sculpins are very effective predators on healthy active fry.

"...Prickly sculpins become mature during their second, third, or fourth year, depending on the population (Patten, 1971), at 4 to 7 cm SL. Spawning can occur from late February through June, although most spawning in California probably takes place in March and April. Natural spawning usually requires temperatures of 8 to 13oC (Kresja, 1965).

"Prior to spawning, prickly sculpins move into areas, in either a freshwater or intertidal zone, that contain large flat rocks and moderate current. The males are ready for spawning before the females and select nest sites underneath the rocks (or in beer cans, auto bodies, or other trash), while the females congregate upstream from the spawning area (Klesja, 1965). Each male then prepares a nest by digging a small hollow underneath the rock and cleaning off the ceiling of the nest. When a female is ready to spawn she moves down into the spawning area and is courted by a male, who lures her into his nest. Further courtship and spawning take place within the nest, mostly at night (Kresja, 1965). During spawning the eggs are attached to the ceiling of the nest in a cluster. The male then chases the female from the nest and guards the eggs until they hatch. Movements of the male help to keep water circulating over the eggs, insuring normal development. Mechanical agitation of fully developed eggs by the male seems to be necessary for hatching (R. J. Kresja, pers. comm.).

"Males frequently spawn with more than one female, so as many as 25,000 to 30,000 eggs have been found in one nest (Kresja, 1965). The number of eggs in a nest is usually much smaller. Individual females produce anywhere from 280 to 11,000 eggs, he number depending on both the size and age of the female (Patten,1971).

"The fry when hatched are 5 to 7 mm TL. They start swimming fairly soon after hatching. As a result, they are swept downstream to large pools, lakes, and estuaries where they assume a planktonic existence for three to five weeks. Such larvae are common in the Sacramento-San Joaquin Delta in the spring (Turner, 1966d). Soon after settling down to the bottom, at lengths of 20 to 30 mm, they start a general upstream movement (McLarney, 1968).

"Prickly sculpins are abundant where found, and have managed to adapt to man-caused alterations of their environment. In Millerton Lake, they are the only native fish still in abundance and are important forage for largemouth bass. Elsewhere, especially as larvae, they may provide forage for salmon and trout, as well as for fish-eating birds. They occasionally prey on salmon eggs and fry, sometimes feeding in redds while the salmon are spawning (Reed, 1967). However, it is unlikely that they be much affect on salmon populations."

5-5. Occurrence in Suisun Marsh

Sculpins occur in the Marsh year round. Spawning, which can take place in the Marsh, occurs from January through May. Young are also carried down from upstream populations (DWR 1997a). Matern et al. (1996) observed that prickly sculpin populations respond strongly to changes in outflow. High outflow years produced peaks in annual mean catches of 6.05, 2.34, 1.20, and 2.89 fish per trawl in 1983, 1986, 1993, and 1995, respectively (DWR 1997a). Since 1980 mean catches per trawl have varied from less than 0.87 to 6.05 fish per trawl. In general, the population has declined from 1983 levels, probably because eight of the 13 subsequent years were dry or critical water years.

6. SPLITTAIL (*Pogonichthys macrolepidotus*)

6-1. Status

Sacramento splittail was listed as threatened by the USFWS on February 1, 1999. However, on June 29, 2000 a federal judge rejected the listing, due to the inadequacy of the science upon which it was made.

6-2. Distribution

The following is quoted from Baxter 1999:

"The geographic distribution of splittail is broader than previously believed and continues to expand as more information is gathered. Adult foraging and spawning migrations occur in the Sacramento River every year and in the San Joaquin River during years with high freshwater outflow. Changes in the timing, magnitude and duration of high river flows (i.e., floodplain inundation) probably affect when and where adults migrate and, thus, their winter-spring distribution and the initial distribution of their offspring. In 1997 and 1998, splittail were captured 60 km and 17 km upstream of previous range limits (Sommer et al. 1997) in the Sacramento and San Joaquin rivers, respectively. Within these limits, juvenile and adult splittail use both river systems extensively during the winter and spring, and there is evidence some fish of all age groups remain in the Sacramento River year-round. At the western edge of their known range, splittail continue to inhabit the Petaluma River and Marsh as they did previous to and during the drought. Use of the Napa Marsh appears to vary with freshwater outflow. Use of Suisun Marsh also varies with outflow, but not as much as in Napa Marsh. The splittail's distribution is broad and expanding and, with the expansion, some adult fish appear to remain resident in the Sacramento River near Red Bluff. Outflow conditions during winter and spring 1998 continued this trend."

6-3. Habitat

Inundated floodplains provide important spawning, rearing and foraging habitat for splittail. Spawning, which seems to be triggered by increasing water temperatures and day length, occurs over beds of submerged vegetation in slow-moving stretches of water, such as flooded terrestrial areas and dead-end sloughs. Adults spawn in the Delta and its tributaries, Yolo and Sutter bypasses, Napa Marsh and Suisun Marsh. Hatched larvae remain in shallow, weedy areas until they move to deeper offshore habitat later in the summer. Young splittail may occur in shallow and open waters of the Delta, Suisun Bay, and San Pablo Bay, but they are particularly abundant in the northern and western Delta (DFG 1992b, DWR 1992).

The downstream distribution (including Suisun Marsh) of splittail appears to be affected by salinity. Although splittail have been collected at salinities as high as 18 ppt and physiological studies show that splittail have critical salinity maxima of 20-29 ppt (Young and Cech 1996), abundance is highest in the 0-10 ppt salinity range (Sommer et al, 1997). Hence, salinity may have limited the downstream distribution of splittail during the recent 6-year drought. Splittail also tolerate a wide range (7-33^{0} C) of water temperatures in the laboratory, which fits well with thermal fluctuations associated with its habitat. Depending upon the acclimation temperature (range 12-20^{0} C), critical thermal maxima ranged from 22-23^{0} C (Young and Cech 1996). Sommer et al. (1997) suggest that temperature may have an affect on abundance in the San Joaquin River system.

6-4. General Ecology

The Sacramento splittail, which has a high reproductive capacity, can live 10-12 years and generally reaches sexual maturity by its second year (Daniels and Moyle 1983, Meng and Moyle 1995, Sommer et al, 1997, Baxter, pers. comm.). Spawning peaks during February through June, but may extend from January-July.

Splittail are benthic foragers that feed extensively on opossum shrimp (*Neomysis mercedis*) and opportunistically on earthworms, clams, insect larvae, and other invertebrates (Caywood 1974, Herbold 1987). Splittail are preyed upon by striped bass and other predatory fish in the estuary. Food selection studies from Suisun Marsh suggest that splittail specifically select *Neomysis* as their main prey item (Herbold 1987). Fullness indices data indicate that condition factors of splittail are linked to *Neomysis* abundance. Splittail did not switch to alternate and more prevalent food items, as was observed for other native resident species.

Analysis of data from the Fall Midwater Trawl Survey (FMWT) collected in the Delta between 1967 and 1998 indicated that splittail abundance indices varied without trend and reached a maximum in 1998 (Baxter 1999). Data from the FMWT, which captures all age groups of splittail, and the Summer Townet Survey (TN), which captures only age 0 splittail, both showed no long-term trend in splittail abundance and detected peaks in abundance in 1978, 1982-83, 1986, 1995 and 1998. However, both the Suisun Marsh and Chipps Island surveys show significantly lower abundance in the early to mid-1980s (Sommer et al., 1997).

Floodplain inundation appears to be a key factor responsible for strong year classes, based on both statistical and limited observational data (Sommer et al, 1997). Higher flows increase inundation of floodplain areas such as the Yolo bypass, which provides spawning, rearing and foraging habitat. The species has little or no stock recruitment relationship. This is best illustrated from data collected in 1995, when exceptionally large numbers of young splittail were produced by a stock that should have been depleted by drought conditions in 7 of the previous 8 years.

Attributes that help splittail respond rapidly to improved environmental conditions include a relatively long life span, high reproductive capacity and broad environmental tolerances (Sommer et al, 1997.). Additional factors that may affect population levels include habitat loss, recreational fishing, entrainment, and toxic compounds.

The effects of introduced species (i.e., planktonic copepods and the Asian clam, *Potamocorbula amurensis*) in reducing the splittail's favored prey, *Neomysis mercedis*, have also been named as possible factors in the decline of Sacramento splittail populations in the estuary (NHI 1992b).

6-5. Occurrence in Suisun Marsh

Splittail are present in the marsh and bay year-round. In 1995 large numbers of splittail larvae were taken in Nurse and Denverton sloughs; however, they were also taken in Cordelia, Denverton, Nurse, Spring Branch and Suisun.

Between 1980-1983 and in 1986, annual mean catch per trawl was greater than 2.09. In all other years the catch was between 0.93 to 0.07 catch per trawl (DWR 1997). Annual abundance of adult splittail has ranged from 0.13 to 4.35 mean catch per trawl. Average catches at or above 1.50 occurred in 1980, 1981, and 1987. All other years produced annual mean catches at or below 0.68.

The following is from Matern et al. 1997:

"As with striped bass, longfin smelt, chinook salmon, and American shad, splittail show increased reproductive success in wet years (Daniel and Moyle 1983). For this reason, abundance of splittail young of the year (YOY) was high [in Suisun Marsh] in 1980, 1982 and 1986. Little recruitment occurred in the Marsh since 1986: apparently adults outnumbered YOY in our catches for most of these years. In 1994, both adult and YOY were at an all time-lows. The wet year of 1995, however, resulted in the highest recruitment since 1986. These YOY appeared to have high survival which was reflected in the higher catches of adults in 1996. We caught more adult splittail in 1996 than any year since 1987. Catches of YOY were higher in 1996 than any year since 1986. This is largely due to the fact that splittail spawn in the spring, which means that a given YOY cohort gets collected over 2 calendar years. In the case of 1996, most of the fish recorded as YOY are from the 1995 class. We began to see some YOY from 1996 toward the end of the year, but, despite the wet year, they were not as abundant as the 1995 cohort. Similarly, in 1997 YOY accounted for a relatively small proportion of the total splittail catch. This may be related to the differences in the timing of the rains of 1995, 1996 and 1997. In 1995, heaviest outflow occurred in March, allowing spawning splittail to take advantage of the flooded vegetation, but in 1996 and 1997 the rains appear to have come too early to favor splittail spawning."

Sommer et al. (1997) note that splittail abundance has not rebounded to the same degree in Suisun Marsh as other Delta locations following recent wet years. They hypothesize that Suisun Marsh abundance may be strongly affected by shifts in the center of spawning activity. In other words, peak Suisun Marsh abundance during 1979-1980 may have been a result of localized spawning in marsh channels. In later years, the center of spawning activity appears to have shifted to the Sacramento and San Joaquin systems. If this hypothesis is correct, it may be difficult to differentiate between a real population decline in Suisun Marsh versus a change in the species' center of distribution.

7. STARRY FLOUNDER (*Platichthys stellatus*)

7-1. Status

There is no special status designated for this species.

7-2. Distribution

The following is from Moyle (1976):

"Starry flounders are found along the coast of the Pacific Ocean, and in the lower reaches of coastal streams, from the Santa Ynez River, Santa Barbara County, north along the Alaskan coast and the Arctic seacoast of Canada, to Bathurst Inlet. A more detailed world-range description can be found in Orcutt (1950). In California, they are particularly common in the Sacramento-San Joaquin Delta and in the lower parts of small coastal streams. Recently they have appeared in San Luis Reservoir and O'Neill Forebay, Merced County, transported there by the California Aqueduct."

The following is quoted from the Wetland Ecosystem Goals Project (Goals Project 1997):

"In the San Francisco estuary, starry flounder are found in three general areas, near Alcatraz in the central bay, in San Pablo Bay (major population), and in Suisun Bay. There is a shift in distribution with growth of the San Francisco population. Age 0 fish are found more commonly in fresh to brackish water, while Age 2 and above are more commonly associated with brackish to marine waters. In recent years there has been a decline in the population in San Pablo Bay, which is associated with a decline in young in Suisun Bay."

7-3. Habitat

Adults inhabit shallow, coastal marine waters, whereas the juveniles appear to be estuarine-dependent and seek out fresh to brackish waters of bays and estuaries as a nursery ground. Starry flounder are most abundant and most diverse in sizes in San Pablo Bay, although many young are found in Suisun Bay (SFEP 1992a).

7-4. General Ecology

The starry flounder is a flatfish that feeds on benthic organisms (Moyle 1976). This native fish can be found in the Bay-Delta Estuary throughout the year (SFEP 1992a). The starry flounder spawn in near-shore areas between November and February. The pelagic eggs and young larvae are found mostly in the upper water column. About two months after hatching, the larvae settle to the bottom (DFG 1992c). Bottom density and tidal currents transport the young into San Francisco Bay (Jassby et al. 1994, SFEP 1992a), where they rear for 1 or more years. As they grow, juveniles move to water of higher salinity within the Estuary. During the late fall and winter, mature starry flounder probably migrate to coast waters to spawn (DFG 1992c).

The following is quoted from Moyle 1976:

"Starry flounders are primarily marine or estuarine fish but they also commonly live in coastal streams, as far as 75 miles from salt water (Gunter, 1942). In streams, they are generally found in low-gradient areas that are influenced by the tide and have sandy or muddy bottoms. There seems to be some seasonal movement in and out of fresh water, since they are common in the Delta during the summer but uncommon in the winter (Ganssle, 1966)....

"In salt water, starry flounders feed on a wide variety of bottom invertebrates, the type changing with their size. Prior to metamorphosis, they feed first on planktonic algae, then on planktonic crustaceans. Small flounders (to 20 cm TL) feed mostly on amphipods and copepods, while large fish feed more on crabs, polychaete worms, and molluscs (Orcutt, 1950). In estuaries, the diet is similar (Porter, 1964; Ganssle, 1966), but in fresh water they may switch to insect larvae that live in soft bottoms, such as cranefly larvae, Tipulidae (Porter, 1964).

"Feeding in fresh water may initially put the flounder under some osmotic stress, since digestion rates are two to three times faster in salt water than they are in fresh water (Porter, 1964). It is not unusual to find starry flounders in fresh water in somewhat emaciated condition. The starry flounders that inhabit fresh water are mostly immature fish less than two years old and 15 cm TL. In the Delta the smallest fish are generally found the highest upstream (Ganssle, 1966). Young of-the-year fish, mostly those 3 to 20 cm TL, grow at rates comparable to those living in salt water (Radtke, 1966). The large flounders (over 20 cm TL) encountered in fresh water seem to be mostly migrants from salt water and it is not known if they spawn in fresh or brackish water....

"In salt water, males become mature at the end of the second year at about 30 cm SL, breeding at the end of the third year at about 35 cm SL. Spawning occurs in shallow water from November through February (Orcutt, 1950)."

Because the starry flounder supports a moderately important sport fishery in California (BDOC 1993), the longest historical record of abundance in San Francisco Bay come from charter boat logs. Most of the estuary's starry flounder catch has occurred in San Pablo and Suisun bays (DFG 1994). A sharp decline in starry flounder catches, most notably in San Pablo Bay, has occurred since 1983 (SFEP 1992a). In general, catch and catch per hour increased between 1964 and 1971, and decreased to 1964 levels by 1976. In 1976, the total starry flounder catch and catch per hour declined rapidly and, except for a brief period in the mid-1980s, has not recovered to anywhere near previous levels (DFG 1992c).

The bay study otter trawl data indicates a dramatic decline in YOY and 1-year old starry flounder abundance since sampling began in 1980 (DFG 1994). Such continued low abundances indicate that recruitment to and/or survival of starry flounder in the bay has been very poor for the past 5 years.

The most critical period for starry flounder has been determined to be March through June, when most of the larvae and juvenile immigration occurs. Also, the amount and location of shallow, brackish water nursery habitat for recently settled and small juveniles is most important during this period. The log average March-June outflow at Chipps Island and the log average 1-year-old starry flounder abundance index the following year have a significant positive relationship. Good recruitment of larvae to nearshore areas is possible during both high and low outflow years, but poor recruitment only occurs when outflow is low

(DFG 1992c). This indicates that starry flounder abundance in the bay probably also depends on ocean conditions, as well as other lesser known factors.

7-5. Occurrence in Suisun Marsh

Starry flounders can be found in the Marsh year round. Spawning, however, likely takes place outside the Marsh in shallow coastal waters or the higher-salinity portions of the estuary (Wang 1986).

Total catch per year of starry flounder caught in trawls varied between 519 in 1980 and 6 in 1993 (Matern et al. 1997). There were only 2 years when starry flounder abundance was greater than 68 individuals per year, 1980 and 1981 (223 individuals per year).

8. STRIPED BASS (*Morone saxatilis*)

8-1. Status

There is no special status designated for this introduced species.

8-2. Distribution

The striped bass is native to streams and bays of the Atlantic Coast. It was first introduced into the Bay-Delta Estuary in 1879. Within 10 years, this highly fecund and voracious predator was supporting a commercial fishery in the Estuary (SFEP 1992a).

8-3. Habitat

California striped bass spend most of their life in the Bay-Delta Estuary and along the Pacific Coast, within a few miles north and south of the Golden Gate (DWR 1992). This anadromous fish resides in the ocean and brackish waters and enters the fresher waters of the estuary and the Sacramento River to spawn (BDOC 1994). Approximately one-half to two-thirds of the striped bass spawn in the Sacramento River system, while the remainder spawn in the lower San Joaquin River. Important spawning areas include the main stem Sacramento River from Sacramento to Colusa, and in the San Joaquin River, between Antioch Bridge and the mouth of Middle River. Striped bass begin spawning in the Delta in spring, during April and May, when water temperatures reach about 60^{0} F; most spawning occurs when water temperatures are between 61 and 69^{0} F (BDOC 1993). Further up the Sacramento River, spawning occurs from about mid-May though mid-June. The difference in timing is due to temperatures rising more slowly in the Sacramento River than the lower San Joaquin River (DWR 1993).

8-4. General Ecology

Striped bass spawn in fresh water where there is moderate to swift currents. With slower currents, many eggs, which are slightly heavier than water, sink to the bottom and die (DFG 1993). The semi-buoyant striped bass eggs drift with river currents and are carried downstream. Larvae hatch 2 to 3 days after spawning. Initially, the larvae receive nourishment from the yolk sac, which is absorbed in 5 to 10 days. As they move downstream toward the Delta, larvae begin feeding on small zooplankton. Upon reaching the western Delta, which is presently their primary rearing area, larvae are large enough to begin feeding or larger organisms such as the opossum shrimp (Neomysis mercedis). Neomysis remains the main food source until the striped bass reach their second year when they become large enough to feed on bay shrimp and small forage fish. They reach maturity at 3 to 4 years of age and may live to 20 to 30 years of age. In recent years, most of the adult striped bass in the Bay-Delta system are in the 4 to 7 year age classes. The older, more fecund fish, are no longer present in great numbers (DWR 1993).

In the Delta channels, adult striped bass primarily feed on fish. In the more saline portions of the Estuary, principal foods include anchovy, shiner perch, herring, and bay shrimp (BDOC 1994).

Beginning in 1982, the DFG stocked striped bass in the estuary, largely as mitigation for various projects, in an effort to maintain the population. The stocking was stopped in 1992 due to concerns that the effort was adding predators which might eat the endangered winter-run chinook salmon (BDOC 1994).

Monitoring of the striped bass population began with the DFG's mid-summer townet survey in 1959 (DFG 1994, SFEP 1992a). This survey, which provides data for a striped bass index, based on the abundance of 38 mm young, peaked at 117.2 in 1965. The four lowest indices occurred from 1988 to 1991 when the average index was 4.9. From 1959-1976, the average abundance index was 66.6; since 1977, the average has been 19.4 (DFG 1994). The declines have been more pronounced in the Delta than in Suisun Bay (SFEP 1992a).

Adult population estimates are made through extensive tagging of legal-sized striped bass during their spring migration to the Delta from the ocean and bays (BDOC 1993). Based on Petersen mark-recapture population estimates, the number of legal-sized adult striped bass was 624,000 fish in 1992. The 1992 abundance estimate for naturally-produced striped bass, excluding hatchery fish, was about 533,000 fish. This indicates a decline from approximately 1 million fish in the 1980s and 1.7 million fish in the late 1960s and early 1970s (DFG 1994). For the years prior to 1976, estimates for the total population of adults in the Estuary were between 1,480,000 to 1,880,000; since 1977, the population ranged from 520,000 to 1,160,000 fish (SFEP 1992a). Population estimates of legal-sized 3-year-old fish, which are the youngest and most numerous component of the adult population, have declined to record lows since 1988 (DFG 1994).

Kimmerer 1997 asserts that the decline in striped bass abundance over the last 2-3 decades appears to have been caused by a combination of increased adult mortality, particularly in fish over age 6, and declining carry capacity for fish between their first summer and recruitment. Although there is no convincing evidence that increasing exports, or decreases in survival during early life, caused the decline (Kimmerer 1997), export losses can be substantial.

In low flow years, losses to export and entrainment may be affected by freshwater diversion, due to the higher proportion of water diverted for export and within-Delta use (Jassby et al. 1995). Higher outflows move a higher percentage of eggs and larvae out of reach of entrainment, and higher diversions lead to higher percentages of entrainment of eggs and embryos (SFEP 1992a). Higher outflows may also shift the entrapment zone to a location downstream of the Delta, where larval striped bass appear to survive better (DWR 1992).

The sharp decline in older bass does not appear to be caused by loss of young fish in the 1970s and subsequent poor recruitment. Bennett and Howard (1997) provide strong evidence that reduced survival is due to changes in migration patterns. They found that migration of older adults had increased since 1977 as a response to generally warmer sea surface temperature and this migration has reduced the abundance of older, more fecund adults and therefore the egg supply.

Previous studies have shown the abundance of young bass is strongly related to flow and perhaps exports (Jassby et al. 1995). However, internal variability of recruitment once was, but no longer is, related to flow conditions in the estuary (Kimmerer 1997). This variation is largely suppressed by density dependent mortality after the first summer.

Most entrainment of striped bass eggs and larvae at the SWP pumping plant occurs during May, June, and July. With some exceptions, such as during the 1976-1977 drought, the number of bass entrained appears to decrease rapidly from September to December. Losses occur due to passage of eggs and larvae through the fish screens, predation in Clifton Court Forebay, and handling and hauling of salvaged bass. Also, reverse flows in the San Joaquin River could impact striped bass by drawing young fish to the export pumps from spawning and nursery areas in the central and western Delta. There is a significant inverse relationship between flow in the lower San Joaquin River and the number of young bass salvaged at the SWP pumping plant in June and July (DWR 1992).

Besides reducing the likelihood of entrainment into diversions, higher outflows are thought to provide additional benefits for striped bass, including increasing the following: low salinity nursery habitat in Suisun Bay; primary productivity (food supply); turbidity (reduces predation on young); and dilution of pollutants. These factors relate to other possible causes for the continuing decline in striped bass abundance (e.g., food availability, competition, and toxics) (SFEP 1992a).

There is a potential for competition for food between young striped bass and the introduced inland silverside in the San Joaquin system. Both species have a preference for *Neomysis mercedis*. Although the inland silverside is an inshore feeder and the striped bass is a pelagic feeder, the food source and feeding sites of these two species overlap in the channels of the San Joaquin system (CUWA 1994).

Agricultural drainage waters that enter the Sacramento and San Joaquin rivers have been acutely toxic to *Neomysis mercedis*, a major prey of young striped bass. There is also evidence that suggests that toxicity adversely affects some bass larvae. However, it is believed that toxicity is not responsible for the striped bass decline. The "background mortality" which results from toxicity, however, has not changed appreciably over the past 30 years (DFG 1992a). However, a study of the effects of rice pesticides on larval striped bass recruitment concluded that during the years investigated (1973-1986), the discharge of water containing pesticides from rice culture, had adversely affected the striped bass population in the estuary. The annual die-off of striped bass during May and June are apparently caused by liver deterioration associated with exposure to industrial, agricultural, and urban pollutants (DWR 1992). Considering that toxic pollutants do impact striped bass to some degree, decreasing the effects of toxics through dilution is consistent with the concept that young striped bass survival improves with increasing outflow (DFG 1992a).

Illegal harvest of undersized striped bass may cause a serious loss to the population. It is estimated that the equivalent of at least 125,000 legal-sized adults are lost each year to poaching, while an average annual loss of an equivalent of 86,000 legal-sized bass occurs due to the SWP pumping plant operations (DWR 1992). However, since illegal harvest of striped bass is not a new problem, and it is well documented that operation of the export facilities causes mortality to young bass, it is unlikely that the harvest of undersized striped bass has been the dominant factor causing the decline in adult bass abundance since 1969 (DFG 1994).

8-5. Occurrence in Suisun Marsh

Striped bass occur in the marsh throughout the year. Spawning can occur in the fresher portions of the marsh and bay from April through July.

Matern et al. (1996) report the following: for most years of the study, striped bass young-of-year were the most abundant fish collected. Mean catch per trawl ranged from 2 to 22 individuals. In 1996 there was a slight decline in mean catch, but due to very low catches of most other species, striped bass YOY outnumbered every other species collected by at least two to one. Striped bass "adults" greater than 1 year old show less fluctuation than YOY and are in a long-term decline. Adult striped bass decreased slightly in 1996 and have not exceeded 0.5 individuals per trawl in the last 11 years.

9. TULE PERCH (*Hysterocarpus traski*)

9-1. Status

There is no special status designated for this species.

9-2. Distribution

The following is from Moyle 1976:

"Tule perch are native to low-elevation waters of the Sacramento-San Joaquin River system, as well as to Clear Lake, Coyote Creek, and the Russian, Napa, Pajaro, and Salinas rivers. In the Pit River (and its reservoirs) they occur as far up as the large falls in Shasta County. They are now apparently extinct in the Pajaro, Salinas, and San Joaquin rivers."

9-3. Habitat

The following is from Moyle 1976:

"Tule perch are basically inhabitants of large, low-elevation streams. In these streams they occupy a wide range of habitats, from sluggish, turbid channels in the Delta to clear, swift-flowing sections of river. Despite their deep bodies, they can live in fast water by taking advantage of eddies behind submerged boulders and logs, or by staying in the slower moving backwaters and edges. In most situations they are associated with beds of emergent aquatic plants or overhanging banks. These areas are important for feeding, breeding territories, and protection of young of the year."

9-4. General Ecology

The following is from Moyle 1976:

"Tule perch seldom venture into brackish water, although they seem to be tolerant of it. In Clear Lake, Lake County, they are most abundant over sand and gravel bottoms (rather than mud), in areas where algae blooms are comparatively light. Tule perch are adapted for feeding on small, hard-shelled invertebrates associated with the bottom or aquatic plants, although they will also feed in midwater on zooplankton. The deep body shape and maneuverable fins, combined with large eyes and protrusible premaxillary bones of the upper jaw, allow the fish to suck or pick up small invertebrates. Both the jaw teeth and the pharyngeal plates are large, for crushing the food. In the Sacramento-San Joaquin Delta, tule perch feed mostly on small amphipods, together with a few midge larvae (Chironomidae) and small clams (Turner, 1966d). Fish collected in brackish water near the mouth of the Napa River, Napa County, were feeding predominately on small brachyuran crabs, although midge larvae and pupae were also important, especially for immature fish (Hopkirk, 1962). In Clear Lake, Lake County, they seem to be primarily midwater feeders, concentrating on zooplankton in the cold season, and chironomid midge and mayfly larvae in the warm season (Cook, 1964). In the Russian River, Mendocino County, tule perch feed on a wide variety of bottom and plant-dwelling invertebrates but most important are the larvae of chironomid midges, baetid mayflies, and blackflies (D. Alley, D. Hilton, ant C. van Dyck, unpublished data).

"Tule perch are gregarious, especially when feeding. In rivers, small groups can be observed strung out in a line by the current, moving slowly upstream while periodically picking at the bottom. In Clear Lake, they school in large numbers especially off tule beds and overhanging trees. However, breeding males in the Russian River were observed to hold small territories under overhanging branches or plants close to shore. Each male defends the territory against other males as well as against fish of other species. The apparent purpose of the territories is to attract females for mating, since courtship can be frequently observed within them. However, each male does not appear to hold one territory for more than a day or so and courtship and mating can also occur away from the territories....

"...Fertilization of the eggs does not take place immediately after [mating] (Bundy, 1970). Instead, the female stores the sperm until about January, when fertilization occurs. Mating occurs in July through September and the young are born in May or June, when food is abundant. The number of young produced per female is 22 to 83, the number increasing with the size of the fish (Bundy, 1970). The young are born head first and begin to school soon after birth. Since they become sexually mature shortly after birth, many of the territorial males observed in the Russian River in August were young of the year.

"Growth in tule perch is most rapid during the first eighteen months after birth, when they are 3 to 4 cm SL (Bundy, 1970). However, the growth rate varies from population to population. At the end of their first summer, Russian River fish reach 5 to 8 cm SL; Clear Lake fish, 6 to 9 cm SL; and Delta fish, 8 to 10 cm SL (Bundy 1970; D. Alley, D. Hilton, and C. van Dyck, unpublished data). The growth differed- tails are maintained, so that by the end of the third year, they will be about 10 to 11 SL, I 1 to 15 cm SL, and 14 to 16 cm SL, respectively. Tule perch apparently seldom exceed 16 cm SL or five years of age.

"Tule perch are abundant in the Russian River, Clear Lake, and locally in the Sacramento Valley. They are one of the most abundant fishes in Lake Britton, a reservoir on the Pit River, Shasta County (D. Hoopaugh, pers. comm.). Although they are still common in the Delta, their populations seem to be greatly reduced from their former abundance. They appear to be extinct in the San Joaquin, Pajaro, and Salinas rivers....

"Habitat change seems to be the major cause of their decline. They tend to disappear from streams with reduced flows, increased turbidity, heavy pollution, or reduced cover, especially reduced emergent vegetation. Their sensitivity to environmental conditions is reflected in the extreme difficulty of maintaining them in captivity for long periods of time."

9-5. Occurrence in Suisun Marsh

Tule perch, which are year-round residents in the Marsh, have historically been one of the most abundant fishes in the marsh (Matern et al. 1996). Tule perch are most frequently caught in the smaller sloughs in the marsh, which possibly reflects the greater otter trawling efficiency in these areas (DWR 1997a).

For 12 of the 16 years of sampling, tule perch ranked in the top four most abundant species in Suisun Marsh (DWR 1997a). Annual mean tule perch abundance peaked from 1980 to 1982, 4.15 to 6.40 fish per trawl, and declined to 0.53 and 0.76 in 1983 and 1984, respectively (DWR 1997a). Abundance levels peaked again in 1987 and 1988 (6.03 and 5.91 fish per trawl). The 1993 and 1994 average catches, 0.48 and 0.69 respectively, decreased to levels below those in 1983 and 1984. The lowest abundance recorded occurred in 1995, when mean catch per trawl was 0.38. U.C. Davis researchers hypothesized that this may have been partially due to interaction between tule perch and exotic gobies which inhabit the same habitat as tule perch. Matern et al. (1996) report that tule perch catches dropped dramatically during the 1989 peak in shimofuri goby abundance and dipped again in 1993 and 1995 during recent yellowfin goby peaks in abundance.

10. YELLOWFIN GOBY (*Acanthogobius flavimanus*)

10-1. Status

No special status is designated for this species.

10-2. Distribution

The following is from Moyle 1976:

"Yellowfin gobies are common in shallow coastal waters of Japan, Korea, and China. They were first collected in the Sacramento-San Joaquin Delta in 1963, where they presumably had become accidentally established after being transported across the Pacific in the seawater system of a ship (Brittan et al., 1963). They are now common throughout the Delta and have been collected along the coast from Elkhorn Slough to Tomales Bay (Miller and Lea, 1972). They are also present in the Delta-Mendota Canal and San Luis Reservoir, Merced County."

10-3. Habitat

The following is from Moyle 1976:

"Yellowfin gobies are found in shallow, muddy littoral areas in fresh, brackish, and salt water. They are well adapted for estuarine living because they are capable of withstanding abrupt changes between fresh and salt water, and can survive water temperatures greater than 28oC (Brittan et al., 1970)."

10-4. General Ecology

The following is from Moyle 1976:

"[Yellowfin goby] usually feed on a wide variety of crustaceans and small fishes associated with the bottom, although algae may be ingested as well. Yellowfin gobies presumably take most of their prey from ambush or by carefully searching the substrate, since they only swim short distances in a jerky manner.

"Yellowfin gobies in Japan become mature after one year (about 10 cm TL) and breed from January to March. Usually, Y-shaped tunnels with two entrances are constructed for breeding in bottoms that are a mixture of mud and coarse sand. Pieces of pipe and other artificial materials may also be used, provided water can flow through. The eggs are teardrop shaped and attached by adhesive filaments to the roof of the burrow. They may be guarded by the male until they hatch (twenty-eight days at 13oC), but frequently they are left unattended.

"The larvae leave the nest soon after hatching at about 4 to 5 mm TL and assume a pelagic existence for an undetermined period of time. While pelagic they feed on zooplankton, especially copepods. At a length of 15 to 20 mm they settle down to the bottom (Dotu and Mito, 1955).

"Yellowfin goby populations in California have exploded since they were first noticed in 1963. They are now one of the most abundant bottom fishes in San Francisco Bay and the Delta, and are still increasing their range. What effect this population explosion will have on native freshwater and estuarine fishes is not known, but freshwater populations of the small tidewater goby might be in some danger of being eliminated through competition. Brittan et al. (1970) noted that in at least one saltwater area, yellowfin gobies may have partially displaced staghorn sculpins. On the positive side, yellowfin gobies have some potential as sport, commercial, or bait fish, at least in salt water. They are considered to be a delicacy in Japan."

10-5. Occurrence in Suisun Marsh

The following is from Matern et al. (1997):

"The yellowfin goby, an Asian exotic, has shown periodic peaks in abundance, most notably in 1993 when high recruitment resulted in a mean catch 16 gobies per trawl. Catches then plummeted to less than one goby per trawl in 1994, but rebounded to almost nine gobies per trawl (most of them YOY, including 665 individuals smaller than 40 mm SL) in 1995. In 1996 mean catch again fell to less than one goby per trawl. Because this species may not reproduce until age two, we expected to see high catches of YOY in 1997 as a result of the strong 1995 year class. However, 1997 catches fell to only 0.72 yellowfin gobies per trawl, bucking the trend observed after the two previous high recruitment peaks in 1984 and 1993."

11. SHIMOFURI GOBY (*Tridentiger bifasciatus*)

11-1. Status

No special status is designated for this introduced species.

11-2. Distribution

Matern et al. (1996) report that the shimofuri goby was first collected in Suisun Marsh in 1985 and has subsequently spread throughout the Sacramento-San Joaquin Delta and into southern California via the State Water Project System (Matern and Fleming 1995).

11-3. Habitat

Shimofuri gobies are found in fresh water and have not been collected in salinities above 22 ppt. Shimofuri gobies tend to live in habitats with structurally complex substrates and may spawn in the same areas.

11-4. General Ecology

Shimofuri gobies spawn from April through September in water less than 5 ppt at 20° C. At this temperature, larvae hatch in about 9 days. Males guard the eggs and often spawn with several females. In Suisun Marsh, this species feeds primarily on benthic invertebrates such as amphipods and mysid shrimp (Matern and Fleming 1995)

11-5. Occurrence in Suisun Marsh

The annual mean catch per trawl remained at or below 2.03 in all years from 1985-1995, except in 1989, when the annual mean catch per trawl increased to 9.12 (DWR 1997a). At that point it was the most abundant species collected in the U.C. Davis trawls. In 1997 shimofuri goby numbers again rose dramatically, making it the second most abundant fish collected in the U.C. Davis trawls, accounting for 19 percent of all the fish collected (Matern et al. 1997).

12. OPOSSUM SHRIMP (*Neomysis mercedis*)

12-1. Status

No special status is designated for this species.

12-2. Distribution

The opossum shrimp (*Neomysis mercedis*) is a native mysid shrimp that is an important food source for many estuarine fish, especially young striped bass. *N. mercedis* is found in greatest abundance in Suisun Bay and the western Delta, although it occurs as far upstream as Sacramento and the lower reaches of the Mokelumne River. The diet of *N. mercedis* consists of phytoplankton, rotifers, and copepods, particularly *Eurytemora affinis* (SFEP 1992a).

12-3. Habitat

The following is from Baracco 1980:

"Neomysis are generally more abundant in the Sacramento-San Joaquin Estuary at the freshwater end of the salinity gradient (Heubach 1969), although salinity by itself is relatively unimportant for this species....Conditions favorable to this species are generally found in the vicinity of Suisun Bay in the summer in...the entrapment zone (Arthur and Ball 1978)....Neomysis are not found in areas of high net velocity, high water transparency, low dissolved oxygen content, and high water temperature. ...Temperature above 18oC (65oF) causes a decrease in abundance when dissolved oxygen concentrations are low (Heubach 1969)."

12-4. General Ecology

During most of the 1970s and 1980s, the opossum shrimp population varied considerably, but at a lower level of abundance than existed in the early 1970s. *N. mercedis* abundance fell dramatically after 1986 and remained at very low levels from 1990 to 1993 (DFG 1994).

Reasons for the system-wide declines of several zooplankton taxa in the Bay-Delta Estuary are not known. Although the declines occurred at about the same time as declines in phytoplankton and various fish species, no cause-and-effect relationships have been established (DWR 1992).

The decline in the abundance of *N. mercedis* and other zooplankton species (e.g., *E. affinis*) that are found in the entrapment zone in relatively high abundances has been correlated with Delta outflow. It is presumed that low outflow reduces *N. mercedis* abundance by (1) restricting the entrapment zone to deeper, more upstream channels, which are less likely to promote high densities of *N. mercedis* because phytoplankton growth is lower in these channels; and (2) producing weaker landward currents along the bottom so that the ability of *N. mercedis* transported downstream to return to the entrapment zone is reduced. It has also been presumed that larger numbers of *N. mercedis* may be exported through the CVP and SWP pumps as a result of the increased proportion of inflow diverted during drought years when the entrapment zone is upstream in the estuary. The location of the entrapment zone within the lower river channels during dry years increases the vulnerability of *N. mercedis* to such displacement (SFEP 1992a). However, analyses by Kimmerer (1992) suggest that exports by the water projects are not a major source of losses for *N. mercedis* and *E. affinis* populations, primarily due to the small percentage of entrapment zone volume (and entrapment zone organisms) diverted. Depending on the timing, location, and quantity of withdrawals, in-Delta water diversions, whose net consumption is on the same order of export flows, may result in a higher rate of loss to resident zooplankton populations than export pumping.

12-5. Occurrence in Suisun Marsh

Matern et al. (1996) report that catches of *N. mercedis* were historically fairly high. However, data have been recently confounded by the 1992 invasion of *Acanthomysis bowmani*, an Asian mysid. Catches of total mysid shrimps were lower in 1995 than ever before and remain low in 1996, but the species composition is unknown. However, several specimens collected from one location in January of 1997 were all *N. mercedis.*

13. SHRIMP-Various Species (*Crangon spp., Heptacarpus stimpsoni,* and *Palaemon macrodactylus*)

13-1. Status

There is no special status designated for any of the above species.

13-2. Distribution

Five species of caridean shrimp (*Crangon franciscorum, C. nigricauda, C. nigromaculata, Heptacarpus stimpsoni,* and *Palaemon macrodactylus*), which seldom exceed 70 mm in total length, dominate the smaller benthic fauna in the Bay-Delta Estuary (SFEP 1992a). *Crangon spp.* are commonly called "bay shrimp" and *Palaemon* is known as "pile shrimp;" collectively, they are often referred to as "grass shrimp." The three species of *Crangon*, as well as the less abundant *H. stimpsoni,* are native shrimp, whereas *P. macrodactylus* was introduced to the Bay-Delta Estuary in the 1950s (DFG 1994). The *crangonid* shrimp are common food items for many estuarine fish (SFEP 1992a).

The California bay shrimp, *C. franciscorum*, moves between marine and brackish water during its life cycle. The larvae hatch in relatively high salinity water. The post-larvae and juveniles migrate upstream to lower salinity nursery area where they grow for 4-6 months. Mature shrimp, which live between 1 and 2 years, migrate downstream to higher salinity water to complete the life cycle (DFG 1992c).

13-3. Habitat

Each of the shrimp species uses the estuary as a nursery area to varying degrees. *P. macrodactylus* and *C. franciscorum* are estuary-dependent. *P. macrodactylus* is most common in Suisun Bay, the western Delta, and areas adjacent to freshwater sources, such as the mouths of creeks in South and San Pablo bays. *C. franciscorum* is found in brackish, relatively warm water, *C. nigricauda* is found in higher salinity and cooler water, and *C. nigromaculata* is primarily a coastal, shallow water species that is most commonly found in the nearshore ocean area adjacent to San Francisco Bay. *H. stimpsoni* is also considered a coastal species, although it is locally abundant in the bay (DFG 1994).

13-4. General Ecology

Crangon spp. and *Palaemon* support a commercial fishery in the bays. Early in the century, when there was a large market for dried shrimp, over 3 million pounds per year were landed. Since 1980, this fishery has landed between 100,000 and 200,000 pounds of shrimp annually. To protect juvenile striped bass, shrimp fishing has been prohibited upstream of Carquinez Strait since 1985 (DFG 1994).

Aside from the commercial catch data, dependable abundance indices for shrimp are only available since 1980. Since that time, there has been a change in species composition in the catches. In the early-1980s, *C. franciscorum* dominated the catches; but in the late 1980s and early 1990s, *C. nigricauda* was dominant, and *C. nigromaculata* and *H. stimpsoni* increased in abundance. This change was caused in part by the relatively stable, high salinities associated with the drought, resulting in increased habitat for species that prefer higher salinities, but decreased habitat for *C. franciscorum*, which prefers lower salinities. Abundance data for *P. macrodactylus* are inconclusive (survey methods probably are inadequate for this species) (DFG 1994).

Reflecting this change in species composition, the contribution of shrimp catches in San Pablo and Suisun bays to the total abundance index declined, while the contribution of Central Bay catches increased. In 1992, the Suisun Bay index decreased to a study period low with only a 3 percent contribution to the total index (DFG 1994).

Biomass indices, which serve as a relative measure of the weight of shrimp available as a food source, have declined since 1986. The divergence between the abundance and biomass indices during the recent drought is due to an increase in abundance of juveniles and species that do not grow as large as *C. franciscorum* (DFG 1994).

Unlike the other caridean shrimp, *C. franciscorum* decreased in abundance in recent years. *C. franciscorum*, which can be found at a wide range of salinities and temperature, exhibits a straightforward response to outflow alone, whereas other species of shrimp appear to respond more to salinity (SFEP 1992a). The response of *C. franciscorum* to outflow has been attributed to two flow-related mechanisms. First, higher river inflows result in larger landward-flowing currents, transporting the small post-larval shrimp into the bay and dispersing them upstream. Second, higher river inflows reduce bay salinity and increase the amount of suitable nursery habitat for juvenile shrimp (Jassby et al. 1995; SFEP 1992a).

The period March to May has been identified as the most critical period for freshwater outflow in the establishment of a strong year class of immature *C. franciscorum* in the bay. There is also a strong positive relationship between the annual abundance of mature *C. franciscorum* and freshwater outflow the previous spring (March-May) when they were recruited to the bay. Therefore, an increase in outflow in March to May should result in an increase in the abundance of *C. franciscorum*. Significant relationships between abundance and outflow were not found for the other species of shrimp. The other species of *Crangon* and *Heptacarpus* are much less estuarine-dependent than *C. franciscorum*, which is affected by freshwater outflows its entire life cycle, and their abundance is affected more by ocean conditions (DFG 1992c).

13-5. Occurrence in Suisun Marsh

Matern et al. (1996) report that *C. franciscorum* abundance fluctuates wildly across years. *P. macrodactylus*, however, has remained at low numbers for the past 6 years. *P. macrodactylus* hit an all-time low in 1994, and despite high outflows and low salinities, remained low in 1995 and 1996. *C. franciscorum*, which does not rely heavily on mysids, has not declined noticeably during the study.

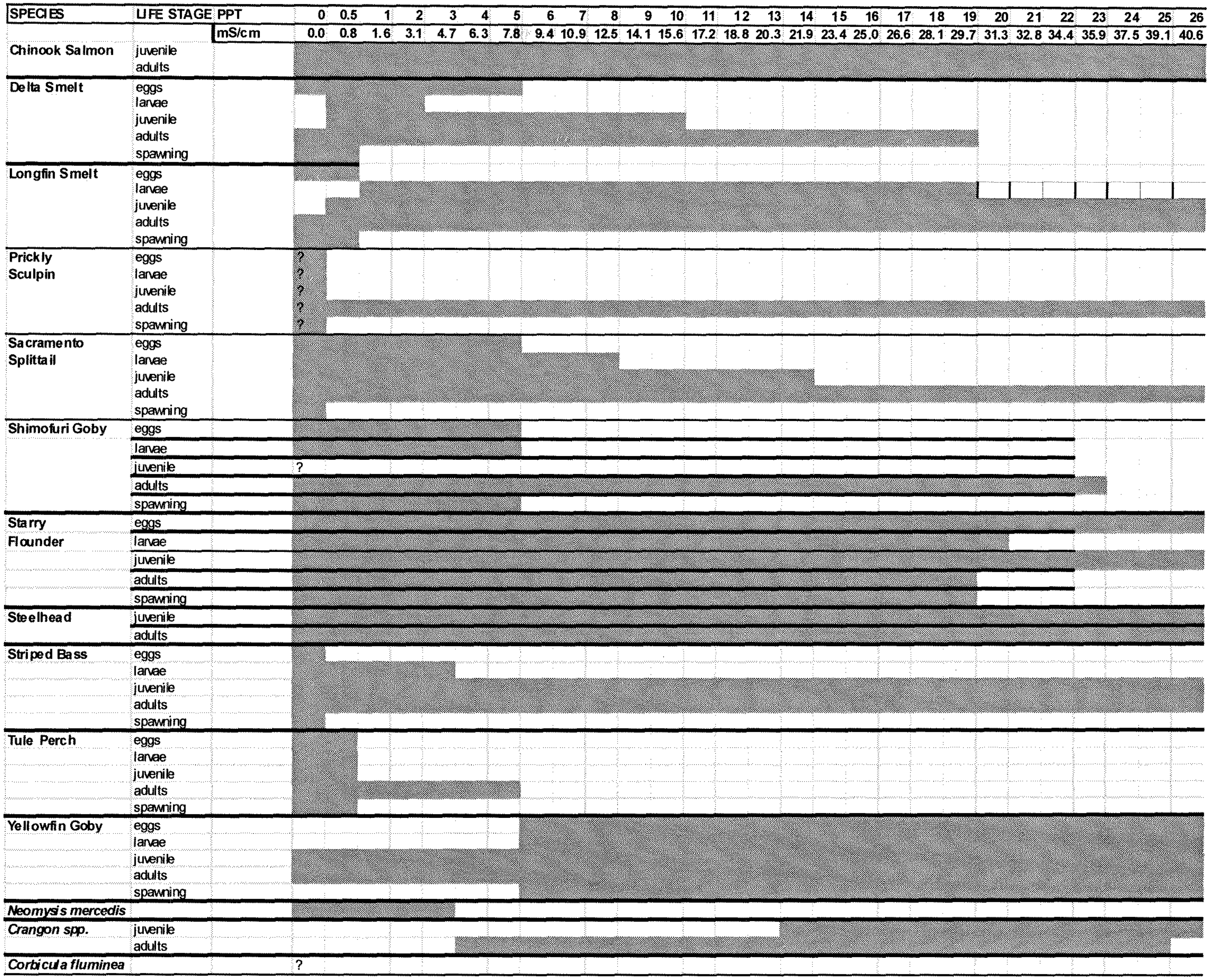
Summary of Salinity and Temperature Tolerances and Recommended Ranges for Selected Species in Suisun Marsh

The following information on salinity tolerance ranges is summarized in Figure 4A-2.

1. CHINOOK SALMON, *Oncorhynchus tshawytscha*
Temperature:
Adult Holding: 5.5-14° C (Boles 1988, Heinze et al 1956)

Recommended Spawning and Egg Incubation:
6 - 13.3° C (Combs and Burrows 1957 and Seymour 1956 as cited in Boles 1988)
10-12.7° C (Bell 1986)

Figure 4A-2 Salinity Tolerance Levels (in ppt) of Various Fish Species Found in Suisun Marsh



Recommended Larvae:
6 - 13.3° C (Combs and Burrows 1957 and Seymour 1956 cited in Boles 1988)
12-14° C (Bell 1986)

Recommended Rearing (unspecified as to size): 10-12.7° C (Bell 1986)

Tolerance Rearing: Chinook salmon tolerated acute increase of approximately 8-10° C and critical thermal maxima (CTMa) differed significantly among the three rearing groups. Duration of the acclimation period (1-11 weeks) did not affect CTMa within the rearing groups, therefore results from all trials during the ten week experimental period were pooled. Fish from the warm rearing group had higher CTMa (27.2+ or -1.2° C) than fish from either the intermediate or cool rearing groups CTMa=26.0+or-1.6 and 25.7+ or -1.6° C, respectively) (Swanson and Cech 1995).

Salinity tolerance of juveniles:
It seems that this parameter is not understood very well, and perhaps is variable among stocks. The following is excerpted from Healy 1991: "Although many chinook fry appear unable to survive immediate transfer to 30 ppt salinity, they are clearly able to survive transfer to 20 ppm or less, and osmoregulatory capability develops quickly in fry exposed to intermediate salinities (Weisbart 1968, Wagner et al. 1969, Clarke and Shelbourn 1985). I have transferred chinook fry directly from downstream migrant traps on the Nanaimo River into sea water of 32 ppm in the laboratory with no apparent short-term ill effects or retardation of growth compared with controls maintained in freshwater and brackish of 15 ppm (Healey, unpublished data). Some chinook fry therefore appear to be able to tolerate immediate transfer to high salinity."

Salinity tolerance ranges from the results of the literature review (CUWA 1994).
Spawning: 0 to 0.5 ppt
Egg: 0 to 0.5 ppt
Larvae: 0 to 0.5 ppt
Juveniles: >=0 ppt
Adult: >=0 ppt

Days to hatch: The duration of incubation ranges from 33 to 178 days, depending on dissolved oxygen, water temperature, biochemical oxygen demand, substrate, etc. (Reiser and Bjornn 1979, Alaska Dept of Fish and Game 1985 cited in Emmett et al 1991).

Fry Habitat: Shaded riverine aquatic habitat and tidal marsh habitat (USFWS 1993, DFG 1982 and 1985, Levy and Northcote 1981 and 1982, Healey 1982, Meyer 1979, Levy et al 1979, McDonald et al 1987, Dorcey et al 1978).

Juvenile migration: A range of 100 - 240 days (winter-run outmigrate for as long as 240 days) (Lisa Holsinger pers. comm.).

Prey preference for juveniles: In fresh water, juveniles eat primarily terrestrial and aquatic insects, cladocerans, amphipods and other crustaceans, and sometimes fish (Becker 1973, Higley and Bond 1973, Scott and Crossman 1973, Croddock et al. 1976, Muir and Emmett 1988, Saga and Glova 1988: all cited in Emmett et al. 1991). In estuaries, juveniles consume gammarid amphipods, benthic grazers (chironomids), harpacticoid copepods, mysids, decapod larvae and fish (Levy and Leavings 1978, Levy et al 1979, Healey 1980, 1982, Kjelson et al 1982, Simenstad et al 1982, Simenstad 1983, McCabe et al 1986: all cited in Emmett et al 1991; and Northcote et al 1979, Levy and Northcote 1981, Schreffler et al 1992).

2. STEELHEAD, *Oncorhynchus mykiss*

Salinity: General salinity tolerance ranges from the results of the literature review (CUWA 1994).
Spawning: 0 to 0.5 ppt
Egg: 0 to 0.5 ppt
Larvae: 0 to 0.5 ppt
Juveniles: >=0 ppt
Adult: >=0 ppt

3. DELTA SMELT, *Hypomesus transpacificus*

Temperature Tolerances: Juvenile, sub-adult and adult were acclimated to 12, 17 and 21° C in freshwater (0 ppt) and brackish water (4 ppt); CTMa were 20.8, 25.4 and 28.0° C and 23.2, 27.0 and 28.9EC, respectively. For fish acclimated to 12, 17 and 21° C, critical thermal minima (CTmin) were 6.4, 7.4, and 7.3° C (Swanson and Cech 1995).

Salinity: Delta smelt tolerated chronic exposure (12 hours) to salinities from 0 ppt to 19 ppt (55 percent seawater). Neither acclimation temperature (17 and 21° C) nor fish size affected salinity tolerance (Swanson and Cech 1995). Larvae and early juveniles salinity range 0.3-1.8 ppt (Unger 1994).

