Methods and Data for Analysis of Potential Distribution and Abundance of Zebra Mussels in California

by

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This report was funded by a grant from the
CALFED Category III Steering Committee
administered by the
California Urban Water Agencies

February 1998

Contents

NOTE: *This report is provided as a technical supplement to the report* The Potential Distribution and Abundance of Zebra Mussels in California *by the same authors.*

Some Background on the Life History of the Zebra Mussel

Zebra mussels grow rapidly, mature quickly, and produce large numbers of small and easily dispersed young. These traits are characteristic of organisms adapted to unstable habitats where fluctuating environmental conditions may cause periodic die-offs, and allow zebra mussels to quickly reach high densities after initial introduction to a favorable habitat or recolonization after an environmental perturbation (McMahon 1996). Within their original distribution in the basins of the Caspian, Aral, and Azov seas, zebra mussels generally do not dominate the biota to the extent that they have in invaded regions. In the northern part of the Caspian Sea, for example, zebra mussels comprise only about 24% of the bivalve biomass (Karateyev et al. 1997).

Zebra mussels reach sexual maturity at shell lengths of 3-10 mm, and females produce from 40,000 to 1.5 million eggs per year. During spawning, gametes (eggs and sperm) are released into the water, where fertilization occurs. Spawning can begin at 10-12° C (50-54° F) and peaks at 15-17° C (59-63° F). The spawning season in warm southern U. S. waters is longer than in northern climates, and some waters may be warm enough for year-round spawning (Nichols 1996).

Zebra mussel larvae, called veligers, typically drift in the plankton for 2-5 weeks, but sometimes overwinter in the water column. When veligers reach 0.14-0.20 mm in length, they must settle from the water column onto hard substrates. Up to 99% of larvae die between hatching and settlement. Post-settlement survival of juveniles is dependent on the suitability of the substrate, the chemical and physical properties of the water, the availability of food, and other factors (Stanczykowska and Lewandowski 1993).

Young mussels secrete tough byssal threads which attach them to hard surfaces. Mussels cannot settle directly onto silt, clay, or fine-grained sand, but they can ultimately become abundant on such substrates by starting a colony on as little as a twig or a pebble. Other mussels settle on the initial settlers, or on empty shells, eventually forming large aggregations (O'Neill 1996). Zebra mussel densities increase with depth to about 2-4 m, then decline. They are rare below 6-8 m, but have sometimes been found as deep as 45 m. Growth rates, life spans, and shell lengths of zebra mussels vary in different regions. Zebra mussels in Lake St. Clair in the Great Lakes are shorter lived (1.5-2 years), faster growing (20 mm/year), and smaller at maximum length (3.0 cm) than European populations. Zebra mussels live 3-5 years in Polish lakes, 3.5 years in British reservoirs, 6-7 years in Swiss lakes, and 6-9 years in some Russian reservoirs, and throughout Europe reach maximum shell lengths of 3.5-4.0 cm (Ram and McMahon 1996).

Zebra mussel larvae eat bacteria, algae, and other small organic particles, which they capture on bands of long cilia that move food through mucus-lined grooves into their stomachs. Adult mussels are active and efficient filter feeders, pumping up to a liter of water per day per adult mussel. They consume bacteria, algae, zooplankton, and organic detritus ranging from particles less than 0.001 mm in length to algal colonies over 3.0 mm in length, but feed preferentially on particles 0.001-0.05 mm in length. Undigested food is extruded in particles called pseudofeces (MacIsaac 1996).

Data Acquisition and Management

We assessed data from 160 sampling locations in California's lakes, reservoirs, streams, rivers, and water conveyance facilities. In selecting sites for analysis, we attempted to capture the range of water quality conditions in the state, show changes that occur along rivers, and target the large water delivery systems.

Most of the data on calcium, pH, temperature and dissolved oxygen levels that we used came from STORET, the U. S. Environmental Protection Agency's (EPA) water quality data clearinghouse. STORET collects and organizes water quality data from the early 1970s to the present that was originally collected by state, federal, and local agencies. The data we used originated with the State Water Resources Control Board, the California Department of Water Resources, the U. S. Bureau of Reclamation, the U. S. EPA, the Nevada Department of Conservation and Natural Resources, the National Park Service, the Orange County Department of Environmental Quality, and the U. S. Forest Service.

EPA's Region IX manager for STORET, Eric Wilson, extracted water quality data for 1980 through 1995 for every sampling location on record in California, for the months of April through September. The records included averages and ranges, the number of sampling events contributing to the averages, the agencies of origin, and the decimal latitude and longitude coordinates. These data were supplied on two spreadsheets of 2,000-3,500 lines each, from which sampling locations were selected and extracted for analysis. These were supplemented with data from the California Department of Water Resources, the City and County of San Francisco, the Metropolitan Water District, the Los Angeles Department of Water and Power, the Contra Costa Water District, the East Bay Municipal Utilities District, the Regional Water Quality Control Boards (Regions 6 and 7), and the Tahoe Research Group. Our agency contacts for obtaining this data are listed in Appendix A and the data that we used in our analysis are in Appendix B.

Two concerns arose with our use of STORET data. First, transferring numbers from sampler, to analyst, to manager, to STORET, to us, provided numerous opportunities for transcription error. However, we conducted spot checks comparing STORET data with the original agency data and found good agreement. Second, sampling and analytical protocols may vary among the agencies contributing data to STORET. Despite these concerns, the relative ease of acquiring and using data from STORET made it an appropriate choice for this broad-scale analysis.

For information on salinity we relied in large part on our knowledge of the California water system to determine that most of the analyzed sites are fully freshwater, augmented by data from the Regional Water Quality Control Boards, Regions 6 and 7, for some inland brackish waters. Salinity data for the San Francisco Bay and Delta were supplied by the U. S. Geological Survey and extracted from the San Francisco Estuary Project's report on X2, a variable characterizing the location of tide-averaged, near-bottom 2 ppt water in the Estuary (Kimmerer and Monismith 1992).

Data on patterns of periodic desiccation in some inland waters were also obtained from the Regional Water Quality Control Boards, Regions 6 and 7.

Selection of Environmental Variables and Ranges

We used dissolved calcium, pH, temperature, dissolved oxygen, and salinity to assess colonization potential at selected sampling locations. These were selected because (a) they are among the best-studied environmental variables that have been correlated with zebra mussel distribution and abundance, (b) zebra mussel physiological tolerance ranges have been established for them, and (c) data on these variables were readily available for many California water bodies. The tolerance ranges used were based on the environmental requirements of zebra mussels during the larval and early growth stages, which are more restrictive than those of adults. As shown in Table 1, adult zebra mussels are more tolerant of lower pH and calcium than are larvae, and adults require a threshold temperature to trigger spawning.

Table 1. Some Environmental Requirements for Adult and Larval Zebra Mussels

Adapted from McMahon (1996).

	Adults	Larvae
Calcium lower limit	12-15 mg/l	15 mg/l
Calcium optimal growth	≥25 mg/l	≥34 mg/l
pH lower limit	6.5	7.3-7.4
pH optimal growth	8.0	8.4
Temperature upper limit	31° C	31° C
Temperature needed for spawning	≥10-12° C	—

Table 2 shows the tolerance ranges of zebra mussels for the five variables used in the assessment. As indicated, the analysis was based on average April through September values, the main period for growth and reproduction. Supporting information for these ranges is as follows:

Calcium. Ramcharan et al. (1992) found that for 76 European lakes zebra mussels were present only where calcium levels were at or over 28.3 mg/l. Padilla (1997) found similar results for over 500 lakes in the former Soviet Union. In North America, however, zebra mussels have become abundant at calcium levels as low as 20-25 mg/l in the St. Lawrence River, in Oneida Lake and the Hudson River in New York, and in Lake Champlain in Vermont (Mellina and Rasmussen 1993; Vermont Department of Environmental Conservation 1998). Zebra mussels have been reported present but not abundant at calcium levels of 18-19 mg/l in Duluth Harbor, Wisconsin; 17 mg/l in the St. Lawrence River; 16-17 mg/l in the Richilieu River in Canada; and 12-15 mg/l in Lake Champlain (Mellina and Rasmussen 1993; Cusson and Lafontaine 1997; Vermont Department of Environmental Conservation 1998; S. Nichols, pers. comm. 1998). The apparent difference in minimum calcium levels required by European and North American populations could be due to

Table 2. Suitability Ranges for Variables Used in the Analysis

Values given are means for April-September unless otherwise stated.

