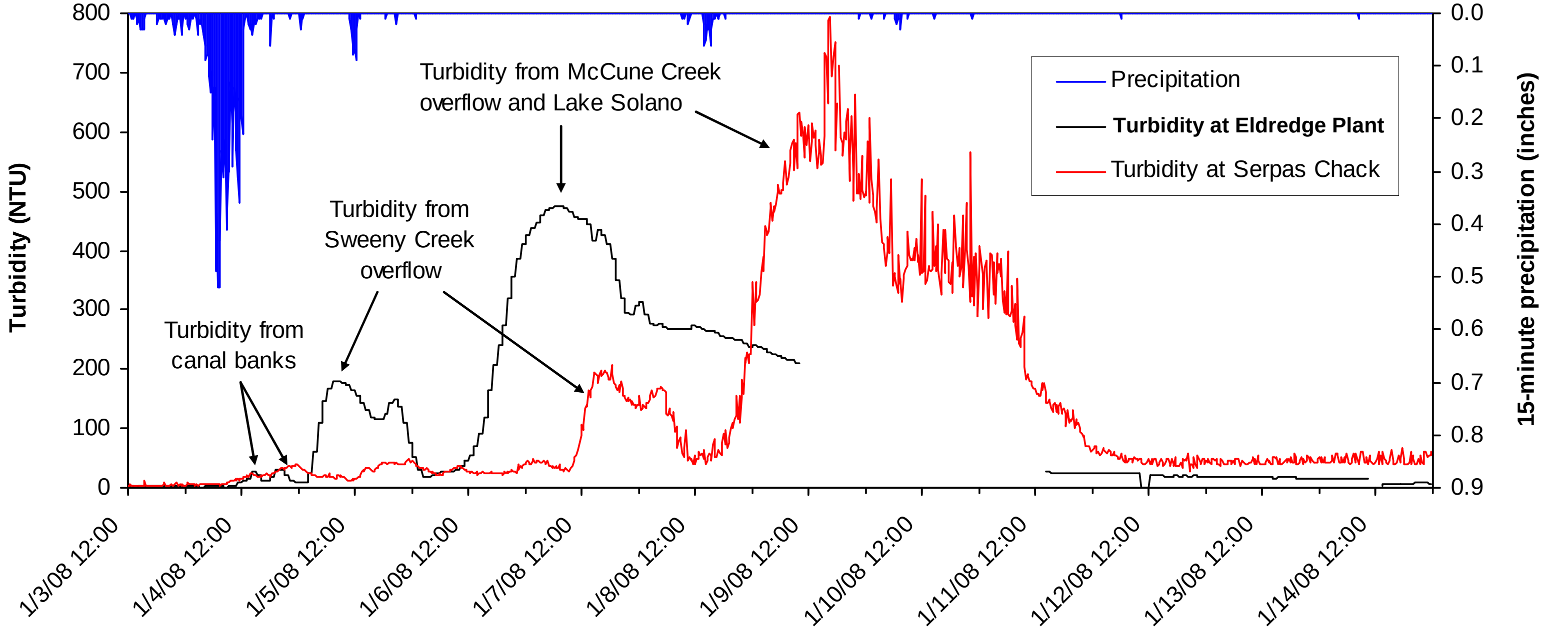


Figure 8.4. Turbidity response at Serpas Check and Eldredge Plant to precipitation intensities recorded by SCWA rain gage at Sweeney Check after January 4, 2008 storm.

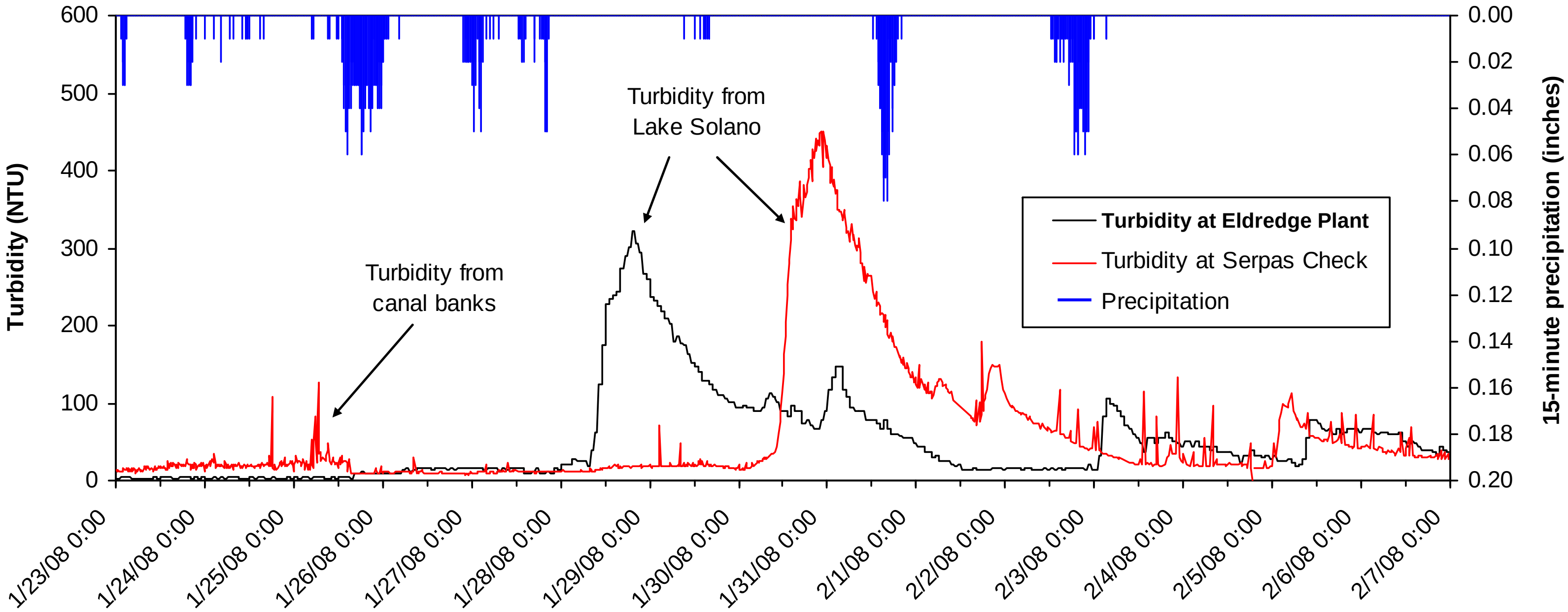


Figure 8.5. Turbidity response at Serpas Check and Eldredge Plant to precipitation intensities recorded by SCWA rain gage at Sweeney Check after January 25, 2008 storm.

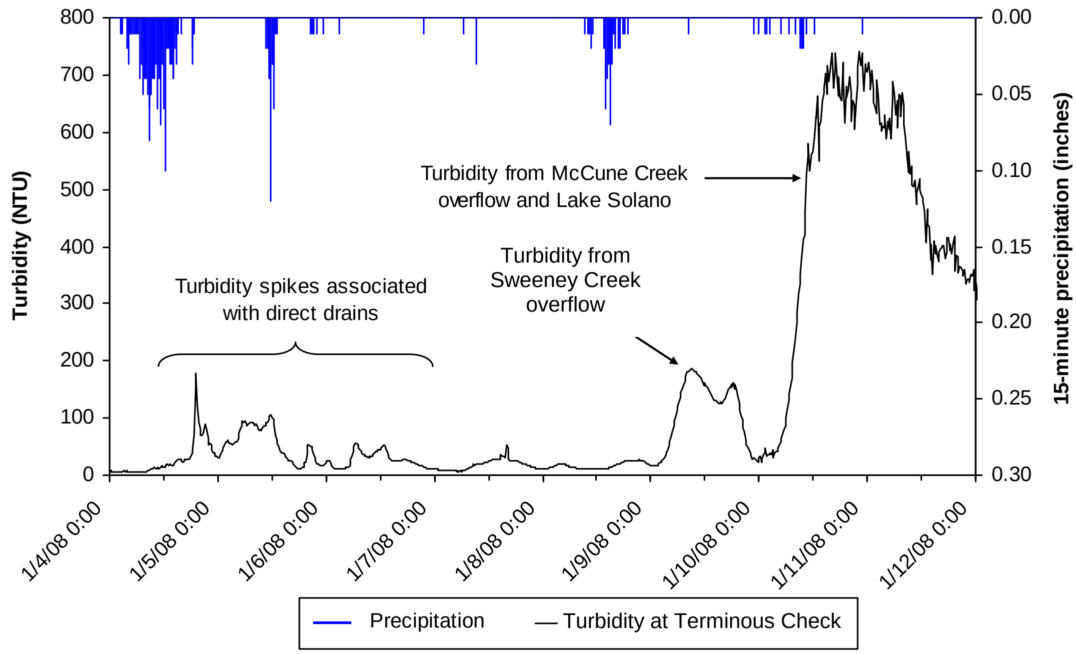


Figure 8.6. Turbidity response at Terminous Check to precipitation intensities recorded by SCWA rain gage at Gregory Hill Station during January 4, 2008 storm.

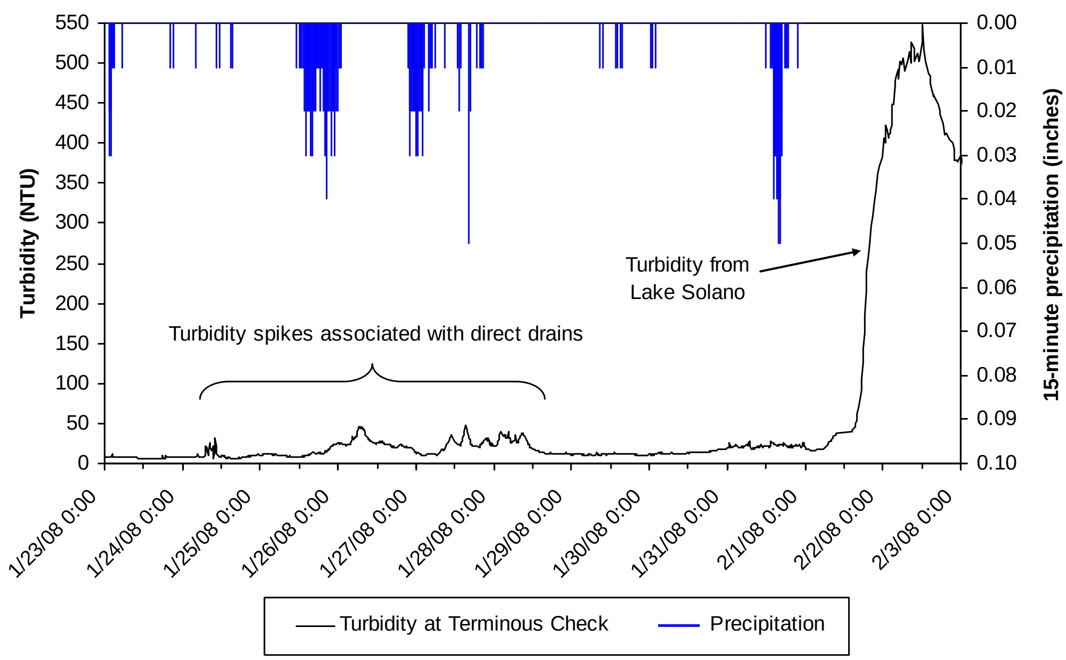


Figure 8.7. Turbidity response at Terminous Check to precipitation intensities recorded by SCWA rain gage at Gregory Hill Station during January 25, 2008 storm.

9. Assessment of Issues and Concerns Regarding Aquatic Vegetation in Putah South Canal

9.1. Purpose

Primary goals of this project were to identify major sources of turbidity and sediment in the PSC and to determine the opportunities and feasibility of turbidity and sediment source control. However, it became apparent during early field assessment and monitoring activities, that aquatic vegetation (algae and aquatic weeds) that enter and grow in the PSC may also be contributing to water treatment and annual canal cleanout costs and difficulties. Therefore, the SCWA included an additional task to the scope of work to review present aquatic vegetation issues and current vegetation management practices, conduct a reconnaissance level assessment of vegetation in the PSC, determine sources and primary species of aquatic vegetation that colonize in sediment deposits along the canal bottom, test a vegetation mechanical harvesting option, and provide the SCWA with recommendations and cost effective solutions for mitigating vegetation growth in the canal. Following is a discussion of activities performed and methods used to evaluate aquatic vegetation management issues in the canal.

9.2. Activities

Assessment of the extent (coverage) of aquatic vegetation growth in the PSC was conducted prior to and after the fall of 2006, 2007, and 2008 cleanout operations (see Chapter 2 in this report). In addition, average thickness of the aquatic weed layer was approximated (by probing and visual inspection) during the 2008 cleanout observations to roughly estimate the volume of weeds growing in the canal. During winter monitoring programs, changes in vegetation density and cover along the canal and in parts of Lake Solano were visually observed. NHC met with and discussed issues related to aquatic vegetation with several water treatment plant operators and Solano Project operators, including Solano Project weed control specialists. Several field reconnaissance campaigns were conducted to identify and photograph the location and types of problems associated with aquatic vegetation in the PSC. Technical assistance was obtained from Dr Lars Anderson, a leading expert in aquatic vegetation from the Exotic and Invasive Weeds Research Unit of the U.S. Department of Agriculture (USDA) – Agricultural Research Service (ARS). In the fall of 2007, NHC staff assisted Dr Lars Anderson to perform aquatic vegetation sampling and species identification logging along the entire length of the PSC from the Headworks to the Terminal Reservoir. From the fall of 2008 to summer of 2009, NHC and Dr Anderson conducted monthly monitoring of biomass influx to the PSC from Lake Solano. In addition to biomass netting, NHC and the Solano Project operators also documented the approximate volume of aquatic vegetation (number of truck loads) removed daily from the trash screens at the Headworks since September 2008. Researchers at the USDA-ARS Exotic and Invasive Weeds Research Unit at UC Davis also initiated a program to collect weed fragments from Lake Solano and to incubate them in the laboratory to determine the viability of the fragments and length of incubation time required to develop the sprouting of turions. NHC also conducted a demonstration pilot study to determine the effectiveness of mechanical harvesting of aquatic vegetation in the canal. Results from these activities are discussed below.

9.3. Issues and Observations

The primary issue of concern for the Solano Project weed control specialist is the need to better understand how best to control algae in the PSC. Controlling algae, especially filamentous algae is essential because it grows very rapidly in the canal and can quickly clog water intake structures, which dramatically affects their performance. Daily “raking” of algae and higher aquatic vegetation (weed fragments) from intake trash racks is labor intensive, costly, and does not address the growing problems associated with the growth of aquatic vegetation in the canal. Solano Project operators used to use stronger 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 application of copper sulfate in the canal to treat algae (Figure 9.1) 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. This is one of the Solano Project operators’ primary concerns. Therefore, there is a need to evaluate (and possibly to update) present treatment methods and determine what herbicides and application methods are most effective and affordable. Also potentially affecting present chemical treatment methods are changing water quality criteria that water users and water treatment plant operators must adhere to. Taste, odor, pH, and some chemical dosing to improve water quality are affected by the presence of copper sulfate, algae, and byproducts from other aquatic vegetation. Water treatment costs have increased measurably over the past five years and are growing issues of concern with the water users. Some treatment facilities are now detecting elevated levels of copper in the sludge materials which are byproducts from their plants’ coagulation and flocculation treatment processes. Some sludge materials may exceed threshold limits set for copper, thus requiring special disposal and higher water treatment and waste disposal costs.

An additional issue that affects the water treatment plants and requires a great deal of coordination from Solano Project weed control staff is related to scheduling herbicide applications. Dosing, frequency, and location of applications greatly affect the success and effectiveness of such treatments. However, some WTPs have to shut down their intakes periodically for periods of several hours to a day following chemical applications upstream from their plants. If multiple applications occur at more than one treatment site, the WTPs may experience multiple copper sulfate plumes passing their intakes that can require them to bypass PSC water (shut down their intakes) until residual copper concentrations return to acceptable levels. This situation can lead to unexpected and inefficient plant operation challenges for operators as well as Solano Project weed control staff.

Chapter 2 summarizes results from the pre- and post-canal cleanout monitoring conducted during the fall of 2006, 2007, and 2008. Discussions with SCWA and Solano Project operators managing and implementing cleanout activities indicate that canal cleanout has become much more difficult in recent years for a number of reasons. One reason is that the annual volume of aquatic vegetation mixed with decaying organic matter (black sludge-like materials – see Figure 9.2) that needs to be removed from the PSC appears to be increasing. It is also getting much more difficult to remove these materials with traditional mechanical methods (bobcats, tractors, backhoes, cranes, and trucks – see Figures 9.3 and 9.4). Canal cleanout now takes a much longer period of time to complete, and because of the characteristics of the organic materials (which is comprised primarily of decaying aquatic vegetation and some sediment), they are easily suspended when disturbed and are therefore almost impossible to remove with tractors. Now that the canal wasteways are no longer used to sluice residual bottom materials from the canal during cleanout, it has become very difficult to remove this type of fluidized sludge material from the canal each year. The effects of not being able to remove these residual fluid sludge materials compounds problems and allows these materials settle to the bottom and remain in the canal after cleanout, so they remain in the canal through the winter and early spring. These materials are likely to contain high quantities vegetative propagules, such as plant fragments, seeds and tubers that survive over winter and produce new aquatic plants and algae during the following spring when day light and water temperatures increase.

9.4. Reconnaissance Level Species Sampling

NHC assisted Dr Lars Anderson to conduct aquatic vegetation sampling and species identification logging along the entire length of the PSC from the Headworks to the Terminal Reservoir. This initial reconnaissance level vegetation sampling and species identification work was completed during several days of field work conducted on September 19, October 3, October 9, and October 17, 2007. Examples of the log sheets developed during this month-long campaign are shown in Figure 9.5. The entire set of data sheets (10 pages) is provided in Appendix D-9.1. A line-cast thatch rake was used to sample the bed and bank vegetation growing along the canal (Figures 9.6 and 9.7). Specific species of macrophytes and algae were noted and ranked according to their prevalence or density (low, medium, or high). After each of three casts of the thatch rake, the cast was examined and species collected with each cast were logged in to develop a 3-cast average of what was found at each sampling location. The results are listed in the field sampling data sheets in Appendix D-9.1. According to the vegetation inventory, primary species prevalent in the PSC include:

- Eurasian watermilfoil
- Sago pondweed
- Horned pondweed
- Elodea
- *Nostoc* (algae)
- *Cladophora* (algae)

- *Rhizoclonium* (algae)
- *Tetraspora* (algae)

9.5. Issues Related to Sediment and Vegetation Management

It was observed that deposition of fine sediments promotes the growth of aquatic weeds which in turn promotes more sediment deposition in the canal. This sediment and vegetation cycle promotes the development of thick layers (or mats) of aquatic weeds and sediment that grow in thickness as more vegetation filters (and captures) suspended sediment out of the water column, which promotes more plant growth. This symbiotic process is observed in the photograph in Figure 9.8. If there was no sediment in the canal or water column, it is likely that there would be much less vegetation (especially macrophytes) growing in the canal. Deposited sediments provide nutrients and a location where attachment, colonization and growth of aquatic vegetation takes place. Aquatic macrophytes (weeds) 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.

Therefore, sediment is not the sole cause of significant canal operational, maintenance, cleanout or water treatment and water quality problems. Together, sediment and the growth of aquatic vegetation result in significant system operations, maintenance, and cleanout problems and lead to increasing annual costs to mitigate. Together, sediment and aquatic vegetation adversely affect water quality and increase water treatment costs. Chapter 10 further discusses how sediment and vegetation affect water quality and water treatment costs. When sediment and aquatic vegetation grow into thick mats of organic material they promote the development of anaerobic sludge materials comprised of fine inorganic sediment and decomposed organic materials that affect water quality and become very difficult to remove mechanically. Annual in-canal cleanout activities will not solve these problems and the problems may continue to grow with time as it becomes more difficult to effectively remove the fine residual materials from the canal. The ultimate solution will require a combination of several activities including operational changes, source-specific management to limit loading of sediment and vegetation into the canal, and testing and improving methods of chemical and mechanical treatment and removal. Recommendations for capital investments, specific in-canal activities, operational adjustments and pilot studies are discussed in Chapter 11.

9.6. Sources of Aquatic Vegetation

Source-specific management and control is very important. Chapters 4 and 8 discuss erosion hazards and identify sources of sediment that enter the canal. Figure 9.9 shows a photograph of Lake Solano, looking upstream (west) from the Headworks. There are thick mats and submerged forests of algae and macrophytes growing in the lake. It is apparent that Lake Solano is the primary source of aquatic vegetation entering the canal through the Headworks. Propagules, including seeds, plant fragments, turions, shoots, and tubers enter with the flows diverted into the canal through the Headworks. Figure 9.10 shows a large bloom of Mosquito Fern (*azolla*) that occurred in the lake during the winter of 2007. Portions of such blooms can enter the canal with flows through the Headworks.

Lake Solano was created over 50 years ago when the Putah Diversion Dam was constructed as part of the Solano Project by the USBR. Since construction of the diversion dam, Lake Solano has been slowly accumulating sediment materials that drain into the lake from tributary streams located downstream from Monticello Dam (NHC 1998). The largest annual runoff and sediment loads entering Lake Solano come from Pleasants Creek. Pleasants Valley and Pleasants Creek are capable of producing and delivering very large volumes of sediment during winter storm events (see Figure 1.11 in Chapter 1). Lake Solano cross-section records examined by NHC (1998) show that Lake Solano has been slowly filling with sediment during the past 50 years. The lake area downstream from the Pleasant Valley Road Bridge used to be considerably deeper. Over time the lake has become much shallower due to sediment deposition and has filled to the point where the depth-averaged water temperatures are warmer and sun light can now penetrate to the lake bottom, thus allowing and promoting the growth of aquatic plants. Therefore, significant portions of Lake Solano are slowly evolving into marshlands which are growing more and more diverse plant communities. Because of its close proximity to the Headworks and inlet to the canal, viable vegetative propagules (tubers, plant fragments, seeds, rhizomes, and turions) can easily enter with the flows being diverted from the lake.

Therefore, Lake Solano is the largest likely source of algae and macrophytes to the canal. Pleasants Creek and the lake are also periodic sources of sediment and turbidity that enter the canal during winter storm events. The key to reducing vegetation-related problems in the PSC is to develop effective means for reducing or eliminating vegetation and sediment from entering the PSC from Lake Solano. However, herbicide treatments and canal cleanout activities are likely to continue for some time until a reasonable balance of vegetation and sediment management measures can be implemented. Several recommendations and ideas for how this may be accomplished are presented in Chapter 11.

Another significant source of vegetation in the canal is the canal itself. Unless the canal is scraped clean of all attached algae and all of the residual seed stock, weed fragments, propagules, and tubers are removed each year during the cleanout, viable sources for new spring crops of vegetation exist inside the canal and are likely to grow in the spring. Figures 9.3 and 9.4 show why it is so difficult to completely clean the 33-mile long canal. Some species of weeds may be blown into the canal as seed stock or enter the canal in lateral flows carrying sediment, seeds, and plant fragments during the winter. However, these sources are likely to be small compared to the annual volume that enters the canal from Lake Solano. One of the pilot studies NHC is recommending is to monitor vegetation loading from Lake Solano, determine the approximate mass of vegetation per unit flow, and identify species that are present in the flow.

9.7. Aquatic Vegetation Monitoring

From the fall of 2008 to summer of 2009, NHC and Dr. Anderson conducted monthly (bi-monthly during winter low flows) monitoring of biomass influx to the PSC from Lake Solano. The purpose of the biomass influx monitoring was to characterize seasonal loading of aquatic weeds into the canal from the lake. The monitoring included aquatic vegetation sampling ("netting") using a 2 ft by 3 ft rectangular aluminum frame with ¼ inch mesh (Figure 9.11). The frame/net assembly was immersed in the water flow such that it was just under the surface and normal to the flow. Biomass flux measurements were conducted in the upper 3 ft of the water column at a few verticals across the flow in front of the Headworks trash screens, at the USGS gage at MP 0.18, and at the inlet to Weyand Canal located at MP 5.6 (Figures 9.12-9.16). To determine the effect of the Headworks screens cleaning on vegetation influx to the PSC, vegetation netting at the USGS gage was conducted separately during baseline conditions (no screen cleaning) and during Headworks screens cleaning activities. Measurements in Weyand Canal were conducted only during spring and summer periods when the canal was operated. Netted vegetation was examined in a laboratory to determine the fragment counts per hour per entire width of the canal, species type, and fragment lengths by species of vegetation. Main results from the biomass influx monitoring are summarized in Table 9.1. Results from a few vegetation netting campaigns are presented in Figures 9.17-9.25. Seasonal variation of the measured vegetation influx is shown in Figure 9.26. Some of the sampling data were still being processed at the time of the preparation of this report. All the biomass monitoring results will be presented in a separate technical memorandum which will be prepared after the monitoring program is completed and all the sampling data are processed. The vegetation monitoring is expected to continue until September 2009.

Vegetation netting results showed that significant amounts of weed fragments are transported from Lake Solano to the PSC Headworks during summer irrigation periods when aquatic vegetation is actively growing. For example, a total of 42,900 vegetation fragments per hour were transported toward the Headworks in the upper 3 ft of the water flow on September 24, 2008 (Figure 9.17). Weed fragments ranged in length from less than 2 cm (less than 1 inch) to 150 cm (59 inches). The dominant length of the vegetation fragments was within 4-12 cm (approximately 1.5-4.5 inches). The most prevalent species were *E. canadensis*, *M. spicatum*, and *P. crispus*. Of the total amount of weed material transported from the lake, only 798 fragments per hour (only about 2%) entered the PSC proper (measured at the USGS gage at MP 0.18 on September 25, 2008, Figure 9.18). The remaining 98% of vegetation (including all fragments longer than about 12 cm, or 4.5 inches), were intercepted by the Headworks trash screens. However, a significant increase in the number of fragments entering the canal occurred during Headworks trash rack mechanical cleaning due to disturbance and shearing of weed materials captured on the screens. Due to the heavy deposition of vegetation on the screens, the screens had to be cleaned twice a day – early in the morning and in the afternoon. A total biomass flux of 16,484 fragments per hour was measured at the USGS gage at MP 0.18 during afternoon's cleaning on September 25, 2008 (Figure 9.19) and 19,133 per hour during morning's cleaning on October 2, 2008 (Figure 9.20). This weed fragment loading rate constitutes about 38% and 45%, respectively, of the total estimated weed supply from Lake Solano to the Headworks. The length of weed fragments sampled in the canal during trash screen cleaning was up to 100-300 cm (39-118 inches), with prevailing fragment length within 4-10 cm (about 1.5-4 inches). According to the measurements conducted on October 2, 2008, total biomass influx to Weyand Intake at MP 5.6 was 1,560 fragments per hour (Figure 9.21). The length of weed fragments floating into Weyand Intake was up to 16 cm (about 6 inches), prevailing length being around 4-8 cm (about 1.5-3 inches).

The amount of weed fragments entering the PSC significantly reduces during winter months. This is due to the decrease of weed growth in Lake Solano, as well as reduced water diversion into the canal from the lake. In spring, weed influx into the canal begins to increase as aquatic plants begin to grow in the lake and more water is diverted into the canal. According to the vegetation measurements conducted on April 14, 2009, a total of 1,050 plant fragments per hour were transported from Lake Solano towards the Headworks in the upper 3 ft of the water flow (Figure 9.25). Prevailing length of plant fragments was around 4-8 cm (about 1.5-3 inches), the maximum length being 14 cm (5.5 inches). Prevailing species were *E. canadensis* and *M. spicatum*. Of the total amount of plant material transported from the lake, 983 fragments per hour (about 94%) entered the PSC trough the trash screens (Figure 9.23). The screens were unable to effectively intercept the floating aquatic plants due to the relatively short lengths of the plant fragments.

During trash screen cleaning (which was conducted once a day), the amount of weed fragments entering the canal increased to 6,441 per hour (Figure 9.24). This amount included the plant fragments entering the canal through the Headworks trash screens, as well as plant material sheared off of the screens during the mechanical cleaning. The length of weed fragments sampled in the canal during trash screen cleaning was up to 20 cm (about 8 inches). Prevailing fragment length was around 4-6 cm (about 1.5-2.5 inches). Total biomass influx to Weyand Intake was 410 fragments per hour (Figure 9.22). The length of weed fragments floating into Weyand Intake was up to 8 cm (about 3 inches), prevailing length being around 2-6 cm (about 1-2.5 inches).

In addition to biomass netting, NHC and the Solano Project operators also documented the approximate volume of aquatic vegetation (number of truck loads) removed daily from the trash screens at the Headworks since September 2008. The results are shown in Figure 9.27 and clearly demonstrate the seasonal character of weed growth and supply from Lake Solano. During summer irrigation period (when water inflow from Lake Solano to the PSC is on the order of 300-600 cfs), usually between 2-4 truck loads of weeds are removed daily from the trash screens. During winter season (when water inflow into the PSC is reduced to around 20-50 cfs), amount of vegetation removed from the trash screens reduces to less than one truck load over a period of a few weeks.

9.8. Laboratory Analyses

Researchers at the USDA-ARS Exotic and Invasive Weeds Research Unit at UC Davis initiated a program to collect weed fragments from Lake Solano and to incubate them in the laboratory to determine the viability of the fragments and length of incubation time required to develop the sprouting of turions. Figure 9.28 shows a floating fragment of Eurasian watermilfoil with emerging roots. Figure 9.29 shows that a Curlyleaf pondweed turion sprouted emerging shoots and roots in an incubator 45 days after collection from Lake Solano. The image shown was taken 7 days after start of sprouting. Results from this laboratory study clearly demonstrated that weed fragments floating from Lake Solano into PSC can grow into live plants.

9.9. Source Management Options for Aquatic Vegetation

The problems associated with aquatic vegetation (macrophytes) and algae in the PSC stem from vegetation entering from Lake Solano (through the Headworks) as well as biomass produced within the canal system. Management options include (1) reducing as much as possible the entrainment of plant propagules into the canal as well as (2) direct control of growth and removal of vegetative materials from within the canal. Both physical exclusion (e.g. screening) at the Headworks, and better management of vegetation within Lake Solano could significantly reduce the import of nuisance vegetation. This will requires a more detailed understanding of propagule loading from Lake Solano and seasonal fluctuations of that load. There are registered aquatic herbicides that could possibly be used to reduce growth of macrophytes and algae within Lake Solano and the forebay. However, this option will require discussions with Solano Project managers and other affected stakeholders so that the benefits and risks are clearly understood.

In-canal management approaches could include physical removal (e.g. localized suction and sieving, brief winter drawdown and sediment removal to reduce subsequent spring growth, and localized sediment shuffling (suspension) followed by downstream screening and removal. Optimal timing of these approaches would need to be determined based on plant growth and water demands. Herbicide/algaecide treatments could include use of in-water applications of either contact or systemic herbicides (preferably in early spring/early summer) and/or use of soil-active systemic herbicides that are applied to the bottom during brief drawdown cycles. Only products registered by the California Environmental Protection Agency/Department of Pesticide Regulation (CAL-EPA/DPR) can be used and would include sufficient pre- and post- application monitoring of active ingredients to comply with both label requirements and probable National Pollutant Discharge Elimination System (NPDES) permit requirements. In addition, any use of herbicides or algaecides would have to be compatible with potable and crop (irrigation) water uses. The efficacy and overall utility (practical uses) of these methods should be evaluated.

At present, it is unlikely that the California Department of Fish and Game would allow use of the (sterile) triploid grass carp as a biological control method due to (1) upstream access to Putah Creek, (2) possibility of escape into irrigation canals, distributary creeks or the Terminal Reservoir, and (3) floodplain elevations. However, this option should be fully vetted before dismissing the method. For example, it may be possible to demonstrate that the fish cannot enter the forebay or Lake Solano and that they would not move downstream to natural waters. This may be worthy of discussion with key agency representatives.

9.10. Mechanical Harvesting Pilot Study

The goal of this pilot study was to test the efficiency of mechanical harvesting to cut and remove submerged vegetation from the PSC and to determine water quality impacts from harvesting activities. The test demonstration was conducted by Aquatic Environments Inc (AEI) on October 16, 2008. A commercially available Aquamarine H5-130 Harvester (Figure 9.30) was used in the pilot test. The H5-130 is a 26.2 ft long, 7.2 ft high, and 6.9 ft wide floating harvester that cuts aquatic weeds and removes plant biomass from the water body. The weight of the harvester is 4,550 lb. The carrying capacity of the harvester is 130 ft^3 or 1,400 lb. It's cutting width is 5 ft and cutting depth is 4.25 ft. The propulsion system consists of two side-mounted paddle wheels. The harvester was transported to the test site on the PSC on a trailer and placed into/removed from the canal by means of a 70 ton crane.

To minimize potential impact to water quality and water users, the harvesting was conducted after the agricultural season and downstream of all the major WTPs, in the Suisun Valley. Three reaches were selected for testing (Figure 9.31):

Reach 1 – Suisun Check between MP 26.87-27.11. The reach is about 700 yd long and is located between Suisun Valley Road at MP 26.87 and a bridge crossing at MP 27.11. Water depth in the canal during testing was about 5-6 ft and stream velocity was around 0.1-0.2 ft/s. The selected reach represented typical conditions in the PSC with respect to volume and density of weed growth. According to visual estimates, about 50-80% of the canal was occupied by weeds growing up to the water surface. The bottom of the canal was covered with 0.5-1 ft thick layer of sediment. Prior to harvesting, turbidity booms were installed at the downstream end of the test section to minimize impact to water quality in the downstream reaches (Figure 9.32). The cutting head of the harvester was lowered to just above the sediment layer in an effort to keep from disrupting sediment deposits. A total of three full passes were made to cut all the submerged vegetation (Figure 9.33). Less than one full load of plant material was collected (about 300 lb). The harvested biomass was disposed of on the south bank of the canal. Upon completion of harvesting, the H5-130 was removed from the canal and transported to the second test location.

Reach 2 – Suisun Check between MP 25.94-26.03. This reach is 150 yd long and is located between the Mankas Check flow control structure at MP 25.94 and Mankas Corner Road at MP 26.03. Water depth in this section of the canal was about 3-4 ft, with a few inches of sediment deposit on the bottom of the canal. About 50-60% of the canal bed was covered with small aquatic plants. A turbidity boom was installed at the downstream end of the test section (Figure 9.34). To test maximum water quality impact from the harvesting in this reach, the cutting head was lowered to the very bottom of the canal to cause maximum disruption of bottom deposits (Figure 9.35). Turbidity was created by pushing the "mats" of sediment and vegetation along bottom, similar to a loosely woven carpet. Two passes were made with very little material collected (about 200 lb). The harvester was removed and the harvested material was placed on the south side of the canal. In this reach, with the lower water level, the harvester was unable to turn around without hitting the canal sides. Once complete, the harvester was removed and transported to the third reach (Figure 9.36).

Reach 3 – Mankas Check between MP 25.77-25.94. This reach extends approximately 280 yd upstream of the Mankas Check flow control structure located at MP 25.94. The flow in the canal was 5-6 ft deep. The canal in this reach was moderately vegetated. According to visual estimates, up to 50-80% of the canal was covered with weeds. Sediment deposit on the canal bottom was a few inches thick. The cutting head was placed above the sediment layer to avoid disturbing the deposits. A total of two full passes were made which removed all available vegetation from the canal (Figure 9.37). Less than one full load of material was removed at this section (about 300 lb) and placed on the south side of the canal.

The following parameters were monitored to determine impacts from harvesting:

- Turbidity and selected water quality characteristics were measured at the downstream end of each harvesting reach (upstream of fragment/turbidity booms). The measurements were made using a hand-held YSI 650MDS multimeter (Figure 9.38) prior to harvesting (baseline conditions) and during harvesting. In Reach 2, an additional measurement was made downstream of the turbidity boom to determine its trapping efficiency. Depth-average multimeter data are presented in Table 9.2 and Figure 9.39.

- Water samples were collected at the downstream end of each reach (upstream of fragment/turbidity booms) before and during harvesting. The samples were subsequently analyzed for selected constituents by Analytical Sciences in Petaluma, CA. Results from laboratory water quality analyses are summarized in Table 9.3 and graphically shown in Figure 9.40. Drinking water standards are also shown in Table 9.3 for comparison.