General salinity tolerance ranges from the results of the literature review (CUWA 1994).
Spawning: 0 to 0.5 ppt
Egg: 0 to 5 ppt
Larvae: 0 to 5 ppt
Juveniles: 0.5 to 10 ppt
Adult: 0.5 to 10 ppt

4. LONGFIN SMELT, *Spirinchus thaleichthys*

Salinity: Larvae and early juveniles (<50 mm) 1.1 -18.5 ppt (Unger 1994). General salinity tolerance ranges from the results of the literature review (CUWA 1994).
Spawning: 0 to 0.5 ppt
Egg: 0 to 0.5 ppt
Larvae: >=0 ppt
Juveniles: >=0.5 ppt
Adult: >=0 ppt

Hatching takes about 40 days at 7o C (Moyle 1976 and CUWA 1994).

5. PRICKLY SCULPINS, *Cottus asper*

Prickly sculpins, live in waters ranging from fresh to salt, in streams ranging from small, cold, and clear to large, warm, and turbid and in lakes and reservoirs ranging from small to large, eutrophic to oligotrophic. Natural spawning usually requires temperatures of 8 to 13° C. They have been found in water up to 28° C (Moyle 1976).

6. SACRAMENTO SPLITTAIL, *Pogonichthys macrolepidotus*

Temperature:
The following is from Cech and Young (1995):
YOY, Juveniles and Subadults: Critical temperature minima: 6.5-7.3° C

Critical temperature maxima:
YOY: Acclimated to 12° C had a CTMa value of 21-22° C
Acclimated to 17 and 20°C had CTMa values of 29-33° C
Large YOY: An increase of 3° C in acclimation temperature resulted in a 3° C increase in CTMa.
For Juveniles and Subadults, a 5° C increase in acclimation temperature resulted in significant 8 and 7° C increases respectively, in CTMa.

Salinity:
Critical salinity maxima: mean CSMa 20-29 ppt, acclimated to freshwater. Significant correlation between size (0.2-192 g) and CSMa (22-27 ppt).

General salinity tolerance ranges from the results of the literature review (CUWA 1994). Splittail spawn in the tidal freshwater and oligohaline portions of the Sacramento-San Joaquin estuary in sloughs, flooded rivers and streams in the Delta with egg presumably being deposited on beds of submerged aquatic vegetation. Planktonic larvae are euryhaline and have been found from freshwater oligohaline portions of the estuary. Juvenile splittail have been collected by beach seine in Suisun Bay and most of the Delta sloughs in late winter and spring months. Adults live mostly in slow moving stretches of the main rives and in the Delta. The distribution of adult splittail includes San Pablo Bay, the lower reaches of the Sacramento River and the Delta.

Spawning: 0 to 5 ppt
Egg: 0 to 5 ppt
Larvae: 0 to 5 ppt
Juveniles: 0 to 5 ppt
Adult: 0 to 5 ppt

Most larvae are found in freshwater, yet they can tolerate water to at least 8 ppt, possibly much higher. Some spawning appears to occur in freshwater areas within the marsh (i.e. Denverton Slough). Larvae found in open water in Suisun Bay are probably transported there from upstream. Juveniles and adults may be swept or migrate downstream into the marsh and bay. There is some evidence that rising temperatures initiate these movements; reduced habitat size and increased densities resulting from dropping river levels probably also influences migration. Juvenile (to age 1+) and adults (age 2+ and older) can easily tolerate water to 10 ppt and are common in water up to 14 ppt. Within the limits of <14 ppt and <28-30 EC, juvenile and adult splittail will inhabit most areas within the Marsh and Bay. Adults may be less common during the spawning period (February-June), especially if the Marsh and Bay are brackish; they will migrate to freshwater to spawn.

7. STARRY FLOUNDER, *Platichthys stellatus*

Salinity: YOY (<70 mm) 0.1-19.7 (Unger 1994)
General salinity tolerance ranges from the results of the literature review (CUWA 1994).
Spawning: >18 ppt
Egg: >30 ppt
Larvae: >=5 ppt
Juveniles: >= 0 ppt
Adult:>=18 ppt

8. STRIPED BASS, *Morone saxatilis*

Temperature: Striped Bass spawning occurs during the months of April, May and June when water temperatures reach 16EC. Eggs hatch in 48 hours at 19° C (CUWA 1994).

Salinity: Most spawning occurs at EC's less than 0.3, although observations have ranged from 1.799 to 5.999 (DFG 1987). Salinity barrier of .55 EC in the San Joaquin River above Venice Island causes a block to spawning migration to historic spawning grounds in the San Joaquin River (SWRCB Phase I Hearing Transcript XLI, 68:1-69:10). An EC of .44 is the highest value at which spawning was observed (Farley 1966). Eggs can withstand EC's of 1.5 if they are allowed to harden first in fresh water (Turner and Farley 1971).

Larvae 5-9 mm salinity range 0.1-2.5 ppt (Unger 1994).

General salinity tolerance ranges from the results of the literature review (CUWA 1994).
Spawning: 0 to 0.5 ppt
Egg: 0 to 18 ppt
Larvae:>= 0 ppt
Juveniles: >= 0 ppt
Adult: >= 0 ppt

Eggs, larvae and YOY are found in both the lower riverine and upper estuarine areas. Most adult bass move downstream after spawning into brackish and salt water where they reside during the summer and fall. Some fish enter the ocean while some may remain in the estuary for a large portion of their life (CUWA 1994).

9. TULE PERCH, *Hysterocarpus traski*

General salinity tolerance ranges from the results of the literature review (CUWA 1994).
Spawning: 0 to 0.5 ppt
Egg: 0 to 0.5 ppt
Larvae: 0 to 0.5 ppt
Juveniles: 0 to 0.5 ppt
Adult: 0 to 5 ppt

Live in low-elevation streams (Moyle 1976) and in cold water streams and reservoirs (Bruce Herbold, USEPA, pers. comm.).

10. YELLOWFIN GOBY, *Acanthogobius flavimanus*

Yellowfin gobies can withstand abrupt changes between fresh and salt water, and can survive temperatures greater than 28° C. They can complete their entire life cycle in fresh water, although usually at least the larval stages are spent in salt water (Moyle 1976).

11. SHIMOFURI GOBY, *Tridentiger bifasciatus*

An exotic species, introduced in the 1960s into the Sacramento-San Joaquin Estuary, *Tridentiger bifasciatus* is commonly found in fresh water and has not been collected in salinities above 22 ppt. By 1989, *T. bifasciatus* was the most abundant adult fish within Suisun Marsh and the third most abundant larval fish collected in ichthyoplankton tow by the DWR in the southern delta. Like the chameleon goby, *T. bifasciatus* prefers habitats with structurally complex substrates and may spawn in the same areas. *T. bifasciatus* spawns from April through September and in water less than 5 ppt at 20° C. At this temperature, larvae hatch in about 9 days. Males guard the eggs and often spawn with several females, which are partial spawners. In Suisun Marsh, *T. bifasciatus* feeds primarily on benthic invertebrates such as amphipods and mysid shrimp (Matern and Fleming 1995).

12. OPOSSUM SHRIMP, *Neomysis mercedis*

Salinity and Temperature: Although this species has broad salinity tolerance, field studies indicate that Neomysis abundance decreases at salinity levels above 7.2 ppt (11.3 mS/cm) and is extremely low when salinity exceeds 18 ppt (Heubach 1969). Temperatures above 18° C (65° F) causes a decrease in abundance when dissolved oxygen concentrations are low (Heubach 1969).

13. BAY SHRIMP, *Crangon spp.*

Salinity:Crangon franciscorum (<26 mm) 1.6-21.6 ppt (Unger 1994)
Crangon nigricauda (<20 mm) 18.1-32.0 ppt (Unger 1994)

Fish Abundance and Diversity in Suisun Marsh

The most comprehensive data set on fish abundance and diversity in Suisun Marsh comes from the U.C. Davis Suisun Marsh Fisheries monitoring program. The U.C. Davis Department of Wildlife, Fish and Conservation Biology began the monthly fish sampling program in 1979. In 1994, U.C. Davis also began a study to assess use of the marsh for fish spawning and rearing of larvae. The goals of these project are to:

- Record long-term changes in fish populations due to environmental fluctuations and species introductions, and add to the growing database on the Sacramento-San Joaquin Estuary.
- Monitor the distribution and abundance of seasonal species of the marsh, especially delta smelt, longfin smelt, chinook salmon, and splittail.
- Track the movement of exotic species of the marsh, especially shimofuri goby and Asian clam.
- To study the effects of the Montezuma salinity control gates and other proposed changes in water circulation on fish populations.
- To augment the understanding of adult fish communities of the marsh with information on other life history stages.
- To determine what extent the relatively undisturbed habitat of the marsh is used by fish for spawning and rearing.
- To determine if special status species such as delta smelt, longfin smelt, and splittail are using the marsh for spawning and rearing.

Methods for this program are as follows:

Sampling at Suisun Marsh is conducted on a monthly basis at 21 sites in the marsh. Sampling is conducted using an otter trawl at all stations except two, where seining nets are used. The following sloughs are sampled: Peytonia, Boynton, Spring Branch, Cutoff, Goodyear, Denverton, Montezuma, and Suisun

(Figure 4A-3). The first six could be classified as small sloughs, the last two are considered large. In small sloughs, a trawl was towed at 4 km/hr for 5 minutes. In the large sloughs the trawl was towed for a longer period of time, 10 minutes, to compensate for small catches. At each site, tidal stage, temperature, salinity, conductivity, and secchi were measured.

1. Fish Species in the Suisun Marsh

Moyle et al. (1986) examined data collected between 1979 and 1986 for the Suisun Marsh study and found that, of the 42 species collected during this time, 21 species were collected on a regular basis. The ten most abundant were striped bass, splittail, threespine stickleback, tule perch, prickly sculpin, longfin smelt, yellowfin goby, Sacramento sucker, Pacific staghorn sculpin, and starry flounder. Another 21 species occurred in small numbers on an irregular basis. Between 1979 and 1997, more than 50 fish species have been caught in Suisun Marsh by U.C. Davis researchers (Table 4A-3).

2. Seasonal Changes in Abundance

Moyle et al. (1986) found that total fish abundance in the marsh exhibited strong seasonality; numbers and biomass were lowest in winter and spring and highest in late summer. Freshwater inflow was highest in the winter and lowest in late summer, when salinities and temperature were highest. However, Matern et al. (1996) also examined monthly trends in catch per trawl and reached somewhat different conclusions. They found that catches were low in late fall and winter months and increased slightly from January to February. Catches peaked from April through June. Catches declined through summer and fall, reflecting the high mortality of the young of the year.

3. Spatial Distribution

Patterns of distribution and abundance of fish in Suisun Marsh have been examined in a number of publications (Moyle et al. 1985, Moyle et al. 1986, Meng et al. 1994). Moyle et al. (1985) summarized 5 years of fish and crustacean abundance data which was collected on a monthly basis from 1979 to 1982. These researchers examined the distribution of fish in two major habitat types: small, dead-end sloughs (7-10 meters wide, 1-2 m deep), which are primarily lined with tules and reeds, such as Peytonia, Boynton, Spring Branch, Cutoff, Goodyear and Denverton; and a large slough, Suisun Slough. They concluded that there are two distinct associations of fish in the marsh: a native fish association that exists in the dead-end sloughs and an association of introduced and seasonal species that existed in the main channels. In the shallow sloughs proportionately more tule perch, prickly sculpin, splittail, and sticklebacks were found. In the larger sloughs, proportionately more staghorn sculpin adults and striped bass were found.

However, Meng et al. (1994), in an examination of 14 years of data on fish abundance in the marsh, found the fish assemblage to be much less predictable than had been concluded in the previous paper. Native species were found more often in small dead-end sloughs, seasonal species were found in larger sloughs, and introduced species were found in both habitats. Further, while there were large fluctuations in the abundance of introduced and seasonal fish, there was a steady decline in the abundance of native fishes.

U.C. Davis researchers evaluated data from 1995 and 1996 to examine variations in abundance and diversity across the marsh. They found that the highest catch per trawl occurred in Spring Branch Slough and the lowest in Boynton Slough. Boynton Slough is distinct from other small sloughs because it receives treated effluent from the Fairfield Sewage Treatment Plant, and because of its bottom substrate, which is mainly composed of loose sediment. Species diversity was highest in Spring Branch and lowest in Nurse Slough and apparently, species diversity was lower in all large and medium sized sloughs than in smaller

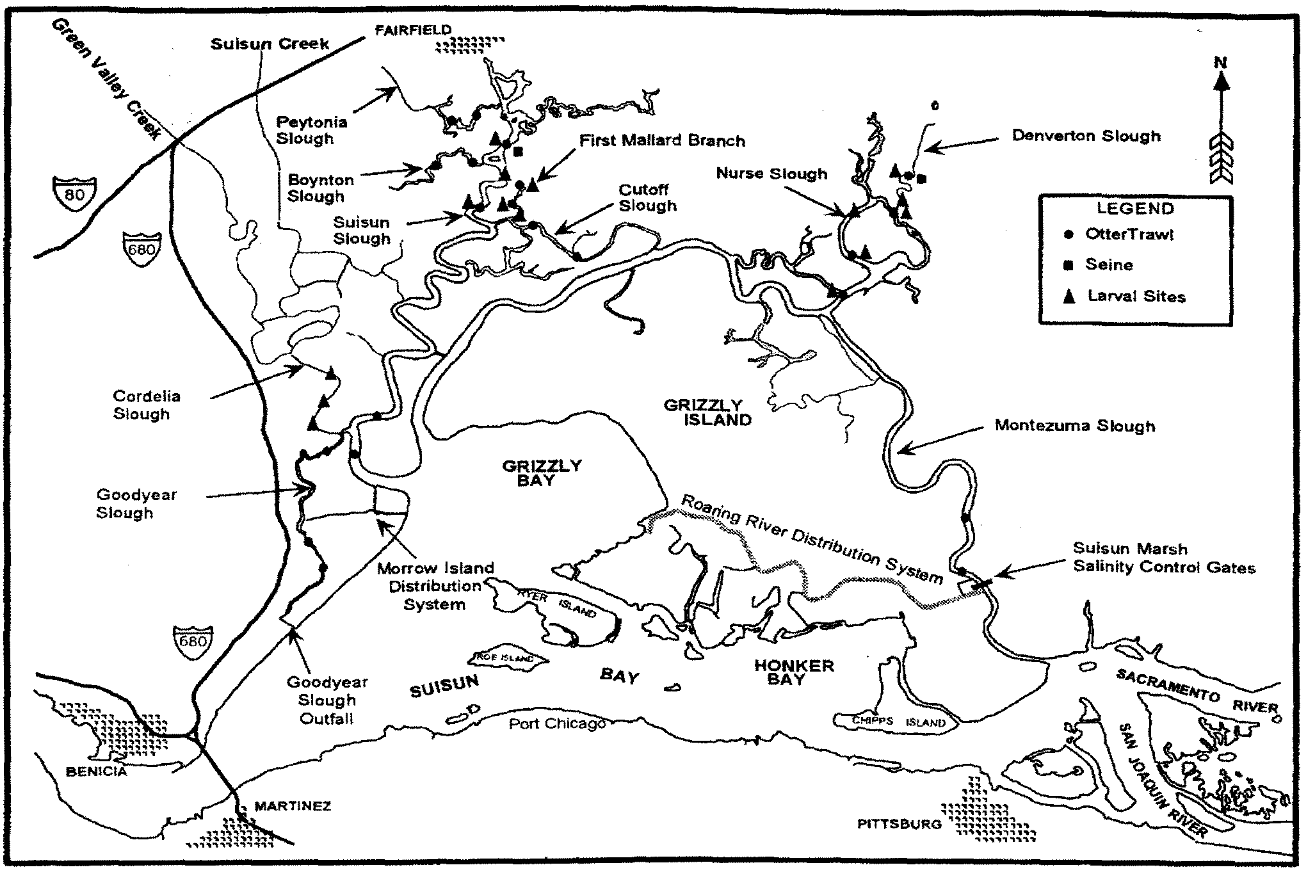


Figure 4A-3 Location of U.C. Davis Fish Monitoring Sites in Suisun Marsh

Table 4A-3 Fish Species in the Marsh

Common Name	Scientific Name	Abbreviation
American shad	*Alosa sapidissima*	ASH
bay pipefish	*Syngnathus leptorhynchus*	BYP
bigscale logperch	*Percina macrolepida*	BLP
black bullhead	*Ictalurus melas*	BC
black crappie	*Pomoxis nigromaculatus*	BB
bluegill	*Lepomis macrochirus*	BG
brown bullhead	*Ictalurus nebulosus*	BB
California halibut	*Paralichthys californicus*	CHA
channel catfish	*Ictalurus punctatus*	CC
chinook salmon	*Oncorhynchus tshawytscha*	KS
common carp	*Cyprinus carpio*	CP
delta smelt	*Hypomesus transpacificus*	DS
fathead minnow	*Pimephales promelas*	FHM
golden shiner	*Notemigonus crysoleucas*	GSH
goldfish	*Carassius auratus*	GF
green sturgeon	*Acipenser medirostris*	GS
green sunfish	*Lepomis cyanellus*	GSF
hitch	*Lavinia exilicauda*	HCH
inland silverside	*Menidia beryllina*	MSS
largemouth bass	*Micropterus salmoides*	LMB
longfin smelt	*Spirinchus thaleichthys*	LFS
longjaw mudsucker	*Gillichthys mirabilis*	LJM
northern anchovy	*Engraulis mordax*	NAC
Pacific herring	*Clupea harengeus*	PH
Pacific lamprey	*Lampetra tridentata*	PL
Pacific sanddab	*Citharichthys sordidus*	PSD
Pacific staghorn sculpin	*Leptocottus armatus*	STAG
plainfin midshipman	*Porichthys notatus*	MID
prickly sculpin	*Cottus asper*	SCP
rainbow trout	*Oncorhynchus mykiss*	RT
rainwater killifish	*Lucania parva*	RWK
Sacramento blackfish	*Orthodon microlepidotus*	GB
Sacramento squawfish	*Ptychocheilus grandis*	SQ
Sacramento sucker	*Catostomus occidentalis*	SKR
shimofuri goby	*Tridentiger bifasciatus*	SG
shiner perch	*Cymatogaster aggregata*	SP
speckled sanddab	*Citharichthys stigmaeus*	DAB
splittail (adult)	*Pogonichthys macrolepidotus*	STA
splittail (young)	*Pogonichthys macrolepidotus*	STY
starry flounder	*Platichthys stellatus*	SF
striped bass (adult)	*Morone saxatilis*	SBA
striped bass (young)	*Morone saxatilis*	SBY
surf smelt	*Hypomesus pretiosus*	SS
threadfin shad	*Dorosoma petenense*	TFS
threespine stickleback	*Gasterosteus aculeatus*	STBK
topsmelt	*Atherinops affinis*	TPS
tule perch	*Hysterocarpus traski*	TP
warmouth	*Lepomis gulosus*	WM
western mosquitofish	*Gambusia affinis*	MQF
white catfish	*Ictalurus catus*	WCF
white crappie	*Pomoxis annularis*	WC
white croaker	*Genyonemus lineatus*	WCK
white sturgeon	*Acipenser transmontanus*	WS
yellowfin goby	*Acanthogobius flavimanus*	YFG

sloughs. While these researchers assert that this reflects in part the efficiency of the sampling gear, it also likely reflects the importance of habitat complexity.

4. Changes in Abundance and Diversity Over Time

Results of the Suisun Marsh fish survey indicate that there has been an overall change over the last 20 years towards a less numerous, less diverse assemblage of fishes (Matern et al 1994, 1995, 1996). Matern et al. report both a general decline in the abundance of most species across years, as well as temporary changes in abundance due to decreases in salinity and changes in flow. The overall change in abundance has been observed for most resident species. The only exceptions are shimofuri goby and yellowfin goby, which have both experienced increases in abundance, particularly in 1989 and 1993, respectively. In terms of diversity, native fishes have declined relative to introduced species. For example, in 1996 natives declined by 51 percent, while exotics declined by 19 percent.

In some instances wet years support increases in species abundance. Matern et al. (1996) assert that wet springs in 1991 and 1992 resulted in high abundance of young-of-the-year striped bass and, during the above normal year of 1993, peaks occurred in the abundance of prickly sculpin and yellowfin goby. These researchers associated the high spawning success of splittail, yellowfin goby, prickly sculpin, Pacific staghorn sculpin, and longfin smelt in 1995 due to the fact that it was a wet year. In the case of splittail, Sommer et al. (1996) report that year-class strength of splittail is positively related to freshwater outflow during the spawning season. This is due to the fact that higher flows increase inundation of floodplain areas, which provide spawning, rearing, and foraging habitat. However, in 1996, a wet year, some species increased in abundance while others declined. Matern et al. state that fish species diversity does not appear to be related to water year type.

5. Spatial Distribution of Larval Fish in Suisun Marsh.

Matern et al. (1996) report the following results from the 1994 Suisun Marsh Larval Fish Survey: surveys indicate that the upper and eastern portions of the marsh seemed to be better habitat for larval fish. The narrow, dead-end sloughs (Spring Branch and Denverton) and wide, upper end of Suisun Slough had the highest catches. Cordelia had the lowest catches, but greatest number of species, reflecting its marine influence. Cordelia differs from other sloughs sampled because it is deep with little shallow water habitat. Delta smelt were found primarily in Nurse and Suisun, large sloughs with a more riverine nature. Longfin smelt were captured in equal portion all over the marsh. The catches for 1994 reflect results of a very dry year with lower than average river flows.

Changes in Phytoplankton and *Neomysis* Abundance in the Suisun Marsh

The following discussion is quoted from Suisun Marsh Salinity Control Gates Fisheries Monitoring 1996 Annual Report (DWR 1999).

"Since 1972, the Department of Fish and Game has conducted field sampling for zooplankton and Neomysis mercedis in Suisun Marsh. In 1976, Fish and Game began taking chlorophyll *a* samples as well. This section discusses the abundance of *Neomysis* and concentration of chlorophyll *a*, an indicator of phytoplankton abundance, over time. *Neomysis* is a euryhaline zooplankton species that has peak abundance in the entrapment zone (Obrebski et al 1992). Although it has broad salinity tolerance, field studies indicate *Neomysis* abundance decreases at total dissolved solid levels above 7.2 ppt (11.3 mS/cm) and is extremely low when salinity exceeds 18 ppt (Heubach 1969). Phytoplankton is the primary food source for *Neomysis*, which in turn, is an important dietary component for many marsh fishes. Phytoplankton abundance can change quickly, which may affect the abundance of *Neomysis* and, indirectly, that of many fish species.

"Historically, three sites (S-32, S-33, S-34) were sampled in Montezuma Slough and one in Suisun Slough (S-42) (Figure 4A-4). S-33 was discontinued in 1977, and S-34 was discontinued in 1984. Since 1984, only S-32 and S-42 have been sampled. The site on Montezuma Slough is about 15 miles downstream of the Salinity Control Gates, at the western end of the slough. In general, *Neomysis* and phytoplankton sampling occurs twice monthly from March through October. Normally there is no sampling in November-March due to naturally low winter abundance of *Neomysis*. In water year 1996, *Neomysis* and chlorophyll sampling were conducted monthly throughout the year.

"At each site, one *Neomysis* sample, two zooplankton samples, and one chlorophyll *a* sample are taken. In recent years, numbers of *Acanthomysis*, a mysid species that has recently invaded from Asia, are also enumerated. Surface temperature, water transparency (Secchi depth), and specific conductance are also measured. *Neomysis* and larger zooplankton are sampled using a bottom-to-surface oblique tow through the water column with nets attached to a tow frame. Tows last 10 minutes. The *Neomysis* net used since 1974 has a mesh size of 0.505 mm and mouth diameter of 30 cm and is 1.48 meters long. The zooplankton net, which is mounted above the *Neomysis* net, is made of No. 10 nylon mesh, has a mouth diameter of 10 cm, and a length of 73 cm. To sample for microzooplankton, a hose is raised from the bottom to the surface of the water column. At the same time, water is pumped through the hose into a carboy. Subsamples are taken from the water in the carboy. Water for chlorophyll *a* samples is taken from a depth of 1 meter.

Chlorophyll *a* Concentration

"Overall, chlorophyll *a* concentration has decreased in Suisun Marsh since 1987 (Figures 4A-5 and 4A-6). This decline in drought years has been attributed partly to decreases in freshwater flows (Monroe et al 1992). Another factor affecting chlorophyll *a* concentration in recent years is the presence of the suspension-feeding clam *Potamocorbula amurensis*, which invaded San Francisco Bay and the estuary in 1987 and has become abundant (Alpine and Cloern 1992; Herbold et al 1992). Alpine and Cloern determined that mean estimated primary production between 1977 and 1990 decreased from 106 to 39 g C m-2yr-1, presumably due to the intensive grazing pressure by the clam in San Francisco Bay and Sacramento/San Joaquin Delta Estuary.

The University of California, Davis, Suisun Marsh fisheries monitoring reports indicate that *P. amurensis* has been collected in many locations in Suisun Marsh (Matern et al 1995). The clam is reported to be abundant near the downstream mouth of Suisun Slough and has invaded the upstream regions of the slough. In 1994, *P. amurensis* was collected near the Suisun Marsh Salinity Control Gates. Although it has been collected at many sites in the marsh, in 1996 it was collected at only three western sites in the Marsh (Matern et al. 1996).

"The decrease in chlorophyll *a* concentrations has been apparent since 1987, when the clam first invaded the bay and estuary. Between 1976 and 1987, 25% of all phytoplankton samples collected were at least 20 ug/L, and 43% were less than 10 ug/L. From 1988 to 1996, approximately 2% of all samples were greater than or equal to 20 ug/L, and 91% of the samples were less than 10 ug/L. The decline appears to have accelerated in recent years: since 1992, 97% of all samples were <5 ug/L. This 9-year decline in chlorophyll a appears most tightly linked to the invasion of *P. amurensis* (Monroe et al 1992).

"Construction and operation of the Suisun Marsh Salinity Control Gates does not appear to have further decreased chlorophyll *a* levels. In water year 1989, the year after gate operations began, chlorophyll *a* was higher than in those years immediately preceding gate installation. For example, chlorophyll *a* values in water year 1988 were 1.3-15.9 ug/L; in 1989 they were 1.3-36.1 ug/L. The peak in 1988 was in April through July, with values of 3.7-15.9 ug/L in Suisun and Montezuma sloughs. In 1989, the peak was later, June-October, and values in the two sloughs were 4.1-36.1 ug/L (above 15 ug/L during 5 of those months).

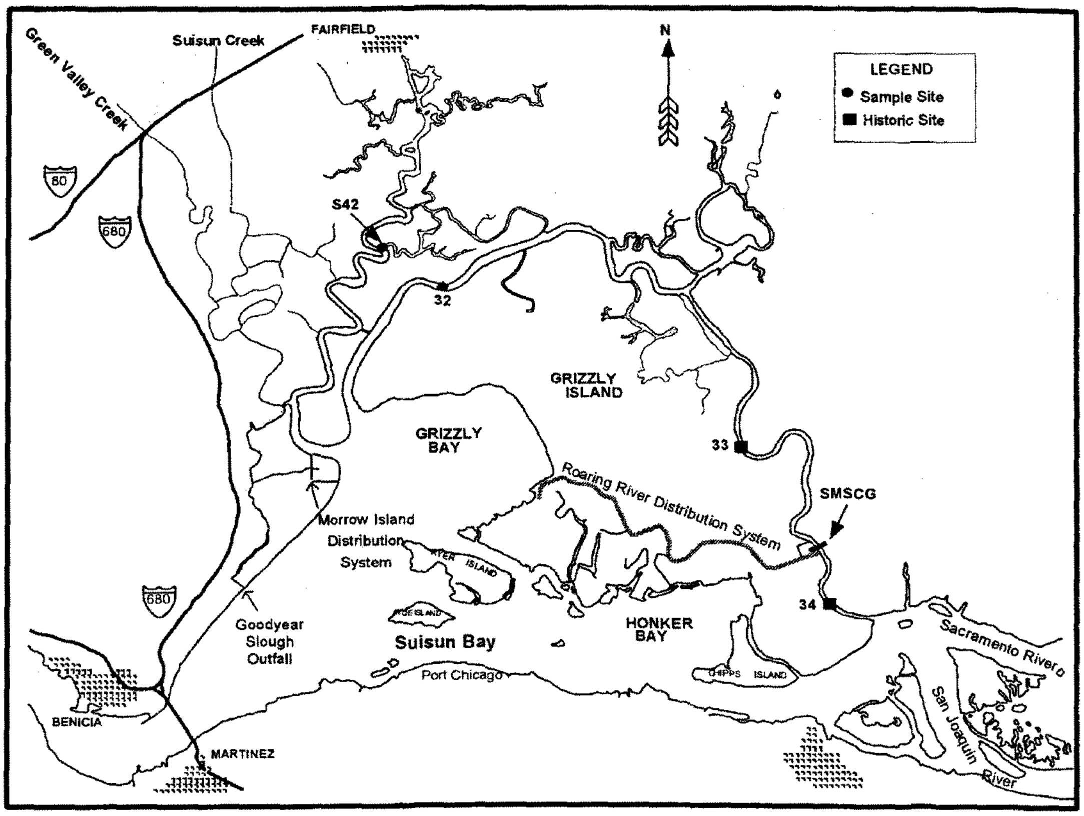


Figure 4A-4 Sampling Sites for *Neomysis*, Zooplankton, and Chlorophyll *a* Surveys

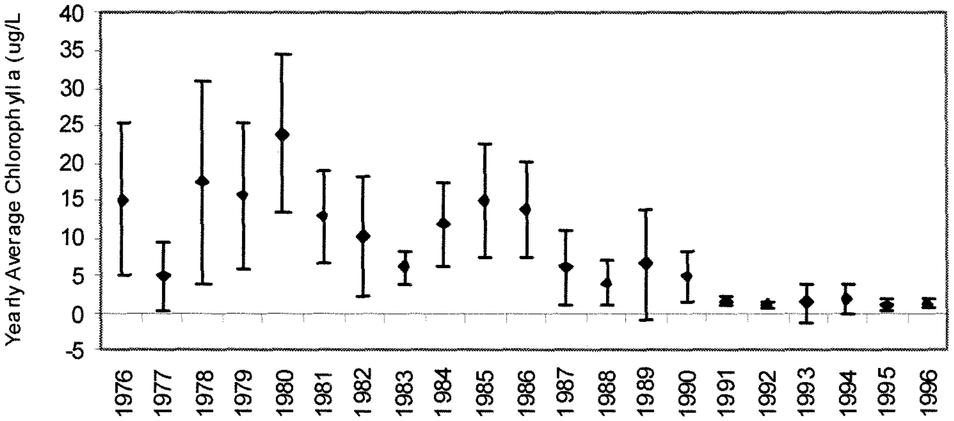


Figure 4A-5 Yearly Average Chlorophyll *a* and Standard Deviation Values for Suisun Marsh, 1976-1996 at Station 32 on Montezuma Slough

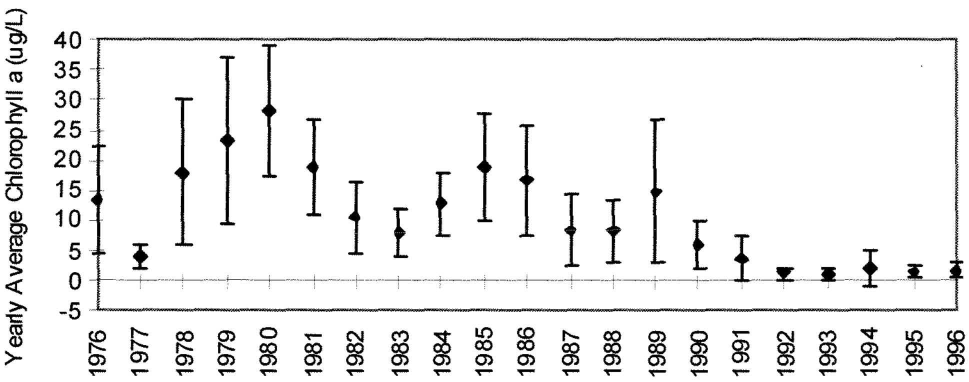


Figure 4A-6 Yearly Average Chlorophyll *a* and Standard Deviation Values for Suisun Marsh, 1976-1996 at Station 42 on Suisun Slough

"Whether the 1989 levels were a result of control gate operations would be difficult to determine, but these data do suggest that the first year of operation did not decrease phytoplankton production.

"In 1990-1991, chlorophyll *a* levels were low (0.8-15.7 ug/L) and similar to levels in 1987-1988 (0.3-20.4 ug/L). There was no phytoplankton bloom in Montezuma Slough in 1992, a critical water year; chlorophyll *a* concentration was less than 2.4 ug/L on all sampling occasions. Concentrations increased somewhat in 1993, peaking at 10 ug/L in May. In 1994 and 1995, chlorophyll concentrations again were low on all sampling occasions. (No samples were taken in January-April 1995.) In 1994, concentrations were 0.3-6.8 ug/L. In water year 1995, the highest and lowest chlorophyll *a* concentrations were both measured in December; chlorophyll *a* in Montezuma Slough was 5.2 ug/L and in Suisun Slough it was below the limit of detection. In water year 1996, chlorophyll *a* ranged from 0.5-2.7 ug/L. Herbold et al (1992) suggest that even with an increase in freshwater flows, phytoplankton productivity may continue to be depressed, since *P. amurensis* can tolerate a wide range of salinity.

Neomysis Abundance

"*Neomysis* has been declining in Suisun Marsh since the 1970s, with the most dramatic decreases evident after 1991 (Figures 4A-7 and 4A-8). This decline is evident despite fluctuations within years and a dramatic peak in abundance in June 1996, when >3570 ind/m3 were observed at Station 32. As illustrated in figures 7 and 8, since approximately 1991, the yearly average abundance of *Neomysis mercedis* has decreased and the variability within years (indicated by the standard deviation lines) has also generally decreased. Between 1972-1976, yearly peaks in abundance were generally between 300-700 ind/m3, but on occasion were >4000 ind/m3. In 1977, a drought year, abundance decreased dramatically to <17 ind/m3. Between 1978-1988, yearly peak abundance of *Neomysis* was >400 ind/m3 in 7 of 11 years in Montezuma Slough and 9 of 11 years in Suisun Slough.

"Since the start of gate operations in November 1988, yearly peak *Neomysis* abundance has ranged from <3 to >3570 ind/m3. In 1991, Neomysis reached levels of 350 ind/m3 in Montezuma Slough and 680 ind/m3 in Suisun Slough, which was relatively high compared to abundance in the Delta at that time (Spaar 1992). Like chlorophyll *a, Neomysis* decreased significantly in 1992, a critically dry year; peak abundance was <16 ind/m3, making it comparable to abundance during the 1977 drought (<17 ind/m3). From 1992-1995, *Neomysis* abundance was <60 ind/m3 on all sampling dates. In 1993, *Neomysis* abundance increased slightly from 1992 levels, peaking at 57 ind/m3. Yearly peak abundance was low again in 1994, with <4 ind/m3. In 1995, abundance was below 1.5 ind/m3 on all occasions, except twice in Suisun Slough (4 ind/m3 in April and 7 ind/m3 in May). Salinity levels may have contributed to low abundance in Suisun Slough in 1992 and 1994; during both years, monthly average specific conductance values at Volanti (S-42) from June/July through October were above 7.2 ppt (11.3 mS/cm), the concentration at which *Neomysis* abundance begins to decline. However, this cannot explain the low *Neomysis* abundance during 1993 and 1995, when specific conductance at S-42 was well below this critical point.

"In water year 1996, *Neomysis* abundance was at extremely low levels (> 1.5 ind/m3) from October 1995 until May 1996, when abundance increased to 6 ind/m3. (Please note that, unlike previous years, *Neomysis* sampling was conducted monthly throughout water year 1996.) A dramatic peak in abundance was observed the following month at Station 32 when >3570 ind/m3 were counted. This is the highest value on record since June 1976 when 4117 ind/m3 were observed at Station S42. The population crashed the following month: no *Neomysis* were observed in the water column during July or August sampling. In September, <1 ind/m3 was observed. It is not known what factors caused this dramatic population increase in June. Historically, *Neomysis* peaked twice during the year, once in May-June and again in the fall; however, *Neomysis* now appear to peak only once during the year, in June (Mecum, pers. com. 1997). Incidentally, this peak in abundance coincided with a dramatic peak in the abundance of *Acanthomysis*, a mysid

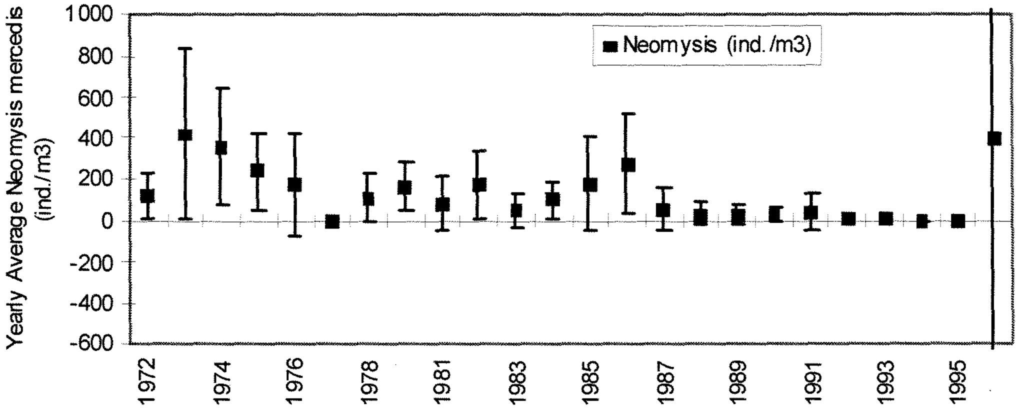


Figure 4A-7 Yearly Average *Neomysis mercedes* Density and Standard Deviation Values in Suisun Marsh, 1972-1996 at Station 32 on Montezuma Slough

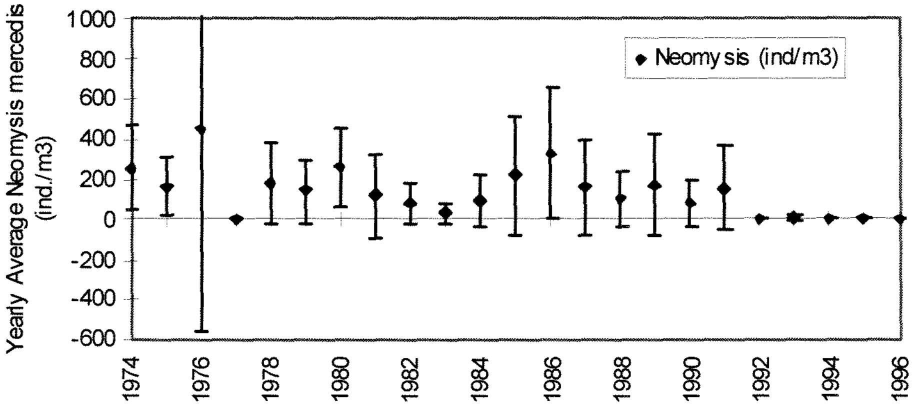


Figure 4A-8 Yearly Average *Neomysis mercedes* Density and Standard Deviation Values for Suisun Marsh, 1974-1996 at Station 42 on Suisun Slough

species that was recently introduced from Asia, which reached 11,544 ind/m3 at Station 32 in June. (Abundance of *Acanthomysis* was less than 37 ind/m3 on all other sampling dates during the 1996 water year.)

"The overall decline in *Neomysis* abundance is consistent with Obrebski et al (1992), who report a decline in the abundance of *Neomysis* and 12 zooplankton species throughout the Delta in all seasons in 1972-1988. They assert that the declines in zooplankton species are not limited to particular regions of the estuary. In Suisun Marsh, the decline is most apparent after 1991 (Mecum, personal communication, 1995). Food limitation, caused by reduced phytoplankton abundance, is the most probable cause for the decline. Orsi and Mecum's (1994) finding of a significant correlation between *Neomysis* abundance and chlorophyll *a* concentration in all seasons during 1968-1993 supports this conclusion.

"Another factor that is likely affecting *Neomysis* abundance is competition with *Acanthomysis* (Orsi and Mecum 1994). *Acanthomysis* may compete for the same phytoplankton resource as *Neomysis*. Orsi and Mecum (1994) report that *Acanthomysis* is present in the estuary at the same salinity as *Neomysis* and is now much more abundant than *Neomysis*. Catches of mysid shrimps by the University of California, Davis, Suisun Marsh fisheries monitoring program were lower in 1995 than ever before, and remained low in 1996. However, the UC Davis researchers do not estimate the relative abundance of *Neomysis* and *Acanthomysis* in their catches.

"The combined impacts of dry/critical water years, low phytoplankton productivity and invasive species, such as *Acanthomysis*, have likely led to the low zooplankton abundance in Suisun Marsh. Without the Salinity Control Gates, the with-project years 1989-1991 (all dry or critical) might have had extremely low *Neomysis* density, as in 1977. The gates may have delayed the impact of the drought on *Neomysis* density until 1992 by reducing April and May salinity and helping to create more favorable conditions for *Neomysis*. Decision 1485 standards for the marsh (11.0 mS/cm April-May) are slightly high for optimum *Neomysis* abundance, but gate operations often keep salinity well below these spring levels. Further, operation of the control gates can produce a saltwater/freshwater interface in the marsh, similar to the entrapment zone in the larger channels and bays of the estuary, providing suitable salinity for *Neomysis*. However, without corresponding increases in chlorophyll *a*, *Neomysis* will be unable to benefit from this."

Relationship Between X2 and Interior Marsh Salinities

Discussions within the Suisun Ecological Workgroup have pointed toward the need to establish the relationship between X2, a measure of salinity and freshwater loading into Suisun Bay, and channel salinities within Suisun Marsh. Since 1979, personnel of U.C. Davis have collected salinity and fish data from stations scattered through several areas of the marsh. The following analysis documents the relationship between X2 and mean salinities on a slough-by-slough basis.

Four sloughs were selected to represent different hydrological units of the marsh:

Montezuma Slough is a deep channel with one end near the mouth of the Sacramento River and the other at Grizzly Bay. Water can readily flow through Montezuma Slough each direction during the tidal cycle. Volume changes little over the tidal cycle compared to other sloughs.

Goodyear Slough is in the southwestern part of the marsh and receives water form inundated shallow pools as the tide recedes. In August 1981 the dead-end upper reach of Goodyear Slough was connected via channels, pipes, and gates with the lower end of Suisun Bay.

Peytonia Slough is in the northwesternmost part of the marsh and receives some freshwater urban runoff from nearby Suisun City. The channel is a shallow deadend slough.

Boynton Slough is near Peytonia Slough but is well separated from urban runoff. It is the discharge site for the Fairfield-Suisun sewage treatment plant. It is also a shallow deadend slough.

Little data exists in the U.C. Davis Suisun fish sampling data set for either of the two sloughs that receive freshwater inputs at their upper ends. It is likely that such sites would show less well-defined relationships with X2.

Data on X2 are taken from calculations of daily total outflow rates contained in DAYFLOW. These calculations use previous day's X2 location and current day's outflow to calculate the current day's X2 location. No effort is made to incorporate changes due to the spring-neap tidal cycle so these values should be considered more as 14-day averages rather than actual daily estimates. On the other hand, salinity data taken during the U.C. Davis fish sampling program were not standardized to any part of the tidal cycle. Values used are the averages of the 2 or 3 samples taken at each location within each slough. Different locations within a slough were usually sampled within 60 minutes of each other.

Figures 4A-9 - 4A-12 illustrate the relationship between X2 and channel salinity. Boynton, which receives substantial quantities of freshwater from sewage treatment plant, shows the lowest level of variance attributable to X2. However, despite differences in their hydrologies and connections to Suisun Bay, the other three sites show similar high levels of variability explainable by Suisun Bay conditions. The size of the coefficient is another measure of sensitivity to Suisun Bay conditions because higher coefficients reflect greater degrees of impact; the more upstream and deadend sloughs do not change as much in salinity with the same level of change in X2 as the more downstream, flow-through sloughs do.

The model is: square root of salinity = constant + coefficient B * X2

	n	p	r-squared	constant	coefficient
Boynton	146	<.001	0.35	-0.418	0.026
Peytonia	143	<.001	0.54	-1.04	0.034
Goodyear	138	<.001	0.61	-1.33	0.047
Montezuma	115	<.001	0.58	-1.91	0.045

Further work that might be pursued includes: (1) correcting the grab sample data by developing a correction based on tidal stage; (2) correcting the X2 data by incorporating the spring-neap tidal condition; (3) restricting analysis to particular seasons to ensure that the relationship is not influenced by any seasonal changes that characterize the estuary; and (4) comparing the results here with salinities predicted from hydrodynamic models.

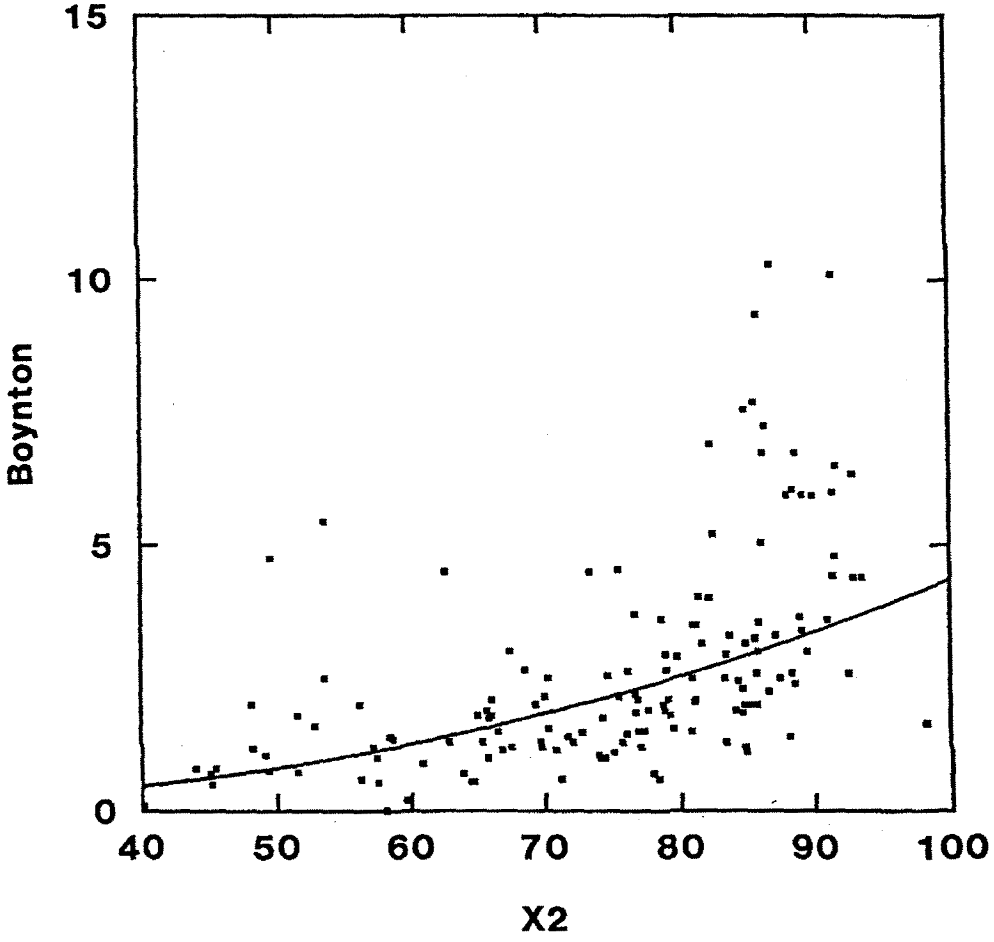


Figure 4A-9 Relationship Between X2 and Channel Salinity in Boynton Slough

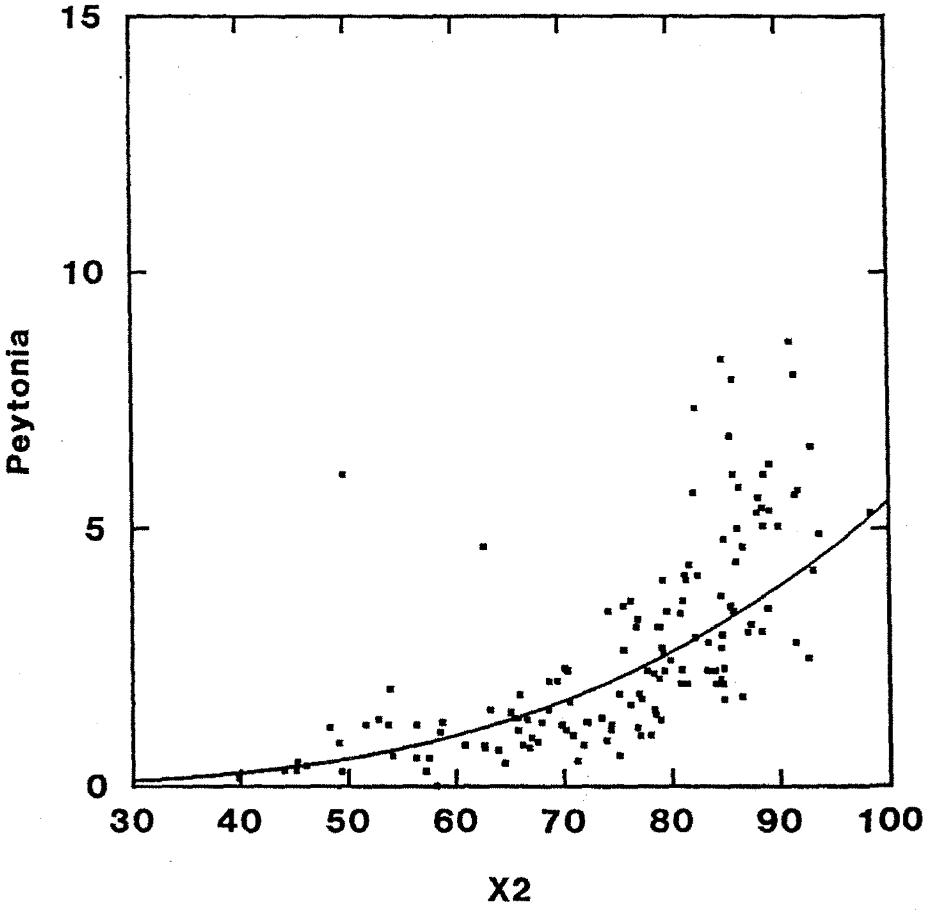


Figure 4A-10 Relationship Between X2 and Channel Salinity in Peytonia Slough

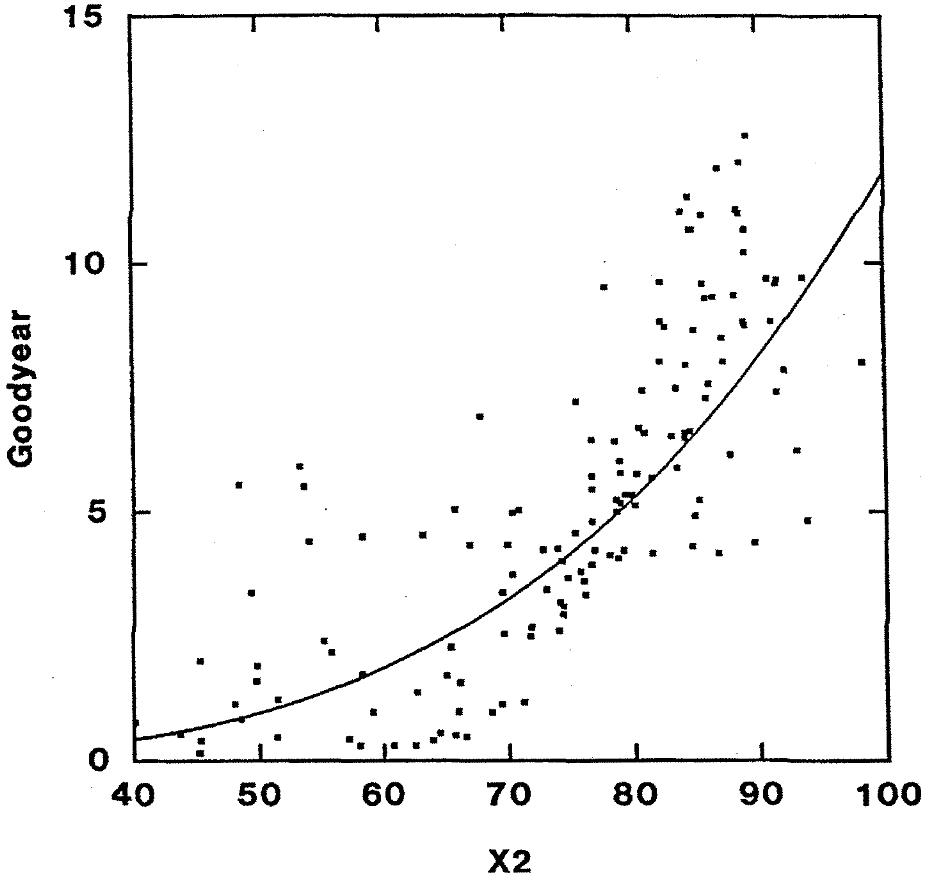


Figure 4A-11 Relatiinship Between X2 and Channel Salinity in Goodyear Slough

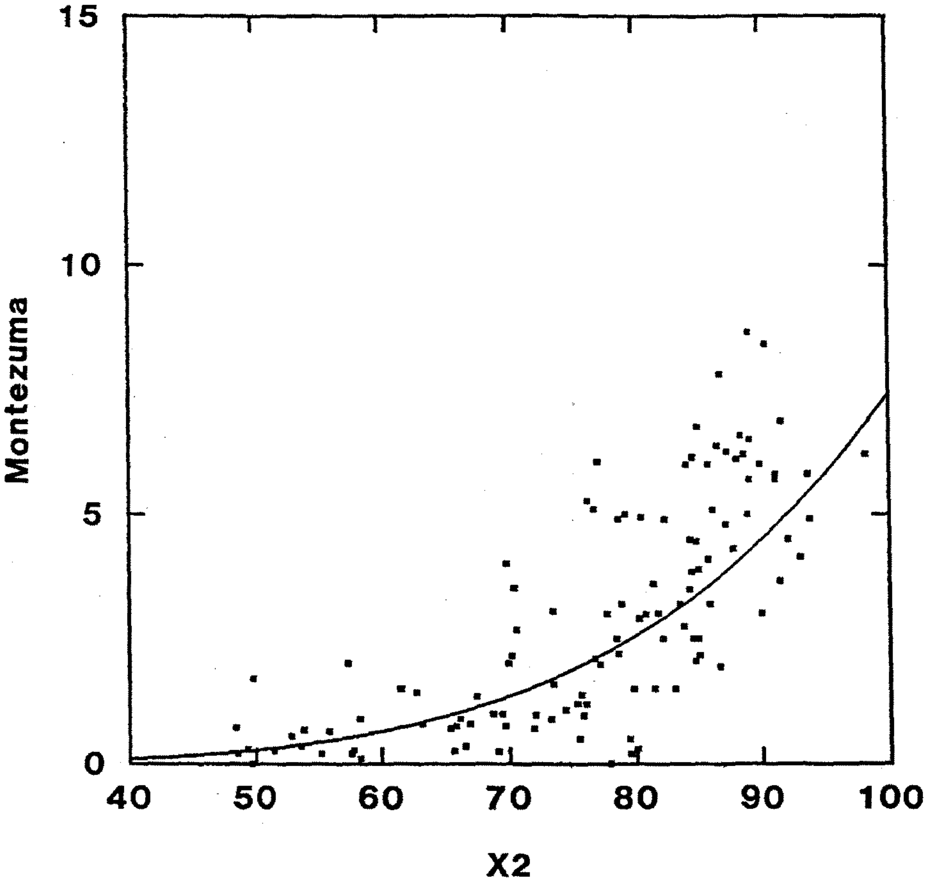


Figure 4A-12 Relationship Between X2 and Channel Salinity in Montezuma Slough

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Table R-1 References used for Table 4A-2. See numbered reference list above.