Suitability:	(1) High	(2) Moderate	(3) Low-to-no
Calcium (mg/l)	>25	15-25	<15
pH	7.5-8.7	7.3-7.5 or 8.7-9.0	< 7.3 or >9.0
Temperature (°C)	15-31, and 10 ≤ maximum ≤31	0-15, and 10 ≤ maximum ≤31	maximum <10 or >31
Dissolved Oxygen (mg/l)	>8	6-8	<6
Salinity (ppt)	<2	2-8 and stable	2-8 and rapidly changing, or >8

genetic differences between the populations; or, it could result from the European lake data reflecting calcium levels needed for reproduction or early development, and the North American data on populations found at lower calcium levels reflecting requirements for settlement and growth.

Published laboratory studies are consistent with either of these interpretations. Zebra mussels poorly regulate hemolymph ion levels and acid/base levels in waters with moderate acidity and calcium concentrations, restricting them to waters with higher pH and calcium levels compared to most other freshwater bivalves. In laboratory studies, zebra mussels did not survive calcium levels below 15 mg/l, where metabolic equilibrium was lost (Vinogradov et al. 1993). In tests of rearing success, the lowest number of deformed larvae occurred at over 34 mg/l of calcium (McMahon 1996). Most of the zebra mussel researchers that we contacted recommended using either 15 or 12 mg/l as a minmum calcium threshold for reproduction and growth.

pH. Zebra mussels have distinct pH-tolerance limits. In the laboratory, a pH of 7.4 to 9.4 is required for veliger development, and development success peaks at around pH 8.4 (Sprung 1993). In the field, Ramcharan et al. (1992) found that a pH of 7.3 was the lower limit of zebra mussel occurrence in 76 European lakes.

Temperature. In North America, zebra mussels normally begin to spawn at 12° C and above, though limited spawning has been reported at 10° C in the Great Lakes and Europe (Nichols 1996). Spawning peaks at about 12-18° C, which is also roughly the optimum temperature for larval development (Sprung 1993). Juveniles and adults are able to grow at a wide range of temperatures, from about 12° C to about 30° C. Populations have become abundant in the southern U.S. where temperatures often reach temperatures of 30° C, yet massive die-offs occur at 31° C. In Europe zebra mussels have become abundant where average winter temperatures are as low as 6° C, but they do not survive freezing (McMahon 1996).

Dissolved oxygen. Zebra mussels are among the least tolerant of low oxygen levels of all freshwater bivalves. The lethal lower limit for adults is about 4 mg/l, or about 20% of saturation, at 18° C. Low oxygen levels of severely polluted waters eradicated zebra mussels from much of the Rhine River during the 1970s. Their oxygen requirements rise in warm water (25° C and over), and decline in colder water allowing overwintering mussels to survive under ice. Low oxygen levels may in part account for the poor colonization success of zebra mussels in eutrophic lakes (McMahon 1996).

Salinity. Zebra mussels' salinity tolerance limits depend not only on salinity levels, but also on the rate of change of salinity and on the composition of the salt. Mussels cannot withstand the short-term fluctuations in salinity levels typical of estuaries and some coastal lagoons. In estuaries such as the tidal reaches of the Rhine River in the Netherlands, mussels reproduce in salinities of up to about 2 ppt. However, in areas of moderately high but stable salinities, such as the Caspian and Aral seas, zebra mussels thrive in salinities of up to 6-12 ppt (Strayer and Smith 1993).

Several other variables that were not included as classification criteria in this study are known to influence zebra mussel distribution. These include:

Turbidity. This measure of the concentration of particulate matter in water is problematic as a classification criteria in that the measurement does not discriminate between the contribution of phytoplankton relative to other inputs such as suspended sediments. Turbidity tolerance thresholds have been proposed for zebra mussels, but researchers disagree about their validity. For example, zebra mussels are now thriving in areas of the lower Mississippi where turbidity considerably exceeds levels previously thought to be their upper tolerance limit (McMahon 1996).

Substrate quantity and quality. A hard substrate is essential for larvae settling out from the water column to begin adult life. However, substrate availability and type may be more important early in the colonization of a new area. In lakes with little hard substrate, zebra mussels can settle on sticks and logs, plants, and other organisms, and then onto each other, eventually forming large mats (Ramcharan et al. 1992).

Phosphorus and nitrogen levels. Stanczykowska and Lewandowski (1993) reported that in Europe zebra mussels tend to be absent in lakes with very low or very high levels of phosphorus. Ramcharan et al. (1992) found that zebra mussel density was negatively correlated with phosphate and nitrate levels, suggesting that more eutrophic lakes are less suitable environments.

Water velocity. Zebra mussel larvae can settle at velocities of up to 1.5 m/sec (O'Neill 1996), above which post-larvae are unable to anchor to substrates. Turbulent conditions in streams and rivers may kill or damage larvae, limiting downstream settlement (Sprung 1993; Horvath et al. 1996). In Europe, zebra mussels are rarely found in rivers and streams less than 30 m wide, perhaps due to the higher velocities found in smaller rivers (Strayer 1991).

Lake size and depth. In Europe, larger, deeper lakes tend to support zebra mussels more frequently than smaller, more shallow lakes, possibly due to the tendency of shallow lakes to freeze in the winter (Strayer 1991).

Food limitation. Because zebra mussels are very efficient filter feeders, pumping water at a rate of up to one liter per mussel per day, they can thrive in waters with moderate to low levels of nutrients. However, waters that are exceptionally low in algal nutrients tend to lack or have very low densities of zebra mussels (Ramcharan et al. 1992).

Method of Assessing Colonization Potential

Sites were scored as being of high, moderate or low-to-no suitability for each of the five selected variables based on a comparison of water quality data with the reported tolerance ranges. High suitability (a score of “1”) means that water chemistry conditions are probably optimal for colonization by zebra mussels, and would support moderate to high abundances if other factors are appropriate. Moderate suitability (a score of “2”) means that water chemistry conditions are adequate for zebra mussel colonization, and would help to support moderate abundances, but high abundances may occur only with the positive contribution of other factors. Low to no suitability (a “3”) means that water chemistry conditions would probably not support zebra mussels, and, should zebra mussels colonize such waters, their densities would likely be low.

Sites were first scored for suitability based one variable at a time using Table 2; then each site's overall colonization potential, consolidating the effect of all variables, was scored using Table 3. If a water body ranked as “3” (unsuitable) for any individual variable, it was scored as having low-to-no colonization potential. If no variable was ranked a “3”, and calcium and pH both ranked a “2” (moderately suitable), then the water body was scored as having a moderate colonization potential. If no variable ranked a “3”, and either calcium or pH ranked a “1”, then the water body was scored as having high colonization potential. Calcium and pH were thus given slightly greater weight than the other variables, consistent with our review of the literature and our discussions with researchers.

Table 3. Scoring System for Assessing Colonization Potential

Suitability ranking for individual variables					Colonization potential
Calcium	pH	Temperature	Dissolved Oxygen	Salinity	
either = 1 and neither = 3		1 or 2			high
both = 2		1 or 2			moderate
at least one variable = 3					low-to-no

In keeping with this scoring system, at a site where water quality was not available for every variable, but one or more of the known variables was a “3,” the site was scored as having low-to-no colonization potential. Also, a few water bodies were classified as unsuitable for zebra mussel colonization based on information on periodic desiccation. The scores for each site are provided in Appendix C.

