Developing Science-Based Strategies to Manage Water Conveyance and Control Weeds and Sediment in Irrigation and Potable Water Supply Canals

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The intent of this paper is to discuss the type and severity of problems facing agencies responsible for providing water supply to municipal, industrial and agricultural water users. This paper describes on-going applied research, field monitoring, laboratory analyses and hydrologic investigations being conducted by Northwest Hydraulic Consultants (NHC) with the Solano County Water Agency (SCWA) and Solano Project Operators to identify the sources and magnitude of sediment, turbidity and aquatic vegetation entering and affecting the Putah South Canal (PSC), located in Solano County, California. The presence and highly variable concentrations of these constituents in the PSC cause increasing canal maintenance and operational costs, and water quality problems for water users that rely on PSC water for their primary source of irrigation, municipal or industrial water supply.

The Federal Solano Project

The PSC is part of the Federal Solano Project, which was constructed in the 1950's by the U.S. Bureau of Reclamation (USBR) to meet water demands of agriculture, municipal, industrial, and military facilities within Solano County in California. The Solano County Water Agency (SCWA) is responsible for the operation and maintenance of the Solano Project on behalf of the USBR. The SCWA in turn has a long-term contract with the Solano Irrigation District (SID, referred to in this paper as the "Solano Project Operators") to implement the operation and maintenance activities associated with the Project. The Project consists of four major facilities: Monticello Dam, Putah Diversion Dam, PSC, and the Terminal Reservoir. The PSC is a 33-mile long concrete-lined open canal extending south along the eastern toe of the English Hills through the Cities of Vacaville and Fairfield to the Terminal Reservoir in Green Valley (Figure 1). The PSC serves municipal, industrial, and agricultural customers and frequently transitions from rural to urban settings. The canal is divided into 12 reaches, or controlled checks. Along the canal, there are 5 operational spills (2 inactive), 11 plant intakes (1 inactive), and approximately 55 pumped or gravity turnouts/laterals consisting of combinations of open channels and/or pipe conveyance infrastructure.

The Solano Project was designed to irrigate approximately 100,000 acres of land. Principal crops are corn, wheat, sugar beets, tomatoes, fruits, nuts, wine grapes, and irrigated pasture. The project is also a major municipal and industrial water supply for over 411,000 people in the cities of Vallejo, Vacaville, Fairfield, Benicia, and Suisun City, supplying about 32,000 ac-ft annually.

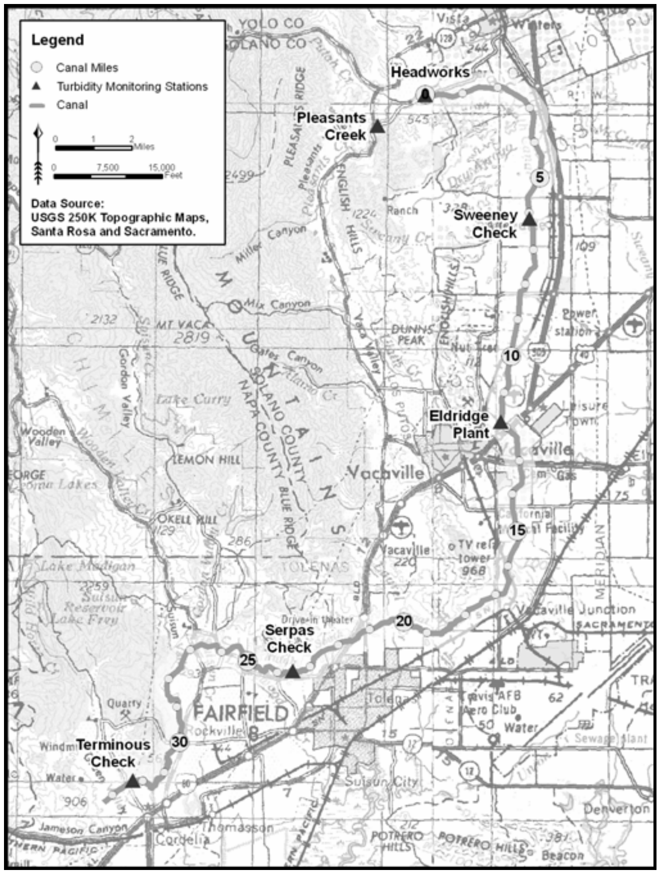

Figure 1. Map of Putah South Canal, Solano County, California.