Suisun Marsh Species	*References Used*
Chinook salmon	1,2,3,4,9,10,11,13,14,15,16,18,19,20, 21,25,26,28,29,30,31,32,33,34,35,39,40; L. Holsinger, pers.comm.
Delta smelt	6, 17, 26, 27, 36, 28
Longfin smelt	6, 38
Prickly sculpin	6, 26
Sacramento splittail	6, 7, 26
Shimofuri goby	23
Starry flounder	6, 26, 38
Steelhead	26, 38
Striped bass	5, 6, 12, 37
Tule perch	26
Opossum shrimp	17
Bay shrimp	38
Corbicula fluminea	22

Chapter 5: Wildlife Subcommittee

Introduction

During the past 3 years, the Suisun Ecological Workgroup Wildlife Subcommittee evaluated the ecological basis for establishing salinity standards for Suisun Marsh wildlife species and their associated habitats. This report includes data and recommendations supporting the subcommittee's evaluations.

Basis for Recommendations

The scope of recommendations is limited to modifying or building upon existing programs for achieving water quality objectives. The natural salinity variability which seasonally occurs with weather, precipitation, and tidal cycles cannot be controlled. Operations of reservoirs and dams, the long-term export and delivery of water from the Central Valley rivers and Delta, and the configuration of Delta and Suisun Marsh exterior levee systems directly impact the natural hydrology of the marsh and influence the Suisun region salinity regime. The Wildlife Subcommittee agreed that it would not advocate physical changes to these established operational activities and facilities. However, other operational activities can be evaluated or modified to influence channel water and resulting soil salinities in the marsh.

The following information and activities contributed, in part, toward the development of the subcommittee's recommendations:

- wetland management activities within the diked managed wetland habitats of the Suisun Marsh,
- historical records and modeling results of past Delta outflows,
- historical records of salinities in Suisun since the 1920s,
- data from geological records,
- past environmental conditions in Suisun Marsh at the inception of the SEW process, which were strongly influenced by past Delta outflow and D-1485,
- current environmental conditions in Suisun Marsh, which are strongly influenced by past Delta outflows, D-1485, and currently, WR 95-6 and WR 98-9, with X2 spring flows; and
- operation of the gates influence on interior marsh salinities.

The outcome of any proposal to continue or modify current salinities has a great degree of uncertainty, with a potential to impact or benefit wildlife populations and habitats within the Suisun Marsh.

Channel water salinity influences the managed and tidal wetlands vegetation and habitat quality available for Suisun wildlife populations. Most of the wildlife species of Suisun Marsh transcend habitat types and utilize most or all of the wetland, upland, and aquatic resources available to them (Table 5-1).

Table 5-1 Existing Habitats in Suisun Marsh

Habitat	*Acreage*	*Percent of Total Habitat*
Managed wetlands	52,000	44.8
Bays and sloughs	30,000	25.9
Upland grasslands	27,700	23.9
Tidal wetlands	6,300	5.4
Total marsh	116,000	100

Wildlife Species and Habitat Selection

Under the direction of SEW, the Wildlife Subcommittee was assigned the task of evaluating the observed and predicted effects of salinity changes on all wildlife species in Suisun Marsh. The wildlife species included are those not covered under Waterfowl and Aquatic Habitats subcommittee assignments. To initiate this assignment, the subcommittee first reviewed the Department of Fish and Game's Grizzly Island birding pamphlet. This list alone covered over 230 species of birds recorded in Suisun Marsh, in addition to all resident and migratory species of mammals, reptiles, amphibians, and invertebrates which may occur in Suisun Marsh.

Wildlife Species Selection

Early in the process, the subcommittee was confronted with the lack of scientific information identifying the effects of salinity on most of the Suisun Marsh wildlife, as well as limited available data with regard to populations or distribution of most wildlife in Suisun Marsh. Many wildlife species in the marsh are found throughout several habitat types, for which changes in salinity may influence habitats differently.

Initially, the subcommittee realized that attempting to evaluate all resident and migratory wildlife species which did not fall under the categories of fish or waterfowl would be an overwhelming task. Instead, the subcommittee compiled a list of key marsh species that represent the physical, biological, and habitat requirements of most wildlife species in Suisun Marsh. With this initial task completed, the subcommittee finalized a short list of representative species, conducted a literature search, and compiled species accounts. Life history characteristics and many other factors were considered while making the list of species, including abundance, distribution, protection status, recreational and economic values, habitat requirements, breeding requirements, salinity tolerance, and foraging needs.

The following example explains the selection process of the Northern Harrier, chosen as the representative species for hawks, owls, falcons, eagles, and kites from the initial list. This group contains 22 species known to occur in Suisun Marsh. Four species are listed as rare visitors and might not be observed every year. Ten birds of prey on the initial list are only occasional visitors to the marsh, and possibly are seen only during migration periods. Three raptors were listed as uncommon in Suisun Marsh wetlands. This elimination process left a list of five resident species to consider for in-depth review. The Northern Harrier was selected as a representative species for the birds of prey and owls of Suisun Marsh.

Although the species list is short, it is the professional opinion of the subcommittee that the species chosen and the habitat classification presented is representative of the Suisun Marsh ecosystem. This list and classification provided assistance when evaluating the current water quality objectives and the potential effects of salinity changes throughout the marsh.

The following list of wildlife species (Table 5-2) identifies those animals for which the subcommittee completed species accounts and used as a basis for salinity recommendations.

Table 5-2 Representative Marsh Species Used in the Development of the Wildlife Subcommittee's Salinity Recommendations.

Common Name	*Scientific Name*
Mammals:	
Salt Marsh Harvest Mouse	Reithrodontomys raviventris halicoetes
Suisun Ornate Shrew	Sorex ornatus sinuosus
River Otter	Lutra canadensis
Tule Elk	Cervus elaphus nannodes
Mink	Mustela vison
Muskrat	Ondatra zibethica
Birds (Other than Waterfowl):	
Pied-billed Grebe	Podilymbus podiceps
Great Egret	Casmerodius albus
Black-crowned Night Heron	Nycticorax nycticorax navevius
Northern Harrier	Circus cyaneus
Golden Eagle	Aquila chrysaetos
Ring-necked Pheasant	Phasianus colchicus
Black Rail	Laterallus jamaicensis
California Clapper Rail	Rallus longirostris obsoletus
American Goldfinch	Carduelis tritis
Lesser Goldfinch	Carduelis psaltria
Belted Kingfisher	Ceryle alcyon
Black Phoebe	Sayornis nigricans
Tree Swallow	Tachycineta bicolor
Suisun Song Sparrow	Melospiza melodia maxillaris
Red-winged Blackbird	Agelaius phoeniceus
Tricolored Blackbird	Agelaius tricolor
American Avocet	Recurvirostra americana *(large shorebirds)
Long / Short-billed Dowitcher	Limnodromus spp. (medium shorebirds)
Western Sandpiper	Calidris mauri (small shorebirds)
Reptiles and Amphibians:	
Northwestern Pond Turtle	Clemmys marmorata marmorata

Species Accounts

Each subcommittee member completed several accounts for the selected wildlife. The main objective of these species accounts was to compile specific information on Suisun Marsh, as well as review and incorporate any published literature regarding salt tolerance or the physiological effects of salinity for the chosen wildlife species. The following species account outline includes:

- status
- description
- life history
- habitat requirements
- physiology primarily associated with salinity
- species interaction within the three defined habitat types
- information associated directly to the Suisun Marsh
- information from outside the Suisun Marsh which could be useful in evaluations; and
- references

Habitat Selection

To address the entire geographic area of the marsh effectively, the subcommittee created a map which divided the marsh into eight subregions. Geographic areas associated with common land forms, channel water salinity, proximity to creek inflow, effects of Delta outflow, and the locations of salinity monitoring facilities were used to establish these boundaries. The subcommittee then addressed associated habitat types within these regions, and identified three habitat groups to associate species habitat use and distribution with potential changes in channel water salinity. The following list summarizes these habitat types:

1. Tidal mudflats/fringing marsh and adjacent water bodies
2. Undiked tidal marsh and adjacent water bodies; and
3. Managed wetlands and associated uplands

Narratives

The biggest challenge in this process has been the lack of scientific information regarding the species considered. With the exception of some listed or game species, there was little published information available for a large majority of Suisun Marsh wildlife species. Even simple information, such as Suisun Marsh population sizes, distributions, or habitat preferences was not available.

The subcommittee used its best professional judgement to develop a final short list of species from Table 12 that might be most affected by changes in salinity. The majority of marsh species, such as shorebirds, are widely distributed and can tolerate wide salinity ranges. The Suisun song sparrow, a generalist endemic to the marsh, also may be unaffected. Some species populations are more sensitive to salinity changes. The population and distribution of species commonly associated with freshwater habitats, including western pond turtle, mink, river otter and muskrat, may decline and recede to fresher environments, if available, during prolonged droughts. The population and distribution of species commonly associated with more saline marshes, including the California clapper rail and salt marsh harvest mouse, may decline and recede to more saline environments, if available, during wet cycles. These fluctuations in population numbers and distribution are natural in a dynamic tidal brackish marsh ecosystem. The subcommittee concluded that the western pond turtle is the species most likely affected by salinity variability and may serve as an indicator species for future monitoring.

Interactions with Other Subcommittees

SEW created five separate subcommittees, each with specific knowledge of Suisun Marsh habitats, to evaluate the habitats with which they were most familiar and best qualified. For example, the Brackish Marsh Vegetation Subcommittee primarily considered tidal wetlands and associated vegetation; the Waterfowl Subcommittee examined diked managed wetlands, habitat management, and waterfowl requirements; and the Aquatic Habitats Subcommittee investigated aquatic habitats and fisheries needs. Evaluating a single resource component of Suisun Marsh was not possible for the Wildlife Subcommittee; wildlife of Suisun Marsh use all of these identified habitats. SEW's subcommittee approach of resource-specific evaluations by subcommittees has enabled the Wildlife Subcommittee to consider wildlife interactions with each of the other three subcommittees' areas. The three draft habitat-specific recommendations of these three subcommittees assisted the Wildlife Subcommittee in formulating recommendations to protect and sustain the existing resources and beneficial uses of the Suisun Marsh ecosystem.

Draft Recommendations

Premises

1. Most wildlife species in Suisun Marsh transcend individual habitat types and utilize most or all of the wetland, upland, and aquatic resources available.

2. The current water quality standards affecting wildlife populations and habitats within Suisun Marsh are based on the May 1995 Bay-Delta Plan and required X2 flows (SWRCB 1995).

3. A natural salinity gradient occurs in Suisun Marsh. Generally, salinities are higher in the western marsh and lower in the eastern marsh. This natural salinity gradient is due to Delta outflow and Suisun Marsh's geographic position in the Bay-Delta estuary. These salinity gradients in Suisun Marsh vary spatially and temporally and are influenced by daily and yearly tidal cycles, seasonal and cyclic variation in local and basin wide precipitation, and Delta outflow. The degree of variation is muted in eastern and central regions of the marsh by operation of the gates.

4. The operations of reservoirs and dams, the long-term export and delivery of water from the Central Valley rivers and Delta, and the configuration of Delta and Suisun Marsh exterior levee systems directly impact natural hydrology of the marsh and influence the Suisun region salinity regime. The Wildlife Subcommittee does not advocate physical changes to these established operational activities and facilities.

5. Cyclic variation between wet periods and drought periods affects the distribution and abundance of vegetation communities and wildlife populations in tidal wetlands and to a lesser degree managed wet-

lands throughout the marsh. This variation contributes to the formation of habitat mosaics and marsh diversity.

6. Wildlife populations likely fluctuate in correlation with existing fluctuations in salinities and resultant habitat changes. Fluctuations are not anticipated to pose a long-term threat to the viability of wildlife populations, but are ecologically appropriate in a brackish marsh system.

General Channel Water Salinity Recommendations

1. Establish a flow-based salinity standard to reflect the basin-wide natural hydrograph of the marsh. These standards should reflect the spatial and temporal changes that would have occurred historically in the marsh as a result of Central Valley Basin hydrology and unimpaired flows, thus reflecting natural viability throughout the year. This would be similar to the current X2 flow requirements for delta outflows which only exist for February through July but would occur year-round.

2. Existing interior marsh salinity standards should not be implemented as compliance standards at stations S-35 and S-97, but should be maintained with other existing stations as salinity monitoring stations. This action will allow salinities to exceed existing standards for the western marsh, and will increase the existing salinity gradient in Suisun Marsh, especially during dry and drought periods.

3. Establish habitat and wildlife monitoring programs using salinity-sensitive species as biological indicators. Establish quantifiable criteria that will trigger the operation of the gates during prolonged drought periods. Operate the gates as needed during prolonged drought periods to prevent irreversible population declines of vulnerable wildlife species and loss of habitat diversity within the marsh.

4. Operate the gates in dry and critical water years and suspend gate operations after the date when most of the managed wetland habitats have been flooded for initial floodup in the fall. Investigate the potential for additional operation protocols that may minimize the effects to tidal habitats from freshening early in the fall. This action will minimize soil salinities in diked habitats and prevent the loss of managed wetland diversity, while allowing for variability above current standards.

5. Flood diked wetland areas managed for higher soil salinities and pickleweed habitat prior to the operation of the gates or after operations have ceased. This activity would assist in the effective management of harvest mouse habitat, even during periods of low salinity.

6. Improve infrastructure and water management on managed wetlands to protect habitat quality and diversity from increased channel water salinities caused by drought or changed salinity standards.

7. Develop new water management strategies and opportunities on managed wetlands to compensate for increased salinities, if salinity standards are increased or gates operation is limited.

8. Improve infrastructure and water management on managed wetlands to ensure long-term protection of wildlife habitat quality and diversity.

Areas of Subcommittee Agreement and Disagreement

Brackish Marsh Vegetation Subcommittee

Areas of Agreement:

1. Establish a flow-based criteria (similar to X2) to produce salinity variability in spring and fall.
2. Additional scientific studies to assist managed wetland managers in effective control and maintenance of soil salinities and acid production.
3. Increased monitoring and research of Suisun Marsh wildlife populations.
4. Interior marsh stations S-35 and S-97 should not come on-line as compliance stations, but should be used as monitoring stations.

Area of Disagreement:

1. Gates should not be operated in late winter and spring in all water years.

Aquatic Habitat Subcommittee

Areas of Agreement:

1. Establish a flow-based criteria (similar to X2) to produce salinity variability in spring and fall.
2. Additional scientific studies to assist managed wetland managers in effective control and maintenance of soil salinities and acid production.
3. Increased monitoring and research of Suisun Marsh wildlife populations.
4. No gate operation in wet water years.

Areas of Disagreement:

1. Maintain low salinities between February through June using gate operations if necessary.
2. No gate operations during October and November unless salinities reach 20 mS/cm.

Waterfowl Subcommittee

Areas of Agreement:

1. The use of management actions as described in the Suisun Marsh Preservation Agreement Amendment 3 to sustain and enhance managed wetlands habitats.
2. Additional scientific studies to assist managed wetland managers in effective control and maintenance of soil salinities and acid production.

3. Increased monitoring and research of Suisun Marsh wildlife populations.

Area of Disagreement:

1. Increases in channel water salinity variability above current standards is needed.

Research Needs

Changes in water quality requirements likely will affect population dynamics of Suisun Marsh wildlife. Information describing past and current wildlife populations is lacking; therefore, the effects of hydrologic changes in the marsh to date have not been documented. Developing adequate monitoring programs is essential to assuring that all beneficial uses of Suisun Marsh will be protected.

1. Monitor the distribution and relative abundance of wildlife species within Suisun Marsh through comprehensive marsh-wide surveys. Studies should encompass tidal and managed wetland habitats.

2. Conduct surveys of floral and associated faunal communities to understand the relationship between floral composition and wildlife species occurrence and abundance.

3. Investigate predicted effects of salinity variability on vegetation trends and wildlife distribution and abundance in tidal and managed wetlands through multi-year, wet and dry climate cycles and periodic extreme years.

4. Investigate floral and faunal responses to various water management strategies on managed wetlands of Suisun Marsh. Important factors include, but are not limited to, frequency, depth and duration of ponding, applied water salinities, and pond morphology and drainage patterns.

5. Investigate the relationship between salinity, water management, and primary productivity within all wetland types of Suisun Marsh (i.e., effects on invertebrates, plant productivity, and seed production).

6. Estimate physiological tolerances to salinity for Marsh wildlife most likely affected physiologically by extremes in marsh channel water salinities (i.e., western pond turtle, river otter, and mink).

7. Investigate the potential for developing and using a western pond turtle population model to represent population responses of other marsh species sensitive to changes in channel water salinities through wet and dry climate cycles and extreme years.

8. If Number 7 above is feasible, investigate the potential for developing an ongoing western pond turtle monitoring program for the purpose of establishing criteria for operation of the gates based upon turtle population numbers and/or distribution. This population trigger would initiate gate operations to prevent the catastrophic decline of marsh species susceptible to prolonged extreme drought cycles.

9. Study habitat use, home ranges, and movements of small mammals in tidal and managed wetlands in Suisun Marsh to understand how their populations are affected by habitat size, shape, changes in habitat composition through time, and proximity to other habitats.

10. Investigate the relative importance of salinity and other habitat elements affecting the abundance and distribution of wildlife utilizing tidal and managed wetlands.

Reference

[SWRCB] State Water Resources Control Board. 1995. Water quality control plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Order WR 95-1. California Environmental Protection Agency.

Chapter 6: Hydrology and Water Quality Subcommittee

Background

The Suisun Ecological Workgroup (SEW) was convened by the Department of Water Resources (DWR) as requested by SWRCB in the 1995 Water Quality Control Plan (WQCP) for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. The goal of the ad hoc multiagency/organization work group is to review the scientific basis for the current salinity standards in Suisun Marsh and make recommendations for comprehensive brackish marsh standards.

Four technical subcommittees—Brackish Marsh Vegetation, Wildlife, Waterfowl, and Aquatic Habitat—were established by SEW to focus on specific areas.

A fifth subcommittee, Hydrology and Water Quality, was also established to provide technical support to the four subcommittees. Flow, tide stage and water quality within Suisun Marsh are a complex function of time-varying Delta outflow, marsh creek flow, and water project facilities operation, including operation of the Suisun Marsh Salinity Control Gates (SMSCG). It was recognized early in the SEW process that these baseline relationships were a key factor influencing vegetation, aquatic, and wildlife ecology.

DWR's Suisun Marsh Planning Section (SMP) conducts planning analysis of proposed operational and facilities modifications for salinity control in Suisun Marsh. Many of these studies on marsh salinity response to facilities or hydrology changes are relevant to SEW. SMP staff participated in the Hydrology and Water Quality Subcommittee.

The Hydrology and Water Quality Subcommittee supported the SEW process by (1) presenting informational reports at SEW meetings and (2) completing directed analyses.

Summary of Informational Reports

Presentations to SEW

The subcommittee made formal presentations at SEW general meetings on the following topics. Finalized reports on these topics follow the summaries.

1. SWRCB Water Quality Control Plan Modeling

   SWRCB requested DWR's SMP support for analysis of the salinity impacts of the 1995 Water Quality Control Plan (DWR, 1997). SMP used computer modeling and data analysis to determine the impacts on marsh salinity of six alternatives including the proposed Suisun Marsh Preservation Agreement Amendment III. Modeling was conducted based on 73-year monthly average hydrology input. Output includes estimates of the frequency that Suisun Marsh standards would be exceeded under each alternative. The exceedence frequency was also estimated with and without operation of the gates. Two formal presentations were made to SEW covering all aspects of the study.

2. Modeling Historical Suisun Marsh Salinity

Discussion within SEW generated interest in modeling pre-levee salinity to better understand the seasonal range and variability of salinity in Suisun Marsh. Chris Enright of DWR prepared a commentary (quoted below) arguing that use of monthly average unimpaired Delta inflow to simulate the pre-levee Suisun Marsh salinity regime would not provide useful results. The combination of flows with mismatching time-scale, magnitude, and temporal characteristics would cause more confusion than elucidation. It was also argued that:

- The present diked and subsided geometry of the marsh would respond to any hydrology differently than the pre-levee marsh geometry.
- Creek inflows are important determinants of marsh salinity for which there is little information about pre-levee patterns.
- The monthly average time scale of the proposed input hydrology damps out salinity variability on ecologically important time-scales of up to several months.

Commentary On Modeling the Pre-Levee Suisun Marsh Salinity Regime

Chris Enright, Suisun Marsh Planning, DWR
September 16, 1998

Summary

"Recent discussion within the Suisun Ecological Workgroup has generated interest in modeling pre-levee salinity to better understand the seasonal range and variability of salinity in the Suisun Marsh. In the analysis set forth in this paper, I argue that using the available monthly average unimpaired Delta inflow to simulate the pre-levee Suisun Marsh salinity regime would not provide useful results. The combination of flows with mismatching time-scale, magnitude, and temporal characteristics would cause more confusion than elucidation. Further, I argue that: 1) the present diked and subsided geometry of the Marsh would respond to any hydrology differently than the pre-levee Marsh geometry, 2) creek inflows are important determinants of Marsh salinity for which there is little information about pre-levee patterns, and 3) the monthly average time-scale of the proposed input hydrologies damp out salinity variability on ecologically important time-scales of up to several months.

Background

"At the May 21, 1998 meeting of the Suisun Ecological Workgroup there was a discussion about the utility of modeling salinity trends in the Suisun Marsh based on "unimpaired" and "natural" flow hydrology. This paper considers the differences between unimpaired and natural flows and the interpretive pitfalls of inferring natural flow salinity characteristics from unimpaired flow estimates. This analysis deserves a thorough review of the available literature on the pre-levee (I will use the phrase "pre-levee" to indicate pre-European arrival landscape conditions) Bay-Delta landscape and climate variability since the last ice age. I have not done this review. The following analysis relies on my own judgement and two reports which discuss the difference between unimpaired and natural Delta outflow. I will summarize the relevant findings of the reports, and suggest some additional factors to consider and sources of uncertainty.

"Following from recent discussion within the SEW, the issue of seasonal mean and variability of salinity has become central. In brief, the argument is that the assemblage of Marsh plants and animals evolved in the pre-levee Marsh under salinity conditions characterized by different seasonal means and annual variability than exist today. Some have argued that water quality standards and facilities operation which provide seasonal mean and annual salinity variability that mimics the historical pattern would be beneficial to Suisun Marsh ecosystem health. This notion has generated interest in modeling the salinity regime of the pre-levee Marsh.

"An estimate of the pre-levee natural flow hydrology is not presently available because of the difficulty in estimating it. Some have suggested that unimpaired Delta outflow estimates made by DWR would provide a reasonable comparative hydrology. The question is, if we simulate long-term Marsh salinity using unimpaired outflow as a surrogate for natural flow, with the existing physical Delta/Marsh configuration, will we learn anything useful?

Unimpaired versus Natural Flow

"Nick Wilcox (SWRCB) presented a summary of monthly average and water-year type average delta outflow based on 1) D1485 hydrology, 2) the 1995 Water Quality Control Plan (WQCP) hydrology, and 3) "unimpaired" hydrology (from DWR, 1994). For reference, I have prepared plots of the data to water year scale (Figure 6-1) and to a common scale (Figure 6-2). As Nick explained, natural and unimpaired flow begin with the same potential natural hydrologic basin runoff. However, the pre-levee natural flow encountered geographical and vegetative landscape features different from today:

- There was higher water retention in virgin mountain and foothill forests before logging and development.
- There was higher groundwater accretion in the Central Valley floor where the permeable area was larger, less compacted, and less subsided.
- There was higher consumptive water use by expansive riparian vegetation.
- Lower natural levees allowed large over-bank storage and retention in the Central Valley during high flow periods and evaporative losses later.
- Many foothill catchments drained to Valley flood basins. There was no connection to the Sacramento River (or tributaries) as there is today.

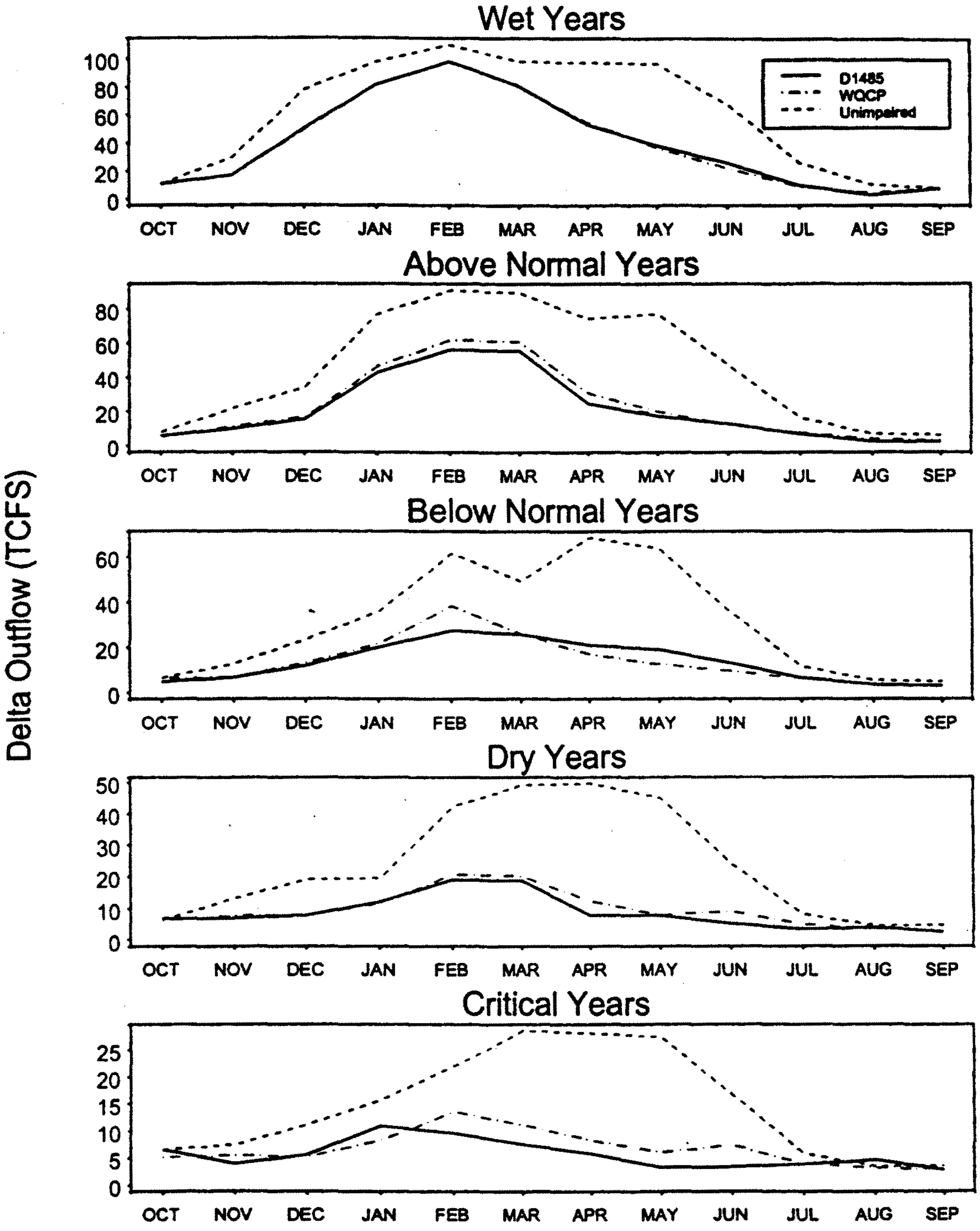
"In contrast, the estimated "unimpaired" flow assumes that mountain watersheds and river channels function in their present configuration with modifications for reclamation, flood control, and navigation.

California Central Valley Unimpaired Flow Data (DWR 1994)

"This report outlines the procedure DWR uses to determine unimpaired Delta outflow. It explains the methods and assumptions used for estimating the unimpaired flow for 24 sub-basins in the Central Valley. The unimpaired flow to the Delta is the sum of the unimpaired flow estimates of the 24 sub-basins. The Delta region is one of the 24 sub-basins.

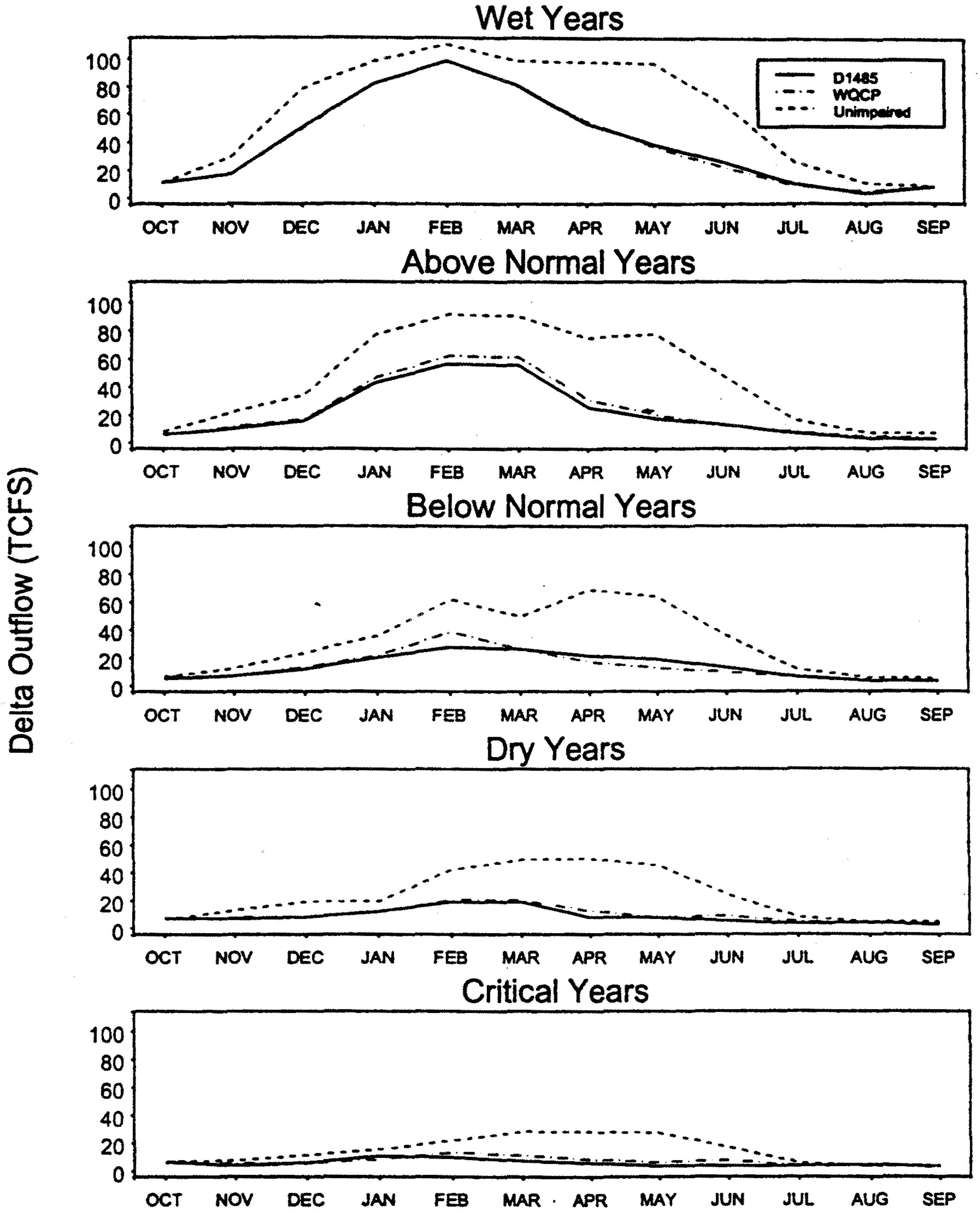
"Aside from a written description of the difference between unimpaired and natural flow, the DWR report does not estimate the seasonal magnitude and timing of the differences. However, the report includes an estimate of "Delta Natural Net Use" and "Delta Unimpaired Net Use" for the period 1922-1992.

Figure 6-1
Delta Outflow: D1485, WQCP, and "Unimparied" 1/



1/ - D1485 outflow from DWRSIM study 1995C6F-SWRCB-467
- WQCP outflow from DWRSIM study 1995C6F-SWRCB-469
- Unimpaired outflow from DWR report, "California Central Valley Unimpaired Flow Data"
(October 1920 through September 1992, Third Edition, August 1994

Figure 6-2
Delta Outflow: D1485, WQCP, and "Unimparied" 1/



1/ - D1485 outflow from DWRSIM study 1995C6F-SWRCB-467
- WQCP outflow from DWRSIM study 1995C6F-SWRCB-469
- Unimpaired outflow from DWR report, "California Central Valley Unimpaired Flow Data"
(October 1920 through September 1992, Third Edition, August 1994

- The estimate of Delta Natural Net Use assumes that all lowland irrigated agriculture and urban areas are replaced with riparian vegetation. Delta net use is estimated as the sum of consumptive use of lowland riparian vegetation, upland native vegetation, evaporation from surface waters, and (minus) lowland precipitation.
- The estimate of Delta Unimpaired Net Use assumes that existing Delta levees and islands are intact. Lowland net use includes water surface evaporation, consumptive use of riparian vegetation, channel seepage, and precipitation. Upland net use includes consumptive use of native vegetation, consumptive use of riparian vegetation, surface water evaporation, and precipitation. In the uplands, all historical irrigated agriculture and urban areas were replaced with native vegetation.

"Figure 6-3 shows the monthly average Delta net consumptive use under natural and unimpaired conditions for the 1921-1992 period according to DWR 1994. Figure 6-4 shows the monthly average total unimpaired inflow to the Delta. To the extent that Delta consumptive use is representative of Central Valley consumptive use, the results are instructive. Some observations based on Figures 6-3 and 6-4 are:

- Overall natural consumptive use is ~15% higher than unimpaired consumptive use in the 1921-1992 period. (During drought periods, natural consumptive use is 20-25% higher than unimpaired consumptive use according to the report).
- The seasonal magnitude of consumptive use is more variable under natural flow conditions.
- The seasonal pattern of unimpaired inflow is synchronized with the fall-winter pattern of Delta consumptive use, but not with the spring-summer pattern.

"The magnitude of in-Delta consumptive use is only about 5% of the magnitude of unimpaired inflow to the Delta. However, if consumptive use in the pre-levee Delta is representative of the larger pre-levee Central Valley landscape, then the unimpaired Delta inflow pattern shown in Figure 6-4 should be conditioned by the consumptive use pattern shown in Figure 6-3, and landscape characteristics of the pre-levee Valley. Quantitative analysis of these characteristics are not offered here. However, a qualitative assessment of the difference between unimpaired outflow and natural outflow might posit the following characteristics:

1. Natural outflow would have a lower peak magnitude than unimpaired outflow because:

- Over-bank storage of flood flows would diminish flood peaks.
- Greater soil permeability of pre-levee foothill and Valley soil would cause greater groundwater accretion.
- The temporal pattern and magnitude of pre-levee consumptive use would moderate peak flows in the spring.

2. The annual volume of natural outflow would be less than unimpaired outflow because:

- There was higher consumptive use by riparian and native vegetation under natural conditions.
- There was higher surface water evaporation from over-bank storage and retention in the Central Valley during high flow periods.
- The Central Valley floor allowed higher groundwater accretion under naturalconditions.

3. The temporal distribution of natural outflow would be shifted toward the summer and fall because:

Figure 6-3

Monthly Average Delta Net Use (1921 - 1992) 1/

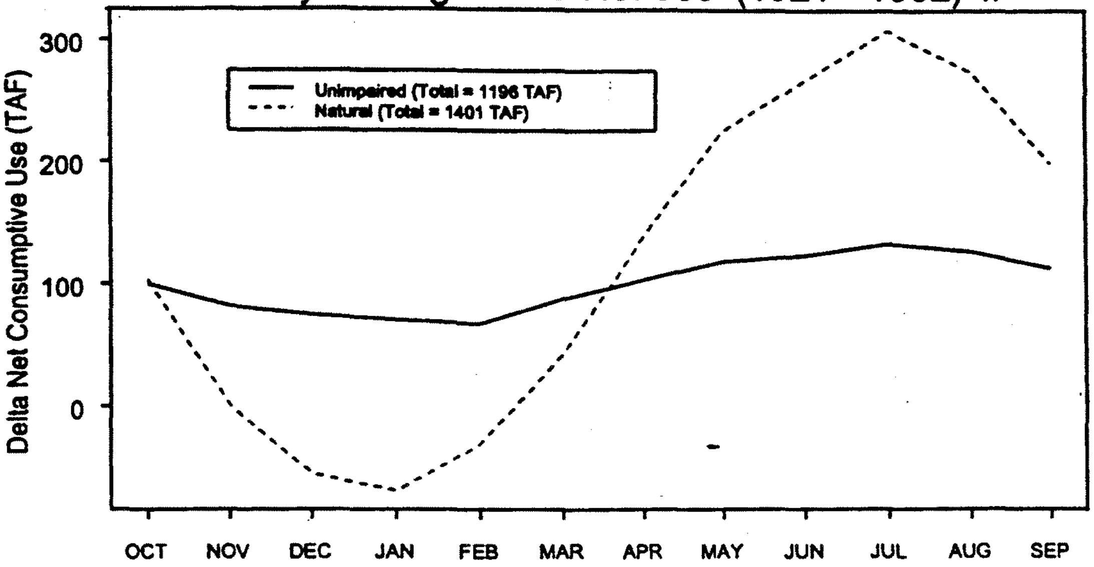
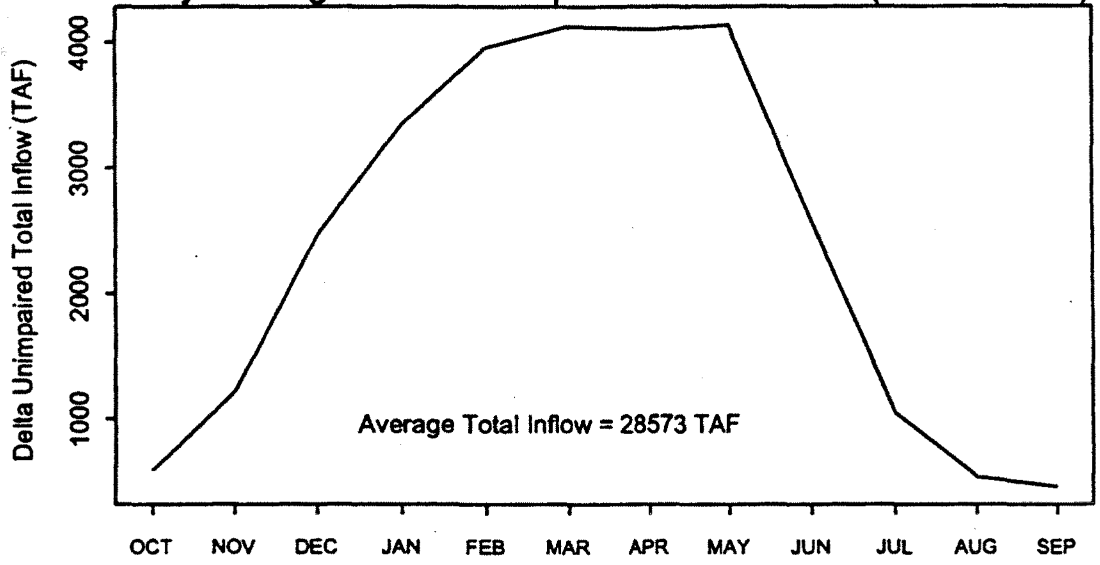


Figure 6-4

Monthly Average Delta Unimparied Total Inflow (1921 - 1992) 1/



Average Total Inflow = 28573 TAF

1/ - From DWR 1994, "California Central Valley Unimpaired Flow Data"
(October 1920 through September 1992, Third Edition, August 1994

- There would be higher foothill water retention and delayed drainage.
- Storage and retention in the Central Valley during high flow periods would drain slowly through the spring and summer.

"Significant differences in the timing and magnitude of natural and unimpaired flows argue for great caution if we wish to model natural Suisun Marsh salinity conditions with unimpaired flow.

Summary of Rebuttal Testimony—Natural and Unimpaired Flow (Fox 1987)

"The author's stated purpose for the testimony to the SWRCB was to estimate the difference between natural and unimpaired flows. Fox defines natural and unimpaired flows similar to the way they were defined above. However, based on an extensive literature search, Fox further assumes that the Central Valley comprised about 1 million acres of tule marsh with 6 million acre feet of storage in natural flood basins. Fox modified the DWR unimpaired Delta outflow (1921-1983) to account for vegetative and geographical differences. A copy of the calculation notes and plot provided in the testimony is shown in Table 6-1 and Figure 6-5. The main conclusions of the testimony are:

1. Average annual natural Delta outflow ranged between 16 and 23 MAF.
2. Average annual unimpaired Delta outflow ranges between 21 and 35 MAF.
3. The difference between natural and unimpaired flows is due to consumptive use by tule marshes in the Valley, and evaporation from natural flood basins.
4. The seasonal distribution of natural Delta outflow is less variable than the unimpaired seasonal distribution due to flood basin storage of natural flows in the winter (Figure 10).

"My impression is that reviews of Fox's analysis have questioned the methods and assumptions used, but that the gist of the foregoing conclusions are more or less accepted. Moreover, Fox's conclusions are consistent with those derived from analysis of the DWR 1994 report.

Other Factors to Consider

"**Pre-levee Bay-Marsh-Delta Bathymetry and Geometry**. Mixing of salt into the Bay/Delta estuary results from a dynamic balance between tidally driven hydrodynamic dispersion (mixes salt upstream), and fresh water outflow (dilutes and advects salt downstream). The extent of tidal mixing is largely a function of the bathymetry of the system. The pre-levee system did not include reclamation of shallow areas for development, maintenance dredging of ports, the deep water ship channel, and extensive channel cutting in the Delta. These features can significantly alter system salinity. In general, increased system volume, especially via channel deepening, will increase the tidal prism and mix salt more readily upstream. Even if perfect natural inflow data was available, the present diked and subsided geometry of the Marsh may effect a very different salinity response to the hydrology compared to the pre-levee Marsh. Pre-levee Marsh lowlands sustained periodic tidal and outflow induced ponding resulting in an expanded tidal prism, ready exchange between ponds and channel, and associated salinity mixing effects. Modern Marsh levees discontinued most of these phenomena. In its place, a regular annual cycle of flooding and draining was imposed. Therefore, meaningful analysis of the pre-levee salinity regime would require an extensive bathymetry revision in the model.

from Fox, 1987

Table 6-1

Table 1. Calculation of Reductions in Unimpaired Outflow under Natural Conditions.

HYDROLOGIC UNIT	NATURAL LAND AREAS (acres)		REDUCTION IN ANNUAL AVERAGE DELTA OUTFLOW (MAF/yr)		TOTAL REDUCTION (MAF/yr)
	Tule Marsh (1)	Flood Basin and Other Riparian (2)	Tule Marsh (3)	Flood Basin and Other Riparian (4)	
Sacramento (DWR Unit 1)	656,000	600,000	3.9 - 5.9	0.9 - 3.0	4.7 - 8.9
Delta	304,000	284,000	0.3 - 1.2	-	0.3 - 1.2
San Joaquin (DWR Unit 17)	58,000	287,000	0.3 - 0.5	0.4 - 1.4	0.7 - 1.9
Tulare (DWR Unit 23)	853,000	83,000	-	-	-
TOTALS	1,871,000	1,254,000	4.5 - 7.6	1.3 - 4.4	5.7 - 12.0

(1) Area of tule marsh was estimated by planimetering from Kuchler's Natural Vegetation Map (4). Channel surface areas and natural levee areas were subtracted from planimetered areas. The resulting areas were compared with estimates used prior to about 1910 in implementing the Swamp and Overflowed Lands Act (5-9. In the Sacramento Basin, Kuchler's map reports as tule marsh what was actually natural levee land, which supported riparian forest and reports as prairie land what was actually tule marsh. Thus, tule marsh was estimated from the natural flood basin area by subtracting the area of natural levees and channels. This is consistent with early hydrologic descriptions of the basin (12,20).

(2) This is the natural flood basin area less tule marsh and channel surface area. Flood basin area was estimated by planimetering from Plate VII, Ref. 13 and Plate LXXIII, Ref. 14. Part of this area was flooded every winter-spring and remained flooded into the summer. The balance supported riparian forest habitat (e.g., willows, oaks) year round. These two land uses are grouped because they have about the same consumptive use.

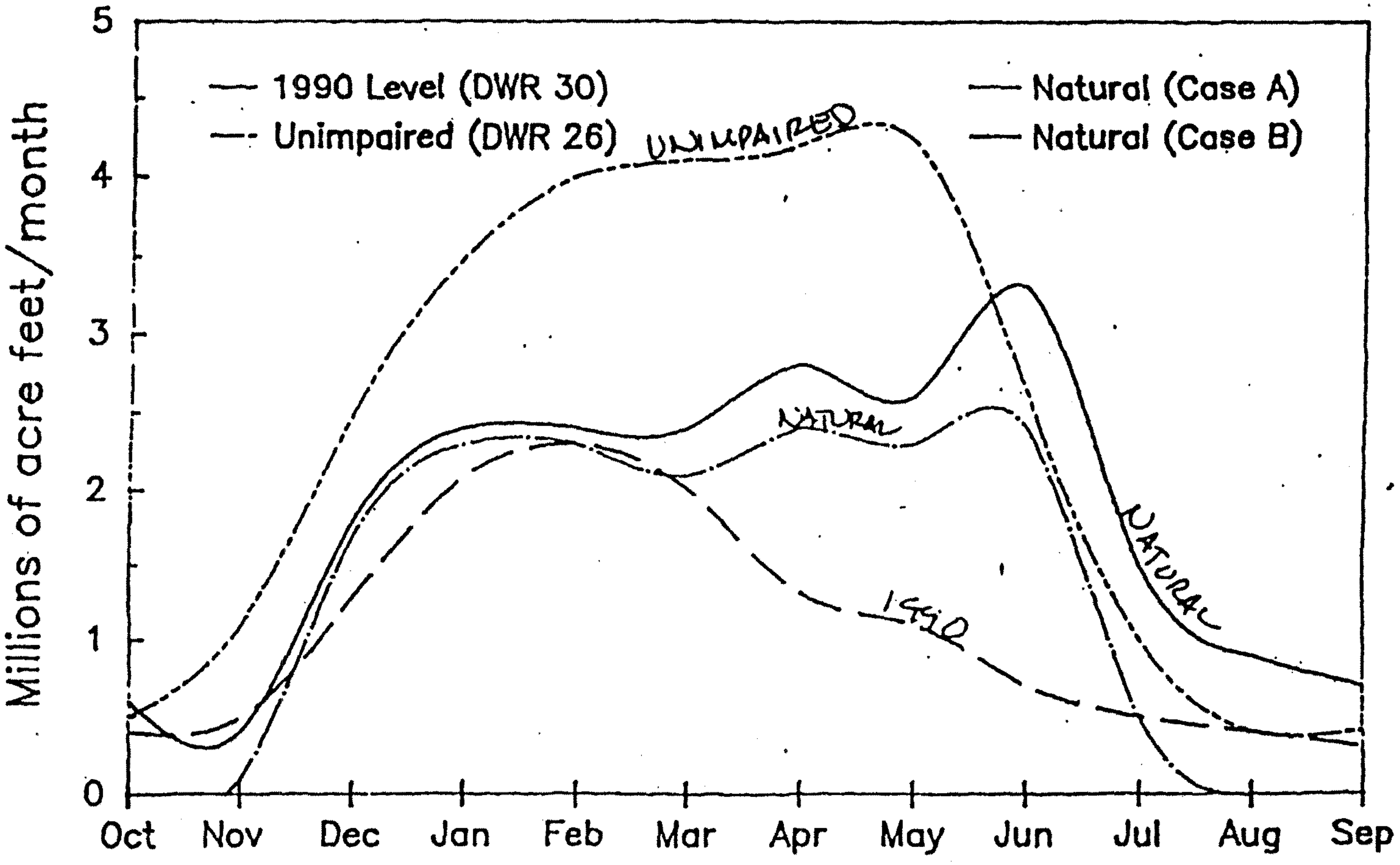
(3) This represents the amount of water consumptively used by tule marshes and is calculated by multiplying the tule marsh area in column #1 by tule water use. The water used by tule marshes is estimated to range from 6 to 9 acre-feet/acre per year (feet of water per year). The higher value (9 feet/yr) is for marshes that have an ample supply of water year round (i.e., are frequently flooded), such as occurred in the Delta and lower Sacramento River (10). This higher value (9 feet/yr) was actually measured in the Delta during 1929-33 (15,16). The lower value (6 feet) is for marshes in which there is little standing water most of the year, such as marshes in Southern California (17-19). The Delta water use value used in these calculacins was 4 feet/yr. This was estimated as the difference between the tule marsh water use (6 to 9 feet/yr) used here and the riparian vegetation evapotranspiration (5.1 feet/yr) used in unimpaired flow calculations.

(4) This value is the amount of water that is consumptively used by riparian vegetation growing along channel banks plus the amount evaporated from natural flood basins. The average water use for both of these items is about 5 feet/yr (16-18). This value was calculated by multiplying the land area in column #2 by 5 feet. The lower value of the reported range corresponds to 25 percent of 5 feet, which is equivalent to evaporation during only three months of the year, while the upper value corresponds to year round water use. No value is reported for the Delta because flood basin and other riparian water use was included in Delta net use in unimpaired flow calculations.

from Fox, 1987

Figure 6-5

Average Monthly Delta Outflow



"**Creek Flows**. Modification of water project operations to meet salinity standards affects the east-west salinity gradient of the Marsh. However, the salinity regime is also influenced by creek inflows. These flows, while comparatively small, exert direct salinity impacts and define a nominal north-south salinity gradient in the Marsh. Indeed, for much of the year, upland marsh salinity may be determined more by creek inflows. Little if any information exists on timing and magnitude of changes to pre-levee creek inflows. Thus, the efficacy of Suisun Marsh salinity analysis under natural/unimpaired Delta outflows would be reduced.