Factors Affecting Potential Abundance

In areas where water chemistry is appropriate for zebra mussels (corresponding to high or moderate colonization potential as estimated in this study) and where zebra mussels have become established, the following factors may affect abundance:

Chemical conditions. Abundances tend to be higher as the calcium, pH, dissolved oxygen, and salinity levels approach the high suitability ranges shown in Table 2.

Temperatures. In Europe, abundances tend to be lower in extremely cold (<6° C in the winter) environments, where threshold temperatures for spawning occur infrequently and ice scour may occur (Stanczykowska and Lewandowski 1993).

Substrate availability. Settlement success, also known as larval recruitment, is dependent on the availability of suitable substrates during the period that planktonic larvae must settle from the water column. Mellina and Rasmussen (1992) found that substrate availability explained between 38% to 91% of the variability in densities of zebra mussels in the Hudson and St. Lawrence rivers and Oneida Lake and explained 75% of the variability in 72 other lake sites described in the literature.

Water velocity and turbulence. Water velocities affect larval settlement and fertilization success. Young zebra mussels are unable to settle from water that is flowing faster than about 1.5 m/sec (6 ft/sec), which limits their ability to settle in many streams and rivers (Jenner and Janssen-Mommen 1993). In addition to impeding settlement, faster waters lower fertilization success by washing gametes downstream, and associated turbulence can damage or kill fragile larvae (Sprung 1993; Horvath et al. 1996). These factors may account for the tendency for zebra mussel densities to be lower in rivers than in lakes (Strayer 1991; Horvath et al. 1996).

Trophic status. In a study of Polish lakes, Stanczykowska and Lewandowski (1993) found that zebra mussel densities were strongly related to the lakes' trophic status (the amount of nutrients and algae in the lake). Lakes with high or very high levels of nutrients and algae had no or low densities of zebra mussels; lakes with medium to low levels of nutrients and algae tended to have medium to high densities of zebra mussels. Also, zebra mussels declined or disappeared as lakes became more eutrophic (richer in nutrients). Ramcharan et al. (1992) found that the density of zebra mussels was negatively correlated with phosphate and nitrate in European lakes, which also suggests that eutrophic lakes are less suitable habitats. Ramcharan et al. (1992) speculate that such lakes may be less suitable because they tend to be lower in oxygen, and because high densities of algae may clog mussels' gills.

Lake size and depth. Stanczykowska and Lewandowski (1993) found that relatively large and deep European lakes that have low to moderate levels of algae and nutrients have higher densities of mussels than relatively small and shallow lakes that are higher in algae and nutrients.

Population structure. The population size in dense populations of zebra mussels tends to fluctuate more than in less dense populations. Stanczykowsa and Lewandowski (1993) recorded periodic sharp population declines in dense populations of zebra mussels comprised of large and heavy individuals, and speculated that this may be due to deteriorating feeding conditions, to parasites or diseases, or to multiple factors acting collectively.

Predation. Hydra (a freshwater organism related to jellyfish), zooplankton and fish (including roach, freshwater drum, sunfish, carp, perch, and walleye) feed on zebra mussel larvae, but do not control zebra mussel densities in European lakes (Mackie and Schloesser 1996). Waterfowl can be voracious consumers of adult zebra mussels. Ducks consumed 57% of the zebra mussels in western Lake Erie in one fall, 90% in Lake Constance in one winter, and 93% in Golpo Lake in

Poland in one winter (MacIsaac 1996; Stanczykowska and Lewandowski 1993). However, zebra mussel populations quickly recovered. MacIsaac (1996) has suggested that waterfowl predation could depress zebra mussel populations over the long term in the southern United States, where waterfowl are present in large numbers for much of the year.

Parasites. The most common zebra mussel parasites are trematode worms and protozoans (one-celled animals). Zebra mussels host fewer parasites than other freshwater mollusks, and mortality caused by parasites does not appear to affect their densities (Mackie and Schloesser 1996).

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Personal Communications

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Appendix A. Water Quality Information Sources and Staff Contacts

City and County of San Francisco. Cindy Wong (650) 872-5965.

Contra Costa Water District. Joe Guistino (510) 688-8270.

Department of Water Resources. Jeff Janik (916) 653-5688.

East Bay Municipal Utility District. Rod Jung (510) 287-1219 .

Los Angeles Department of Water and Power. Doug Ball (213) 367-3222.

Metropolitan Water Agency. Dave Crocker (909) 392-5149.

Regional Water Quality Control Board, Region 6. (916) 542-5400. Region 7: (619) 346-7491.

STORET—U. S. Environmental Protection Agency, Region IX. Eric Wilson (415) 744-1964.

Tahoe Research Group. Patty Arneson (916) 583-3279.

Appendix B. Water Quality Data Used in the Analysis

				Data	— Calcium —		— pH —		— Temperature —			— DO —	
Site		Lat.	Long.	source 1	n	avg	n	avg	n	avg	max	n	avg
1	Alamo River near Calipatria	-115.39	33.10	STORET	29	177	81	8.0	223	26.5	32.5	81	7.4
2	All American Canal 2	-114.71	32.75	STORET	1	67	11	7.9	1	28.0	30.4	11	8.0
3	American River at Nimbus Dam	-121.22	38.64	STORET	9	4	31	7.1	31	17.5	19.0	31	8.2
4	American River near Carmichael	-121.37	38.57	STORET	1	5	25	7.0	25	18.4	19.5	25	8.6
5	Anderson Reservoir at dam	-121.63	37.16	STORET	23	33	1	7.7	3	19.8	21.0	3	9.3
6	Antelope Lake	-120.50	40.02	DWR	9	9	16	7.6	16	15.5	23.1	14	8.6
7	Arroyo Seco near Soledad	-121.33	36.28	STORET	5	62	5	8.2	5	20.1	22.0	4	10.0
8	Bear River near Wheatland	-121.41	39.00	STORET	26	10	28	7.8	4	18.1	20.6	28	9.0
9	Black Butte Reservoir	-122.34	39.81	STORET	21	31	22	8.0	22	21.1	28.4	22	6.5
10	Butte Creek near Chico	-121.71	39.73	STORET	5	10	23	7.8	19	17.3	22.0	22	10.3
11	Cache Creek near Lower Lake	-122.57	38.92	STORET	6	22	32	7.8	27	20.8	27.0	32	8.3
12	Calero Reservoir near New Almaden	-121.77	37.18	STORET	74	26	55	8.1	55	19.2	23.8	55	8.3
13	California Aqueduct near Check 21	-119.98	36.02	STORET	48	18	53	7.9	53	21.4	27.0	52	8.4
14	California Aqueduct at Check 41	-118.83	34.93	DWR 3	51	22	53	7.9	87	20.8	26.3	83	8.5
15	California Aqueduct near Kettleman City	-119.98	36.02	DWR	84	23	52	7.7	117	22.3	26.8	118	8.5
16	Camanche Reservoir 4	-120.91	38.23	STORET	14	3	23	7.1	23	17.6	26.2	23	8.0
17	Carmel River near Carmel	-121.87	36.54	STORET	2	33	1	7.7	34	16.7	20.5	1	9.8
18	Chowchilla River below Buchanan Dam	-119.99	37.22	STORET	4	15	5	7.6	5	17.7	27.0	5	10.9
19	Clear Lake -upper arm	-122.87	39.06	STORET	38	20	77	7.9	77	21.0	27.8	77	7.4
20	Clear Lake - lower arm	-122.68	38.97	STORET	37	21	77	7.7	78	21.2	27.8	78	7.8
21	Clifton Court	-121.56	37.83	STORET	49	15	100	7.9	100	20.5	26.5	99	8.8
22	Colorado River at Aqueduct intake 5	-114.16	34.32	STORET	34	79	12	8.0	30	22.3	28.0	7	7.6
23	Colorado River Aqueduct-Lake Mathews 6	-117.43	33.83	MWD	30	77	30	8.5	30	24.4	29.0	106	8.9
24	Contra Loma Reservoir	-121.75	37.96	CCWD	15	19	15	7.5	19	17.7	26.5	4	10.6
25	Cosumnes River at Michigan Bar	-121.04	38.50	STORET	12	6	18	7.5	8	21.0	28.7	17	8.6
26	Coyote Creek below Anderson Dam	-121.63	37.17	STORET	23	35	23	8.0	42	13.8	22.0	23	10.2
27	Crystal Springs Reservoir	-121.50	37.58	CCSF	5	13	6	8.2	5	18.5	25.4	nd	nd
28	Delta Mendota Canal 2.2 mi S of Firebaugh	-120.43	36.83	STORET	9	28	1	8.0	11	19.3	26.0	6	7.6
29	Delta Mendota Canal at head	-121.59	37.78	STORET	12	20	2	7.6	22	20.6	25.0	6	8.9
30	Don Pedro Reservoir at influent	-120.31	37.88	STORET	11	3	1	6.5	1	23.7	23.7	1	8.1
31	Lake Sonoma- Dry Creek Arm	-123.02	38.72	STORET	4	14	8	7.5	12	16.3	23.0	12	8.5
32	Eagle Lake	-120.74	40.62	STORET	25	9	31	9.1	31	15.7	22.5	30	8.8