Sediment and Aquatic Vegetation Problems

During the spring and summer months approximately 75% of the water deliveries provided through the PSC are for irrigation and agricultural uses. Municipal and industrial (MI) water users along the PSC withdraw raw water year round from the canal and treat it in order to meet current drinking water standards. Sudden and dramatic increases in turbidity in the canal water can occur during winter storm periods. Turbid water can enter the canal during storm events from lateral sources along the canal and through the Headworks located at the Lake Solano Diversion Dam at the head of the canal (Figure 1). These turbidity pulses create operational problems for the water treatment plants (WTPs) and increase costs for treating the water supply distributed to their customers. When possible, the plants will close their intakes and temporarily forego excessively turbid water or water that has just received chemical treatments to control algae. However, with increasing urban development and population growth throughout Solano County (as of 2007 its population was estimated at 411,680; with 4.34% growth since 2000) there is increasing demand for potable water supply as well as a continued need for irrigation water for agricultural use. Increasing demand places greater constrains on the WTPs abilities to by-pass turbid or algaecide (Copper Sulfate) laden canal waters. Some plants, such as the Waterman WTP in Fairfield only have the system storage capacity to by-pass PSC water for 24 hours until they need to accommodate less desirable quality water to meet user demands. This leads to increased operational and water treatment costs.

Sediment entering the PSC settles and deposits along the bottom of the canal. Sediment deposition promotes aquatic weed growth and algae blooms, which impact water quality in the canal and, in turn, promotes more sediment deposition due to the rapid growth of thick stands of aquatic weeds. For maintenance purposes, SCWA and the Solano Project Operators attempt to de-water and clean the entire canal of accumulated aquatic vegetation and sediment deposits each year. Essentially, the canal is drained and sediment, aquatic vegetation and biological detritus are mechanically removed reach by reach. Canal cleanout requires extensive labor, heavy equipment, and vast logistical planning and coordination. Canal cleanout operations interrupt water supply to treatment plants and affect water turbidity and water quality in sections of the canal located downstream from active vegetation and sediment cleanout activities. The efficiency of the cleaning process is limited by the inability to completely drain the canal, with the result that bottom deposits have a slurry-like nature which make them very difficult to remove mechanically (Figures 2 and 3). Formerly, Solano Project Operators utilized wasteways along the canal to completely drain and flush the canal, but increased environmental concerns have since discontinued their use.

Figure 2. Removal of aquatic weeds and sediment from Sweeney Check at MP 6.15.
Photo of October 19, 2006.

Figure 3. Pushing sediment and vegetative detritus down Union Check at MP 14.80.
Photo of November 3, 2006.

The major goals of this on-going study are to:

1. Assess geomorphic and hydrologic processes contributing to increases in sediment loading, turbidity, and growth of aquatic vegetation in the canal;
2. Identify and quantify the major sources of turbidity and sediment entering the canal, and identify causes and seasonal differences;
3. Determine sources and primary species of aquatic vegetation (algae and macrophytes) that colonize in sediment deposits along the canal bottom;
4. Determine composition and characteristics of the sediment and vegetation materials that are causing project operational difficulties, increasing annual maintenance costs, and frequent water quality and water treatment problems;
5. Develop recommendations and cost effective solutions for mitigating these problems in the canal;

Project tasks included: monitoring annual canal operations, canal cleanout activities, winter storm monitoring (turbidity and suspended sediment concentrations), identification of sources of sediment, hydraulic measurements in the canal and Lake Solano, assessment of annual sediment budgets, water user surveys, and aquatic vegetation assessments. Following is a summary of the major on-going monitoring, laboratory and field testing activities associated primarily with issues and problems related to the growth and decay of aquatic vegetation and annual removal of sediment and vegetation from the PSC.