"**Instantaneous Versus Monthly Average Flows**. Salinity variability over various time-scales is a key ecological issue. It is at least limiting, if not spurious, to use models to characterize salinity variability when only monthly average inflows are used as boundary conditions. For example, a monthly average inflow of 25,000 cfs could be obtained by maintaining the instantaneous inflow at 25,000 cfs for one month, or by beginning the month with a week of low inflow, followed by a week of extremely high inflow, followed by two weeks of rapidly waning inflows. The unimpaired flow pattern would be especially susceptible to this sort of hydrograph. Despite the same monthly average flow, salinity variation between the two scenarios would be very different. Using monthly average inflows, rather than, say, the daily inflow average, will affect salinity variability within time-scales of one day to several months.

Conclusion

Based on all of the foregoing considerations, I believe that using the available monthly average unimpaired Delta inflow to model the pre-levee salinity Suisun Marsh salinity regime would be misleading. The combination of flows with mismatched time-scale, magnitude, and temporal characteristics would create more confusion than understanding. Moreover, the present diked and subsided geometry of the Marsh would respond to any hydrology differently than the pre-levee geometry."

Summary of Directed Analyses

The Hydrology and Water Quality Subcommittee conducted directed analyses based on informational needs of SEW. The following two reports were presented to SEW.

1. *Salinity Impacts of the Suisun Marsh Salinity Control Gates under D-1485 and 1995 Water Quality Control Plan Salinity Standards*

   The seasonal magnitude and variability of Suisun Marsh salinity emerged as a key issue in the SEW process. To characterize the spatial and temporal salinity regime, SEW requested that the Hydrology and Water Quality Subcommittee analyze modeling data from 73-year analysis done for SWRCB to identify the seasonal range and magnitude of salinity in various locations of the marsh. Specifically, SEW requested information on the impact of the 1995 WQCP compared to D-1485 standards, and the impact of the gates.

   The subcommittee prepared graphical/statistical analysis including "area-frequency" plots of the 73-year tendency for salinity to be greater than specified values, and "box-and-whisker" plots showing variance and central tendency on a monthly basis.

2. *Investigation of the Relationship Between X2 and Fish Abundance in the Suisun Marsh* (This report is not included below because discrepancies were discovered in the data, which rendered the study results questionable.)

The location of 2 ppt salinity (X2) has been identified as a useful index that integrates hydrodynamics, salinity, and multi-trophic level abundance in Suisun Bay. This study used a similar approach to investigate correlation between fish abundance and X2 on an east-west transect in the marsh. The Hydrology and Water Quality Subcommittee collaborated with the Aquatic Habitat Subcommittee in the analysis. The team determined the monthly average location of X2 along Montezuma Slough and correlated it with the monthly, 19-year U.C. Davis fish sampling database. As noted above, this report is not included because of discrepancies in the data.

Salinity Impacts of the Suisun Marsh Salinity Control Gates

Throughout the SEW process, questions arose regarding the affect of the Suisun Marsh Salinity Control Gates on channel water salinity in Suisun Marsh. To provide SEW a basic understanding of the impact of the gates, the Hydrodynamics Subcommittee presented salinity results from two 73-year (1922-1994) Delta Simulation Model 1 (DSM1) runs in both tabular and graphical format. The two runs used are Alternatives 1 and 3 from a study performed by the Suisun Marsh Branch for SWRCB. The study compares six alternatives for implementing the WQCP, and is entitled *Suisun Marsh 73-Year Model Study in Support of SWRCB Draft EIR for Implementing the Water Quality Control Plan of the San Francisco/Sacramento Delta Estuary (DWR, 1997).*

Salinity output from Alternatives 1 and 3 of the DSM1 73-year runs were used to generate a series of plots for compliance and monitoring stations in the marsh. Alternative 1 was run under the WQCP hydrology, and Alternative 3 was run under the D-1485 hydrology. The purpose of these plots was to provide a comparison of salinities with and without gate operation, as well as to compare salinities under the two hydrologies. Inferences based on the plots should be drawn with care considering they are based solely on modeling results. The accuracy of the model is characterized in Appendix B of DWR 1997. Two types of plots were provided:

- Exceedence Frequency - line plots (2 sets)
- Salinity Range - box and whisker plots (3 sets)

Exceedence Frequency Plots

There are two sets of exceedence frequency plots, one for the D-1485 hydrology (Appendix 1A) and one for the WQCP hydrology (Appendix 1B). These plots expressly compare salinity differences with and without gate operation. Exceedence frequencies (percent of time that monthly average salinity exceeds a given concentration) with and without gate operation are shown on a month-by-month basis for October through May over the 73-year period modeled. For any given month, monthly average salinity parameters for the 73 months available were ranked from low to high and plotted. For example, plots for October include ranked salinities from all 73 Octobers in the study. Four salinity parameters are shown on the line plots.

- Average Maximum Salinity - monthly average of daily maximum salinity;
- Mean High Tide Salinity - monthly average of high-high and high-low salinities;
- Average Daily Mean Salinity - monthly average of daily mean salinity; and
- Average Minimum Salinity - monthly average of daily minimum salinity.

Plots for nine locations are presented and correspond to nine of the marsh monitoring stations. The locations are shown on Figure 6-6. All stations except Hill Slough (S04) and Hunter Cut (S54) are compliance stations, and have an associated monthly salinity standard. The monthly standards are indicated on the plots by a horizontal dashed line.

Salinity Range Plots

There are three sets of salinity range comparison plots shown in box and whisker format. The titles are listed below and the plots are presented in Appendices 2A, 2B and 2C, respectively. All comparisons are made on a monthly basis.

- 2A. Monthly mean of daily high tide salinity, WQCP hydrology, with gate operation versus monthly mean of daily high tide salinity, WQCP hydrology without gate operation;
- 2B. Monthly mean of daily high tide salinity, WQCP hydrology, with gate operation versus monthly mean of daily high tide salinity, D-1485 hydrology, with gate operation; and
- 2C. Monthly mean of daily high tide salinity, WQCP hydrology, with gate operation versus average of daily mean salinity, WCP hydrology, without gate operation.

All mean high tide salinity data for these plots are end-of-month means as calculated by DSM1. End-of-month means represent a progressive running average of the daily high tide salinity over an entire month. The last value of the month is the parameter used in this analysis.

These plots show data on a month-by-month basis. For any given month, the 73 months available (corresponding to the 73 year model runs) are divided among three water year categories based on their water year classification as determined by DWR's Division of Flood Management. The "wet years" category includes wet and above normal years, "average years" are below normal years, and "dry years" include dry and critical years. For example, October may have 12 months in the wet category, 42 in the average category, and 16 in the dry category. The total months included is 73. Of note here is that October and November are lagged 1 water year since they reflect hydrologic conditions from the previous water year more than the present one.

The boxes on these plots represent the middle half of the data, the line inside the box is the median value, and the "whiskers" show the extreme points. There are two boxes shown for each monthly plot, one box for each parameter compared.

The numbers in parenthesis below the boxes indicate (as a percentage) the number of months out of 73 that the gates were operated to meet standards.

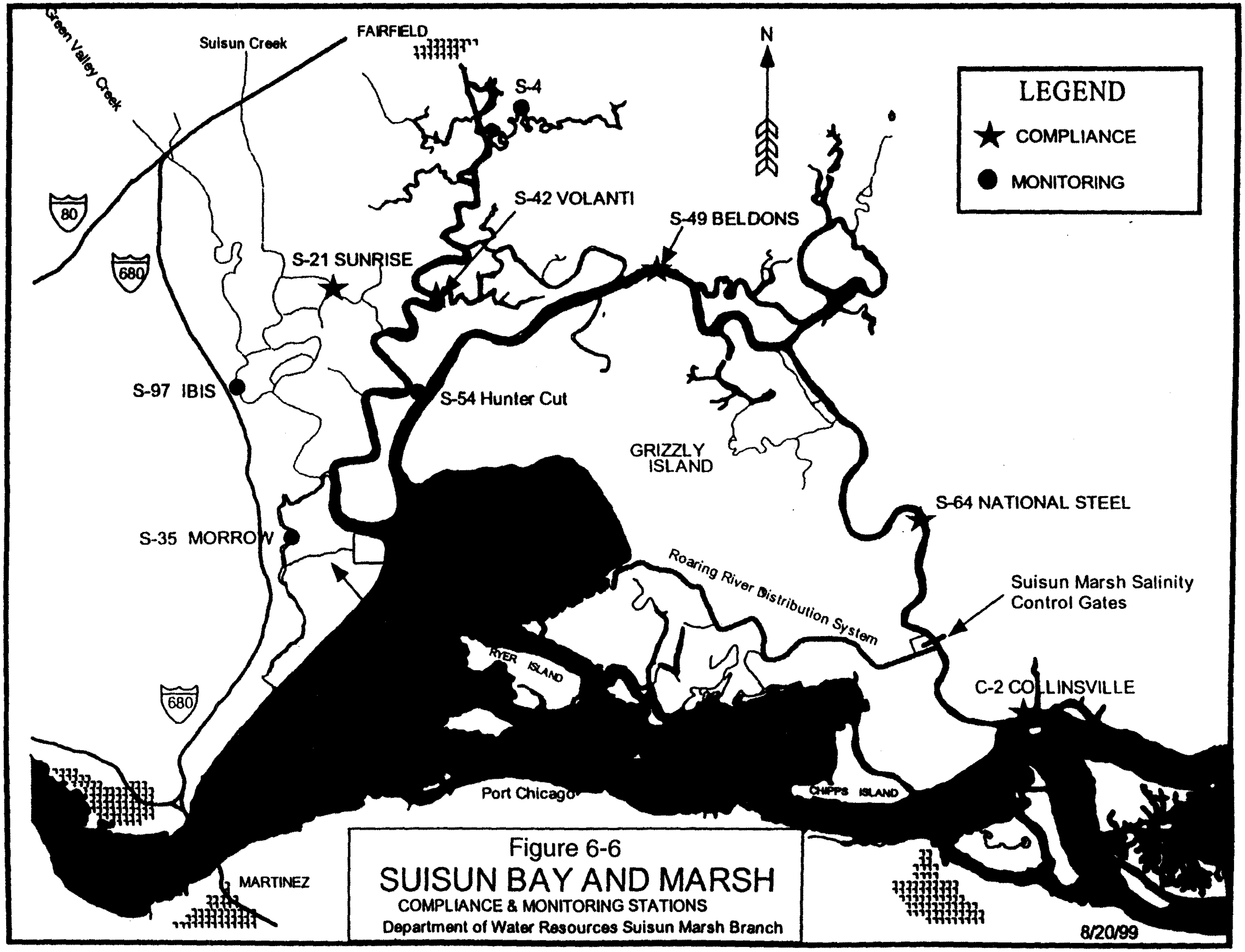


Figure 6-6
SUISUN BAY AND MARSH
COMPLIANCE & MONITORING STATIONS
Department of Water Resources Suisun Marsh Branch

References

[DWR] California Department of Water Resources. 1997. Suisun Marsh 73-Year Model Study in Support of the SWRCB EIR for Implementing the Water Quality Control Plan of the San Francisco-Sacramento-San Joaquin Delta Estuary. Sacramento (CA): California Department of Water Resources, Environmental Services Office, Suisun Marsh Branch.

Fox Phyllis. 1994. Summary Rebuttal Testimony- Natural and Unimpaired Flows. Testimony to California State Water Resources Control Board in 1987.

[DWR] California Department of Water Resources. 1994. California Central Valley Unimpaired Flow Data (October 1920 through September 1992). 3rd ed.

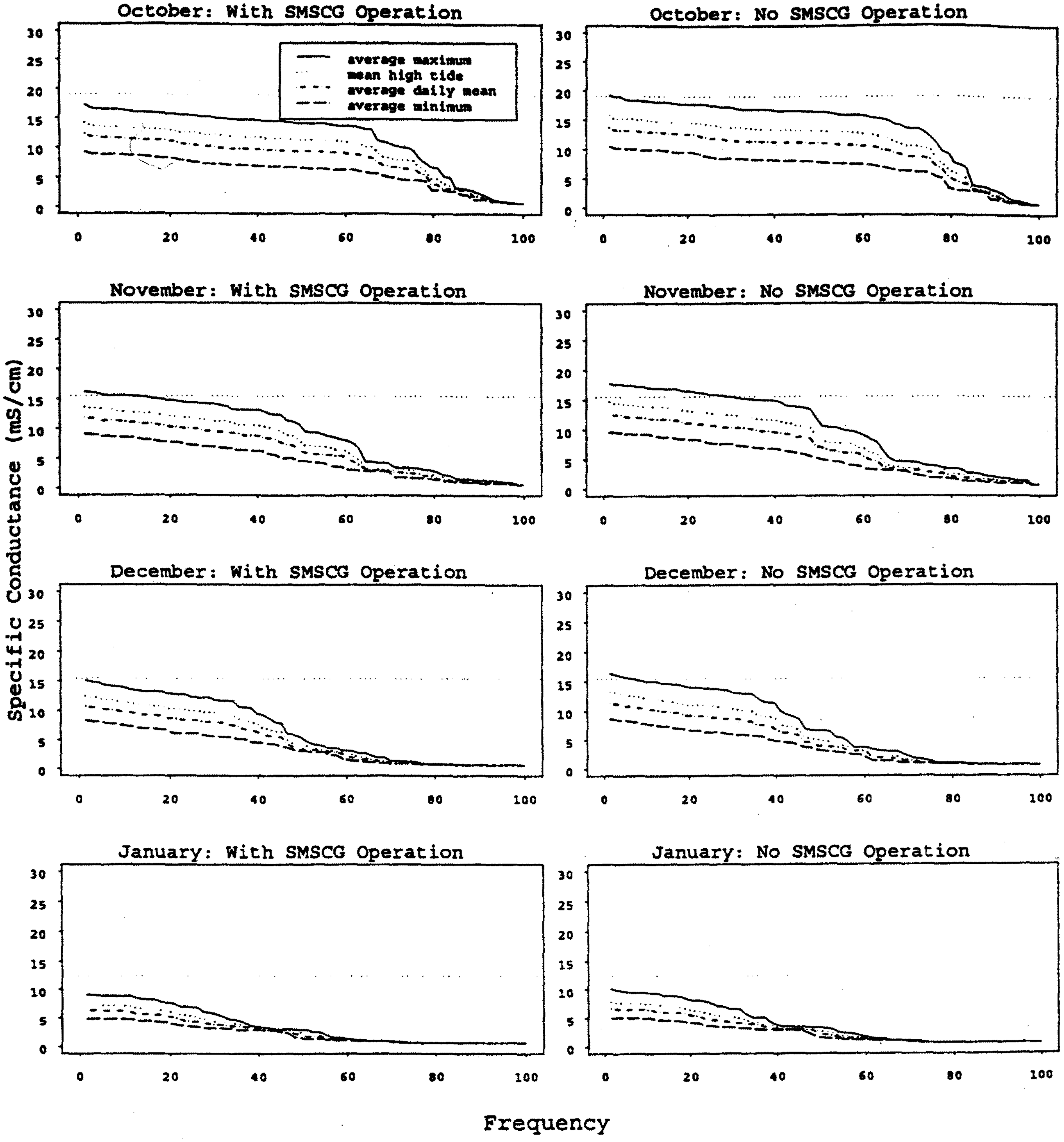
[DWR] California Department of Water Resources. 1997. Suisun Marsh 73-year Model Study in Support of SWRCB Draft EIR for Implementing the Water Quality Control Plan of the San Francisco-Sacramento Delta Estuary. Sacramento (CA): Department of Water Resources, Environmental Services Office, Suisun Marsh Branch.

Appendix 1A

Exceedance Frequency Plots
D1485 Hydrology

Collinsville (C2)
National Steel (S64)
Beldon's Landing (S49)
Hill Slough (S04)
Volanti (S42)
Sunrise (S21)
Hunter Cut (S54)
Ibis (S97)
Goodyear Slough (S35)

Station C2 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/



October: With SMSCG Operation

October: No SMSCG Operation

November: With SMSCG Operation

November: No SMSCG Operation

December: With SMSCG Operation

December: No SMSCG Operation

January: With SMSCG Operation

January: No SMSCG Operation

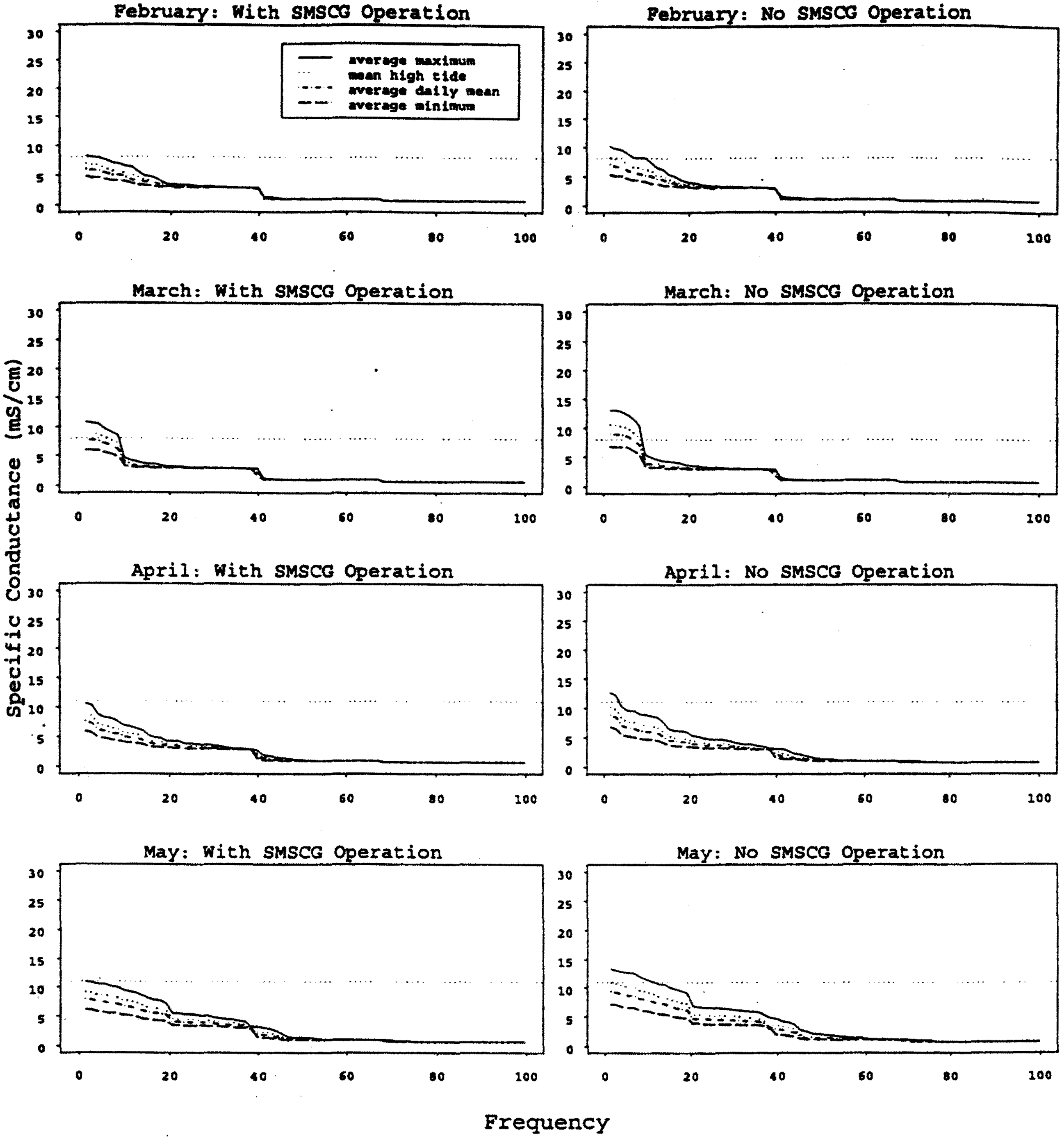
1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

Station C2 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/



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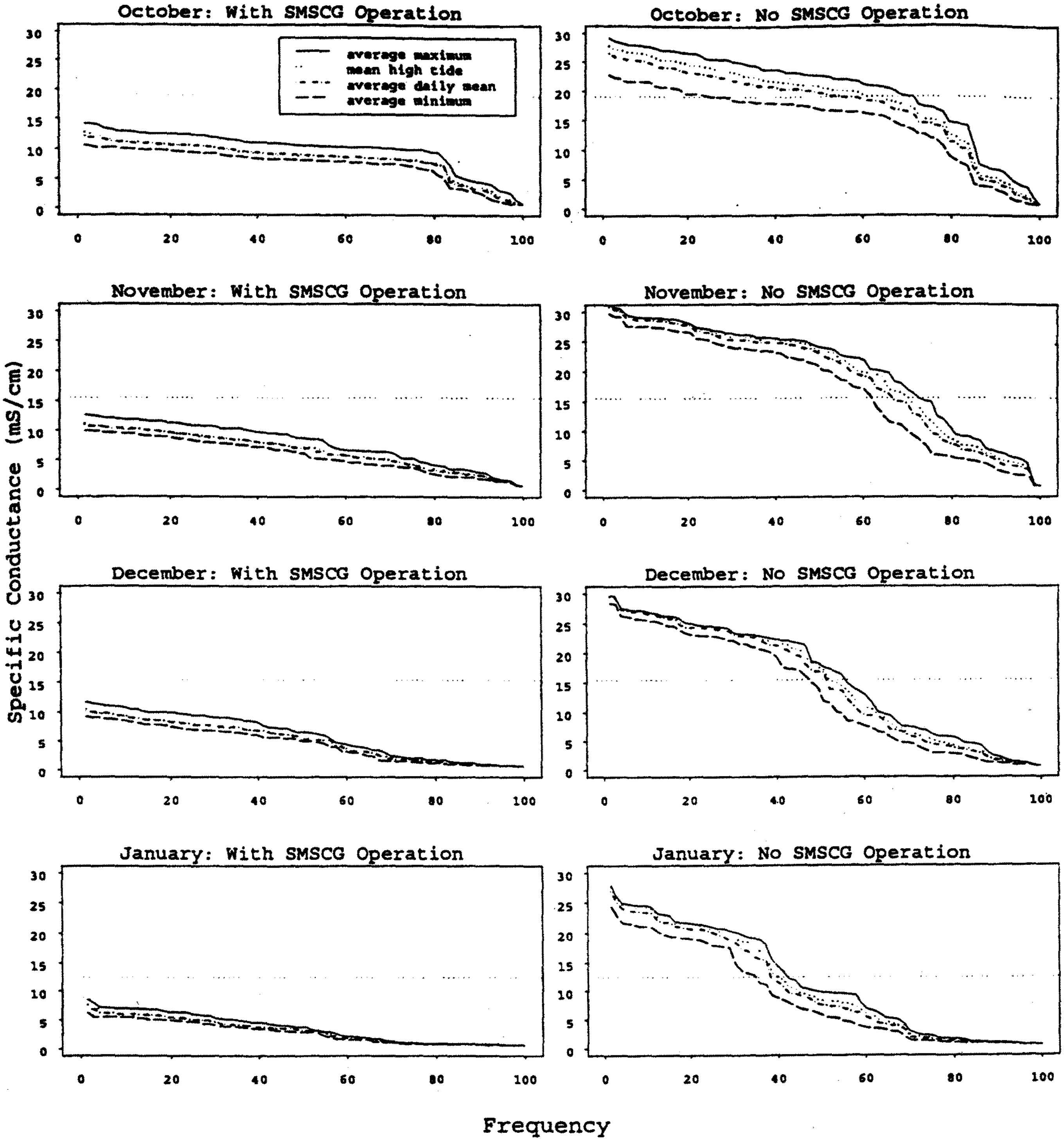
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

Station S64 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/


October: With SMSCG Operation
October: No SMSCG Operation
November: With SMSCG Operation
November: No SMSCG Operation
December: With SMSCG Operation
December: No SMSCG Operation
January: With SMSCG Operation
January: No SMSCG Operation

1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
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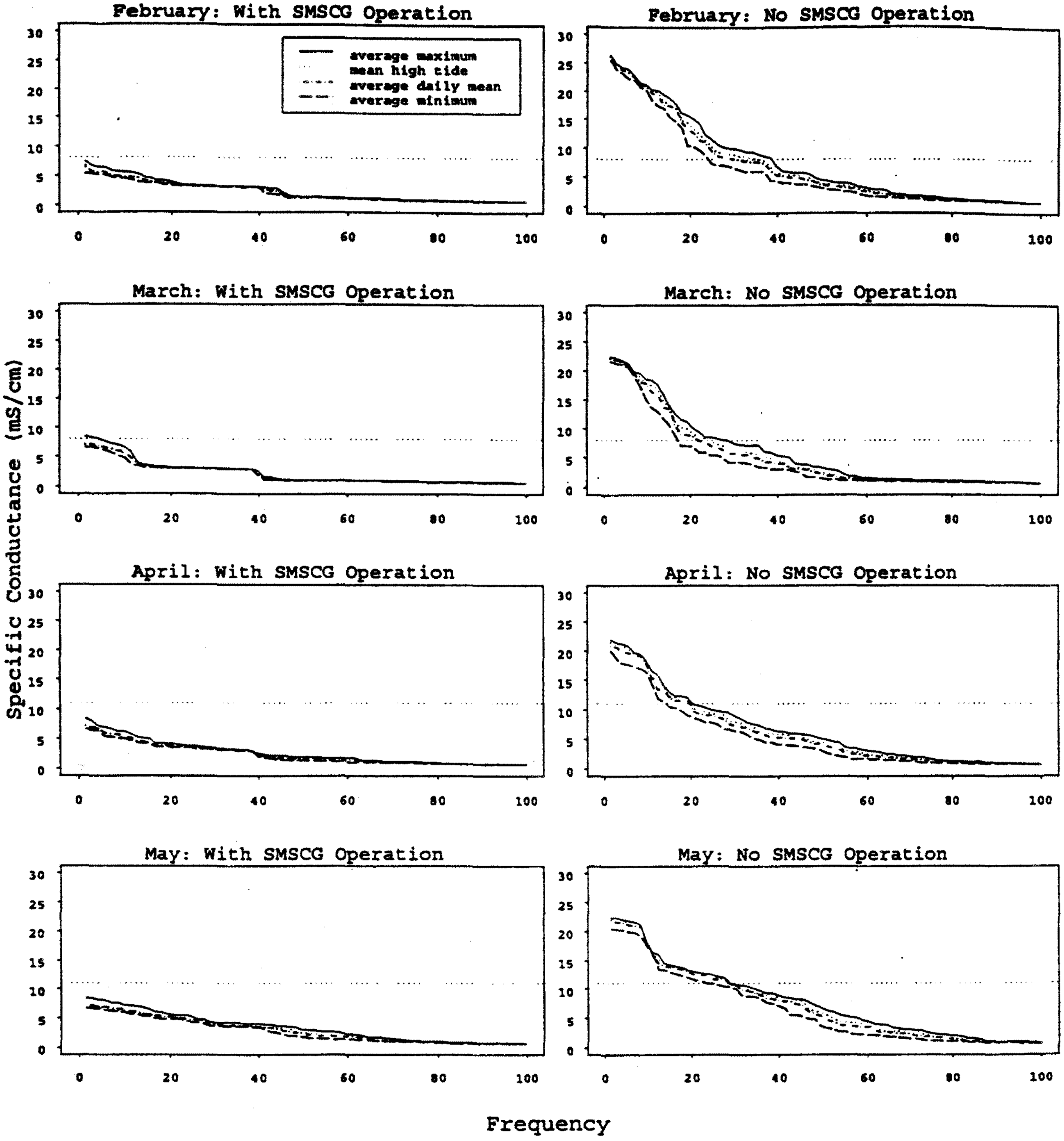
All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S64 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

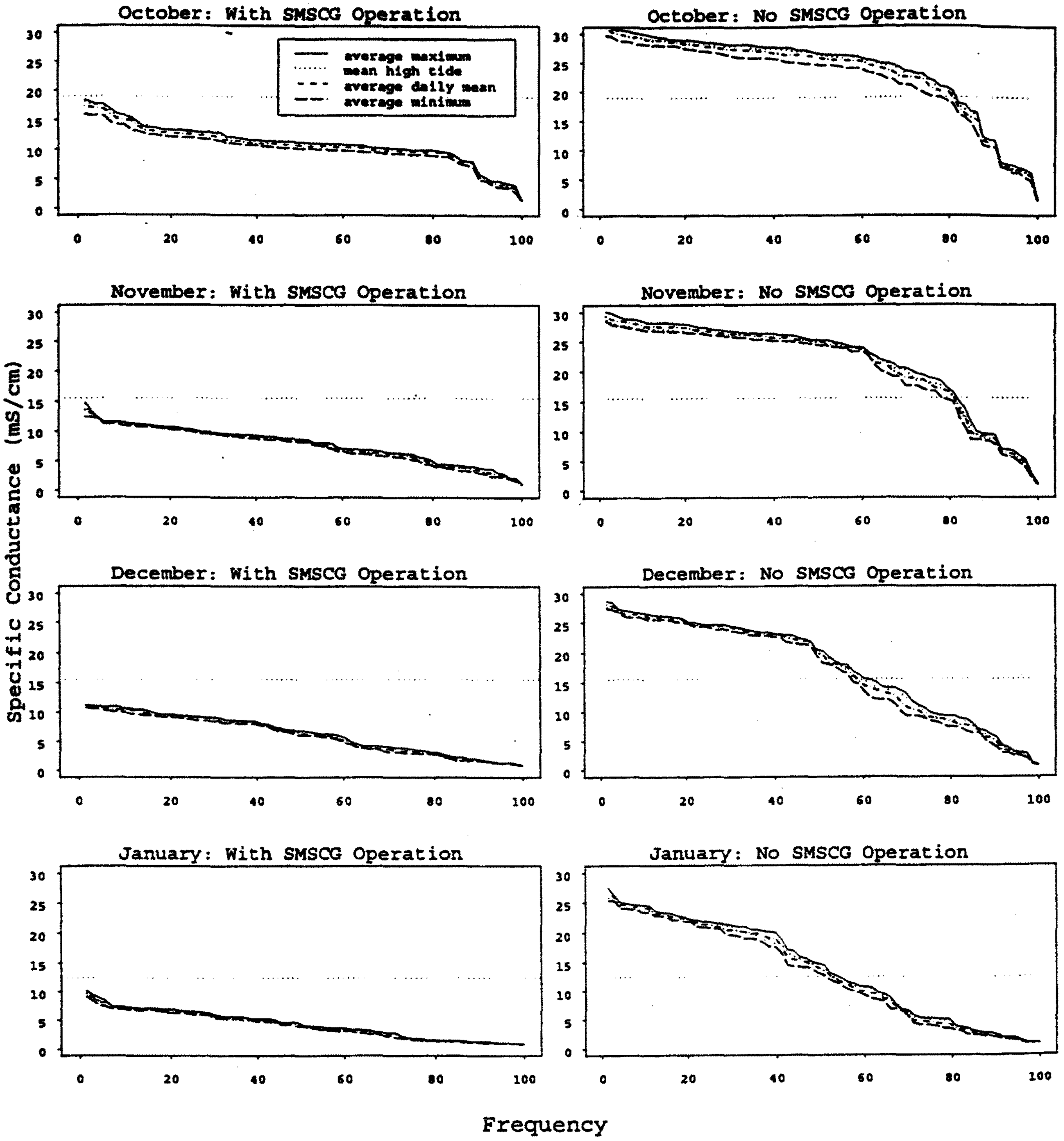


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S49 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

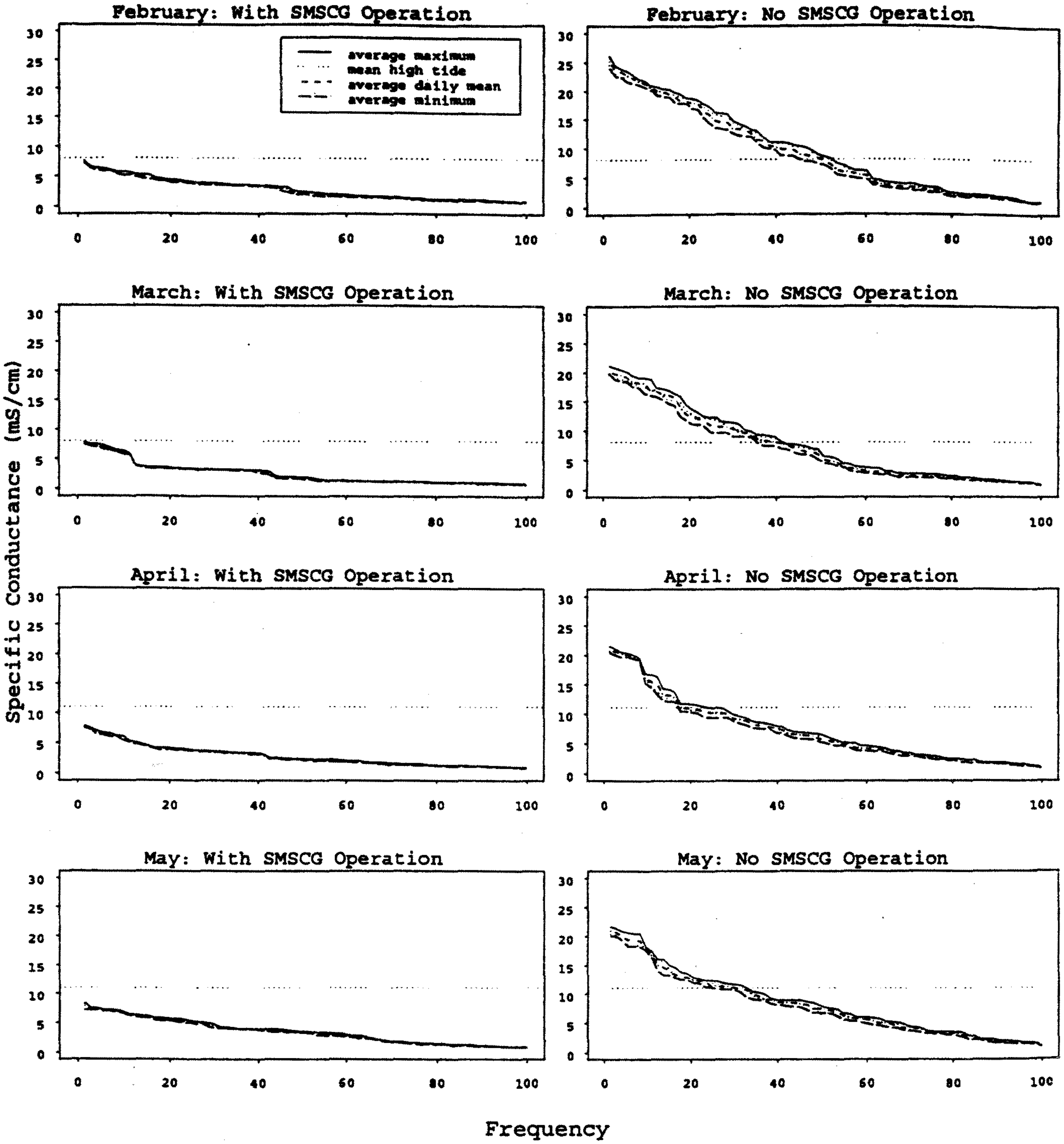


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S49 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/



1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
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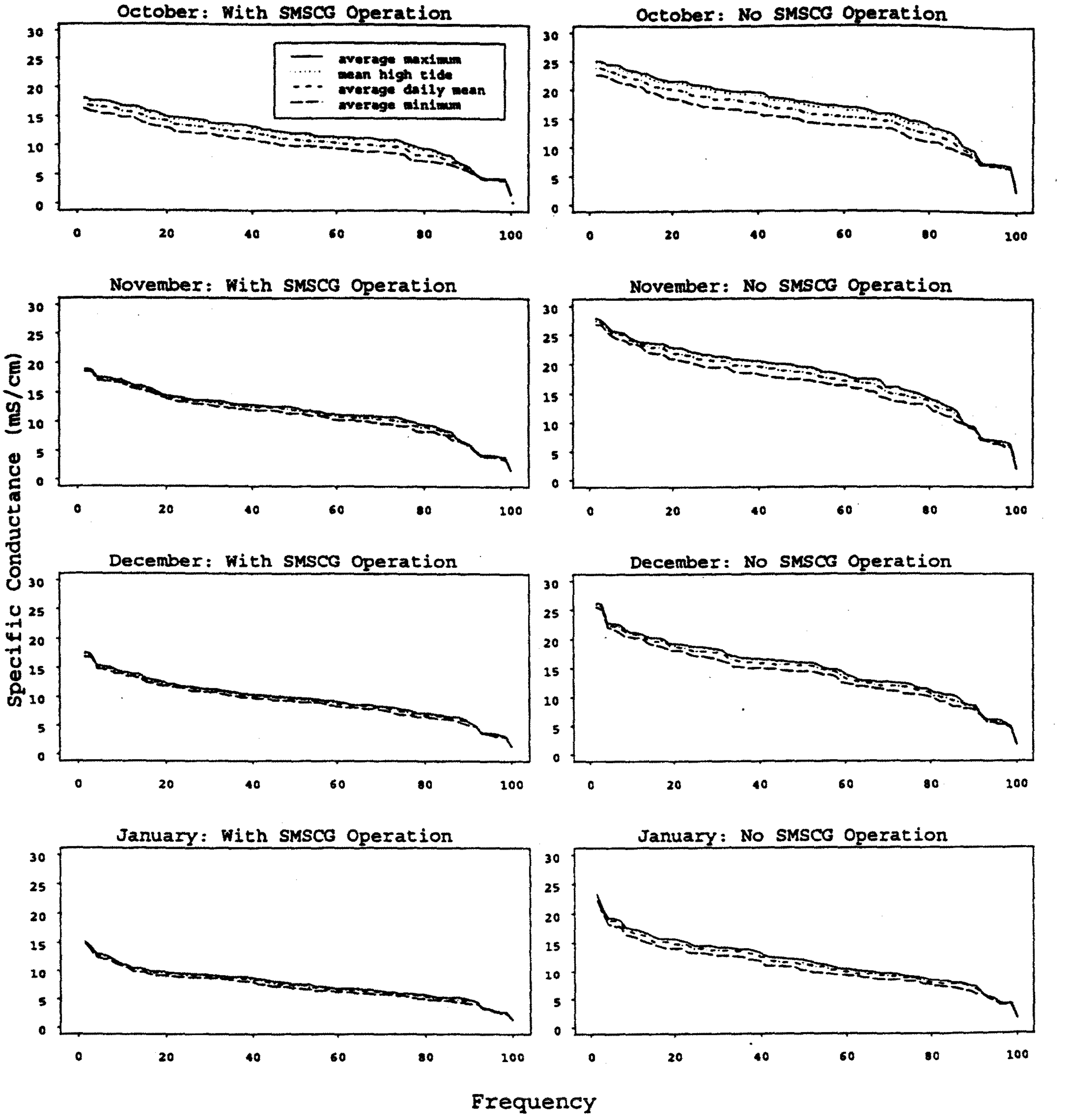
All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

Station S64 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/



1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
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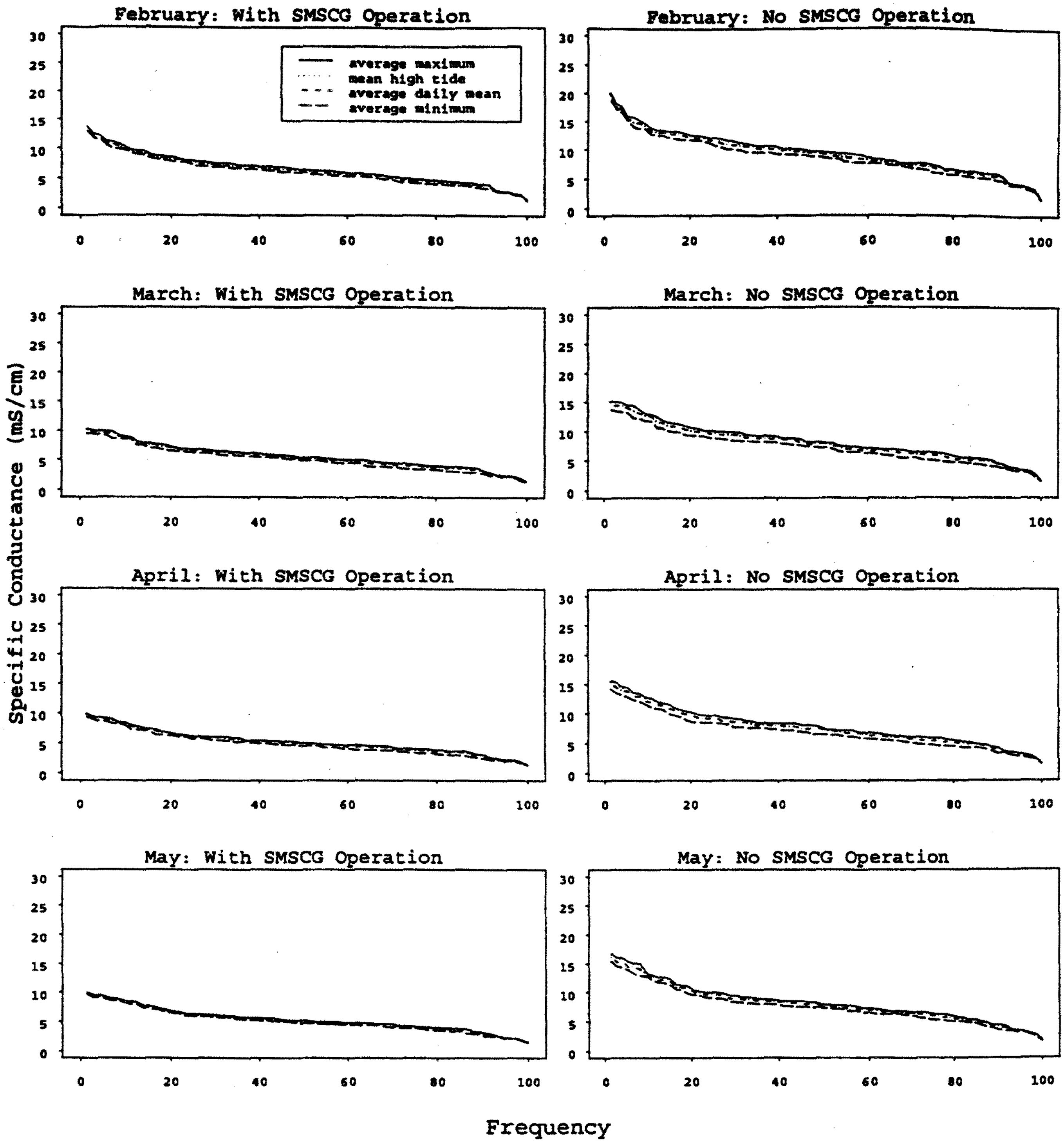
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S04 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

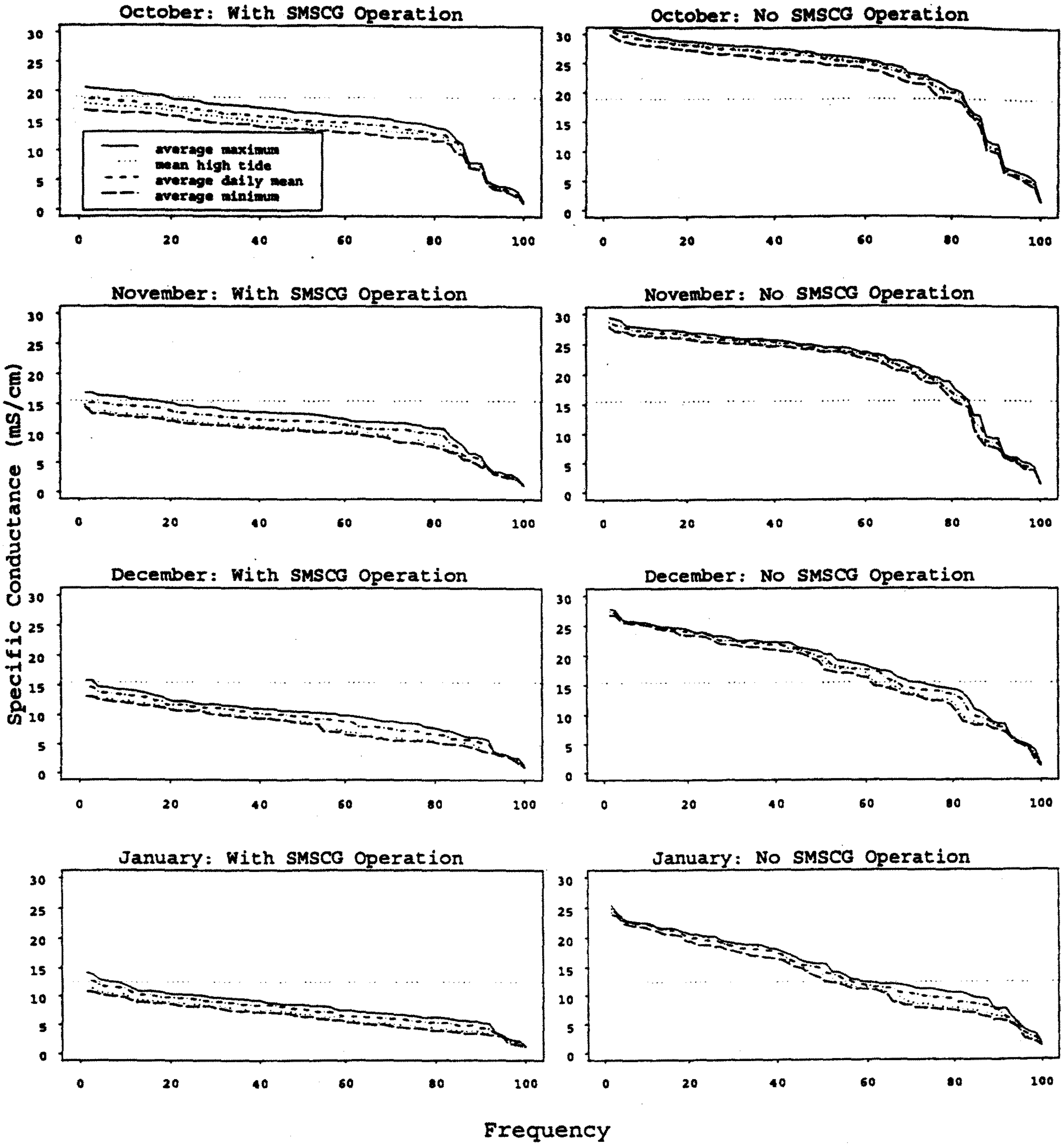


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S42 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/



October: With SMSCG Operation

October: No SMSCG Operation

November: With SMSCG Operation

November: No SMSCG Operation

December: With SMSCG Operation

December: No SMSCG Operation

January: With SMSCG Operation

January: No SMSCG Operation

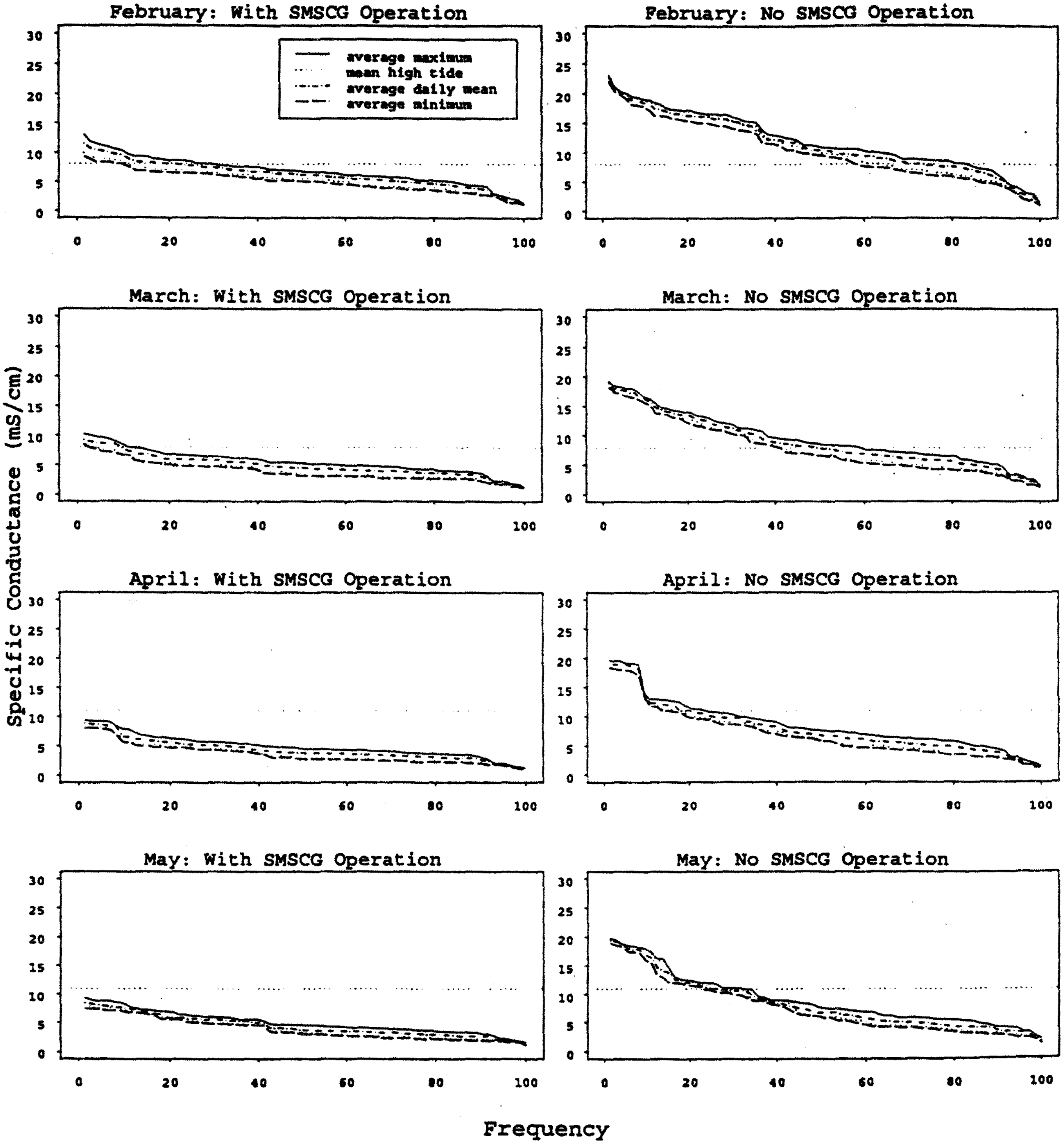
1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

Station S42 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

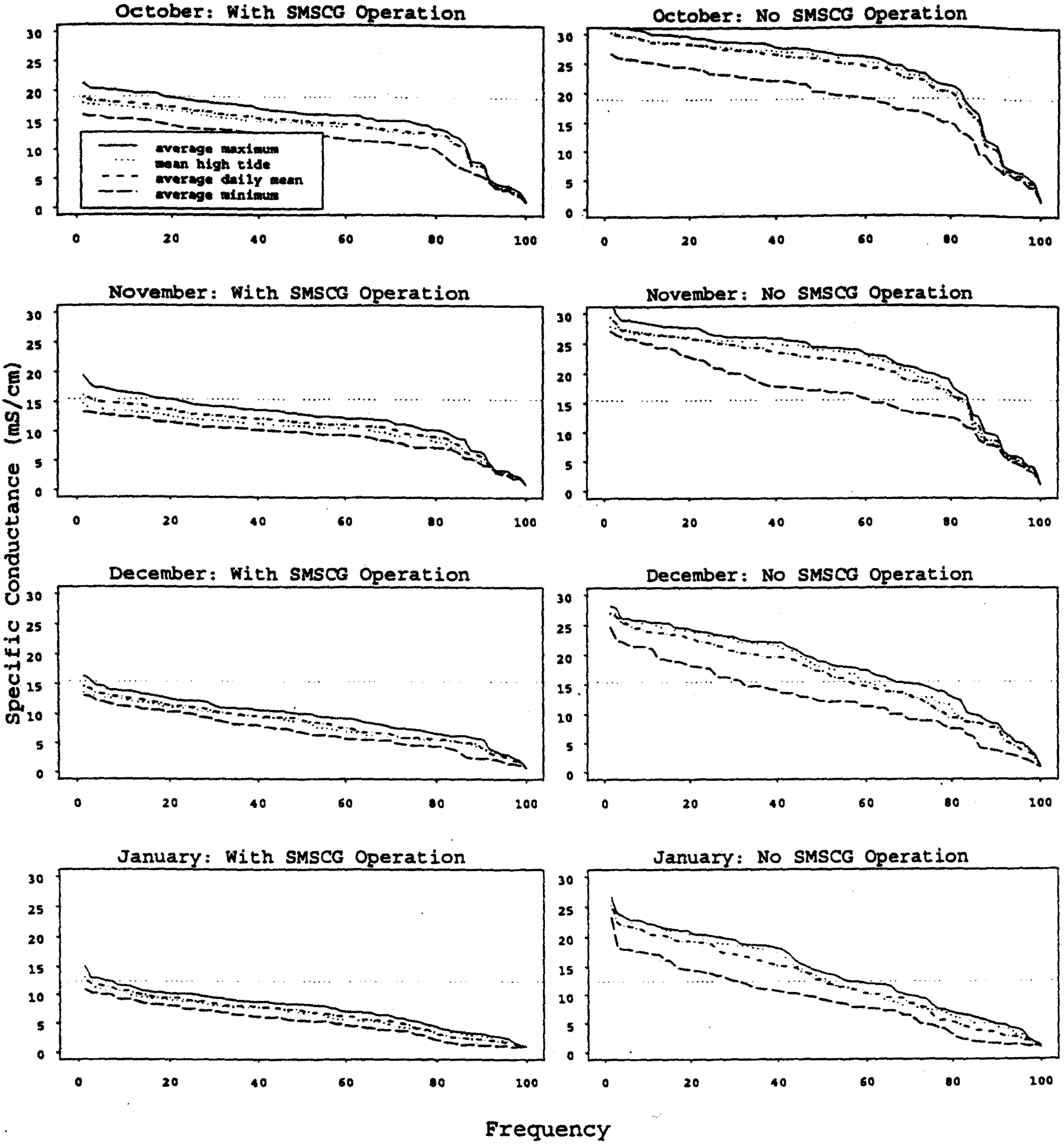


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.

