Inventory of Water Diversions in Four Geographic Areas in California's Central Valley

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Abstract

Water diversions in California, used primarily for agricultural, municipal, and industrial applications, have been considered a possible culprit in the decline of many California fishes. In 1991, the California Department of Fish and Game (DFG) initiated a study using the Global Positioning System (GPS) to inventory water diversions. The initial focus was on the Sacramento-San Joaquin Delta (Delta) and the Suisun Marsh, then continued to the Sacramento River and the San Joaquin River Basin, The inventory was to find, quantify, describe, and categorize diversions along waterways where California fish may be affected by water diversions. As of April 1997, 3,356 diversions have been located and mapped in a Geographical Information System (GIS). Approximately 98.5% of the diversions identified were either unscreened or screened insufficiently to prevent fish entrainment. The GPS data were post-processed to provide a horizontal accuracy of ±5 meters. The information was primarily collected by visual inspection of diversions on the stream bank. Information is maintained in a Microsoft Access database.

Introduction

California's Central Valley waterways support a rich diversity of fish species that are ecologically, economically, and recreationally important. Much of the water necessary for the survival of these species, however, is diverted out of the streams primarily for agriculture, but also for industry and municipalities.

A few researchers have attempted to estimate the number of Central Valley water diversions. Hallock and Van Woert (1959) estimated that there were 900 water diversions on the San Joaquin and Sacramento rivers above the Delta, which are used by anadromous fishes. Of the 900 diversions, only a small portion were specifically identified and described. Brown (1982) estimated 1,850 water diversions in the Delta based on an inventory conducted by the U.S. Bureau of Reclamation (USBR) in 1963–1964 and limited field observations.

These previous inventories were based on estimates and did not accurately assess the true number of diversions, nor did they maintain a database to monitor diversion modifications or relocations. In fact, water diversion inventories were not the objective of past studies, rather the objectives were to estimate water export volumes from geographic regions or fish losses due to entrainment. They did not identify all diversions in the area and map each diversion.

Past studies often located water diversions by visual observation while driving levee roads (Brown 1982). The corresponding odometer reading was then compared with river miles and river banks on maps to determine the locations of individual diversions (Hallock and Van Woert 1959; USBR 1963, 1964; Brown 1982). Another source of water diversion location and information in the Automated Water Rights Information Management System (AWRIMS) managed by the State of California Water Resources Control Board. AWRIMS gives locations of water diversion using the Public Land System, providing accuracies within 40 acres.

Comparisons of these earlier data did not correspond to GPS locations. DFG determined that a standardized and accurate database of water diversions was necessary before the magnitude of diversion-related fish losses could be recognized and addressed.

The GPS is a satellite-based positioning system maintained and operated by the U.S. Department of Defense (DOD). The use of GPS by the scientific community is growing due to its ease of use and high degree of accuracy. Examples of such uses include radiotelemetry studies of moose populations under various types of canopies (Moen and others 1996) and mapping and counting ponds used by breeding waterfowl (Strong and Cowardin 1995). With differential correction, the accuracy of GPS is usually within two meters of the true location 50% of the time, and within five meters 95% of the time (Trimble Navigation Ltd. 1992).

The objectives of our study were to find existing Central Valley water diversions, map them using GPS and GIS, and to identify and categorize them as screened or unscreened. The database of water diversions created by this program can easily be updated with future surveys to identify changes to location, size, and other features. Future objectives of the program will include prioritizing fish screen projects. GPS was selected as the survey method because of its ease of use, superior accuracy, application to various mapping programs and GIS compatibility.

Methods and Materials

Our study began with four regions established based on watershed drainages and similar geographic features (Figure 1). The initial focus was on the Sacramento-San Joaquin Delta (defined in California Water Code, Section 1220) and Suisun Marsh (defined in California Water Code, Sections 29101 and 29002–29003) since many ecologically, commercially, and recreationally popular fish species either reside in these areas or pass through them during some stage of life. These species include the chinook salmon (*Oncorhynchus tshawytscha*), striped bass (*Morone saxatilis*), white sturgeon (*Acipenser transmontanus*), delta smelt (*Hypomesus transpacificus*), Sacramento splittail (*Pogonichthys macrolepidotus*), and steelhead (*Oncorhynchus mykiss*). The survey for water diversions then continued to the San Joaquin River Basin (San Joaquin River mile 72.4 to the confluence with the Merced River, as well as the Stanislaus, Tuolumne and Merced rivers) and the Sacramento River (river mile 59.4 to Keswick Dam).

