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Kesterson Crisis: Sorting Out the Facts

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Historical Overview

About 3.6 million acre-feet of water are diverted annually from northern California to the San Joaquin Valley by federal and state water projects to provide irrigation water for about 1.4 million acres of farmland (Gaines, 1988). Large scale importation of surface water combined with the fine-textured soils on the west side of the valley necessitates subsurface drainage to lower the water table and control salt buildup on irrigated lands. Over the past 40 years numerous investigations have evaluated drainage needs and assessed options for drainage water disposal (for example, see USBR, 1955; USDA, 1972). Drainage water disposal options considered or implemented in the 1960's and 1970's included reuse for crops/pasture/wetlands, dilution and disposal in local waterways, evaporation basins, and a master drain to the Pacific ocean, either directly or through the San Joaquin/Sacramento River Delta. Projected quantities of subsurface drainage water needing disposal range up to 170,000 acre-feet by the year 2015 (USBR, 1983) and up to 668,000 acre-feet by the year 2085 (IDP, 1979).

In response to this need the United States Bureau of Reclamation (USBR) began planning and construction activities in the mid-1960's for the San Luis Drain, a master drain to dispose of salt-laden agricultural drainage water from the west side of the Valley. The San Luis Drain, a concrete-lined structure was expected to traverse the 209 mile distance from Kettleman City to the San Joaquin-Sacramento River Delta. The first stage of Kesterson Reservoir, 1283 acres of unlined shallow ponds, was designed as a regulating facility to control drainage water discharges into the Delta. In 1969 and 1970, negotiations between the California Department of Fish and Game, the United States Fish and Wildlife Service (USFWS) and the USBR resulted in agreements specifying use of Kesterson Reservoir for conservation and management of wildlife. Construction was completed by 1970. By 1975, construction of the San Luis Drain halted when it was only 40% complete due to financial and environmental concerns. Thus as illustrated in Figure 1, Kesterson Reservoir became the terminal discharge area for the San Luis Drain.

Anticipated environmental impacts of Kesterson operations focused almost exclusively on problems related to seepage and water-logging of nearby lands. Numerous studies were conducted to evaluate seepage potential and concluded that 40% of the water would seep through the fine-grained surface layer into the underlying aquifer (Luthin, 1966). Ecological concerns regarding "reuse" of drainage water for wetlands focused on excessive salinity.