Station S21 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/


October: With SMSCG Operation

October: No SMSCG Operation

November: With SMSCG Operation

November: No SMSCG Operation

December: With SMSCG Operation

December: No SMSCG Operation

January: With SMSCG Operation

January: No SMSCG Operation

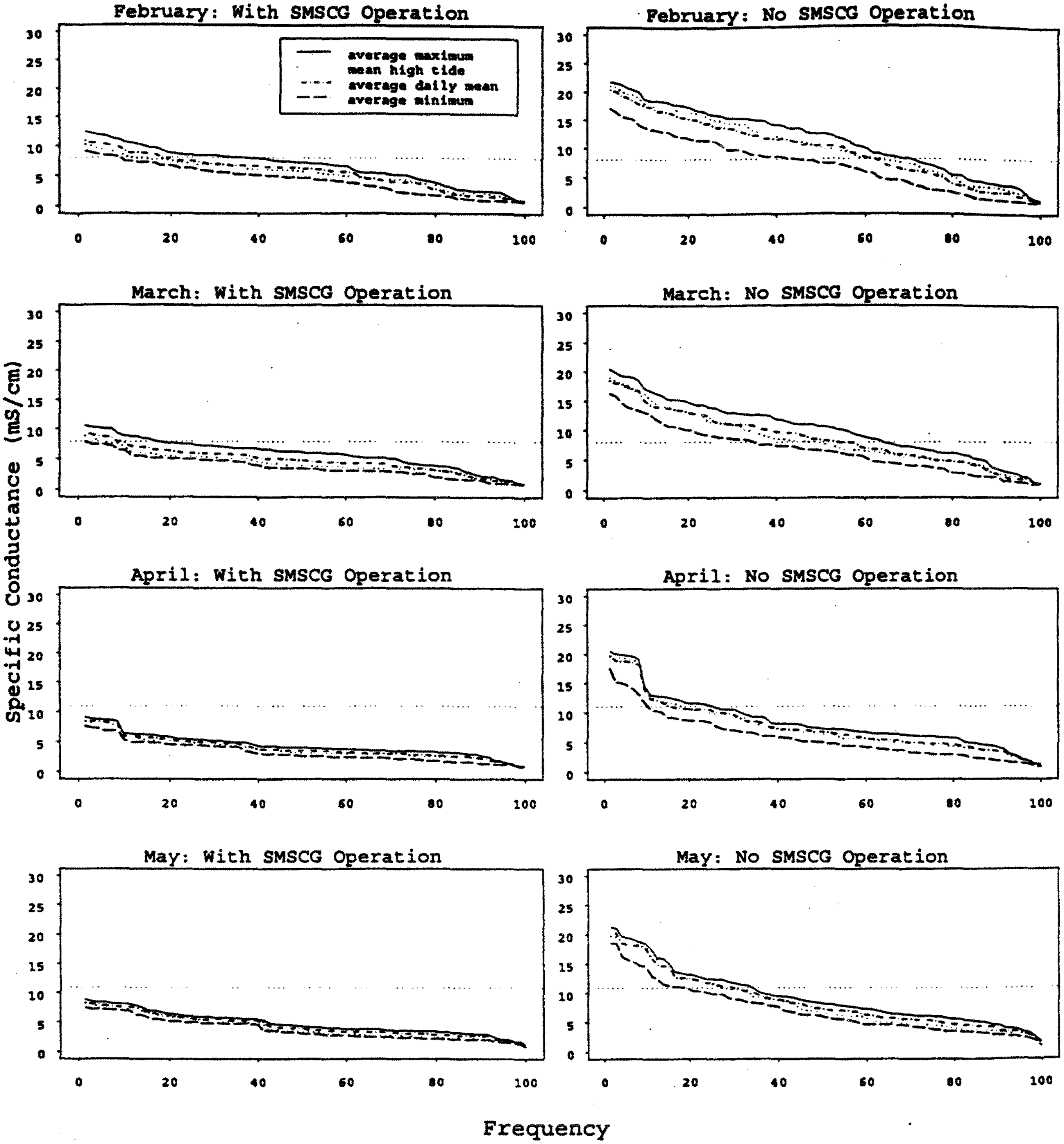
1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

Station S21 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

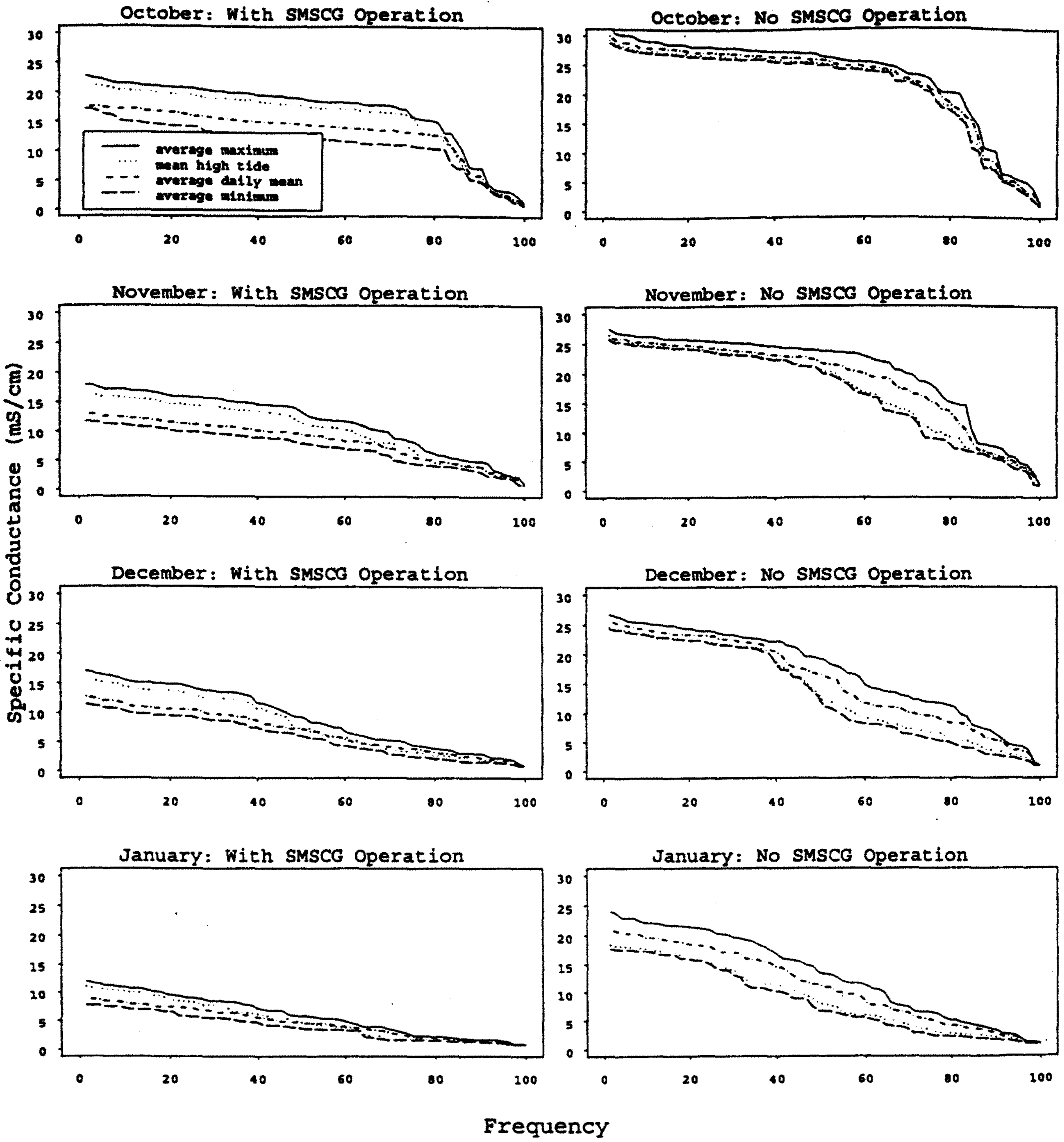


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S54 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

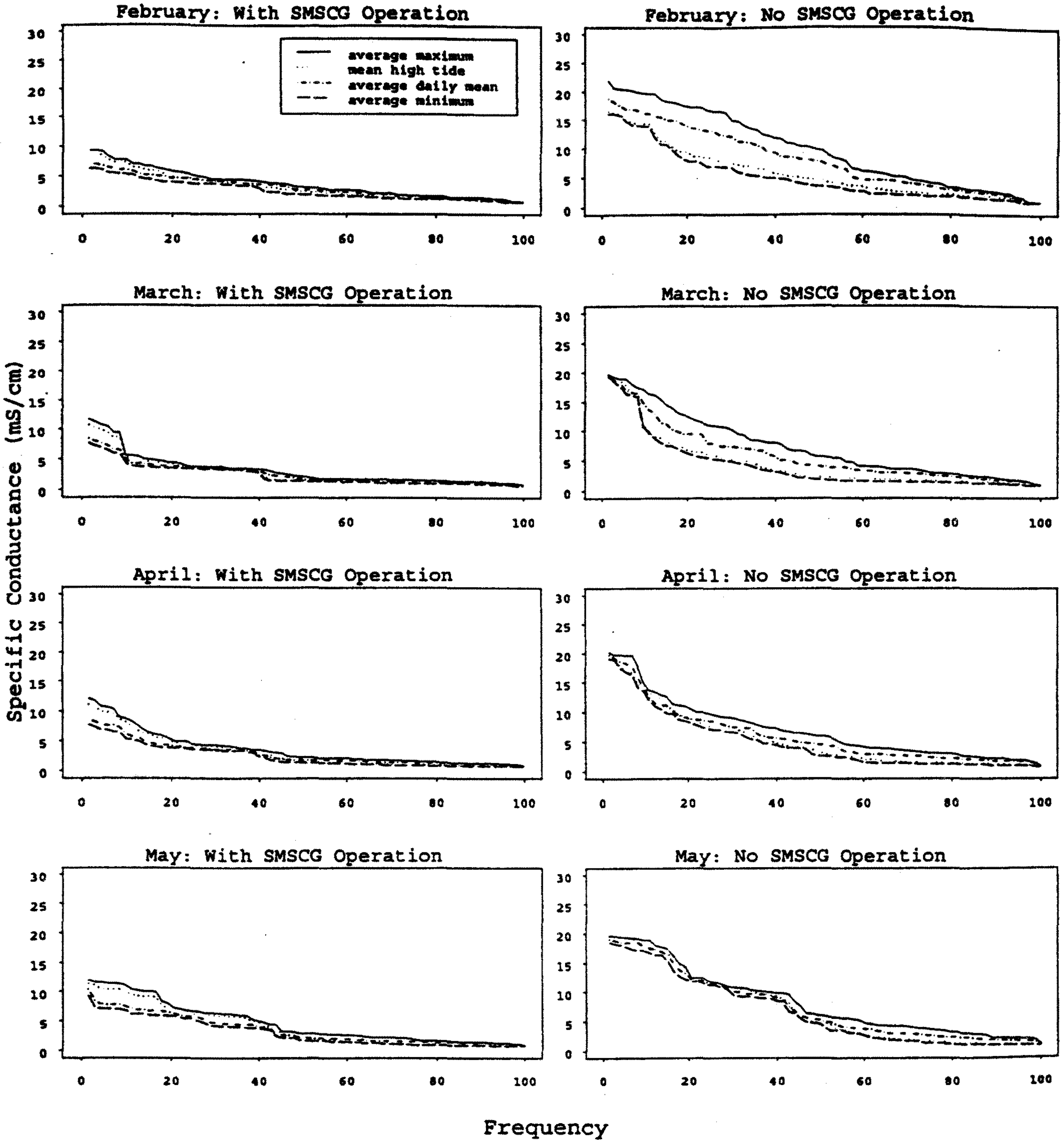


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S54 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

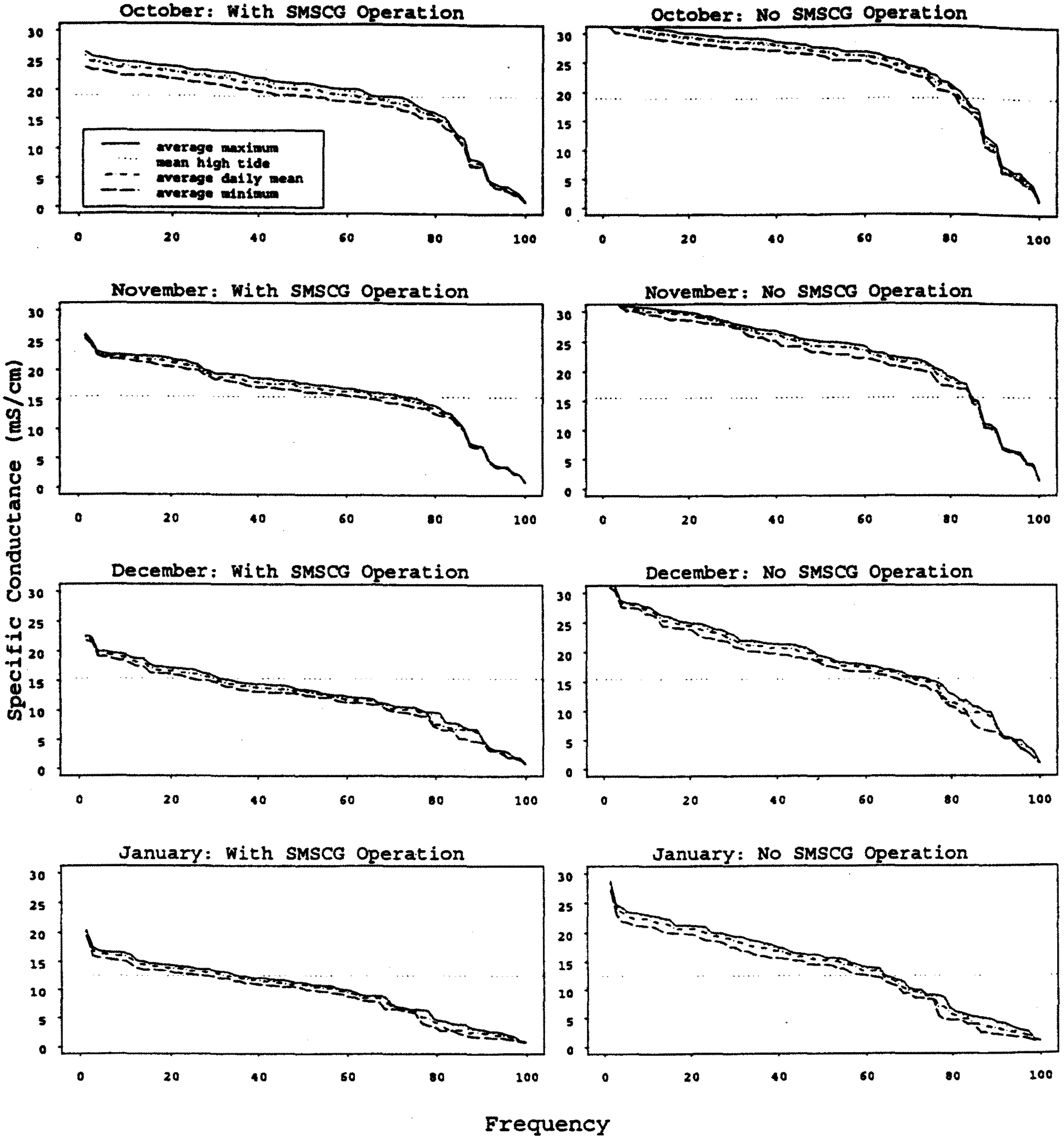


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S97 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

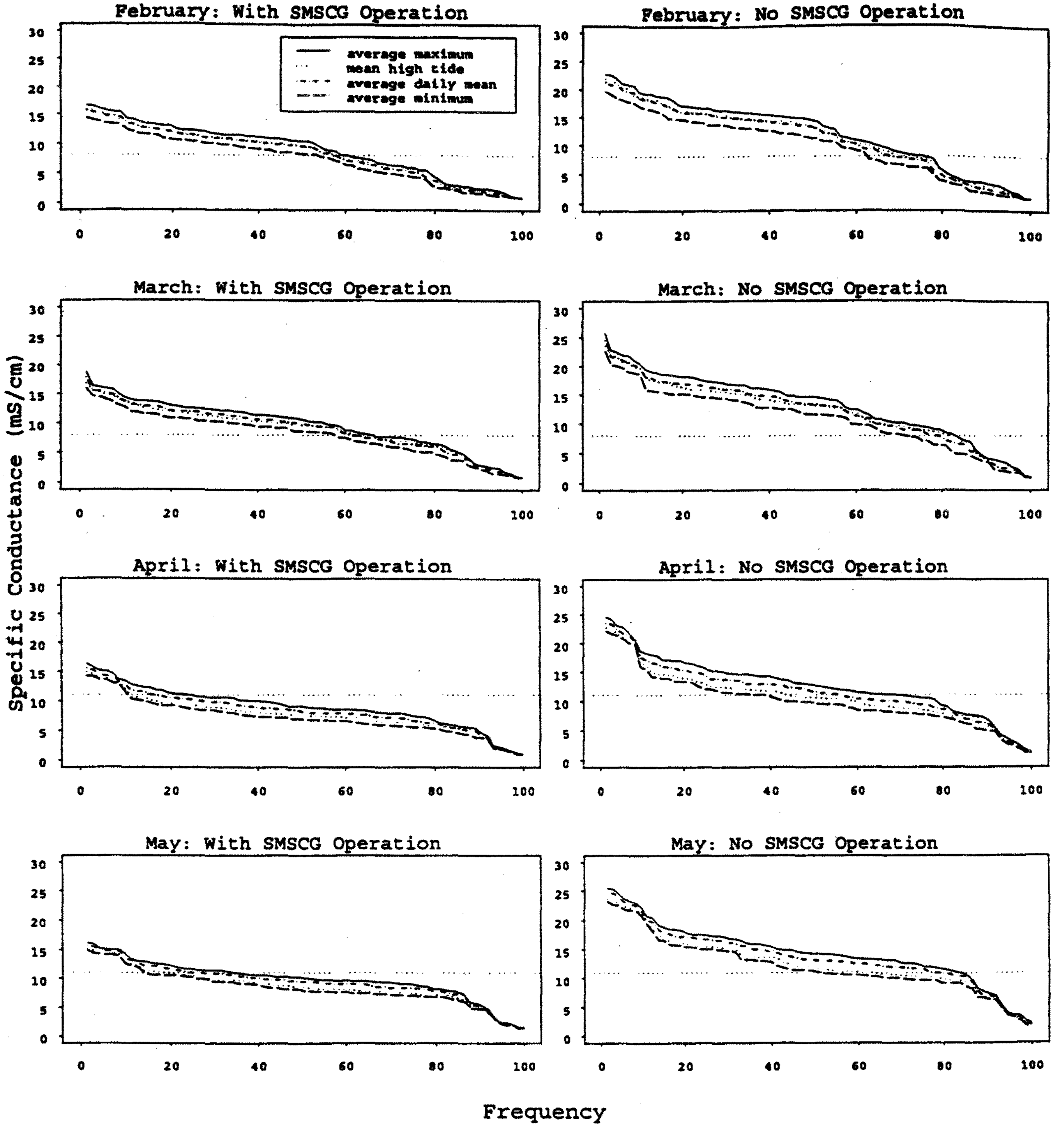


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S97 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

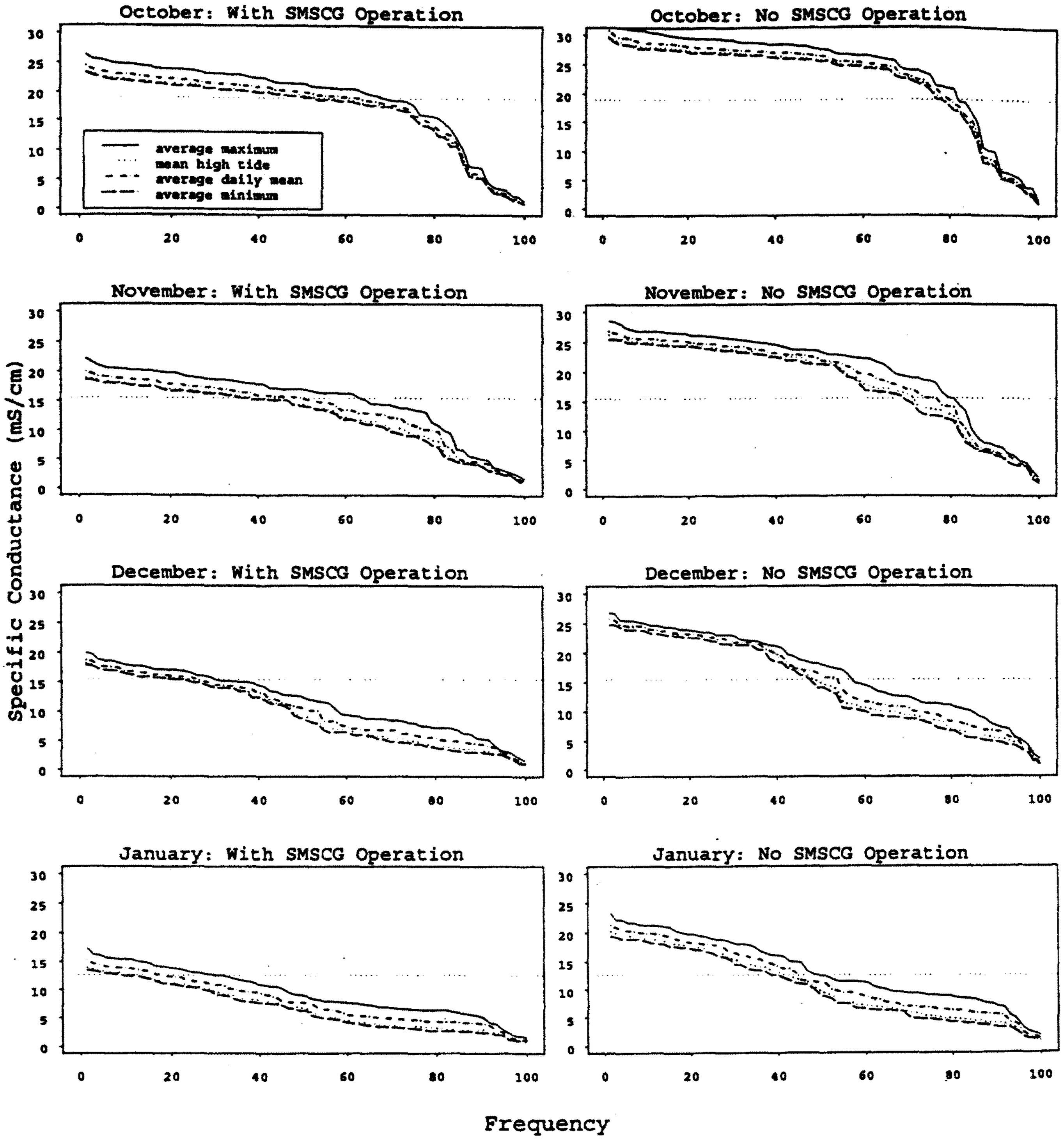


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S35 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/

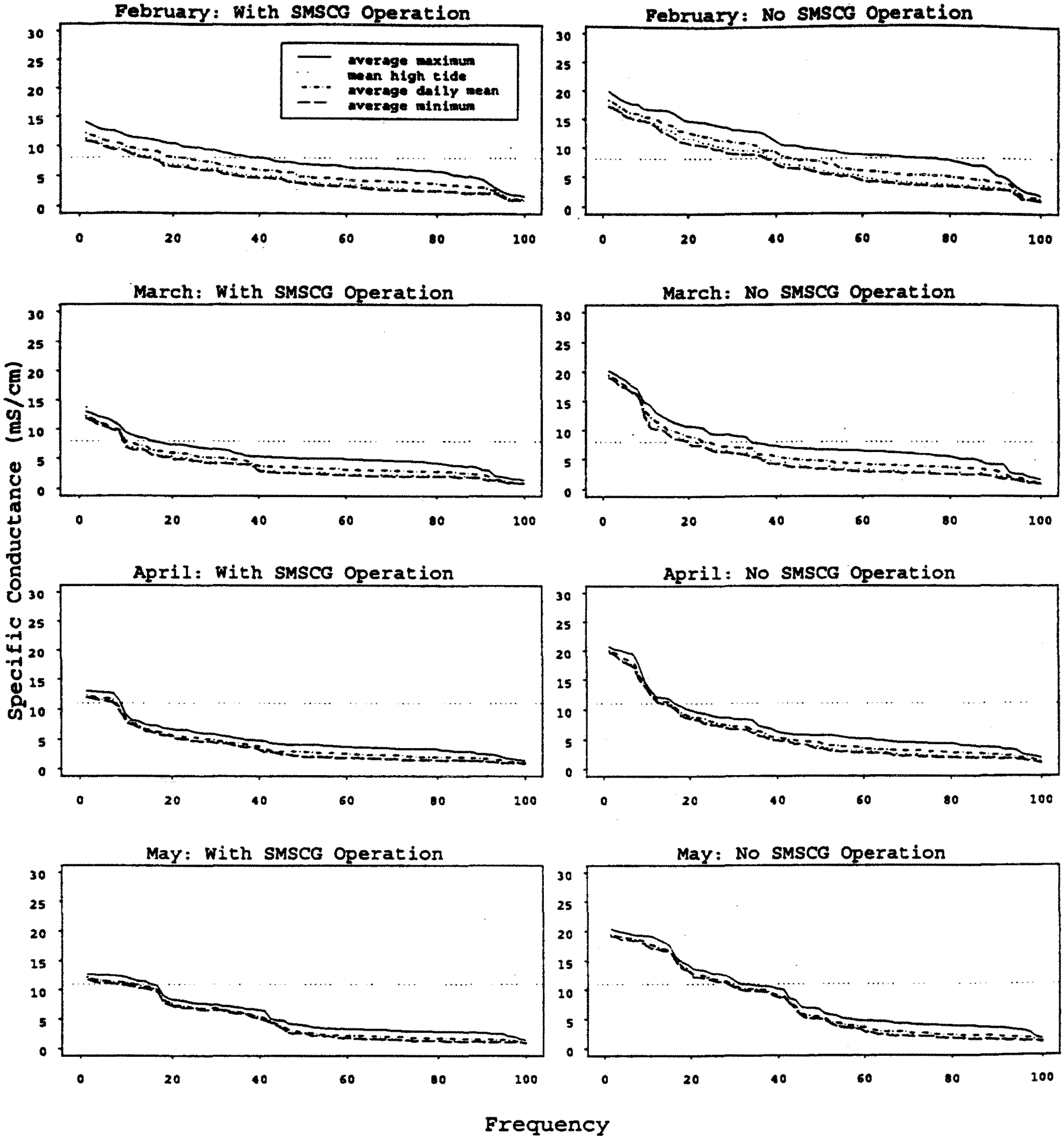


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S35 Specific Conductance 1/
D1485: With SMSCG Operation 2/
Without SMSCG Operation 3/



1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 3,7,11,23 in 73avgsal.xls.
3/ Excel Tabs 1,5,9,21 in 73avgsal.xls.

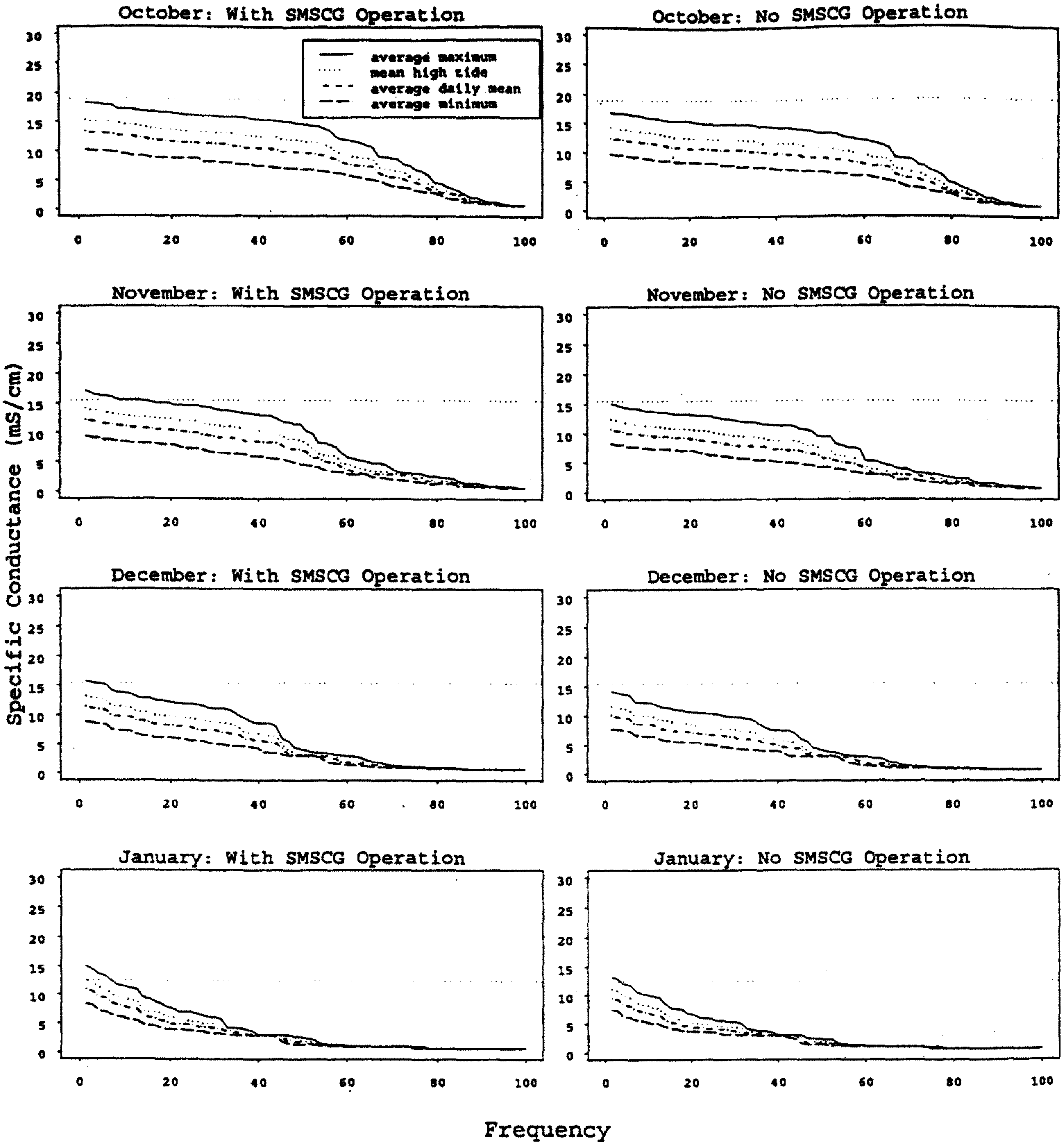
All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Appendix 1B

Exceedance Frequency Plots
WQCP Hydrology

Collinsville (C2)
National Steel (S64)
Beldon's Landing (S49)
Hill Slough (S04)
Volanti (S42)
Sunrise (S21)
Hunter Cut (S54)
Ibis (S97)
Goodyear Slough (S35)

Station C2 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

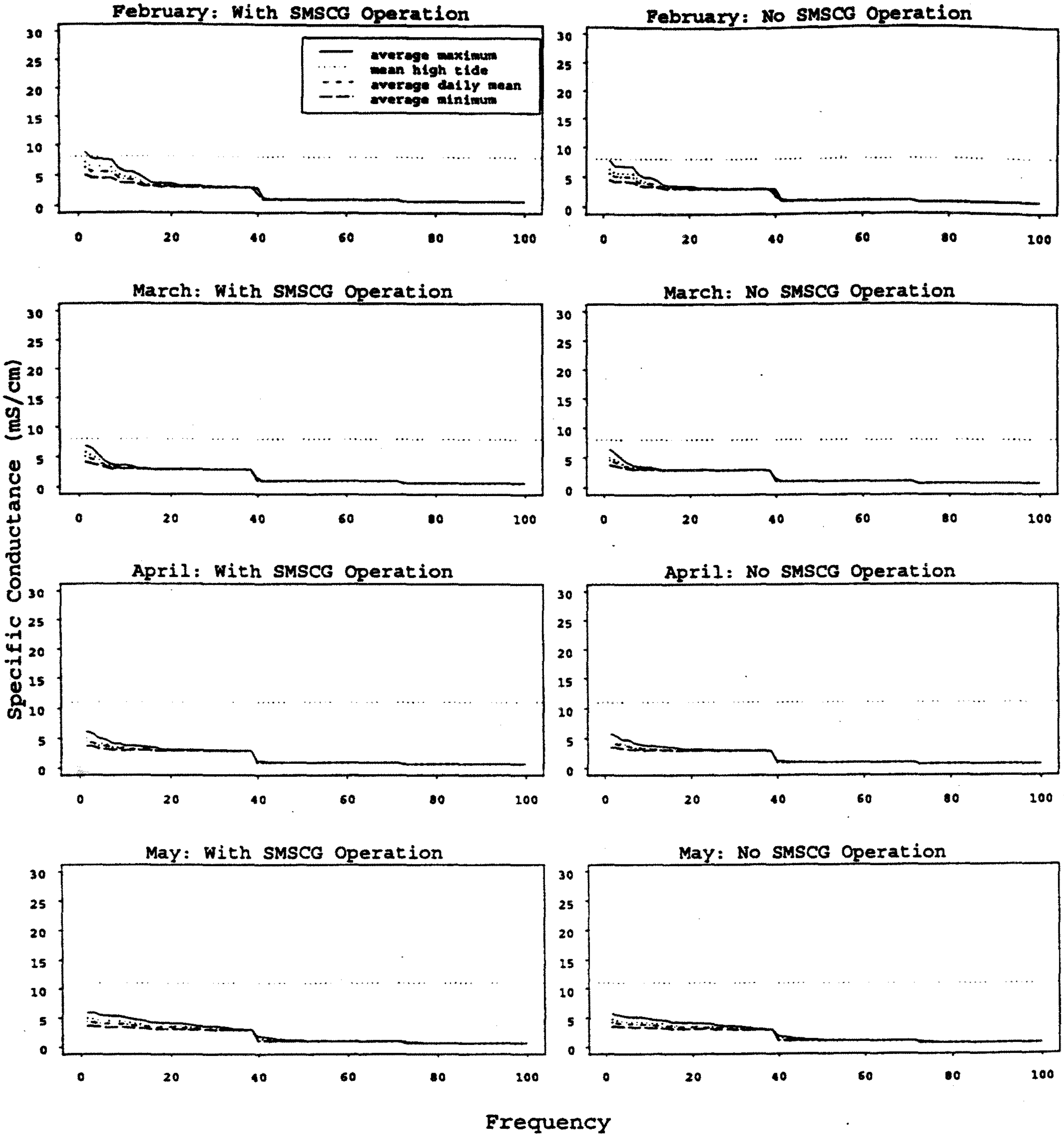


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station C2 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/



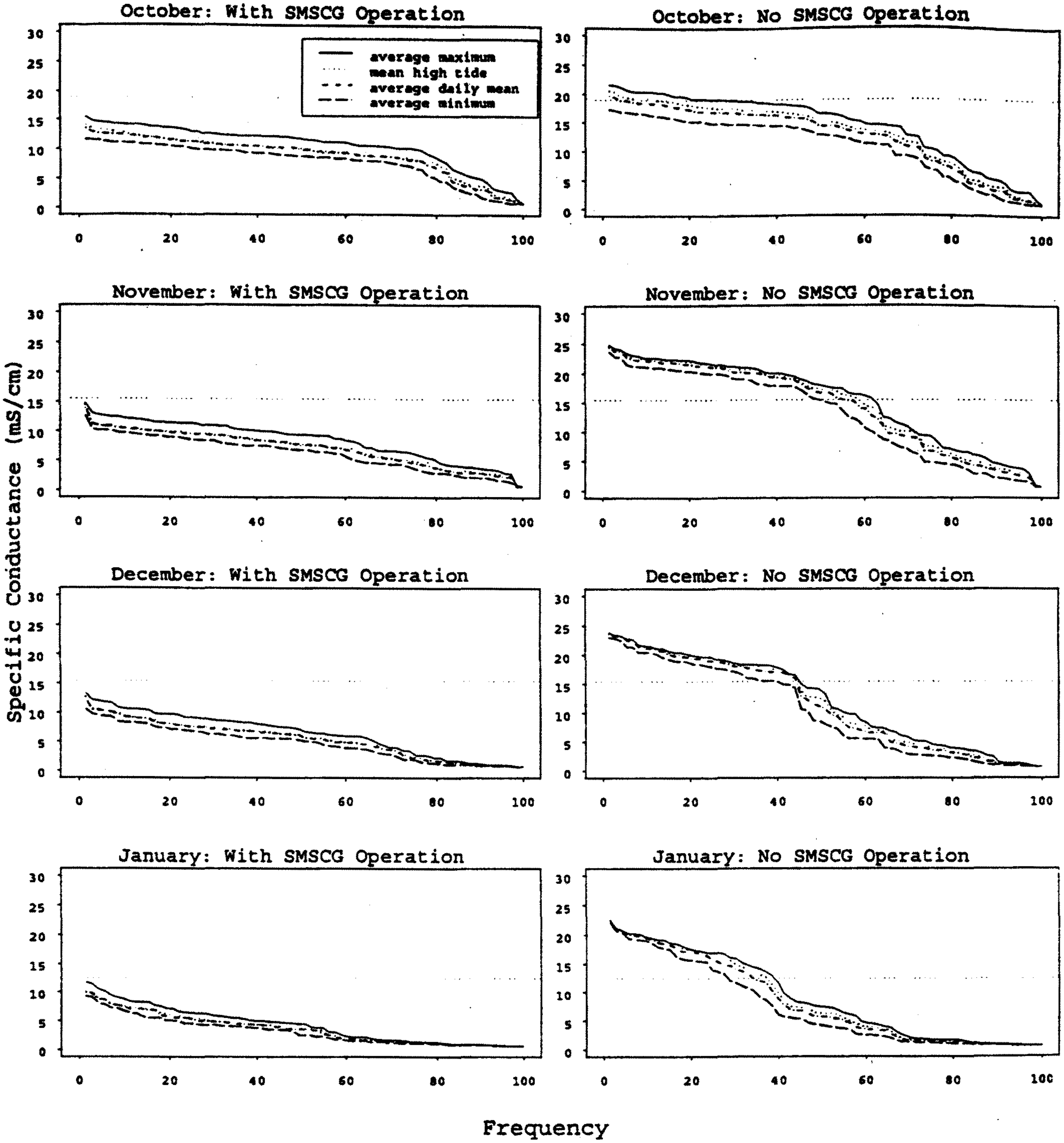
1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

Station S64 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

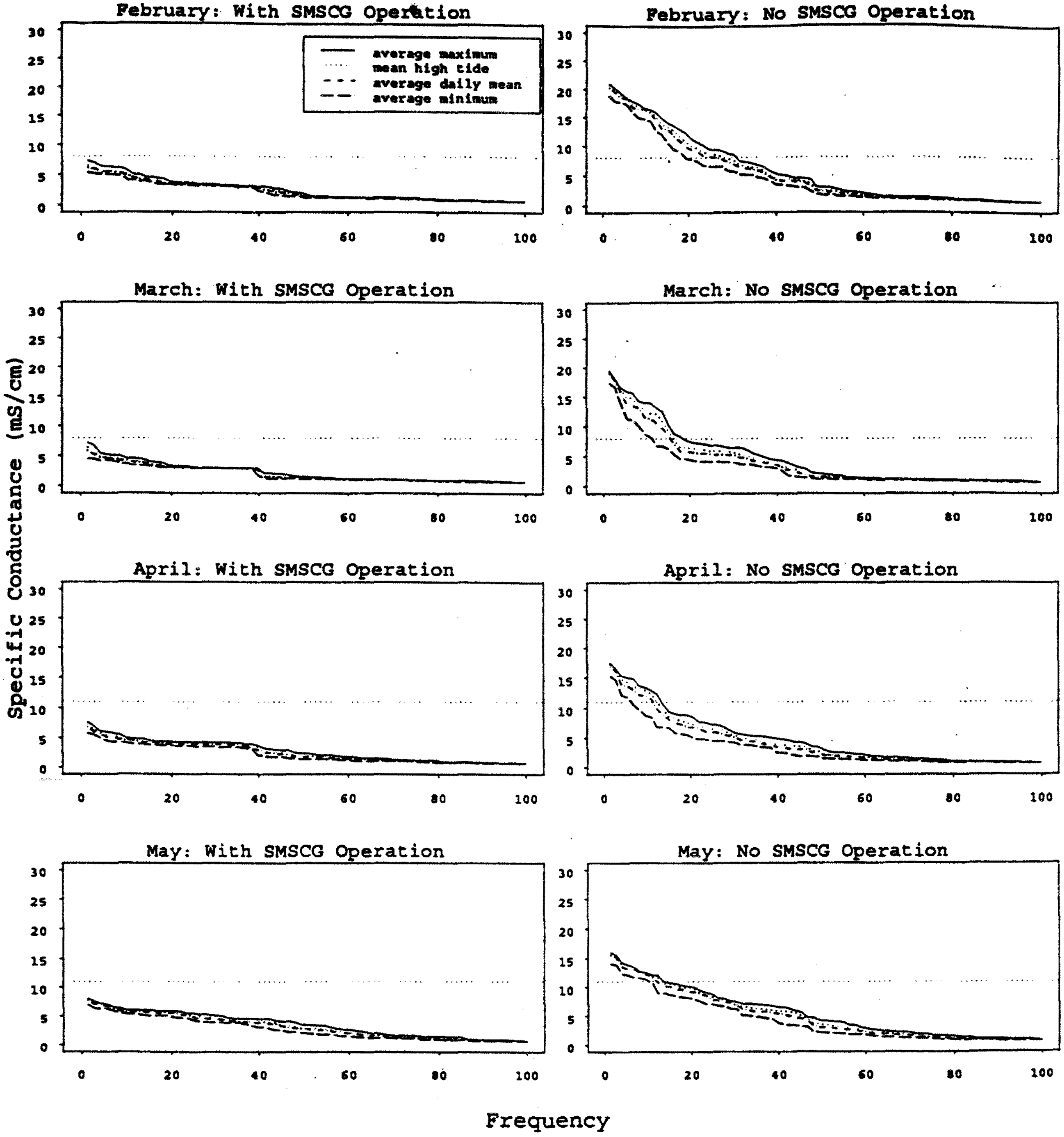


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S64 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

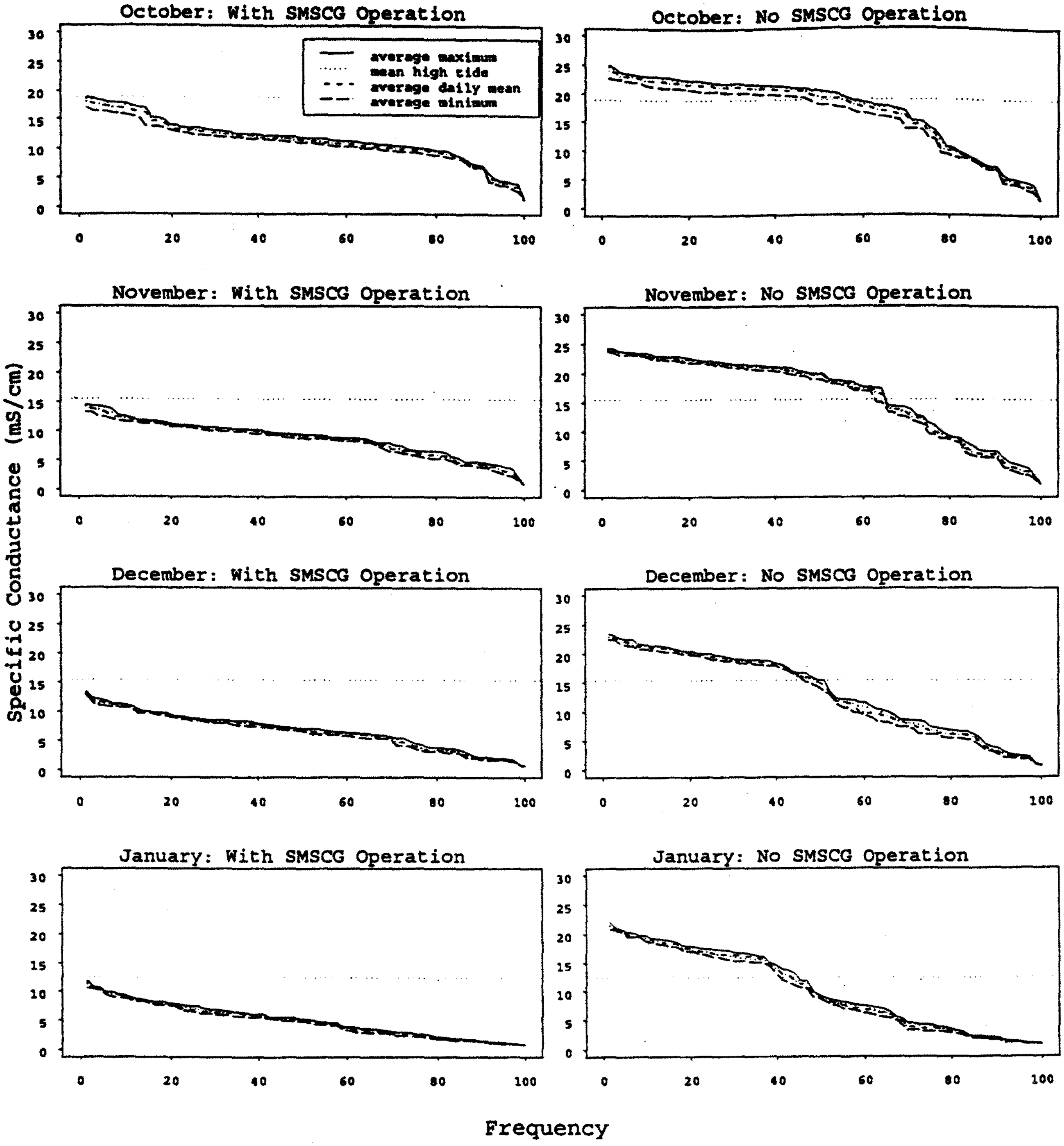


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S49 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

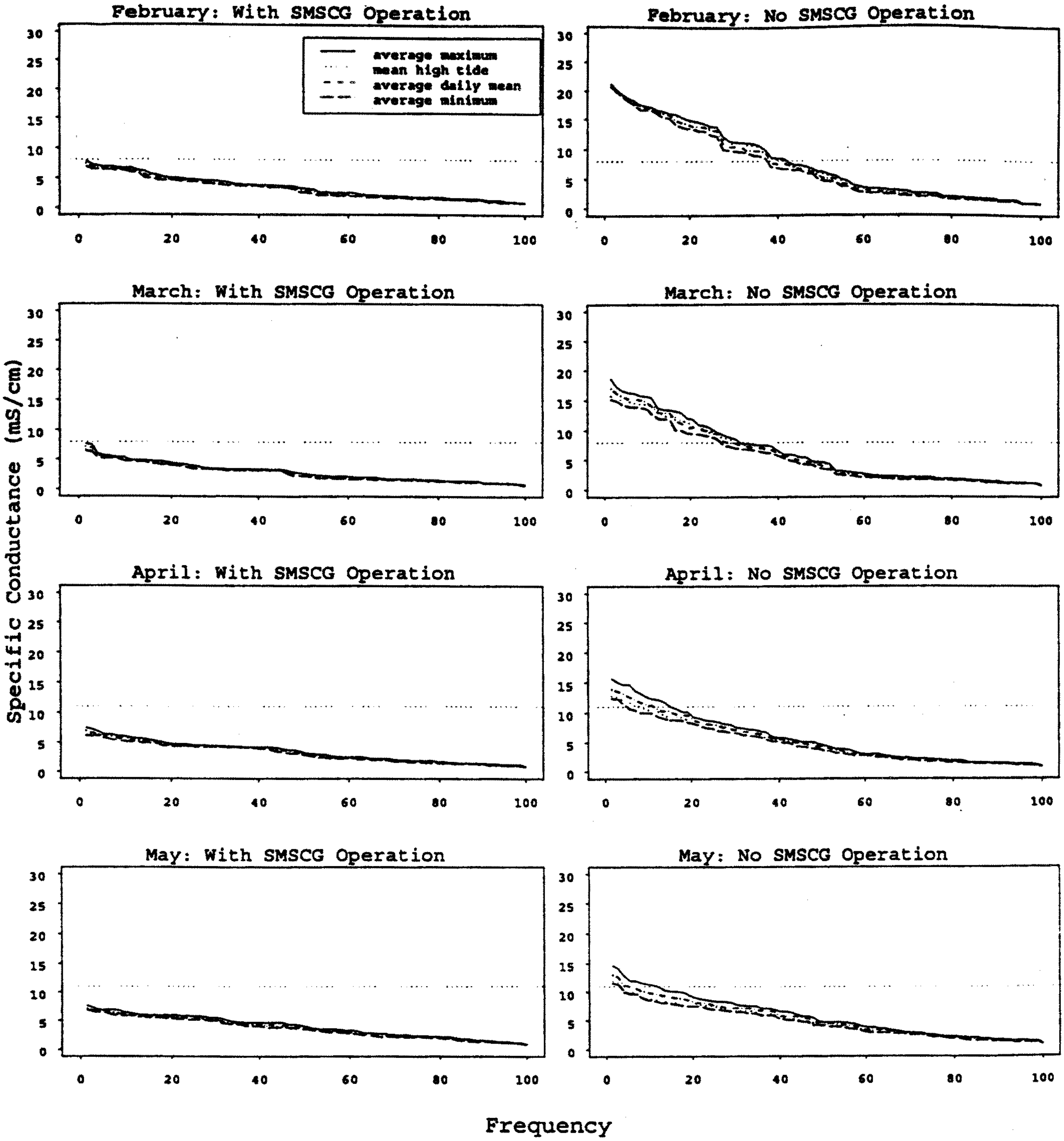


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S49 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

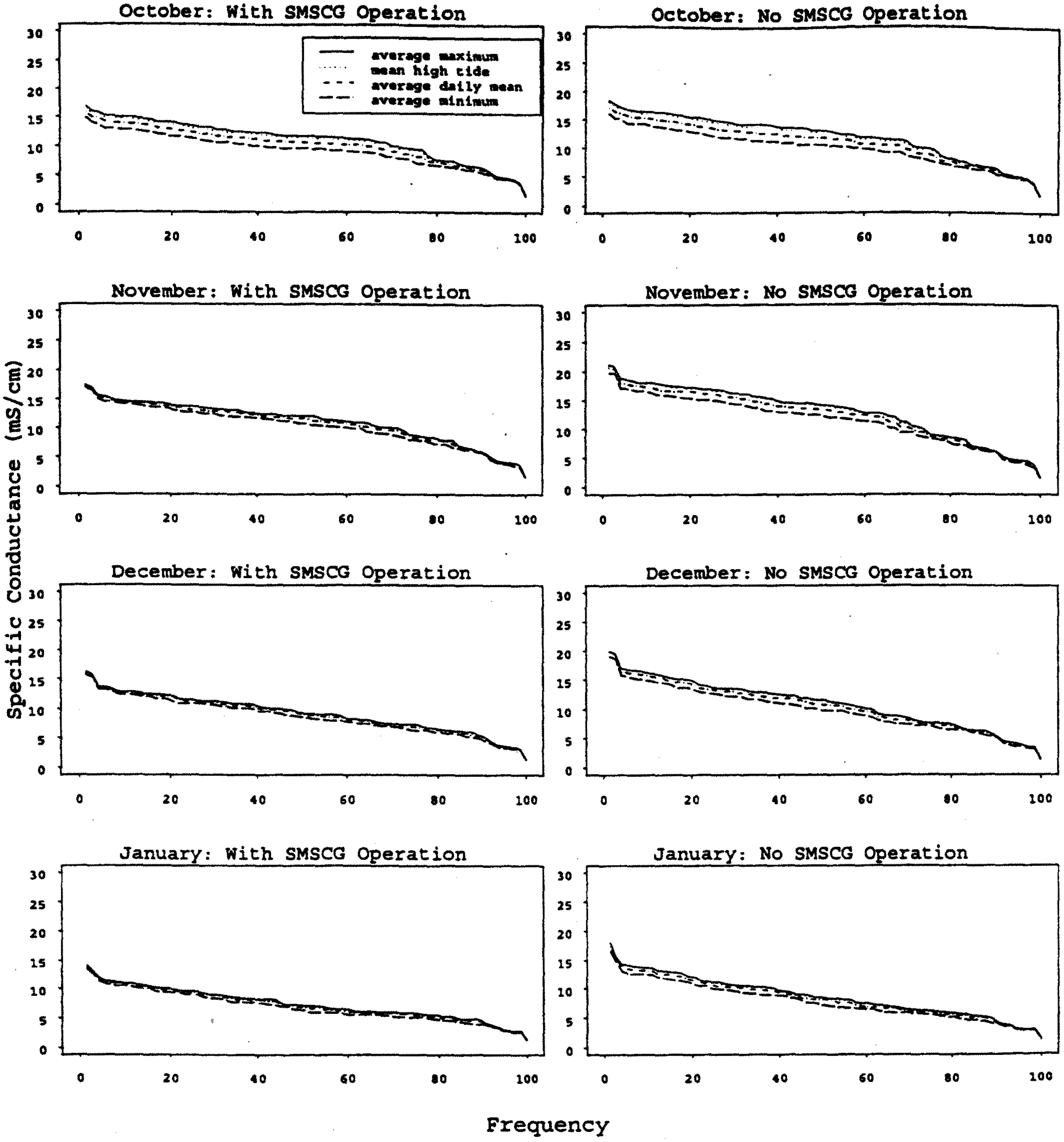


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S04 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