Field

A physical search to locate water diversions was made by boat, driving levee roads, or by walking the banks of waterways. A Pathfinder Basic Plus and a GeoExplorer, two portable GPS receivers manufactured by Trimble Navigation Limited, were used to geographically locate the position of water diversions. Topographical and navigational maps were used to systematically survey waterways, eliminating the possibility of data duplication.

Upon visual discovery of a water diversion, collection of data points was initiated using a GPS receiver. Data points were received via radio signals sent from 24 NAVSTAR satellites operated and maintained by the DOD (Trimble Navigation Ltd. 1982). Collection of points was made at, or as close to, the point of diversion as possible. Between 180 and 200 data points were collected at each site and stored in the receiver as individual rover files with unique file numbers. A location consisting of more than four diversions were treated as a single point of diversion.

Along with the GPS data, other attributes and a physical description of the diversion were recorded including type of diversion, intake size (outside diameter to the nearest inch, as measured with a logger's diameter tape), type of discharge, bank location, screen type (when present), river system or waterway, and likely primary use of the diverted water. Photographs were taken of each diversion or intake structure. Discharge outfalls or structures were only photographed if unique or uncommon to the region.

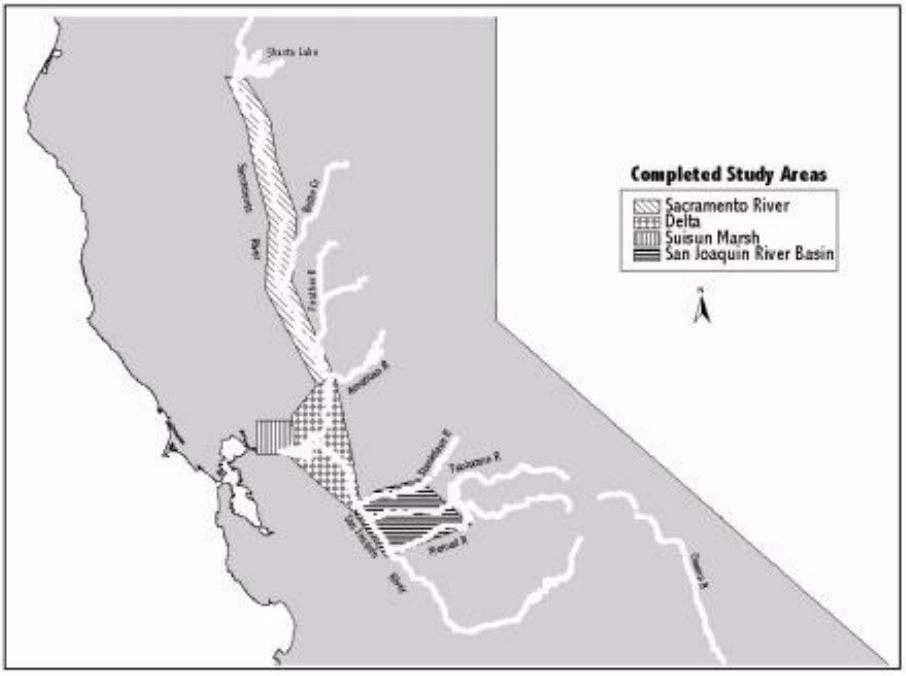

Figure 1 The water diversion study area showing the four geographic areas surveyed: mainstem Sacramento River, Sacramento-San Joaquin Delta, Suisun Marsh, and San Joaquin River basin watershed

Office

At the completion of each field day the rover files were uploaded to a personal computer. These files were then differentially corrected using the post-processing software, pFinder. Differential correction is the process of comparing the raw GPS positions (rover), to a known location (base station). Base station files were downloaded from various locations: USFWS offices in cities (including Sacramento, Susanville, Porterville, and Eureka); Trimble Navigation Ltd.; and other companies that operate base stations throughout the State. After post-processing, GPS data and associated attributes were entered, stored, and maintained in a Microsoft Access database. This information has been used to create a GIS layer output to a North American Datum 27 (NAD-27) Teale-Albers projection to be compatible with DFG's Arcview GIS system.

Each diversion is stored in the database as an individual record where it is assigned a unique identification number. Associated with the identification numbers are the map coordinates of the diversions, as well as its attributes and owner identification number. The owner identification relates to another Microsoft Access database containing the names and addresses of diversion owners. Determination of ownership is attempted through the research of water rights applications in AWRIMS, signs on the diversions, or through personal communication with the owners themselves.