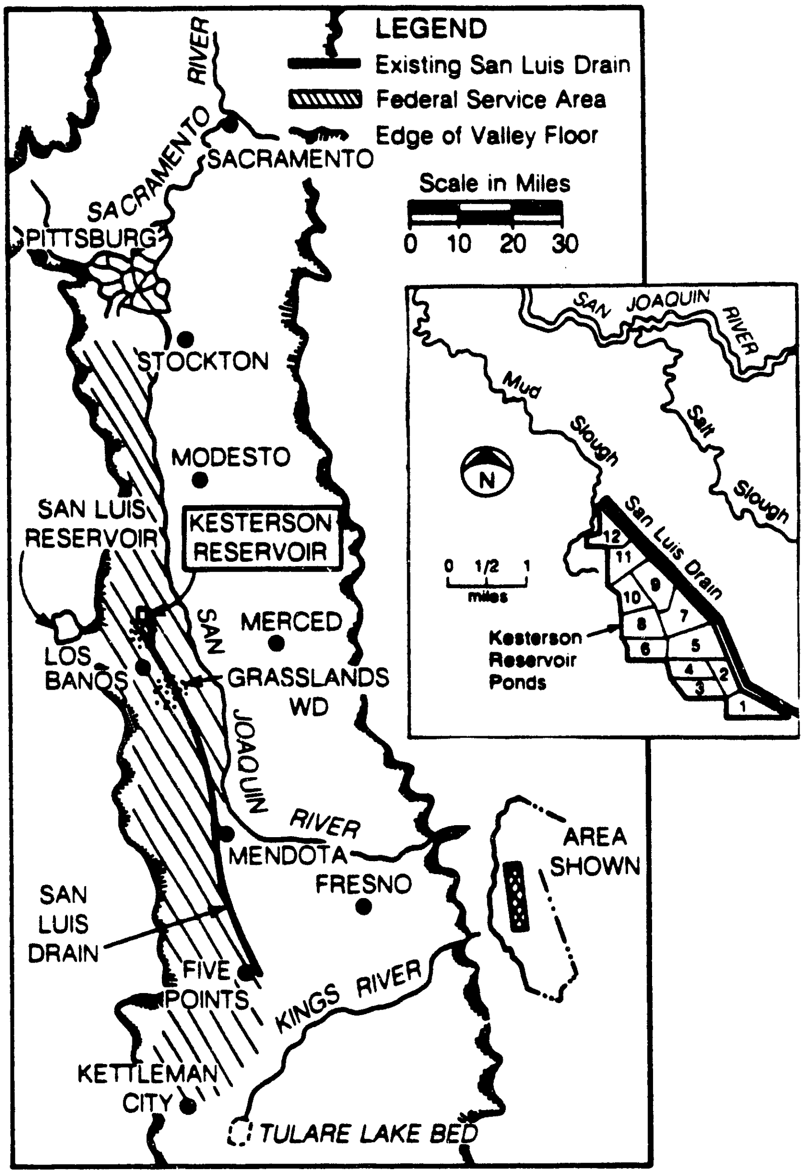

Figure 1. Location map of Kesterson Reservoir, Merced County, California. Inset shows the 12 ponds comprising the 1283-acre first stage of Kesterson Reservoir.

From 1972 to 1978 high quality water delivered to Kesterson provided wetland habitat for thousands of migratory waterfowl in autumn (USBR, 1986a). In spring, mallards, gadwalls, cinnamon teal, ruddy ducks, and redheads nested and raised their young there. In addition, numerous other varieties of water birds such as eared grebes, avocets, black-necked stilts, American Coots, great and snowy egrets, and western sandpipers used Kesterson throughout the year. These birds continued extensive use of Kesterson after drainage water deliveries began in 1978.

By 1981, drainage water provided most of the water to Kesterson and by 1982 elevated levels of selenium were detected in fish at Kesterson by the USFWS (Saiki, 1986). Deformed embryos of water birds, adult mortality and poor reproductive success were observed in 1983. Tests indicated that selenium poisoning was the most probable cause (Ohlendorf et al., 1986). A hazing program was implemented in September, 1984, to discourage use of Kesterson by waterfowl. The program consisted of numerous "cannons" that exploded at intervals of several minutes, employees who used both blank and live rounds shot from rifles to scare the more persistent birds, and various other tactics such as scarecrows to keep the water birds away. The hazing program was largely effective in eliminating use by migratory waterfowl during the autumn and winter seasons. But during spring, nesting attempts continued and some birds such as coots and a variety of shore birds were difficult if not impossible to discourage. On April 27, 1984, a landowner from an adjacent property petitioned the Central Valley Regional Water Quality Control Board (CVRWQCB) drawing attention to the problems at Kesterson. After the CVRWQCB declined to take action on this petition an appeal was made to State Water Resources Control Board (SWRCB). The following year the SWRCB issued Order WQ 85-1, requiring cleanup and abatement at Kesterson. This action led to a series of regulatory proceedings and policy decisions that resulted in closure of Kesterson Reservoir by June 1986 (USBR, 1986a; 1986b; and 1986c).

Environmental Consequences of Kesterson Operation

From 1981 to 1986 Kesterson received from 6000 to 8500 acre-feet annually of subsurface drainage water from WWD. In surface water samples from Kesterson, boron, molybdenum, chromium, selenium, and total dissolved solids sometimes exceeded either drinking water, EPA aquatic wildlife criteria, or other relevant ambient goals. Of these, selenium and TDS most consistently and by the largest factor exceeded the applicable environmental criteria (the EPA's drinking water standard for selenium is 10 ppb). Selenium concentration in drainage water ranged from 24 to 430 μg/l and TDS ranged from 1,270 to 45,200 mg/l. An estimated 9000 kg of selenium was delivered to Kesterson between 1981 to 1986.

Trace elements delivered to Kesterson accumulated in the surface sediments and organic detritus (a layer of decaying aquatic and/or terrestrial vegetation deposited on the pond bottoms) by evaporative concentration, and/or various other biogeochemical processes (LBL, 1987). None of the soil samples exceeded TTLC criteria (total threshold limit concentration) for classification as hazardous waste under the California Health and Safety Code. Nor did they exceed standards for hazardous waste based on the STLC (soluble threshold limit concentration) which is a measure of the soluble and mobile fraction of the inventory. However, many samples of organic detritus exceeded the 100 mg/kg-soil TTLC for selenium. As a result of these initial synoptic samplings, and evidence suggesting that elevated levels of selenium were primarily responsible for observed water bird death and deformities, selenium was identified as the main contaminant of concern and became the driving factor in the environmental remediation efforts. In the following paragraphs the extent of selenium contamination at Kesterson will be described briefly under three broad categories: wildlife, groundwater, and soils.