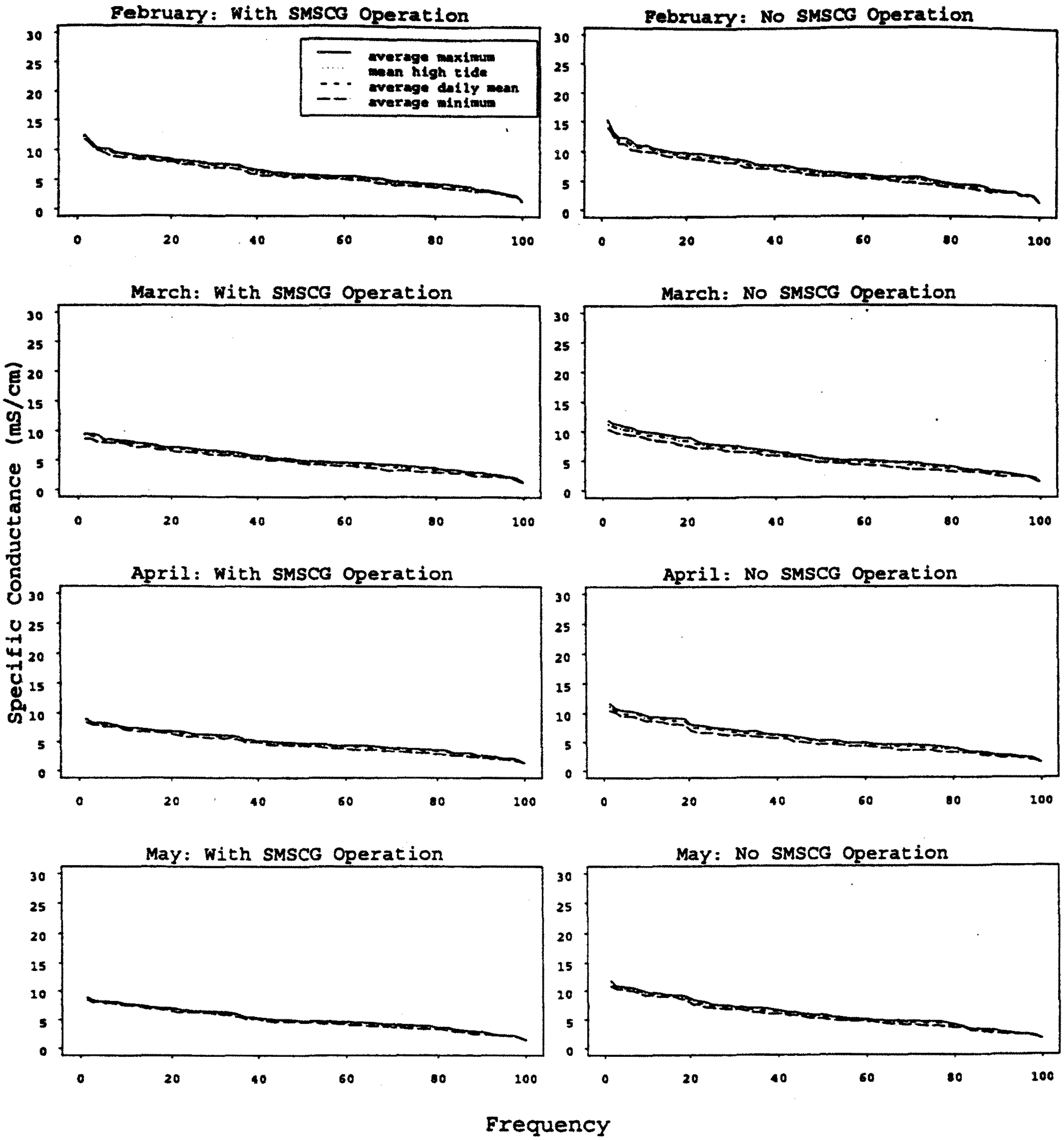


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S04 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

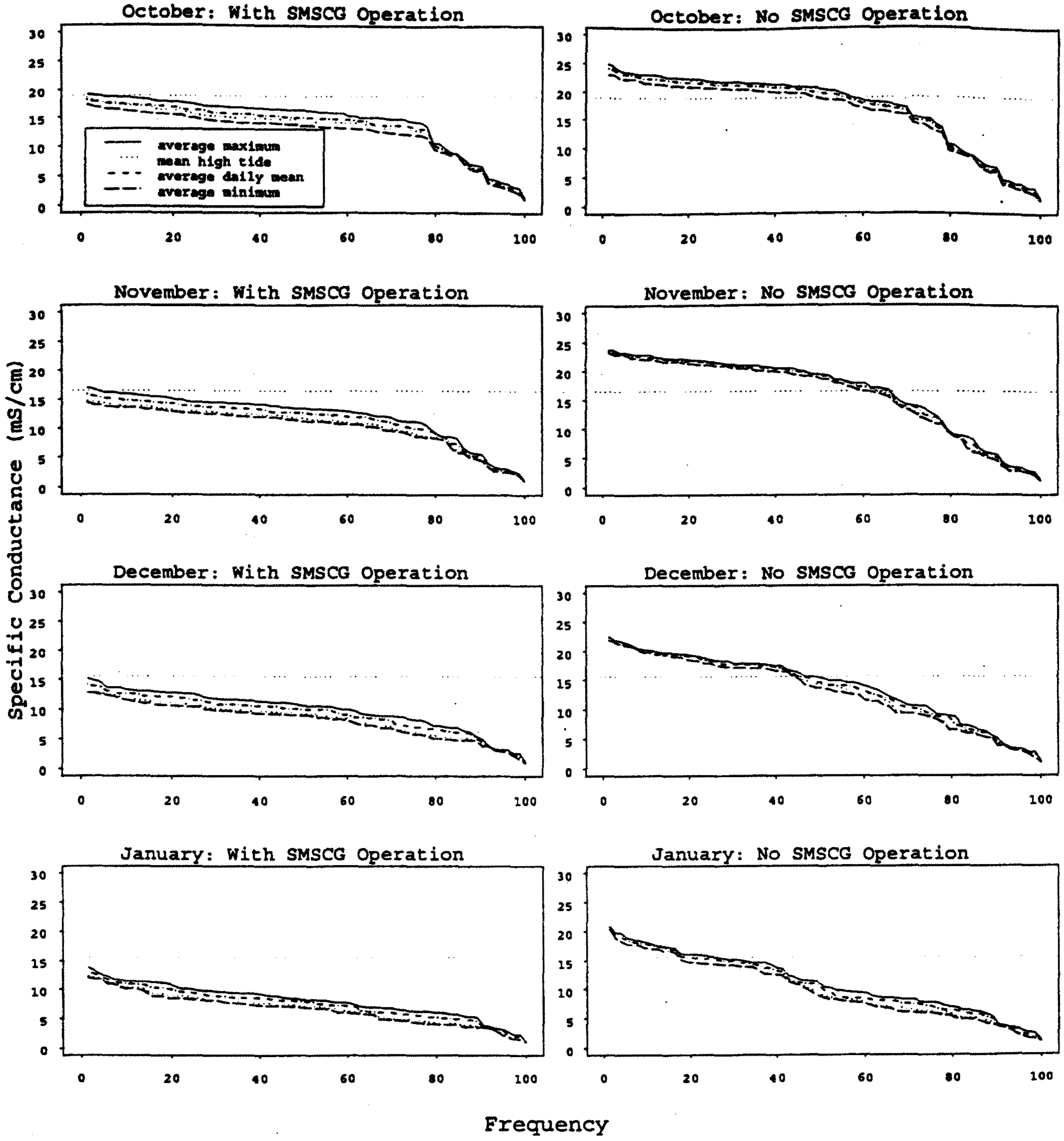


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S42 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/



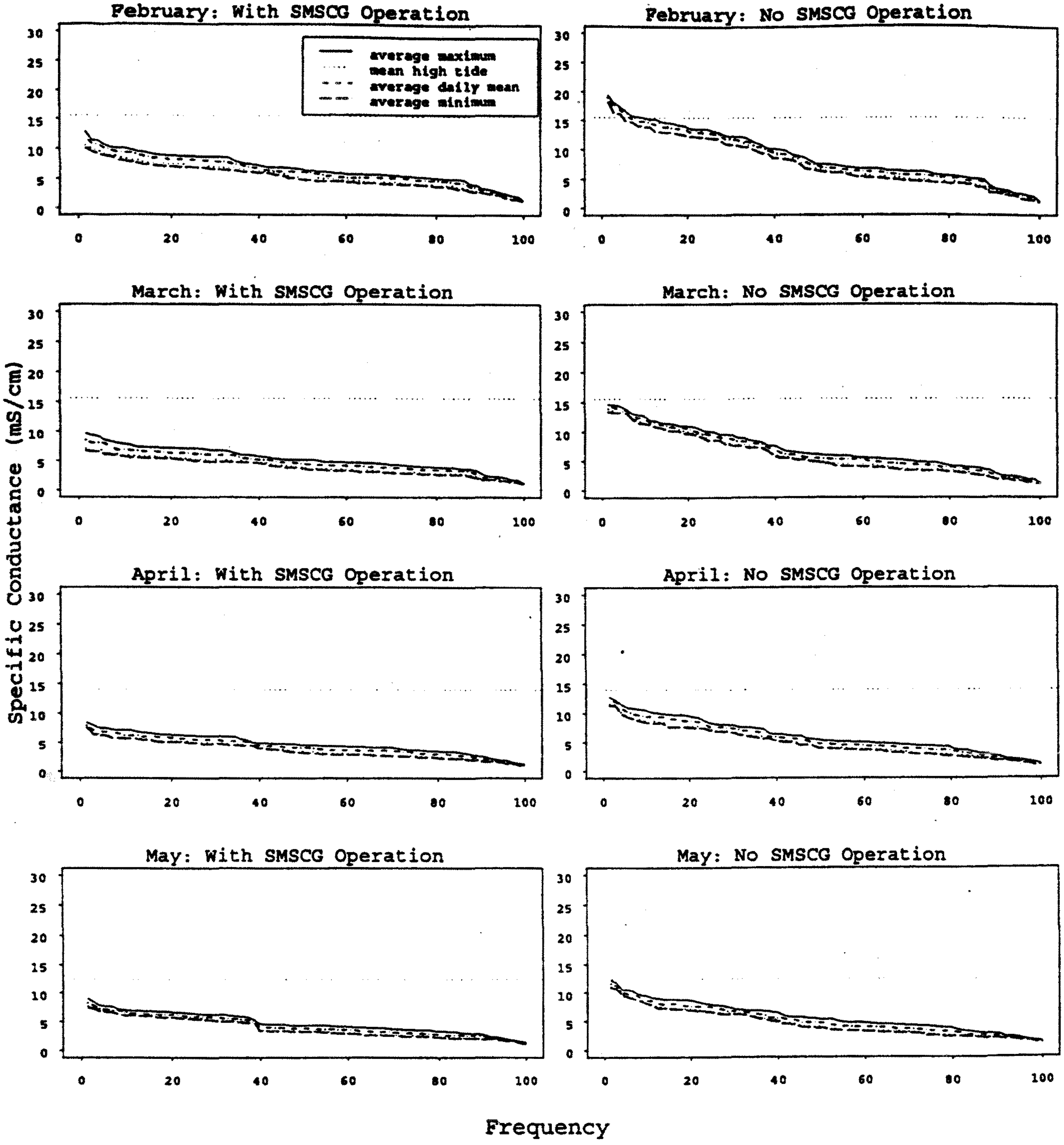
1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

Station S42 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/



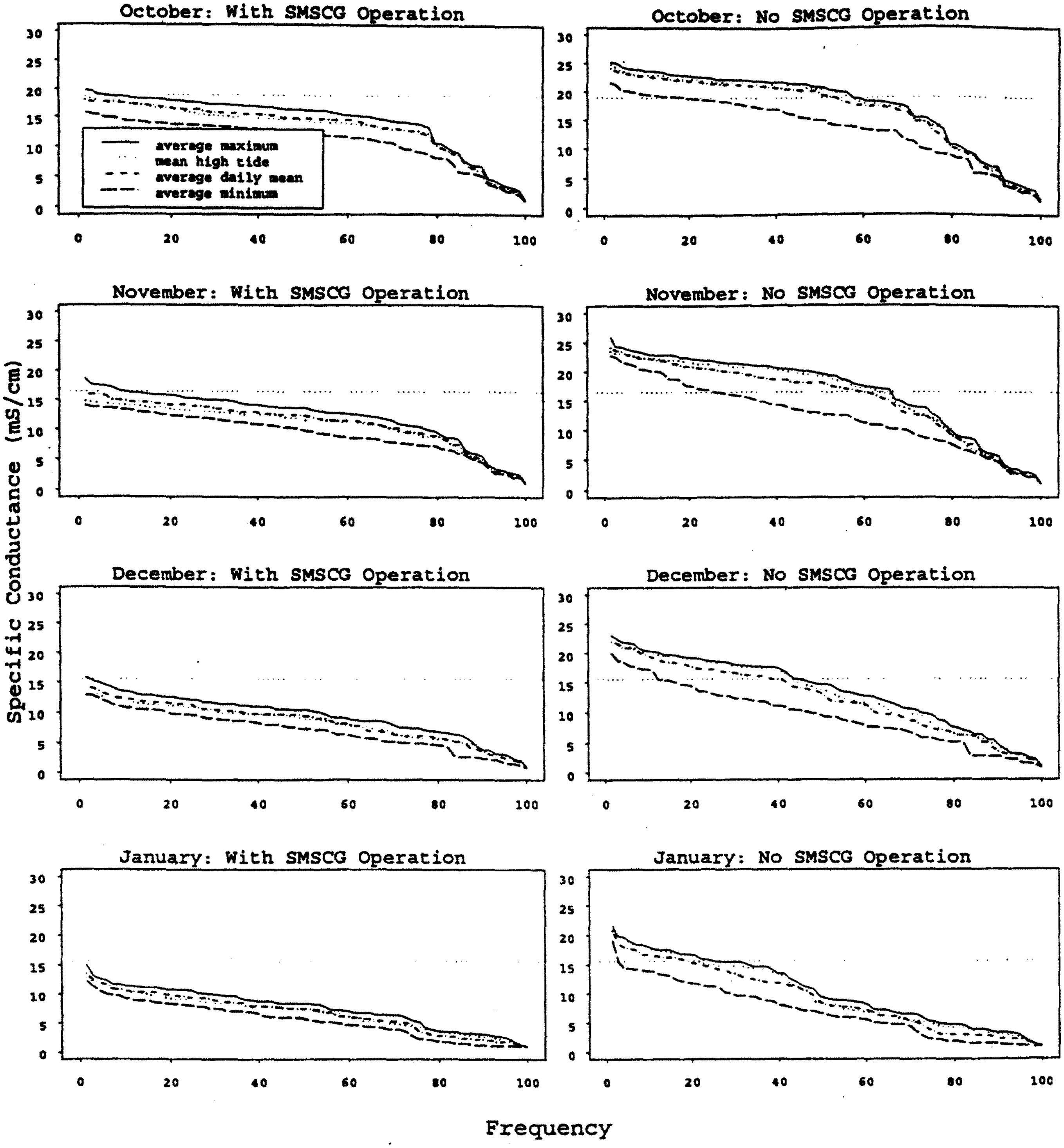
1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

Station S21 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

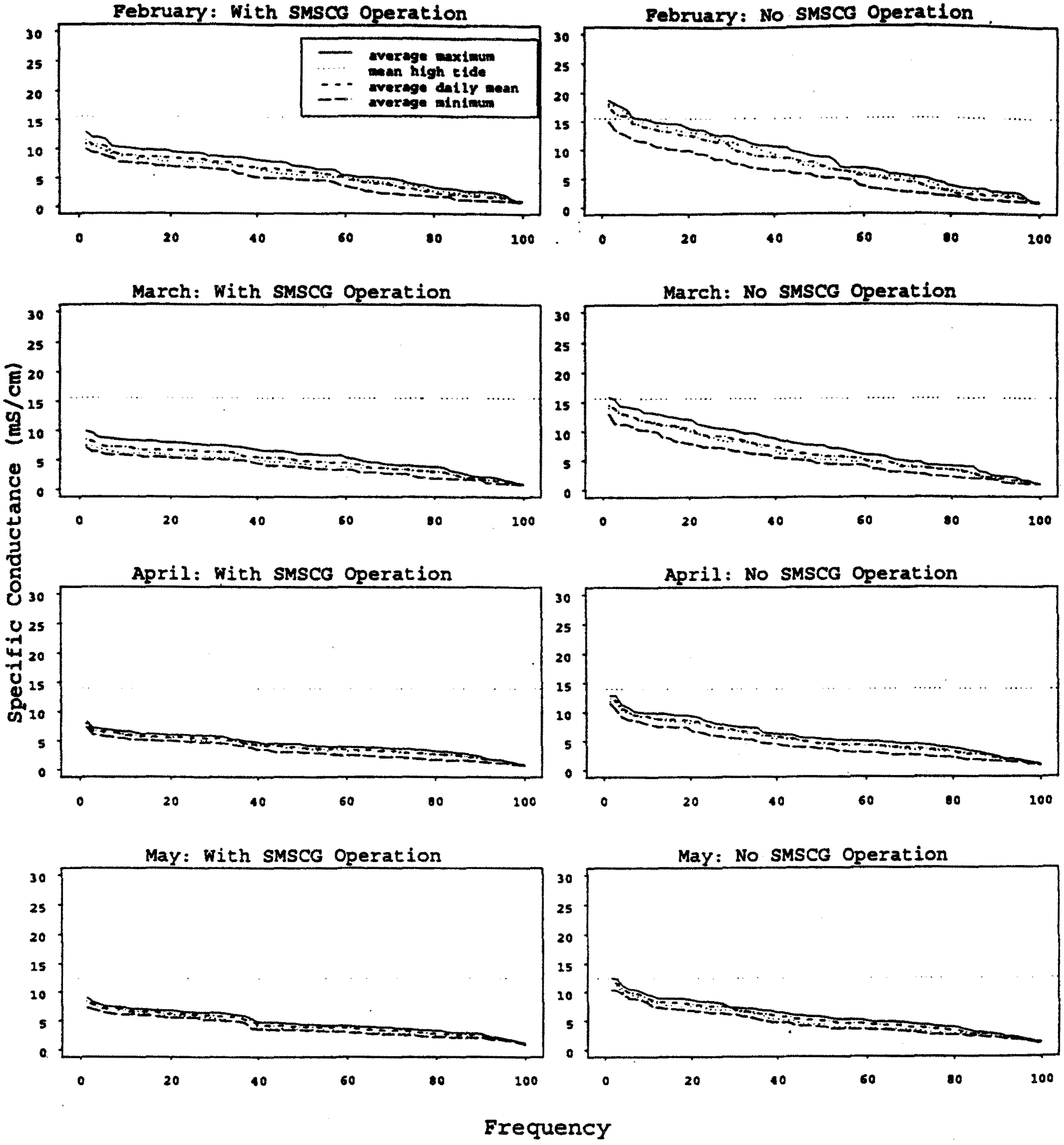


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S21 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/



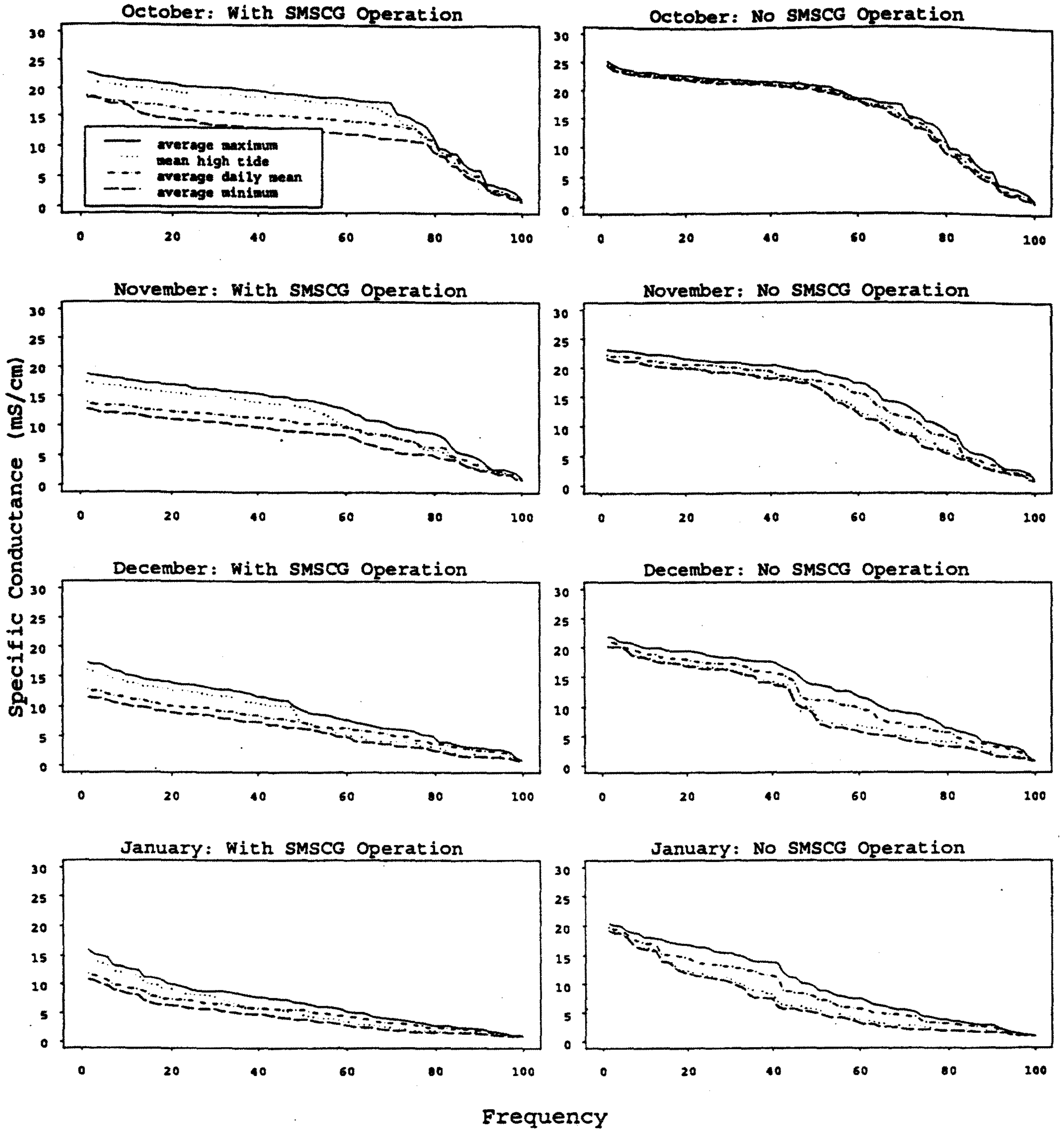
1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

Station S54 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

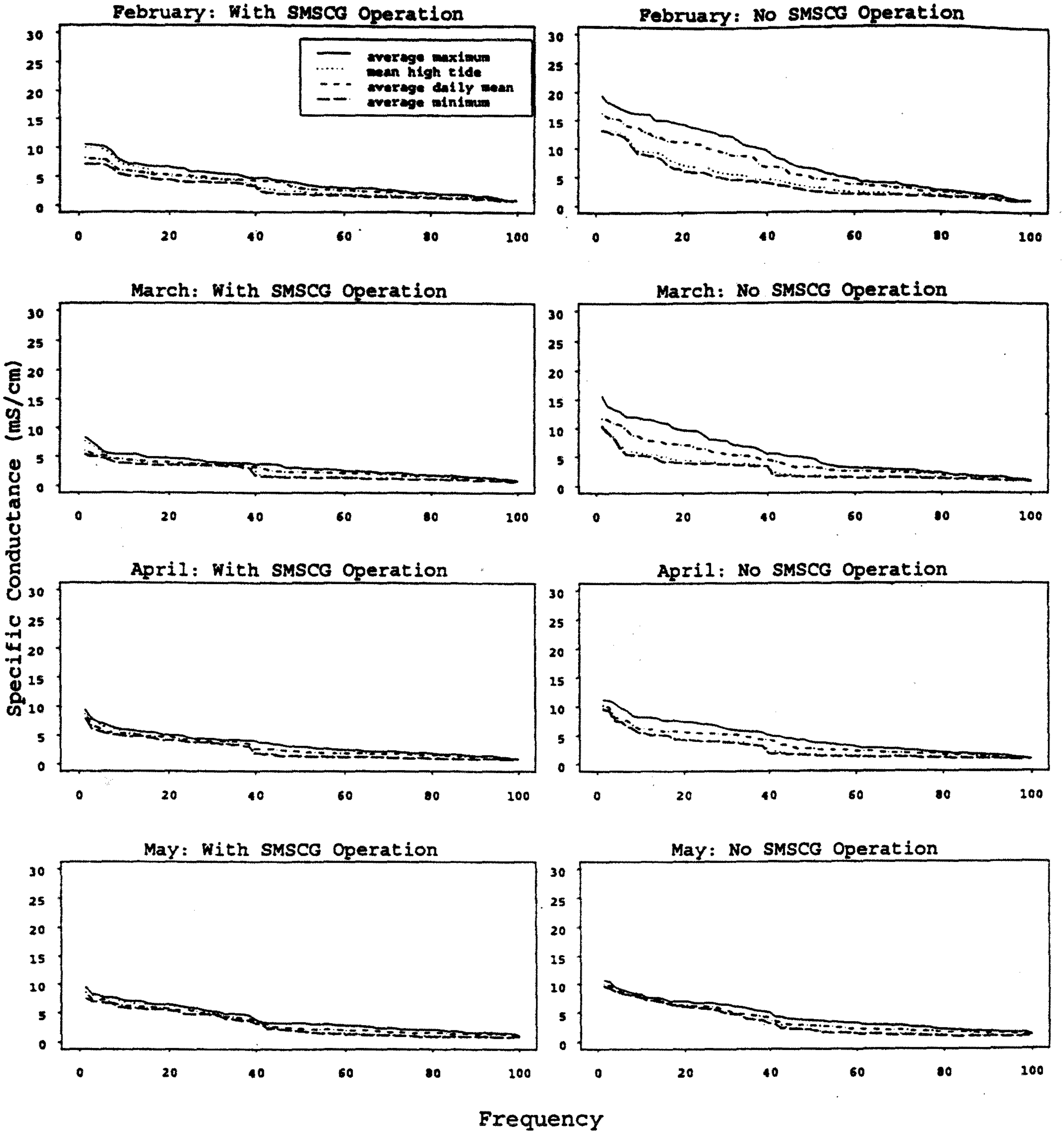


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S34 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

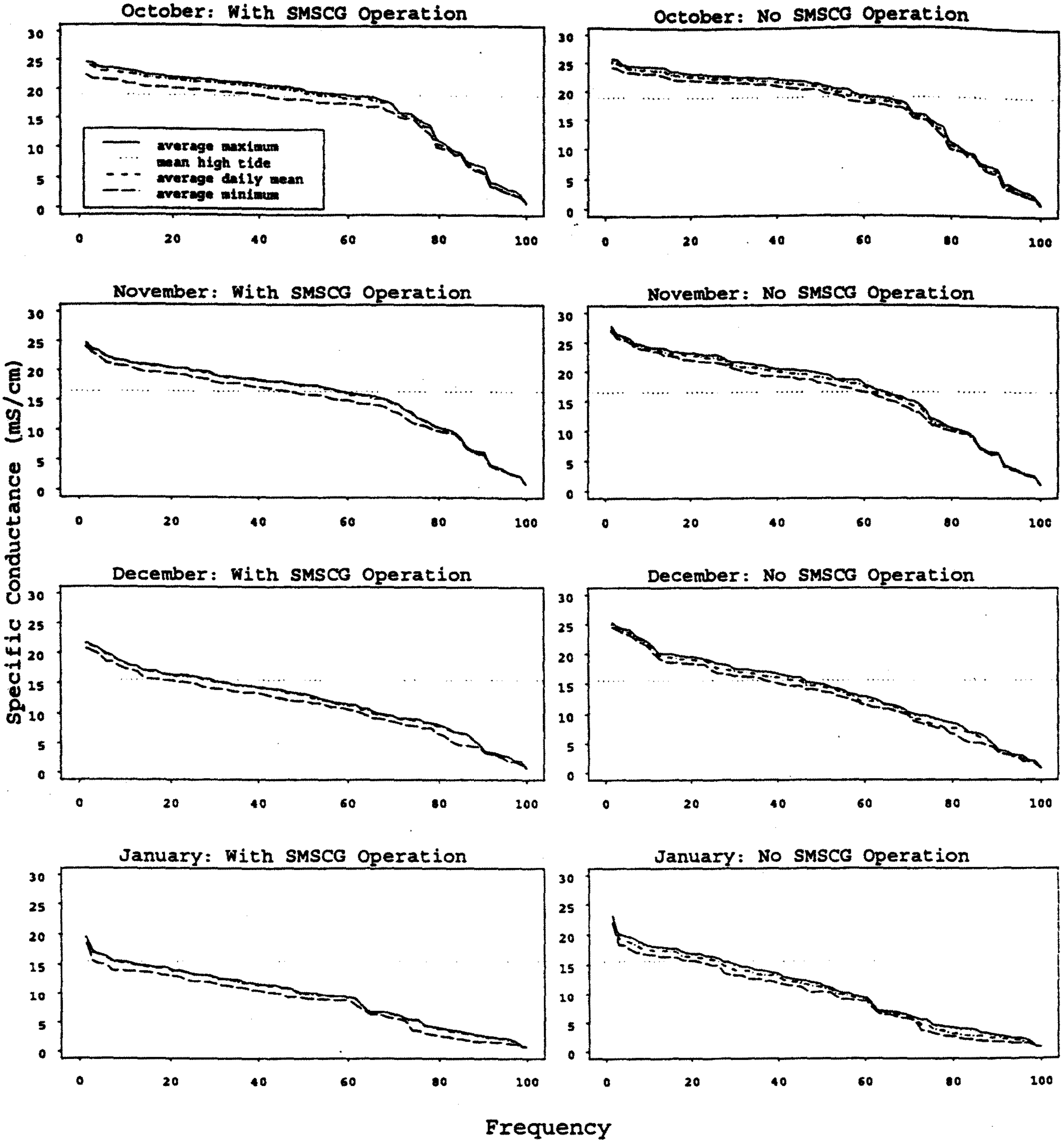


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/



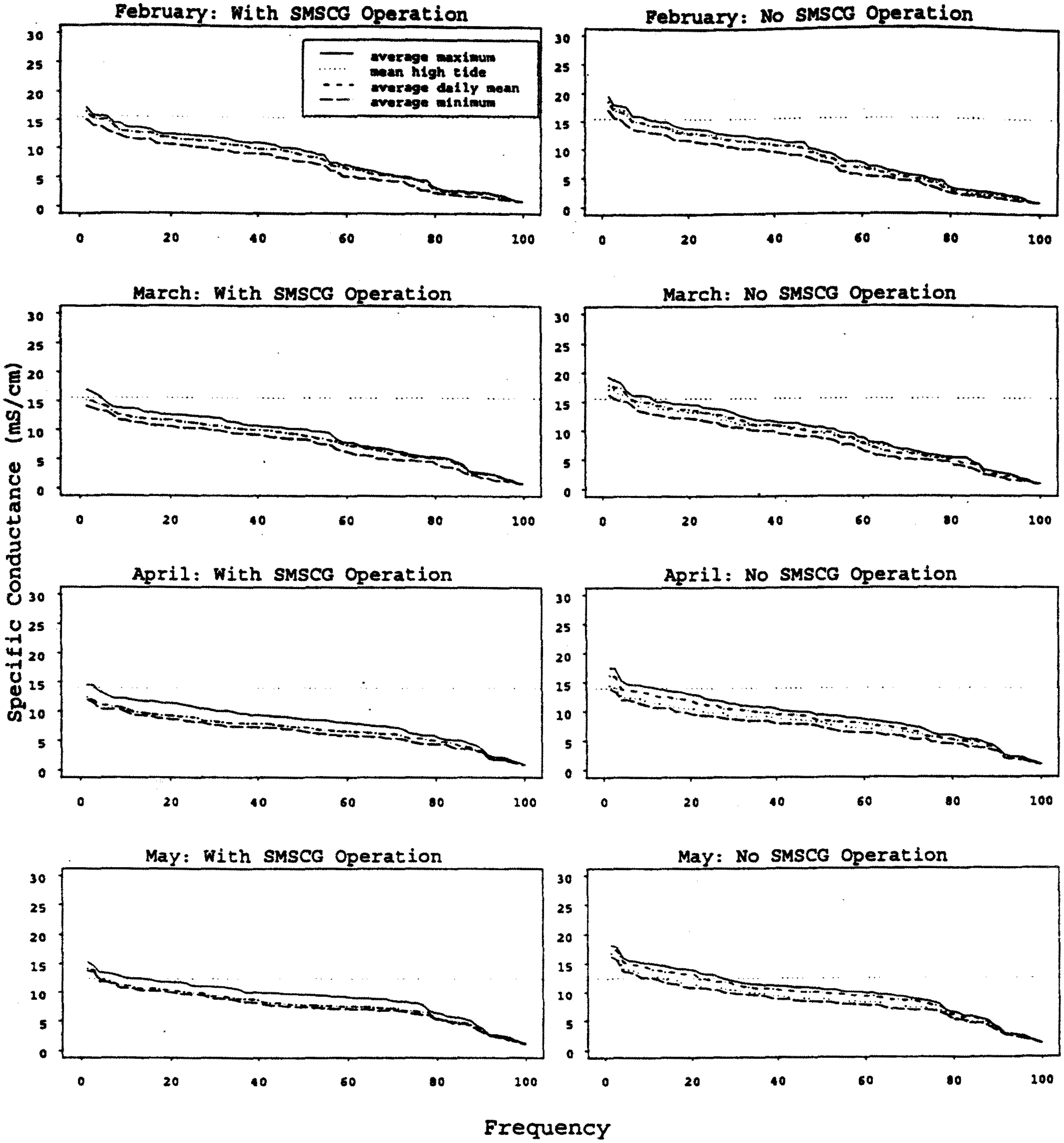
1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.

DWR Suisun Marsh Planning

WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

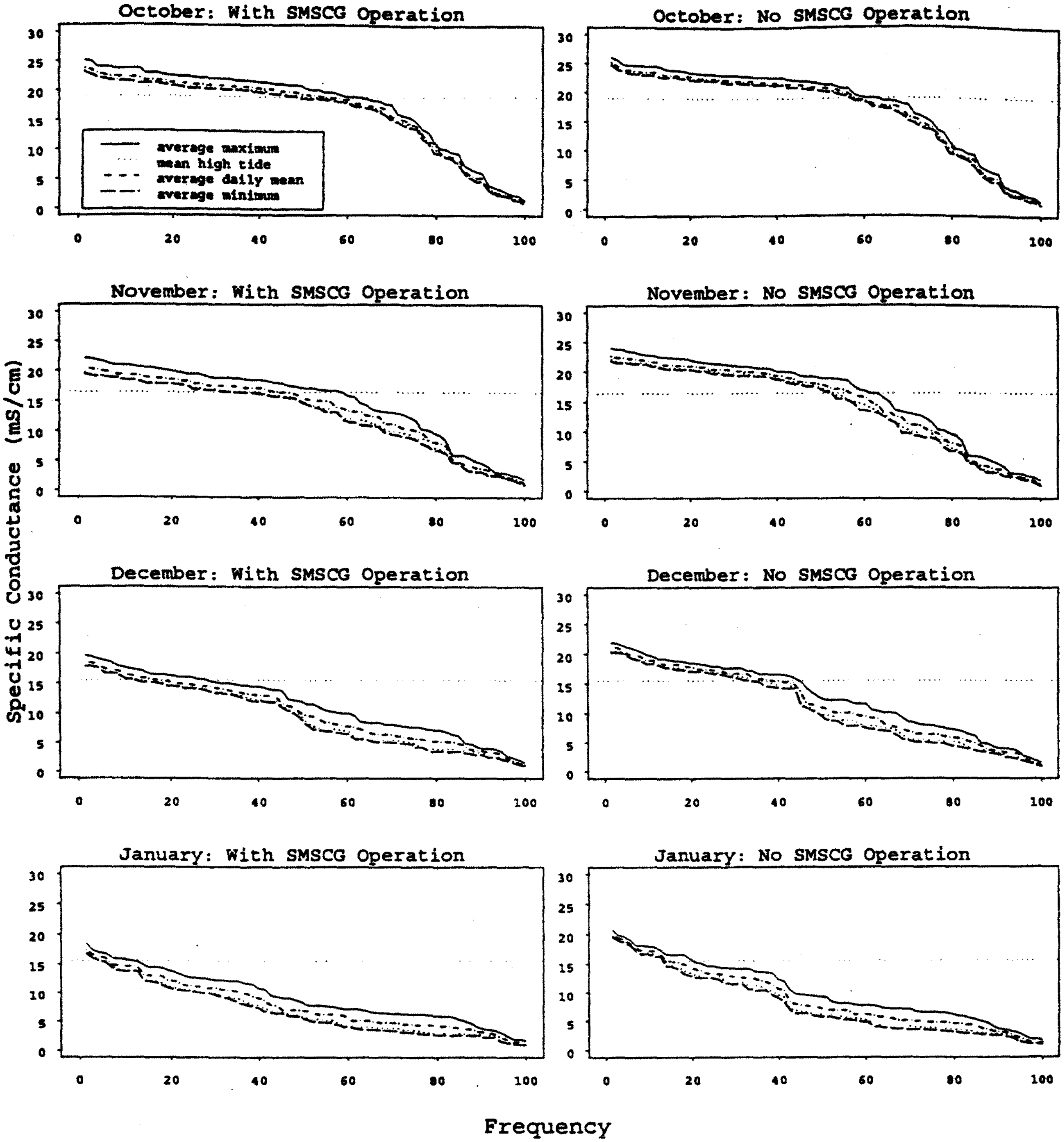


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Station S35 Specific Conductance 1/
WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/

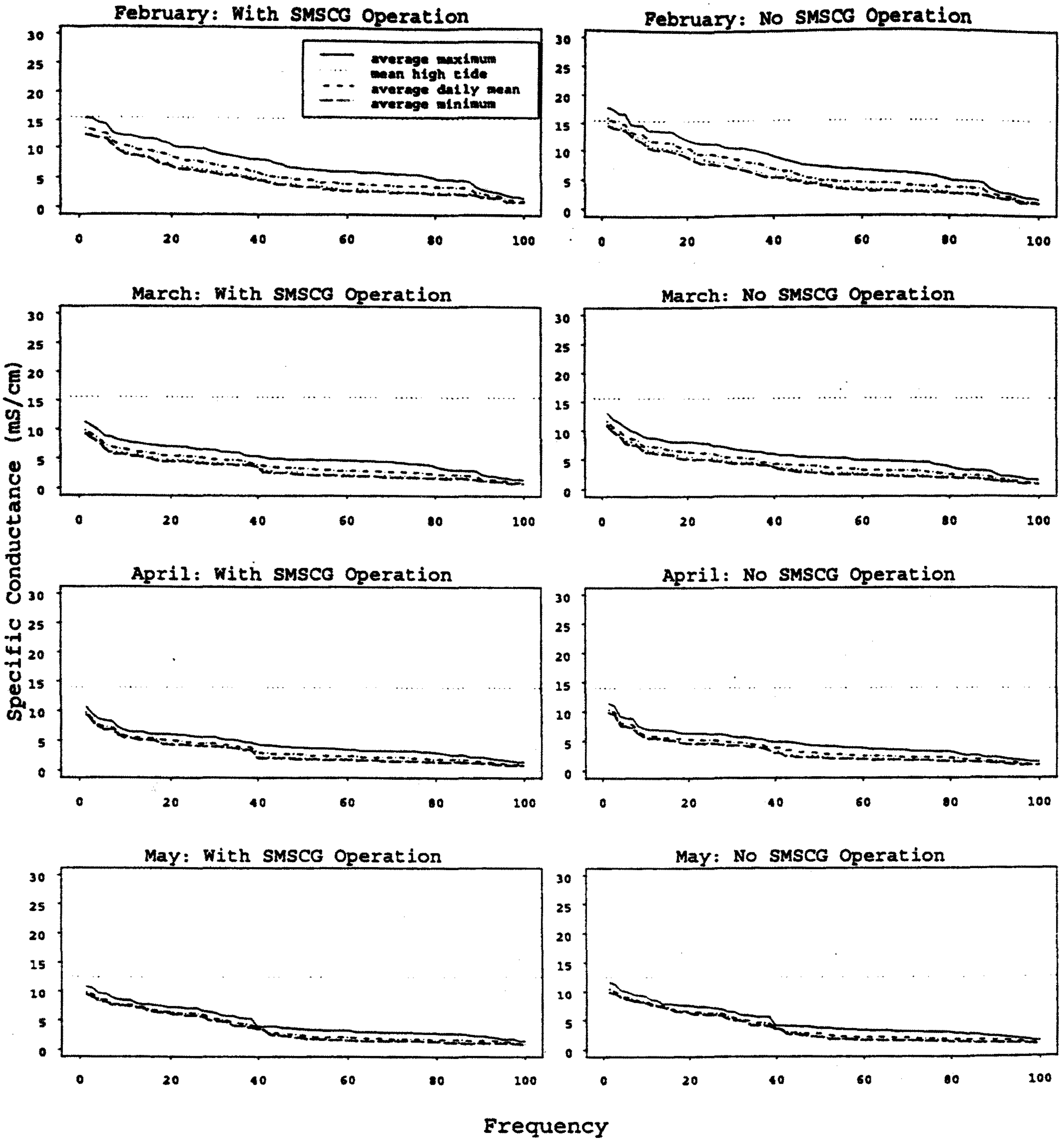


1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

WQCP: With SMSCG Operation 2/
Without SMSCG Operation 3/



1/ October - May Monthly Averages of 73 Year DSM1 Model Salinity Data (1922 - 1994).
End of Month Mean High Tide Salinity = Monthly average of high-high and high-low tide salinities.
Average Minimum Salinity = Monthly average of daily minimum salinity.
Average Maximum Salinity = Monthly average of daily maximum salinity.
Average Daily Mean = Monthly average of daily mean salinities.

2/ Excel Tabs 4,8,12,24 in 73avgsal.xls.
3/ Excel Tabs 2,6,10,22 in 73avgsal.xls.

All salinity data were ranked and associated with an exceedance frequency.
Nominal monthly standards indicated by dashed line. Deficiency standards not shown.
DWR Suisun Marsh Planning

Appendix 2A

Salinity Range Plots:

Monthly mean of daily high tide salinity, WQCP
hydrology, with gate operation
VS.
Monthly mean of daily high tide salinity, WQCP
hydrology without gate operation

National Steel (S64)
Hill Slough (S04)
Volanti (S42)
Sunrise (S21)
Hunter Cut (S54)
Ibis (S97)
Goodyear Slough (S35)

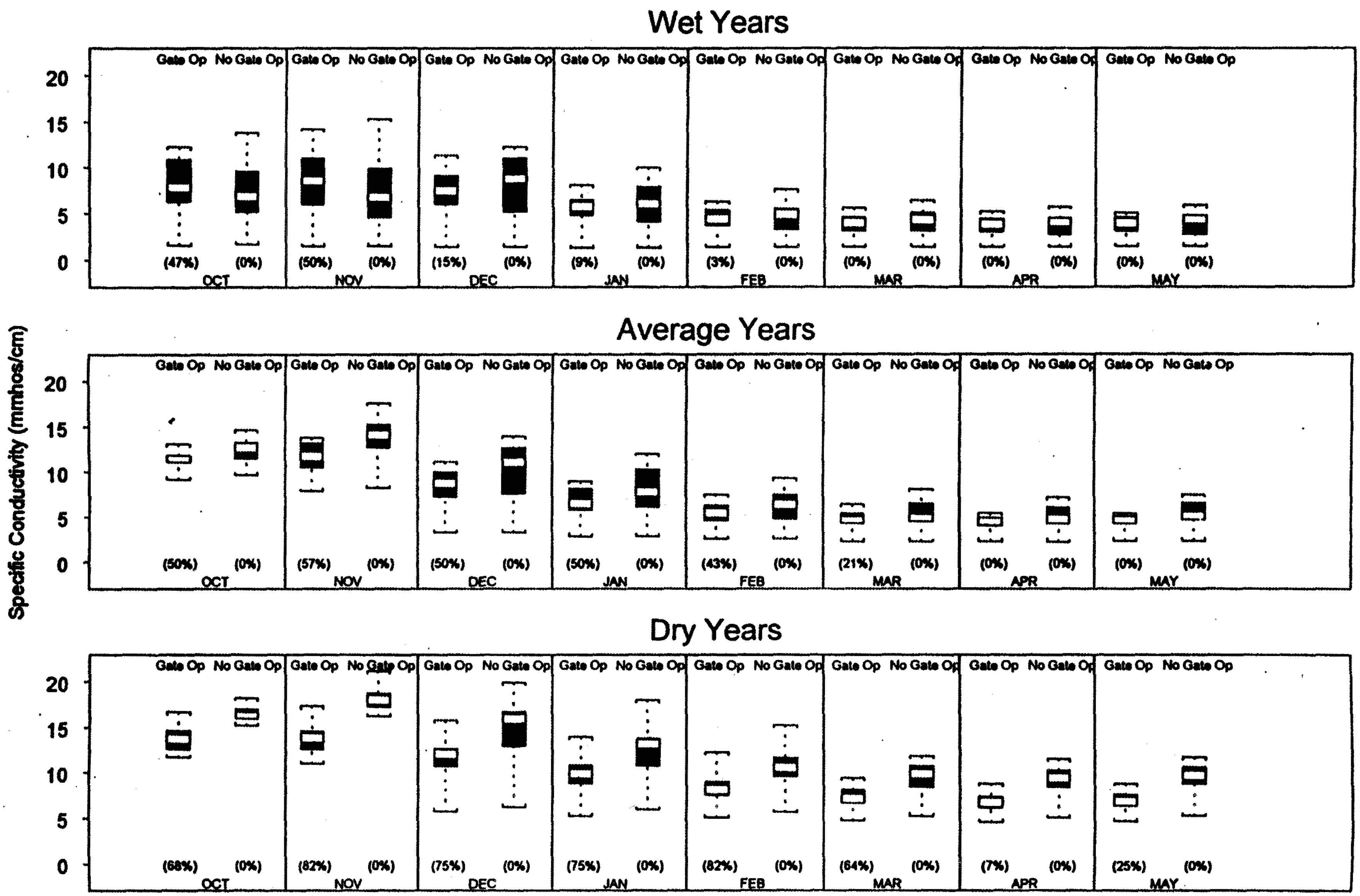
Monthly Mean of Daily High Tide Salinity With SMSCG Operation and WQCP Hydrology

vs.

Monthly Mean of Daily High Tide Salinity Without SMSCG Operation and WQCP Hydrology

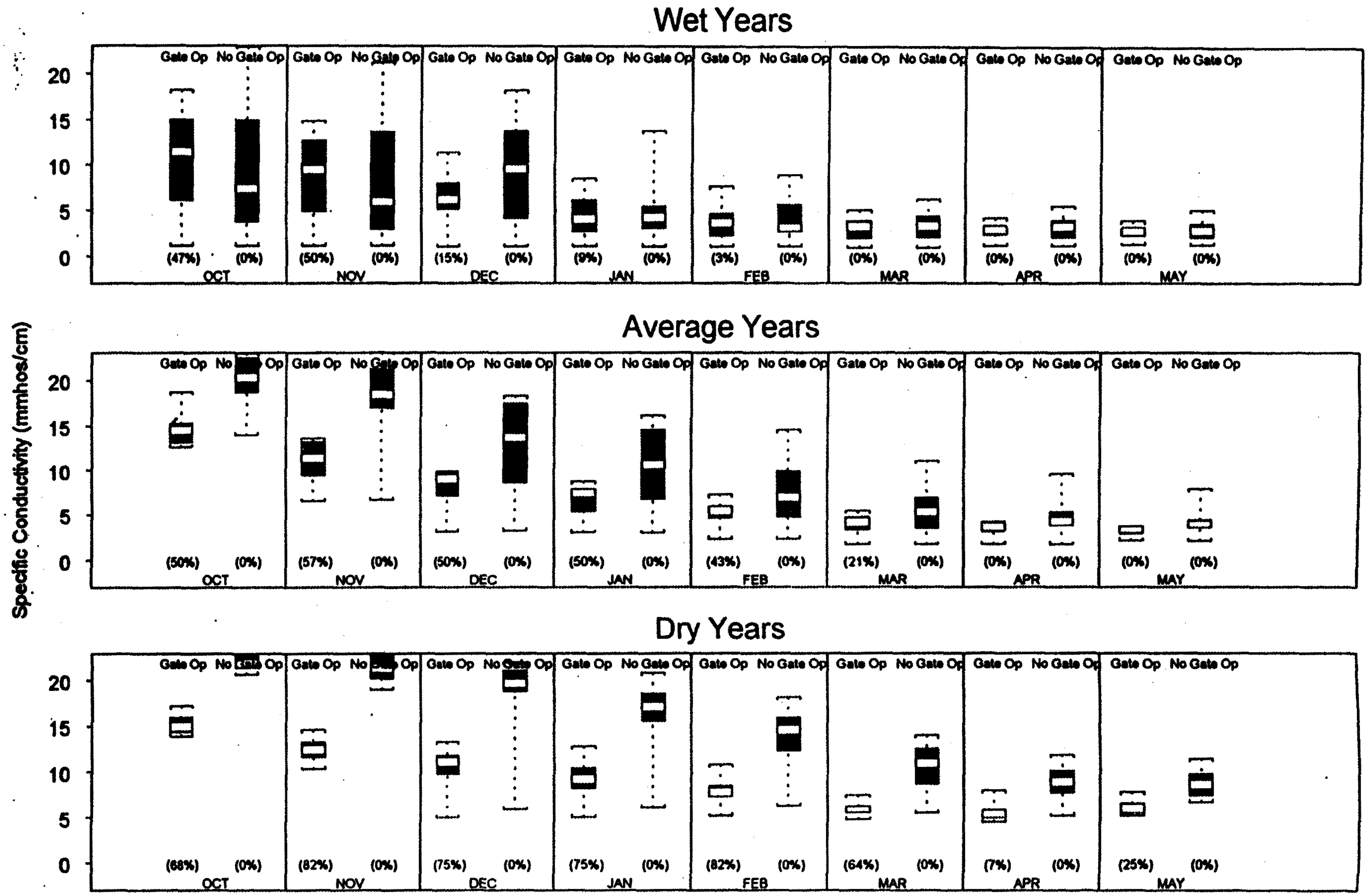
Hill Slough at S04

Mean of Daily High Tide Salinity *with* SMSCG Operation and WQCP Hydrology (Gate Op) vs Mean of Daily High Tide Salinity *without* SMSCG Operation and WQCP Hydrology (No Gate Op) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside

Chadbourne Slough at S21
Mean of Daily High Tide Salinity *with* SMSCG Operation and WQCP Hydrology (Gate Op) vs Mean of Daily High Tide Salinity *without* SMSCG Operation and WQCP Hydrology (No Gate Op) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points.