Appendix B. Water Quality Data Used in the Analysis

				Data	— Calcium —		— pH —		— Temperature —			— DO —	
Site		Lat.	Long.	source 1	n	avg	n	avg	n	avg	max	n	avg
33	East Highline Canal 7	-115.28	32.70	STORET	5	76	8	8.3	8	25.2	30.0	7	7.6
34	Eel River at Scotia	-124.10	40.49	STORET	43	31	100	8.3	115	20.4	24.0	100	9.7
35	Eel River near Dos Rios	-123.34	39.63	STORET	6	23	33	8.1	30	19.6	29.0	33	9.5
36	Eel River at Black Butte River	-123.08	39.83	STORET	4	27	12	7.9	8	17.6	27.0	12	10.3
37	Eel River South Fork Near Miranda	-123.78	40.18	STORET	5	21	33	8.1	29	19.1	26.0	33	10.8
38	Russian River near Ukiah	-123.19	39.20	STORET	9	20	34	7.4	35	13.6	22.0	32	10.2
39	Feather River Middle Fork near Portola	-120.44	39.82	STORET	13	12	16	7.5	3	14.3	19.5	16	8.4
40	Feather River near Nicolaus	-121.58	38.90	STORET	5	8	12	7.5	11	18.4	20.5	12	9.9
41	Folsom Lake near Folsom	-121.16	38.71	STORET	6	4	46	7.0	46	16.2	24.3	46	7.2
42	Frenchman Lake	-120.45	39.92	DWR	8	12	14	7.8	14	13.3	17.8	14	9.0
43	Fresno River near Daulton	-119.89	37.10	STORET	6	18	7	7.5	7	15.4	22.0	6	9.7
44	Friant-Kern Canal at Friant	-119.70	37.00	STORET	6	2	6	6.7	6	15.9	22.0	6	9.9
45	Glenn-Colusa Canal near Hamilton City	-122.02	39.74	STORET	1	9	1	8.0	1	20.0	20.0	1	9.8
46	Goose Lake	-120.42	42.42	RWQCB 6	nd	nd	nd	nd	nd	nd	nd	nd	nd
47	Hetch Hetchy Reservoir	-119.78	37.93	CCSF	nd	8 to 9	nd	7.8	nd	nd	nd	nd	nd
48	Honey Lake	-120.30	40.25	RWQCB 7	nd	nd	nd	nd	nd	nd	nd	nd	nd
49	Indian Valley Reservoir	-122.54	39.08	STORET	24	17	25	7.8	24	15.6	26.0	24	6.4
50	Iron Canyon Reservoir	-121.99	41.05	STORET	3	8	3	7.8	3	14.1	17.1	3	10.4
51	Kaweah River at Three Rivers	-118.90	36.44	STORET	4	10	4	7.6	4	17.5	25.0	4	10.0
52	Kaweah River below Terminus Dam	-119.01	36.41	STORET	8	9	10	7.4	10	16.3	24.0	10	9.8
53	Kern River above Fairview	-118.48	35.94	STORET	6	4	6	7.3	6	11.5	15.0	6	10.3
54	Kern River near Bakersfield	-118.86	35.44	STORET	8	10	10	7.5	10	18.2	23.0	10	9.1
55	Kings River near Trimmer	-119.14	36.87	STORET	15	2	111	7.3	117	16.7	23.5	106	9.7
56	Kings River - South Fork at Cedar Grove	-118.75	36.81	STORET	5	2	8	7.2	8	10.6	19.0	8	10.1
57	Klamath River at Hamburg	-122.98	41.83	STORET	9	13	56	8.2	49	19.4	26.5	57	9.7
58	Klamath River near Klamath	-124.00	41.51	STORET	46	15	103	8.4	120	19.0	23.5	102	9.4
59	Klamath River at Orleans	-123.53	41.30	STORET	5	13	76	7.9	71	17.0	27.0	76	10.2
60	Klamath River below Iron Gate Dam	-122.44	41.93	STORET	12	12	66	8.2	59	18.4	24.0	67	9.6
61	Lake Almanor- east arm	-121.11	40.24	STORET	1	8	19	7.8	19	10.0	14.5	3	9.4
62	Lake Britton at Ferry Crossing	-121.67	41.02	STORET	3	10	3	7.8	3	14.5	17.6	3	7.5
63	Lake Castaic	-117.58	34.55	DWR	37	30	119	9.0	115	21.3	27.7	117	10.1
64	Lake Davis	-120.50	39.92	DWR	16	8	142	7.7	140	17.3	23.6	143	6.7