- Vegetation flux was sampled at the downstream end of each reach (upstream of fragment/turbidity booms) before and during harvesting. The measurements were conducted in the upper 3 ft of flow using a 2 ft by 3 ft rectangular frame with ¼ inch mesh (Figures 9.41 and 9.42). Sampled vegetation was analyzed in a laboratory to determine the fragment counts per hour per canal width, species type, and fragment lengths by species of vegetation. Vegetation netting results obtained for Reaches 1, 2, and 3 are shown in Figures 9.43, 9.44, and 9.45, respectively.

According to the multimeter data (Table 9.2, Figure 9.39), water temperature was constant in Reach 1 and increased in Reaches 2 and 3. The observed changes in water temperature were due to sunlight effect and were not related to harvesting. Dissolved Oxygen (DO) increased in Reach 1 and decreased in Reaches 2 and 3, while pH slightly increased in all the test reaches. However, the observed changes in DO and pH were insignificant. The most noticeable effect of harvesting was the increased level of water turbidity. Measured turbidity increased from less than 1 NTU before harvesting up to 10-11 NTU during harvesting in Reaches 1 and 3 (where sediment layer was left intact) and up to 16 NTU during harvesting in Reach 2 (where sediment layer was intentionally disturbed). The observed increase in turbidity, however, was far below the level of concern for water users and can be easily treated at WTPs.

Results of laboratory analysis of water samples (Table 9.3 and Figure 9.40) also indicated that harvesting did not produce any significant impact on water quality characteristics. Most constituents were either non-detectable or found in very small quantities. The only parameters that slightly exceeded existing drinking water standards were turbidity and iron.

Monitoring of vegetation flux revealed that harvesting did increase the amount of floating weed fragments in the canal (Figures 9.43-9.45). Measured total number of fragments increased by an order of magnitude from 132 to 550 fragments per hour during baseline conditions to 2,376 to 5,247 per hour during harvesting operations. Prevailing species in the test reaches were *S. pectinata* and *M. spicatum*. To prevent plant material dispersal to the downstream reaches, the fragments need to be contained by means of fragment and turbidity booms. The pilot test demonstrated insufficient trapping efficiency of the presently available booms. However, the design and implementation of the booms can be improved specifically for the PSC.

In general, the harvesting pilot study demonstrated that mechanical harvesting is an effective means for removing (harvesting) submerged vegetation quickly from the canal. Harvesting can disturb bottom sediments in the canal which may increase turbidity and impact water quality. However, the observed water quality impacts from the localized harvesting were generally insignificant. The only parameters that slightly exceeded existing drinking water standards were turbidity and iron. Although most of the removed biomass was contained inside the harvester, harvesting operations did increase (by an order of magnitude) the amount of weed fragments floating with water flow down the canal. To minimize impacts on downstream reaches, the weed fragments and the turbidity plume produced by harvesting activities should be contained immediately below the harvesting site. However, currently available fragment and turbidity booms appeared not to be very effective and need to be modified. Given the significantly varying dimensions of the PSC (bottom width reduces from 12 ft in the upstream reaches to 5 ft in the downstream reaches, while water depth reduces along the canal from about 10 ft to 5 ft), different harvesters will be needed to clean different canal sections. Harvesters will also need to be modified to clean algae from canal panels. Due to many structures crossing the canal and limited access to some reaches, harvesting operations will require significant logistic support and will most likely have to be restricted to the strategic, most problematic locations. Because harvesting essentially trims growing weeds and does not remove root structures, weeds can re-grow. Hence periodic harvesting (1-3 times per year) may be necessary to control and maintain plant populations. Minimal water quality impact observed during the pilot study indicates that mechanical harvesting has a potential for large-scale application without affecting water users.

Results from these limited tests show that a mechanical harvester of similar size and configuration is capable of cutting up to 2 acres of aquatic vegetation in an 8-hour day using the same double pass method applied during the tests. After including a time estimate for interruptions needed to move the harvester up and over existing obstacles (checks, bridges and pipelines), a conservative (low) approximate daily harvesting distance is approximately 6,000 to 7,000 feet of canal per 8-hour day, depending on the number of obstacles found in a specific reach. The cost for the harvester and a 3-person crew is approximately $1,250 to $1650 per day. A conservative estimate for the cost of a mobile lift crane to "pick-and-put" the harvester in and out of the canal is approximately $1,850 to $2,350 per day depending on the equipment and type of contract that is obtained. Therefore, the estimated cost to operate the harvester of similar size with a crane is $3,100 to $4,000 per day, or approximately $3,500 per day or $2,850 per canal mile. These costs could be reduced if SCWA owned and operated their own the equipment and/or negotiated a long-term canal maintenance contract with a mechanical harvesting company. Aquatic Environments, Inc estimated that the same small harvester that was used during the pilot tests could harvest (mow and remove) approximately 14 to 16 tons of vegetation per day, depending on the length and thickness of growth. This results in a cost of approximately $225 to $250 per ton of vegetation removed in an 8-hour day. Not all of the canal is experiencing high rates of aquatic week growth. Therefore, if we assume that only 10 miles of canal contains the most dense "forests" of aquatic weeks, then it may cost about $35,000 per mowing to mow and remove vegetation from the most problematic reaches in the canal. These are reasonable estimates, but costs could be much less if the harvesting equipment and deployment methods could be refined to be more efficient for the setting. A large scale pilot test (to cover 2 – 3 miles of canal) may help SCWA and a potential contractor "fine tune" these costs estimates.

9.11. Summary and Recommendations

Based on initial observations, 3 to 4 species of aquatic plants (some native, some exotic) successfully grow, reproduce, and contribute most of the rooted biomass along the majority of the canal system. Filamentous algae also contribute significant biomass both in suspension and as attached (colonial filaments) along the sides and bottom of the canal. Seasonal production of biomass is generated along the canal, but is augmented by imports from Lake Solano and drainage basins immediately upstream from the Headworks. Significant amounts of floating plant fragments enter the PSC through the Headworks, especially during screen cleaning activities. These fragments can settle in the canal and evolve into live plants. Vegetation influx into the canal from Lake Solano has a seasonal pattern, dramatically increasing during summer periods and decreasing during winter seasons. Seasonal senescence (die-back) of this biomass contributes to the overall organic load in the canal and when combined with fine sediments probably increase the hypoxic conditions in the sediment deposits. Even if all of the vegetation were successfully removed within the canal in one season, new propagules of both macrophytes and algae would continue to infest the canal from the upstream sources. This suggests that a fully integrated source management strategy is needed that includes both in-canal actions (physical and/or herbicides), as well as source management of exotic (non-native) plants in Lake Solano and the Headworks forebay. The magnitude of the upstream sources and their seasonal components need to be assessed further. This is probably best accomplished through coordination among Solano Project operators and managers so that access to the system is adequate and so that any management options and proposed solutions are arrived at by consensus supported by the scientific-based evaluation of risks, benefits, costs and long-term goals.

One viable option to reduce aquatic vegetation growth in the canal is to conduct periodic mechanical harvesting at strategic, most problematic locations. A pilot study demonstrated that mechanical harvesting is an effective means of fast removal of submerged vegetation from the canal. At the same time, harvesting operations do not appear to have significant impact on water quality. This indicates that mechanical harvesting has a potential for large-scale application without adversely affecting water users. Existing harvesting equipment and operational procedures may be modified and optimized for the conditions observed in the PSC to increase their effectiveness. Based only on the initial pilot tests, it may cost approximately $3,500 per day or about $2,850 per canal mile to hire an outside contractor to provide mechanical harvesting services. It may be possible to lower the daily cost if the equipment and methods are refined to meet site-specific conditions.

Table 9.1. Summary of biomass influx monitoring results.

Date & Time	Location	Conditions	Total number of plant fragments (per hour per canal width)	Prevailing fragment length (inches)	Prevailing species
09/24/08 14:30	Headworks (lakeside)	Baseline	42,900	1.5-4.5	*E. canadensis* *M. spicatum* *P. crispus*
09/25/08 11:26	USGS gage MP 0.18	Baseline	798	1.5-3	*E. canadensis* *M. spicatum*
09/25/08 14:20	USGS gage MP 0.18	Headworks screen cleaning	16,484	1.5-4.5	*E. canadensis* *M. spicatum* *P. crispus*
10/02/08 9:00	USGS gage MP 0.18	Headworks screen cleaning	19,133	1.5-4	*E. canadensis* *M. spicatum* *P. crispus*
10/02/08 10:05	Weyand Intake MP 5.6	Baseline	1,560	1.5-3	*E. canadensis* *M. spicatum* *P. crispus*
12/11/08 10:00	USGS gage MP 0.18	Headworks screen cleaning	2,670	1-2.5	*E. canadensis* *C. demersum* *M. spicatum*
1/29/09 9:15	USGS gage MP 0.18	Baseline	0	-	-
1/29/09 10:13	USGS gage MP 0.18	Headworks screen cleaning	13,020	1-3	*E. canadensis* *M. spicatum* *C. demersum*
02/25/09 8:40	Headworks (lakeside)	Baseline	3,525	1-1.5	*E. canadensis* *M. spicatum* *C. demersum*
02/25/09 9:25	USGS gage MP 0.18	Baseline	29	1	*E. canadensis* *C. demersum*
02/25/09 11:00	USGS gage MP 0.18	Headworks screen cleaning	2,793	1-1.5	*E. canadensis* *M. spicatum* *C. demersum*

(Table is continued on next page)

Table 9.1. (continued)

Date & Time	Location	Conditions	Total number of plant fragments (per hour per canal width)	Prevailing fragment length (inches)	Prevailing species
04/14/09 10:10	Weyand Intake MP 5.6	Baseline	410	1-2.5	*E. canadensis M. spicatum*
04/14/09 11:30	USGS gage MP 0.18	Baseline	983	1-2.5	*E. canadensis M. spicatum*
04/14/09 12:55	USGS gage MP 0.18	Headworks screen cleaning	6,441	1.5-2.5	*E. canadensis M. spicatum*
04/14/09 13:45	Headworks (lakeside)	Baseline	1,050	1.5-3	*E. canadensis M. spicatum*
05/12/09 10:06	Weyand Intake MP 5.6	Baseline	750	1-2.5	*E. canadensis M. spicatum*
05/12/09 11:29	USGS gage MP 0.18	Baseline	542	1-3	*E. canadensis M. spicatum*
05/12/09 13:02	USGS gage MP 0.18	Headworks screen cleaning	9,690	1-4	*E. canadensis M. spicatum*
05/12/09 13:45	Headworks (lakeside)	Baseline	4,050	2.5-4.5	*E. canadensis M. spicatum*
06/30/09 8:07	USGS gage MP 0.18	Headworks screen cleaning	N/A	N/A	N/A
06/30/09 9:05	Headworks (lakeside)	Baseline	N/A	N/A	N/A
06/30/09 9:50	Weyand Intake MP 5.6	Baseline	N/A	N/A	N/A
06/30/09 10:45	USGS gage MP 0.18	Baseline	N/A	N/A	N/A

N/A = Not available (data are being processed)

Table 9.2. Depth-average water quality data measured with YSI 650MDS multimeter during vegetation harvesting pilot test on October 16, 2008.

Location	Measurement	Water temperature (^oC)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)
Reach 1 MP 27.1	Baseline	14.1	10.4	7.74	0.8
	Harvesting	14.1	11.4	8.29	3.0
	1st turn around	14.1	11.3	8.32	10.8
	2nd turn around	14.1	12.5	8.29	6.7
Reach 2 MP 26.0	Baseline	14.3	15.0	6.54	0.6
	Harvesting	14.9	13.3	8.17	4.3
	1st turn around	14.9	14.2	8.54	16.2
	D/s of turbidity boom	15.2	13.1	8.55	6.1
Reach 3 MP 25.9	Baseline	15.4	15.1	8.39	0.1
	Harvesting	15.6	15.6	8.50	9.8
	1st turn around	15.7	14.8	8.61	5.0
	2nd turn around	15.8	12.7	8.68	7.1
Drinking water standard		-	-	6.5-8.5**	1*

* Primary drinking water standard; ** Secondary drinking water standard.

Table 9.3. Water quality laboratory results for samples collected during vegetation harvesting pilot test on October 16, 2008.

Constituent	Baseline			Harvesting			Drinking water standard
	MP 27.11	MP 26.03	MP 25.94	MP 27.11	MP 26.03	MP 25.94	
Phosphorus (mg/L)	ND	ND	ND	ND	ND	ND	0.005**
Nitrite (mg/L)	ND	ND	ND	ND	ND	ND	1*
Nitrate (mg/L)	ND	ND	ND	ND	ND	ND	10*
Total Nitrogen (mg/L)	0.4	0.41	0.47	0.41	0.51	0.71	
Total Kjeldahl Nitrogen (mg/L)	0.4	0.41	0.47	0.41	0.51	0.71	
Copper (mg/L)	ND	ND	ND	ND	ND	ND	1.3*, 1**
Iron (mg/L)	0.21	ND	0.14	0.28	0.34	0.49	0.3**
Manganese (mg/L)	ND	ND	ND	ND	ND	ND	0.05**
Mercury (µg/L)	ND	ND	ND	ND	ND	ND	2*
Turbidity (NTU)	2.2	0.7	0.8	1.1	1.0	1.3	1*
Total Alkalinity (mg $CaC0_3$/L)	170	170	160	170	160	160	
Bicarbonate Alkalinity (mg $CaC0_3$/L)	170	170	160	170	160	160	
Carbonate Alkalinity (mg $CaC0_3$/L)	ND	ND	ND	ND	ND	ND	
Hydroxide Alkalinity (mg $CaC0_3$/L)	ND	ND	ND	ND	ND	ND	
Total Suspended Solids (mg/L)	10	ND	6	8.5	20	33	
Dissolved Organic Carbon (mg C/L)	3.2	2.9	2.7	2.9	3.4	3.1	
Total Organic Carbon (mg C/L)	3.1	2.8	3.2	3.1	3.3	3.1	

MP = milepost; ND = Not detectable; * Primary drinking water standard; ** Secondary drinking water standard.

Figure 9.1. Application of copper sulfate at Headworks. Photo of September 25, 2008.

Figure 9.2. Aquatic vegetation, organic sludge, and sediment removed from Sweeney Check during canal cleanout. Photo of October 18, 2006.

Figure 9.3. Backhoe removing sediment, vegetation, and sludge deposits from Sweeney Check. View upstream. Photo of October 19, 2006.

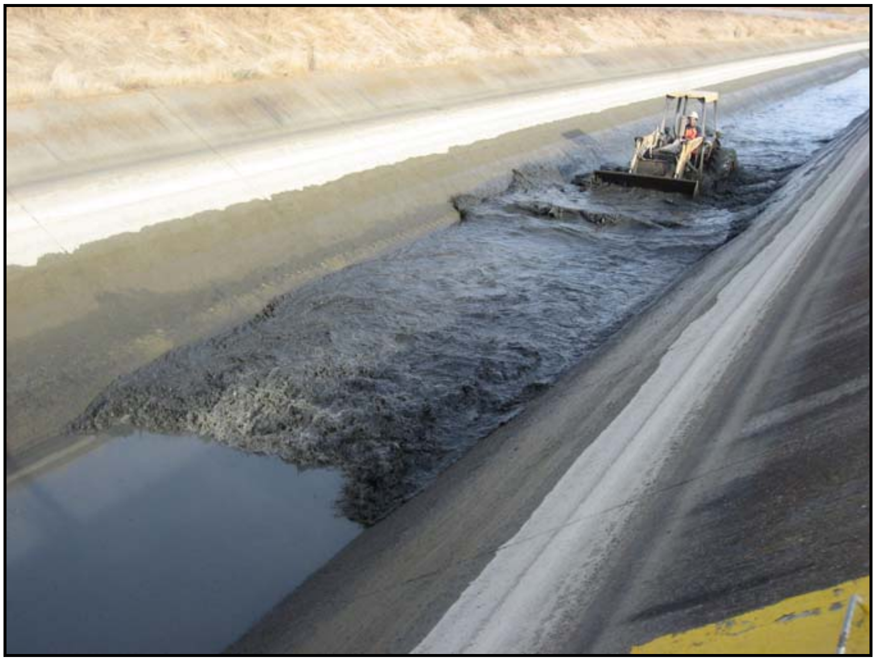
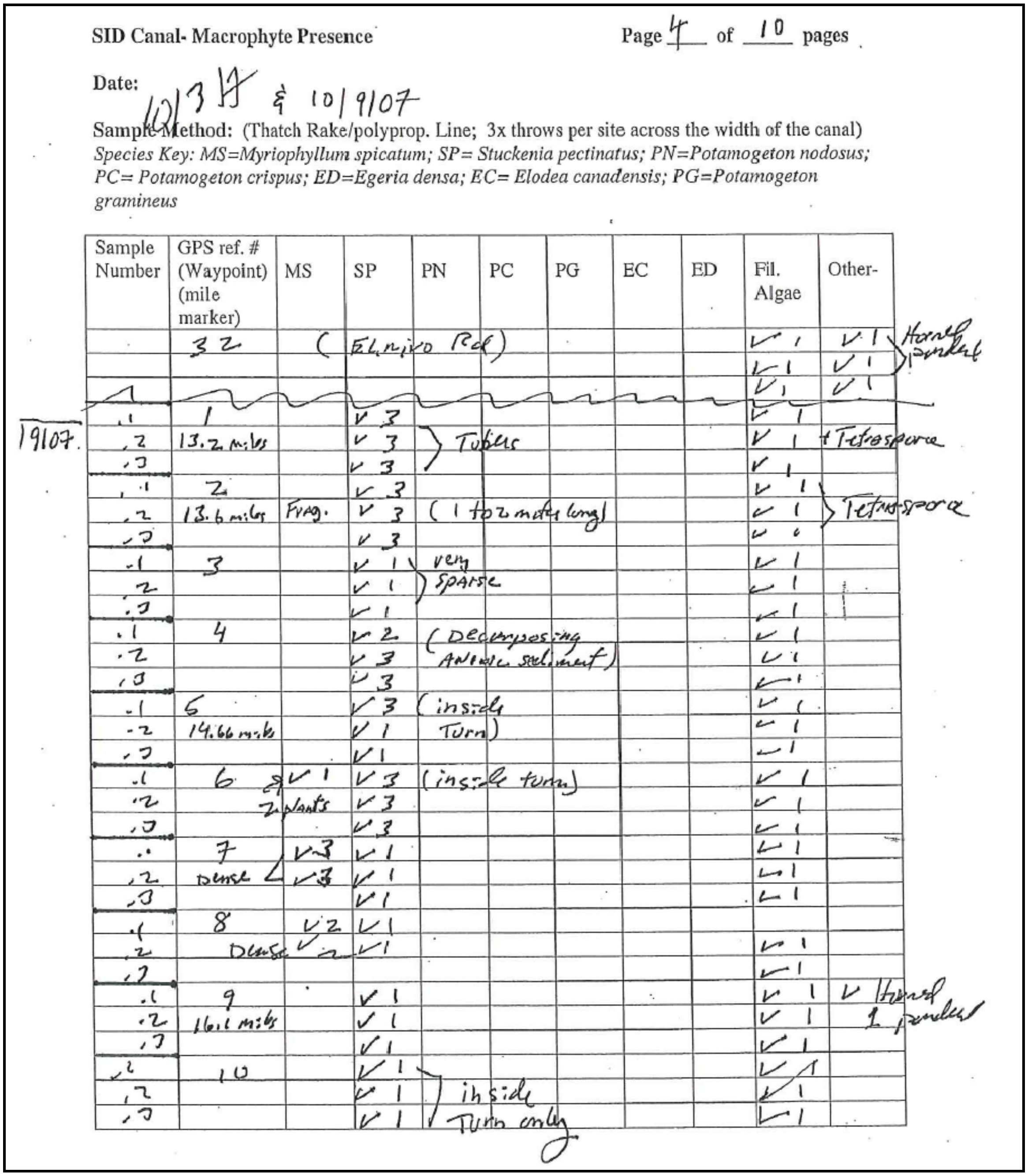


Figure 9.4. Tractor pushing sediment, vegetation, and sludge deposits downstream in McCoy Check. Photo of October 30, 2006.



SID Canal- Macrophyte Presence

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Date: 10/3/07 & 10/9/07

Sample Method: (Thatch Rake/polyprop. Line; 3x throws per site across the width of the canal)
Species Key: MS=Myriophyllum spicatum; SP= Stuckenia pectinatus; PN=Potamogeton nodosus; PC= Potamogeton crispus; ED=Egeria densa; EC= Elodea canadensis; PG=Potamogeton gramineus

Sample Number	GPS ref. # (Waypoint) (mile marker)	MS	SP	PN	PC	PG	EC	ED	Fil. Algae	Other-
	32	(	El Nido Rd)						✓ 1	✓ 1 } Horned pondweed
									✓ 1	✓ 1
									✓ 1	✓ 1
.1	1		✓ 3						✓ 1	
10/9/07. .2	13.2 miles		✓ 3	} Tubers					✓ 1	+ Tetraspora
.3			✓ 3						✓ 1	
.1	2		✓ 3						✓ 1	
.2	13.6 miles	Frag.	✓ 3	(1 to 2 meter long)					✓ 1	} Tetraspora
.3			✓ 3						✓ 1	
.1	3		✓ 1	} very sparse					✓ 1	
.2			✓ 1						✓ 1	
.3			✓ 1						✓ 1	
.1	4		✓ 2	(Decomposing anoxic sediment)					✓ 1	
.2			✓ 3						✓ 1	
.3			✓ 3						✓ 1	
.1	5		✓ 3	(inside					✓ 1	
.2	14.66 miles		✓ 1	turn)					✓ 1	
.3			✓ 1						✓ 1	
.1	6	✓ 1	✓ 3	(inside turn)					✓ 1	
.2		2 plants	✓ 3						✓ 1	
.3			✓ 3						✓ 1	
.1	7	✓ 3	✓ 1						✓ 1	
.2	Dense	✓ 3	✓ 1						✓ 1	
.3			✓ 1						✓ 1	
.1	8	✓ 2	✓ 1							
.2	Dense	✓ 2	✓ 1						✓ 1	
.3									✓ 1	
.1	9		✓ 1						✓ 1	✓ Horned 1 pondweed
.2	16.1 miles		✓ 1						✓ 1	
.3			✓ 1						✓ 1	
.1	10		✓ 1	} inside turn only					✓ 1	
.2			✓ 1						✓ 1	
.3			✓ 1						✓ 1	

Figure 9.5. Example page from Log of Canal Macrophyte Presence prepared by Dr Anderson during field sampling activities conducted in fall of 2007.

Figure 9.6. Photo of Dr Anderson examining vegetation gathered from a cast with his thatch rake in Putah South Canal in October 2007.

Figure 9.7. Photo of Dr Anderson examining vegetation gathered from a cast with his thatch rake in Putah South Canal in October 2007. Note black organic sludge materials draining from vegetation mat.

Figure 9.8. Thick mats of attached algae growing on canal sides and thick mats of macrophytes growing on canal bottom in Serpas Check. A mixture of sediment and decayed plant materials lies beneath the mats of macrophytes. These deposits can become 6 to 18 inches thick.
Photo of November 9, 2006.

Figure 9.9. Thick mats of aquatic vegetation growing in Lake Solano.
View upstream from Headworks. Photo of October 10, 2006.

Figure 9.10. Large bloom of Mosquito Fern (*azolla*) in Lake Solano.
Photo of February 9, 2007.

Figure 9.11. Aquatic vegetation sampler (2 ft by 3 ft frame with ¼ inch mesh). Photo of September 24, 2008.

Figure 9.12. Aquatic vegetation sampling in front of Headworks trash screens. Flow left to right. Photo of September 24, 2008.

Figure 9.13. Aquatic vegetation sampling at USGS gage at MP 0.18. Flow right to left. Photo of September 25, 2008.

Figure 9.14. Aquatic vegetation sampling at USGS gage at MP 0.18. Flow left to right. Photo of September 25, 2008.

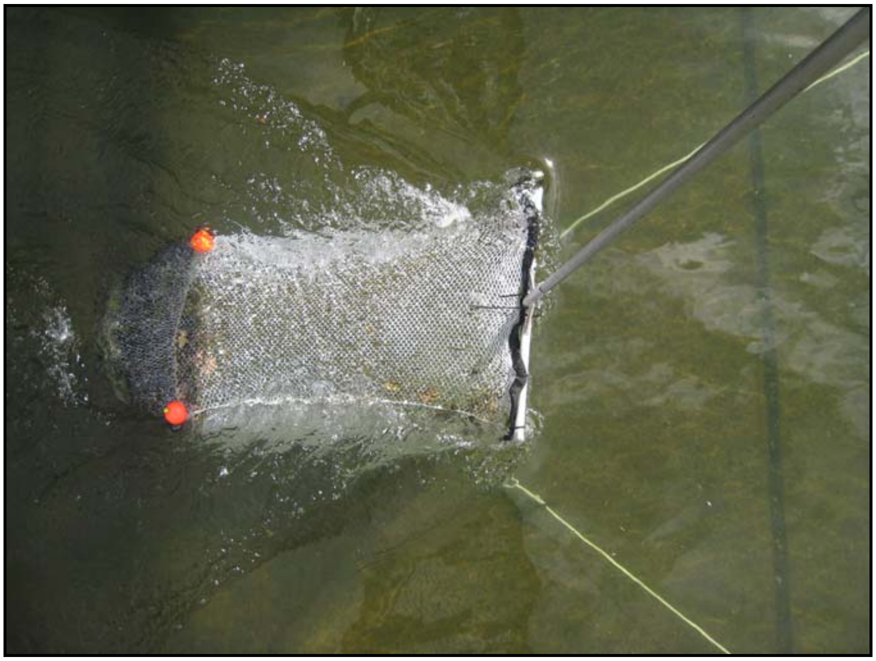


Figure 9.15. Deployed aquatic vegetation sampler. Flow right to left. Photo of September 25, 2008.

Figure 9.16. Collection of netted vegetation for subsequent laboratory analysis. Photo of September 24, 2008.

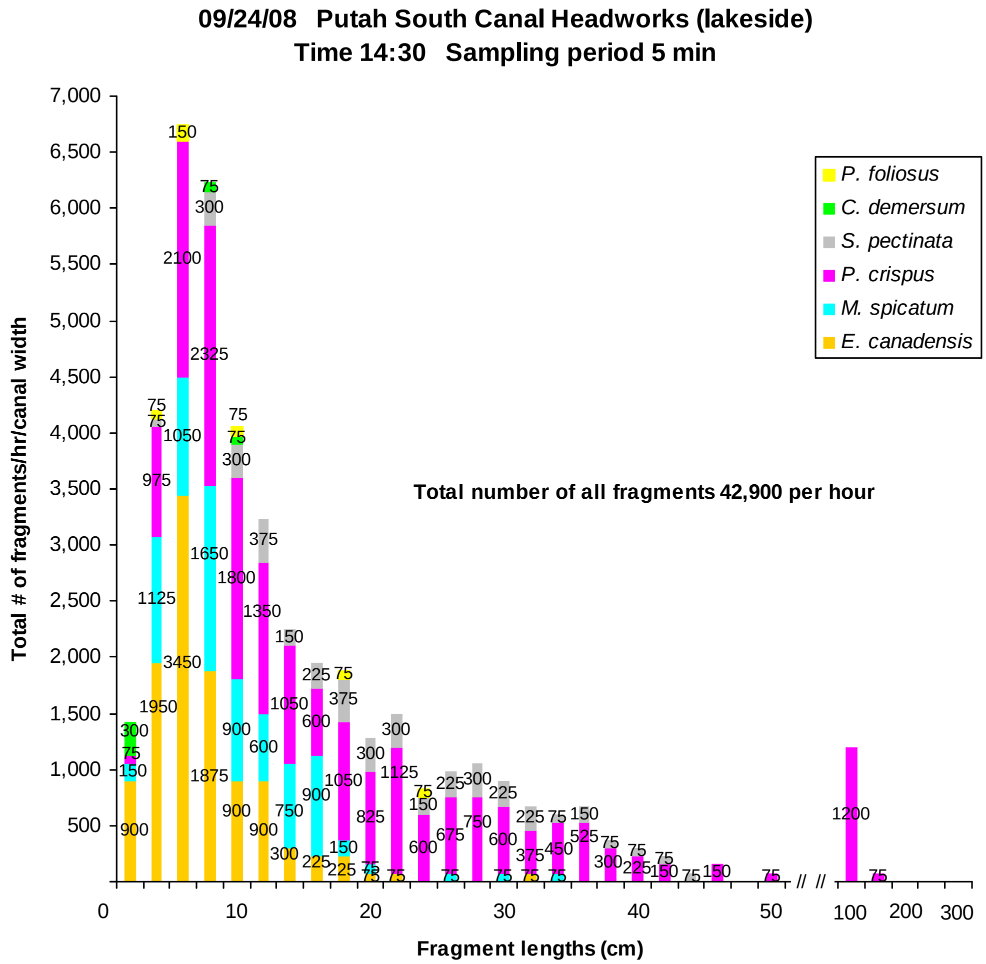


Figure 9.17. Total vegetation influx from Lake Solano measured in front of PSC Headworks trash screens on September 24, 2008.

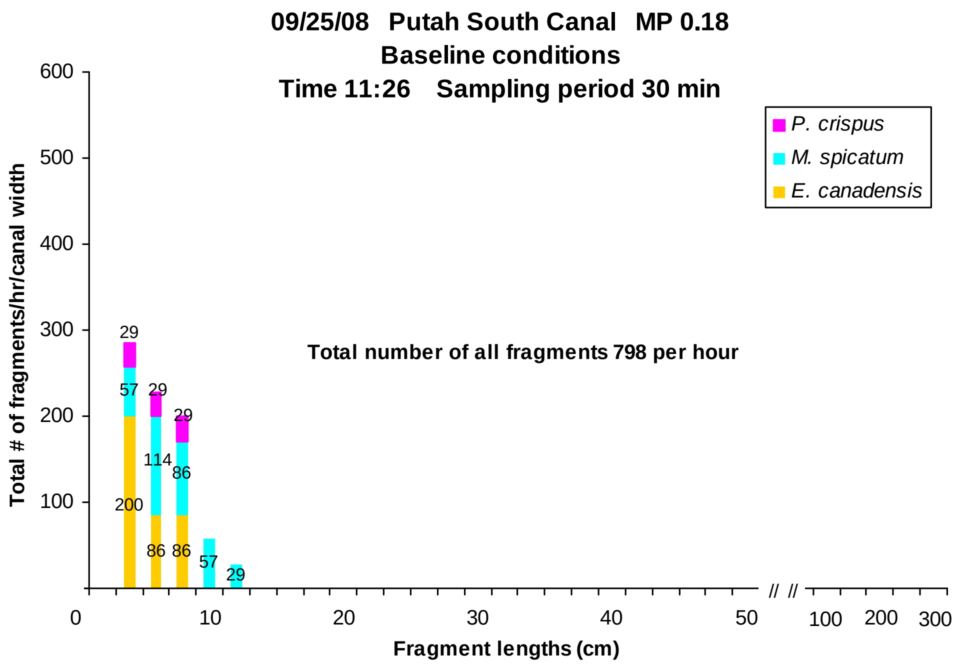


Figure 9.18. Total vegetation flux in Putah South Canal at USGS gage at MP 0.18 measured during baseline conditions on September 25, 2008.

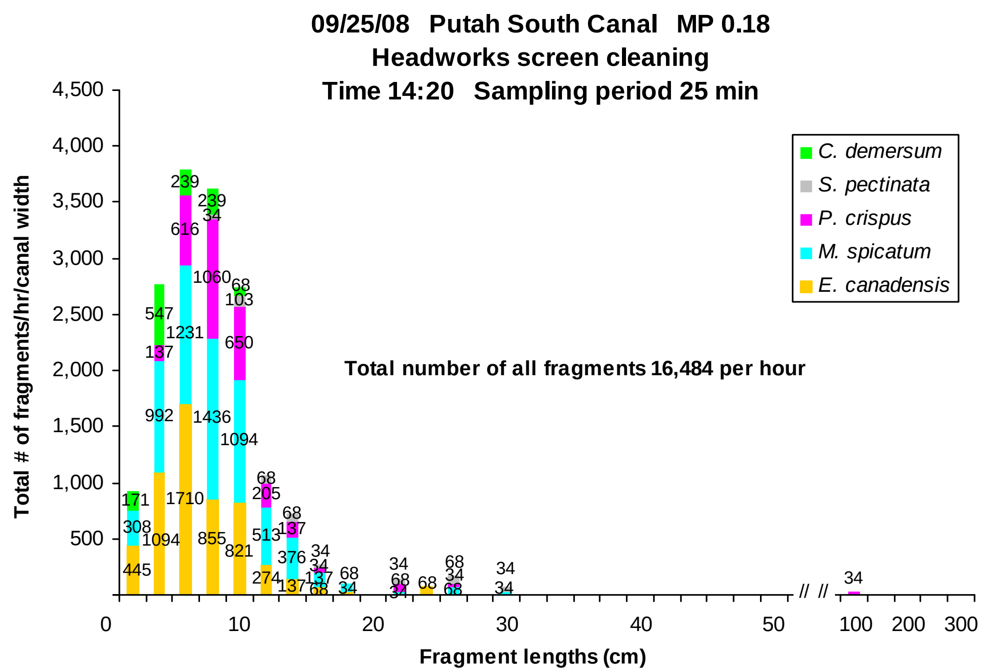


Figure 9.19. Total vegetation flux in Putah South Canal at USGS gage at MP 0.18 measured during afternoon's Headworks trash screens cleaning on September 25, 2008.

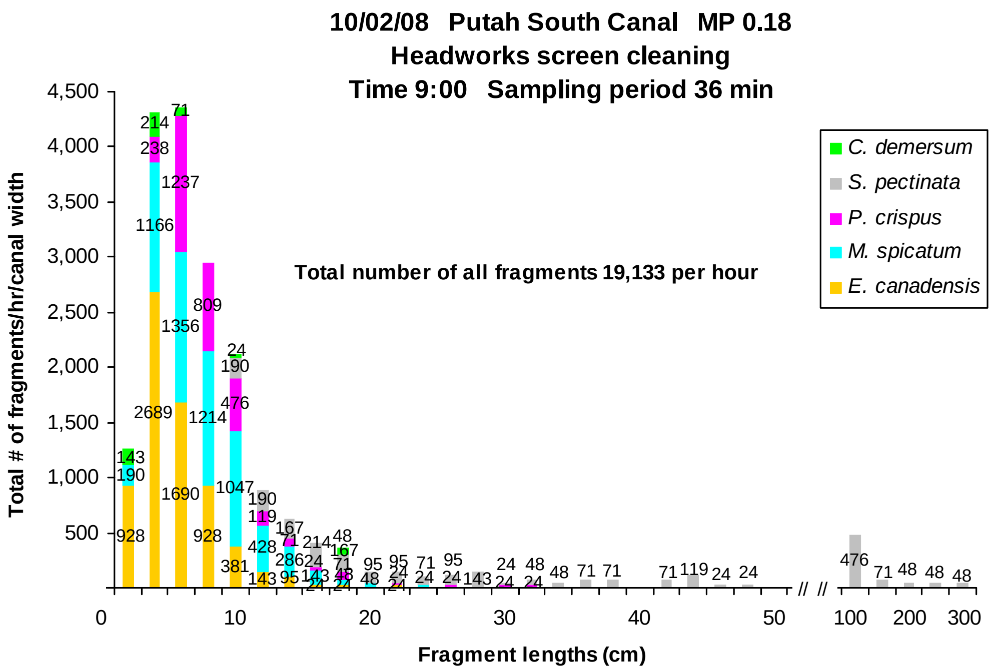


Figure 9.20. Total vegetation flux in Putah South Canal at USGS gage at MP 0.18 measured during morning's Headworks trash screens cleaning on October 2, 2008.