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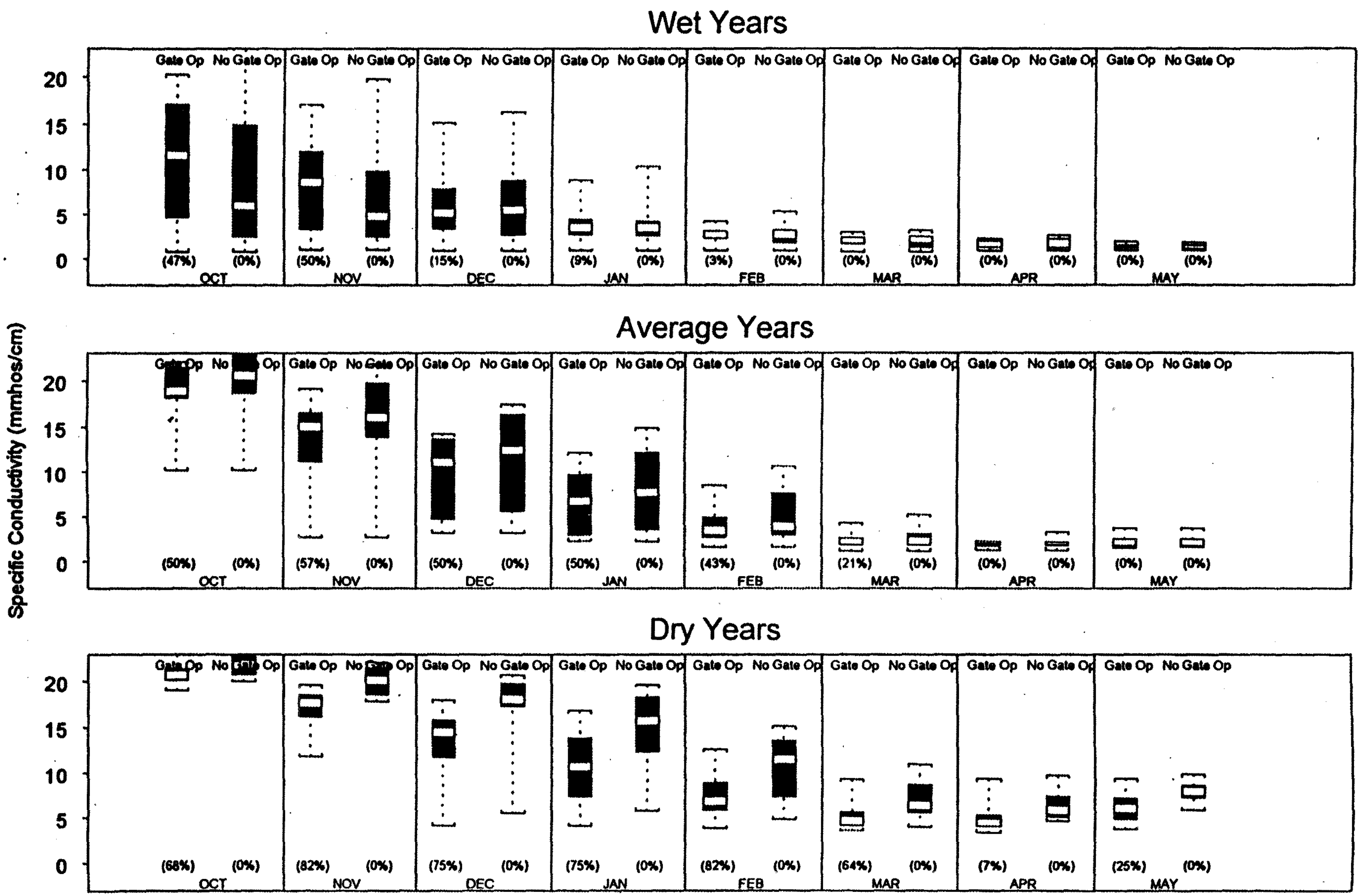
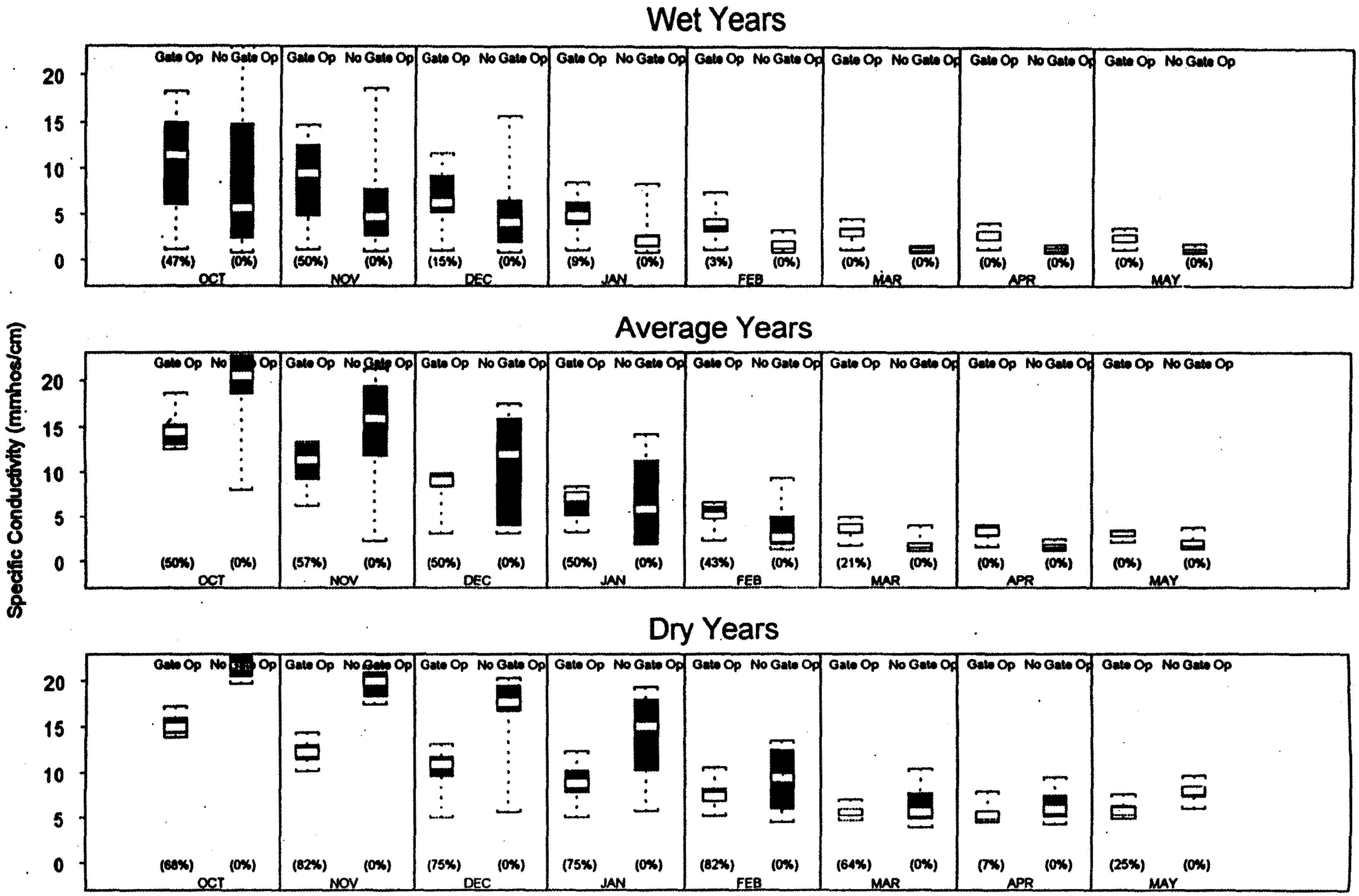
Goodyear Slough at S35
Mean of Daily High Tide Salinity *with* SMSCG Operation and WQCP Hydrology (Gate Op) vs Mean of Daily High Tide Salinity *without* SMSCG Operation and WQCP Hydrology (No Gate Op) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points.

Volanti Slough at S42
Mean of Daily High Tide Salinity *with* SMSCG Operation and WQCP Hydrology (Gate Op) vs Mean of Daily High Tide Salinity *without* SMSCG Operation and WQCP Hydrology (No Gate Op) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points.

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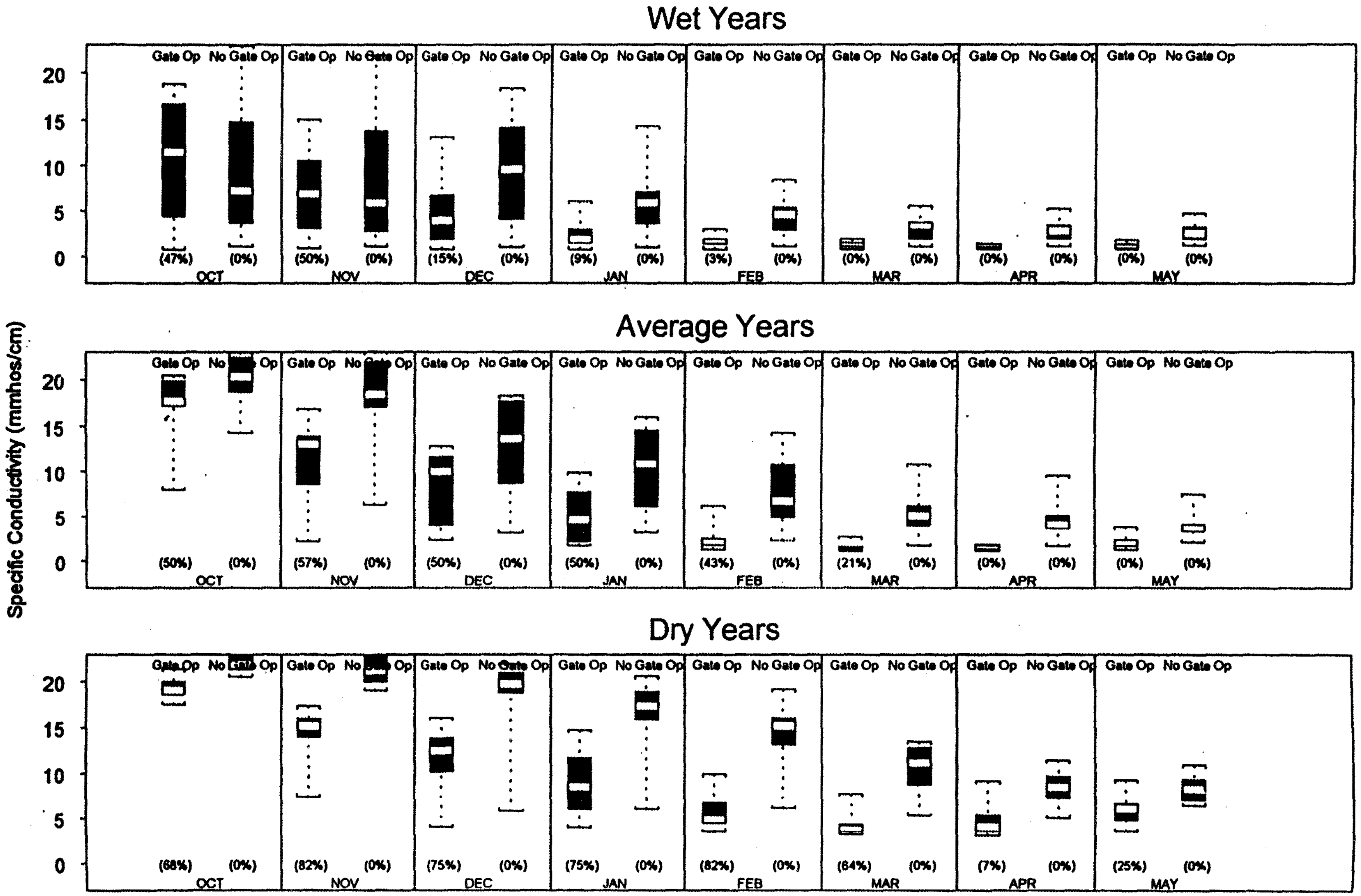
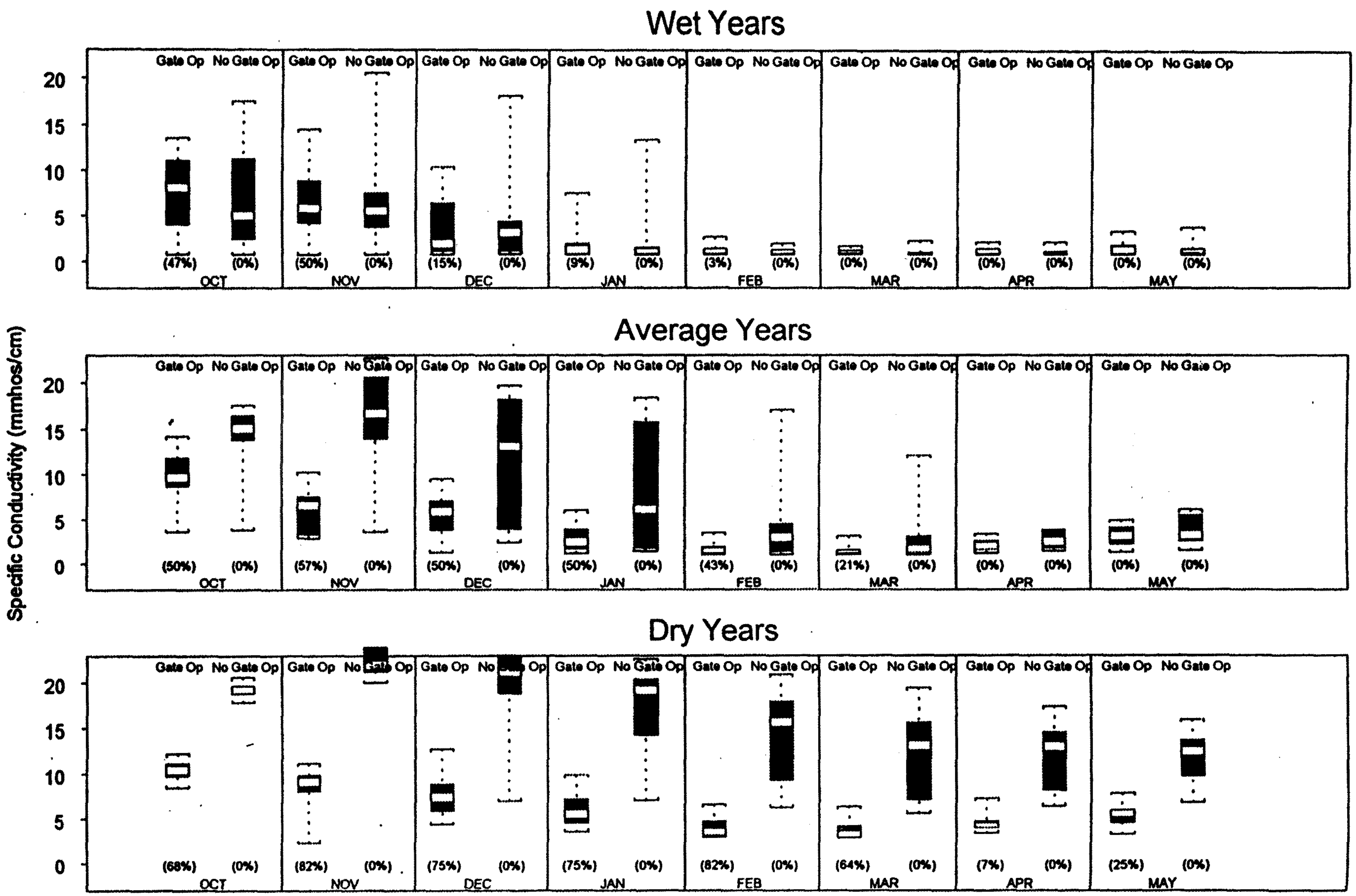
Montezuma Slough at S54

Mean of Daily High Tide Salinity *with* SMSCG Operation and WQCP Hydrology (Gate Op) vs Mean of Daily High Tide Salinity *without* SMSCG Operation and WQCP Hydrology (No Gate Op) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside
the box is the median value, and the "wiskers" show the extreme points

Montezuma Slough at S64
Mean of Daily High Tide Salinity *with* SMSCG Operation and WQCP Hydrology (Gate Op) vs Mean of Daily High Tide Salinity *without* SMSCG Operation and WQCP Hydrology (No Gate Op) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points.

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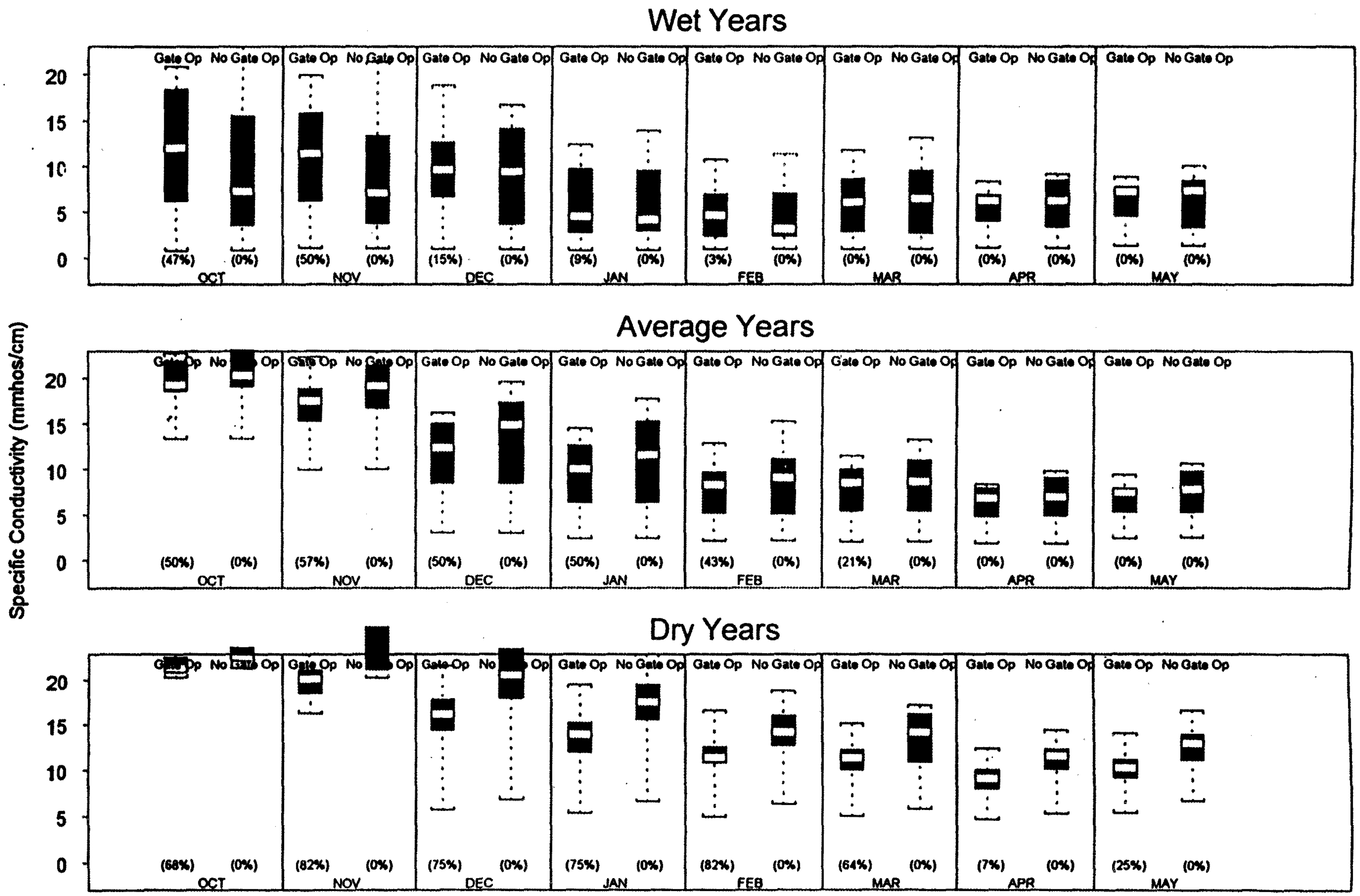
Cordelia Slough at S97
Mean of Daily High Tide Salinity *with* SMSCG Operation and WQCP Hydrology (Gate Op) vs Mean of Daily High Tide Salinity *without* SMSCG Operation and WQCP Hydrology (No Gate Op) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points

Appendix 2B

Salinity Range Plots:

Monthly mean of daily high tide salinity, WQCP hydrology, with gate operation
VS.
Monthly mean of daily high tide salinity, D1485 hydrology, with gate operation

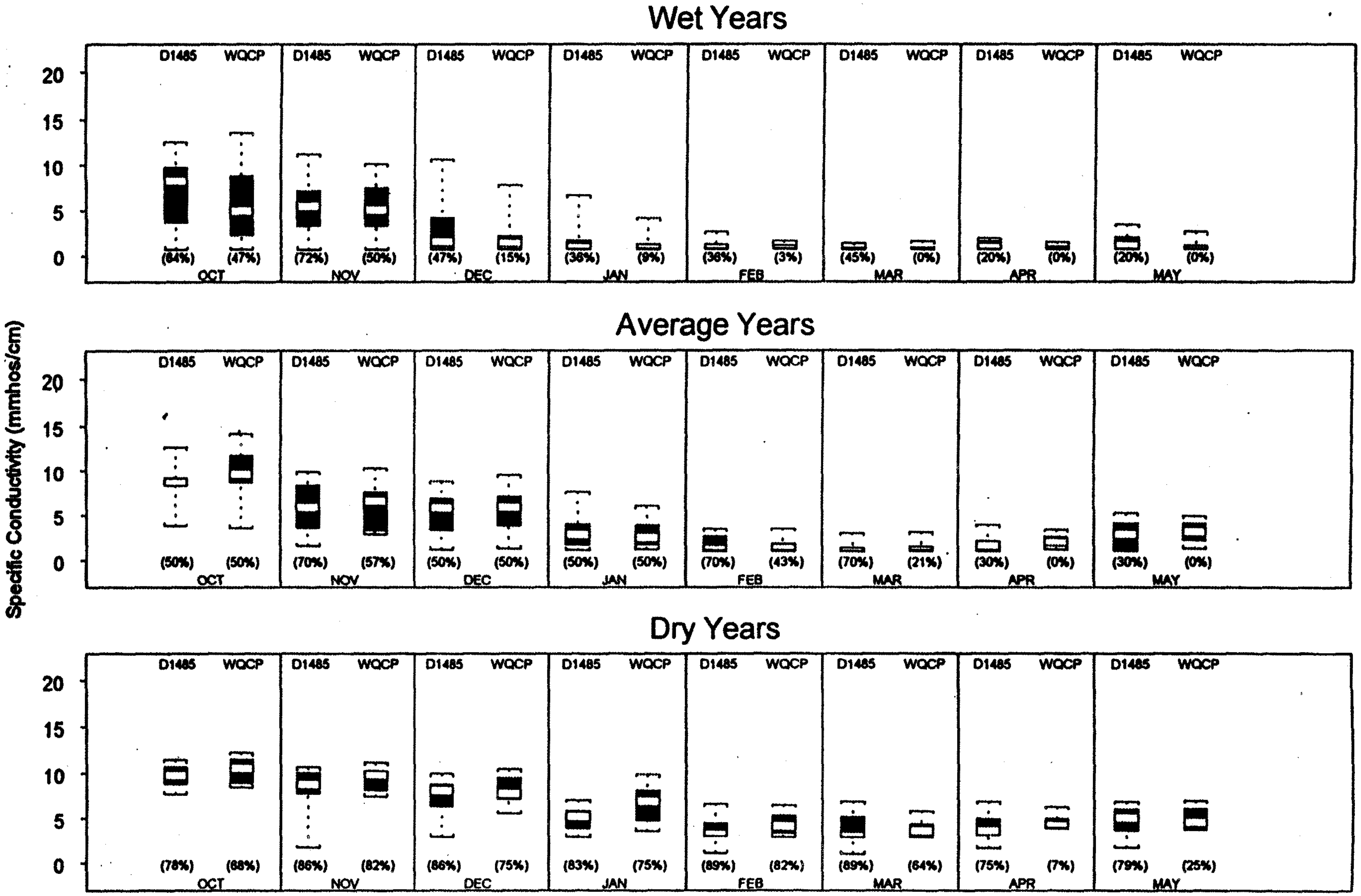
National Steel (S64)
Hill Slough (S04)
Volanti (S42)
Sunrise (S21)
Hunter Cut (S54)
Ibis (S97)
Goodyear Slough (S35)

Monthly Mean of Daily High Tide Salinity With SMSCG Operation and D1485 Hydrology

vs.

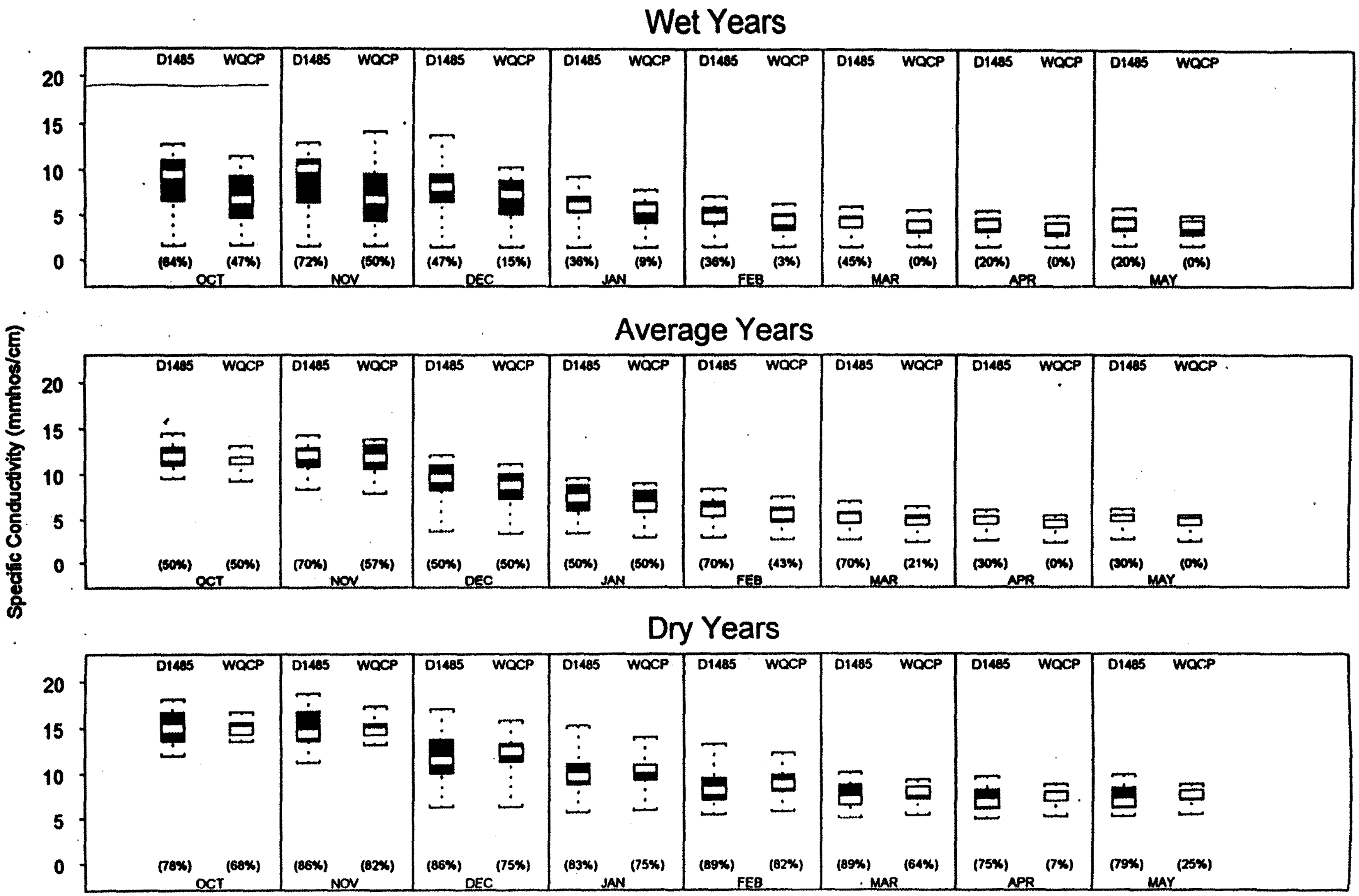
Monthly Mean of Daily High Tide Salinity With SMSCG Operation and WQCP Hydrology

Montezuma Slough at S64
Mean of Daily High Tide Salinity with SMSCG Operation and *D1485* Hydrology (D1485) vs Mean of Daily High Tide Salinity with SMSCG Operation and *WQCP* Hydrology (WQCP) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points

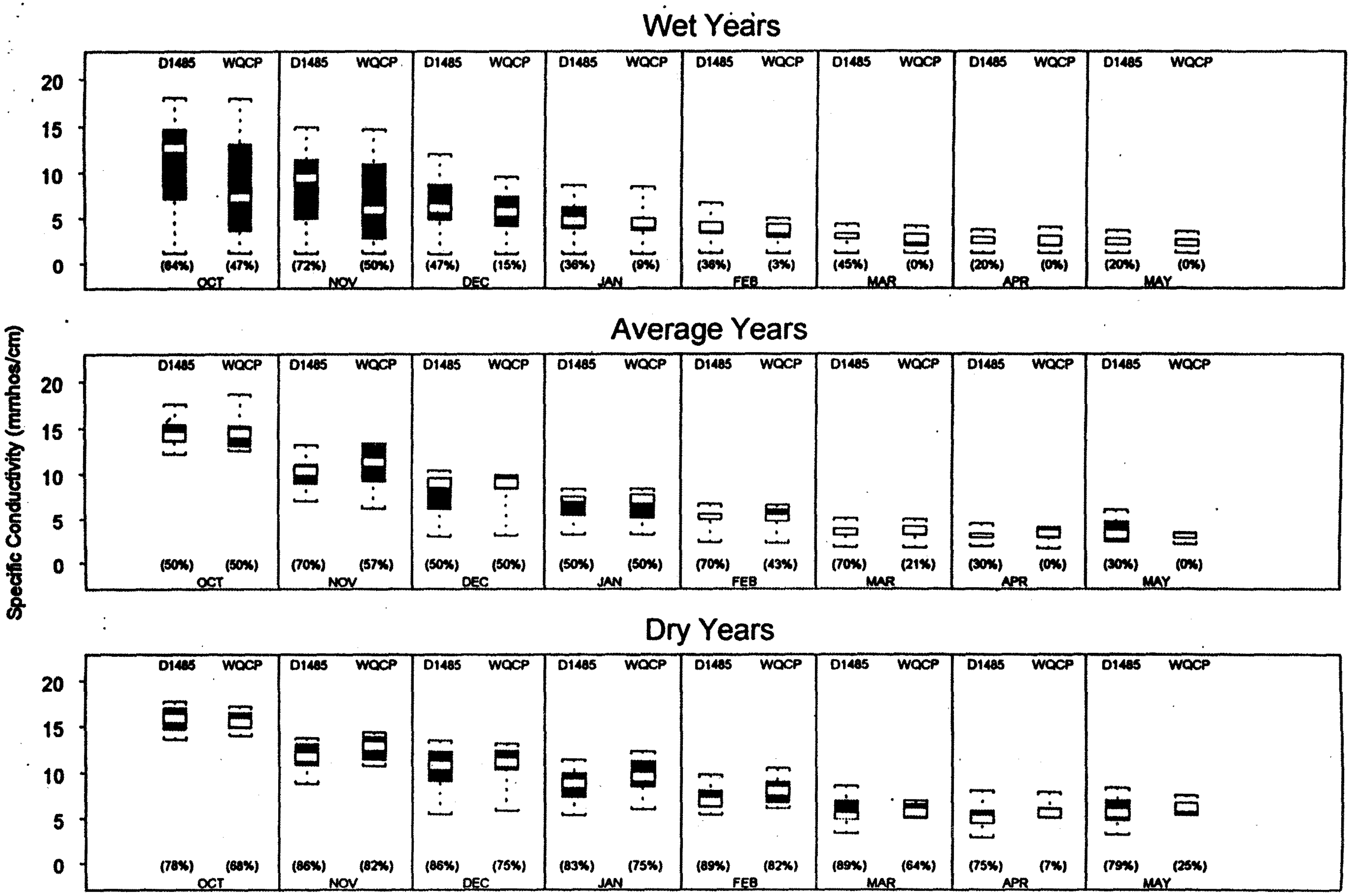
Hill Slough at S04
Mean of Daily High Tide Salinity with SMSCG Operation and *D1485* Hydrology (D1485) vs Mean of Daily High Tide Salinity with SMSCG Operation and *WQCP* Hydrology (WQCP) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points.

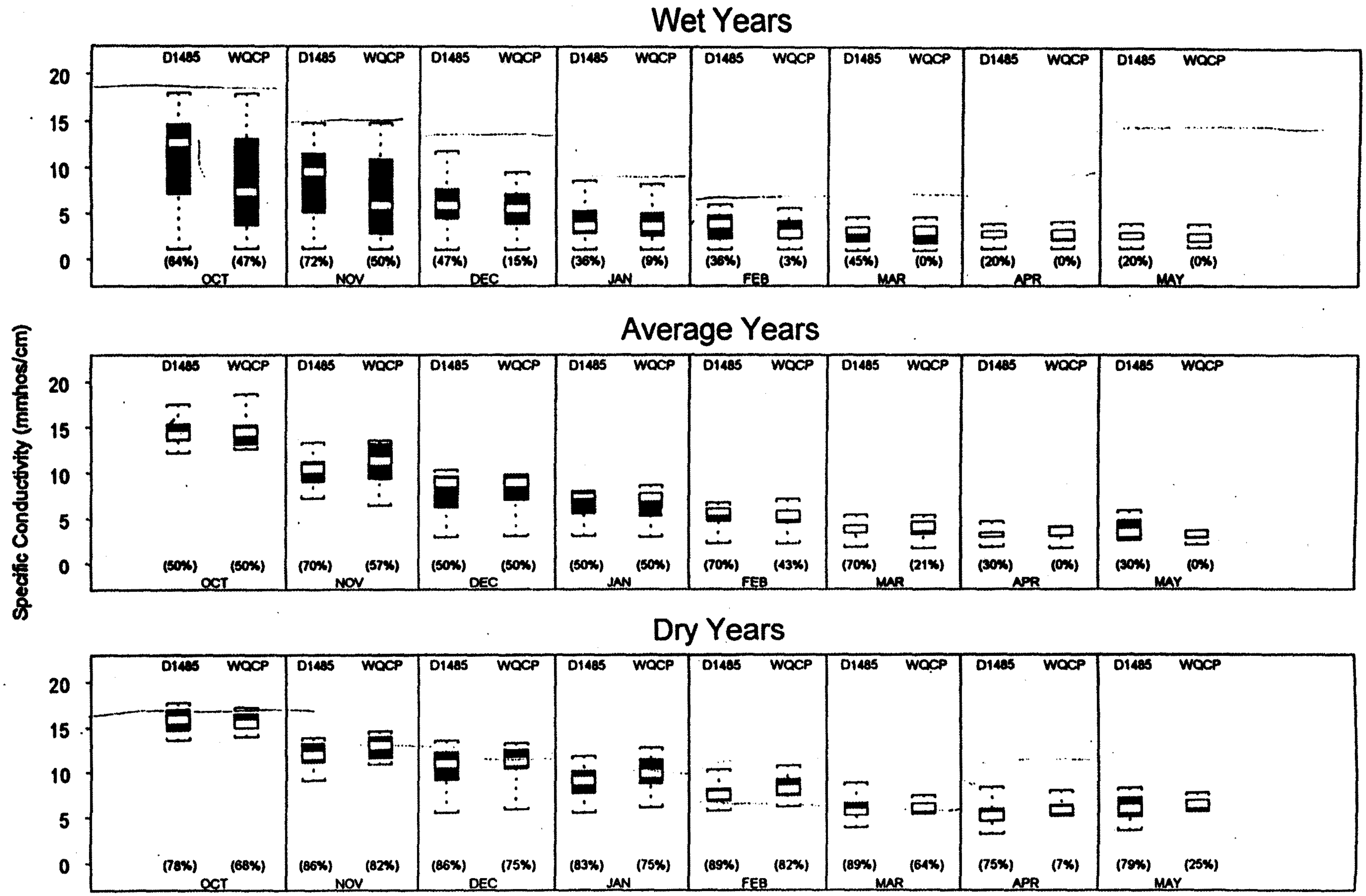
DWR Suisun Marsh Planning

Volanti Slough at S42
Mean of Daily High Tide Salinity with SMSCG Operation and *D1485* Hydrology (D1485) vs Mean of Daily High Tide Salinity with SMSCG Operation and *WQCP* Hydrology (WQCP) 1/



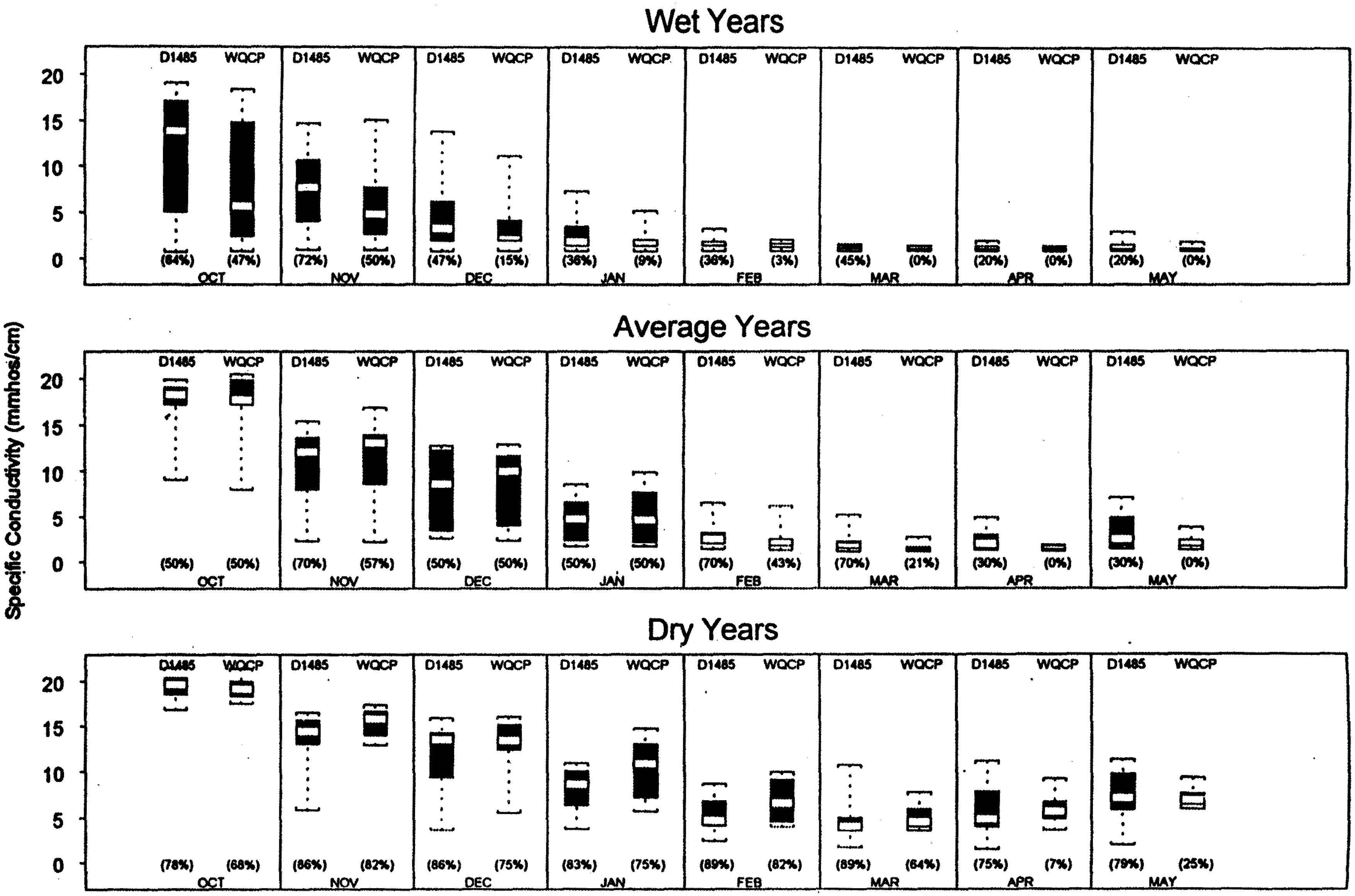
1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points

Chadbourne Slough at S21
Mean of Daily High Tide Salinity with SMSCG Operation and *D1485* Hydrology (D1485) vs Mean of Daily High Tide Salinity with SMSCG Operation and *WQCP* Hydrology (WQCP) 1/



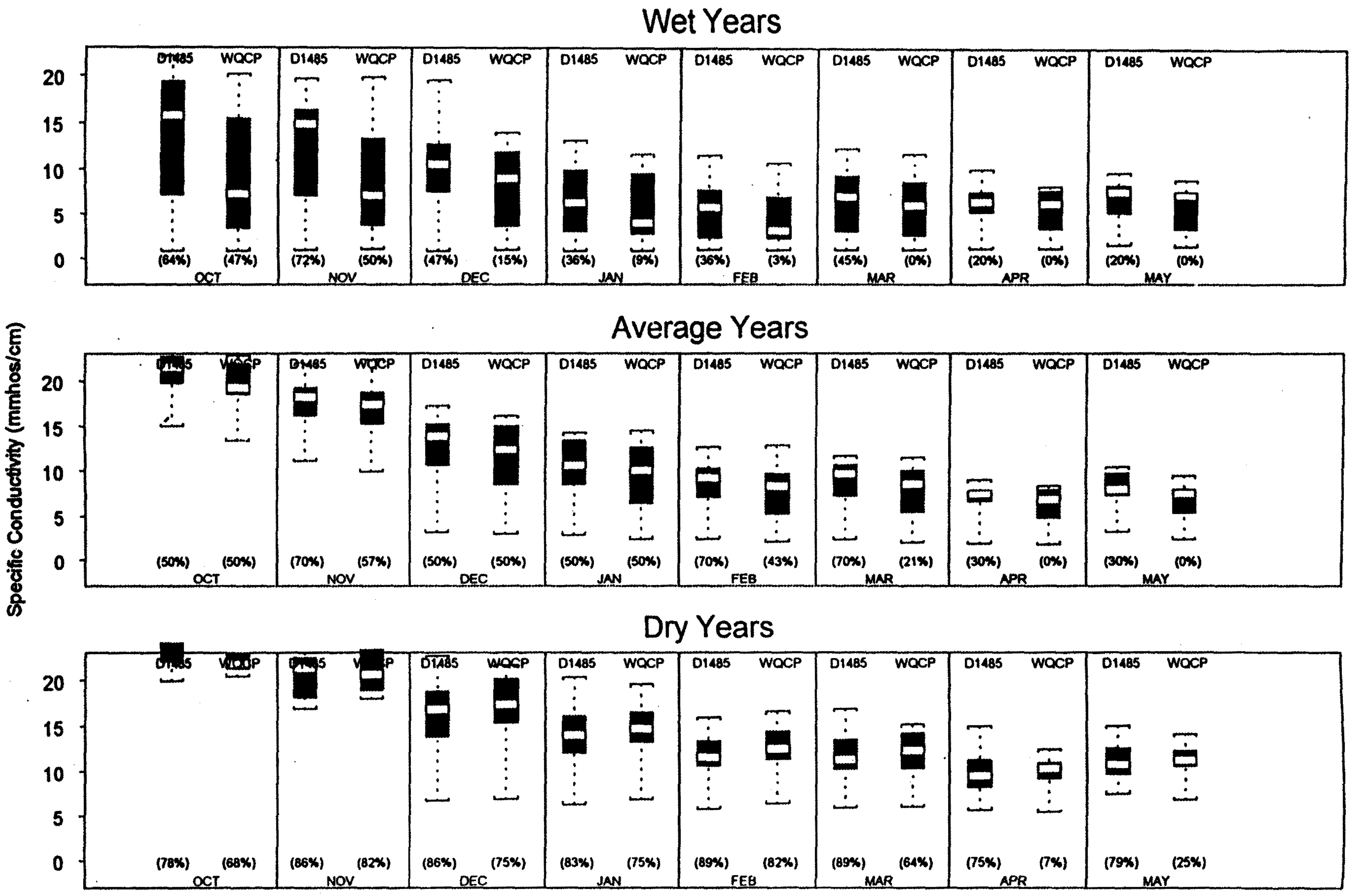
1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points.

Montezuma Slough at S54
Mean of Daily High Tide Salinity with SMSCG Operation and *D1485* Hydrology (D1485) vs Mean of Daily High Tide Salinity with SMSCG Operation and *WQCP* Hydrology (WQCP) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points

Cordelia Slough at S97
Mean of Daily High Tide Salinity with SMSCG Operation and *D1485* Hydrology (D1485) vs Mean of Daily High Tide Salinity with SMSCG Operation and *WQCP* Hydrology (WQCP) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points.

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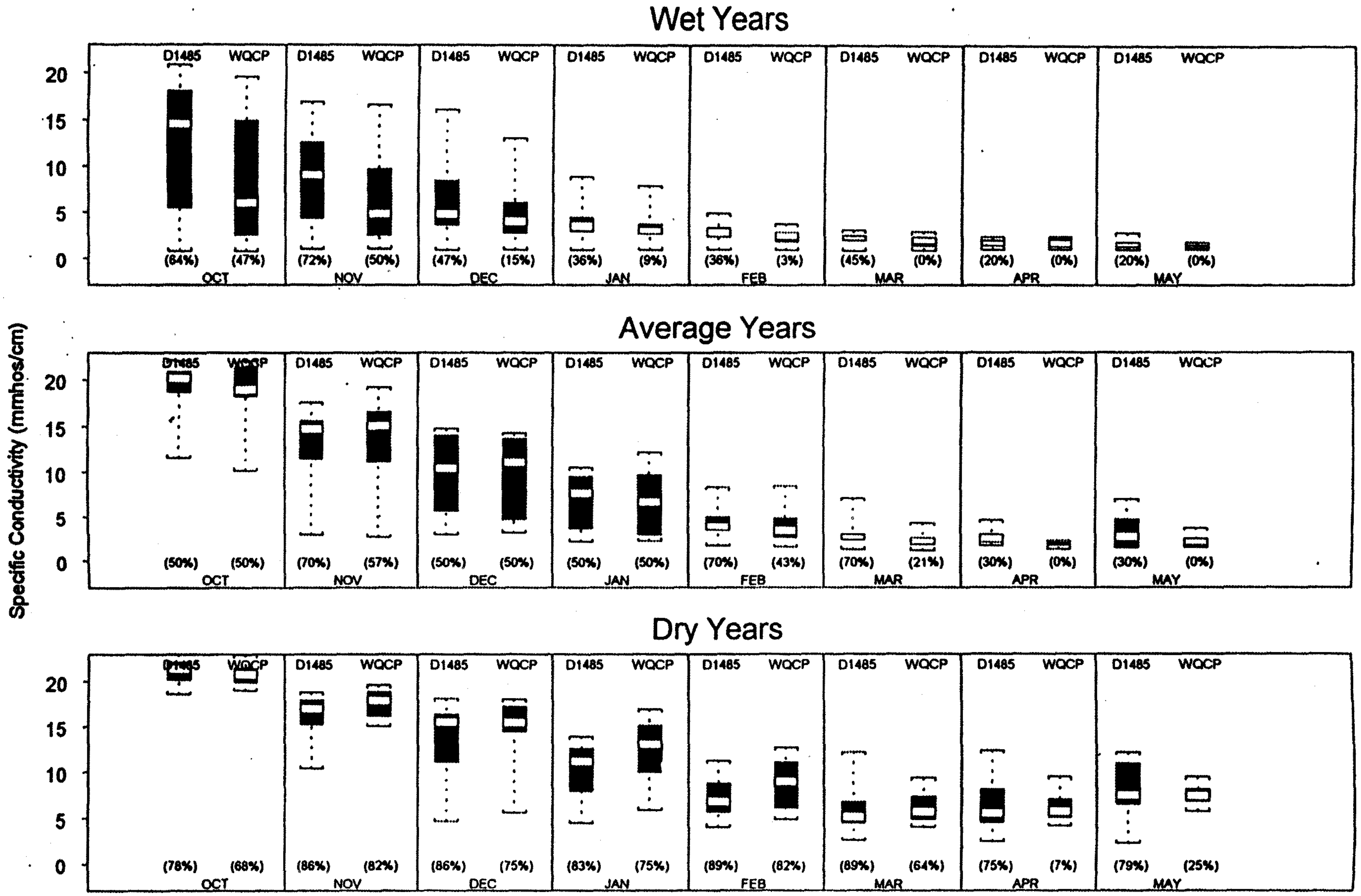
Goodyear Slough at S35
Mean of Daily High Tide Salinity with SMSCG Operation and *D1485* Hydrology (D1485) vs Mean of Daily High Tide Salinity with SMSCG Operation and *WQCP* Hydrology (WQCP) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points

Appendix 2C

Salinity Range Plots:

Monthly mean of daily high tide salinity, WQCP hydrology, with gate operation
VS.
Average of daily mean salinity, WCP hydrology, without gate operation

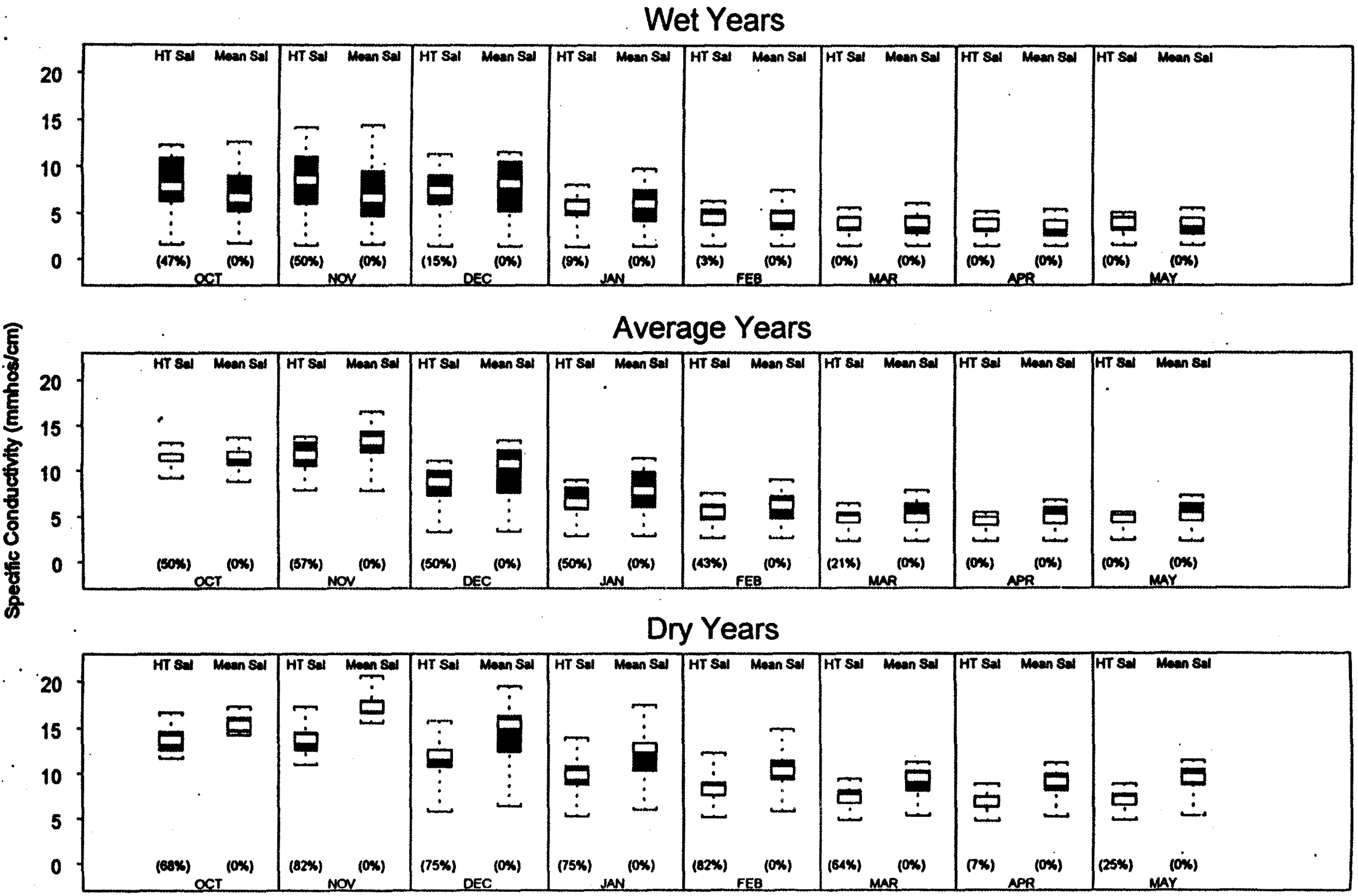
National Steel (S64)
Hill Slough (S04)
Volanti (S42)
Sunrise (S21)
Hunter Cut (S54)
Ibis (S97)
Goodyear Slough (S35)

Monthly Mean of Daily High Tide Salinity With SMSCG Operation and WQCP Hydrology

vs.