Wildlife. Dead or deformed embryos of water birds were found in numerous nests monitored at Kesterson from 1983 to 1985. For example, in 1983 of 397 stilt eggs monitored, dead or deformed embryos were found in 60 of them (Ohlendorf, et al., 1986). Sampling at the nearby Volta refuge during the same time period revealed no incidence of deformity. Dozens of dead adult American Coots with selenium toxicosis were also found (Ohlendorf et al., 1988). An estimated 411 eared grebes were "lost" in 1983, where "lost" includes dead or deformed embryos as well as chicks that presumably hatched but failed to survive (USBR, 1986b). At present no data on the total number of birds killed or "lost" by selenium poisoning at Kesterson have been compiled, but estimates indicate that except for the tricolored blackbird they are small in comparison to the

San Joaquin Valley population as well as small in comparison to losses due to hunting, road kills, and nuisance control (USBR, 1986b). During 1986, an entire colony of 47,000 tricolored blackbirds failed to successfully reproduce and an estimated 82,150 tricolored blackbird eggs and chicks were "lost" (USBR, 1986b). Acute selenium toxicosis from eating contaminated insects is the presumed cause of nesting failure. This loss is large in comparison to the estimated population of 133,000 tricolored blackbirds in California (USBR, 1986b). Subsequent investigations in nearby control areas without selenium contamination found a similar failure to reproduce successfully (USBR, 1987).

Health and reproductive success of small mammals has also been studied by scientists from the USFWS at Kesterson. Clark (1987) concluded that no impacts due to selenium toxicosis had been observed in small mammals. However, potential exposure of predators such as raptors, kit fox, and coyotes to elevated levels of selenium is high because whole-body concentrations in mammals averaged 11 mg/kg in 1984 (Clark, 1987). Comparable whole-body selenium concentrations were not measured from the Volta refuge, but selenium concentrations in the thighs of rabbits were 17 times higher at Kesterson (Clark, 1987). In addition, studies on domestic dogs indicate dietary concentrations of 7 mg/kg will inhibit growth and concentrations of 20 mg/kg cause severe nervous system disorders, cirrhosis of the liver, inhibition of ovarian and testicular development (Clark, 1987). Limited studies found 2 of 11 coyotes had liver selenium levels within the range associated with selenium toxicosis in domestic dogs, and one of these showed signs of selenium toxicosis. No negative impacts to the endangered San Joaquin Valley kit fox were detected due largely to limited use of Kesterson.

Groundwater. Kesterson overlies two aquifers used for domestic purposes (not necessarily drinking water), irrigation, stock watering, and industrial processing supply (CVRWQCB, 1988). The shallowest extends from about 10 ft below the ground surface to a depth of 200 ft. Locally this aquifer is isolated from the underlying aquifer by the Corcoran Clay, a 30 ft-thick layer of lacustrine sediments. No evidence for sub-Corcoran transport was observed, therefore the remainder of this discussion is limited to the shallow aquifer. The native groundwater underlying Kesterson is naturally high in TDS. Groundwater from the vast majority of wells within the immediate vicinity of Kesterson exceeds the EPA recommended maximum TDS of 1000 mg/l for drinking water. Boron concentrations in many of the wells also exceed levels commonly associated with toxicity problems in plants (0.7 mg/l) and range up to 7 mg/l (CVRWQCB, 1988). Selenium concentrations in native groundwater are low with an average of 1.8 μg/l for 89 wells located upgradient of Kesterson (CVRWQCB, 1988).

Approximately 3500 acre-ft of drainage water seeped annually into the shallow aquifer from 1981 to 1986, creating a plume with an areal extent of about 1600 acres. The average plume depth is estimated to be about 60 ft (LBL, 1987). Lateral migration has carried the plume as much as 1000 ft from the eastern border of the ponds (LBL and ANR, 1990). One of the important early findings was that selenium was being removed from the drainage water before it migrated into the shallow aquifer. In 1985 selenium was found in only 16 wells at concentrations in excess of 10 μg/l. Most of these wells were located in two small areas, each with an areal extent of less than 250 by 250 ft. Studies suggested that selenium removal was due to biologically mediated transformation from the selenate form to the highly insoluble elemental form (LBL, 1987). These investigations also indicated that mobility of selenium in the upper aquifer is limited by the low redox potential (<200 mV) which thermodynamically favors the elemental form over the more mobile selenate and selenite forms (LBL, 1987).