Appendix B. Water Quality Data Used in the Analysis

				Data	— Calcium —		— pH —		— Temperature —			— DO —	
Site		Lat.	Long.	source 1	n	avg	n	avg	n	avg	max	n	avg
65	Lake Del Valle at Glory Hole	-121.71	37.63	DWR	29	32	49	8.5	49	17.8	24.2	47	7.8
66	Lake Perris at inlet	-117.17	33.83	DWR	14	26	53	8.5	53	23.2	27.6	53	8.7
67	Lake Tahoe	-120.08	39.13	TRG	nd	8	nd	7.7	nd	nd	nd	nd	nd
68	Lake Berryessa at dam	-122.10	38.51	STORET	2	17	4	7.3	26	15.1	24.1	21	8.9
69	Lake Havasu at Parker Dam	-114.13	34.30	STORET	79	75	220	7.8	274	22.5	32.4	274	6.5
70	Lake Isabella at Engineer Point	-118.46	35.66	STORET	2	7	70	7.5	70	16.9	22.1	70	6.4
71	Lexington Reservoir at dam	-121.99	37.20	STORET	24	36	201	7.9	201	16.3	24.5	201	7.0
72	Lower Alkali Lake	-120.08	41.25	RWQCB 6	nd	nd	nd	nd	nd	nd	nd	nd	nd
73	Los Angeles Aqueduct-- Grant Lakes	-119.08	37.83	LADWP	14	6	13	7.4	14	12.7	18.0	14	7.8
74	Los Angeles Aqueduct-- Merritt Cut	-118.00	36.02	LADWP	11	17	76	8.2	81	20.2	26.2	76	8.1
75	Los Angeles Aqueduct—Tinemaha	-118.02	37.08	LADWP	17	21	23	8.3	23	19.5	25.4	17	7.6
76	Los Angeles River at Long Beach	-118.21	33.82	STORET	29	75	79	9.7	82	27.9	34.0	80	19.3
77	Mad River near Arcata	-124.06	40.91	STORET	7	22	25	7.9	21	18.0	23.5	25	10.5
78	Mammoth Creek at Highway 395	-118.90	37.64	STORET	21	9	21	7.9	27	10.7	18.0	1	10.2
79	Mariposa Creek below Mariposa Dam	-120.16	37.30	STORET	8	25	8	8.0	9	17.6	23.0	8	12.2
80	McCloud Reservoir at dam	-122.07	41.13	STORET	3	8	3	7.6	3	10.0	11.4	3	10.1
81	McCloud River above Shasta Lake	-122.22	40.96	STORET	13	13	43	7.8	32	14.1	20.0	44	10.3
82	Merced River near Stevinson	-120.93	37.37	STORET	21	10	23	7.5	22	21.2	32.5	22	8.6
83	Merced River - South Fork near El Portal	-119.89	37.65	STORET	1	3	1	7.3	1	10.0	10.0	1	10.9
84	Stanislaus River- Middle Fork at Dardanelle	-119.83	38.34	STORET	10	3	4	7.3	4	7.9	11.0	4	10.1
85	Millerton Lake near Friant Dam	-119.70	37.01	STORET	10	3	70	7.1	70	17.0	27.4	70	9.1
86	Mojave River near Victorville	-117.32	34.57	STORET	12	34	13	7.9	17	25.2	32.0	15	7.3
87	Mokelumne River at Woodbridge	-121.30	38.16	STORET	33	4	81	7.3	87	18.8	22.5	82	9.1
88	Mono Lake	-119.12	38.00	RWQCB 5	nd	nd	nd	nd	nd	nd	nd	nd	nd
89	Nacimiento Reservoir - lower arm	-121.06	35.73	STORET	7	28	1	8.0	1	22.0	22.0	1	8.7
90	Napa River near Napa	-122.30	38.37	STORET	36	28	66	8.1	105	19.4	24.5	67	9.2
91	New River at international boundary	-115.50	32.67	STORET	2	250	542	7.7	529	27.4	31.8	0	0.0
92	North Bay Aqueduct at Barker Slough	-121.78	38.28	DWR	54	18	66	7.6	66	19.9	26.8	66	7.3
93	Old River at Tracy Road Bridge	-121.45	37.80	STORET	31	32	104	7.8	128	21.2	27.0	118	7.6
94	Old River Intake	-121.33	37.91	CCWD	7	9	7	7.4	6	22.0	25.3	3	9.0
95	Owens River below Tinemaha	-118.23	37.05	STORET	15	18	17	8.1	19	17.8	23.0	18	8.5
96	Pajaro River at Chittenden	-121.60	36.90	STORET	30	81	33	8.1	68	18.6	23.0	33	7.9

Appendix B. Water Quality Data Used in the Analysis

				Data	— Calcium —		— pH —		— Temperature —			— DO —	
Site		Lat.	Long.	source 1	n	avg	n	avg	n	avg	max	n	avg
97	Pardee Reservoir	-120.83	38.25	EBMUD	10	3	11	7.6	nd	nd	nd	nd	nd
98	Pillsbury Lake near Potter Valley	-122.96	39.41	STORET	1	18	1	7.8	1	16.8	16.8	1	8.8
99	Pine Flat Reservoir above dam	-119.32	36.83	STORET	5	3	3	7.2	2	13.0	17.0	2	6.5
100	Piru Creek release from Pyramid Dam	-118.76	34.64	STORET	40	32	32	7.8	41	14.6	22.0	38	10.1
101	Pit River - South Fork near Likely	-120.44	41.23	STORET	10	10	17	8.1	14	15.4	25.0	17	9.0
102	Pit River near Canby	-120.93	41.41	STORET	8	19	31	8.1	27	18.9	25.5	31	8.6
103	Pit River near Montgomery Creek	-122.03	40.85	STORET	14	10	31	7.9	23	16.5	19.5	31	9.9
104	Putah Creek below Monticello Dam 8	-122.09	38.53	STORET	68	16	44	7.8	2	12.5	12.9	15	9.4
105	Pyramid Lake at inlet	-118.80	34.68	DWR	36	24	107	8.4	108	20.8	28.4	105	8.9
106	Rock Slough at Plant	-121.66	37.97	CCWD	35	12	23	7.7	21	21.8	nd	nd	nd
107	Sacramento River at Delta	-122.42	40.94	STORET	15	6	4	7.9	14	16.1	19.5	4	10.0
108	Sacramento River at Freeport	-121.50	38.46	STORET	60	11	103	7.7	382	19.5	25.0	105	8.8
109	Sacramento River at Keswick	-122.44	40.60	STORET	45	9	81	7.5	112	11.2	15.0	87	10.4
110	Sacramento River near Red Bluff	-122.19	40.29	STORET	3	9	11	7.5	109	12.4	15.5	11	10.7
111	Salinas River near Bradley	-120.87	35.93	STORET	6	48	6	8.1	6	21.3	23.5	6	9.4
112	Salinas River near Chualar	-121.55	36.56	STORET	45	49	59	8.4	100	22.4	28.5	66	9.5
113	Salmon River at Somesbar	-123.48	41.38	STORET	7	9	56	7.6	52	15.4	23.5	56	10.2
114	Salton Sea - midpoint near County Line	-115.95	33.42	STORET	22	1416	9	8.3	8	26.6	32.0	0	0.0
115	San Andreas Reservoir	-122.42	37.60	CCSF	5	13	7	8.2	5	22.5	25.4	nd	nd
116	San Antonio River below San Antonio Dam	-120.85	35.80	STORET	7	50	8	8.2	8	20.3	24.0	7	11.3
117	San Antonio Reservoir	-121.83	37.68	CCSF	5	28	7	8.4	7	24.1	26.2	nd	nd
118	San Benito River near Willow Creek School	-121.20	36.61	STORET	7	27	8	8.4	8	21.3	26.0	8	10.1
119	San Diego River at El Capitan Dam 9	-116.81	32.88	STORET	2	24	1	8.0	3	26.0	31.0	17	8.5
120	San Gabriel River at Azusa	-117.91	34.15	STORET	41	43	7	8.3	8	19.6	26.0	7	8.9
121	San Joaquin River at Antioch ship channel	-121.81	38.02	STORET	131	33	155	7.8	161	20.8	25.0	160	8.5
122	San Joaquin River near Stevinson 10	-120.93	37.31	STORET	33	59	39	7.8	39	22.6	29.0	37	8.1
123	San Joaquin River at Highway 152 Bridge	-120.55	37.06	STORET	2	31	2	7.8	2	22.0	22.0	2	8.7
124	San Joaquin River Below Friant Dam	-119.72	36.98	STORET	10	3	10	7.1	10	12.8	22.0	10	11.6
125	San Joaquin R - S Fork at Mono Hot Springs	-118.96	37.31	STORET	11	1	14	7.3	14	12.2	17.0	13	8.5
126	San Lorenzo River near Boulder Creek	-122.14	37.21	STORET	7	76	7	8.3	7	14.1	17.0	7	9.6
127	San Luis Reservoir at trashracks	-121.08	37.05	DWR	47	24	51	8.3	51	19.6	25.2	43	9.8
128	San Luis Rey River at Oceanside	-117.36	33.22	STORET	32	147	82	8.0	312	25.7	35.0	80	8.7