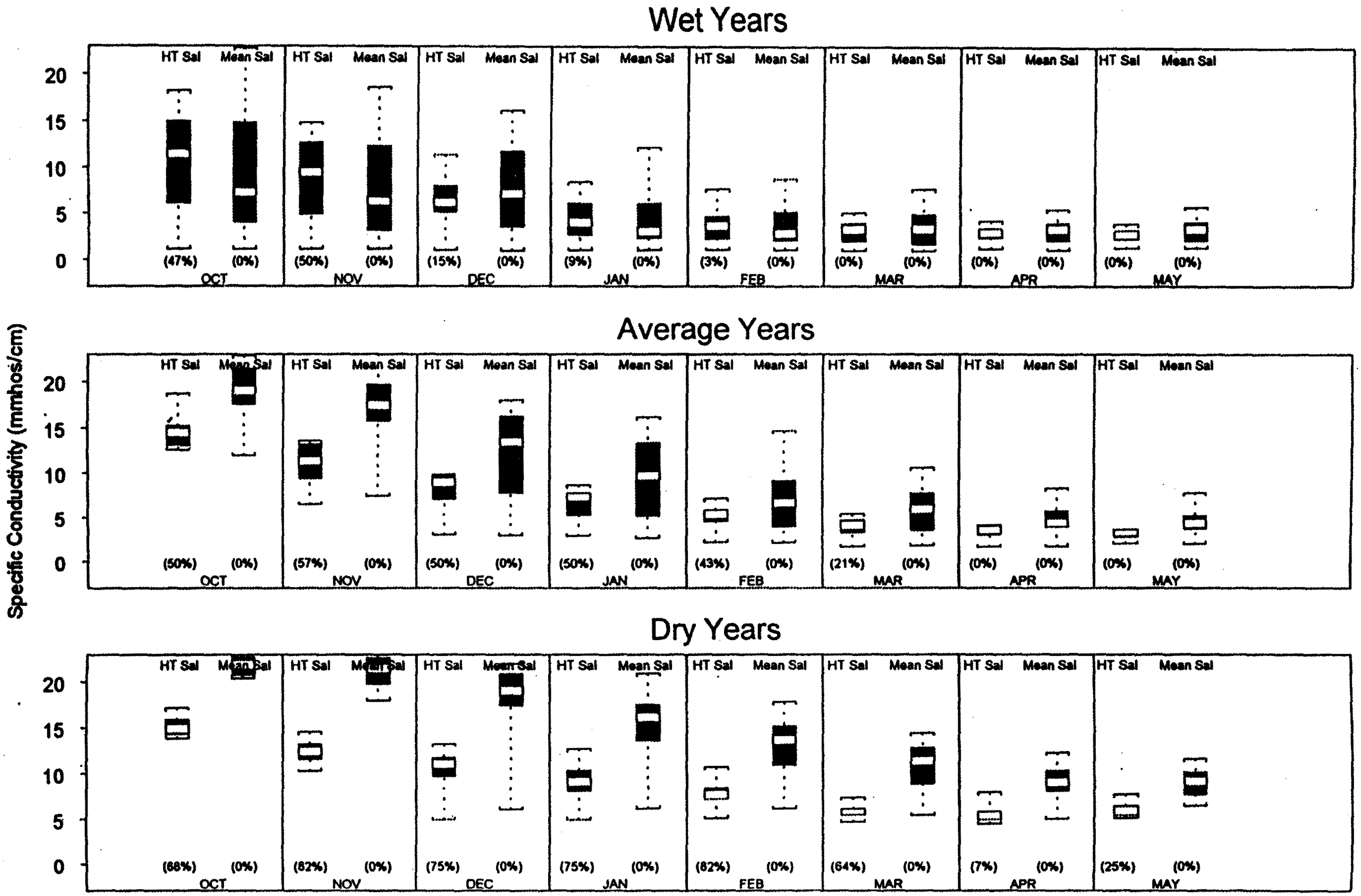
Monthly Mean of Daily Mean Salinity Without SMSCG Operation and WQCP Hydrology

Hill Slough at S04
Mean of Daily High Tide Salinity with SMSCG Operation and WQCP Hydrology (HT Sal) vs Average of Daily Mean Salinity without SMSCG Operation and WQCP Hydrology (Mean Sal) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside

Chadbourne Slough at S21
Mean of Daily High Tide Salinity with SMSCG Operation and WQCP Hydrology (HT Sal) vs Average of Daily Mean Salinity without SMSCG Operation and WQCP Hydrology (Mean Sal) 1/

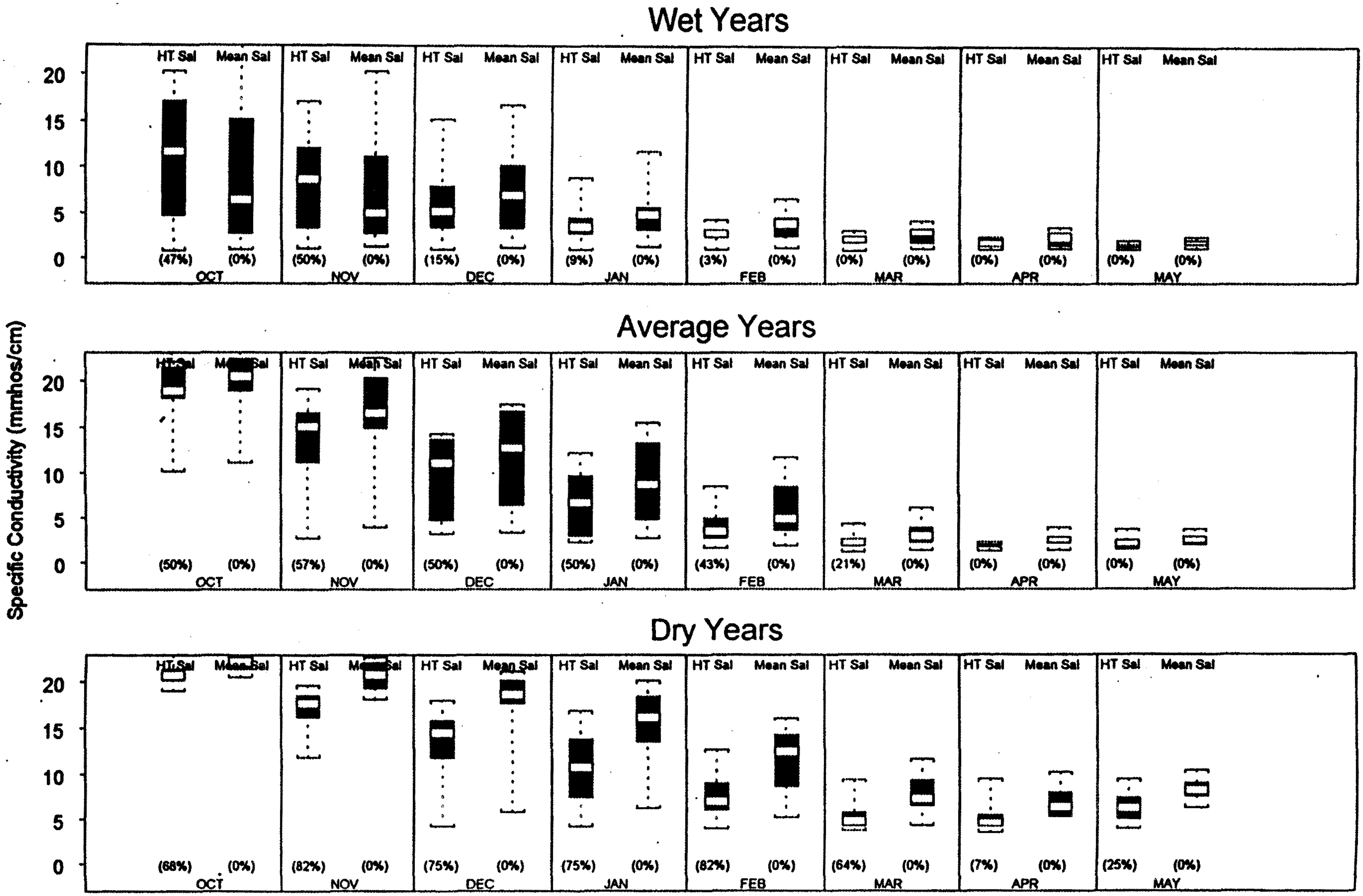

Wet Years

Average Years

Dry Years

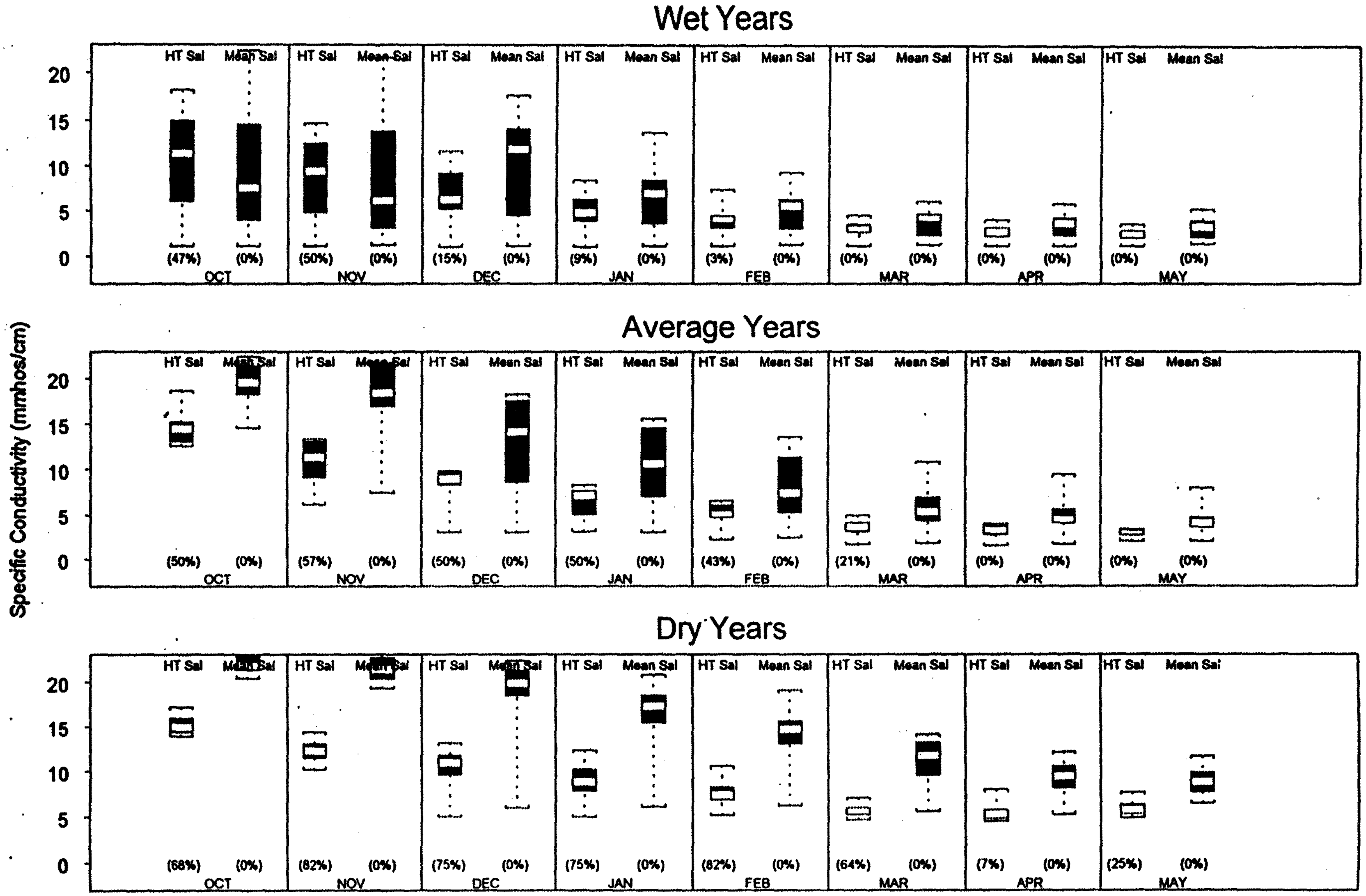
1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside

Goodyear Slough at S35
Mean of Daily High Tide Salinity with SMSCG Operation and WQCP Hydrology (HT Sal) vs Average of Daily Mean Salinity without SMSCG Operation and WQCP Hydrology (Mean Sal) 1/



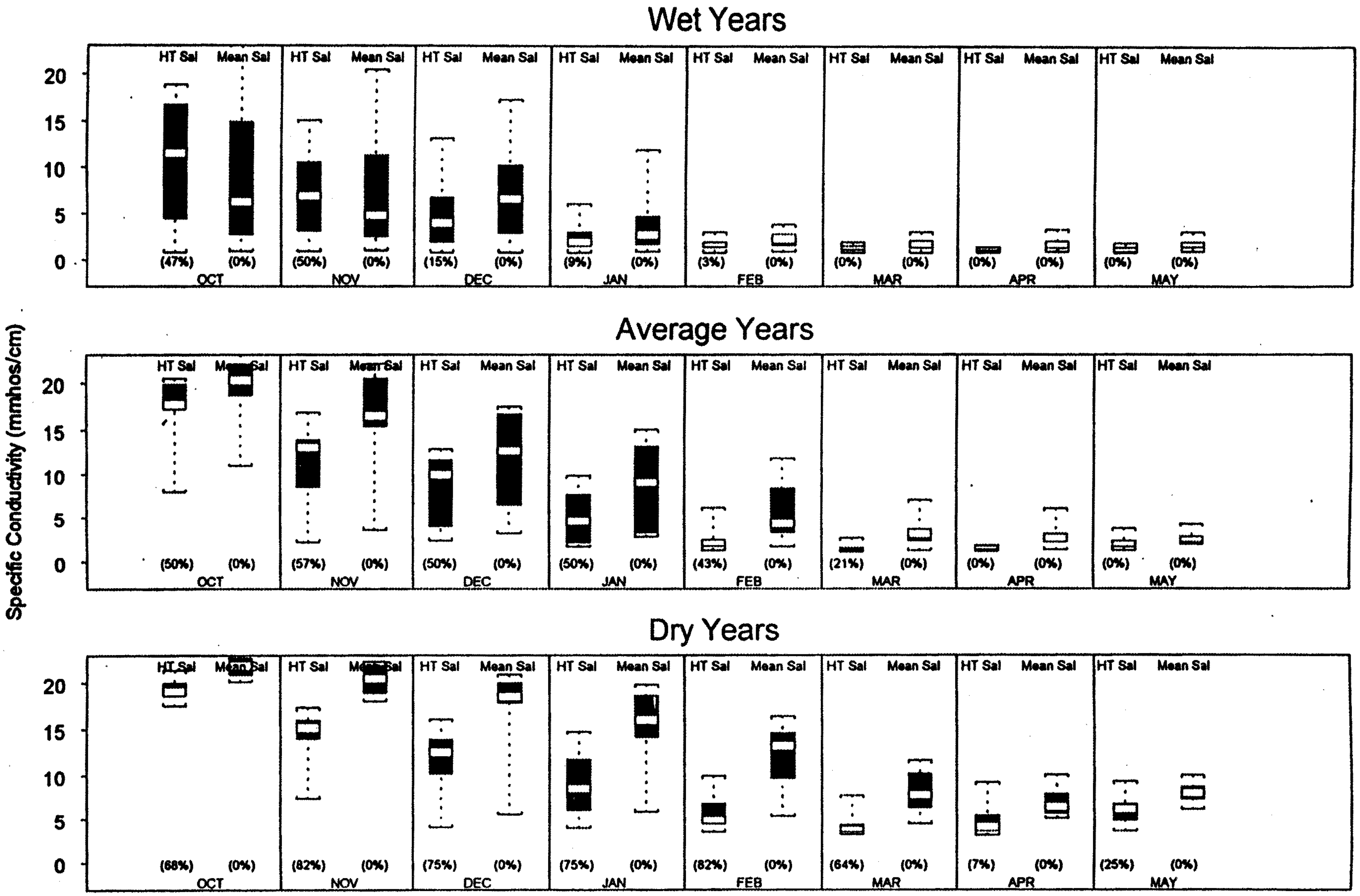
1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside

Volanti Slough at S42
Mean of Daily High Tide Salinity with SMSCG Operation and WQCP Hydrology (HT Sal) vs Average of Daily Mean Salinity without SMSCG Operation and WQCP Hydrology (Mean Sal) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside

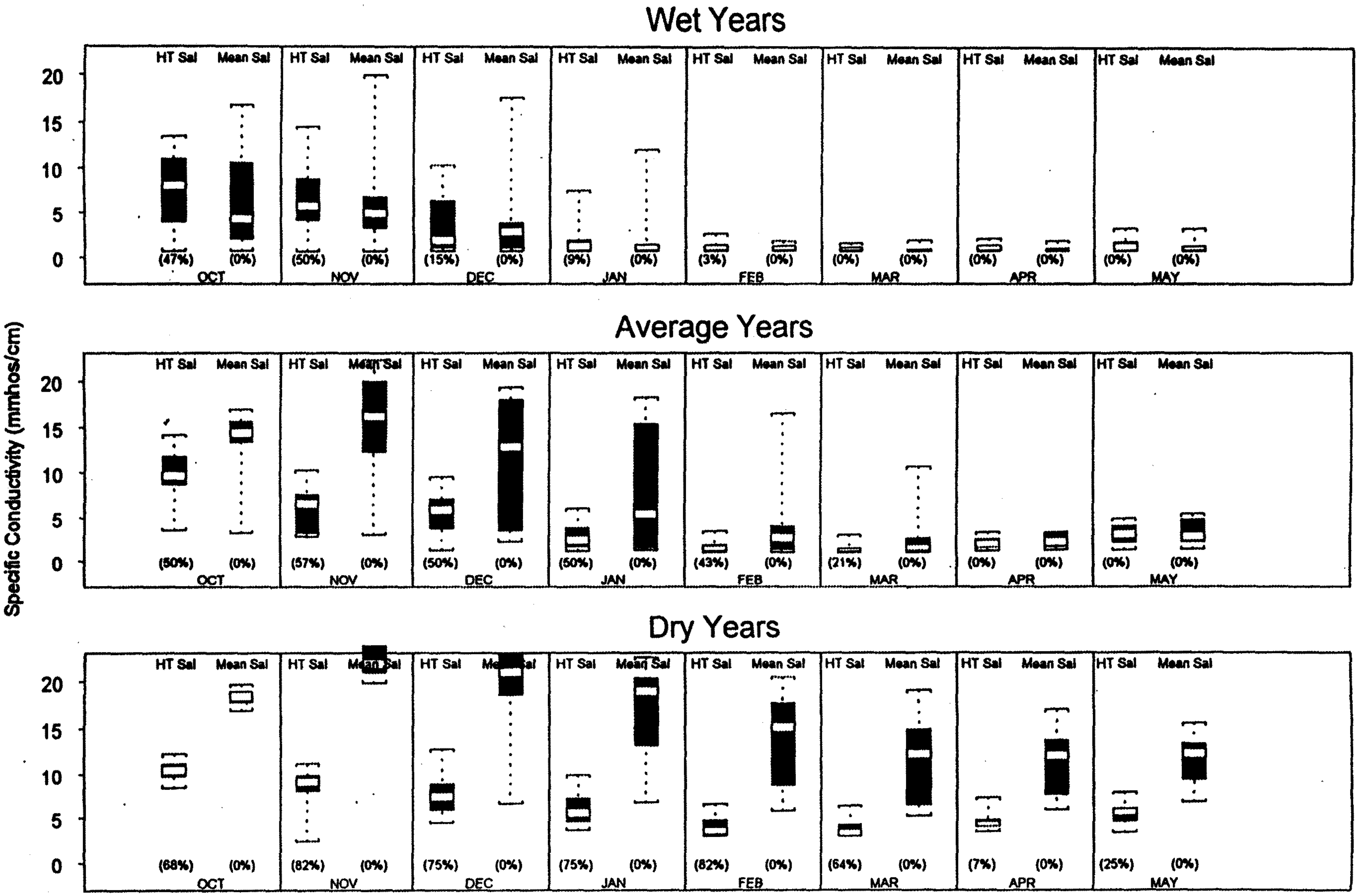
Montezuma Slough at S54
Mean of Daily High Tide Salinity with SMSCG Operation and WQCP Hydrology (HT Sal) vs Average of Daily Mean Salinity without SMSCG Operation and WQCP Hydrology (Mean Sal) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points

DWR Suisun Marsh Planning

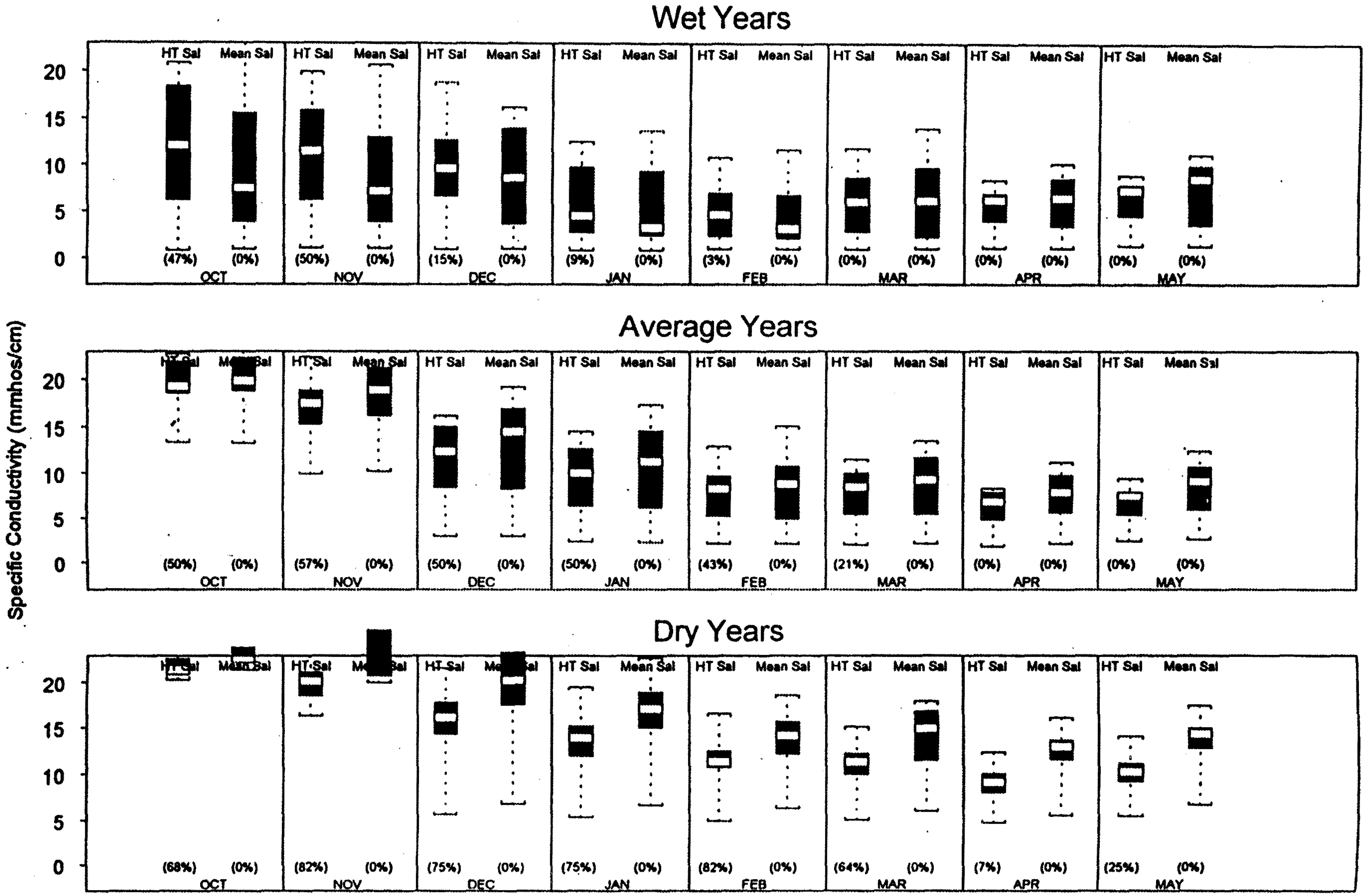
Montezuma Slough at S64
Mean of Daily High Tide Salinity with SMSCG Operation and WQCP Hydrology (HT Sal) vs Average of Daily Mean Salinity without SMSCG Operation and WQCP Hydrology (Mean Sal) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside the box is the median value, and the "wiskers" show the extreme points.

DWR Suisun Marsh Planning

Cordelia Slough at S97
Mean of Daily High Tide Salinity with SMSCG Operation and WQCP Hydrology (HT Sal) vs Average of Daily Mean Salinity without SMSCG Operation and WQCP Hydrology (Mean Sal) 1/



1/ - Each boxplot represents the end-of-month parameter salinity from 73-Year DWRDSM output for SWRCB WQCP EIR Analysis
- October and November data are lagged one water year
- "Wet Years" include wet and above normal water year ouptut; "Average Years" are below normal year output; "Dry Years" include dry and critical year output
- Number in parenthesis indicates the percentage of months that the SMSCG is operated to meet standards
- The box shows the range of the middle half of the data, the line inside

Chapter 7: Alternative Recommendation for Consideration in the SEW Process

This chapter is a suggested alternative recommendation for consideration in the SEW process. This recommendation includes an approach for defining channel water salinity standards in Suisun Marsh as well as a proposed operational strategy for the Suisun Marsh Salinity Control Gates. It is based on a review of the recommendations made by four SEW subcommittees, information provided SEW during the past 2 years of deliberations, and pertinent literature. Also included is the biological basis for the recommendation.

Alternative Recommendation

Internal Suisun Marsh Channel Water Salinity Standards

Internal Suisun Marsh channel water salinity standards will be those described in the 1995 Water Quality Control Plan and contained in Water Right Order 95-6 with the exceptions that S-35 and S-97 will be eliminated as compliance stations; the trigger for defining a deficiency period at stations S-21 and S-42 will be changed to the Sacramento Valley Water Year Hydrologic Classification system index; and the previous month's Eight River Index will be used to define the channel salinity criteria that applies on a sliding scale basis between the normal standard to deficiency standard for S-21 and S-42.

Suisun Marsh Salinity Control Gate Operation Strategy

Suisun Marsh Salinity Control Gate operation will be allowed from September through the end of May, whenever needed to sustain the internal Suisun Marsh channel water salinity criteria described above.

Biological Basis for the Alternative Recommendation

The biological basis for the alternative recommendation is formed on three foundations: (1) Paleosalinity information based on benthic cores and stratigraphic information based on wetland core samples suggest that modeled estimates of unimpaired flows can provide reasonable approximations of outflow that would have occurred in the absence of upstream water development. Furthermore, the 1995 WQCP standards, such as those for the marsh, result in outflows that, while not as high as would have occurred without the water projects, nevertheless provide a floor of protection. (2) From an ecological perspective the standards and gate operation do not interfere with the environmental variability of stage and salinity that are important determinants of healthy and functional tidal wetlands in Suisun Marsh. (3) Published information on the requirements of special status plants found in Suisun Marsh, such as the soft birds beak and Suisun thistle and the reason for their decline, are primarily related to habitat fragmentation, competition with exotic plant species, and periods of high outflow. Their status is not tied to the marsh standards and gate operation.

Suisun Marsh Standards and Gate Operation Mimic Pre-Project Hydrology

A comparison of current outflows with unimpaired outflows was completed to evaluate the suitability of Suisun Marsh standards currently in the 1995 WQCP.

Historical Flows - Unimpaired and 1995 WQCP

In Volume 2 of CALFED's ERPP, it was noted that spring flows before water projects averaged 40,000 to 60,000 cfs in normal years, 20,000 to 40,000 cfs in dry years, and 8,000 to 14,000 cfs in the driest years. With water project development, spring flows averaged 15,000 to 30,000 cfs in normal years, 6,000 to 10,000 cfs in dry years, and 2,500 to 3,000 cfs in the driest years.

Operational models can be used to estimate unimpaired Delta outflow. By making adjustments to the model, flows can be simulated under conditions which assume no upstream storage reservoirs and no export pumping from the Delta. Model output was provided to SEW by Mr. Nick Wilcox, State Water Resources Control Board, for the 3 drier water year types. Model output suggests that the standards provide a floor of protection rather than an enhancement above unimpaired flows. (See Tables 7-1, 7-2, and 7-3.)

Table 7-1 Average Monthly Delta Outflow (cfs)

	March	*April*	*May*	*June*	*July*	*August*	*September*
Unimpaired	49,607	68,746	63,985	36,110	11,758	5,748	5,319
WQCP	26,067	17,328	12,915	9,782	6,505	4,003	3,008

Table 7-2 Average Monthly Delta Outflow (cfs) Dry Water Years

	March	*April*	*May*	*June*	*July*	*August*	*September*
Unimpaired	49,199	49,680	45,148	24,227	8,218	4,660	4,661
WQCP	20,228	12,463	8,041	9,058	4,993	3,497	3,023

Table 7-3 Average Monthly Delta Outflow (cfs) Critical Water Years

	March	*April*	*May*	*June*	*July*	*August*	*September*
Unimpaired	28,576	28,071	27,388	16,874	5,924	3,587	3,639
WQCP	11,253	8,400	6,219	7,469	4,001	3,293	3,025

An assessment of minimum unimpaired outflows for the March through September period below (Table 7-4) also suggests that during the control season the marsh standards in the 1995 WQCP provide only a floor of protection. In the March through May period, WQCP flows are 30 to 65 percent of flows predicted for the unimpaired condition. Flows in the June through September period, when there are no Suisun Marsh standards, tend to be very close to flows that would have occurred under unimpaired conditions.

Table 7-4 Minimum Monthly Delta Outflow (cfs) Water Years 1922-1993

	March	*April*	*May*	*June*	*July*	*August*	*September*
Unimpaired	8,620	11,125	14,491	5,916	3,123	2,472	2,622
WQCP	6,066	5,882	5,139	5,949	4,001	2,992	3,008

Suitability of Using Unimpaired Data

Some SEW participants have suggested that modeled output of impaired flows may not be useful for assessing Suisun Marsh channel water salinity standards. They contend that significant changes in the watershed of the Central Valley have occurred that make comparing modeled unimpaired outflows with what actually occurred problematic. For instance, some researchers believe that flow rates and patterns today have been dramatically altered and that estimates of unimpaired flows generally overestimate flows that would have actually occurred. Phyllis Fox and others (SWRCB testimony 1987) contended that flows were likely to have been much less historically than currently for several reasons, including the more extensive tidal wetlands and higher E/T rates compared to current conditions. Discussions during SEW meetings also centered on the undiked conditions present prior to the 1850s that would have affected outflow.

There are, however, several reasons for rejecting these contentions based on a review of the Central Valley's watershed, patterns of precipitation and outflow, and prehistoric information on flow and salinity.

Central Valley Watershed and Precipitation and Outflow Patterns

Prehistoric topographic features would have tended to smooth out runoff patterns during both wet and dry years. Native vegetation would have tended to have a similar effect.

Regional differences in temperature and geology affected flows of freshwater and sediment through the Delta tributaries and the estuary (Draft CALFED Strategic Plan December 1998). For instance, because of typically milder winter temperatures, most of the precipitation in the Coast Range occurs as rain so that tributaries draining the eastern slope of the Coast Range produce peak flows during the rainy months, with reduced base flows from late spring through fall. In contrast, tributaries that drain the western flank of the Sierra Nevada usually carry peak flows later during late spring and early summer because they are fed by melting snow, with late summer and fall base flows greatly reduced following the snowmelt. Tributaries that drain volcanic formations around Mount Shasta and Mount Lassen also carry peak flows during late spring, but summer and fall base flows are relatively higher and colder since they are fed by cold glacial melt water that flows from springs.

Historical Flows Prior to Marsh Reclamation

Researchers in the San Francisco Bay have used isotopic records for mollusks in bay sediment to reconstruct a paleosalinity record over the past 5,900 years to make inferences about paleo-streamflow during that period (Ingram and others 1996). The results of this evaluation indicated that over the last 700, years Delta flow into the bay averaged 1,250 cms (cubic meters per second) or approximately 45,000 cfs. This is close to the average of 40,000 cfs predicted for the average pre-diversion value (unimpaired) using methods proposed by Nichols and others (1986).

The most recent period of low river inflow to the bay was between 160 and 210 years ago, with another dry period between 300 to 550 years ago. These were periods of extended drought with Delta flows as low as 10,000 to 12,000 cfs (Ingram and others 1996).

The work of Ingram and others (1996) suggests that the unimpaired model output may represent a close approximation of flow conditions that have supported healthy brackish tidal marsh communities in Suisun Marsh and bay.

The above information supports the 1995 WQCP objectives as being protective of Suisun Marsh, existing tidal marshes, and tidal marshes that will be restored in the future.

Wetland Stratigraphic Information

Wells and Goman (1995) collected and analyzed core samples at two locations on Brown's Island at the eastern edge of Suisun Bay. Their methods used comparisons between organic content and trace metals and observations of wetland plant seeds as indicators of the influence of sea water intrusion and hydrologic conditions. Under modern conditions Brown's Island supports vegetation adapted to brackish water, notably *Scirpus acutus, Scirpus americanus, Typha angustifolia*, and *Distichlis spicata.*

Wells and Goman (1995) concluded through stratigraphic interpretation that between 6,300 and 6,800 years ago, conditions were similar to Sacramento today, fresh to slightly brackish. Between 5,100 and 6,300 years ago, conditions became more saline with sea level rise. *Scirpus* seeds increased during this period. From 4,100 to 5,100 years ago, *Scirpus* seeds began decreasing and *Typha* was present throughout the period. The stratigraphy described for this period indicated that the rates of sea level rise and sedimentation alternatively superseded each other so that incipient marshes formed and were subsequently drowned.

The authors noted that in the period from 2,300 to 4,100 years ago, *Scirpus* was rare and *Typha* was present throughout, indicating fresh tidal marsh. Even during this fresh period, three distinct peaks in Cd occurred about 3,000 years ago, indicating dry periods imbedded within this generally fresh period. During this period, conditions indicated increased drainage from the Sacramento-San Joaquin basin. From 900 to 2,300 years ago, a rapid shift to brackish marsh most likely ocurred from increased inundation due to sea level rise. In the past 2,300 years, brackish conditions returned and are still present today. While there was an indication of extreme flooding about 500 years ago, Wells and Goman (1995) generally found that for core samples from more recent times (above 600 cm), the correlation between organic content and trace metals was poor.

Ecological Variability and the Ecosystem Approach

Recently the focus of managing our fish, wildlife, and plant resources has been on using an ecosystem approach and describing ecosystems as healthy or unhealthy. This approach includes restoring or rehabilitating ecological processes and functions such as restoring at least a semblance of the pattern, magnitude, and duration of flows, hydrodynamic conditions, and salinity. Variability is an important dimension of ecosystems since they are dynamic and subject to changes at every frequency—diurnal, meteorological, seasonal, successional, climactic, evolutionary, geological, and astronomical (Callicott 1992).

Restoration projects have looked to historical conditions to help define conditions needed to sustain a restored habitat. Westman (1991) noted that defining those historical conditions can often only be done in general terms.

Development of the X2 standard and other components of the 1995 WQCP used this ecosystem approach. For instance, Delta outflow requirements in spring were used to meet X2 partially rehabilitated outflow conditions and included a component of variability.

Any ecosystem approach must take into account human uses of and influence on the system. For instance, reclamation of tidal wetlands and management of those wetlands as seasonal managed wetlands is part of the ecosystem.

Patterns of channel water salinity in Suisun Marsh vary interannually (based on a given year's hydrology, unique meteorological conditions, e.g., El Niño/Southern Oscillations ENSO phenomenon), intra-annually (based on a given year's rainfall pattern and seasonal variation in rainfall), daily (based on tides, winds, managed wetland drainage, Delta outflow), and historically (based on longer term patterns such as those associated with Pacific inter-decadal oscillation patterns (Harrison 1998)) or even longer term dry and wet patterns such as those reported by Fritts and others (1979) and Stine (1994).

Based on the information presented above, operation of the gats under the WQCP hydrology with the Suisun Marsh standards proposed in this alternative will not interfere with the variability needed to sustain ecosystem health or conflict with the outflow pattern and resulting internal channel water salinity that would have occurred under unimpaired flow conditions.

Catastrophic Dry Periods

As noted above, however, there have been occasions of extreme drought conditions such as those indicated nearly 3,000 years ago by Wells and Goman (1995). Periods such as those are likely to be much drier than any experienced in the last 100 years. Under those extremely dry conditions, the criteria in the 1995 WQCP would not be achievable and reservoirs will likely be depleted. Given those conditions, Delta outflow and gate operations would not be sufficient to meet the 1995 WQCP standard in Suisun Marsh. SMPA Amendment III includes a waiver under those catastrophic conditions.

Ecological Requirements of Listed Plants

Suisun thistle is an endangered perennial tidal marsh plant with a severely restricted distribution. It is susceptible to catastrophic events such as disease outbreaks and severe drought as well as habitat conversion and fragmentation and increased salinity due to upstream withdrawal of fresh water.

Soft bird's beak is an annual that flowers between July and September and is found in association with salt grass and pickleweed dominated tidal marshes near the limit of tidal action (Stromberg 1986). Recorded sightings suggest this plant may be limited to a combined distribution of no more than 20 acres.

The federal register petition (USFWS 1995) noted that changes in freshwater inflow has adversely affected the Suisun thistle and soft bird's beak. Water project operations have diverted over 50 percent of the historical annual inflow of freshwater. These reductions over the last 40 years have adversely affected brackish marshes by making them more saline (Pavlik 1992). Pavlik (1992) noted that salt stress reduced plant abundance of salt tolerant plants.

Functional Tidal Wetlands

Besides the patterns of hydrology and resulting channel and soil pore salinity, a critical component of a fully functioning tidal wetland in Suisun Marsh is topographic gradation from open water through low and high marsh to its transition to upland. The ability of rare plant communities to sustain populations of listed plants such as Suisun thistle and soft bird's beak through lengthy periods of high water, such as occurred in the last series of wet years, is in part linked to this broad range of gradual transition.

Both Suisun thistle and soft bird's beak occur in salt water or brackish water tidal marshes. Since 1850, habitat has been drastically curtailed. Only 15 percent (or 30,000 acres) of the original tidal marshes remain (Dedrick 1989). Both plants are restricted to the narrow tidal band in higher elevation zones. Soft bird’s beak occurs in the fringing marshes of San Pablo and Suisun bays. Suisun thistle is found in fringing marshes in selected locations in Suisun Marsh.

Stage Effects

Expansion of the low and middle marsh plant communities at the expense of high marsh plant communities is an expected outcome of wet water years as the depth and duration of flooding increase on the marsh surface. For instance, DWR’s plant ecologist reported that American bulrush is dominant in the middle marsh zone and that it dramatically increased in spatial extent during recent wet water years (DWR letter to Mr. Joel A. Medlin, October 15, 1996).

Operation of the gates has little or no effect on stage in Suisun Marsh's tidal wetlands. Modeling information evaluated prior to the installation of the gates suggested minor influences in the immediate vicinity of the structure that diminished rapidly as the distance increased from the structure.

Tidal vs. Non-tidal Wetlands

The significance of hydroperiod and soil water or soil pore salinity is different for tidal and non-tidal wetlands. Information collected on managed wetlands, however, provides insight into how the duration and timing of inundation influences the competitive advantages of several wetland plant species. Pickleweed is found under flooded conditions between 0 and 8 months of the year. The “optimum” period was noted as 6 months. Prolonged soil submergence reduced the competitive ability of pickleweed. Salt grass was found to have its greatest competitive ability under conditions of very little or no soil submergence. Narrow-leaf cattail, *Typha angustifolia*, is typically found under conditions in which soil is submerged between 6 and 11 months of the year. If soil submergence was less than 5 months, its competitive ability was reduced.

Conclusion

Based on the information presented it is unlikely that the level, duration, and pattern of salinities in the Suisun Marsh channels will be fresher compared to historical unimpaired conditions. Furthermore, WR 95-6 marsh standards are not inconsistent with the standards that would protect Suisun Bay's existing tidal wetlands and are not inconsistent with the standards needed to support the restoration of fully-functioning tidal wetlands in Suisun Marsh. WR 95-6 marsh standards as modified in the alternative recommendation presented in this chapter will effectively mimic the historic pattern of channel water salinities in below normal, dry, and critical years without affecting the hydroperiod in Suisun Marsh.

The standards proposed in the alternative recommendation provide a surrogate for natural preproject water quality; they restore a semblance of the relationship to channel water salinities that would have been provided by historical flows; and gate operations help mimic those unimpaired conditions. The alternative also recognizes the importance of environmental variability in sustaining a healthy ecosystem.

Adaptive Management

While existing data support these conclusions and the standards upon which they are based, they can be assessed using adaptive management. The conclusions could be framed as testable hypotheses and focused research, and monitoring conducted to test those hypotheses.

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Chapter 8: Recommendations for Additional Research and Monitoring

Introduction

Four SEW subcommittees made recommendations for research and monitoring activities that address ecological questions regarding Suisun Marsh which they believe warrant further study. The following topics were developed specifically for Suisun Marsh; however, some could be applied to other areas of the Delta. The list was submitted to the CALFED Comprehensive Monitoring, Assessment and Research Program (CMARP).

Brackish Marsh Vegetation Subcommittee

- Studies to determine the spatial and temporal variability of structure and dynamics of tidal wetland plant communities. Determine the relationship of vegetation pattern to depth and duration of flooding, soil salinity, soil redox potential, soil pH, and channel water salinity.
- Studies to determine the critical life stages and range of edaphic requirements of sensitive plant species, including listed species and species recognized to be in decline, which could become further endangered by management actions.
- Studies to track the spread of invasive species in the marsh. Determine the dynamics of invasive species and their relationship to aqueous salinity regimes.
- Studies to track the distribution of rare plants in the marsh.
- Comparative study of tidal marsh and managed marsh communities to determine mechanisms promoting species diversity.

Waterfowl Subcommittee

- Studies to determine the distribution, abundance, and nutritional value of plants used as food by wintering waterfowl. By identifying plants important in the diet of waterfowl wintering in Suisun Marsh, managers may meet the needs of waterfowl by practicing better water management techniques that promote the growth of nutritious, preferred food plants.
- Studies to determine the relationship between waterfowl brood survival and channel water salinity. Grizzly Island has some of the highest mallard nesting densities in north America. The question of what happens to broods post hatch in Suisun Marsh needs further study. To better estimate Suisun's contribution to the Pacific Flyway, it would be helpful to know how many ducklings survive the critical 14-day period when they are most sensitive to channel water salinity, and how many broods survive to fledge.
- More extensive waterfowl population surveys in the marsh to determine habitat choice or preference. Through examination of these preferred habitats, it should be possible to determine desirable salinity levels.

- Studies to evaluate salinity tolerances of aquatic invertebrates used as food by waterfowl. This information may exist, but to date has not been found. An intensive literature search is likely required; however, some answers may be revealed by commissioning work with existing data sets (i.e., DFG Bay-Delta Salt Slough system in the San Joaquin Valley).
- Determine how food availability influences clapper rail distribution and fitness by assessing the abundance and productivity of invertebrate prey items, and how these prey items are influenced by temporal and spatial variations in salinities in tidal marsh.
- Determine the extent of intermarsh movements by clapper rails within Suisun Marsh and with other marshes in the San Francisco estuary, and how dispersal and colonization movements are related to marsh size, shape, position, habitat characteristics, and population dynamics.

Aquatic Habitat Subcommittee

- Suisun Marsh is thought to be an important refuge for native species that exist in the Bay-Delta region. Given this, what are the impacts of the invasions of *Potamocorbula amurensis* (Asian clam), *Acanthomysis bowmani* (an Asian mysid), *Eriocheir sinensis* (Chinese mitten crab), and *Tridentiger bifasciatus* (Shimofuri goby) on native aquatic species in the marsh? Has the introduction of these species into the estuary increased the relative importance of the marsh as a rearing area for juvenile fishes? What are the population dynamics of these invasive species and how are they affected by channel water salinity in the marsh? If low outflow caused by drought and diversions facilitates the establishment of nonnative species, what level of outflow would protect against future invasions?

  Special studies should be conducted to determine which water quality parameters affect the spread of invasive species. Studies should also be conducted to determine whether significant interactions (competition, predation, interference, etc.) exist between species that have recently invaded Suisun Marsh, and how these invasive species are impacting marsh species. Future monitoring should include sampling of benthos.

- How is the decline in chlorophyll *a*, zooplankton, and *Neomysis mercedis* impacting fish in Suisun Marsh? What is the distribution and abundance of zooplankton in the marsh? Future monitoring should include more widespread sampling for zooplankton.
- How does the aquatic habitat in Suisun Marsh compare to other habitats in the Bay-Delta region?

  A special study comparing the secondary productivity in Suisun Marsh with that of other habitats in the region would provide important information on the role of Suisun Marsh in the Bay-Delta estuary.

- What is the role of shallow water habitat in Suisun Marsh? What is the feasibility of altering the structure of existing levees (e.g., creating "benched levees") in some locations in the marsh to create shallow water habitat?

  The Aquatic Habitat Subcommittee's initial investigations suggest that the availability of shallow water habitat plays a greater role in species abundance and distribution than does salinity. Shallow water habitat provides refugia, spawning and rearing areas, and supports a much broader food chain than do channelized sloughs. In addition to any special studies addressing the role of shallow water habitat, the subcommittee recommends that a monitoring program be implemented to characterize and track long-term changes in marsh habitat (channel morphology, plant types, etc.) using GIS.

- What quantity of "salinity habitat" (habitat in the optimal salinity range for a given species) exists for different species of fish in Suisun Marsh?

Unger (1994) and others have suggested that the X2-Abundance relationships found in Suisun Bay can be partly explained by the covariance of X2 and habitat availability. Characterizing the relationship between species salinity preferences and habitat availability is more complex in Suisun Marsh, due to the influence of freshwater inflows and managed wetland operations. The subcommittee recommends investigating ways to characterize these relationships.

- What is the optimal salinity range for various sensitive fish species in Suisun Marsh? What are the impacts of outflow, the success of invading species, toxic compounds, quantity and quality of shallow water habitat, on recruitment success of larval and juvenile fishes?

  More information is needed regarding the early life stages of Suisun Marsh fishes (Bennett and Moyle, 1996). Special studies that increase our understanding of sensitive species in Suisun Marsh need to continue. More information on which factors have the greatest impact on early life stages of Suisun Marsh fishes is needed to expand our understanding of aquatic ecosystem dynamics.

- What impacts do the Suisun Marsh Salinity Control Gates have on the distribution, movement, and abundance of fish and aquatic invertebrates in Suisun Marsh?

  The subcommittee recommends that a monitoring program be developed that clearly examines the impact of operation of the gates on aquatic resources in Suisun Marsh. One study that has specifically examined the impact of gate operations on aquatic species is the SMSCG Adult Salmon Migration Evaluation was conducted in 1993 and 1994. A related study currently in its third year is the SMSCG Salmon Passage Study, which is being conducted to determine whether a modification to the SMSCG flashboard design facilitates fish passage. Future monitoring should examine the impact of gate operations on abundance and distribution of phytoplankton, zooplankton, mysids, and resident and seasonal fishes. Further, studies should be conducted to determine whether gate operations deter or promote the abundance of nonnative species.

- What is the effect of duck club management on the water quality in Suisun Marsh? What is the impact of managed wetland drain water on aquatic organisms in receiving sloughs? If club management has an adverse impact on aquatic species, what alternative management strategies can be used that would be less harmful to aquatic species?

  Scientists from UC Davis studying fish abundance and distribution in Suisun Marsh have occasionally observed fish kills in the smaller deadend sloughs that are apparently due to the discharge of poor quality (possible anoxic) water from the managed wetlands into these sloughs. A special study or monitoring program should be implemented to determine the impact of these periodic events.

- What is the role of contaminants from urban runoff in the Suisun Marsh ecosystem? Future monitoring should include sampling for contaminants.

- What is the role or effect of the Fairfield sewage disposal into Boynton Slough in Suisun Marsh?

  Fish abundance appears to be lower in Boynton Slough than in other areas of Suisun Marsh. A special study to examine the impact of the effluent inflow on fish abundance and diversity would be useful.

- What effect does freshwater inflow from creeks have on the channel water salinity of Suisun Marsh? What effect does this have on the aquatic organisms present in Suisun Marsh sloughs?

The Western Salinity Control Test conducted by DWR demonstrated that increased freshwater flows to the western Suisun Marsh significantly reduced salinity in the affected sloughs. A special study or monitoring program could investigate the effect of freshwater inflow on resident fish in Suisun Marsh.

- What is the relationship between X2 and the distribution and abundance of aquatic species in Suisun Marsh? What is the relationship between X2 in Suisun Marsh and X2 in the Bay-Delta estuary? Do the X2 standards in Suisun Bay provide adequate protection for aquatic species of Suisun Marsh?

  Initial investigation by the subcommittee revealed no apparent correlation between the position of X2 and abundance of aquatic species in Suisun Marsh. However, it is possible when salinities that are optimal for various fish species occur at the entry points to the Suisun Marsh, there may be greater opportunities for aquatic species to move into and use Suisun Marsh. The subcommittee recommends investigating the salinity-fish abundance relationship from this perspective.

Wildlife Subcommittee

- Comprehensive surveys to determine distribution and relative abundance of all wildlife species (such as salt marsh harvest mice, clapper rail, western pond turtle, river otters, mink, etc.) within Suisun Marsh. Studies should compare tidal vs. managed wetland habitats. Special studies for threatened and endangered species should include incidental information for other non-listed species.
- Studies to determine optimal salt marsh harvest mouse habitat in a brackish marsh environment, in both tidal and managed wetlands, including: percent cover, percentage of pickleweed, percentage of open ground, plant community associations, duration and depth of inundation, water and soil salinities, and marsh geomorphology to produce these habitat conditions.
- Determine the extent of interhabitat movements by salt marsh harvest mice within Suisun Marsh and how dispersal and colonization movements are related to habitat patch size, shape, position, vegetation, and populations.
- A genetic study of harvest mice should be undertaken. Recent surveys for the endangered salt marsh harvest mouse have found many harvest mice with field characteristics intermediate between the salt marsh harvest mouse and the more common western harvest mouse. Mitigation, management and recovery efforts for the salt marsh harvest mouse would be greatly assisted by a genetic study to differentiate between the two species and determine whether they are hybridizing.
- A comparison of seasonal dispersal ranges and survival of small mammals in tidal and diked wetlands of Suisun Marsh.
- Studies to determine how changes in channel water salinity spatially and temporally affect habitat types in both managed and tidal wetlands.
- Studies to determine physiological salinity tolerances for life requirements of Suisun Marsh wildlife (such as clapper rails, pond turtles, black rails, river otters, etc.).
- Studies to quantify the relationship between reproductive success, juvenile and adult survival and habitat use for clapper rails and salt marsh harvest mice in Suisun Marsh.
- Conduct bathymetry surveys of the marsh covering all wet areas so that accurate representations of the amount and location of shallow water habitat can be assessed. Characterizing the effect of bathymetry and topography on structure and function of plant, animal, and fish communities is basic and essential.

- Conduct continuous channel salinity and tide stage data to reference sensitive tidal wetlands such as Hill Slough tidal marsh, Peytonia Slough Ecological Reserve, and Rush Ranch/Cutoff Slough tidal marsh.
- What effect does freshwater inflow from creeks have on the channel water salinity of Suisun Marsh? What effect does this have on the aquatic organisms present in marsh sloughs?
- The Western Salinity Control Test conducted by DWR demonstrated that increased freshwater flows to the western Suisun Marsh significantly reduced salinity in the affected sloughs. A special study or monitoring program could investigate the effect of freshwater inflow on resident fish in the marsh.
- What is the relationship between X2 and the distribution and abundance of aquatic species in the marsh? What is the relationship between X2 in the marsh and X2 in the Bay-Delta estuary? Do the X2 standards in Suisun Bay provide adequate protection for aquatic species of Suisun Marsh?
- Initial investigation by the Aquatic Habitat Subcommittee revealed no apparent correlation between the position of X2 and abundance of aquatic species in the marsh. However, it is possible that when salinities that are optimal for various fish species occur at the entry points to the marsh, there may be greater opportunities for aquatic species to move into and use the marsh. The Aquatic Habitat Subcommittee recommends investigating the salinity-fish abundance relationship from this perspective.
- What is the relationship between channel water, pond water, and soil water salinity in the managed wetlands?
- Obtain holistic data regarding interaction of food web linkages between tidal wetland plant communities by intertidal plant zone and adjacent terrestrial and aquatic food webs.
- Identification of potential keystone species that may serve as management targets for marsh ecosystem sustainability.
- Evaluation of current hydrodynamic and salinity models and their applicability for use as management tools in tidal wetland systems.