Soil. Two extensive synoptic sampling programs have been carried out to determine the distribution of selenium in Kesterson soils. The first was carried out on a grid pattern with one sample per 5-acre area, the second with a 1-acre spacing. Total selenium concentrations range from less than detection to 85 mg/kg in the surface soils. Levels of up to 306 mg/kg have been measured in the detrital layer. About 75% of the selenium delivered to Kesterson is concentrated within the surface-most 6-inch layer of organic debris and soil, 95% of this is in forms not readily removed with a soil solution extract (LBL, 1987). The majority of soils below the surface-most 6 inches have selenium concentrations below 4 mg/l. The remainder of selenium in the soil profile is distributed in the 6 to 10 ft-thick vadose zone, the region between the ground surface and water table. Selenium concentrations in the vadose zone decline on average in a logarithmic manner with depth. Soil solution selenium concentrations ranged from several thousand μg/l at a depth of 6 inches to several hundred μg/l at a depth of 3 ft.

Environmental Remediation

As a necessary prerequisite to remediation activities an attempt was made to identify appropriate cleanup goals. In the absence of regulatory guidelines, goals were chosen according to the best available knowledge regarding effects of selenium on wildlife, relationships between soil selenium and plant uptake, by analogy to other areas with documented selenium contamination. As a result of this effort the following goals were identified: 4 mg/kg selenium in soil; 2 to 5 μg/l selenium in surface water; 3 mg/kg (on a dry weight basis) in food chain items for waterfowl and 5 mg/kg for food chain items for fish; and 10 μg/l in groundwater. None of these goals recognized the important role that selenium speciation plays in its environmental toxicity.

In October, 1986 the USBR, in cooperation with the USFWS and the U.S. Army Corps of Engineers issued the Kesterson Program Environmental Impact Statement (EIS) outlining four alternative remedial action plans: the flexible response plan; the immobilization plan; the wetland restoration/onsite disposal plan; and the offsite disposal plan (USBR, 1986a). The first two of these were unconventional alternatives based on taking advantage of the tendency for selenium to be immobilized under anaerobic conditions. The flexible response planned called for flooding the most contaminated ponds with a supply of selenium-free water in order to keep the sediments submerged, thereby maintaining anaerobic conditions. The "flexible" part of this plan referred to the need for flexibility in water management operations, leaving open options for permanently or temporarily drying out portions of Kesterson. Motivation for proposing this alternative was two-fold. First, data from a 1-acre test pond at Kesterson demonstrated that selenium concentrations in surface water would meet the 2 to 5 μg/l surface water goal and that selenium concentrations in food chain items dropped rapidly as the seleniferous drainage water was replaced with a selenium-free water supply. Second, this alternative promised to be the least expensive if proved successful. The immobilization plan was an extension of the flexible response plan that included better controlled water operation or a site cap to keep selenium immobile. The wetland restoration/onsite excavation plan included excavating surface sediments to a depth of 6 inches, storing them in an onsite landfill, installing groundwater extraction wells and reestablishing the marsh at Kesterson. The offsite disposal plan involved excavating contaminated soils and taking them to a Class II landfill. Capital cost estimates ranged from 1 million dollars for the wet-flexible response plan to 144 million dollars for the offsite disposal plan (USBR, 1986a).

In December, 1986, the USBR issued the Closure and Post-Closure Plan for Kesterson in order to comply with SWRCB Order WQ 85-1. They outlined a "phased-approach" to remedial action at Kesterson where the flexible response plan would be implemented first. If this failed the immobilization plan would be implemented. Should this fail too, the onsite disposal plan would be implemented. Time-lines and interim numeric goals for selenium concentrations in food chain items were included in the phased-approach (USBR, 1986c). Stated motivation for proposing a phased-approach included potential cost savings, flexibility in remedial actions, and opportunities to use the latest research results from Kesterson-related studies. Underlying this approach was recognition of the uncertainty with regard to a number of factors, including appropriateness of the stated remediation goals and effectiveness of all the remediation plans (including the onsite disposal plan). On January 26, 1987 this plan was presented at a hearing before the SWRCB. On April 19, 1987, the SWRCB issued Order WQ 87-3, rejecting the phased approach while accepting the proposed onsite disposal plan and remanding the remaining Kesterson-related issues to the CVRWQCB. On August 14, 1987, Waste Discharge Requirements for the onsite landfill and excavation program were adopted by the CVRWQCB.