Project Operation, Maintenance and Water Treatment Problems Associated with Aquatic Vegetation

There is an accumulation of the black anoxic floc-like organic material (Figures 4 and 5) deposited along the canal bottom each year as a direct result of the growth and decay of aquatic vegetation. There is also a close linkage between the sediment introduced into the canal, and the volume of aquatic biomass capable of being produced each year. Figure 6 illustrates the primary sources and relationships between sediment and vegetation in the canal. Deposited sediments provide nutrients and a location where colonization and growth of aquatic vegetation takes place, particularly aquatic macrophytes that rapidly colonize sediment deposits along the canal bottom, along the inside of canal bends, upstream of canal check structures, as well as in panel cracks and seams. Thick mature patches of aquatic macrophytes encourage further capture and settling of fine sediments from the water column, and provide a location where inorganic sediments combine with vegetation and other organic detrital materials. These thick mats of sediment and organic bottom materials become anaerobic during the summer and fall and generate hydrogen sulfide and other odor-causing and water quality treatment problems, especially during annual canal cleanout operations when these deposited materials are disturbed. Thick growths of aquatic vegetation can clog irrigation turnouts, plug drip emitters, reduce water treatment plant intake efficiency, and lead to increased operations and maintenance costs. This situation occurs frequently at the Waterman WTP's Intake that is located just upstream from the Serpas Check structure (Figure 4).

Controlling algae, especially filamentous algae, is essential because it grows very rapidly in the canal and can quickly clog water intake structures and dramatically affect their performance. Daily "raking" of algae and higher aquatic vegetation to clear intake trash racks is labor intensive, costly, and does not address the increasing problems associated with the growth of aquatic vegetation in the canal. Solano Project Operators used to use rapid acting herbicides that were more effective at controlling algae and other vegetation, but the application of broad-range herbicides, such as *acrolein*, is no longer allowed. Present vegetation management consists of applications of copper sulfate in the canal to treat algae and manual "raking" and removal of vegetation from intake screens. Chemical treatment scheduling and dosing rates are managed similarly to schedules and practices established several years ago and may not be meeting present day needs with respect to application rates, schedules, or locations. Therefore, present treatment methods are being re-evaluated and updated to determine what herbicides and application methods are most effective and affordable. Also potentially affecting present chemical treatment methods are State and Federal changes occurring to the quality criteria that water users and water treatment plant operators must adhere to which limit chemical treatment methods that can be used in the PSC.

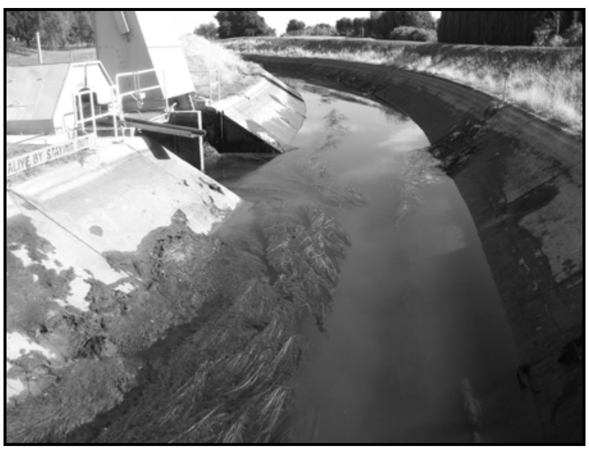

Figure 4. Thick growth of algae and macrophytes that plug the intake to the Waterman WTP located just upstream of Serpas Check. Photo of November 9, 2006.

Figure 5. Water samples from Putah South Canal collected during 2007 cleanout. The sample on the right was just collected; the sample on the left had settled for about 30 minutes. Both samples contain high concentrations of organic materials (decomposed vegetative materials) with a little sediment.

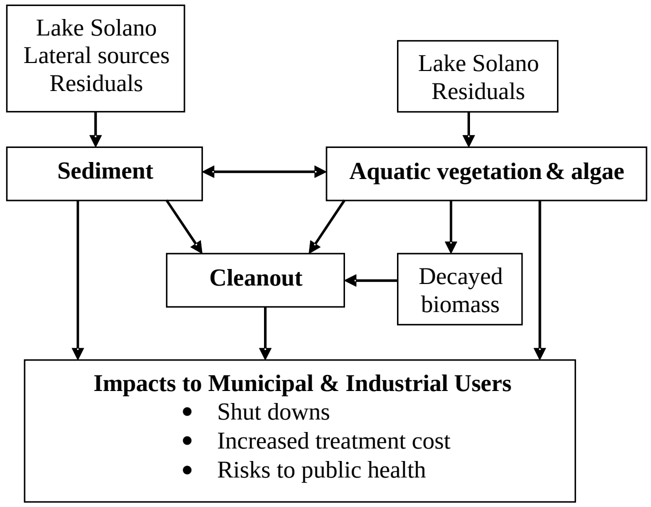

Figure 6. Sources and relationships between sediment and aquatic vegetation.