Results

As of April 1997, 3,356 diversions have been located and mapped using GPS (Figure 2). Of these, 424 diversions were along the Sacramento River above the I Street Bridge in Sacramento (Figure 3), 298 diversions were found within the San Joaquin River Basin (Figure 4), 2,209 diversions were within the Delta, and 366 diversions were in the Suisun Marsh (Figure 5). Individual diversion sites containing a group of more than four diversions account for 31 points in our database. These points, if counted individually, add 144 diversions to the total number. These results have been placed on a layer of DFG's GIS as coverage files of 1:250,000 scale United States Geological Survey (USGS) topographic maps using ArcView (version 3.0).

Along with the locations of each diversion, we identified their attributes including the type of diversion and type of fish screen (if present) (Table 1). According to our data, a regional preference is evident for each diversion type. Floodgates are almost exclusively used in Suisun Marsh, while siphons are the preferred method of diversion in the Delta. Pumps are necessary in the Sacramento River and the San Joaquin River Basin because the land elevation is higher relative to water elevation. Furthermore, the Sacramento River study area contained the highest percentage of fish screens that are designed to meet

current DFG criteria—almost 6%. The Delta, which had the highest density of water diversions, had fish screens on only 0.7% of the intakes.

The intake size of the diversions also varied based on region. Ninety percent of the diversion intake sizes in the Delta measured between 12 and 24 inches, whereas the Suisun Marsh was composed of 90% floodgates, with intake sizes between 36 and 48 inches. Fifty-four percent of the San Joaquin River diversions measured between 9 and 16 inches. Greater variability of diversion intake diameters for the Sacramento River and San Joaquin River Basin regions may be due to the higher horsepower pumps that are necessary to move water out of streams where more head differential exists. The largest water diversion in our database, to date, occur in the Delta where water is transported through large pumping plants into the California Aqueduct (State Water Project) and the Delta-Mendota Canal (Central Valley Project).

Discussion

Water diversions have been suggested as a significant cause of the loss and decline of many resident and migratory fish species. Most water diversions are unscreened, and to date, very little information has been reported on the entrainment losses of fish due to unscreened water diversions. Species such as the chinook salmon, steelhead, striped bass, white sturgeon, delta smelt, and Sacramento splittail, are valuable resources to California because of their ecological, commercial, and recreational importance or because they contribute to the rich biological diversity in California. Winter-run chinook salmon, delta smelt, Sacramento splittail, and steelhead are currently listed as endangered or threatened. Most small diversions do not entrain many young salmon and steelhead, however, collectively considerable numbers may be taken (Hallock and Van Woert 1959).

Other west coast states including Washington, Oregon, and Idaho, have undertaken similar inventories on water diversions (John Easterbrooks, personal communication), but on a smaller scale. Their surveys are mainly on watersheds where migrating anadromous fish may be adversely affected by water diversions. The data being collected are neither post-processed nor applied to a GIS. Our inventory of California water diversions is of much greater magnitude and accuracy than other west coast states.