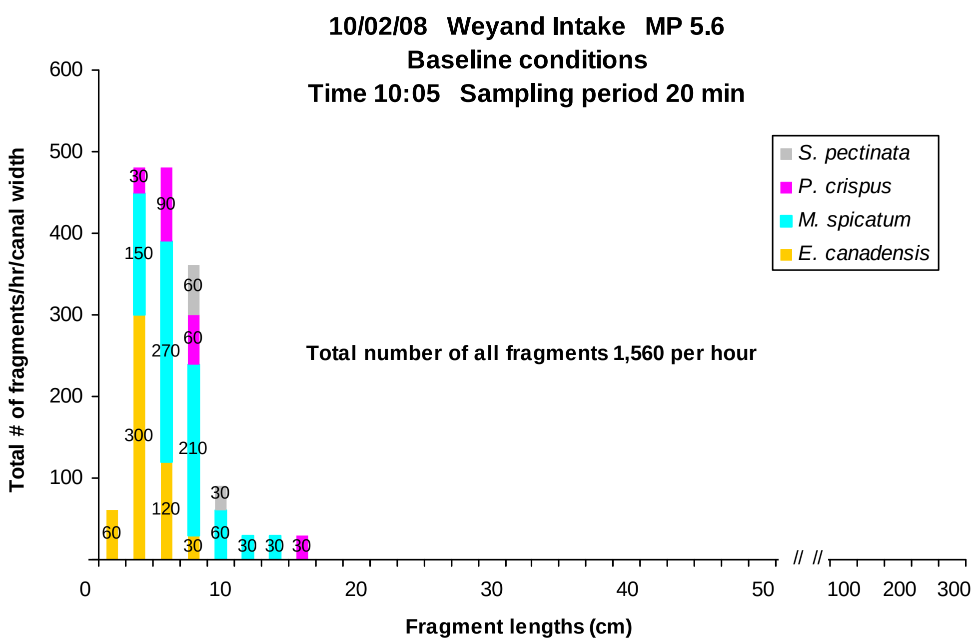


Figure 9.21. Total vegetation influx from Putah South Canal to Weyand Intake at MP 5.6 measured during baseline conditions on October 2, 2008.

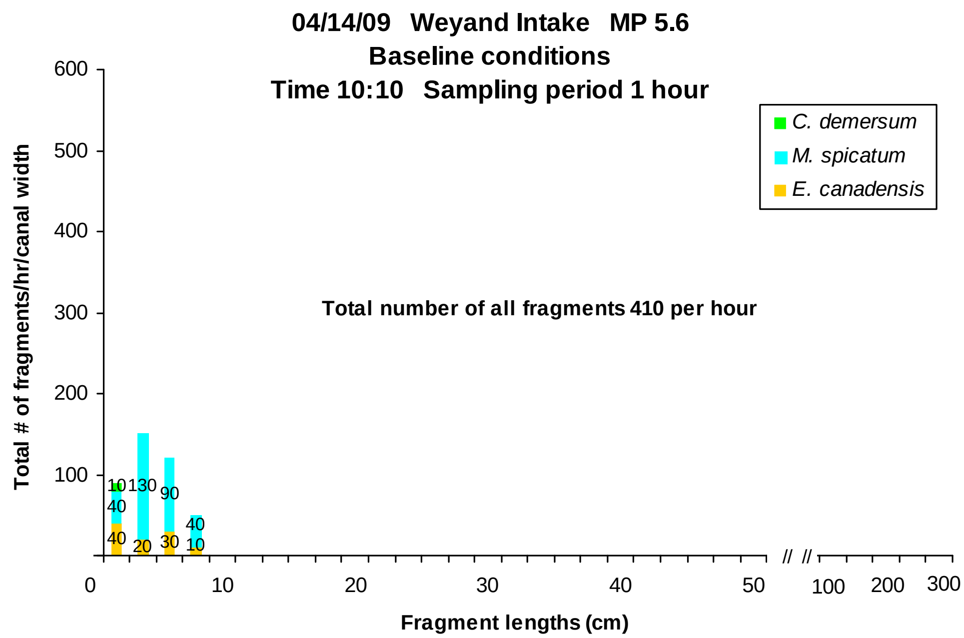


Figure 9.22. Total vegetation influx from Putah South Canal to Weyand Intake at MP 5.6 measured during baseline conditions on April 14, 2009.

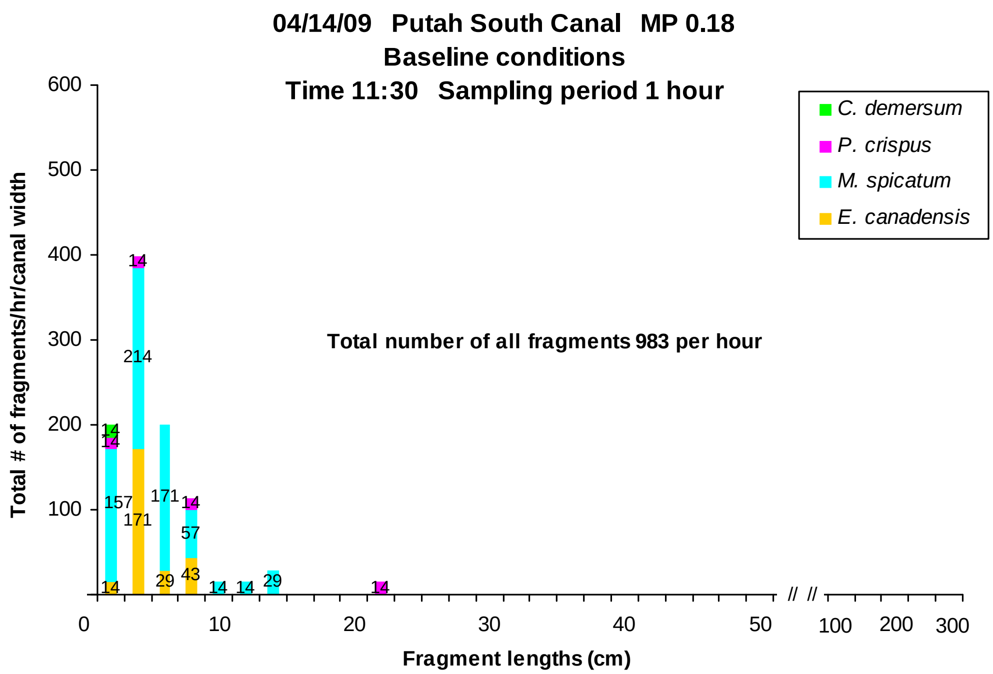


Figure 9.23. Total vegetation flux in Putah South Canal at USGS gage at MP 0.18 measured during baseline conditions on April 14, 2009.

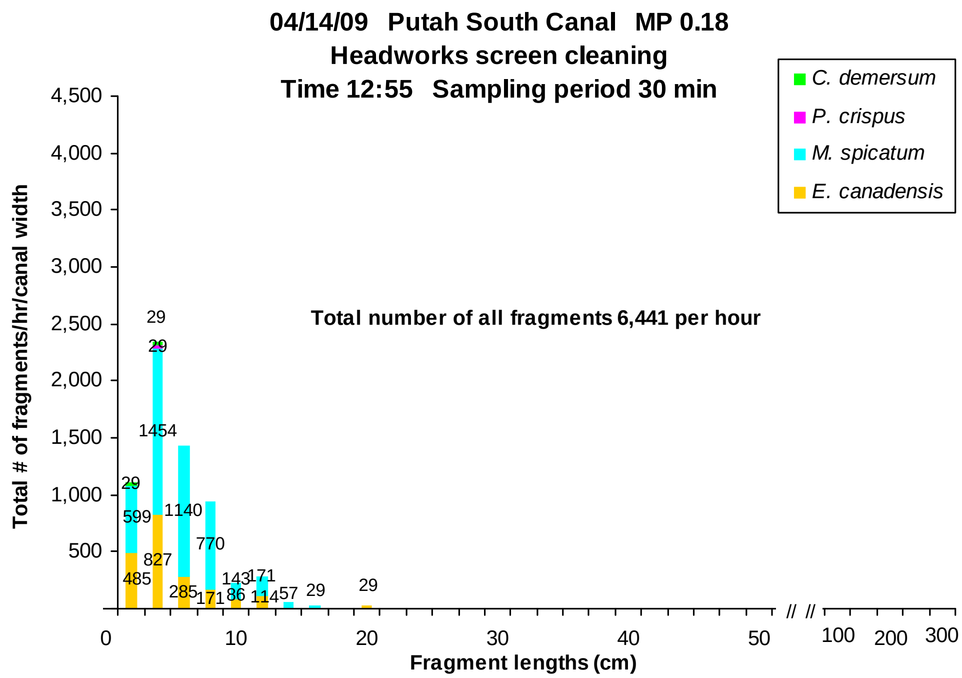


Figure 9.24. Total vegetation flux in Putah South Canal at USGS gage at MP 0.18 measured during Headworks trash screens cleaning on April 14, 2009.

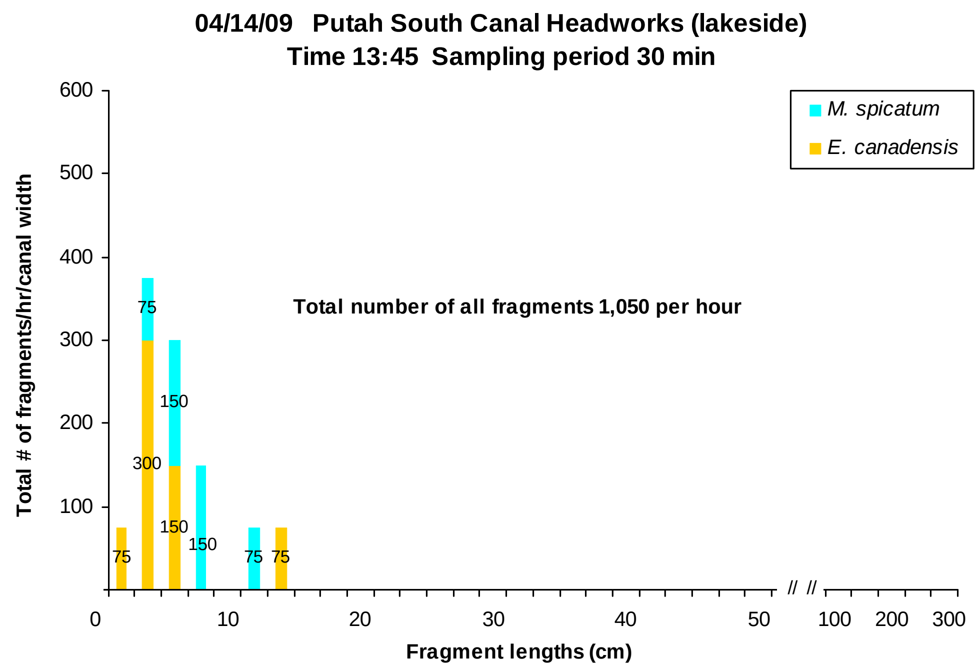


Figure 9.25. Total vegetation influx from Lake Solano measured in front of PSC Headworks trash screens on April 14, 2009.

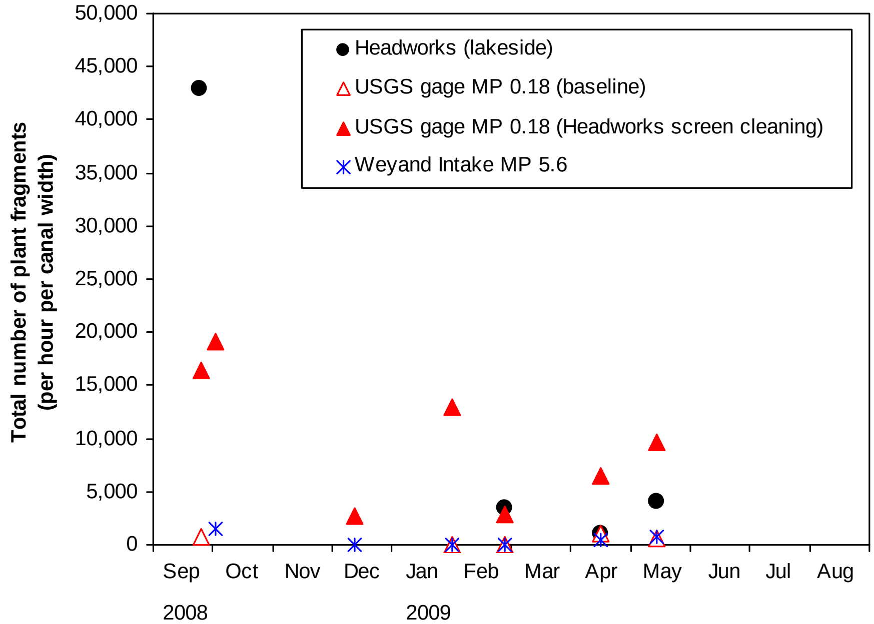


Figure 9.26. Seasonal variation of measured total vegetation influx.

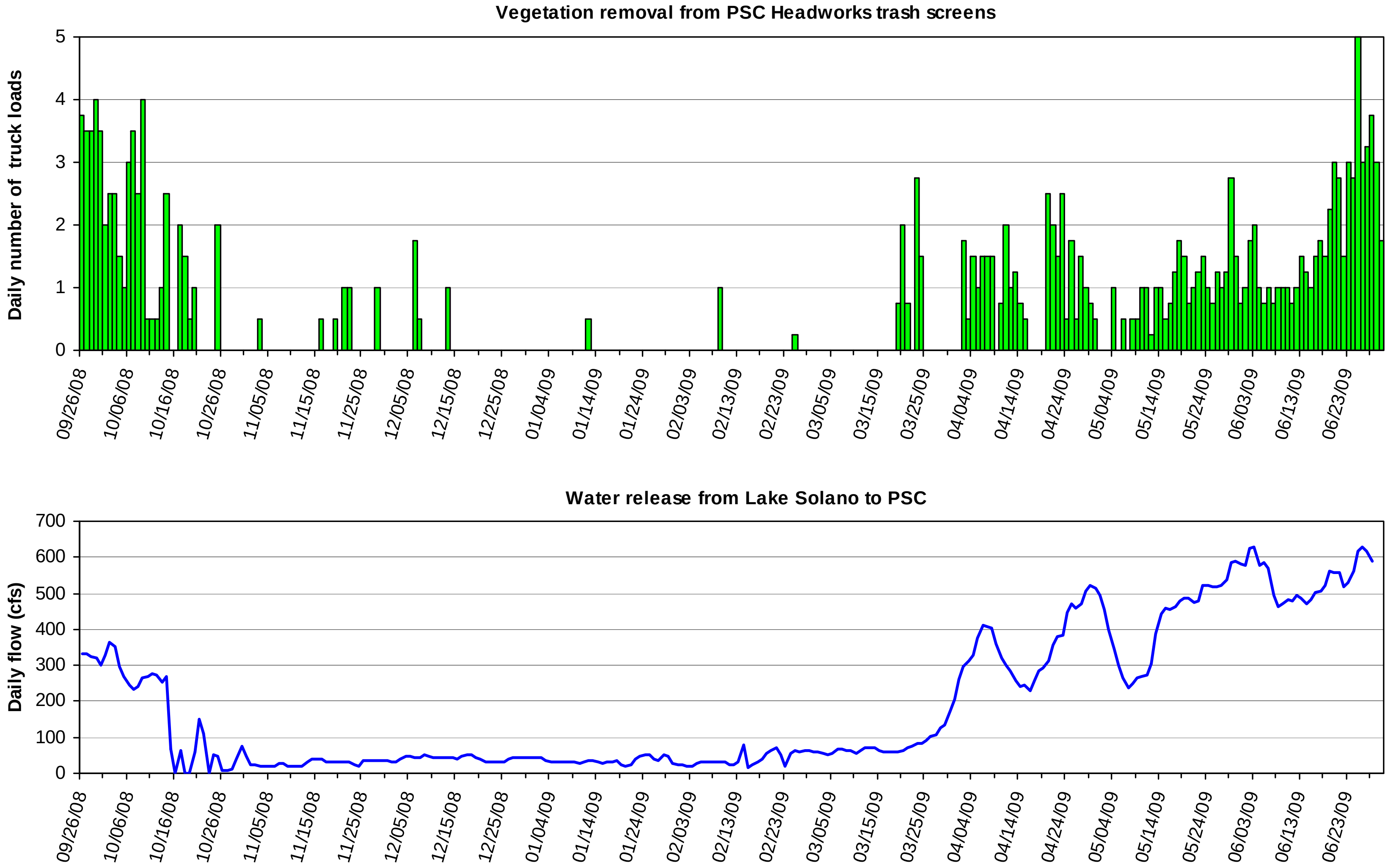


Figure 9.27. Daily number of truck loads of vegetation removed from PSC Headworks trash screens and daily water release from Lake Solano to Putah South Canal.

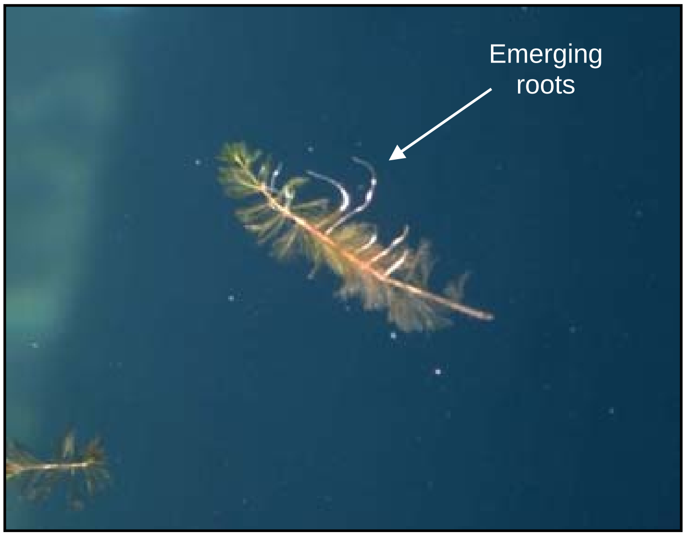


Figure 9.28. Floating fragment of Eurasian watermilfoil with emerging roots.

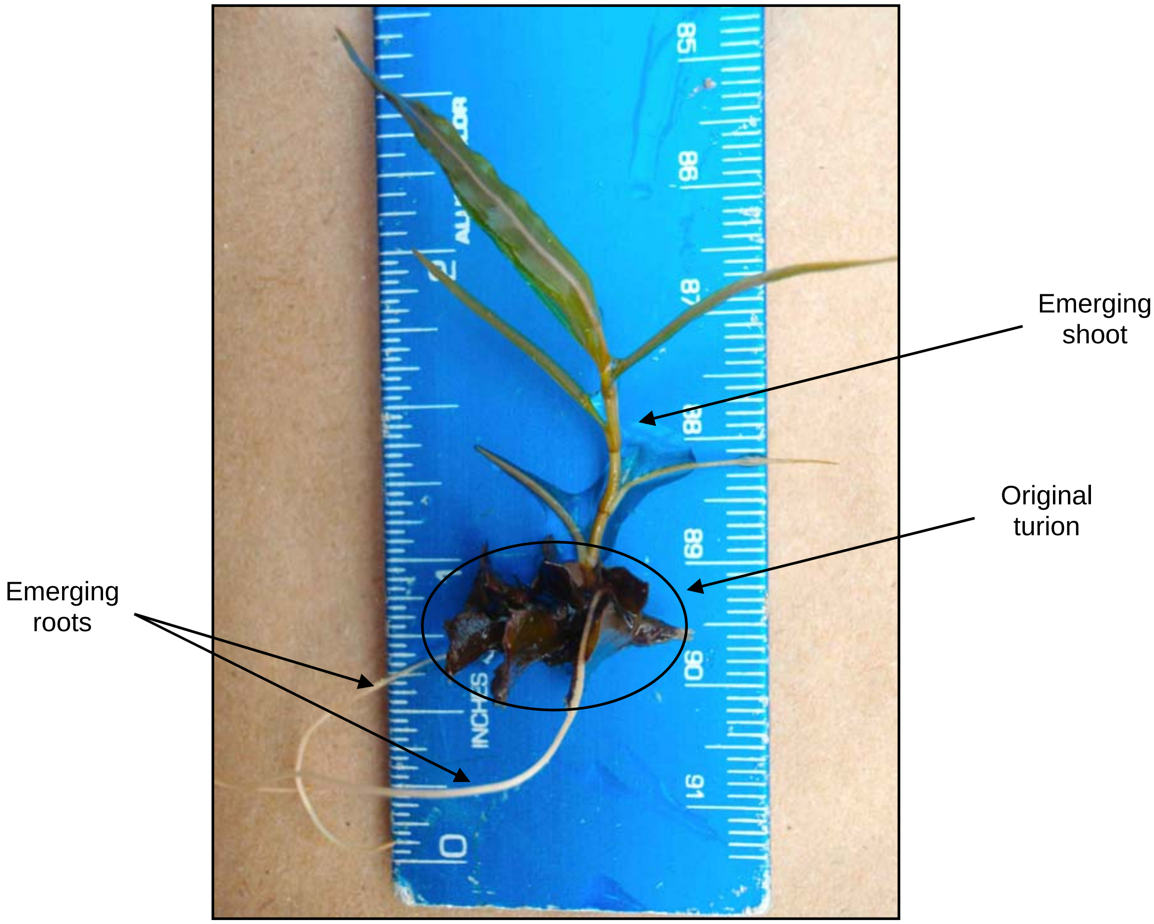


Figure 9.29. Curlyleaf pondweed turion sprouted in incubator 45 days after collection from Lake Solano. Image shown was taken 7 days after start of sprouting.

Figure 9.30. Aquamarine H5-130 Harvester. Photos of October 16, 2008.

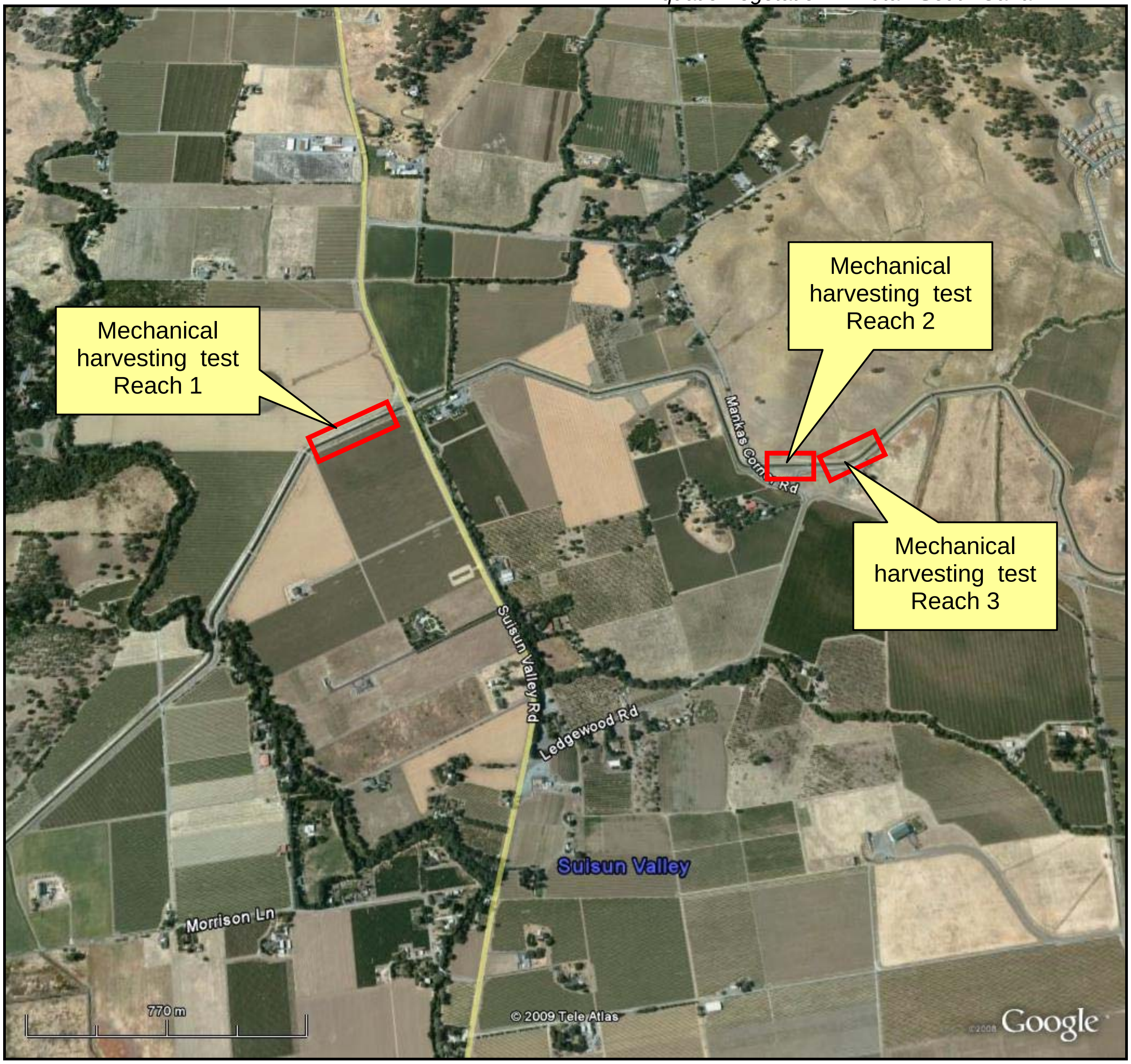


Figure 9.31. Location of mechanical harvesting test reaches.

Figure 9.32. Fragments and turbidity booms in Reach 1. Flow right to left. Photo of October 16, 2008.

Figure 9.33. Aquatic plant harvesting in Reach 1. View downstream. Photo of October 16, 2008.

Figure 9.34. Turbidity boom in Reach 2. View upstream. Photo of October 16, 2008.

Figure 9.35. Cutting vegetation and pushing sediment in Reach 2. View downstream. Photo of October 16, 2008.

Figure 9.36. Moving harvester into Reach 3. View upstream. Photo of October 16, 2008.

Figure 9.37. Harvesting in Reach 3. View downstream. Photo of October 16, 2008.

Figure 9.38. YSI 650MDS multimeter.

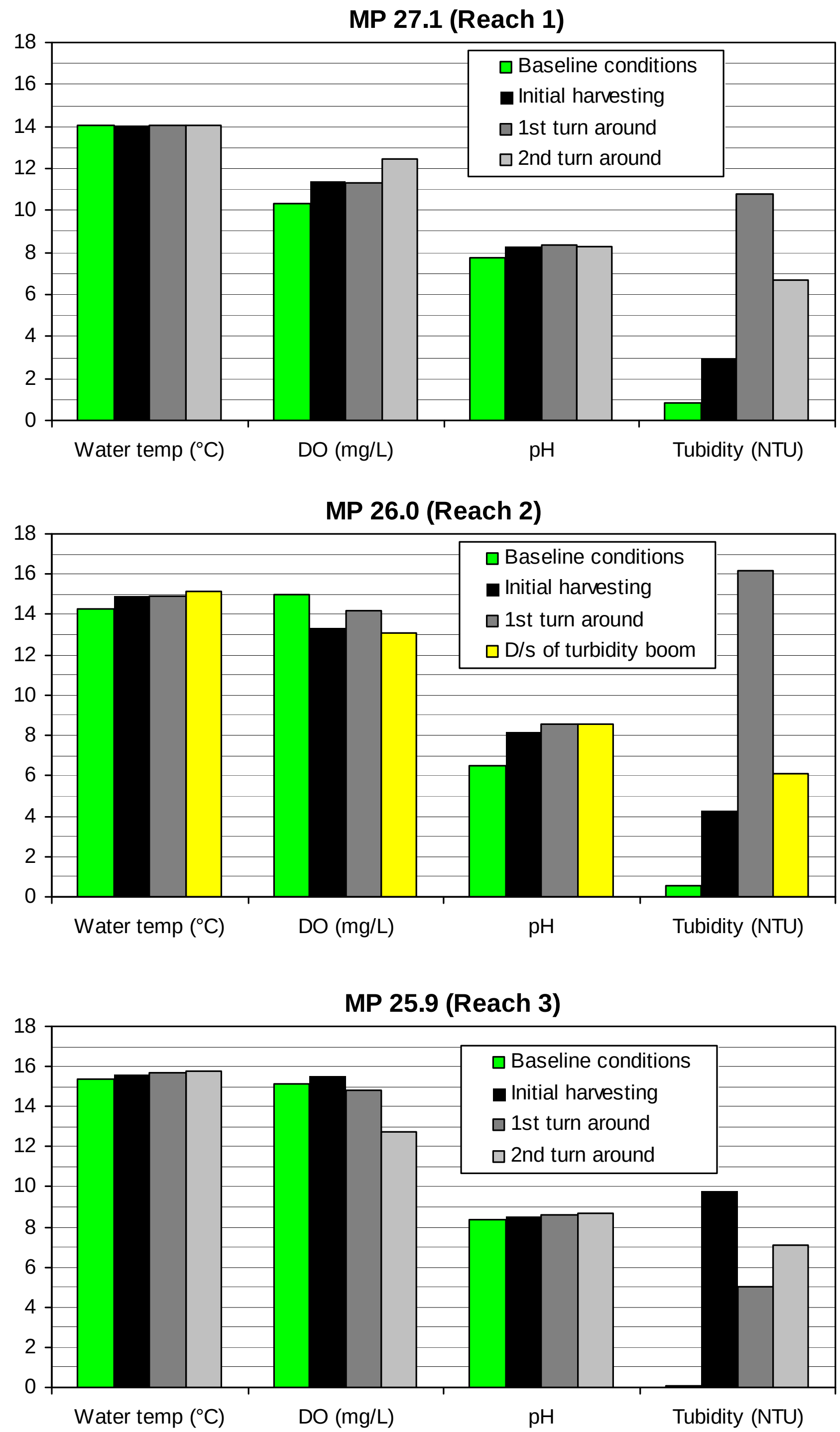


Figure 9.39. Average water quality data measured with YSI 650MDS multimeter during vegetation harvesting pilot test on October 16, 2008.

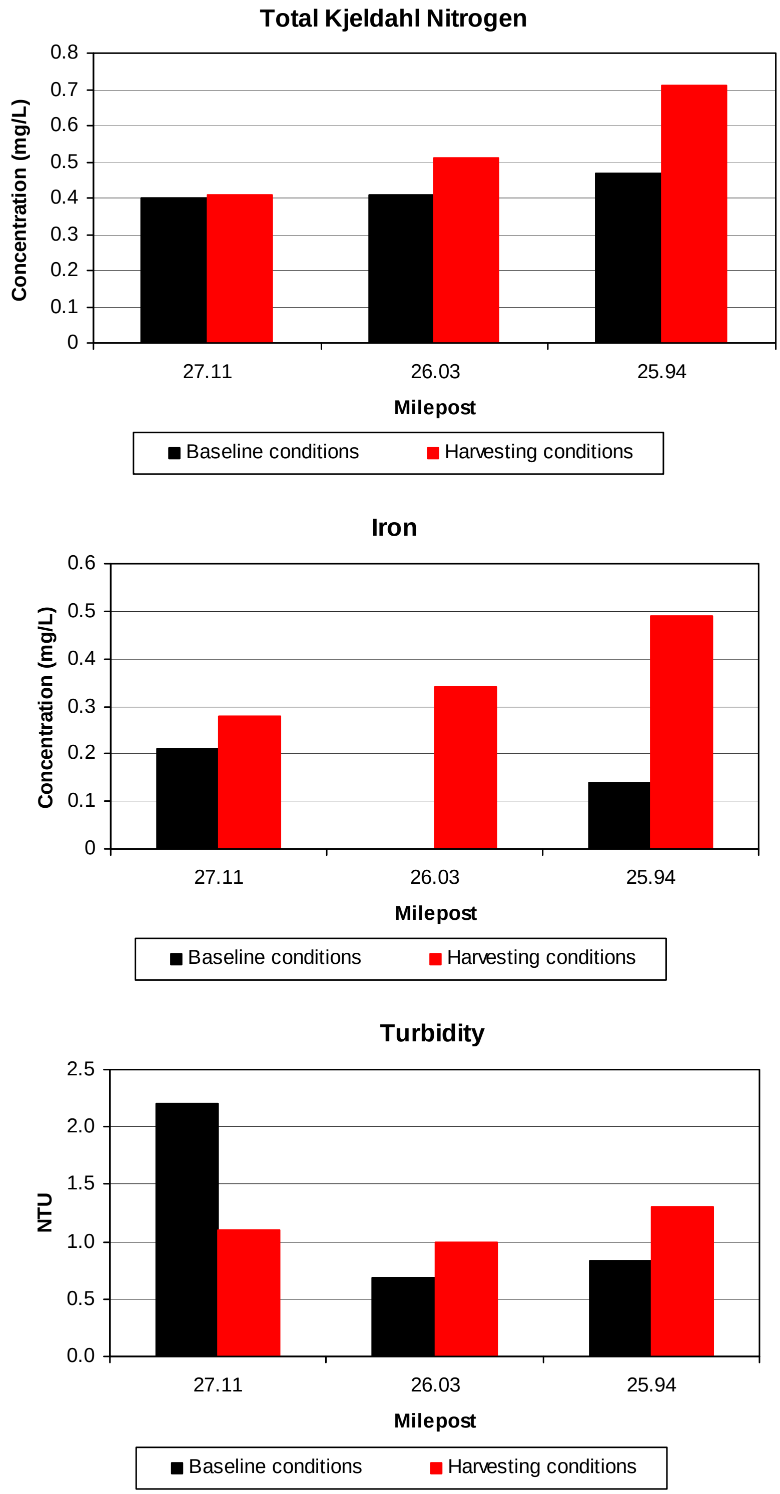
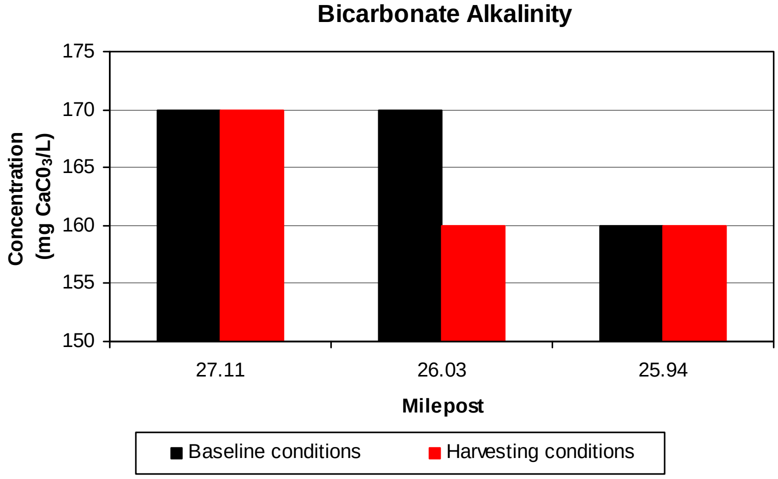
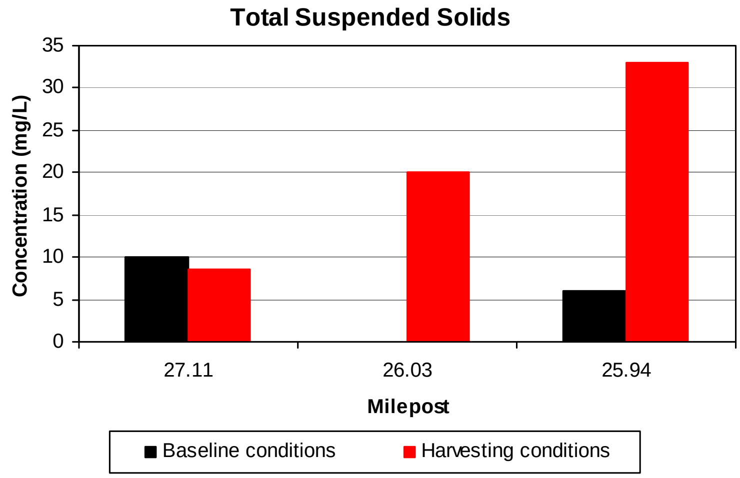


Figure 9.40. Water quality laboratory results for samples collected during vegetation harvesting pilot test on October 16, 2008.





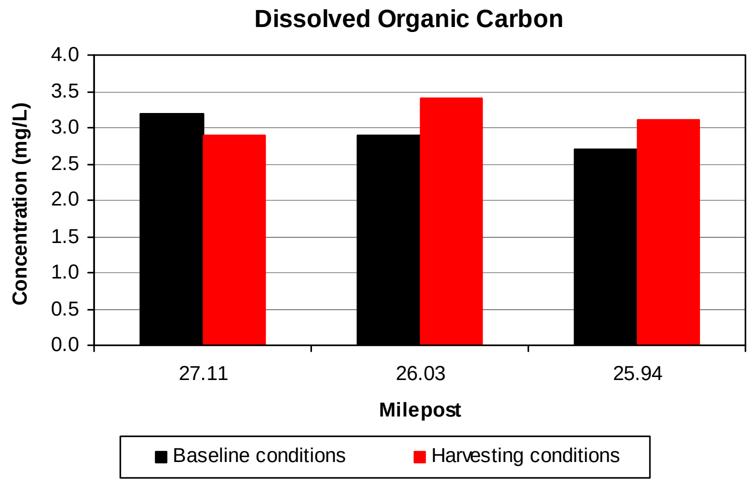


Figure 9.40. (continued).