Field and Laboratory Activities

During the fall periods of 2006, 2007 and 2008, just prior to canal cleanout, NHC measured the approximate thickness of sediment deposits along the canal and estimated the percent coverage of aquatic vegetation in all checks along the canal (Figure 7). NHC observed a range of volumes of sediment deposits on the order of 1,000 to 12,000 cubic yards per year depending on rainfall and runoff conditions that occur during a given rainy season. During these three years the greatest sediment deposition, and thickest weed populations, were observed to occur upstream from checks, along the inside of canal bends and in areas where there is usually some sediment accumulated on the canal bottom. During the 2008 canal cleanout monitoring, NHC estimated the total weed volume within each check before and after canal cleanout. These results are shown in Figure 8. Total volume of weeds in the canal prior to and after the cleanout were approximately 2,000 and 100 cubic yards, respectively.

Field reconnaissance and vegetation survey campaigns were conducted to identify, list and photograph the location and types of aquatic vegetation found in the PSC. Technical assistance was provided from Dr Lars Anderson. In the fall of 2007, NHC staff assisted Dr Anderson to perform aquatic vegetation sampling and species identification logging along the entire length of the PSC from the Headworks to the Terminal Reservoir. According to the vegetation inventory, the primary species prevalent in the PSC include: (1) Eurasian watermilfoil, (2) Sago pondweed, (3) Horned pondweed, (4) Elodea, (5) *Nostoc* (algae), (6) *Cladophora* (algae), (7) *Rhizoclonium* (algae), and (8) *Tetraspora* (algae).

Beginning last fall 2008, NHC and Dr. Anderson have also been conducting monthly biomass monitoring and aquatic vegetation “netting” near the Headworks of the canal. Vegetation was “netted” during a given period of time using a 2-foot by 3-foot rectangular screen with 1/4-inch mesh. Netted vegetation was examined and the fragment counts per hour, species type, and fragment lengths by species of vegetation entering the canal from Lake Solano were documented. Figure 9 presents results from one of the vegetation netting campaigns. Vegetation netting results showed that a significant increase in the number of fragments entering the canal occurred during Headworks trash rack cleaning due to disturbance and shearing of weed materials captured on the screens. Aquatic vegetation biomass “netting” will continue monthly through June, 2009. Also, since September, 2008, NHC and the Solano Project Operators have documented the approximate volume of aquatic vegetation removed daily from the trash screens at the Headworks (Figure 10). Researchers at the USDA-ARS Exotic and Invasive Weeds Research Unit at UC Davis have also initiated a program to collect weed fragments from Lake Solano and to incubate them in the lab to determine the viability of the fragments and length of incubation time required to develop the sprouting of turions. Results from these on-going monitoring and laboratory activities will provide important information regarding the seasonal loading of aquatic weeds into the canal from Lake Solano and will also help to prepare viable alternatives for managing aquatic weed problems in the canal.

Potential Aquatic Weed Management Alternatives Being Considered

Following are several potential aquatic weed management alternatives being considered for this project:

1. Improve the vegetation screening efficiency and sediment extraction at the Headworks (first line of defense). Intercept, screen and keep aquatic vegetation and sediment form entering the canal;
2. Modify the upper checks (second line of defense) to trap, isolate and remove fugitive vegetation and sediment in the upper checks as much as possible. This will greatly reduce the extent of the problems and amount of annual cleaning required;
3. Design and implement an effective herbicide treatment program (third line of defense) to reduce growth and survival of algae and aquatic weeds in the canal;
4. Design and implement an aggressive Best Management Practice (BMP) program along the canal to reduce or eliminate lateral sediment loading into the canal (also a third line of defense). This will reduce sediment and nutrient loading and thus potential weed and algae colonization. Reducing the sediment loading will greatly reduce costs for annual cleanout and interruption to water supply during cleanout;
5. Provide supplemental backup water storage and supply for WTPs so they can survive for longer periods of time without canal flow during cleanout or during rare winter storm events that may require shutdowns;
6. Test and evaluate alternative methods for more efficient canal cleanout.