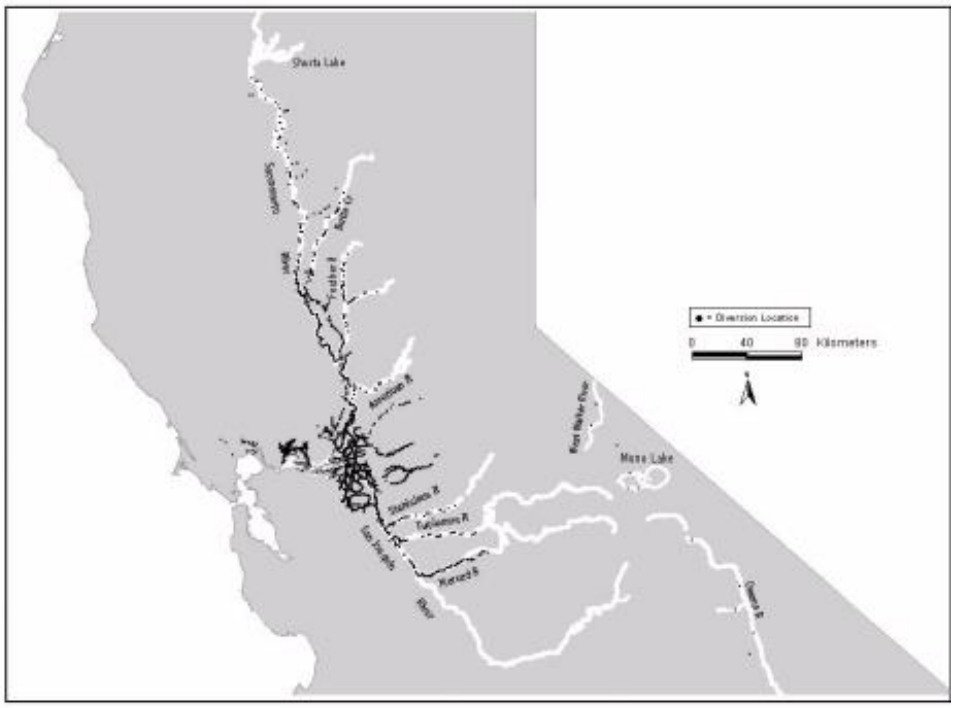

Figure 2 The Global Positioning System has been used to locate and map 3,356 water diversions in California as of April 1997

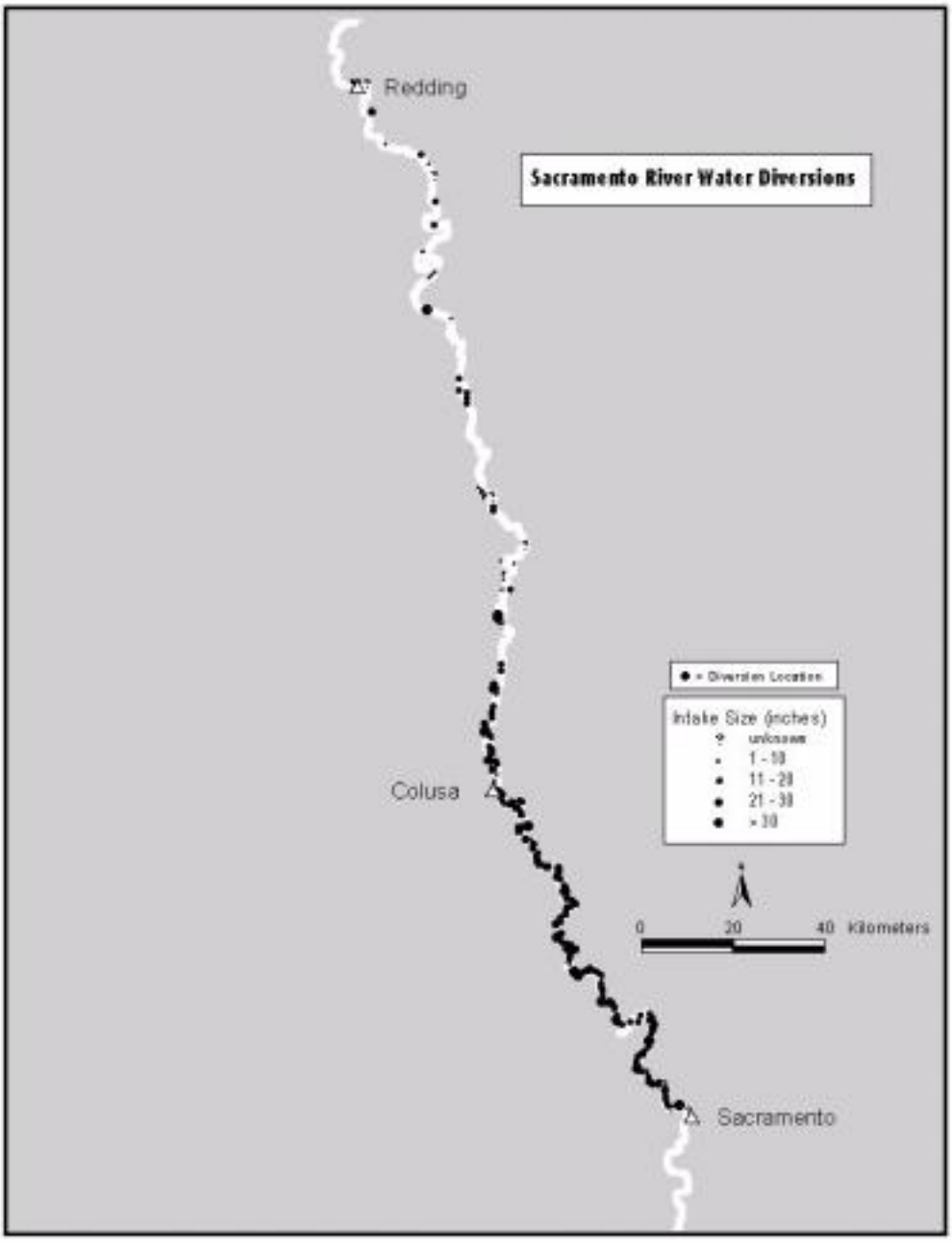

Figure 3 Four hundred and twenty-four water diversions have been identified on the Sacramento River between Keswick Dam and Sacramento at the I Street Bridge as of April 1997