Appendix B. Water Quality Data Used in the Analysis

				Data	— Calcium —		— pH —		— Temperature —			— DO —	
Site		Lat.	Long.	source 1	n	avg	n	avg	n	avg	max	n	avg
129	San Pablo Reservoir	-122.08	37.83	EBMUD	9	18	10	8.5	nd	nd	nd	nd	nd
130	Santa Ana River at Mwd Crossing	-117.45	33.97	STORET	12	94	nd	nd	177	23.2	34.5	nd	nd
131	Santa Clara River at LA-Ventura Co line	-118.70	34.40	STORET	21	122	36	8.2	41	22.5	28.0	34	8.1
132	Santa Ynez River at Narrows near Lompoc 11	-120.43	34.64	STORET	1	110	32	8.0	32	20.1	30.5	4	9.6
133	South Bay Aqueduct at Santa Clara Terminus	-121.83	37.58	DWR	30	18	34	7.9	34	20.8	26.3	34	9.1
134	Scott River near Fort Jones	-123.02	41.64	STORET	7	19	23	8.1	19	19.8	25.5	23	10.2
135	Sespe Creek near Fillmore	-118.93	34.45	STORET	1	86	6	8.6	7	20.9	26.0	5	9.1
136	American River - South Fork near Lotus	-120.95	38.82	STORET	22	2	31	7.2	31	15.0	18.5	31	10.0
137	Shasta Lake near Shasta Dam	-122.41	40.73	STORET	16	9	61	7.5	61	16.0	26.0	61	7.3
138	Shasta River below Dwinnell Reservoir	-122.38	41.55	STORET	2	11	27	8.1	26	17.8	24.5	27	8.0
139	Silverwood Lake at San Bernardino	-117.33	34.28	STORET	90	18	92	8.4	109	19.1	26.5	109	9.0
140	Siskiyou Lake - upper end near Shasta City	-122.35	41.29	STORET	3	3	20	7.1	20	12.3	16.3	20	9.3
141	Smith River near Crescent City	-124.08	41.79	STORET	29	7	81	8.2	100	17.4	22.5	81	9.6
142	South Bay Aqueduct at Mile 16.27	-121.77	37.65	STORET	6	17	6	8.1	6	20.5	23.3	6	9.6
143	South Bay Pumping Plant	-121.62	37.78	STORET	nd	nd	44	7.9	44	19.7	24.1	43	8.3
144	South Yuba River near Cisco	-120.56	39.32	STORET	12	3	12	7.1	2	11.8	13.4	12	10.1
145	Stanislaus River at Ripon	-121.11	37.73	STORET	38	8	40	7.5	39	17.3	24.8	38	9.2
146	Tehama-Colusa Canal near Red Bluff	-122.20	40.15	STORET	9	10	49	7.6	41	14.5	18.5	49	10.5
147	Thermalito Afterbay	-121.67	39.50	DWR	47	8	59	7.2	61	17.7	24.4	59	9.4
148	Thomes Creek at Paskenta	-122.53	39.89	STORET	19	31	79	8.2	74	20.3	32.1	78	9.5
149	Trinity River at Hoopa	-123.67	41.05	STORET	7	16	33	7.8	28	16.9	26.5	33	10.2
150	Trinity River at Lewiston	-122.80	40.72	STORET	7	4	26	7.6	22	10.9	13.0	26	11.1
151	Trinity River near Burnt Ranch	-123.44	40.79	STORET	4	9	22	7.6	18	15.5	20.0	22	10.2
152	Truckee River at Farad 12	-120.03	39.42	STORET	72	8	71	7.6	102	11.2	18.5	6	8.3
153	Tule River below Success Dam	-118.92	36.06	STORET	15	18	12	7.6	12	18.6	28.0	12	9.6
154	Tuolumne River at La Grange Bridge	-120.46	37.67	STORET	11	3	18	7.1	18	12.6	16.0	18	10.4
155	Tuolumne River at Modesto	-120.99	37.63	STORET	36	13	40	7.8	39	21.8	30.0	38	9.7
156	Upper Alkali Lake	-120.42	42.25	RWQCB 6	nd	nd	nd	nd	nd	nd	nd	nd	nd
157	Upper San Leandro Reservoir	-122.17	37.07	EBMUD	14	26	10	8.5	nd	nd	nd	nd	nd
158	Van Duzen River near Bridgeville	-123.89	40.48	STORET	7	25	33	7.9	30	17.2	22.0	33	10.1
159	Whiskeytown Reservoir at dam	-122.54	40.60	STORET	4	5	6	7.3	6	15.0	23.3	6	8.0
160	Yuba River near Marysville	-121.52	39.18	STORET	19	7	24	7.5	6	16.3	18.1	24	10.0

Appendix B. Water Quality Data Used in the Analysis

			Data	— Calcium —		— pH —		— Temperature —			— DO —	
Site	Lat.	Long.	source 1	n	avg	n	avg	n	avg	max	n	avg

Notes

For some sites where certain data were not available, data from adjacent sites were substituted, as noted below.

1 CCSF = City and County of San Francisco
CCWD = Contra Costa Water District
DWR = California Department of Water Resources
EBMUD = East Bay Municipal Utility District
LADWP = Los Angeles Department of Water and Power
MWD = Metropolitan Water District of Southern California
RWQCB = Regional Water Quality Control Board, Regions 6 or 7
STORET = US Environmental Protection Agency's STORET database
TRG = Tahoe Research Group
2 Maximum temperature is from the Coachella Canal, supplied by RWQCB Region 7.
3 pH data are from STORET.
4 Calcium data are from the Mokelumne River near Mokelumne Hill.
5 Dissolved oxygen and pH data are from the Colorado River below Parker Dam.
6 Dissolved oxygen data are from Lake Perris.
7 Temperature data are from the Colorado River at Parker Dam.
8 Dissolved oxygen data are from Putah Creek near Winters.
9 Dissolved oxygen data are from the San Diego River at Old Mission Dam.
10 Calcium data are from the San Joaquin River at Vernalis.
11 Dissolved oxygen data are from the Santa Ynez River at Los Laureles.
12 Dissolved oxygen data are from the Truckee River below Farad.

Appendix C. Site Rankings for Individual Variables and Colonization Potential

Site		Dissolved calcium	pH	Temper- ature	Dissolved oxygen	Colonization potential
1	Alamo River near Calipatria	1	1	3	2	3
2	All American Canal	1	1	1	1	1
3	American River at Nimbus Dam	3	3	1	1	3
4	American River near Carmichael	3	3	1	1	3
5	Anderson Reservoir at dam	1	1	1	1	1
6	Antelope Lake	3	1	1	1	3
7	Arroyo Seco near Soledad	1	1	1	1	1
8	Bear River near Wheatland	3	1	1	1	3
9	Black Butte Reservoir	1	1	1	2	1
10	Butte Creek near Chico	3	1	1	1	3
11	Cache Creek near Lower Lake	2	1	1	1	1
12	Calero Reservoir near New Almaden	1	1	1	1	1
13	California Aqueduct near Check 21	2	1	1	1	1
14	California Aqueduct at Check 41	2	1	1	1	1
15	California Aqueduct near Kettleman	2	1	1	1	1
16	Camanche Reservoir	3	3	1	1	3
17	Carmel River near Carmel	1	1	1	1	1
18	Chowchilla River below Buchanan Dam	2	1	1	1	1
19	Clear Lake - upper arm	2	1	1	2	1
20	Clear Lake - lower arm	2	1	1	2	1
21	Clifton Court	2	1	1	1	1
22	Colorado River at Aqueduct intake	1	1	1	1	1
23	Colorado River Aqueduct - Lake Mathews	1	1	1	1	1
24	Contra Loma Reservoir 1	2	1	1	1	1
25	Cosumnes River at Michigan Bar	3	2	1	1	3
26	Coyote Creek below Anderson Dam	1	1	2	1	1
27	Crystal Springs Reservoir 2	3	1	1	1	3
28	Delta Mendota Canal 2.2 mi S of Firebaugh	1	1	1	1	1
29	Delta Mendota Canal at head	2	1	1	1	1
30	Don Pedro Reservoir at influent	3	3	1	1	3
31	Lake Sonoma- Dry Creek Arm	3	1	1	1	3
32	Eagle Lake	3	3	1	1	3
33	East Highline Canal	1	1	1	2	1
34	Eel River at Scotia	1	1	1	1	1
35	Eel River near Dos Rios	2	1	1	1	1
36	Eel River at Black Butte River	1	1	1	1	1
37	Eel River South Fork Near Miranda	2	1	1	1	1
38	Russian River near Ukiah	2	2	2	1	2
39	Feather River Middle Fork near Portola	3	2	2	1	3
40	Feather River near Nicolaus	3	2	1	1	3
41	Folsom Lake near Folsom	3	3	1	2	3
42	Frenchman Lake	3	1	2	1	3
43	Fresno River near Daulton	2	2	1	1	2
44	Friant-Kern Canal at Friant	3	3	1	1	3
45	Glenn-Colusa Canal near Hamilton City	3	1	1	1	3
46	Goose Lake 3	— — — — — — — — — no data — — — — — — — — —				3
47	Hetch Hetchy Reservoir	3	1	— — no data — —		3
48	Honey Lake 3	— — — — — — — — — no data — — — — — — — — —				3
49	Indian Valley Reservoir	2	1	1	2	1
50	Iron Canyon Reservoir	3	1	2	1	3
51	Kaweah River at Three Rivers	3	1	1	1	3
52	Kaweah River below Terminus Dam	3	2	1	1	3
53	Kern River above Fairview	3	2	2	1	3
54	Kern River near Bakersfield	3	1	1	1	3