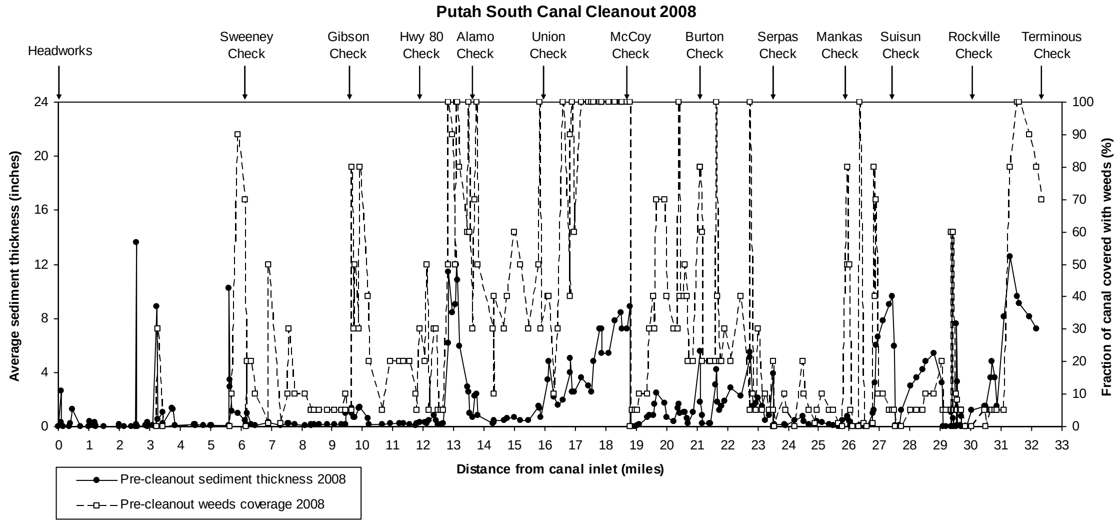

Figure 7. Longitudinal variations of average thickness of sediment deposits and weed growth prior to fall 2008 cleanout.

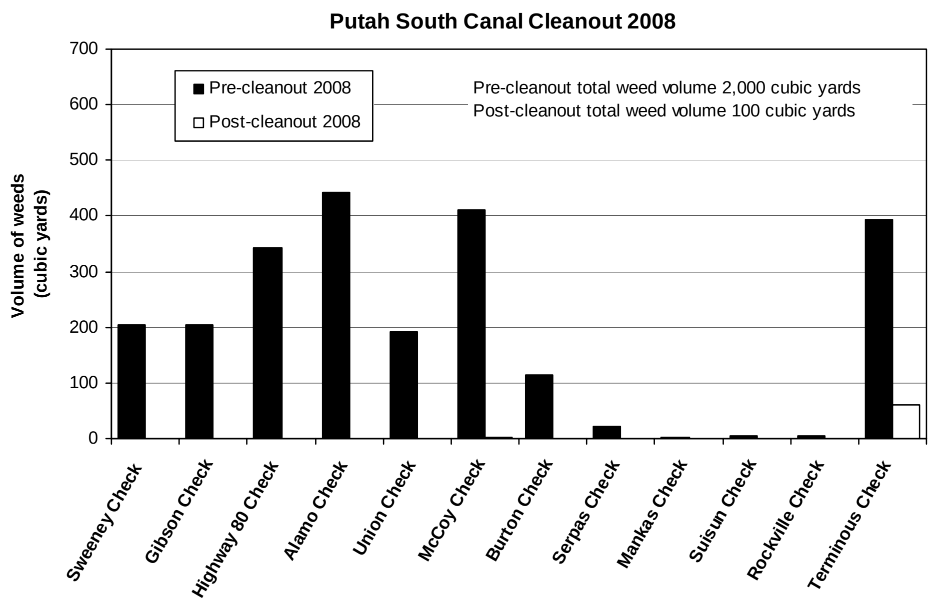

Figure 8. Estimated volumes of aquatic weed mass in each check before and after fall 2008 canal cleanout.