Concurrent with developing detailed excavation plans, research and monitoring activities continued. In particular, three lines of research were producing critical information. First, the importance of the selenium inventory in the vadose zone became apparent. As mentioned previously, soil water selenium concentrations of several thousand μg/l were typical within the top 6 inches and concentrations remained as high as several hundred μg/l at a depth of 3 ft. These values are far in excess of surface water goals and also provide high concentrations for uptake by rooted plants. Serious doubts about the effectiveness of the 4 mg/l cleanup goal for soils arose. These doubts were confirmed as winter approached and the water table rose due to flooding surrounding duck clubs. Several hundred acres of pools formed as the water table rose above the ground surface. Selenium concentrations in these pools were as high as in drainage water because the highly seleniferous soil water was driven to the soil surface by the rising water table (LBL, 1987). Pools that formed in excavated test plots showed similarly high concentrations of selenium (LBL, 1988).

Concurrently, researchers from the University of California found that naturally occurring fungi in Kesterson soils could convert selenium into a gaseous form that could be safely dissipated into the atmosphere. Laboratory results suggested that as short as one-year may be sufficient to deplete the surface inventory of selenium if the soils were kept moist and amended with organic carbon (Karlson and Frankenberger, 1988). Questions remained regarding the time frame required to remove a significant fraction of the selenium inventory under more representative conditions and what associated costs would be. Nevertheless, this innovative technique was very appealing as a way to permanently remove selenium from Kesterson soils.

The final piece of critical information came from biological monitoring data. With the cessation of drainage water input to Kesterson much of the area dried out. This decreased water bird use and provided opportunities to evaluate selenium concentrations in upland habitat at Kesterson. Preliminary data suggested that selenium concentrations in upland food chain organisms were much lower than in the aquatic food chain. The dominant vegetation, salt grass, was below the 3 mg/kg food chain goal. In addition selenium concentrations in grasshoppers, an important food chain item at Kesterson, averaged 3.1 mg/kg. This was far lower than the 22 to 175 mg/kg observed in aquatic insects during 1985 (Ohlendorf et al., 1986).

As a result of this new information, on April 15, 1988, just two months before excavation was to begin, the USBR requested that the SWRCB reconsider Order WQ 87-3. The SWRCB agreed and in two hearings over the next two months received and concurred with evidence that the excavation plan would not succeed in eliminating wildlife exposure to hazardous levels of selenium. As an alternative to excavation the USBR requested more time to evaluate the extent of selenium-contaminated pools that would form each winter, to continue field-trials of selenium volatilization, and to evaluate further risks created by upland habitat at Kesterson. On July 5, the SWRCB issued Order WQ 88-7, requiring the USBR to fill all areas to a height of 6 inches above the elevation of the rising groundwater by January 1, 1989. In addition, reports on the effectiveness of volatilization and conditions in the upland habitat were requested by December 1, 1988. On July 6, 1988 a contract was let for filling the pool areas. Approximately one million cubic yards of soil from nearby projects filled 713 acres to an average depth of 10 inches. In addition, nearly 200 acres of cattail stands were cut down and disked to eliminate nesting habitat for tricolored blackbirds. The filling operation was completed within the specified time with an associated program cost of about 10.5 million dollars. Total program cost to date, including monitoring, the EIS, hazing, research and the aforementioned filling program, is estimated at 23 million dollars.

On April 1, 1989, the USBR submitted a series of reports to the SWRCB that: evaluated effectiveness of the filling operation; updated research results on volatilization as a remedial measure; assessed ongoing risk to wildlife; and proposed a management plan for Kesterson. These reports concluded that the filling operation successfully eliminated pools created by rising groundwater but that during years with rainfall in excess of 50% of normal, significant ponding of rainwater was anticipated. Rainfall greater than 50% of normal is expected to occur once in ten years. Food chain contamination and exposure risks created by these pools can only be evaluated as they occur. Biological monitoring data from upland and fill areas continued to indicate that these areas were comparatively safe to wildlife, and no deformities or unusually low rates of reproductive success were observed. Experiments on microbial volatilization continued to show promise, but significant scientific issues remained to be resolved. On the basis of this information the USBR proposed to continue biological and groundwater monitoring, continue research activities aimed at identifying long-term selenium dissipation strategies, and submit a yearly site management plan. The SWRCB accepted this plan and these efforts are ongoing.