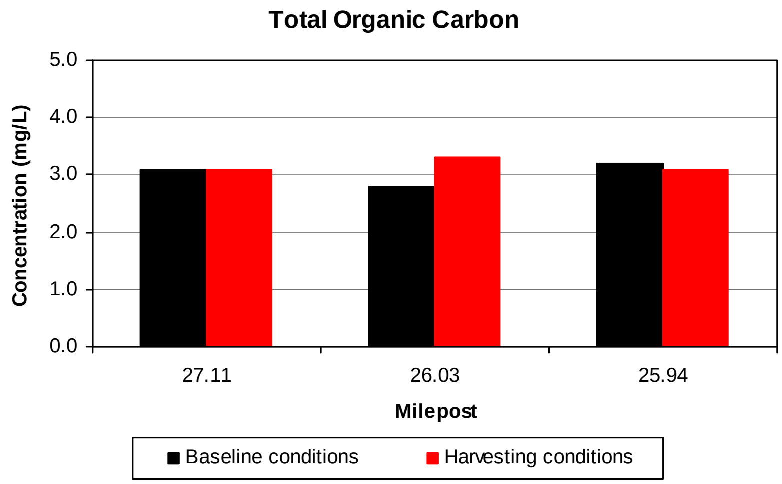
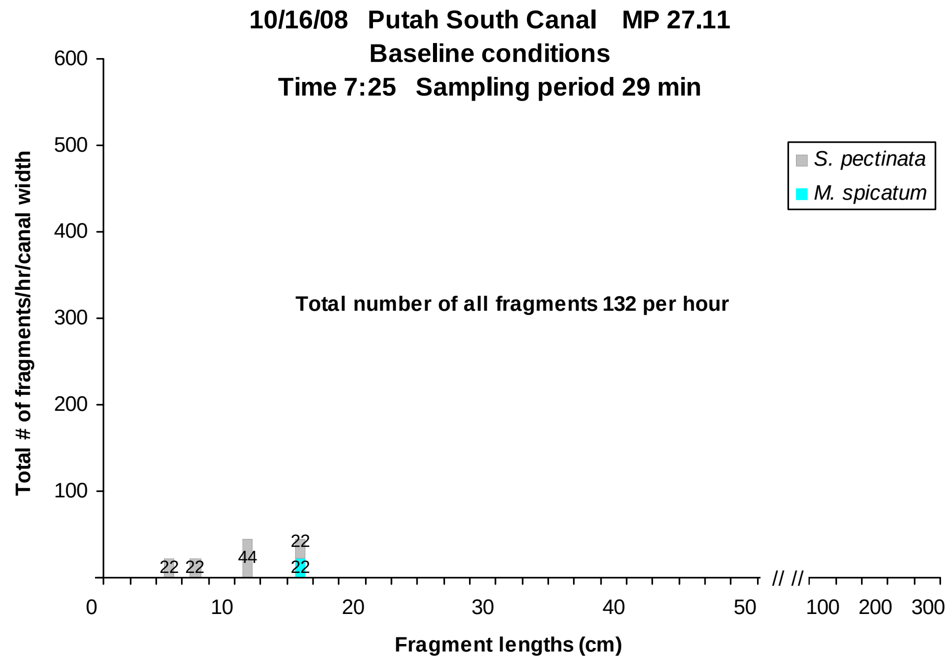


Figure 9.40. (continued).

Figure 9.41. Vegetation netting in Reach 1. Flow right to left. Photo of October 16, 2008.

Figure 9.42. Vegetation netting in Reach 2. View downstream. Photo of October 16, 2008.



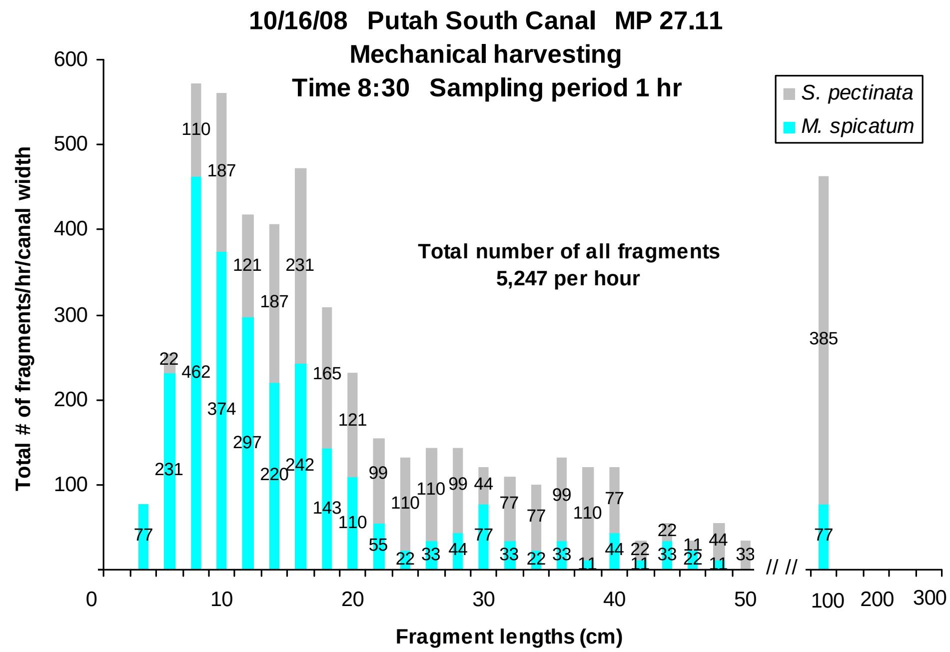
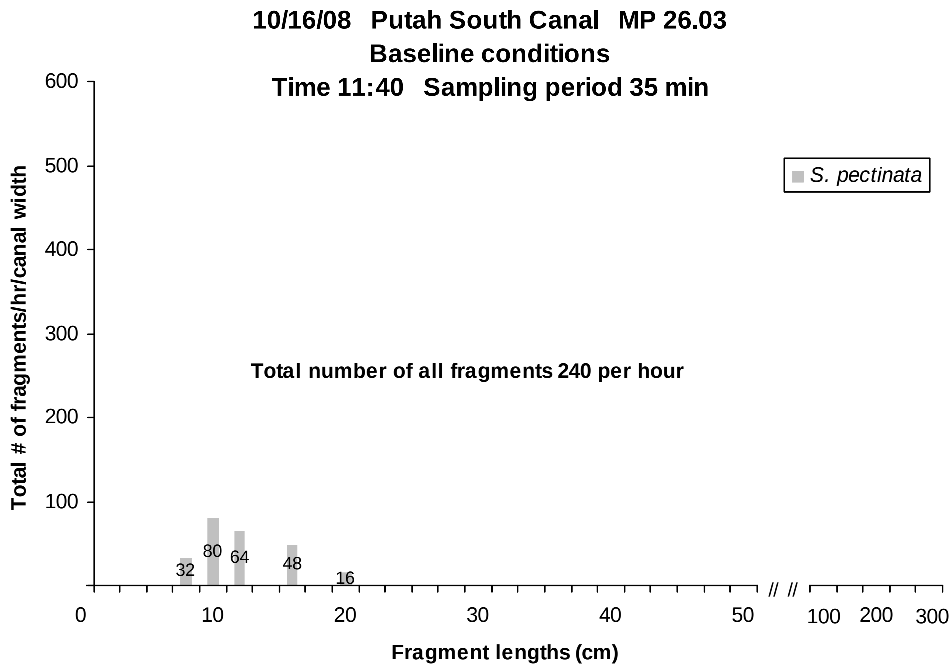


Figure 9.43. Total vegetation influx measured at MP 27.11 (Reach 1) on October 16, 2008 before and during vegetation harvesting.



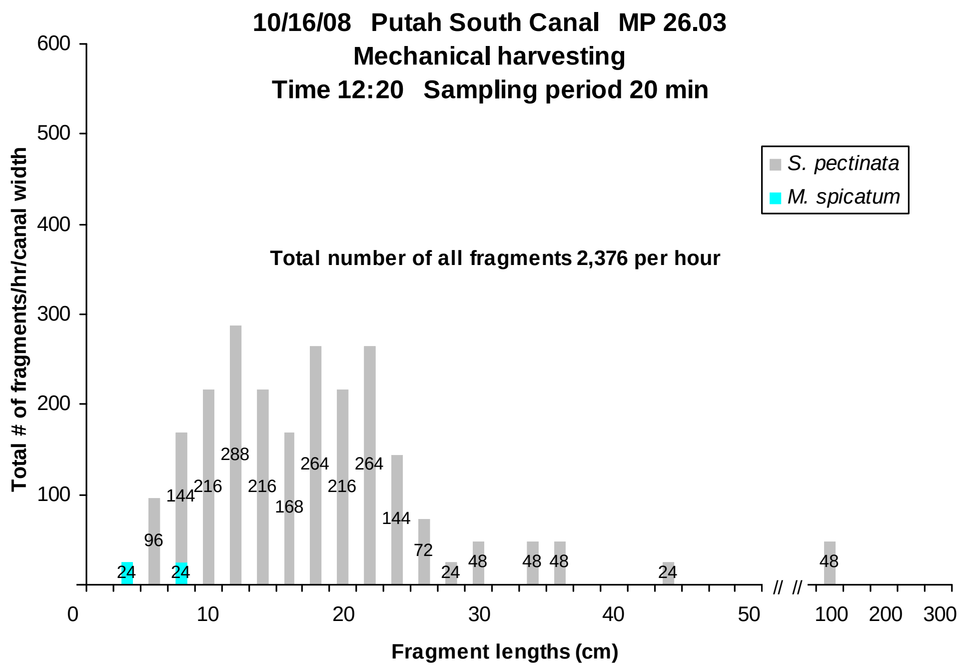


Figure 9.44. Total vegetation influx measured at MP 26.03 (Reach 2) on October 16, 2008 before and during vegetation harvesting.

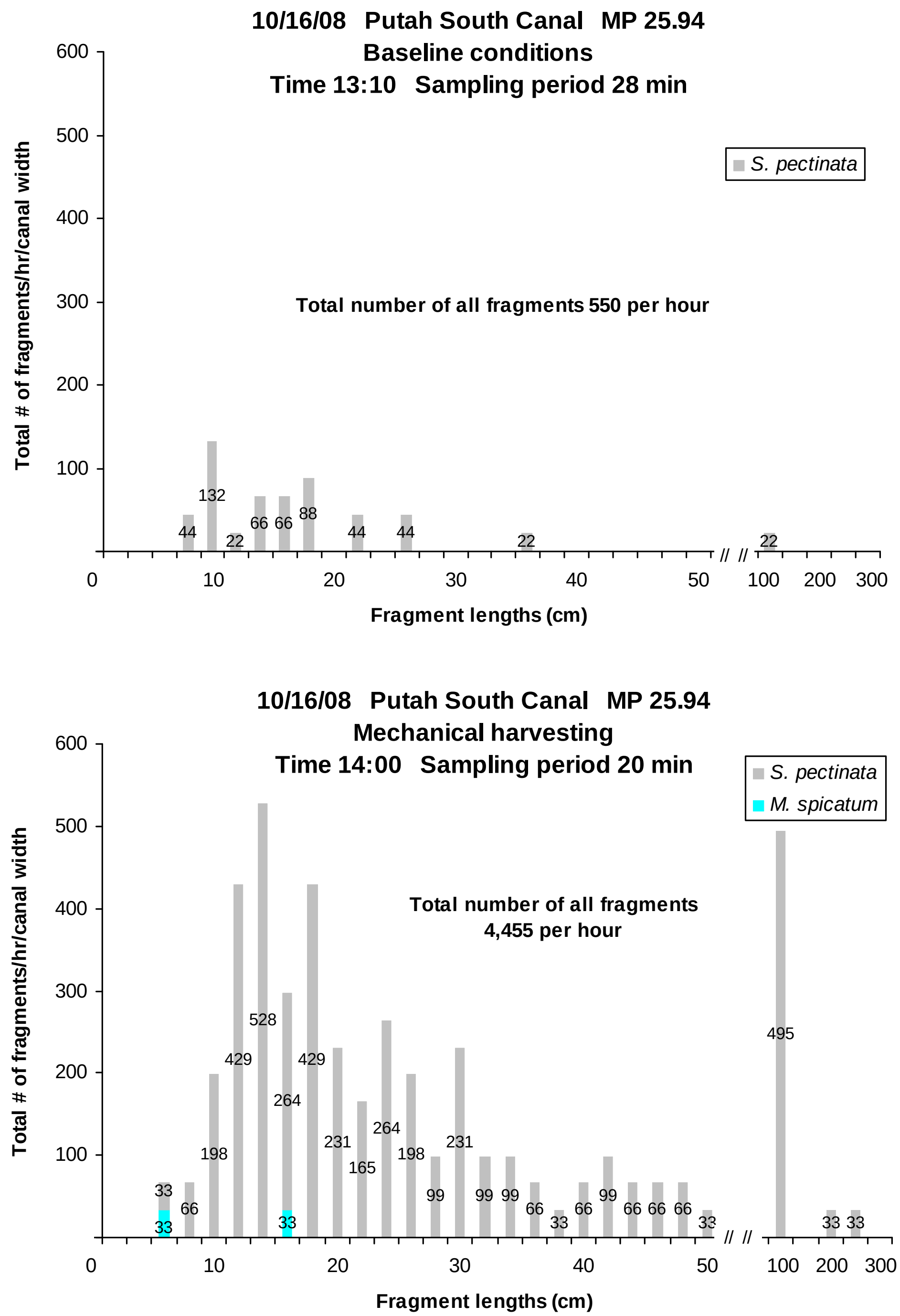


Figure 9.45. Total vegetation influx measured at MP 25.94 (Reach 3) on October 16, 2008 before and during vegetation harvesting.

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10. Issues Related to Water Quality and Water User Concerns

10.1. Background

The objective of this chapter is to summarize issues and findings related to water quality and to discuss how sediment inputs into the canal, along with the growth of aquatic vegetation is possibly creating water quality and water treatment issues for several of the WTPs served by the PSC. WTPs reported that they experience their most significant water quality and water treatment issues during the annual canal cleanout operations in the fall when their water supply from the canal is interrupted and water treatment costs increase during cleanout activities. Additional water quality and water treatment associated problems occur during heavy winter storms when large pulses of highly turbid waters occasionally enter the canal from the Headworks or from lateral sources. Also during the spring and summer irrigation season, Solano Project operators frequently apply copper sulfate at different locations along the canal to reduce the growth of algae. During chemical treatments, water treatment plants may have to temporarily bypass PSC water and/or shut down their treatment plants in order to let canal water with high concentrations of copper sulfate pass their intakes. This interrupts their water supply and water treatment schedules.

Most problems associated with interruptions to WTPs water supply and water quality treatment problems ultimately arise because the plants may not have an alternate source of acceptable raw water or sufficient storage in their systems to survive during source interruptions greater than 24 hours at a time. If sufficient additional storage were available to all of the WTPs, they could temporarily bypass the PSC as a water source during periods when the water quality is unacceptable. Provision of temporary alternate sources of raw water would also extend the period of time that the Headworks could remain closed in the winter during periods when highly turbid water is passing down Putah Creek. This chapter deals only with water quality issues arising within the PSC. Details related to plant capacities and storage restrictions of the individual WTPs is not included. Also, detailed analyses were not performed regarding specific causes of water quality and water treatment issues related to the chemical characteristics of raw water entering the canal, such as low alkalinity concentrations during prolonged rainy periods.

As part of this project, interviews were conducted with operators at all of the WTPs served by the PSC. Results of these interviews are presented in Appendix E-10.1. A questionnaire and list of discussion topics were prepared and sent to all of WTP operators that rely on PSC water for a portion or all of their annual water supply. Telephone and on-site interviews were also conducted with most of the operators to discuss topics listed in the questionnaire. These interviews indicated that the most significant water supply and water quality treatment problems experienced by the WTPs are associated with interruption to their water supply and very poor water quality during and immediately following the annual canal clean-out activities. These problems were particularly acute during the fall 2007 cleanout (see SCWA memo in Appendix

E-10.2). As a result, 12 canal water samples were collected by NHC on November 19, 2007 in the Serpas, Burton, and McCoy Checks during active cleanout activities in the canal (see NHC memo in Appendix E-10.3). The SCWA analyzed the samples collected by NHC for a number of water quality constituents and summarized the results from their laboratory analyses in a report presented in Appendix E-10.4. Earlier characterizations of water quality issues were provided by Archibald and Starr (2006). The following sections summarize key results from the above documents to provide a short, integrated perspective on water quality issues using excerpts from the above-stated reports where appropriate.

10.2. Water Quality Issues Reported by Water Users

Water quality issues reported by PSC water users vary seasonally as shown in Table 10.1. A general characterization, especially for those WTPs that rely exclusively on the PSC for their source for water supply, is that water quality is acceptable for 9-10 months out of the year and that the highest levels of turbidity (and low water quality) are associated with periodic short-duration events, such as intense storm events, or during or immediately after canal cleanout operations in the fall. However, most of the time raw water supply provided by the PSC is of high water quality and is typically of no concern to the WTPs. Water supply interruptions do, however, create difficulties for water treatment operators as well as Solano Project operators.

Not all of the water quality issues listed in Table 10.1 can be practically addressed since they reflect normal, large-scale watershed processes related to the regional geology, soils, topography, and vegetation within the Berryessa and Pleasants Valley watersheds which are outside the SCWA's or Solano Project operators control. Examples of such issues include high Dissolved Organic Carbon (DOC) levels at the start of the runoff season, low alkalinity during spring following high runoff events, or problems associated with source switching or blending with other raw water sources having different water quality characteristics.

During significant storm events large increases in turbidity can occur. In general, short term turbidity spikes of less than 200 NTUs do not pose a problem for the WTPs. However, turbidity levels significantly greater than 500 to 1,500 NTUs have been observed. The WTPs have varying capacities to treat highly turbid water because of different treatment processes. For example, turbidities in excess of 200 NTUs begin to pose difficulties at the Waterman WTP and they may need to shut down their water intake, whereas turbidities of up to 1,800 NTUs can be accommodated at the Cement Hill WTP. However, in both cases, treatment costs increase significantly.

During typical winter and spring runoff conditions, the occurrence of turbidity spikes does not always result in the need to shut down inflows from the PSC. Even if exceptionally high turbidities necessitated a shut down, water demand during the winter is at its annual low point such that the finished water in storage can usually meet demand for a much longer period of time (24 to 48 hours) than during fall cleanout (maximum 24 hours).

The WTPs have the capacity to "look ahead" to discern if a turbidity spike is approaching their intakes in the canal. Both the real-time SCWA turbidity data and communication between Solano Project operators and WTP operators provides a warning of when high turbidities may reach a given WTP. At the Waterman WTP, the typical lag time between entry of highly turbid water to the Headworks and its arrival at the water intake to the plant is typically about 4 days. In general, locally generated increases in turbidity from lateral inflows during storms tends to be minor, up to 40 NTUs (unless the storm is extreme) in comparison with the turbidity of influent water into the canal at the Headworks or from surface water overflows during flood events that enter directly into the canal.

10.3. Water Quality Issues Associated with Fall Cleanout

In general, the fall cleanout operations generate the greatest scheduling challenges for WTP operators and Solano Project operators as well as the greatest water treatment problems and costs for the WTPs, particularly at the Waterman and Cement Hill WTPs that rely exclusively on PSC water for their supply. To determine the impact of cleanout activities on water quality characteristics, NHC collected 12 water samples along the McCoy, Burton, Serpas, and Mankas Checks on November 19, 2007 and 5 water samples along the Alamo, Union, Burton, and Serpas Checks between October 27, 2008 and November 10, 2008. Figure 10.1 shows samples of exceptionally turbid and poor quality water remaining in the canal at the conclusion of mechanical cleanout activities in the fall of 2007. The fall 2007 samples were analyzed in two sets; one set of analyses was conducted on the raw sample and a second set of the same analyses was conducted on the relatively clear supernatant from samples that were allowed to settle for a period of 24 hours. The SCWA summarized the results from their laboratory analyses of the samples in a report issued on January 23, 2008 (see Appendix E-10.4). Table 10.2 lists the maximum concentrations of the major water quality constituents determined during laboratory analyses of canal water samples collected during cleanout. Drinking water standards are also shown in this table for comparison. While the values listed in Table 10.2 represent the worst water quality conditions from the samples collected, they aptly demonstrate the severity of the problems facing WTPs who attempt to avoid taking these sludge-like materials into their plants during and for some time following cleanout operations. Appendix E-10.5 provides a summary of the major water quality findings reported by the SCWA during the May 1, 2008 Project Check Point Meeting in Vacaville. Table 10.3 presents the major water quality constituents measured for the fall 2008 water samples. The water quality data presented in Tables 10.2 and 10.3 show that PSC cleanout water contains very high concentrations of nutrients, metals, organic carbon as well as high values of color, turbidity, and alkalinity. Without extensive dilution and settling time, the water in the canal during cleanout operations is untreatable.

In general, intake water during and immediately after cleanout requires very high levels of chlorine, which in itself may become an issue as a precursor to the formation of Trihalomethanes (THM). For example, at the Waterman WTP, THMs reached levels approaching 50 μg/L after cleanout in 2007, as opposed to typical concentrations of 4-6 μg/L. At Waterman WTP, it was also found that the chlorine residual in treated water leaving the plant was rapidly consumed, which could be a potential public health issue. The bacteriological quality of intake water during and immediately after cleanout is typically very poor, however, NHC is unaware of any existing Biological Oxygen Demand (BOD) or bacterial analyses on similar water samples. Levels of Dissolved Organic Carbon (DOC) are not exceptionally high, but the levels of chlorine required to obtain the mandated residual are often very high and are disproportionate to the levels of DOC in the influent water. Therefore, it is recommended that samples similar to those collected during the 2007 and 2008 cleanouts be assessed for similar water quality constituents as well as for Dissolved Oxygen (DO), BOD, bacteria and other microorganisms.

Another key issue is that the canal sludge contains a very high load of decomposing organic material which creates anoxic conditions. After cleanout, influent water can have a black color, strong odor and taste, and elevated levels of hydrogen sulfide. It is also possible that anaerobic conditions within the canal bottom sediments results in the reduction and dissolution of metals which are then mixed into the water column once the canal is refilled. For example, a sample taken after the canal was refilled on November 9, 2006 at the NBR WTP by Laura Albidress had concentrations of 72.4 mg/L of iron, 1.6 mg/L of manganese, and 0.43 mg/L of copper. These levels exceed the secondary drinking water maximum contaminant levels (MCLs) for iron and manganese. Typical PSC concentrations are less than 1.0 mg/L for iron and are non-detectable for manganese and copper. High levels of soluble multivalent cations of iron and manganese, which are in reduced form, are highly effective at combining with reactive chlorine species. Weekly laboratory sheets provided by the Waterman WTP during the 2006 cleanout period showed a significant jump in chlorine doses when manganese concentrations increased over 1.0 mg/L.

10.4. Trends

Water quality during and immediately following cleanout is becoming progressively worse. NBR WTP reports that prior to 2004, there was no need for high levels of chlorination at NBR and Waterman WTPs. Waterman, Cement Hill and NBR WTPs all report a very serious upward trend in THMs during cleanout without any commensurate upward trend in DOC. Upward trends in dissolved iron and manganese have been noted, and increased black color, hydrogen sulfide, and odor also appear to be taking place. Cement Hill and Waterman WTPs, which rely exclusively on PSC water, are having the greatest difficulties in dealing with high levels of black color, turbidity, objectionable odor, and high THM formation.

There may be a relationship between a trend in increasing duration and severity of anoxic residual water conditions and increasing levels of THMs during the cleanout period that is associated with Solano Project operators discontinuation of the canal wasteways and what is likely to be a “carryover” load of organic detritus that now remains on the bottom in sections of the canal. The fact that DOC levels have not been increasing may be associated with different forms or species of carbon associated with anaerobic decomposition that have a greater affinity for THM formation than do the typical DOC species (associated with aerobic decomposition) entering the canal at the Headworks.

Fine bottom sediments, along with live, dead, and decaying aquatic algae and macrophytes combine to form a black floc and sludge with sufficient density to generally remain on the bottom of the canal. However, during cleanout, three sections (checks) of the canal are drained (partially drained) at a time to allow equipment access into the canal to mechanically remove accumulated sediments and organic detritus from the upstream most section that is drained in the canal. However, checks cannot be totally drained and this process typically leaves up to one foot or more of water in the check being cleaned. This relatively large remaining volume, in combination with its high concentrations of relatively low density sludge-like material results in a situation where mechanical cleaning merely stirs the majority of the biological materials and blends these fine anoxic black floc-like materials with fine sediments. However, very little of this material is removed during the cleanout because it is essentially a fluid slurry and cannot be removed mechanically. Because the wasteways are no longer utilized, this material remains in the canal and is increased each year with the introduction of additional fine sediment and the creation of additional biomass. These residual materials are likely to be comprised of organic materials, fine sediments, and mixed populations of biological microorganisms. Field evidence suggests that over time these anoxic fluid-sludge like deposits may continue to accumulate, and could eventually reach levels where the thickness and concentrations of these residual materials are such that they begin to become drawn into the WTPs during high water demand periods with canal flows that are sufficient to re-suspend these materials into the water column.

10.5. Relationships Between Sediment and Aquatic Vegetation

While the presence of the anoxic black floc is a direct result of the growth and decay of aquatic vegetation, there is a close linkage between the introduction of sediment into the canal and the volume of aquatic biomass capable of being produced each year. Figure 10.2 illustrates the primary sources and relationships between sediment and vegetation in the canal. Deposited sediments encourage the growth of aquatic vegetation, 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 are sources of hydrogen sulfide and other odor-causing and water quality treatment problems, especially during annual canal cleanout operations. Thick growth of aquatic vegetation can reduce water treatment plant intake efficiency and lead to increased maintenance and water treatment needs. This situation occurs frequently at the Waterman WTP's Intake that is located just upstream from the Serpas Check structure (Figure 10.3).

10.6. Increasing Challenges for Water Treatment Plants and Solano Project Operators

Following is a list of the primary challenges for WTP operators during the fall: (1) WTPs must meet increasing public demands for potable water, especially during warm weather periods; (2) they have to periodically treat raw water from the PSC for poor water quality, especially during and after canal cleanout; and (3) they need to manage supply and demand during periods of interrupted supply during canal cleanout. Primary challenges for Solano Project operators include: (1) increasing regulatory constraints placed on how canal cleanout and vegetation management operations can be performed; (2) there are now internal policies against using wasteways along the PSC to sluice residual sediment deposits from the canal during cleanout operations; (3) extremely low canal gradients and flow velocities severely limit Solano Project operators' ability to drain and clean the canal rapidly and completely; (4) limited water storage capacity available to WTPs to survive periods of plant shut-downs and increasing demand for urban water supply limits the amount of time treatment plants can be off-line during canal cleanout, which makes canal cleanout more difficult and costly to perform; and (5) options for the chemical treatment of aquatic vegetation are becoming more limited and perhaps less effective. This gives rise to the need to more frequently re-water sections of canal that are being cleaned or drained in order to supply downstream water users, such that cleaning can be done only for short periods of time between individual checks. This, in turn, makes the logistics of both the canal cleanout and WTP operations especially complicated. Solano Project operators and WTP operators work very well together to coordinate canal cleanout operations; however, trends are showing that it is becoming more difficult and time consuming each fall to complete canal cleanout which places a bigger burden (time-wise and budget-wise) on both parties.

10.7. Initial Laboratory Polymer Testing for Settling Sediment

The main purpose of this laboratory test was to investigate whether application of environmentally acceptable polymers (flocculation settling agents) can reduce turbidity and accelerate settling of suspended sediments in the canal during winter storm events and enhance coagulation of fine sediment deposits and organic bio-materials (sludge and decomposing aquatic vegetation) for more effective mechanical removal during annual cleanout operations. The test was conducted by Applied Polymer Systems Inc. (APS) in their laboratory in Atlanta, Georgia. NHC provided APS with samples of water and sediment deposits collected from Pleasants Creek (at Putah Creek Road) and from the PSC (in Sweeney Check) in the fall of 2008. Pleasants Creek is the major source of sediment in Lake Solano and ultimately in the PSC. The bed material sample from the creek was mainly composed of silt and clay and represented the type of sediment that enters the PSC at the Headworks during winter storms. The sediment sample from the PSC was composed of the fine, black, organic material that can be found in many locations along the canal. All the water and sediment samples were combined and thoroughly mixed to recreate the worst case water conditions in the canal. This composite water-sediment mixture is shown in Figure 10.4. A few blends of polymers (polyacrylamides) were tested to determine which one is the most effective flocculent for PSC water and sediments. The blends testes were Floc Log formulas 707a, 706b, 702b, and 703d#3. The results of these tests are compared in Figure 10.5.

According to the APS's laboratory analyses, the most effective formula for the PSC sediments was 703d#3. Of the products tested, this formula provided the best flocculation and chelation of the PSC's fine mucky sediments. While solidifying the slurry composite sediments, there were also significant reductions in turbidity and phosphates (PO_4^{-3}). The initial water quality parameters for the composite PSC water-sediment slurry were:

Turbidity = 159 NTU, pH = 7.12, hardness = 425 ppm ($CaCO_3$), and PO_4^{-3} = 128 ppm.

After applying the 703d#3 Floc Log formula to the slurry, with a reaction time of 15-30 sec, the levels of turbidity and phosphates were:

Turbidity = 61.5 NTU (a 61% reduction), PO_4^{-3} = 1.7 ppm (a 99% reduction).

These results indicate that proper application of the 703d#3 Floc Log formula in the PSC has potential significant benefits. First, reduction in turbidity would reduce the needs for WTPs shut downs during winter storms and canal cleanout activities. Second, the reduction in phosphates could create phosphorus starved conditions. Since phosphorus is an essential nutrient used by plants to convert light energy to chemical energy during photosynthesis and is important for plant growth, starving (or stripping) the system of phosphorus may reduce the growth of aquatic weeds in the canal.

Use of National Sanitation Foundation (NSF) approved polymers in water and wastewater treatment processes is very common in California and throughout the Sacramento Valley. However, in order to use the selected polymer in the PSC, it is necessary that the selected product complies with Federal (NSF and EPA) and State of California Regional Water Quality Control Board (CRWQCB) standards. Testing procedures required to meet Federal and state regulations on polyacrylamide products are clear. Regulations are focused towards minimizing the acrylamide monomer. For every application of polyacrylamide products there is some residual acrylamide that is left in the system after the reaction has taken place. Acrylamide is a carcinogen and a neurotoxin affecting the nervous system and blood as well as increasing the risk of getting cancer to people with long term exposure. Because of this fact, acrylamide is mandated by the EPA as a primary drinking water standard and by the California Safe Drinking Water Act (Proposition 65). As stated under federal and state law "a public water system which uses acrylamide in drinking water shall certify annually to the Department that the concentration of monomer does not exceed 0.05% monomer in polyacrylamide dosed at 1 mg/L or equivalent." The 703d#3 Floc Log formula contains two polymers. The first polymer is 35.34% by weight with the acrylamide content at 0.0184%. The second polymer is 4.42% by weight with the acrylamide content at 0.023%. The remainder of the materials are additives to assist flocculation and water clarity. These additives are not toxic according to APS. According to APS, if dosed correctly neither of the two polymers contained in the 703d#3 Floc Log formula would exceed Proposition 65 or EPA (0.05% residual acrylamide) requirements.

10.8. Bench Scale Polymer Application Tests

The purpose of the bench scale tests performed by NHC was to further test the effectiveness of using polymers to enhance settling of PSC sediments (bottom sludge materials). Another goal of the tests was to determine if polymers will also increase the bulk density of settled materials and possibly improve materials handling characteristics. Initial laboratory testing by Applied Polymers Systems Inc. (APS) in 2008 determined that the Floc Log polymer formula 703d#3 was ideal for use with sediments and sludges found in the PSC (this is described in the previous section). The 703d#3 polymer formula was used to conduct the following two tests. The first test was a turbidity and suspended sediment reduction test designed to determine if polymers can significantly reduce the settling time of PSC bottom sludge and sediment mixtures and improve water clarity. The second test was designed to determine and compare the bulk densities of the settled materials for the settled control sample (no polymers) and the settled test samples (after adding the formula 703d#3 polymers). This test was conducted to determine if polymers can increase the bulk density of settled materials and to allow the material to be removed by mechanical means.

10.8.1. Methods

NHC collected bottom sludge materials and water from the PSC at milepost (MP) 13.55 just upstream of the Alamo Check in front of the old wasteway on June 17, 2009 (see Figure 10.6). This sampling site was suggested by Stan Walker of SID because it is one of the most difficult canal sections to clean each fall. Bottom sludge and sediment materials were collected from the canal by using a scoop bucket attached to a long pole (see Figure 10.6.). The materials were placed in a sealed 10-gallon container and transported in an ice chest back to NHC's laboratory for testing.

NHC prepared laboratory equipment and apparatus to test the effects that the polymer would have on PSC sediment settling rates and water clarification (Figure 10.7). A total of seven sediment settling tests were conducted. For each of the seven tests, 30 grams of PSC bottom materials were added to seven 500 mL beakers which were then filled with PSC water to a total volume of 350 mL in each beaker. One beaker sample was used as a control (no polymers added) and the remaining six beakers were used to test the effectiveness of adding the prescribed dose of polymer compound 703d#3 as recommended by APS. The prepared samples were thoroughly mixed on a laboratory mixing table until all of the sludge and sediments materials were in suspension. Initial turbidity readings were recorded at half the depth for each sample. For each of the samples in the polymer test group, 2 grams of the 703d#3 Floc Log material were then added and the contents were remixed. The control and polymer test mixtures were then set aside and allowed to settle. During the settling period, turbidity was recorded every 30 seconds for the control sample and every 10 seconds for the polymer test samples. After the settling tests were completed, the water and materials in the control beaker and the supernatant from each of the polymer test samples were bottled and delivered to Sunland Analytical Lab in Rancho Cordova, CA for suspended sediment analyses.

Five gallons of PSC water and an appropriate dose of the 703d#3 formula were added to the remaining sediment materials in a 10 gallon bucket. The mixture was thoroughly mixed to allow contact and reaction of the polymers. A similar control bucket sample was prepared with no polymers added. Both the control bucket and the polymer-aided bucket were also taken to Sunland Analytical Lab for bulk density testing of the settled materials.

10.8.2. Results

Time series photographs of the control and test group settling rates are shown in Figures 10.8 and 10.9 respectively. The supernatant (clear water) in the polymer test beakers became clear after approximately 30 to 60 seconds while the supernatant from the control group still appeared to be very turbid after 600 seconds of settling. For the control sample, turbidity readings reduced from an initial 1,200 NTUs to 80 NTUs after 600 seconds (10 minutes). For all six polymer tests, turbidity significantly reduced from an initial approximately 1,200 NTUs down to 2 to 7 NTUs (by approximately 99.5%) after 120 seconds (2 minutes) or less. In five of the six test samples, turbidity was reduced to less than 10 NTU in less then 30 seconds. Figure 10.10 shows a summary of the turbidity measurements.

Laboratory results from the suspended sediment and bulk density tests are summarized in Tables 10.4 and 10.5, respectively. The initial suspended sediment concentration for the control sample was 8,800 mg/L. The average of the initial sediment concentrations for all six polymer test samples was similar to the control sample (on the order of 8,000 mg/L). However, the sediment concentrations in all six polymer tests dropped rapidly to an average of 30 mg/L (by about 99.5%) in less than 2 minutes. Therefore, all of the polymer tests achieved more than two orders of magnitude reduction in total suspended solids (TSS) in less than 2 minutes. Bulk density results indicated that the density of the settled materials increased by approximately 50% with the application of polymers relative to the control sample.

Given that NSF approved polymers are used commonly in potable water treatment processes throughout California and that the test results herein demonstrate how well polymers improve settling, water clarification and increase the bulk density of settled materials, NHC recommends that a field scale polymer aided settling and sludge thickening pilot study be considered during this fall's cleanout period. NHC recommends that SCWA test the applicability of commercially available portable sludge separators and polymer-aided sludge separators this fall. Figure 10.11 shows an example of a potable polymer-aided sludge thickening device that could possibly be used to test the effectiveness of portable sludge enhancement equipment to improve canal cleanout effectiveness.