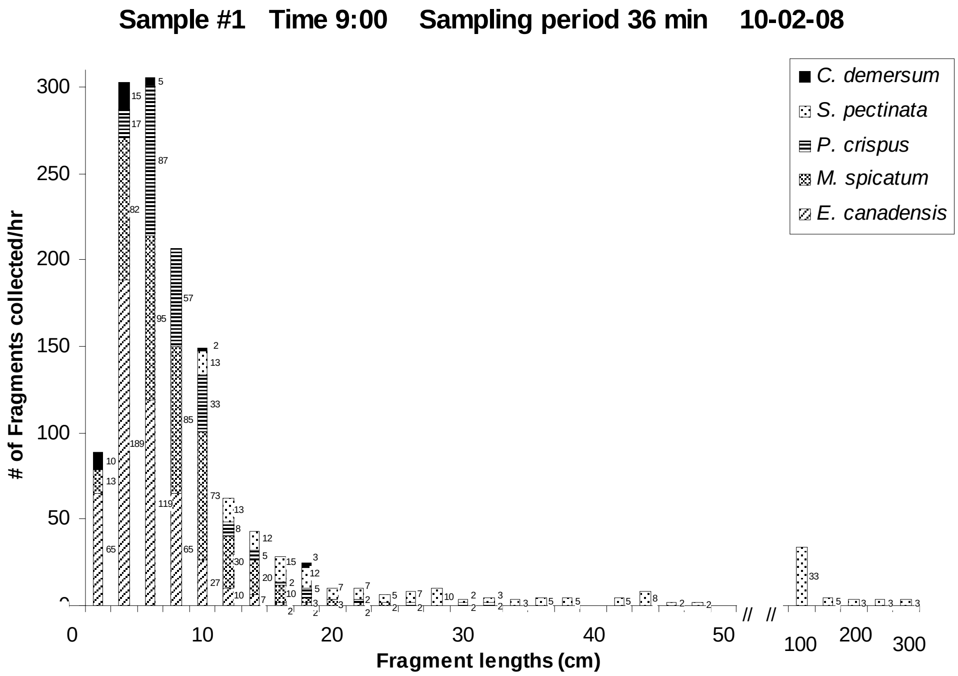

Figure 9. Typical results from aquatic vegetation "netting" just downstream from Headworks (10-02-08)

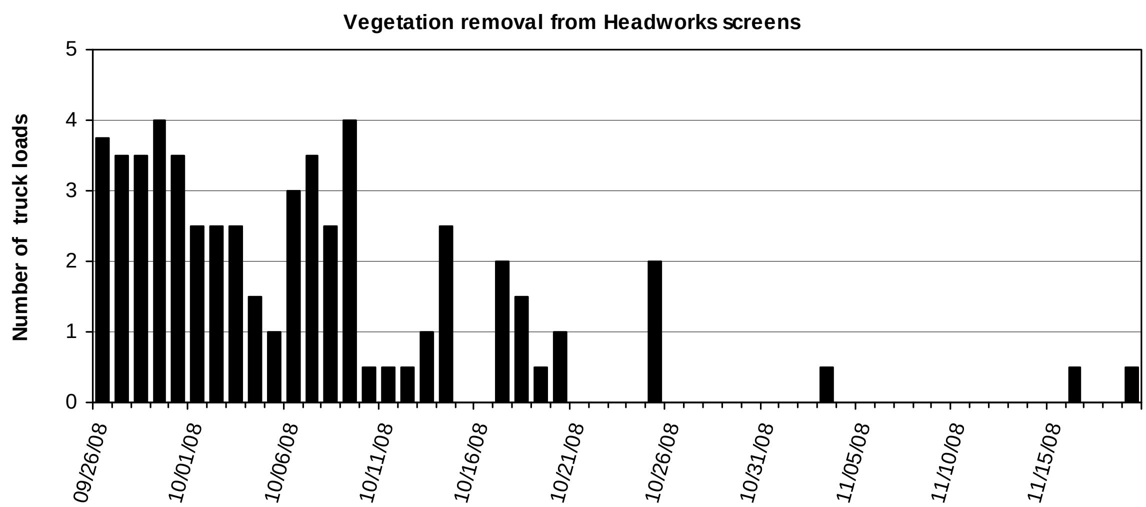

Figure 10. Daily log of the number of truck loads of aquatic vegetation removed from trash racks at Headworks (entrance to PSC)