References

CH2M Hill, 1989. Kesterson Reservoir 1990 Biological Monitoring Plan and 1989 Preliminary Sample Data. Prepared for USBR Mid-Pacific Region, Sacramento, Ca.

Clark, D.R., 1987. Selenium Accumulation in Mammals Exposed to Contaminated California Irrigation Drainwater. *The Science of the Total Environment*, 66 (1987), 147-168.

CVRWQCB, 1988. Beneficial Use Assessment per State Water Resources Control Board Order WQ 87-7. Central Valley Regional Water Quality Control Board, Sacramento, Ca.

Frankenberger, W.T. Jr., 1990. Dissipation of Soil Selenium by Microbial Volatilization at Kesterson Reservoir. Report prepared for the USBR Mid-Pacific Region, Sacramento, Ca.

Gaines, R.W., 1988. West San Joaquin Valley Agricultural Setting. Report prepared for the U.S. Bureau of Reclamation under Contract No. 7-CS-20-05230, Mid-Pacific Region, Sacramento, Ca.

IDP, 1979. Final Report of the Interagency Drainage Program. Sacramento, Ca.

Karlson, U., and W.T. Frankenberger Jr., 1988. Effects of Carbon and Trace Element Addition on Alkyselenide Production by Soil. *Soil Sci. Soc. of Am. J., 52,* 1640-1644.

LBL, 1987. Hydrological, Geochemical, and Ecological Characterization of Kesterson Reservoir: 1987 Annual Report. Lawrence Berkeley Laboratory Report, LBL-24250, Berkeley, Ca.

LBL, 1988. Hydrological, Geochemical, and Ecological Characterization of Kesterson Reservoir: 1988 Annual Report. Lawrence Berkeley Laboratory Report, LBL-26438, Berkeley, Ca.

LBL and ANR, 1990. Hydrological, Geochemical, and Ecological Characterization of Kesterson Reservoir: 1989 Annual Report. Lawrence Berkeley Laboratory Report, LBL-27993, Berkeley, Ca.

Luthin, J.N., 1966. Report on Expected Seepage into Salt Slough and the San Joaquin River from the Kesterson Enhancement Area Western Merced County. Special report to the California Department of Water Resources. Sacramento, Ca.

Ohlendorf, H.M., D.J. Hoffman, M.K. Saiki, and T.W. Aldrich, 1986. Embryonic Mortality and Abnormalities of Aquatic Birds: Apparent Impacts of Selenium from Irrigation Drainwater. *The Science of the Total Environment,* 52 (1986), 49-63.

Ohlendorf, H. M., A. W. Kilness, J. L. Simmons, R. K. Stroud, D. J. Hoffmann and H. F. Moore, 1988. Selenium Toxicosis in Wild Aquatic Birds. *Journal of Toxicology and Environmental Health, 24,* 67-92.

Saiki, M. V., 1986. A Field Example of Selenium Contamination in an Aquatic Food, Chain. In Proc. Symposium on Selenium in the Environment. California State University, Fresno, Publication No. CATI/860201, pp. 67-76.

USBR, 1955. Report on the Feasibility of Water Supply Development, San Luis Unit, Central Valley Project, California. USBR, Mid-Pacific Region, Sacramento, Ca.

USBR, 1983. Kesterson Reservoir, First Stage Technical Report. Prepared in support of Report of Waste Discharge to the California Regional Water Quality Control Board. Mid-Pacific Region, Sacramento, Ca. Kesterson Reservoir Closure and Cleanup Plan. Submitted to the California State Water Quality Control Board as per Order WQ 85-1. Mid-Pacific Region, Sacramento, Ca.

USBR, 1986a. Kesterson Program Environmental Impact Statement. Mid-Pacific Region, Sacramento, Ca.

USBR, 1986b. Kesterson Program Risk Assessment. Mid-Pacific Region, Sacramento, Ca.

USBR, 1986c. Kesterson Program Closure and Post-Closure Maintenance Plan. Mid-Pacific Region, Sacramento, Ca.

USDA, 1972. Mendota-Gustine Study, Fresno and Merced Counties, California. Soil Conservation Service Report, Grasslands Water District, Los Banos, Ca.

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