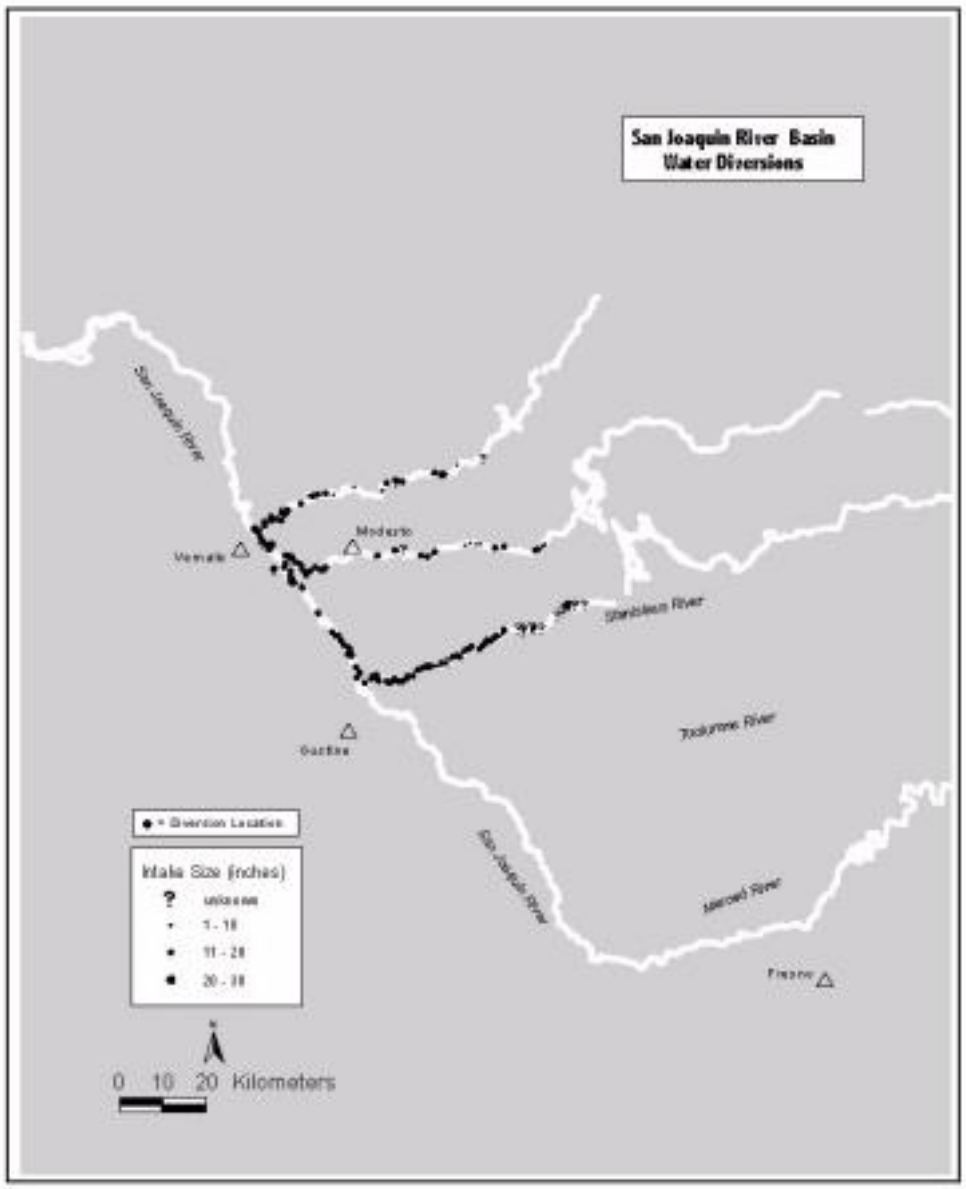

Figure 4 Two hundred and ninety-eight water diversions have been identified on the San Joaquin River between the lower boundary of the Sacramento-San Joaquin Delta and the mouth of the Merced River including the major tributaries as of April 1997