10.9. Summary

Following is a summary of results obtained to date:

- The periodic occurrence of plumes of highly turbid water passing through the canal is caused by significant winter storm events. Occurrence of these events may cause some WTPs to shut down for short periods of time in order to prevent ingestion of untreatable water. Treatment of high turbidity water increases plant treatment costs. Some PSC WTPs currently use polymers to aid with settling and other treatment processes.

- Aquatic vegetation (living and decayed) is becoming a significant source of water quality problems within the PSC relative to the WTPs.

- Suspended and deposited sediment of all sizes greatly exacerbate water quality problems by increasing water treatment costs and accelerating the growth of algae and aquatic macrophytes.

- Mechanical canal cleaning methods are incapable of removing the fluid-like black floc materials and much of the fine sediments that are the principal source of the water quality problems experienced during cleanout.

- The volume of fluid-like floc and fine bottom deposits (sludge) appears to be increasing each year as a new "crop" of aquatic vegetation is produced, dies, settles to the bottom, and decomposes into other forms of organic bio-mass that may harbor mixed biological populations of microorganisms. Disturbance of these bottom deposits during annual canal clean activities generates a significant decline in water quality in the vicinity of cleanout activities.

- Water quality characteristics of these fluid-like floc materials are very poor and are leading to increased annual canal cleanout and water treatment costs.

- Polymers are commonly used in water and wastewater treatment plants throughout California and are commonly applied during potable water treatment processes. The Waterman and NBR WTPs use polymers in their water treatment processes. There are numerous NSF approved polymers that are acceptable for use in potable water supply treatment processes.

- Polymers accelerate settling of suspended materials and help reduce concentrations of other water quality constituents such as nutrients and metals.

- Laboratory experiments conducted to date indicate that use of controlled doses of polymers greatly accelerates settling of suspended sediments and floc-like materials.

- Polymers reduced the total suspended solids concentrations in the tests reported herein by approximately 99.5% (from about 8,000 mg/L to an average of 30 mg/L) in less then 2 minutes.

- Polymers reduced the turbidity of completely mixed PSC water, sludge and sediment mixtures by about 99.5% within 40 to 120 seconds (turbidity was reduced from approximately 1,200 NTUs after mixing to an average of 5 NTUs in less then 120 seconds).

- Polymers also increased the bulk density of settled sediment and sludge materials by approximately 50%.

- The use of polymers in combination with "gravity belt sludge thickening equipment" show good promise as sludge enhancement methods and may provide an alternative for removing and treating the black residual sludge materials left from annual cleanout activities. Full scale long-term applications of such equipment warrant further testing to select appropriate NSF approved polymer compounds, to determine proper dosing rates and to select the most appropriate equipment for the job.

Table 10.1. Summary of significant seasonal and spatial variations in water treatment issues*.

Winter	Spring	Summer	Fall
High turbidity Low alkalinity	High turbidity Low alkalinity	Weed control Copper sulfate treatments High organics High hardness	Cleanout operations Supply interruptions Weed control Copper sulfate treatments High organics High solids High iron and manganese High chlorite demand High treatment costs

* These issues are amplified immediately upstream of canal checks.

Table 10.2. Maximum contaminant concentrations measured from 12 samples collected during fall 2007 canal cleanout (reported in SCWA memo of January 23, 2008).

Contaminant	Raw sample concentration	Supernatant concentration	Drinking water standard
Phosphorus (mg/L)	41	1.9	
Nitrate (mg/L)	0.16	-	10*
Ammonia (mg/L)	7.5	-	
Total Nitrogen (mg/L)	250	-	
Total Kjeldahl Nitrogen (mg/L)	250	6	
Copper (mg/L)	73	0.48	1.3*, 1**
Iron (mg/L)	739	14	0.3**
Manganese (mg/L)	12.2	1.1	0.05**
Mercury (µg/L)	4.6	-	2*
Color (color units)	191,000	-	15**
Turbidity (NTU)	20,600	150	1*
pH	7.8	-	6.5-8.5**
Total Alkalinity (mg $CaC0_3$/L)	1,270	-	
Total Dissolved Solids (mg/L)	420	-	500**
Total Suspended Solids (mg/L)	71,000	-	
Total Organic Carbon (mg/L)	106	5.9	

* Primary drinking water standard; ** Secondary drinking water standard.

Table 10.3. Water quality data for 5 samples collected during fall 2008 cleanout.

Constituent	MP 13.76	MP 14.33	MP 16.85	MP 19.21	MP 22.72	Drinking water standard
Phosphorus (mg/L)	0.77	14	60	1	2	0.005**
Nitrite (mg/L)	ND	ND	ND	ND	ND	1*
Nitrate (mg/L)	ND	ND	ND	ND	ND	10*
Total Nitrogen (mg/L)	6.3	90	63	5.8	12	
Total Kjeldahl Nitrogen (mg/L)	6.3	90	63	5.8	12	
Copper (mg/L)	0.72	10	63	0.83	3.1	1.3*, 1**
Iron (mg/L)	32	470	2200	21	74	0.3**
Manganese (mg/L)	0.63	7.2	33	0.73	1	0.05**
Mercury (µg/L)	ND	ND	8.4	ND	ND	2*
Turbidity (NTU)	27	76	62	50	37	1*
Total Alkalinity (mg $CaC0_3$/L)	160	250	370	160	190	
Bicarbonate Alkalinity (mg $CaC0_3$/L)	160	250	370	160	190	
Carbonate Alkalinity (mg $CaC0_3$/L)	ND	ND	ND	ND	ND	
Hydroxide Alkalinity (mg $CaC0_3$/L)	ND	ND	ND	ND	ND	
Total Dissolved Solids (mg/L)	190	420	500	210	350	500**
Total Suspended Solids (mg/L)	1,300	27,000	98,000	990	2,400	
Dissolved Organic Carbon (mg C/L)	3.4	25	80	5.2	8.2	
Total Organic Carbon (mg C/L)	3.5	20	90	6.2	8.5	

MP = milepost; ND = Not detectable; * Primary drinking water standard; ** Secondary drinking water standard.

Table 10.4. Suspended sediment data prepared by Sunland Analytical Lab from NHC bench scale polymer test samples and one control sample.

Sample	Sample location	Test method	Total suspended solids (mg/L)	
			Initial	Final
Control	Milepost 13.55	SM2540D*	8,800	N/A**
Test 1	Milepost 13.55	SM2540D*	8,000	15
Test 2	Milepost 13.55	SM2540D*	8,000	25
Test 3	Milepost 13.55	SM2540D*	8,000	40
Test 4	Milepost 13.55	SM2540D*	8,000	36
Test 5	Milepost 13.55	SM2540D*	8,000	33
Test 6	Milepost 13.55	SM2540D*	8,000	31

* SM = Standard methods: ** Significant settling was not achieved within testing period.

Table 10.5. Measured bulk densities (control versus test samples) for settled sludge materials from NHC bench scale polymer tests.

Sample	Sample location	Moisture (%)	Bulk density (lb/ft^3)
Control	Milepost 13.55	77	22.4
Test	Milepost 13.55	78	33.4

Figure 10.1. Water samples from Putah South Canal collected near water surface during 2007 cleanout. Sample on the right was just collected; sample on the left had settled for about 30 minutes. Both samples contain high concentrations of organic materials with little or no mineral sediment.

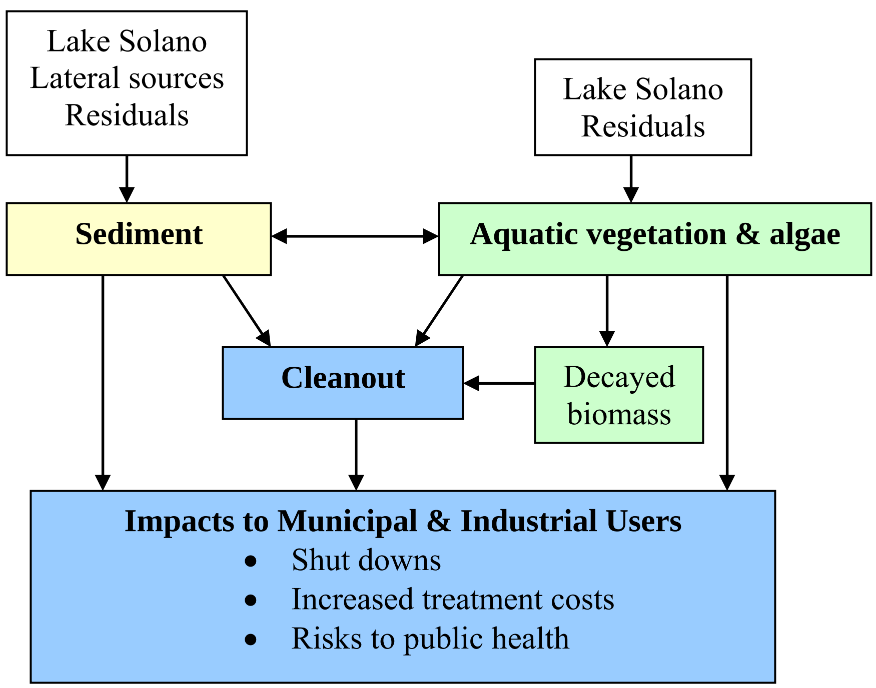


Figure 10.2. Sources and relationships between sediment and aquatic vegetation.

Figure 10.3. Thick growth of algae and macrophytes at intake to Waterman WTP located just upstream of Serpas Check at MP 23.51. View upstream. Photo of November 9, 2006.

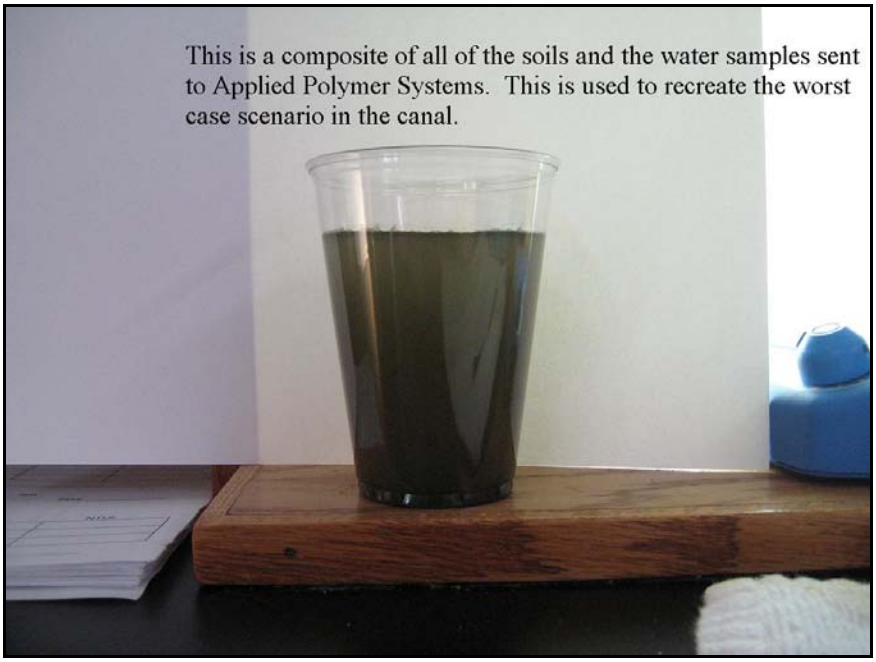
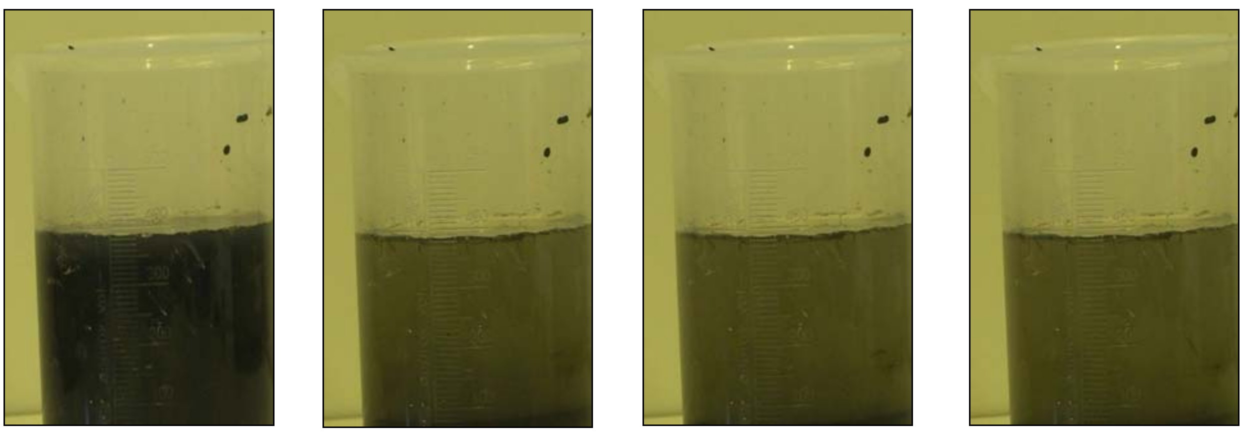


Figure 10.4. Composite water-sediment mixture from Pleasants Creek and Putah South Canal before application of polymers. Initial turbidity is 159 NTU.

Figure 10.5. Composite water-sediment mixture from Pleasants Creek and Putah South Canal after application of four polymer mixtures. Results from formula 703d#3 are shown in the far left of photo.

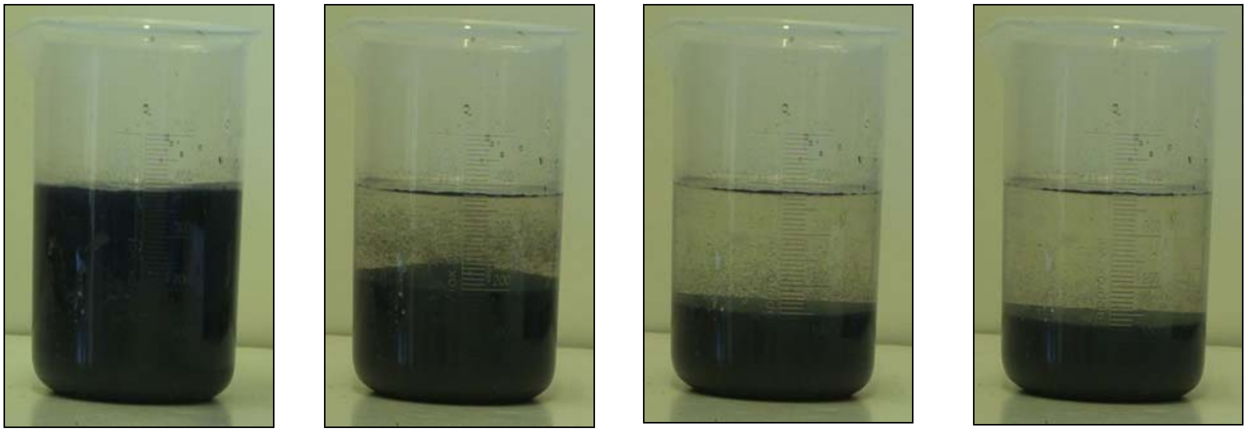
Figure 10.6. Field collection of PSC bottom sediments and sludge materials on June 17, 2009 for use in bench scale polymer application tests.

Figure 10.7. Laboratory set-up for NHC bench scale polymer tests.



t = 0 seconds t = 200 seconds t = 400 seconds t = 600 seconds

Figure 10.8. Time-lapse photos showing settling of control sediment-water sample, with no polymers added. The sample was obtained from Putah South Canal at MP 13.55.



t = 0 seconds t = 20 seconds t = 40 seconds t = 60 seconds

Figure 10.9. Time-lapse photos showing settling of test sediment-water sample, after adding Floc Log formula 703d#3. The sample was obtained from Putah South Canal at MP 13.55.

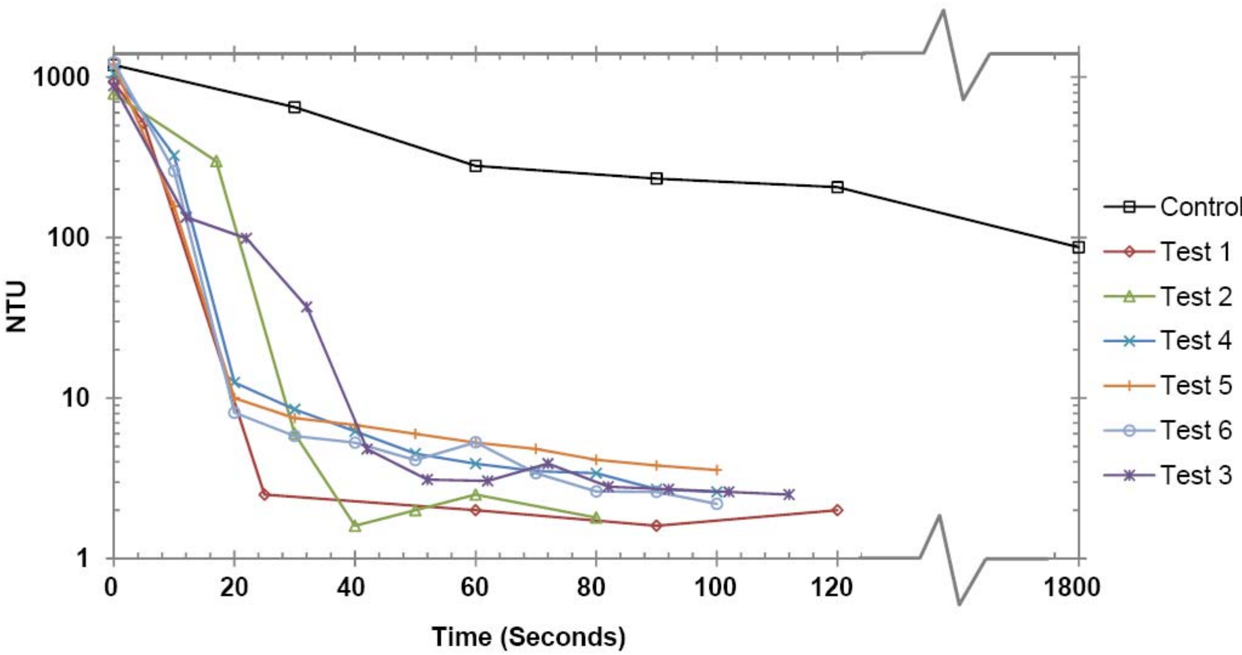
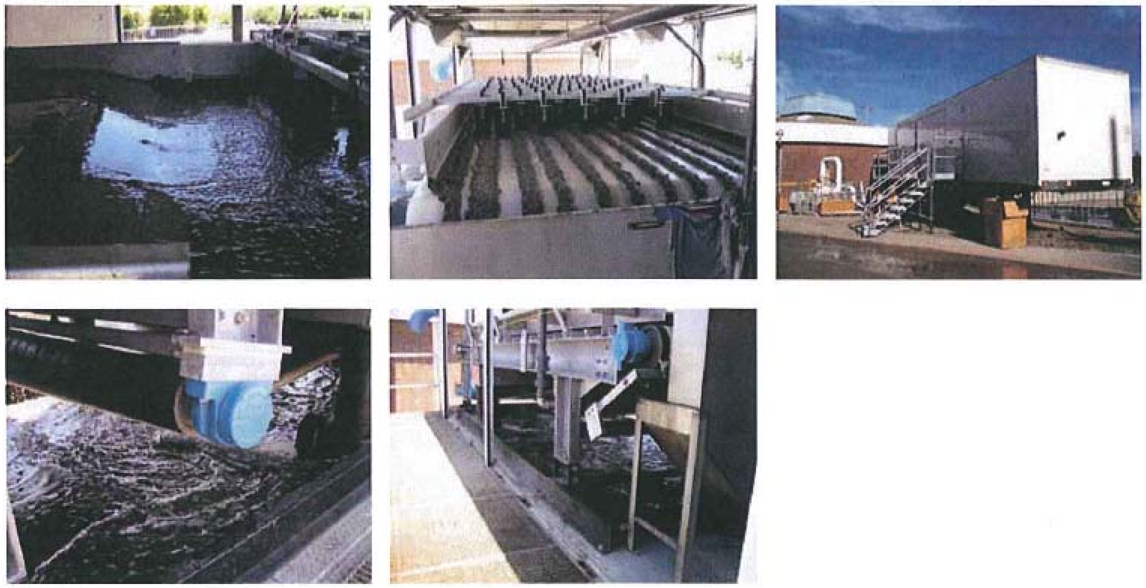


Figure 10.10. Time series of turbidity readings from six bench scale test samples (colored lines) versus the control sample (black line).

Gravity Belt Thickener for Rent



Available for rent at $4,500/month (half the usual rate)
It is mounted on a 1.7 METER TRAILER (for easy transport)

This Gravity Belt Thickener -- model RB 817.3 manufactured by Roediger Pittsburgh, Inc. – is rated to thicken a feed rate of 300 GPM of Raw or Mixed Liquor sludges and has been used for co-thickening, as well. The unit can thicken sludges to a concentration of four to eight percent. The unit comes with a Roediger model No. L-2 polymer system. Discharge sludge thickness is determined by adjustment of sludge feed, belt speed, and polymer dosage.

The unit contains a 55-gallon stainless steel cake hopper, a progressive cavity discharge pump with a Variable Frequency Drive (VFD) to vary speed

The Unit has the following features:
- In line venture mixer
- 100 gallon stainless steel flocculation tank
- Belt gravity zone has an area of 76 square feet
- 14 rows of individually adjustable plows
- Pneumatically adjusted belt tensioning
- Pneumatically adjusted belt tracking
- Automatic belt washing, with a wash water booster pump
- Polyester monofilament wovenware belt with 316 SS seams
- VFD Thickener Drive with AC motor

The unit is mounted on a DOT approved 42' x 8.5' trailer. The unit can be easily transported via highways to facilities anywhere in the continental United States and has been leased to treatment plants as far away as Indiana.

Utility requirements:
Electrical 460 volt, 3 phase, 60 Hz is standard, 2.0 Horsepower Drive units
Washwater @ 85psi (min.)
Pneumatics (instrument air) 1 cfm at 80 psi min, 250 psi max

Figure 10.11. Example of a trailer mounted gravity belt thickener for rent that can be used to test how well polymer-aided sludge enhancement equipment perform to separate bottom sludge materials from residual water following traditional canal cleanout (www.dsrsd.com/construction_projects_section/GBT_sludge_thickeners).

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11. Recommendations for Managing Sediment and Vegetation

11.1. Purpose and Background

This chapter presents recommendations for managing sediment and vegetation in the Putah South Canal (PSC). These recommendations are based on results from work activities completed during the past three years. The intent of this chapter is to provide a detailed summary and description of all reasonable measures considered to date. Because this year's annual report is prepared as an expansion and update to last year's report, many of the following descriptions were previously included in the 2008 final report (NHC 2008). However, based on results from the current year's activities additional recommendations are described and some of the 2008 recommendations have been modified or omitted. In most cases, readers can move directly to Section 11.7 which summarizes the measures described below and distills them into a small set of high priority measures that will have the greatest likely benefit in managing sediment and vegetation in the PSC.

Table 11.1 provides a list of the highest priority recommendations categorized according to (1) sediment control, (2) aquatic vegetation control, (3) supplemental water supply, and (4) pilot studies. Perhaps the most important (highest priority) combination of recommended capital improvements to alleviate sediment and vegetation problems includes a comprehensive rehabilitation of the PSC Headworks facilities with new high capacity screens, automated screen cleaners and winter-time sediment control features (described herein). The best results can be achieved by implementing a series of high priority improvements in phases over the next few years as they can be afforded. A conceptual schematic showing possible locations of various new project components recommended for sediment, aquatic weed, and algae control is presented in Figure 11.1. Figure 11.2 provides more details regarding recommendations for facilities improvements and re-operation at the PSC Headworks. The following sections discuss recommended canal and facilities improvements, modifications to canal operation and maintenance (O&M), actions requiring easements or landowner agreements, pilot studies and other technical analyses needed to formulate specific designs for recommended improvements.

11.2. Capital Improvements

Install a pipeline from upper Putah Creek to Headworks

Pollutant: Sediment and vegetation.
Source: Lake Solano.
Category: Major capital improvement.

Recommendation priority based on benefits to costs and likelihood of success: Expensive, but a very effective solution to long-term sediment and vegetation problems and this will greatly reduce annual maintenance and canal cleaning costs. Expected effectiveness: Very high.

Description: Project Operators close the Headworks during large storm events to limit the amount of suspended sediment entering the PSC from Lake Solano. However, the combined storage capacity in the PSC and WTPs is limited and can only provide enough in-line storage for 1-2 days of water supply before the Headworks must be reopened to meet downstream water demands. During major storms, or prolonged rainy periods, Lake Solano can remain highly turbid for weeks at a time such that turbid inflows are routinely delivered into the PSC because of water demands. Population growth is increasing water supply demands during the winter months which will worsen this problem over time.

This recommended project would take clean water from Putah Creek at a location sufficiently upstream from Lake Solano and turbid tributaries (at or below the outlet from Lake Berryessa), thus avoiding sources of aquatic vegetation and sediment inflow and deliver the clean water through a pipeline directly into the PSC (see Figure 11.1). This would require construction of a two- to three-mile long, 50-75 cfs capacity pipeline. Such a pipeline would provide continuous, uninterrupted delivery of clean water into the PSC and allow the Headworks to remain closed throughout the entire winter season, thereby eliminating the majority of the sediment loading into the canal from Lake Solano through the Headworks. This will reduce the growth of aquatic vegetation in the canal by greatly reducing the amount of soil substrate and nutrients available and greatly reduce aquatic vegetation loading into the PSC as well. The pipeline would also provide an alternate source of clean water to the PSC during periods in the summer and fall when the PSC may need to be drained for maintenance or cleaning. Construction of a three mile long pipeline would be very expensive and require extensive environmental review and permits.

Install water tight gates during winter on lake-side of intake screens at Headworks

Pollutant: Sediment.
Source: Lake Solano.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high depending on seasonal storm intensity.

Description: One of the annual sources of turbidity and sediment entering the canal comes from suspended sediment from Lake Solano and sediment deposits located in front of the Headworks that can be resuspended during spring ramp up into the irrigation season. During the summer irrigation season there is a depression in the lake bottom in front of the Headworks (refer to Chapter 6, ADCP Measurements). Fine sediments deposit in this depression during the winter months when flows through the Headworks are low and suspended sediment concentrations are high in Lake Solano. These sediment deposits can be re-entrained and enter the PSC during winter flood periods and during ramp up into the summer irrigation season when flow into the canal increases. NHC recommends that the intake screens at the Headworks be retrofitted with water tight slide gates that can be lowered down along the lake-side face of the screens prior to winter to keep sediment-laden waters from entering near the bottom of the Headworks intake. The slide gates should be fitted with an adjustable uppermost 3-5 ft inflow section that can be opened or closed to allow cleaner surface water to enter the Headworks during winter months, rather than pulling sediment-laden bottom water into the Headworks from the lake. This will keep a significant portion of the near-bottom sediment from entering the forebay. In addition to the outboard slide gates, NHC recommends installing sediment sluice pipes with low level inlets to intercept some of the bed load sediments entering the forebay and discharge it back to Putah Creek downstream of the diversion dam. Figure 11.2 (#3 and #7) shows the proposed locations of the outboard slide gates and new bottom sluices and pipes.

Aquatic vegetation grows rapidly in Lake Solano during the summer irrigation period. Fragments of vegetation typically collect near the water surface on the Headworks trash screens (see Chapter 9 for additional discussions of problems associated with aquatic vegetation). The existing trash screens should be replaced or modified to allow water inflow to the Headworks from the middle section of the water column instead of the surface to prevent/reduce floating fragments of aquatic plants from entering the canal during summer flow periods (also, see next recommendation). Physical and/or numerical modeling will be needed to evaluate alternative Headworks modifications.

Replace existing Headworks trash racks with high capacity screens and automated screen cleaning equipment

Pollutant: Aquatic vegetation and debris.
Source: Lake Solano.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Very high.

Description: Lake Solano is the primary source of aquatic plants (especially macrophytes) that enter and grow in the PSC. Significant amounts of floating plant fragments are transported from the lake to the canal, especially during summer irrigation periods. Vegetation influx monitoring results (see Chapter 9) indicated that the present trash screens at the Headworks intercept a significant portion of the floating plant fragments but that they are still fairly ineffective at keeping plant materials from entering the PSC. Chapter 9 discusses that even though a significant amount of vegetation collects on the screens there is still a dramatic amount of plant fragments that enter the canal during mechanical cleaning of the Headworks trash screens due to disturbance and shearing of weed materials captured on the screens. These fragments (10’s of thousand per day) propagate into the canal, settle to the bottom and begin to grow in sediment deposits in the canal, which eventually evolve into thick colonies of live plants.

To reduce aquatic vegetation influx to the PSC, the existing manually operated Headwork screen cleaning equipment should to be modified or replaced with more effective high capacity screens and automated screen cleaning devices. Following is a list of currently available types of screen cleaners that could be considered for installation at the PSC Headwork:

- Brackett Bosker Raking Machine (Figure 11.3): This screen and cleaning machine is designed for effective, high capacity removal of coarse debris/large weed fragments deposited on bar screens. The racking machine consists of a horizontally moving trolley and a vertically moving gripper. The automated racking machine travels on tracks to the designated screen area and stops over the selected pickup point. The gripper descends to the bottom of the screen, collecting debris in its jaws. Cylinders close the gripper and the hoist elevates the gripper and debris to the trolley. The trolley and gripper return to the dump areas, where the gripper opens and releases debris into the hopper, trailer or other dumpsite. Debris collection cycle continues until the selected screen area is clean. The racking machine can be retrofitted into existing installations without significant modifications. Capacities of the racking machine range from 550 lb through 6,600 lb per lift. The Bosker screens and self-cleaning equipment can be custom designed for screen openings and cleaning rates to meet water management needs. Senior NHC staff has spoken with the distributors of this equipment and understand that there are Bosker screens and self-cleaning installations operating in the Sacramento valley.

- Brackett Green Dual Flow Band Screen (Figure 11.4): The screen is designed to provide fine filtration of raw water and eliminate debris carry-over to the clean side of the screen. The screen has an endless band of moving screening panels. The influent water flows enters the interior of the Dual Flow Band Screen through both the ascending and descending traveling band screens. Clean water discharges through a single exit at the back of the screen. Debris is carried to deck level by ascending screens and deposited into a sluice trough by gravity and a water back-wash. Debris not cleared form the screen mesh by one cleaning cycle simply returns to the influent water to be removed by the next cleaning cycle. Seals between adjacent panels and between the moving band and side frame completely isolate the debris loaded water from the clean water side of the band. Advantages of this device are that it can be designed to capture fine suspended material similar to the plant fragments that presently enter the PSC through the Headworks.

- Brackett Green Traveling Band Screen (Figure 11.5): The screen is designed for installation on raw water intakes where a continuous and efficient means of removing floating and suspended solids is required. The screen can be fitted with mesh aperture sizes ranging from 1.5 mm to 10 mm. The Traveling Band Screen has an endless band of screening panels through which the water passes. Debris collected on the mesh panels is raised to deck level and removed by backwashing. The screen is custom designed for each individual application to incorporate specific features to suit the operating and site conditions. Depending on a specific situation, the Traveling Band Screen can be designed to provide dual flow, central flow, or through flow patterns (see Figure 11.5). With the dual and central flow patterns, debris not cleared from the moving panels cannot be carried over to the clean water area.

- Brackett Green Double Entry Drum Screen (Figure 11.6): This high capacity screen consists of a vertically rotating drum and is designed for installation on large volume raw water intakes. The drum screen needs little maintenance and effectively removes floating and suspended solids from influent water automatically. After entering from both sides, the water flows radially from the inside to the outside of the drum through mesh panels arranged around its periphery. The drum screen can be fitted with mesh ranging from 1.5 mm to 10 mm. These mesh panels are cleaned, with the assistance of gravity, by backwashing at deck level. The Brackett Green Double Entry Drum Screens are purpose designed for each individual intake with specific features, as necessary, to suit the particular operating and site conditions. The screens can be built to diameters exceeding 65 ft and width up to 20 ft. Advantages of this device is that it is designed with high volume raw water capacity and will capture fine suspended material similar to the plant fragments that presently enter the PSC through the Headworks.

- Aqua System 2000 Inc. (AS2I) Inline/Side Sweep Screen Cleaner (Figure 11.7): The AS2I cleaner is a simple, low power, low maintenance, self-cleaning device that is ideal for water takeouts similar to the Weyand takeout structure. The main feature of the cleaner is a large movable nylon bristle brush mounted on an endless chain. Plant matter accumulated on bar screens is gently swept from the screen with the brush and either deposited into a debris bin (inline cleaner) or pushed downstream (side cleaner). This cleaner can be readily adapted to large or small applications where trash problems range from surface debris to entrained plant matter. Aqua System 2000 Inc. representatives (Telephone discussions with NHC, 2009) estimate that the installation cost of the sweep cleaner on the PSC inlet screens for something like irrigation takeouts would be about $27,000 +/-. The inline cleaner may be more appropriate for the Headwork screens, while the side cleaner is more suitable for irrigation takeouts, small water intakes, and WTP intakes. NHC's opinion is that this type of automated screen cleaning device is best suited for most lateral takeouts along the PSC.

- MultiDisc Fine Screen (Figure 11.8): The screen is designed to capture and remove small debris from the flowing water. The screen design is based on circulating, crescent-shaped mesh panels that are connected at the rear by a revolving chain and installed across the channel. Debris is captured and retained at the face of the ascending panel and is carried to deck level, where it is removed by means of a high-volume spray system. Maximum screen installation water depth is 8.5 ft. The screen width ranges from 3.25 ft to 7.75 ft. Mesh panel apertures range from 1 mm to 10 mm. Because of the fine mesh, the MultiDisc Screen could be used for secondary filtering of waters (to capture small plant fragments that pass the primary screens) in the PSC.

Install additional trash screens inboard from the primary trash screens at the Headworks

Pollutant: Aquatic vegetation.
Source: Lake Solano.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: In order to greatly minimize aquatic vegetation influx into the PSC, it may be more effective and perhaps less costly to install more than one screening device at the Headworks.

Additional racks of vegetation screens with finer mesh diameter screens could be installed in the Headworks forebay immediately behind the existing trash screens. These need to be high capacity self cleaning screens designed to capture small plant fragments that pass through the primary outboard screens at the Headworks. Various types of screens and automated screen cleaners that could be considered for these additional screens are discussed above. It could be that one, two or three sets of screens and screen cleaners would have more success removing most of the small fugitive plant fragments from the lake then one primary screen. The operation of a single screen is limited because designs may call for a significantly larger screen opening diameter for the primary screen due to the large loading rate it experiences adjacent to the lake. Installing two or more finer screens just downstream from the primary screen would more effectively remove even the very fine vegetation fragments from the water. These "polishing screens" would only need to be in place and operated during months with high flow and high vegetation loading from Lake Solano. This alternative warrants further analyses.

Modify forebay (inlet basin) to Putah South Canal

Pollutant: Sediment.
Source: Lake Solano.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: Winter storms dramatically increase turbidity and suspended sediment concentrations (SSC) in Lake Solano and, subsequently, in the PSC. Even if the inlet gates are closed, suspended sediments settle in the PSC forebay (inlet basin between trash screens and sluice gates) and are then entrained into the canal when the gates are re-opened. There are several options that may significantly reduce deposition and re-entrainment of sediment in the PSC forebay. Options to reduce deposition focus on agitation of water in the basin to keep sediment in suspension and diversion of coarser sediments to keep them from entering the forebay. Options that might be employed at the Headworks and forebay include:

- Maximize discharge of sediment-laden water through the existing bypass pipe (sluice).
- Install additional low level release pipes (new bottom sluices) from the forebay to return a substantial flow of sediment-laden water to Putah Creek downstream of the diversion dam (see Figure 11.1, and #s 4, 5, 7 in Figure 11.2).
- Install a seasonal high pressure air bubble agitator consisting of a piping manifold system on the floor of the forebay to distribute the release of compressed air. A portable compressor could be deployed as needed to minimize the capital investment (# 4 in Figure 11.2). Air pulses will suspend the sediment, while water is flushed through the sluice back to Putah Creek below the diversion dam.
- Install multi-directional high pressure water jets to back flush sediment through the sluice and out of the forebay into the lake where it will be carried downstream through Gates 11 and 12 at the diversion dam (#4, 5, and 7 in Figure 11.2).