Appendix C. Site Rankings for Individual Variables and Colonization Potential

Site		Dissolved calcium	pH	Temperature	Dissolved oxygen	Colonization potential
55	Kings River near Trimmer	3	2	1	1	3
56	Kings River - South Fork at Cedar Grove	3	3	2	1	3
57	Klamath River at Hamburg	3	1	1	1	3
58	Klamath River near Klamath	2	1	1	1	1
59	Klamath River at Orleans	3	1	1	1	3
60	Klamath River below Iron Gate Dam	3	1	1	1	3
61	Lake Almanor - east arm	3	1	2	1	3
62	Lake Britton at Ferry Crossing	3	1	2	2	3
63	Lake Castaic	1	2	1	1	1
64	Lake Davis	3	1	1	2	3
65	Lake Del Valle at Glory Hole	1	1	1	2	1
66	Lake Perris at inlet	1	1	1	1	1
67	Lake Tahoe	3	1	—— no data ——		3
68	Lake Berryessa at dam	2	2	1	1	2
69	Lake Havasu at Parker Dam	1	1	3	2	3
70	Lake Isabella at Engineer Point	3	2	1	2	3
71	Lexington Reservoir at dam near Los Gatos	1	1	1	2	1
72	Lower Alkali Lake 3	———————— no data ————————				3
73	Los Angeles Aqueduct - Grant Lakes	3	2	2	2	3
74	Los Angeles Aqueduct - Merritt Cut	2	1	1	1	1
75	Los Angeles Aqueduct - Tinemaha	2	1	1	2	1
76	Los Angeles River at Long Beach	1	3	3	1	3
77	Mad River near Arcata	2	1	1	1	1
78	Mammoth Creek at Highway 395	3	1	2	1	3
79	Mariposa Creek below Mariposa Dam	2	1	1	1	1
80	McCloud Reservoir at dam	3	1	2	1	3
81	McCloud River above Shasta Lake	3	1	2	1	3
82	Merced River near Stevinson	3	2	3	1	3
83	Merced River - South Fork near El Portal	3	3	2	1	3
84	Stanislaus River - Middle Fork at Dardanelle	3	3	2	1	3
85	Millerton Lake near Friant Dam	3	3	1	1	3
86	Mojave River near Victorville	1	1	3	2	3
87	Mokelumne River at Woodbridge	3	3	1	1	3
88	Mono Lake 4	———————— no data ————————				3
89	Nacimiento Reservoir - lower arm	1	1	1	1	1
90	Napa River near Napa	1	1	1	1	1
91	New River at international boundary	1	1	3	no data	3
92	North Bay Aqueduct at Barker Slough	2	1	1	2	1
93	Old River at Tracy Road Bridge	1	1	1	2	1
94	Old River Intake	3	2	1	1	3
95	Owens River below Tinemaha	2	1	1	1	1
96	Pajaro River at Chittenden	1	1	1	2	1
97	Pardee Reservoir	3	1	—— no data ——		3
98	Pillsbury Lake near Potter Valley	2	1	1	1	1
99	Pine Flat Reservoir above dam	3	3	2	2	3
100	Piru Creek release from Pyramid Dam	1	1	2	1	1
101	Pit River - South Fork near Likely	3	1	1	1	3
102	Pit River near Canby	2	1	1	1	1
103	Pit River near Montgomery Creek	3	1	1	1	3
104	Putah Creek below Monticello Dam	2	1	2	1	1
105	Pyramid Lake at inlet	2	1	1	1	1
106	Rock Slough at Plant	3	1	1	no data	3
107	Sacramento River at Delta	3	1	1	1	3
108	Sacramento River at Freeport	3	1	1	1	3