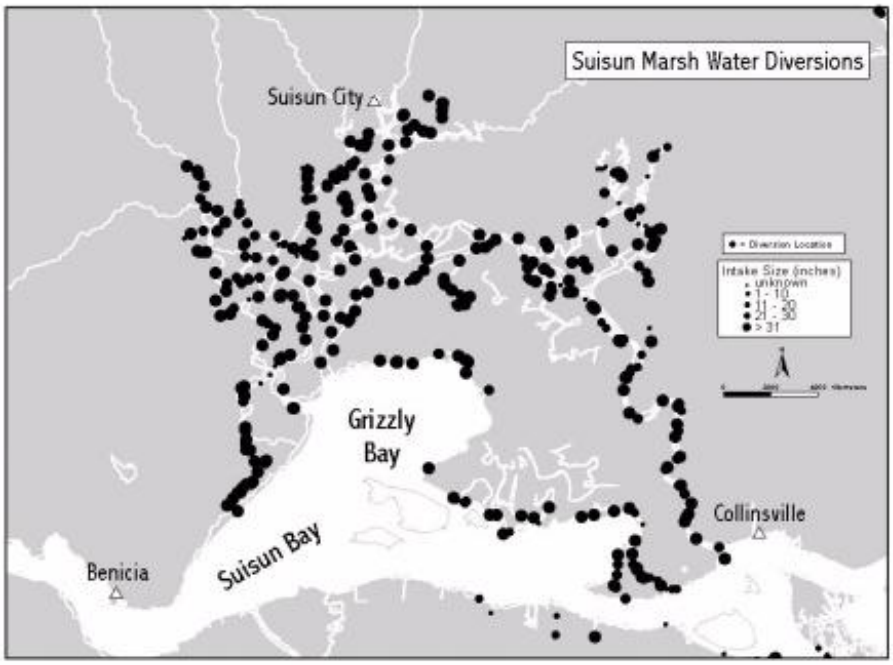

Figure 5 In the Suisun Marsh and the Sacramento-San Joaquin Delta, 366 and 2,209 water diversions, respectively, were identified and mapped using the Global Positioning System as of April 1997

Table 1 Percent and number of diversion types found in each of the four geographic study areas

	Delta		*Sacramento River*		*San Joaquin River Basin*		*Suisun Marsh*	
	%	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*
Vertical pump	19.1	423	27	114	48	143	3	11
Slant pump	7.3	161	41	173	9	27	---	---
Centrifugal pump	17	375	19	80	34	100	<1	2
Siphon	45	994	<1	1	<1	1	---	---
Floodgate	3.6	79	---	---	---	---	79	328
Unknown[a]	1.3	28	5	21	3	8	1	4
Misc.[b]	6.7	149	8	35	6	19	17	69
Total		2209		424		298		414
Screened	1%	17	6%	25	1%	2	2%	8

[a] Diversions are classified as unknown when they cannot be definitively identified due to their location (private property or concealed by brush), missing parts, or hybridized pumps.

[b] Miscellaneous diversions are other devices used to move water. These include submersible pumps, Archimedes screw pumps, weirs, portable pumps, channels, culverts, and variable speed pumps.

We compared data from previous studies on water diversions conducted by the USBR (1963–1964) and Brown (1982) with our data for five selected Delta islands and noted several differences (Table 2). Approximately 21% of the diversions on the islands identified in the 1982 report had changed location. Some differences can be attributed to alternate methods, diversion relocation, or the consolidation of several small diversions into a centrally located large diversion. Since locations and sizes of water diversions could become an important source of information for issues including water pollution cases and fish screen planning, these discrepancies support the need for a comprehensive and standardized database. Water diversion GIS data should be kept in a format that is acceptable and easily accessible by various agencies and private individuals.

Table 2 A summary of changes in agricultural diversions on five islands between the DWR water diversion survey (Brown 1986–1987) and GPS data collected by DFG through April 1997

Island	*Total # of diversions in 1993–1994*	*Deletions since 1987*	*Additions since 1987*	*Intakes increased in size*	*Intakes decreased in size*
Bacon	30	14	7	8	2
Bouldin	38	11	11	11	---
McDonald	36	5	9	8	2
Twitchell	22	2	2	8	1
Venice	24	---	2	---	1
Total	150	32	31	35	6

Currently, along with the four geographic regions already surveyed, the American River and parts of the Mono Lake Basin have been surveyed (Figure 2). The study is ongoing to complete the San Joaquin River, the major tributaries to the Sacramento River, the coastal rivers and streams, and all watersheds containing migratory or resident fish populations that might be affected by water diversions.

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