Modify tainter gates at inlet to Putah South Canal to meter flow over the top during winter

Pollutant: Sediment.
Source: Lake Solano.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: The existing tainter gates at the Headworks (see Figure 1.6 in Chapter 1) can be modified with adjustable slots or ports near the top of each gate so cleaner water is metered through the ports near the top of the closed gates during the winter thus avoiding passage of sediment laden bottom waters from the forebay into the PSC (see #6 in Figure 11.2).

Reconfigure check control gates

Pollutant: Sediment.
Source: Lake Solano and lateral sources.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Presently, most check control gates draw waters (and sediment) from the bottom of the canal. The gates can be reconfigured to spill cleaner water over top which will enhance sediment settling and trapping in backwater zone upstream of the gates. Physical and/or numerical modeling can be used to evaluate alternative modifications of check control gates. Settling of suspended sediment in front of the gates can be accelerated by using bio-acceptable polymers (flocculation settling agent) in the upper most checks in the PSC. The objective of adopting this recommendation is to settle, trap and isolate sediment entering the PSC from Lake Solano in the uppermost checks, thereby reducing the need for cleanout of the lower checks. This approach also has the potential for reducing the growth of aquatic vegetation in the lower checks by reducing the amount of sediment substrate available in downstream checks for aquatic vegetation to become established and flourish. Following preliminary numerical or physical modeling assessments, this recommendation would first be implemented in the Sweeney Check to assess its effectiveness. If needed, additional downstream checks could also be retrofitted. This approach may work best during low flow winter months.

Reconfigure and/or relocate water intakes

Pollutant: Sediment.
Source: Lake Solano and lateral sources.
Category: Major capital investment.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high depending on location of intake.

Description: Concrete intake sills are located near the bottom at many water intake structures in the PSC. If intake sill elevations are near the bottom it promotes water withdrawal from the bottom that leads to sediment ingestion and deposition in the intake structures that affects maintenance and water quality in the WTPs. Some intakes are located within sediment deposition zones just upstream from canal checks or other control structures. An example is the Waterman WTP, which is located along the inside of a bend in the backwater reach just upstream of the Serpas Check structure. Significant sedimentation and aquatic vegetation growth occur in this reach which creates chronic intake maintenance and water quality problems for the plant. Water intakes experiencing significant sedimentation/vegetation problems should be relocated away from flow control structures and reconfigured according to site-specific conditions to draw cleaner waters from upper portions of the water column. Physical and/or numerical modeling will be needed to test and design alternative water intake reconfigurations.

Install automated water intake screen cleaners at water intakes and takeouts

Pollutant: Aquatic vegetation.
Source: Lake Solano and in-canal sources.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: Vegetation captured on trash screens installed at numerous water intakes and upstream from check structures in the PSC blocks the screens and requires regular manual maintenance to remove the vegetation. Manual maintenance often dislodges some of the captured materials allowing them to flow downstream to colonize or be captured on the next set of screens. The process of cleaning accumulated vegetation from irrigation takeouts, WTP intake screens and check structures can be automated and made more effective by installing automated screen cleaners similar to those suggested for the Headworks screens (discussed above). Selection of a specific type of screen cleaners for a particular water intake depends on site-specific hydraulic conditions and severity of sedimentation and vegetation accumulation problems (see Figures 11.7 and 11.8).

Develop alternative and/or supplemental water sources

Pollutant: Sediment and aquatic vegetation.
Source: Lake Solano.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: The principal constraint that limits the amount of time the Headworks can remain closed during high turbidity winter periods or during annual cleanout is the lack of in-canal storage and/or alternative water supply sources. One option is to take water from Lake Berryessa or a clear water portion of Putah Creek upstream of major sediment sources and deliver it through a pipeline directly to the canal while the Headworks remains closed. The pipe should have the capacity needed to provide minimal water supply during the Headworks closure periods. However, it is realized that construction of such a pipe will require significant capital investments and might not be economically feasible in the short term. However, this alternative may have significant long-term benefits and should be evaluated as a possible long-term solution that is planned and constructed in the future.

As an interim measure, water storage facilities (tanks or small reservoirs) could be constructed along the canal to reduce the impacts during canal closure due to cleanout or winter storm events. This would provide supplemental water supply and would allow all, or portions of the PSC to be closed for longer periods of time. For example, land near the Union Check (Noonan Reservoir Site) could be used as a storage pond to aid PSC operations. The land is publicly owned and could be used for clean water storage during the winter time. The increase in storage would allow the Headworks to remain closed for longer periods of time and still serve the needs of the WTPs. The site could also be used as a settling pond for sediment laden water in the PSC. If plumes of sediment did enter the PSC, the Union site could serve as a settling/storage pond to allow the sediment to settle out and the clean water could be returned back into the PSC.

Another option is to install wells along the PSC and use them as local supplemental water sources to pump into the PSC or into supplemental water supply pipelines along the PSC while the Headworks is closed. According to the SCWA, ground water can be used as a supplementary source only in the Vacaville or North Vacaville area, since the quality of ground water in the Fairfield area is poor. To assess the feasibility of this option, further analysis is needed to assess ground water resources and alternative well locations in the study area.

A further option would be to increase the finished water storage at the various WTPs, or establish inter-ties between systems that have alternate reliable raw water sources.

Install supplemental water supply distribution pipeline along Putah South Canal

Pollutant: Sediment and aquatic vegetation.
Source: Lake Solano and lateral sources.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: Solution to the needs for alternative supplemental water supplies will require a combination of additional reliable supplemental water sources as well as a supplemental water distribution system (pipe line) to be able to move water from its source to where it is most needed (see Figure 11.1 and #9 in Figure 11.2). Therefore, the purpose of this option is to install a supplemental water supply bypass pipeline along the entire canal or around the most critical sections of canal such as the Union, McCoy, Burton, and Serpas Checks. The pipeline would be connected to each check and would serve NBR, Cement Hill, and Waterman WTPs during canal cleanout periods or when water in these checks is of very poor quality. Extension of the pipeline below the Serpas Check would allow pumping of additional waters to Waterman WTPs from storage found in downstream sections of the canal during canal shut-down periods. During winter high turbidity storm events, this pipeline could be used to supply clean water from one or more alternative supplemental water sources (discussed in previous sections). This project could be constructed several phases starting with supply options located in the vicinity of the water treatment plants.

Increase capacity of McCune Creek overchute flume

Pollutant: Sediment.
Source: Lateral (from McCune Creek).
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: The flow capacity of the McCune Creek overchute flume was recently doubled, however, McCune Creek overtopped both overchute flumes and discharged sediment laden water into the canal during the January 4, 2008 storm event (see Figures 3.6 and 3.7 in Chapter 3). Increasing the conveyance capacity of the flume would effectively eliminate the possibility of future impacts to the PSC. SCWA believes that during that event the Putah Creek Road Bridge opening was the limiting factor and therefore increasing the flume capacity could be gained by increasing the capacity of the bridge on the Putah Creek Road. SCWA estimated the recurrence interval of over 1,000 years for the January 4, 2008 event which indicates that additional improvements to the flume may not be cost effective because events of this magnitude are very rare. At a minimum, NHC recommends that both canal abutment faces be armored with appropriate geotextile matting materials or rip rap rock protection to avoid bank erosion if such an event were to occur again.

Increase flood capacity for Sweeney Creek or install engineered flood overtopping structures

Pollutant: Sediment.
Source: Lateral (from Sweeney Creek).
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: There have been three overtopping events into the PSC from Sweeney Creek in the last eight years. Overtopping flows from Sweeney Creek are one of the major lateral sources of sediment into the PSC. If it is not possible to make channel improvements that reduce the risks for overtopping into the PSC, then SCWA should consider installing engineered weir structures that will allow water to safely leave Sweeney Creek and enter into the canal without damaging the canal lining or eroding the canal banks (see Figure 11.1).

Increase flood conveyance across PSC near Suisun and Ledgewood Creeks

Pollutant: Sediment.
Source: Lateral.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: Suisun and Ledgewood Creeks have limited conveyance capacities and the PSC acts like a dam across the Suisun Valley during major floods. Ponded stormwater from the valley can overtop the canal banks along hundreds, if not thousands of lineal feet of the canal during major floods, such as the December 31, 2005 event. The solution is to either significantly increase the capacity of Ledgewood Creek, or to raise the upslope side of the canal and construct one or more flumes or siphons to convey floodwaters across the PSC. Increasing the capacity of Suisun Creek appears to be less viable because of its location, permit requirements, and its more naturalistic pattern and extensive riparian corridor.

Install silt curtains in upper checks

Pollutant: Sediment.
Source: Lake Solano.
Category: Minor capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Low.

Description: Install silt curtains in the upper checks of the PSC during the winter months to intercept suspended sediment coming from Lake Solano. This technique warrants further testing to determine its effectiveness, costs, and impacts on flows in the canal. Field and/or numerical model tests can be conducted to further evaluate this alternative.

Install in-canal sediment extractors

Pollutant: Sediment.
Source: Lake Solano.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Low to medium depending on sediment grain size.

Description: Sediment extractors have been used successfully in water supply and irrigation canals around the world. They could be installed in the upper checks to remove near-bottom sediments from the canal. Different types of sediment extractors are used in canal systems (Lawrence et al. 2001). A vortex tube sediment extractor (Figure 11.9) consists of one or more slotted tubes laid flush with the canal bottom. One end of the tube is closed, the other is open and connected to an escape channel. Water and sediment flowing near the bed of the channel upstream is diverted through the vortex tube and discharged from the canal to an escape channel. A strong vortex flow is developed in the tube, which, provided the tube dimensions have been chosen correctly, prevents sediment from settling and blocking the tube. In most cases the extracted flow is returned to the stream via an escape channel (Figure 11.10). A tunnel sediment extractor (Figure 11.11) consists of a row of tunnels placed at the bed of a canal that divert water and sediment moving near the bottom of the canal. High velocities are necessary in the tunnels to prevent sediment deposition.

Sediment extractors are aimed at extracting coarser (sand-size) sediment moving along the bottom. Given that sediments in the PSC mostly consist of fines (silt and clay) that are uniformly mixed vertically within the water column, installation of bottom sediment extractors in the PSC are not likely to be effective or economically feasible. Additional numerical or physical modeling is needed to determine the dimensions and effectiveness of sediment extractors for application in the PSC.

Provide in-line sediment settling basin(s) in Sweeney Check

Pollutant: Sediment.
Source: Lake Solano.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Low.

Description: Lake Solano is the major source of sediment in the PSC. Installation of an in-line or in-parallel sediment settling basin(s) within the Sweeney Check could intercept some of the sediment load coming from the lake and from lateral sources in this reach. A settling basin is an enlarged section of the canal, where the flow velocities are reduced to the level needed to ensure that sediment settles and is trapped in the basin. Settling of suspended sediment could be accelerated by using bio-acceptable polymers (flocculation settling agent) at strategic locations. Settled sediment could be sluiced back to Putah Creek via a low level outlet located at the downstream end of the basin or mechanically removed from the basin. Twin basins could be used, so that sediment removal and maintenance could be performed in one basin while the second passes irrigation water to the canal system. A typical settling basin layout is shown in Figure 11.12.

Given that sediments transported from Lake Solano are generally very fine (mostly silt and clay) and take a long time to settle in quiet flow conditions, construction of a very large settling basin or a series of basins may be required to effectively trap these fine sediments. Additional technical analyses are needed to assess the feasibility and cost benefits of installing settling basins in the PSC.

Install spillway gates in upper checks

Pollutant: Sediment.
Source: Lake Solano, lateral.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Low to medium.

Description: Installation of a series of additional submerged spillway gates in upper checks would help intercept a portion of the sediment load coming from Lake Solano and could be used to trap sediment entering from lateral overflows of McCune and Sweeney Creeks. Sediment would settle to the bottom and accumulate in the backwater zone upstream of the gates. This isolates the impacts of lateral sediment loading to a small portion of a check in the upper reaches of the canal. Settling of suspended sediment in front of the spillway gates could be accelerated by using a flocculation settling agent (polymer). Cleaner water would be drawn over the gates from the upper layer of the water column. The accumulated sediments would be removed mechanically during annual canal cleanouts. Screens could be added to the gates to intercept floating aquatic vegetation.

In addition to trapping sediment, spillway gates would also provide additional water storage in the canal above the current operational water levels when necessary to maximize canal storage. Presently, the PSC is operated as a series of checks (water storage reservoirs) separated by 12 flow control gates (see Figure 1.8 in Chapter 1). Maximum storage volume within the checks is limited by the maximum water surface elevation at the downstream flow control gate. At the canal longitudinal slope of 0.0001-0.00015, there is a substantial additional upstream storage volume in the canal located above this limiting elevation. At present this additional storage volume can not be used. Installing internal gates would allow using this additional storage volume and thereby would increase internal water storage capacity of the PSC during shut down periods.

To provide easy access to the canal during cleanout operations, the Obermeyer spillway gate system could be used (Obermeyer Hydro Inc. 2006). This system consists of a row of steel gate panels supported on their downstream side by inflatable air bladders (Figures 11.13 and 11.14). By controlling the pressure in the bladders, the elevation of the gates can be easily adjusted within the system control range (full inflation to full deflation) and accurately maintained at user-selected set-points. During canal cleanout, these gates would be laid flush with the canal bottom. The advantages of the Obermeyer spillway gate system are:

- Automatic water level control to maintain needed discharge.
- The bottom hinged design allows for passage of debris without becoming blocked or jammed.
- Sediments are deposited upstream of gates and no bottom sediment pass through.
- Clean surface water spills over top of gate.
- Gates can be fully lowered (fully deflated).
- Gates are very vandal and damage resistant.

Additional technical analysis is needed to assess the sediment trapping efficiency, costs, and benefits of installing intermediate spillway gates in the upper PSC checks.

Install inflatable rubber dams in upper checks

Pollutant: Sediment.
Source: Lake Solano, lateral.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Low to medium.

Description: Another option to trap a portion of the sediment entering the PSC from Lake Solano or from overflows at McCune or Sweeney Creeks is to install a series of submerged inflatable rubber dams in the upper checks of the canal (Figures 11.15-11.17). Sediment would settle and accumulate in backwater zones upstream of the dams and cleaner surface water would spill over the top of the dams. The dams could be fully deflated (collapsed) to provide access to the canal. In addition to trapping sediment, the rubber dams would also provide additional water storage in the canal above the current operational water level during canal shut down periods. Additional technical analysis is needed to assess the sediment trapping efficiency, costs, and benefits of installing rubber dams in the PSC.

Eliminate direct drain #5

Pollutant: Sediment.
Source: Lateral.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Drain # 5 drains a watershed with an area of approximately 30 acres and it is primarily agricultural land. This direct drain is estimated to be the second largest contributor of sediment to the PSC below the Serpas Check and is a chronic source of sediment entering the canal. This project would route water currently discharged through the drain west to Ledgewood Creek. The project would require acquisition of property and permits to expand the existing right-of-way to the north to install a drainage ditch of sufficient capacity.

Eliminate direct drain #6

Pollutant: Sediment.
Source: Lateral.
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Because of its watershed size, 57 acres, and agricultural land use, this direct drain is estimated to be the largest contributor of sediment to the PSC below the Serpas Check, and is a chronic source of sediment entering the canal. This project would route water currently discharged through the drain west to either/both Ledgewood and Suisun Creeks. The project would require acquisition of permits and property to expand the existing right-of-way to the north to develop drainage ditches of sufficient capacity. If water is routed to Ledgewood Creek, it would also require the development of a cross drain under Suisun Valley Road.

Apply gravel on remaining reaches of access roads that drain into canal

Pollutant: Sediment.
Source: Lateral.
Category: Minor capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Apply a 3-inch thick crushed gravel blanket on approximately 0.4 miles of native surface on the non-operational sides of access road segments that drain directly into the canal via direct drains #5 and #6. These road segments represent disturbed areas that are often maintained in a disturbed condition by frequent blading of the roads which contributes to annual erosion and the production of fine sediments. These sediments are then more easily delivered to the canal. Install rock lined ditches as needed. Implementation of this action will eliminate a significant chronic source of sediment entering the canal. This action is not required if direct drains #5 and #6 are eliminated.

Apply gravel mulch on canal banks that have low revegetation potential

Pollutant: Sediment.
Source: Lateral.
Category: Minor capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Apply 3-inch thick gravel mulch on right bank reaches 36, 45, 46, 47, and possibly others. These reaches appear to have soil types that limit the amount of ground cover that can be attained through vegetation. The gravel mulch would constitute a maintenance-free means for greatly reducing elevated surface erosion rates on these banks. There may be other means to attain the same objective.

Apply gravel mulch on broad-spectrum herbicide treated canal banks

Pollutant: Sediment.
Source: Lateral.
Category: Minor capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Apply 3-inch thick gravel mulch on all canal banks that are currently maintained in a barren condition (bare earth) through the application of broad-spectrum herbicides. The gravel mulch would constitute a maintenance-free means for greatly reducing elevated surface erosion rates on these banks. Continued application of herbicides would likely be required but at reduced rates. There are other ways to reduce or elimination surface erosion on such banks. However, this approach is best utilized where revegetation is not desirable or where problem soils prevent revegetation.

Eliminate monocotyledon herbicide use on canal banks and stabilize as needed

Pollutant: Sediment.
Source: Lateral.
Category: Minor capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Prior to the 2008/2009 rainy season PSC canal banks were treated with monocotyledon herbicides to kill grasses and maintain the canal banks in a barren condition along many miles of the canal, primarily through the cities of Fairfield and Vacaville. This was implemented according to SID’s “brown-out” weed control spray plan. This practice is a significant recurring expense and leads to chronic erosion of canal banks. This recommended action would cease the broad application of grass-killing herbicides. As a trial, during the 2008/2009 rainy season no herbicide applications were made and several miles of the canal experienced a high volunteer recruitment of Italian rye grass (see Chapter 5). This 2008/2009 trial demonstrates that a significant portion of the brown-out areas will slowly revegetate themselves with endemic grasses over time. However, other measures, such as application of gravel mulch, or acrylic copolymers might be needed to manage or eliminate surface erosion in those locations where revegetation efforts are unsuccessful.

Install erosion control measures to minimize canal bank erosion at chronic overtopping sites

Pollutant: Sediment.
Source: Lateral.
Category: Minor capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: Erosion from canal banks during overtopping events is a minor lateral source of sediment but one that is easily controlled through the application of riprap, cellular confinement mats, turf reinforcement mats, or other equivalent measures to prevent the loss of canal bank and access road soils that occurs when overtopping flows cascade down the canal bank. The highest priority application for this measure would be in the vicinity of the Sweeney Creek check. Examples of several erosion control measures are provided in Figures 11.18 and 11.19.

11.3. Operations

Operate diversion dam to flush lake sediment from in front of Headworks

Pollutant: Sediment.
Source: Lake Solano.
Category: Operations.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: Flushing is a method of removing sediment deposits to restore and maintain storage capacity as well as to pass inflowing winter sediment through the system during storm events. Current operation procedures for the diversion dam do not specifically consider flushing of sediment from Lake Solano during winter storm events (referred to as winter pass through). However, periodic flushing of sediment accumulated in the lake, especially those deposits located in front of the Headwork would help to lessen the sedimentation problems in the lake and reduce the amount of sediment entering the PSC from the lake deposits. Sediment flushing would require modifying operation procedures for the diversion dam. Assessment of potential environmental impacts or benefits of seasonally flushed sediments on the downstream reaches of Putah Creek may be required.

Modify flow management procedures in Lake Solano during storms and increase post-storm releases from Lake Berryessa

Pollutant: Sediment.
Source: Lake Solano.
Category: Operations.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: The recommendation is similar to the above except its objective is to minimize the duration of time that Lake Solano has unacceptably high levels of turbidity during and following storms. Once highly turbid tributary inflows require closure of the Headworks, the diversion dam gates would be opened to freely pass turbid inflows through the lake. This will slightly drop water levels in Lake Solano and increase flow velocities through the Lake, thereby reducing the amount of sediment deposited in the lake that may be subject to re-entrainment and entry into the PSC. During significant winter storm events, releases from Lake Berryessa would be held to a minimum until tributary runoff volumes fall to below a determined threshold. At that point, clear water releases from Lake Berryessa would be greatly increased for a short period (a pulse) to flush the remaining turbid water in Lake Solano downstream. Once the turbidity in the lake becomes acceptable, releases from Lake Berryessa would be returned to normal. This alternative would require substantial planning, assessment of potential environmental impacts and permits from state and federal agencies. Perhaps periodic pulse releases from the diversion dam is the only practical alternative. Operational requirements and benefits of this alternative are best evaluated by using unsteady hydrodynamic numerical and/or physical models.

Improve storm monitoring and forecasting procedures

Pollutant: Sediment.
Source: Lake Solano.
Category: Operations.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: High intensity winter storms drastically increase turbidity and suspended sediment concentration (SSC) of waters entering the PSC from Lake Solano. Storm monitoring and forecasting procedures need to be improved to be prepared in advance for such storm events. Real-time Doppler radar information and precipitation gage data from the National Weather Service (NWS) should be used to track the location, movement and intensity of approaching weather fronts and associated areas of intense rain. A network of real-time rain gages could be installed at key locations around the PSC (in addition to the existing rain gages at Putah Diversion Office and Sweeney Check) and in the upper basin of Pleasants Creek (which is the major source of turbidity and sediment in Lake Solano). These rain gages would provide real-time information on rainfall intensity in the area.

Continuously monitored turbidity data from the SCWA probes installed on Pleasants Creek, Putah Creek, and at the PSC Headworks serve as a warning system of approaching turbid waters. Of these three turbidity stations, only the Pleasants Creek and Headworks data are available in real time. A self contained non-telemetered turbidity sensor currently exists on Putah Creek at Pleasants Valley Road. This station should also be made real-time to provide additional advanced notice of increased turbidity and to serve as a backup in case of malfunction of the Pleasants Creek probe. A reliable turbidimeter with Liquid Crystal Display (LCD) readout needs to be installed in Lake Solano at the Headworks. This will allow Solano Project operators to see what the turbidity is in Lake Solano and how rapidly it is increasing in order to determine when to close the Headworks gates. Solano Project operators need to be able to check the turbidity remotely while they are on call at home and when they are physically onsite at the Headworks.

An Operator's Webpage should be developed for the PSC. The page would provide all of the necessary rain and turbidity information so that Solano Project operators could make quick and informed decisions. The page would need to be accessed remotely from home and at the Putah Diversion Office. Data collected from major storm events should be archived for future analyses and comparison to past storm events.

Modify operation of Headworks during winter storm events

Pollutant: Sediment.
Source: Lake Solano.
Category: Operations.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: To reduce influx of suspended sediment and turbid water through the PSC Headworks during winter storm events, operation of the Headworks should be conducted in accordance with the protocol compiled from NHC, SCWA, and the Solano Project operators (see Appendix C-6.2). Weather forecast and real-time Doppler radar information would provide an early (1-2 day) warning of an approaching storm. Recommended actions: be alert, check the reliability of telemetered turbidity and rain gage sensors before storms occur, attempt to surcharge the PSC prior to the event and avoid draining the PSC during the event so water supplies last longer. If possible fill the entire canal with excess water that can be used as a backup supply of water if the Headworks needs to be closed. Significant increase in rain intensity recorded at the local real-time rain gages would serve as a warning that flash floods and turbidity slugs in local streams might occur within a few hours. Another warning – look for significant increases in turbidity in Pleasants Creek (or Putah Creek) by viewing real-time readings from SCWA's upstream most real-time turbidity stations. Action: alert water users, closely watch the Headworks turbidity readings, be prepared to close the Headworks. According to the SCWA turbidity data (see Figures 3.15 and 3.25 in Chapter 3, and Figure 11.20 in this chapter), it takes about 3-6 hrs for a turbidity plume to arrive at the Headworks from Pleasants Creek and 1-3 hrs to arrive from Putah Creek at Pleasants Valley Road, depending on flow. Final warning – look for rapid increases in turbidity at the Headworks. When the lake turbidity reaches 200 NTU at the Headworks, close the gates and activate alternative sources of water supply (if available) downstream from the Headworks. Notify all WTPs in advance of the Headworks closure. When the gates are closed, open the rightmost gates (Gates 11 and 12) in the diversion dam to provide sweeping flows in front of the Headworks intake screens to remove sediment deposits and maximize discharge of sediment-laden water through the existing bypass pipe. The PSC gates should remain closed until turbidity levels decrease back to 200 NTU or there are urgent demands for water supply from water users. System operating protocols during storm periods should be periodically updated as more information and experience is obtained.

Modify screen cleaning operations at PSC Headworks

Pollutant: Sediment and aquatic vegetation.
Source: Lake Solano.
Category: Operations.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: Trash screens are installed in front of the PSC forebay to prevent debris and floating weeds from entering the canal. The screens are mechanically cleaned on a regular basis depending on how much vegetation or debris accumulates during the day. The PSC gates typically remain open during screen cleaning. Screen cleaning operations remove large debris and vegetation and, at the same time, disturb and release into the PSC significant amounts of sediment, weed fragments, and algae dislodged from the screens during screen cleaning. Therefore, until new more efficient screens and automated screen cleaners are installed at the Headworks, NHC recommends that screen cleaning operations be changed to reduce the amount of plant fragments that enter the PSC during cleaning. First, temporarily reduce the flows into the PSC or close the PSC gates before cleaning the screens. Then initiate flushing of the PSC forebay with backflow (by, for example, pumping clean waters from the canal or Lake Solano into the forebay). At the same time, open the rightmost gate in the diversion dam (Gate 12) to provide sweeping flows in front of the screens. Then begin aggressive cleaning of the screens. Backflow pressure from the forebay into the lake will push sediment and weeds detached from the screens into the lake and through the gate in the diversion dam into the downstream reaches of Putah Creek. After the cleaning is completed, reduce the flow in the rightmost diversion dam gate and re-open the gates in the forebay to the canal. This is a temporary stop-gap operation intended to reduce sediment and vegetation loading into the PSC until new more effective automated screens are installed at the Headworks.

Reactivate wasteways

Pollutant: Sediment and aquatic vegetation.
Source: Lake Solano and lateral sources.
Category: Operations and major capital improvements.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Decomposition by-products from algae and aquatic weeds and fine sediments cannot be removed effectively during annual canal cleaning using existing mechanical methods. This situation contributes to the accumulation and continual buildup of these materials in the canal. The USBR anticipated the need for regular canal cleanout and provided several "wasteways" along the canal where in-canal deposits could be periodically flushed from the canal. However, use of the wasteways was discontinued a number of years ago due to concerns regarding possible downstream impacts.

Reactivation of wasteways (particularly McCoy Wasteway) would greatly help to remove these deposits from checks upstream from the McCoy Wasteway during fall cleanouts. Prior to using the McCoy Wasteway, settling basins should be installed in the wasteway channel downstream from the wasteway outlet to capture sediment and debris and keep them from entering the McCoy Basin. Settling of sediment could be accelerated by using bio-acceptable polymers (flocculation settling agents) if necessary. Material accumulated in the settling basins would be removed mechanically when the wasteway is not being operated and the settling basins are dry. Should polymers (flocculation agents) be used, their application will not affect water quality in the PSC proper since there will be no outflow from the settling basins into the canal. Physical and/or numerical modeling is needed to evaluate the effectiveness of reactivation of wasteways and to determine the proper operational procedures. Environmental compliance and permitting will be necessary.

One of the constrains with respect to activating McCoy Wasteway is the need to manage water levels in the McCoy Basin to protect the California Goldfield which is a listed plant species. This could be accomplished by pumping excess water from the McCoy Basin into the PSC instead of (or along with) metering the discharge to downstream receiving waters prior to, during or after use of the wasteway.

Develop a canal overtopping emergency response plan

Pollutant: Sediment.
Source: Lateral.
Category: Operations.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: This action would develop an “emergency” response plan to prevent or reduce the amount of sediment that enters the canal from lateral overtopping flows (Sweeney, Alamo and McCune Creeks, and others) during significant storm events. This along with NHC’s previous recommendation (above) to stabilize chronic overtopping areas to reduce additional damage to the canal banks will reduce periodic sediment loads. SCWA and the Project operators would meet to plan and develop emergency response programs for specific overtopping sites along the canal so as to limit the amount of damage and sediment loading from adjacent floodplains to the smallest lineal extent of canal as is possible. Measures such as the placement of inflatable water-bag dams or rapid deployment of sediment screens to trap incoming sediment, use of SID laterals to flush out sediment laden water out of the canal, or possibly obtaining emergency permits to activate former wasteways during such events could be considered.

11.4. Maintenance

Isolate, de-water and clean the most "difficult" sections of canal (instead of entire checks)

Pollutant: Sediment.
Source: Lake Solano and lateral sources.
Category: Operations.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: To increase effectiveness of cleaning operations, follow-up cleanout could be conducted in short isolated sections of the canal after the initial large-scale cleanout is completed. This method of isolating and cleaning selected sections of canals is used, for example, in Union Canal in Edinburgh, Scotland, where draining of the entire canal is impossible (see Figures 11.21 and 11.22). This cleanout method of isolating cleanout activities into smaller cells could be implemented during periods with low water demand (fall and winter) and would include the following steps: (1) complete traditional large-scale annual cleanout activities in early fall, then (2) return later to sections of the canal where it was most difficult to remove residual sludge and sediment deposits. Isolate and clean the critical sections of canal one by one by using portable dams (this could be scheduled over a period of several calendar months as weather and time permits); (3) each isolated section would be de-watered; (4) water would be pumped around the isolated section through portable pipes to provide water supply to the downstream reaches; (5) residual sludge, sediment and vegetation would be mechanically removed from the isolated section; (6) when complete, that section would be refilled and the next critical section would be scheduled for cleaning. This method would greatly simplify the logistics of trying to thoroughly clean the entire canal in a matter of weeks during one very compressed cleaning period in the fall. Especially if the cleanout occurs during an unexpected hot period, similar to what was experienced in the fall of 2008. This recommended method of isolating and cleaning the most difficult sections more thoroughly as time permits after the initial fall canal cleanout may provide cost savings and help to reduce stress and confusion during the traditional one-time annual cleaning campaign by eliminating the need to rapidly drain, clean and then refill checks in order to maintain a supply of water to the WTPs during high demand. It would allow for more thorough cleaning of isolated areas as needed.

Use mechanical vegetation harvesting methods to manage and remove in-canal vegetation

Pollutant: Aquatic vegetation.
Source: Lake Solano and lateral sources.
Category: Operations.
Recommendation priority based on benefits to costs and likelihood of success: Low to medium.

Description: Copper sulfate is currently applied to the canal to reduce algae growth, which has little or no effect on higher aquatic weeds (macrophytes). The use of stronger chemicals necessary to kill macrophytes is not done because of constraints placed on chemical treatments applied to potable water supplies. As a result, large volumes of aquatic weeds grow annually. Removal of aquatic weed biomass through mechanical means (mowing and harvesting) would greatly reduce the annual accumulation of plant biomass and the formation of the black anaerobic floc which constitutes a severe and increasing problem for the WTPs. Mechanical methods include chaining, using excavators and backhoes, and mechanical harvesting. Dragging a chain attached to tractors on either side of the canal can be an effective technique for aquatic plant removal. Chaining dislodges plant material that must be captured and removed from the canal manually or by mechanical means. Plant material that is not collected may contribute to the dispersal of the plants and more extensive weed infestation. This method is not easy to implement or control and, therefore, is less desirable.

Plants may also be physically removed from the canal with a backhoe, dragline, or similar excavating equipment. This method is already used in the PSC during fall cleanout operations and is best used when the canal is drained. Aquatic weeds can also be removed from the canal using different types of mechanical harvesters when the canal is full. These machines typically include a height-adjustable cutter bar and a basket or conveyor for collecting the cut plants. Mechanical harvesters can be floating or tractor-mounted. Regular maintenance and removal (by mechanical mowing and harvesting) of macrophytes in chronically infested reaches is likely to be cost effective. Mechanical harvesters must be able to remove approximately two tons of plant material for every mile of canal economically and effectively (Sytsma and Parker 1999). Multiple harvests during a growing season are usually required to control aquatic plants. Chapter 9 in this report summarizes results from a pilot study of mechanical harvesting conducted during the fall of 2008 in the PSC.

Recover canal bank toe width and revegetate/stabilize

Pollutant: Sediment.
Source: Lateral.
Category: Heavy maintenance.
Recommendation priority based on benefits to costs and likelihood of success: Low.

Description: The majority of the canal banks do not have their original design cross-section due to surface erosion or landslides of the canal banks. Periodic removal of sediment accumulated along the toe of the canal bank slope provides for some local storage of sediment eroded in the future, as opposed to it being delivered directly into the canal. However, if done too aggressively, removal of this material can also increase erosion rates by undercutting the toe and over-steepening the canal bank, which itself can lead to further erosion. Also, field observations indicate that where there is abundant grass cover on the toe, regardless of the lack of horizontal toe width, there appears to be much less sediment delivery, relative to other sources of sediment. Removal of the material also eliminates vegetative cover on the toe which greatly increases subsequent sediment delivery. Installation of temporary erosion control measures along the toe, such as wattles or "socks" can reduce sediment delivery but sediment accumulated in back of them must be handled, otherwise it will be washed into the canal once the temporary erosion control is removed. NHC recommends that SCWA uses NHC's erosion hazards GIS database to prioritize reaches for treatment. SID could use the "long reach" excavator to remove the material accumulations from the toe. A temporary erosion control measure would then be placed along the edge of the toe and the disturbed area would be reseeded with native grasses. Other measures might also be applied, such as the application of a tackifier to reduce erosion during the first year following the maintenance activity. Erosion of fine sediments could actually increase for the first year or two following treatment unless erosion control countermeasures (installation of temporary erosion control measures, application of tackifiers and reseeding) are implemented.

Regrade access roads to minimally acceptable inslope and export spoil

Pollutant: Sediment.
Source: Lateral.
Category: Heavy maintenance.
Recommendation priority based on benefits to costs and likelihood of success: Low.

Description: The general approach to maintaining the canal access roads is to maintain the outside ditch flowline. This approach pulls out accumulated sediment deposited in the ditch and pushes the material to the edge of the upslope canal bank. Over decades, this activity tends to result in a steeper inside-sloping road section such that the canal bank height increases over time. This occurs particularly where there is a cut slope on the outside edge of the right-of-way that is prone to mass wasting. In such locations, instead of the sloughed material being removed, it is bladed to the outside of the access road. This approach to road maintenance leads to locating accumulations of loose earth and gravel along the edge of the canal bank, which is then subject to slippage and failure, or to direct side casting down the slope. It also leads to steeper insloped roads, which increases the amount of erosion from the road travel way.

This recommended activity would remove loose, over-steepened soil along the edge of the upslope canal bank, and reduce the inslope to approach the original design condition. It would be preferentially applied in areas where there are cut slopes bordering the outside edge of the access roads. It would also be applied in locations where there is a high berm of loose material along the edge of the road. In general, the outside berm would be bladed back onto the travelway. If the volume of the material is such that the minimally-acceptable inslope cannot be achieved, then excess material would be exported.

Eliminate side casting

Pollutant: Sediment.
Source: Lateral.
Category: Maintenance.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: Excessive "pulling" of sediments eroded off of the access roads leads to the formation of a berm of loose unvegetated material along the edge of the access road. Eventually, to maintain the width of the travel way, some of this berm material gets pushed off the roadway and is sidecast down the canal banks; either being directly deposited into the canal or depositing on the toe where it will need to eventually be removed by mechanical means. Because of this, side casting leads to additional maintenance expense. This action would train motor grader operators to reduce the accumulation of bermed material on the edge of the canal bank and eliminate direct side casting of material down the bank.

11.5. Recommended Actions Requiring Easements or Landowner Agreements

Cover crop/no till requirements on direct drains #5 and #6 watersheds

Pollutant: Sediment.
Source: Lateral.
Category: Legal agreements.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: In lieu of eliminating this major chronic source of sediment below the Serpas Check, this recommended action would require landowners within watersheds of direct drains #5 and #6 to practice no-till cultivation. This might eliminate the use of the land for some crops and would require the establishment and maintenance of a grass or other permanent groundcover in orchard and vineyard areas. If implemented, this measure could reduce sediment loading by 80-90%.