Appendix C. Site Rankings for Individual Variables and Colonization Potential

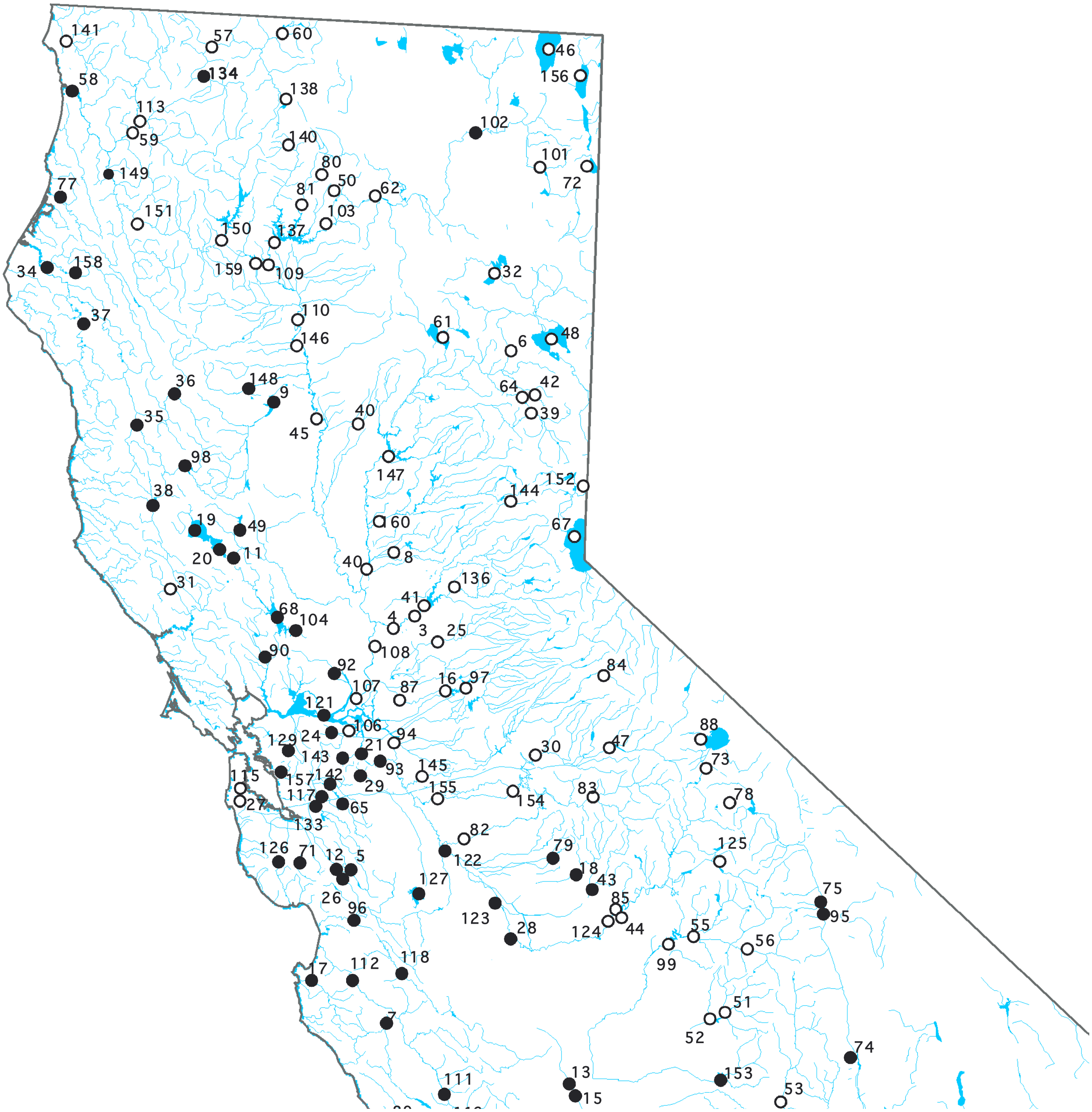
Site		Dissolved calcium	pH	Temper-ature	Dissolved oxygen	Colonization potential
109	Sacramento River at Keswick	3	1	2	1	3
110	Sacramento River near Red Bluff	3	2	2	1	3
111	Salinas River near Bradley	1	1	1	1	1
112	Salinas River near Chualar	1	1	1	1	1
113	Salmon River at Somesbar	3	1	1	1	3
114	Salton Sea - midpoint near County Line 4	1	1	3	no data	3
115	San Andreas Reservoir 2	3	1	1	1	3
116	San Antonio River below San Antonio Dam	1	1	1	1	1
117	San Antonio Reservoir 2	1	1	no data	1	1
118	San Benito River near Willow Creek School	1	1	1	1	1
119	San Diego River at El Capitan Dam	2	1	1	1	1
120	San Gabriel River at Azusa	1	1	1	1	1
121	San Joaquin River at Antioch Ship Channel	1	1	1	1	1
122	San Joaquin River near Stevinson	1	1	1	1	1
123	San Joaquin River at Highway 152 Bridge	1	1	1	1	1
124	San Joaquin River Below Friant Dam	3	3	2	1	3
125	San Joaquin R - S Fork at Mono Hot Springs	3	2	2	2	3
126	San Lorenzo River near Boulder Creek	1	1	2	1	1
127	San Luis Reservoir at trashracks	2	1	1	1	1
128	San Luis Rey River at Oceanside	1	1	3	1	3
129	San Pablo Reservoir 1, 2	1	1	1	1	1
130	Santa Ana River at MWD Crossing	1	no data	3	no data	3
131	Santa Clara River at LA-Ventura Co. line	1	1	1	1	1
132	Santa Ynez River at Narrows near Lompoc	1	1	1	no data	1
133	South Bay Aqueduct at Santa Clara Terminus	2	1	1	1	1
134	Scott River near Fort Jones	2	1	1	1	1
135	Sespe Creek near Fillmore	1	1	1	1	1
136	American River - South Fork near Lotus	3	3	2	1	3
137	Shasta Lake near Shasta Dam	3	1	1	1	3
138	Shasta River below Dwinnell Reservoir	3	1	1	1	3
139	Silverwood Lake at San Bernardino	2	1	1	1	1
140	Siskiyou Lake - upper end near Shasta City	3	3	2	1	3
141	Smith River near Crescent City	3	1	1	1	3
142	South Bay Aqueduct at Mile 16.27	2	1	1	1	1
143	South Bay Pumping Plant	2	1	1	1	1
144	South Yuba River near Cisco	3	3	2	1	3
145	Stanislaus River at Ripon	3	1	1	1	3
146	Tehama-Colusa Canal near Red Bluff	3	1	2	1	3
147	Thermalito Afterbay	3	3	1	1	3
148	Thomes Creek at Paskenta	1	1	3	1	3
149	Trinity River at Hoopa	2	1	1	1	1
150	Trinity River at Lewiston	3	1	2	1	3
151	Trinity River near Burnt Ranch	3	1	1	1	3
152	Truckee River at Farad	3	1	2	1	3
153	Tule River below Success Dam	2	1	1	1	1
154	Tuolumne River at La Grange Bridge	3	3	2	1	3
155	Tuolumne River at Modesto	3	1	1	1	3
156	Upper Alkali Lake 3	— — — — — — — — — no data — — — — — — — — —				3
157	Upper San Leandro Reservoir 1, 2	1	1	1	1	1
158	Van Duzen River near Bridgeville	1	1	1	1	1
159	Whiskeytown Reservoir at dam	3	2	1	1	3
160	Yuba River near Marysville	3	2	1	1	3

Appendix C. Site Rankings for Individual Variables and Colonization Potential

Site	Dissolved calcium	pH	Temperature	Dissolved oxygen	Colonization potential

Notes

1 No temperature data were available. Temperature assumed to be moderately to highly suitable based on regional conditions.
2 No dissolved oxygen data were available. Oxygen level assumed to be moderately to highly suitable.
3 Low-to-no colonization potential due to periodic dessication and possibly high salinity, based on data from RWQCB Regions 6 and 7.
4 No colonization potential due to high salinities (70-90 ppt).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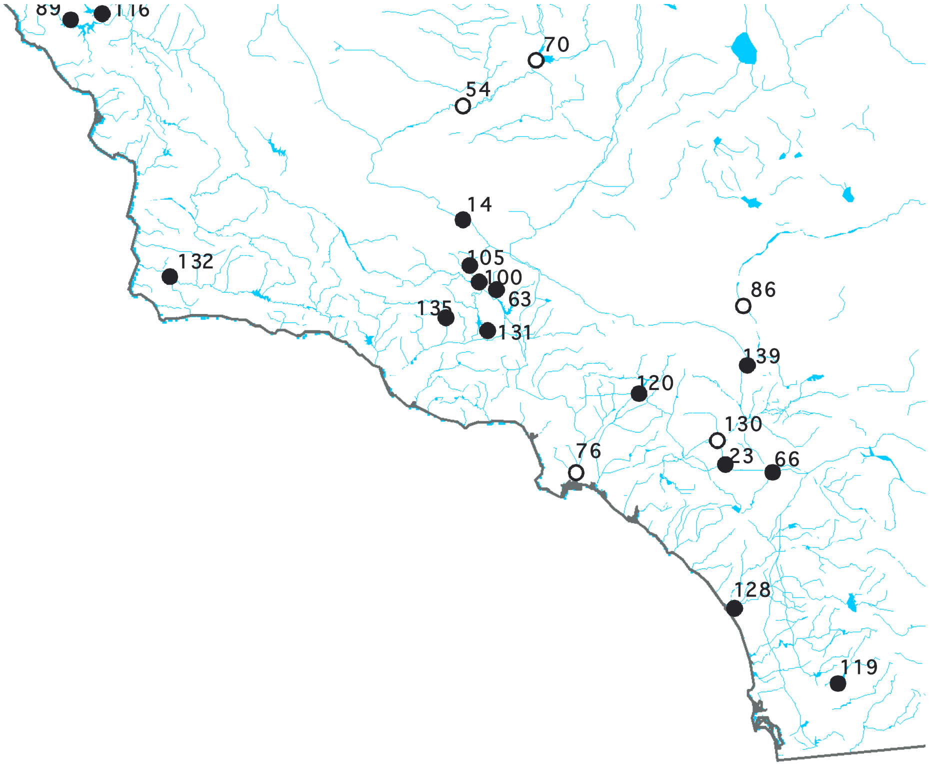
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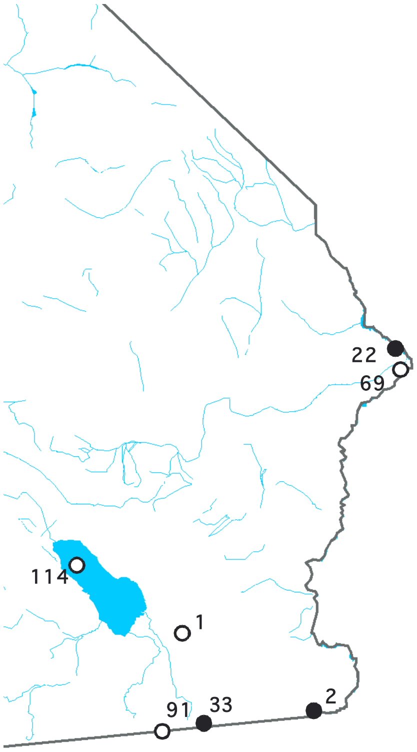
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