Reconnect open drains on west side of Suisun Valley

Pollutant: Sediment.
Source: Lateral.
Category: Legal agreements.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: Direct drains #7-13 were disconnected which allows all storm water entering them to discharge directly into the canal instead of being transported over the canal and discharged on the other side of the canal as it was in the past. This recommendation would reconnect the drains with overchutes, but it may require landowner agreements to establish a floodway easement and possible construction of a drainage ditch to convey flows to existing downstream drains.

Construct settling basin(s) along Pleasants Creek

Pollutant: Sediment.
Source: Lake Solano (from Pleasants Creek).
Category: Major capital improvement.
Recommendation priority based on benefits to costs and likelihood of success: Low.

Description: Pleasants Creek is the major contributor of sediment into Lake Solano. Construction of a settling basin (enlarged channel section with reduced flow velocities) along the creek would help to intercept some sediment coming from the creek. The settling basin should be located in the downstream reach near the lake and could be combined with a stream habitat enhancement project. Such a channel modification project would require extensive environmental review and permits from various agencies and could be costly to plan, permit, and implement. It may be more effective to install a series of grade control/sediment retention structures along Peasants Creek instead of attempting to build one large sediment basin. Further evaluation of the costs and benefits of this alternative are needed.

11.6 Pilot Study, Additional Study for Prescription Development

Test means for flushing sediment from Lake Solano

Pollutant: Sediment.
Source: Lake Solano.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: Means for flushing sediment deposited in Lake Solano and especially from areas in front of the PSC Headworks and in the PSC forebay should be tested in order to find practical means for passing sediment past the diversion dam without it depositing in the forebay or entering the PSC. If actual field testing is not practical, then numerical and physical models could be used to test the efficacy of this alternative.

Conduct bathymetric and vegetation survey in Lake Solano

Pollutant: Sediment and aquatic vegetation.
Source: Lake Solano.
Category: Additional study.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Lake Solano is the only source of water and one of the major sources of sediment and vegetation in the PSC. Sediment is delivered to Lake Solano from its tributaries including Putah Creek (metered outflow from Lake Berryessa), Pleasants Creek (the largest contributor of sediment), Canyon Creek, Thompson Creek, Bray Creek, and Proctor Draw. A portion of the sediment transported by these streams is deposited in Lake Solano, reducing its storage capacity and impacting project operation and maintenance, water delivery, water quality and clarity. No significant dredging of Lake Solano has occurred other than localized debris and sediment removal in the vicinity of the Headworks in the 1990's. Over time the lake has become much shallower due to sediment deposition and has filled to the point where the depth-averaged water temperatures are warmer than a couple of decades ago and sun light can now penetrate to the lake bottom in many areas, thus allowing and promoting the growth of aquatic plants. Therefore, significant portions of Lake Solano are slowly evolving into marshlands which are growing more and more diverse plant communities. Dense stands of aquatic plants accelerate sediment deposition in those portions of the lake. Because of its close proximity to the Headworks and inlet to the canal, viable plant fragments, seeds, and vegetative propagules (tubers, plant fragments, rhizomes, and turions) can easily enter the PSC with the flows being diverted from the lake.

However, present sediment and vegetation conditions in Lake Solano are largely unknown. The last study of the lake was conducted a decade ago and was concerned mainly with sedimentation issues related to their effects on water delivery to the canal (NHC 1998). This past study revealed a significant sediment deposit in the lake in front of the PSC Headworks. This sediment can be re-entrained and enter the PSC during winter flood periods and during spring and summer irrigation seasons when flows into the canal are increased. Existing bathymetric and aquatic vegetation conditions in Lake Solano should be updated to determine present-day sedimentation and vegetation growth trends and to predict likely future changes that may occur in the lake, particularly in the vicinity of the Headworks. This information would help to develop appropriate recommendations for operating the Solano Diversion Dam and for managing sediment and vegetation inflow at the PSC Headworks.

Conduct bathymetric and aquatic vegetation survey in Terminal Reservoir

Pollutant: Sediment and aquatic vegetation.
Source: Lake Solano and lateral sources.
Category: Additional study.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Turbidity data collected at the SCWA's monitoring stations installed along the PSC indicate that turbidity plumes generated by winter storms propagate from the Headworks and local drainages all the way down to Terminal Reservoir. This indicates that some fine sediment is gradually accumulating in Terminal Reservoir (reducing its storage capacity over time) and could possibly affect water quality. However, there are no present data available regarding current reservoir conditions. NHC recommends that present-day conditions in Terminal Reservoir be established to determine if sedimentation problems exist and to predict future trends and potential problems that could occur with time. This study should include survey of present-day bathymetry, measurement of fine sediment deposits, bed material sampling, water quality analysis, and aquatic vegetation survey.

Test "isolated sections" cleanout method

Pollutant: Sediment.
Source: Lake Solano and lateral sources.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: Medium to high.

Description: A method of cleaning short isolated sections of the canal is suggested in Section 11.4. This method includes isolating a critical section of the canal with portable dams, draining the section, pumping water around the isolated section not to interrupt water supply, and mechanically cleaning the section. A field test of this method is needed to determine its effectiveness for the conditions of the PSC. The test should be conducted during fall or winter low flow period in a selected, small section of the canal (probably in one of the downstream checks, which are less critical in terms of water supply).

Conduct jar tests and larger-scale polymer field tests

Pollutant: Sediment.
Source: Lake Solano and lateral sources.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: Preliminary laboratory experiment and bench scale polymer application tests (see Chapter 10) indicated that there is good potential for applying polymers to accelerate settling of suspended sediments and to densify slurry deposits in the PSC. A few blends of polymers were tested and a blend most effective for PSC water and sediments was selected. It was also concluded that if dosed properly, the selected polymer blend would comply with NSF, Federal and State water quality standards. The following two pilot studies are recommended to help further define the potential beneficial uses of polymers to manage and remove sediment from the PSC.

1.) Determine the best polymer type and dosage using standard jar tests. Standard jar tests would be conducted monthly during critical periods when flows are high and when sediment and algal concentrations are high. A few types of polymers from different manufacturers would be tested in standard jar testing apparatus to determine which polymer compound and dosing rate works best for conditions found in the PSC. Similar tests would be conducted for samples of slurried bottom materials typically found during annual cleanout. Results from these tests would allow SCWA to select the most effective polymer type for each type of application (summer, winter, and cleanout) and be able to establish fairly reliable dosing rates for those three conditions. Most water treatment laboratories posses jar testing apparatus and conduct standard “jar tests” regularly so they can adjust their plant’s dosing rates seasonally. It might be possible for one of the WTPs along the PSC to conduct these tests if NHC collects the samples and provides the polymers for testing.

2.) Conduct large-scale polymer field testing. In order to further assess the applicability and costs of using polyacrylamides for the PSC conditions, NHC suggests conducting a large-scale *in-situ* field test. Sediment and organic laden PSC bottom materials and water from the canal would be pumped into a mixing tank where the water and sediment slurry would be thoroughly mixed with the polymers and then the water would be moved through a series of settling tanks via hoses and pipes. The main objectives of this tank test would be to determine the effectiveness, feasibility, dosing levels, water quality impacts, and potential cost of large-scale applications of the selected polymers for settling suspended sediments and densification of biological slurry deposits in the PSC. If successful, results from the field tests would be used to design full scale treatments in a manageable, cost effective, and environmentally friendly manner.

Test effectiveness of "gravity belt sludge thickening devices" to enhance sludge thickening and separation from water during canal cleanout

Pollutant: Vegetative decomposition products.
Source: Canal.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: The water and wastewater treatment industry often use sludge thickening devices to separate sludge materials from water. Devices such as gravity belt sludge thickeners, drum and belt press thickeners are reliable and are commonly used by water treatment industries to remove sludge from water. Commercially available sludge separator and thickening devices are available for rent and often are available as portable units mounted on flat-bed truck trailers for easy deployment to project sites (Figure 11.23). Rental costs vary from approximately $4,000 to $9,500 per month depending on treatment capacity needed. Some units also come with polymer-aided pre-flocculation tanks used to greatly accelerate the sludge-water separation process. NHC recommends that a pilot test with one of these portable units be conducted adjacent to the PSC during fall cleanout. After project operators remove as much sediment and black sludge as they can using traditional mechanical means, this pilot test would pump some of the remaining sludge and water slurry mixture from the canal through the sludge thickener. Sludge processing rates, efficiency, costs and water quality characteristics of the cleaned water (supernatant water) would be determined.

The second tests would determine how much improvement occurs if polymers are added in the pre-flocculation chamber. If the post-treated water quality (turbidity, SSC, etc) is acceptable after being processed through the sludge separator, a second larger-scale trial could be conducted on a second day of testing. During these tests the process would attempt to pump and treat all of the residual water and sludge remaining in the check after normal cleanout activities. The tests could be conducted at night if necessary so not to disturb or delay other canal cleaning activities. Supernatant water could be discharged back into the canal downstream from the check structure. This series of pilot tests would provide valuable information to determine if this portable, site-specific sludge treatment method is effective and affordable. This method of removing and treating the residual sludge materials will only need to be implemented in the most difficult to clean (chronic) reaches of the PSC.

Continue pilot studies to revegetate herbicide treated canal banks

Pollutant: Sediment.
Source: Lateral.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: Surface erosion from barren canal banks is considered to be a chronic, but minor source of sediment. A plot study at nine sites along the canal was initiated in fiscal year 2009 to assess the feasibility of revegetation efforts and to identify species which provide the most effective erosion control (see Chapter 5). Because of drought conditions that occurred during the winter 2008-2009, the results are partially inconclusive. This recommended action would continue the revegetation plot studies and expand it to include scarification and hydro mulching which would simulate actual implementation of revegetation prescriptions.

Test use of acrylic copolymers on canal banks currently treated with broad-spectrum herbicide in lieu of revegetation or gravel mulch treatments

Pollutant: Sediment.
Source: Lateral.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: Surface erosion from barren canal banks is considered to be a chronic, but are a minor source of sediment. This action might be preferred in areas where maintaining the canal bank in a barren condition is preferred for visibility considerations. This action would apply acrylic copolymers (Figure 11.18) as a surface erosion control agent on canal banks on different soil types and differing application rates to test the cost-effectiveness and longevity of such treatments in comparison to alternative treatments.

Test use new technologies, “floc-logs” for fine sediment control at direct drains

Pollutant: Sediment.
Source: Lateral.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: Much of the coarse sediment associated with discharge from the direct drains accumulates on the canal bottom at the point of discharge and can be readily removed if sufficiently dewatered. Fine sediments (silts and clays), however, are entrained into the flow. There are new technologies aimed at the removal of fine sediments, but they may be either infeasible because of highly variable discharge rates or not cost effective, i.e. it may simply be more cost effective to remove the turbidity through settling at the terminal reservoir. This recommended action would evaluate methods and benefits of using “floc-logs” to reduce turbidity discharged from direct drains.

Conduct large-scale mechanical harvesting test

Pollutant: Aquatic vegetation.
Source: Lake Solano.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: Low to medium.

Description: Mechanical harvesting provides a potential means for controlling vegetation growth in the canal and reducing the level of cleanout effort (and costs) necessary each year. A successful demonstration pilot study was conducted in the fall of 2008 to determine the effectiveness of mechanical harvesting in the PSC (Chapter 9). Test harvesting was conducted in a three very short reaches in the downstream portion of the PSC (away from the major water users) and was closely monitored by SCWA and NHC staff. This pilot test demonstrated that mechanical harvesting is an effective means for rapid removal (mowing) of submerged vegetation from the canal and, at the same time, does not cause a significant impact on water quality characteristics. An additional, larger-scale harvesting test is needed to determine more reliable costs, benefits, and specifications for canal-specific harvesting equipment. NHC recommends that a large-scale application be performed in a few of the most problematic reaches in the main portion of the canal (such as the Waterman WTP and/or the McCoy and Alamo reaches). A large-scale aquatic vegetation harvesting test program would be conducted using a commercially available harvester. Turbidity and vegetation fragment booms (nets) would be installed at the downstream end of each harvesting reach. Vegetation would be cut just above the sediment layer (so not to disturb sediment deposits), collected into the harvester, and then disposed off on the canal banks. Water quality and biomass flux downstream of the mowed sections would be monitored to assess impacts from the mechanical vegetation removal. The large-scale test would provide essential information needed to design “customized harvesting equipment” that is best suited for use in the PSC. Data from the tests could be provided to vendors of harvesting equipment to seek capital cost estimates for the equipment and/or cost estimates for annual maintenance contracts.

Test effectiveness of cleaning canal sides to remove algae

Pollutant: Aquatic vegetation.
Source: Lake Solano.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: This pilot study would test and demonstrate the benefits and costs of mechanical removal (brushing) of algae from the canal side slopes. Monitoring of algae regrowth in the cleaned section would show the effectiveness, benefits and cleaning frequency of such thorough cleaning activities.

Test effectiveness of ultrasonic algae control

Pollutant: Aquatic vegetation.
Source: Lake Solano.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: Low to medium.

Description: Different ultrasounic devices are commercially available that are specially designed to control algae growth in a variety of water systems including lakes, ponds, and rivers. These devices transmit a complex pattern of ultrasonic vibrations through the water column. The vibrations match critical resonance frequencies of vital algae membranes causing them to tear or break and ultimately causing the algae to die. These vibrations are harmless to humans, animals, fish and aquatic plants and have no impacts to water quality. The maximum effective range is about 500 ft for green roaming algae and up to 1,300 ft for blue-green algae. Different algae types are affected differently by this technology. Some algae are disabled in days while some require a few weeks to be completely dead.

This pilot study would test the effectiveness of commercially available ultrasounic devices to control algae in the PSC at selected locations and settings. One of the questions that needs to be answered is whether ultrasound is effective in killing algae in slow flowing water such as the PSC. An ultrasonic devise would be installed at selected locations where established algae populations are present. Ideally, the test site should be located upstream of, or as far away as possible from chemical application locations to eliminate the effect of chemical treatment on algae growth in the test reach. Daily monitoring of algae conditions in the test reach would be conducted to determine the effectiveness of ultrasonic algae control. If successful, ultrasonic algae control devices could be installed at strategic locations in the PSC such as the Headwork, near major water intakes, and reaches that are most severely affected by algae growth.

Test effects of shading

Pollutant: Aquatic vegetation.
Source: Lake Solano.
Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: Low to medium.

Description: Aquatic plants, like all plants, require light for photosynthesis. Shading may be one of the means for managing (reducing) aquatic vegetation. This pilot study would assess the effectiveness of seasonal shading on aquatic vegetation growth in the PSC. The test would be conducted in one of the most problematic reaches (such as Terminous Check). Shading would be installed in a short (300-500 ft long) section of the canal with already established mature aquatic vegetation. Monitoring of the shaded reach would be conducted at one month intervals to determine vegetation conditions and to establish the period required to kill or significantly reduce the vegetation in the shaded areas. An other test site could be shaded prior to the active growing season and monitored to see if aquatic plants colonize the shaded reach of canal or not. Water samples would also be collected and analyzed in a laboratory to determine if there are any effects of dying vegetation on water quality characteristics. If successful, portable shading could be installed at selected strategic locations along the PSC where vegetation growth problems are most severe and undesirable, such as upstream of flow control structures and in the vicinity of major water intakes.

Investigate use of aeration or ozone treatments to manage algae

Pollutant: Vegetation.
Source: Lake Solano.

Category: Pilot study.
Recommendation priority based on benefits to costs and likelihood of success: Low.

Description: Investigate the use of aeration or ozone treatments to prevent the occurrence of anoxic conditions within the most problematic reaches of the canal, especially in the vicinity of water intakes to WTPs. Because of the extremely low velocities, conditions within the canal are analogous to an urban lake, and strategies of controlling algae and weeds in urban lakes may be highly applicable here. These include the use of aeration, ozone and "farming" aquatic macrophytes to strip out nutrients from the water column to reduce the growth of algae. Such treatments can also reduce odor problems. A small pilot study could be developed to test the effectiveness of these treatment options.

Determine effect of present ground water conditions on stability of canal's concrete panels

Pollutant: Sediment.
Source: Lateral.
Category: Additional study.
Recommendation priority based on benefits to costs and likelihood of success: Medium.

Description: The portion of the total in-canal volume that can be used for water storage and supply during Headworks closure periods is limited by the necessity to maintain minimal water depths within the canal to prevent concrete panels from being damaged by high ground water pressures. However, no information is available as to what is this minimal water depth required in different sections of the canal. This investigation would establish seasonal variation of ground water levels along the canal and would determine minimal water depths required for canal's panels to remain stable. Results from this study would be used to determine which sections of the canal could be drained safely to pre-specified depths. This would allow maximal use of the canal storage capacity during canal shut down periods (during winter high turbidity events and annual canal cleanouts).

Prepare "project performance monitoring program" and enhanced GIS data management system to track costs and performance of project improvements

Pollutant: Sediment and vegetation.
Source: Lake Solano, lateral and in-canal sources.
Category: Additional planning activity.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: NHC recommends that a detailed "project performance monitoring program" be developed to track costs and performance (short and long-term) of individual capital improvements and other changes in project operations. Such a program would greatly benefit from also improving or expanding SCWA's present GIS system to accommodate and assess project performance monitoring data, capital improvement cost, O&M costs, and overall project performance. Evaluation of annual results will allow SCWA and Solano Project operators to determine (quantify) how each improvement is performing with time, how much it costs to install, maintain and operate, and whether project improvements are meeting expectations.

Apply multi-dimensional (2-d or 3-d) numerical or physical models to evaluate and design project alternatives

Pollutant: Sediment and vegetation.
Source: Lake Solano, lateral and in-canal sources.
Category: Additional planning activity.
Recommendation priority based on benefits to costs and likelihood of success: High.

Description: Numerical or physical models provide a very cost-effective means for testing and evaluating recommended capital improvements and operations alternatives presented in this chapter. NHC recommends that 2-d or 3-d hydrodynamic numerical and/or physical models be used to further evaluate the feasibility, design requirements, and potential benefits of several of the major capital improvements and operations alternatives recommended for the PSC Headworks and Putah Diversion Dam. A physical model of the diversion dam and Headworks facilities could be used to evaluate several structural, mechanical, and operational aspects of the alternatives presented herein. A mobile boundary physical model (capable of simulating sediment transport processes) is also ideal for evaluating the effectiveness of sediment sluicing or removal alternatives as well as vegetation screening alternatives. NHC has experienced staff and operates several in-house numerical as well as physical modeling facilities in North America.

11.7. Summary of Recommendations

According to data collected during the course of this study, sediment enters the PSC from two major sources: (1) from Lake Solano and (2) from lateral sources located along the canal (including overbank flow, surface erosion of canal earth banks, bank sloughing, and local open drainages). The most likely primary source of aquatic vegetation entering the canal is from Lake Solano. Aquatic plant fragments enter the canal from the lake, attach to sediment deposits and canal walls, and grow into live plants that expand into thick colonies. Therefore, management of sediment and aquatic vegetation in the PSC should be focused, first, on prevention or maximum reduction of sediment and vegetation inflow into the canal ("preventative actions") and then on reducing sediment accumulation and plant growth in the canal proper ("corrective, or remedial actions"). Corrective actions should also include provision of alternative/supplemental backup water supply for the PSC users during canal shut down (Headworks closure) periods that occur during winter high turbidity events and annual cleanouts. The overall recommended approach for sediment and vegetation management in the PSC includes preventative and corrective actions as summarized below.

Preventive actions:

- First line of defense – Headworks: Intercept, remove and keep sediment and aquatic vegetation from entering the PSC.
- Second line of defense – upper checks (Sweeney and Gibson Checks): Trap and remove fugitive sediment and vegetation in the upper checks as much as possible.
- Third line of defense – Best Management Practices (BMPs): Design and implement an aggressive BMP program along the PSC to reduce lateral sediment loading.

Corrective (remedial) actions:

- Modify flow control gates and water intakes to reduce downstream distribution and spreading of sediment along the canal and encourage sediment deposition at intake structures.
- Design and implement a more effective aquatic vegetation management program to reduce introduction, growth and survival of fugitive weeds and algae in the PSC. This program may include a combination of installing more effective screening devices, modifying chemical treatment programs, mechanical harvesting, application of ultrasonic devices to kill algae, and installation of shading to reduce weed/algae growth.
- Implement more effective canal cleanout methods.
- Maximize internal storage capacity of the canal for use as a backup water supply during canal shut down and Headworks closure periods.
- Provide supplemental backup water storage and supply for WTPs during periods of canal shut down and closure of the Headworks during winter high turbidity events and during fall cleanouts.

NHC developed conceptual level recommendations and suggestions for managing turbidity, sediment, and aquatic vegetation in the Putah South Canal based on the results of this study. The recommendations are grouped by category: (1) capital improvements; (2) operations; (3) maintenance; (4) actions requiring easements or legal agreements; and (5) pilot studies and additional analyses needed for prescription development. Each recommendation targets specific problems in the PSC. However, given the severity of sediment- and vegetation-related problems currently observed in the canal, the best results are likely to be achieved by implementing an integrated program of improvements and modifications. Table 11.1 summarizes "primary" recommended Putah South Canal capital improvements, re-operation recommendations, pilot studies, and alternative water supply options that are most likely to contribute to reducing sedimentation and aquatic vegetation growth in the canal. The improvements are grouped in this table by their main purpose and ranked according to their installation cost, operation and management cost, and expected effectiveness and benefits. Additional recommendations are presented earlier in this chapter but are not included in Table 11.1 because they are not considered to be "primary recommendations." Figure 11.1 presents a conceptual schematic showing possible locations of many of the recommended capital improvements.

Capital improvements aimed at reducing sediment inflow to the PSC from Lake Solano include modification of the Headworks and flow control gates, installation of settling basins, silt curtains, sediment extractors, and internal spillway gates or dams in the upper canal checks. Effectiveness of many of the proposed sediment-detention structures may be increased by application of NSF approved flocculation settling agents (polymers) to accelerate settling of suspended sediment. Results from recent polymer settling tests show that polymers greatly reduce settling time, improve water clarity, and increase the bulk density of settled materials.

For operational improvements, periodic flushing of sediment deposited in Lake Solano in front of the Headworks and in the PSC forebay will help to lessen the sedimentation problems in the lake and will reduce the amount of sediment entering the PSC from the lake deposits. Additionally, water intakes experiencing significant sedimentation problems could be reconfigured or relocated according to site-specific conditions to draw waters from cleaner upper layers of the canal.

Development of alternative water sources would also help to reduce sediment inflow to the PSC from Lake Solano. The most effective way to reduce sediment inflow into the canal from the lake during high turbidity events is to close the Headworks. Because of the ongoing winter demand for M&I water, the fundamental restriction on keeping the Headworks closed is a lack of supplemental, alternative water sources. Additional water storage could be provided by increasing the usable storage capacity of the canal (for example, by installing additional internal gates between major check structures) and/or installing storage tanks or small reservoirs at strategic locations along the canal. These are major capital improvements and may need to be implemented over a period of several years. Alternative water sources can be provided with a water supply pipeline from Lake Berryessa or from Putah Creek upstream of Lake Solano, as well as ground water wells. These alternatives warrant further evaluation.

Sediment loading from lateral sources located along the canal can be significantly reduced by implementing an aggressive large-scale BMP program (to reduce erosion of canal banks), installing localized erosion control measures along frequently overtopped banks, and eliminating sediment inflow from open drains.

For the canal cleaning, in-canal sediment deposits could be removed more effectively by reactivating wasteways, however these actions will require special permits. Cleanout operations may be aided by maximizing and utilizing in-canal water storage and by providing alternative water supply sources during cleanout. Alternative water supplies during cleanout will greatly reduce logistical constraints and provide more time for Solano Project operators to thoroughly clean the canal. The use of NSF approved sediment settling aids (polymers) and portable commercial sludge thickening equipment could also help improve the canal cleanout, and warrants field testing and evaluation. Development of new improved methods is important because current cleanout methods are not capable of removing the fine anaerobic floc and sludge materials that continue to accumulate and cause water quality and water supply disruptions for the WTPs.

The influx of aquatic vegetation into the PSC from Lake Solano can be significantly reduced by installing more effective high capacity screens and automated screen cleaning equipment at the Headworks. This can be achieved by replacing the Headworks screens with more effective narrow mesh screens and automated screen cleaners. It is also recommended that the benefits and costs of installing a series of finer screens downstream from the Headworks with automated trash cleaners be evaluated. Removal of plant fragments can be greatly increased with a series of finer and finer screens (polishing screens) in the upper checks of the canal. Improved high capacity fine screens with automated screen cleaners may also be installed at the main water intakes to intercept fugitive plant fragments. Growth of weeds and algae in the canal proper may be reduced by a combination of screening, chemical treatments, mechanical harvesting, application of ultrasonic devices to kill algae, and installation of shading to reduce weed/algae growth.

NHC also recommends that a detailed project performance monitoring program be developed to track costs and performance of individual capital improvements and changes is project operations. Such a program should rely on expanding and improving SCWA's present GIS system to be able to store and evaluate data, costs and performance results over time.

The recommendations presented in this report are based on available information and review of various options available for controlling sediment and aquatic vegetation in the PSC. Additional technical assessment and design analyses are needed to evaluate the feasibility and cost/benefits of the recommended large-scale capital improvements and modifications listed herein. Therefore, NHC also recommends that numerical and possibly physical models be used to test and evaluate selected recommended improvements and operations alternatives presented in this chapter.

Alternatives that were either reduced to a low priority or removed from initial list of recommendations

After initial consideration the following alternatives were either reduced to a low priority at this time, or they were removed from the list of initial recommendations following discussions with SCWA and the Project Operators.

Capital improvements:

- Increase flood flow capacity of Sweeney Creek in vicinity of PSC to reduce overtopping flows into PSC (low priority at this time).
- Install automated in-canal sediment extractors (low priority at this time).
- Install seasonal silt curtains in upper checks (low priority at this time).
- Install in-line or parallel sediment settling basin(s) in upper checks (low priority at this time).
- Retrofit or relocate intake for Waterman WTP downstream from Serpas Check (low priority at this time).
- Perform selective dredging and vegetation management in Lake Solano (intended to reduce sediment and vegetation loading into the PSC) (omitted).
- Install sediment traps on all direct drains (omitted).
- Construct managed seasonal wetlands adjacent to PSC in upper checks to provide winter time water storage and sediment filtration (omitted).

Maintenance:

- Develop, plan and implement mechanical harvesting of vegetation in PSC (low priority at this time).
- Lay back canal banks to avoid mass wasting (soil slips and landslides) in high bank areas (omitted).

Pilot studies:

- Test use of soil amendments to increase vegetation growth and density in areas with poor soil characteristics (omitted).
- Conduct field tests to determine the effectiveness of current $CuSO_4$ algae treatments (omitted).
- Test feasibility of using weed eating fish to control vegetation in PSC (omitted).
- Monitor turbidity and inflowing sediment load to PSC during summer irrigation season (omitted).
- Conduct aquatic vegetation species inventory of Lake Solano and monitor species changes and growth rates over time; determine if there are in-lake vegetation management opportunities (omitted).
- Investigate use of aeration or ozone algae treatments (omitted).

Table 11.1. List of primary capital improvements, re-operation activities, and pilot studies recommended for Putah South Canal.

Capital improvement or recommended action	Purpose	Installation cost*	O&M cost**	Expected effectiveness and benefits
Sediment control				
Construct a pipeline to bring clear water from the outlet at Monticello Dam or from a location in Putah Creek well upstream from Lake Solano or sediment producing tributaries, directly to the PSC (see Fig. 11.1)	Provide reliable clean water supply; reduce or eliminate sediment and vegetation problems entering PSC from Lake Solano or tributary watersheds upstream from Headworks	High	Low	High
Install water tight gates outboard of Headworks trash screens during rainy season (see #3 in Fig. 11.2)	Draw cleaner surface water from Lake Solano; reduce inflow of high turbidity water during winter storms	Low to med	Low	Medium to high
Install Headworks forebay flushing system (see #4, 5, 7 in Fig. 11.2)	Modify the Headworks forebay (high pressure jets and sluice pipes) to back flush sediment deposited in the forebay; reduce sediment loading into the PSC	Medium	Low to medium	Medium to high
Modify tainter gates at inlet to the PSC (#6 in Fig. 11.2)	Draw winter flows over the top of the gates; reduce transport of bottom sediments into the PSC	Low to med	Low	Medium
Reconfigure PSC check gates	Spill water over the top of the gates during winter periods; reduce propagation of sediment to downstream checks	Medium	Medium	Medium
Reconfigure and/or relocate water intakes	Reduce sediment and vegetation issues at specific intakes	Medium	Medium	Medium to high
Install auto screen cleaners at water intakes (see Figs. 11.7 and 11.8)	Reduce vegetation and O&M costs at specific water intakes	Medium	Low	Medium to high
Increase capacity of the McCune Creek overchute flume	Reduce sediment loading into the PSC from the McCune overchute	Medium	Low	Medium
Increase flood capacity of Sweeney Creek or install flood overtopping structures along canal banks (Fig. 11.1)	Reduce sediment loading into the PSC from Sweeney Creek	Medium	Low	Medium to high
Increase flood conveyance across PSC near Suisun and Ledgewood Creeks	Reduce sediment loading into the PSC from Suisun and Ledgewood Creeks	Medium	Low	Medium to high
Install additional intermediate spillway gates or inflatable rubber dams in upper checks (Figs. 11.13-11.17)	Settle suspended sediment in upper checks; isolate lateral sediment loading to small portion of a check; provide increased water storage during canal winter shutdowns	Medium	Medium	Low to medium
Eliminate direct drains #5 and #6	Reduce lateral sediment loading into PSC; reduce annual cleanout costs	Medium	Low	Medium
Apply gravel on remaining reaches of access roads that drain into canal	Reduce lateral sediment loading into PSC; reduce annual cleanout costs	Medium	Low	Medium
Apply gravel mulch on canal banks with poor soils and low vegetation growth potential	Reduce lateral sediment loading into PSC; reduce annual cleanout costs	Medium	Low	Medium
Eliminate (or greatly reduce) monocotyledon herbicide use on canal banks	Reduce lateral sediment loading into PSC; reduce annual cleanout costs	Medium	Low	Medium
Install erosion control measures (riprap, cellular confinement mats, turf reinforcement mats, etc) at frequently overtopped canal bank locations on Sweeney, Alamo, Ledgewood Creeks (Figs. 11.1, 11.18, and 11.19)	Protect earthen banks against surface erosion and panel damage during large storms	Medium	Low	Medium to high
Reactivate wasteways (particularly McCoy Wasteway) (Fig. 11.1)	Flush deposits from the PSC during cleanouts; will likely require permits and settling basins downstream from wasteways	Low	Low	Medium
Implement comprehensive BMP program	Reduce sediment supply from banks and other lateral sources	Medium	Low	Medium

O&M = operation and maintenance; * Installation cost: low <$500,000, medium $500,000-$2,000,000, high >$2,000,000;
** O&M cost: low <$100,000 per year, medium $100,000-$500,000 per year, high >$500,000 per year.

Table 11.1. (continued).

Capital improvement or recommended action	Purpose	Installation cost*	O&M cost**	Expected effectiveness and benefits
Sediment control				
Develop modified diversion dam and Headworks operating rules to apply during winter storms, during spring ramp-up into irrigation season, and during canal cleanout periods (#1 in Fig. 11.2)	Improve ability to keep turbid water from entering the Headworks and reduce canal sediment cleanout	Low	Low	High
Modify flow management procedures in Lake Solano during storms and increase post-storm releases from Lake Berryessa	Reduce sediment loading into PSC; reduce annual PSC maintenance costs	Low	Low	Medium to high
Improve storm monitoring and forecasting procedures	Reduce sediment loading into PSC; reduce canal maintenance costs	Low	Low	Medium to high
Modify Headworks operations during winter storm events to reduce sediment to PSC	Reduce sediment loading into PSC; reduce canal maintenance costs	Low	Low	Medium to high
Develop a canal overtopping emergency response plan	Reduce sediment loading into PSC; reduce canal repair and cleanout costs	Low	Low	Medium to high
Clean short sections of the canal instead of entire checks (see Figs. 11.13-11.17 and 11.21-11.22)	Isolate, dewater, and clean most difficult sections of canal checks; reduce cleanout costs and improve effectiveness	Low to medium	Low to medium	Medium
Aquatic vegetation control				
Install new Headworks screens with auto cleaner (see #2 in Fig. 11.2 and Figs. 11.3-11.6)	More effectively intercept and remove weed fragments and trash; reduce influx of aquatic vegetation from Lake Solano; reduce screening O&M costs	Medium to high	Medium	High
Install additional fine screens with auto cleaners in the Headworks forebay and in upper checks (Fig. 11.1)	Intercept and remove fugitive aquatic vegetation that passes though the Headworks screens; operate during summer irrigation season	Medium to high	Medium	High
Install new fine screens with auto screen cleaners at intakes (Fig. 11.7 and 11.8)	Intercept and remove aquatic vegetation at major agricultural and municipal water intakes	Medium	Medium	High
Ultrasonic algae control devices (Fig. 11.1)	Potentially kill algae and reduce chemical treatment needs (needs testing)	Medium	Low	Low to medium
Shading at specific locations (Fig. 11.1)	Kill weeds and algae; reduce vegetation loading on intake screens and vegetation growth in the PSC (needs testing)	Low	Low	Low to Medium
Supplemental water supply				
Assess availability and cost for supplemental water supply sources (Figs 11.1 and 11. 2)	Provide additional water storage, supplemental supply and lengthen periods of time that the PSC can be closed for cleanout or to pass high turbidity flows during winter storms	Assessment cost is low	Low to medium	High
Design and construct water bypass pipeline along the PSC (Fig. 11.1)	Provide access to alternative sources of water supply during canal winter shutdowns and fall cleanouts	High	Low to medium	High
Construct supplemental water supply reservoirs and tanks (Fig. 11.1 and #9 in Fig. 11.2)	Provides additional water supply sources during canal winter shutdowns and annual cleanouts; increases the allowable shutdown period (see Fig. 11.20)	High	Low to medium	Medium to high
Construct a supplemental water supply pipeline from Lake Berryessa or upper Putah Creek (well upstream from Lake Solano) to the Headworks (see Fig. 11.1)	Provide alternative water supply; reduce or eliminate sediment and vegetation problems from Lake Solano (expensive, but most reliable solution to water supply, sediment and vegetation problems in PSC)	High	Low	High
Install ground water wells	Provide alternative water supply and reduce pore water pressures on canal panels during winter months	Medium	Low	Low to medium

O&M = operation and maintenance; * Installation cost: low <$500,000, medium $500,000-$2,000,000, high >$2,000,000;
** O&M cost: low <$100,000 per year, medium $100,000-$500,000 per year, high >$500,000 per year.

Table 11.1. (continued).

Capital improvement or recommended action	Purpose	Installation cost*	O&M cost**	Expected effectiveness and benefits
Monitoring and pilot studies				
Conduct field tests with trailer mounted gravity belt sludge thickening equipment (Fig. 11.23)	Determine the performance of sludge dewatering and enhancement equipment (with and without polymers)	Low	None	High
Test means for flushing sediment deposited in Lake Solano from in front of the Headworks prior to spring ramp up for irrigation flows (see #1 in Fig. 11.2)	Determine if opening gates 11 and 12 will remove sediment deposits from the area immediately in front of the trash screens	Low	Low	High
Filed test (or evaluate with models) Headworks forebay flushing system (see #4 in Fig. 11.2)	Suspend sediment deposits in the forebay using high pressure water jets; flush suspended deposits back through trash screens and sluice pipe into Putah Creek below the diversion dam	Low	Low	Medium to high
Continue to test and monitor sediment control BMPs along the PSC	Determine the effectiveness of various BMPs for erosion control	Low to medium	Low	High
Test ultrasonic algae control devices (Fig. 11.1)	Determine effectiveness of commercially available ultrasonic devices to kill algae and reduce chemical treatment needs	Low	Low	Low to medium
Conduct bathymetric and aquatic vegetation surveys in Lake Solano and Terminal Reservoir	Determine present sediment and vegetation conditions	Medium	Low	Low to medium
Conduct jar tests and larger-scale polymer field tests	Determine best polymer type(s) and dosing requirements for settling suspended sediments in the PSC	Low	Low	Medium
Continue pilot studies to revegetate herbicide treated canal banks	Simulate and test actual implementation of revegetation prescriptions	Low	Low	Medium
Test mechanical methods to remove algae	Determine the effectiveness and benefits of mechanical removal of algae from canal sides	Low	Low to medium	Low to medium
Test shading at specific locations (Fig. 11.1)	Test effectiveness for controlling weeds and algae; reduce vegetation loading on intake screens and vegetation growth in the PSC	Low	Low	Low to Medium
Conduct full scale test (in one or two checks) of mechanical vegetation harvesting (Fig. 9.30)	Remove in-canal vegetation; reduce plant material loading; reduce canal cleanout costs; improve water quality	Medium	Medium	Low to medium
Prepare “project performance monitoring program” and enhanced GIS data management system	Track costs and performance (short and long-term) of project improvements	Low	Low	High
Apply multi-dimensional (2-d or 3-d) numerical or physical models	Use modeling to evaluate the feasibility, design requirements and potential benefits of major capital improvements and operations alternatives recommended for the Headworks and Putah Diversion Dam	Low	Low	High

O&M = operation and maintenance; * Installation cost: low <$500,000, medium $500,000-$2,000,000, high >$2,000,000;
** O&M cost: low <$100,000 per year, medium $100,000-$500,000 per year, high >$500,000 per year.

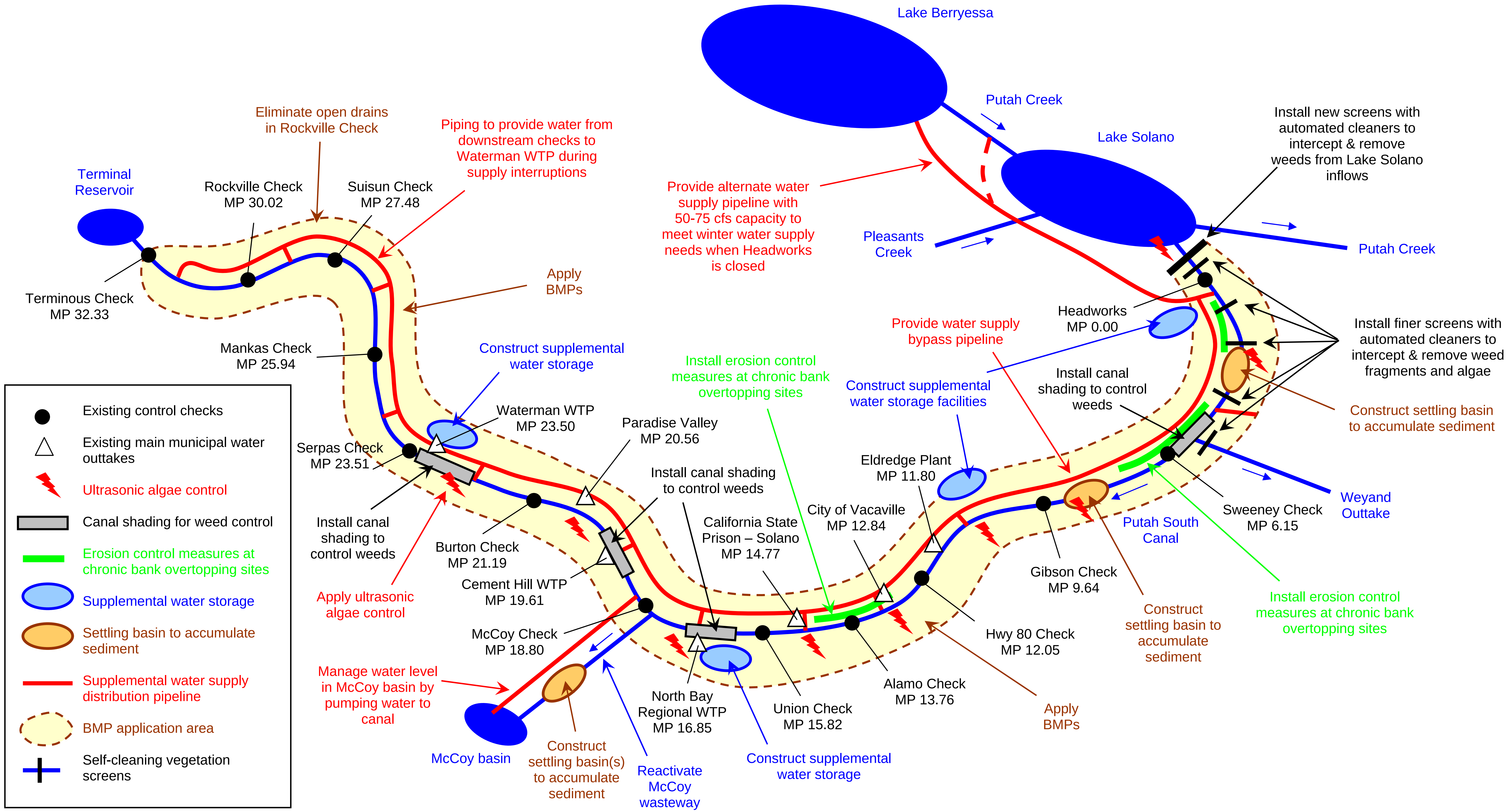


Figure 11.1. Conceptual schematic showing locations of recommended capital improvements to Putah South Canal for sediment, weed, and algae control.

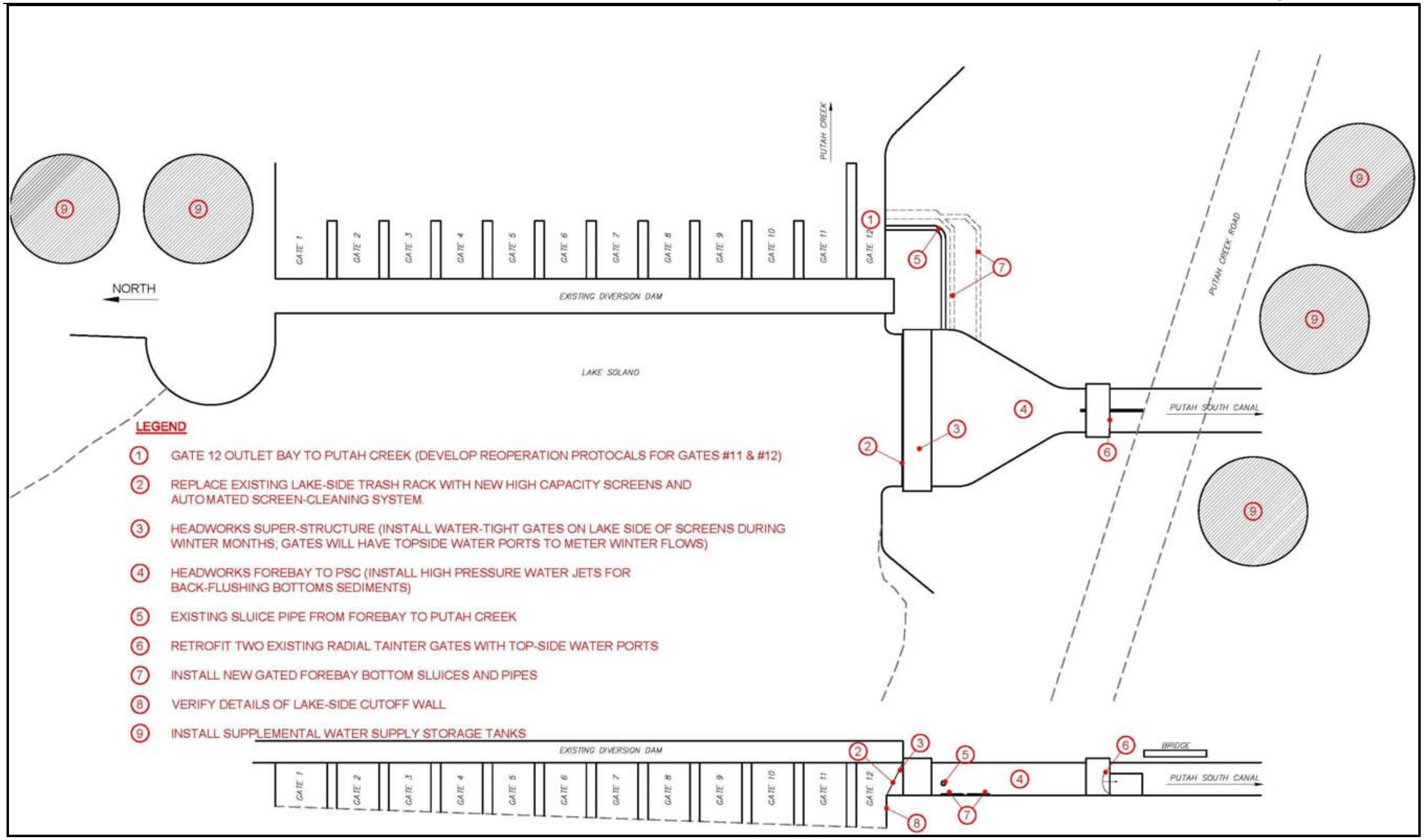


Figure 11.2. Recommended improvements to facilities at Putah South Canal Headworks and diversion dam.

Figure 11.3. Brackett Bosker Raking Machine. Images by Eimco Water Technologies (http://www.glv.com).

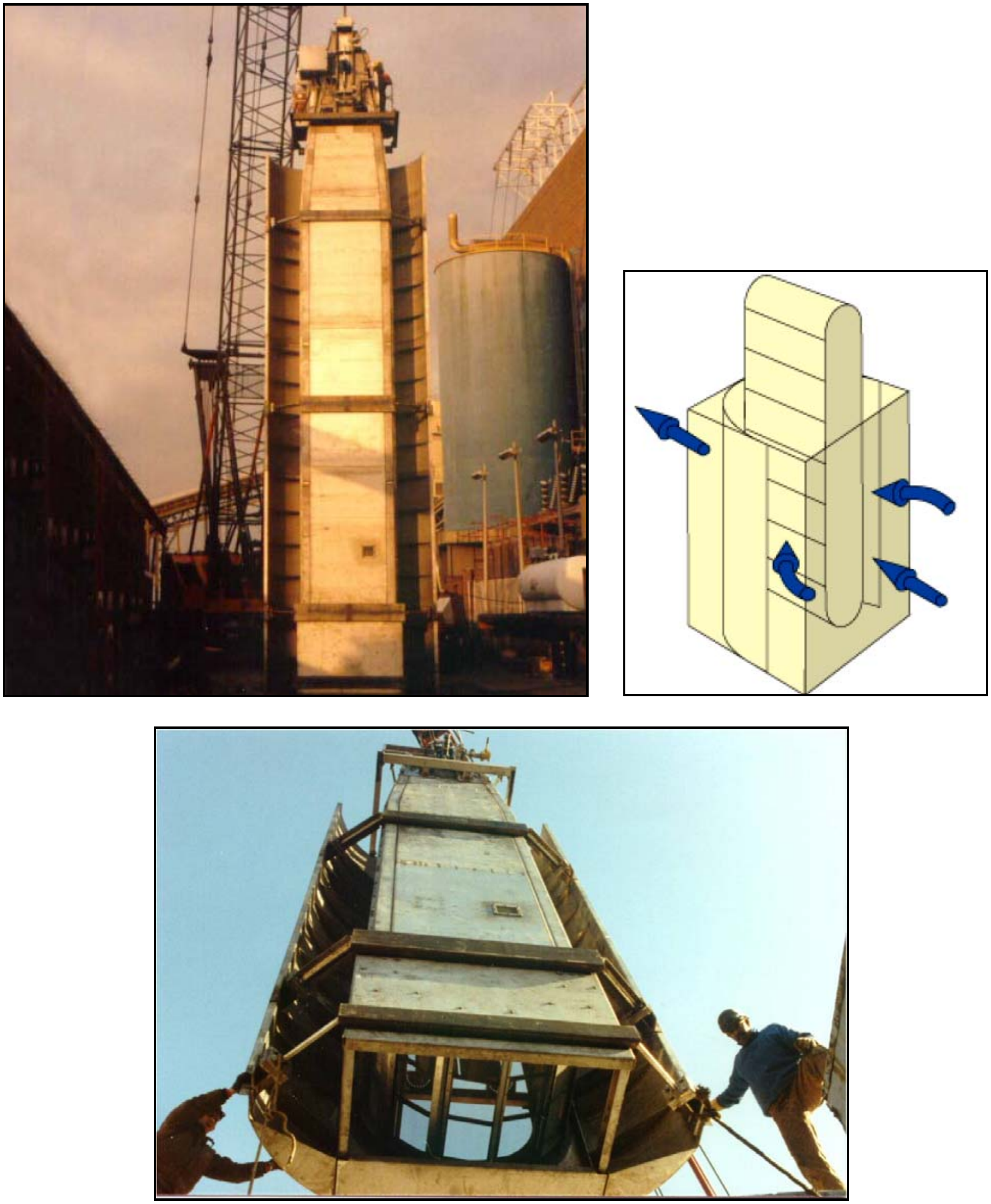


Figure 11.4. Brackett Green Dual Flow Band Screen. Images by Eimco Water Technologies (http://www.glv.com).

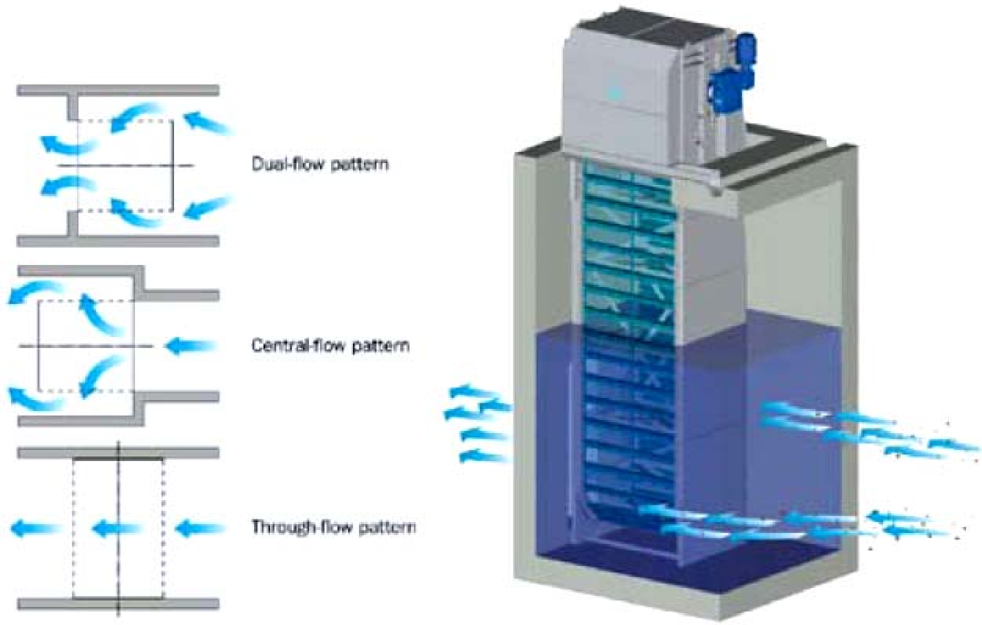


Figure 11.5. Brackett Green Traveling Band Screen. Images by Eimco Water Technologies (http://www.glv.com).

Figure 11.6. Brackett Green Double Entry Drum Screen. Images by Eimco Water Technologies (http://www.glv.com).

Figure 11.7. Aqua System 2000 Inc. Inline Screen Cleaner (top) and Side Screen Cleaner (bottom). Photos provided by Aqua System 2000 Inc (http://www.aquasystems2000.com).

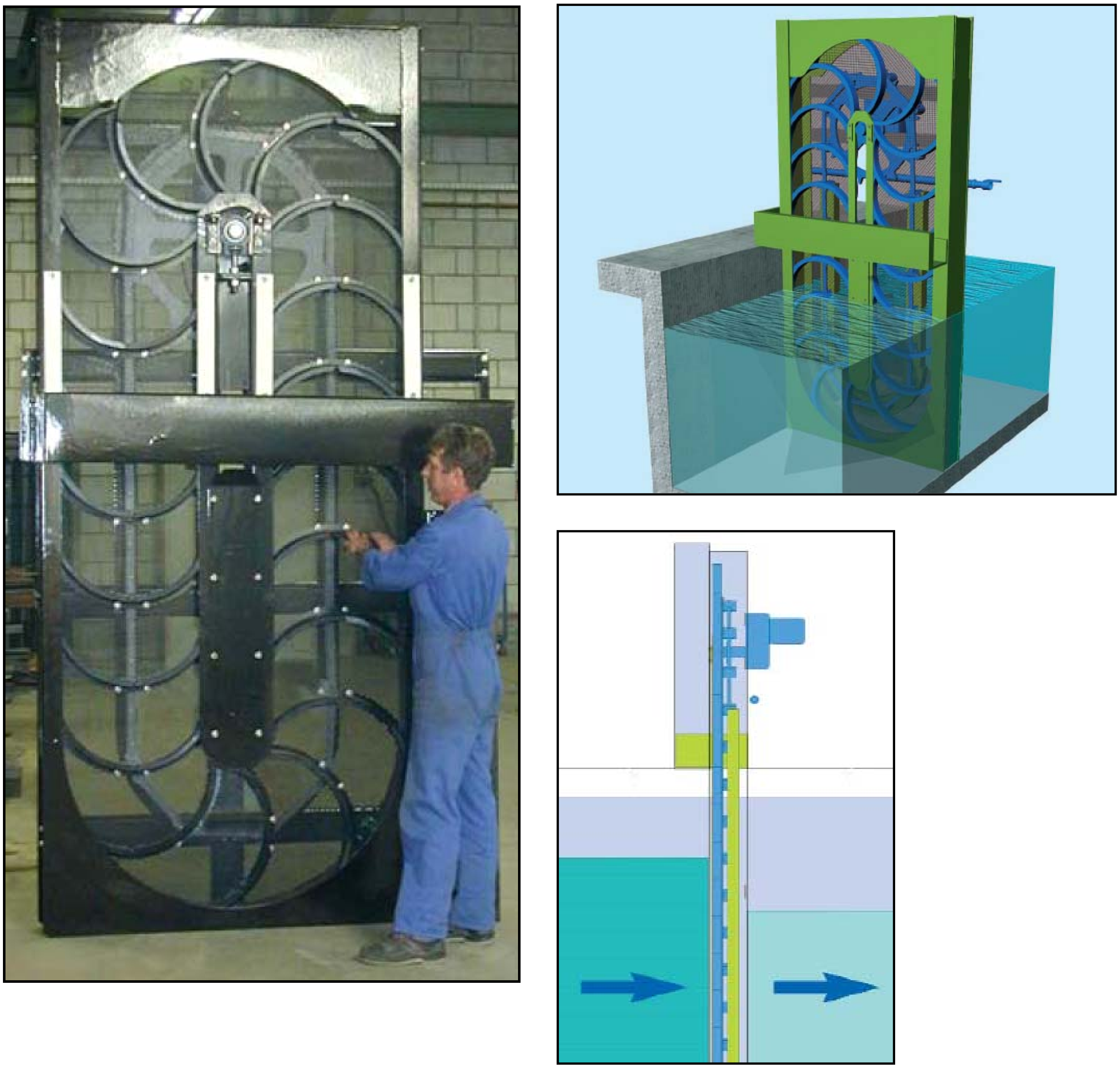


Figure 11.8. MultiDisc Fine Screen. Images by Infilco Degremont Inc. (http://www.degremont-technologies.com/).

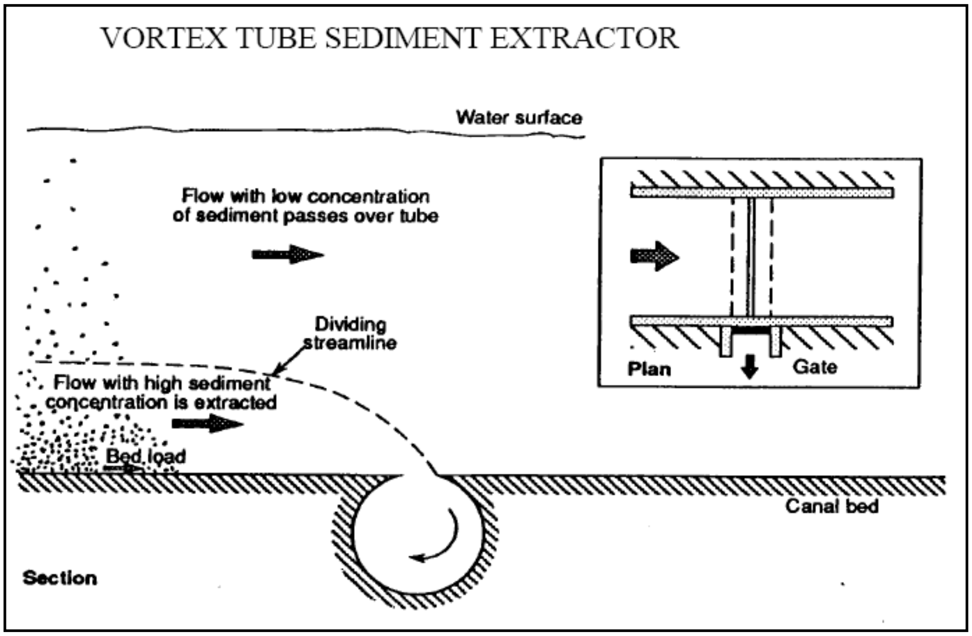


Figure 11.9. Vortex tube sediment extractor (from Lawrence et al. 2001).

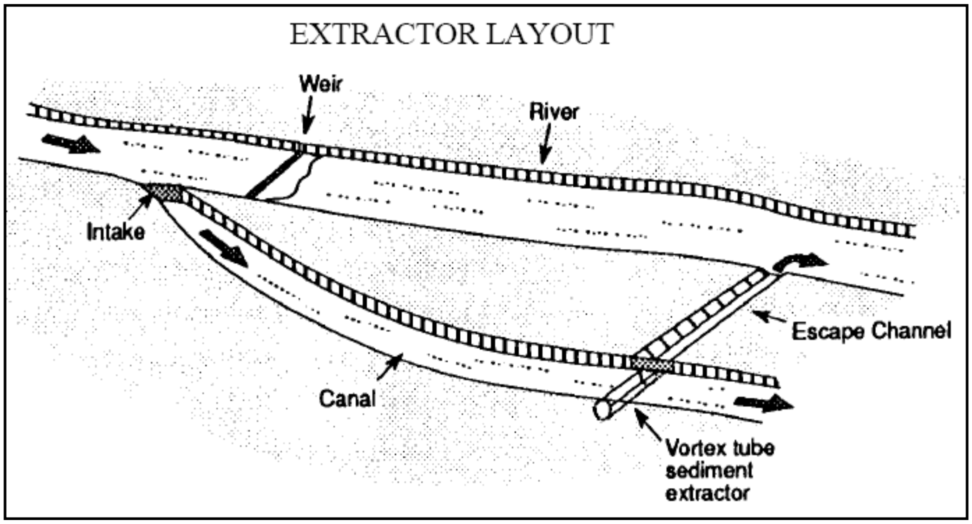


Figure 11.10. Sediment extractor layout (from Lawrence et al. 2001).

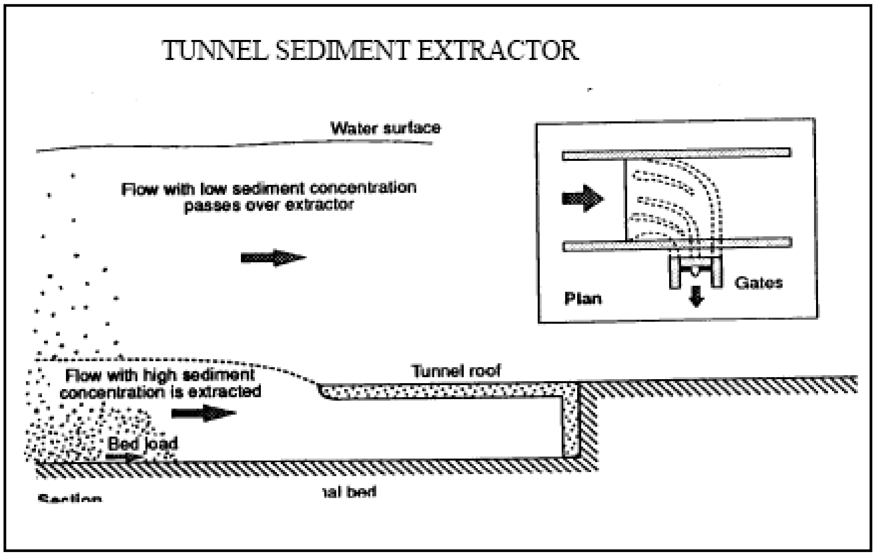


Figure 11.11. Tunnel sediment extractor (from Lawrence et al. 2001).

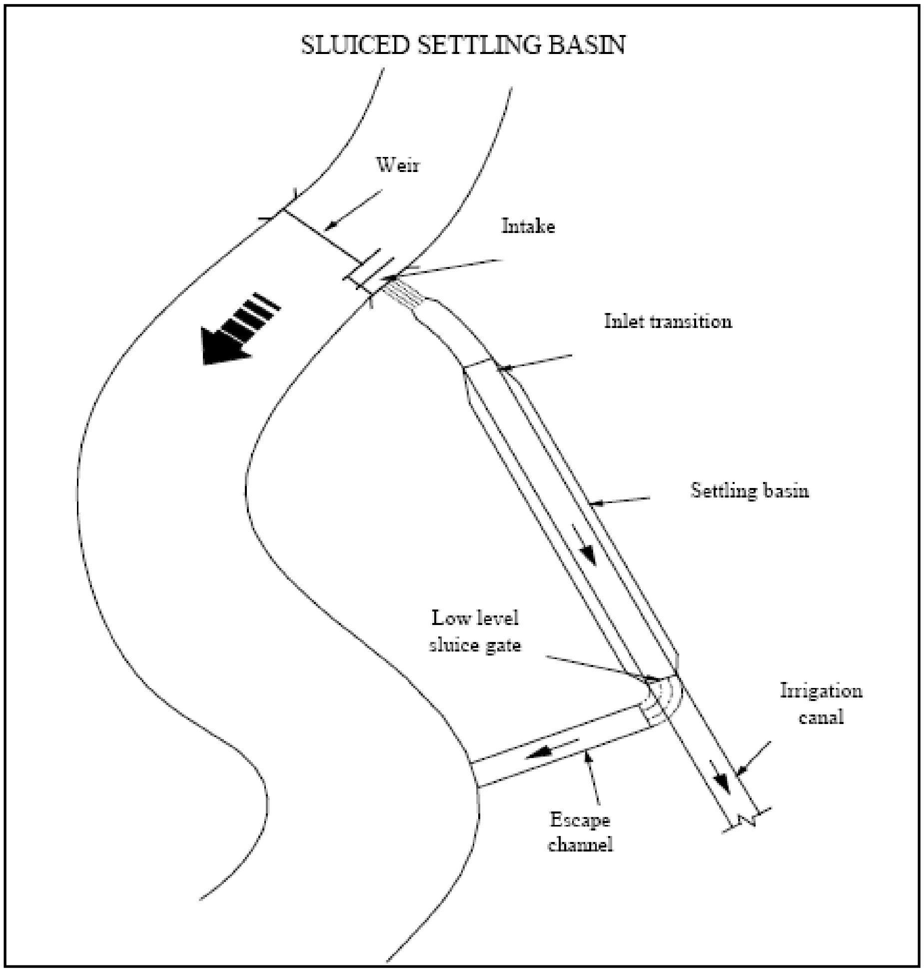


Figure 11.12. A typical sluiced settling basin (from Lawrence et al. 2001).

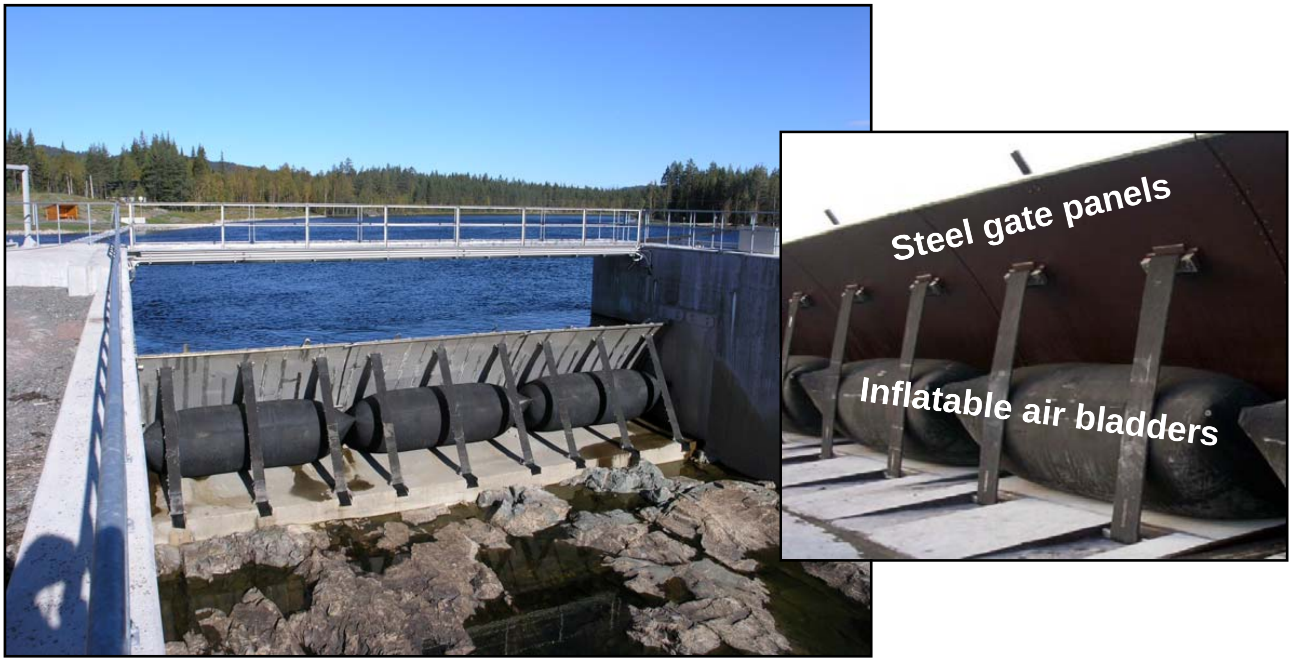


Figure 11.13. Obermeyer spillway gates. Photos from http://www.obermeyerhydro.com and http://www.dyrhoff.co.uk.

Figure 11.14. Sinnissippi Dam with Obermeyer spillway gates. Photo from http://www.obermeyerhydro.com.

Figure 11.15. Inflated rubber dam on Lake Elsinore, California. Photo from http://www.nctimes.com.

Figure 11.16. Inflated rubber dam on Russian River, California. Photo from http://ca.water.usgs.gov.

Figure 11.17. Deflated dam on Alameda Creek, California. Photo from http://www.alamedacreek.org.

Figure 11.18. Application of polymers for erosion control. Photos from http://www.siltstop.com.

Figure 11.18. (continued).

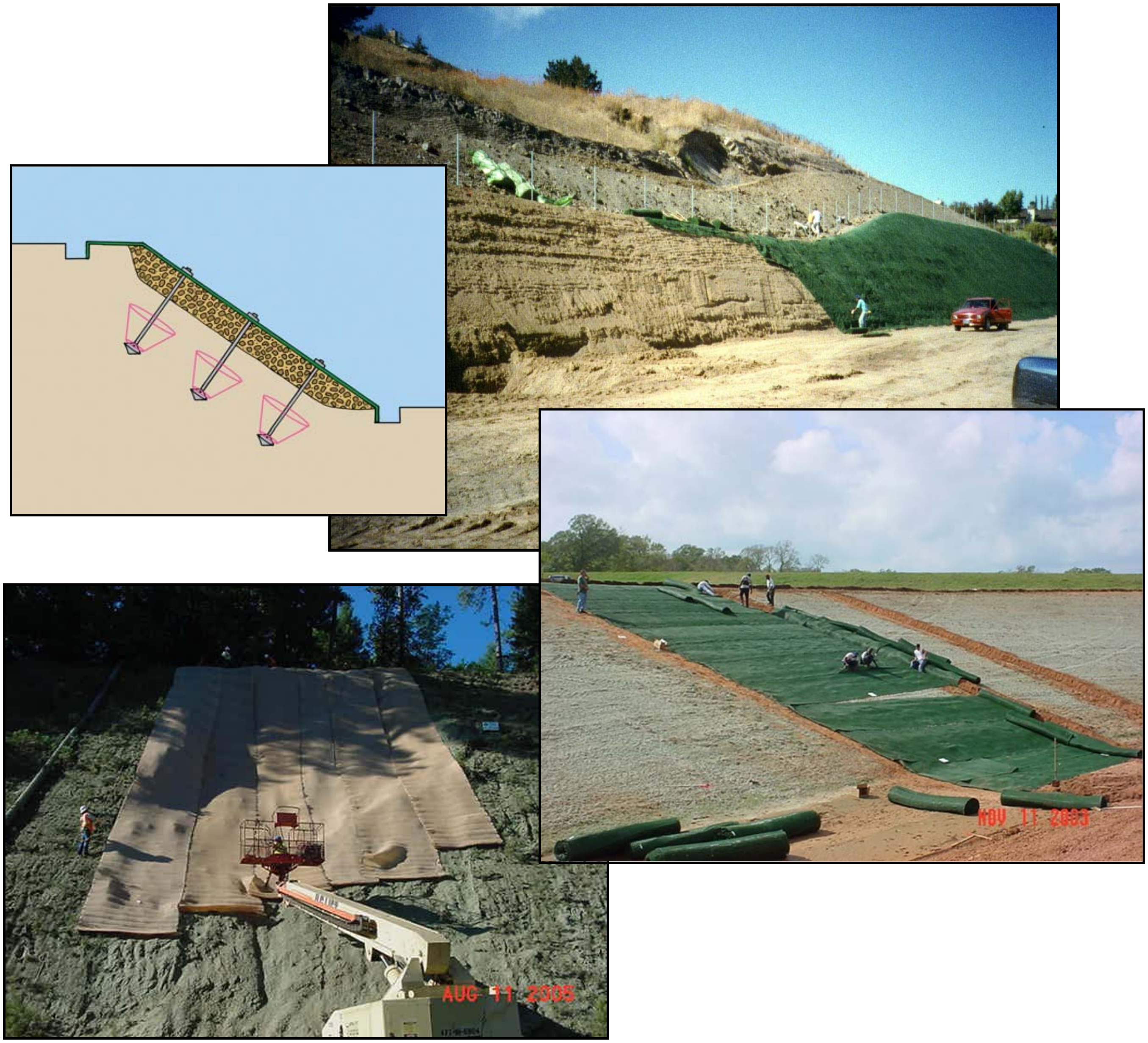


Figure 11.19. Turf Reinforcement Mats applications. Images provided by Propex Geosynthetics (http://www.propexinc.com)

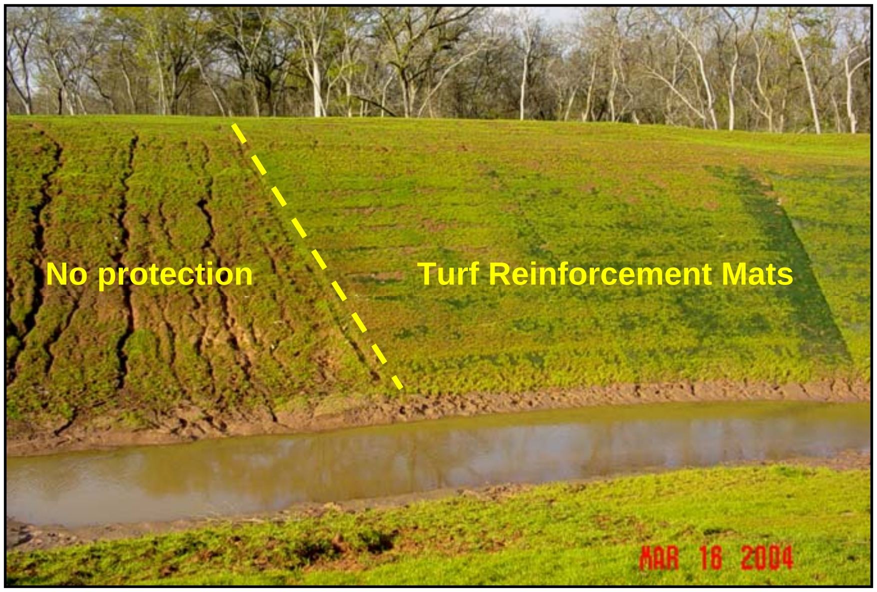


Figure 11.19. (continued).

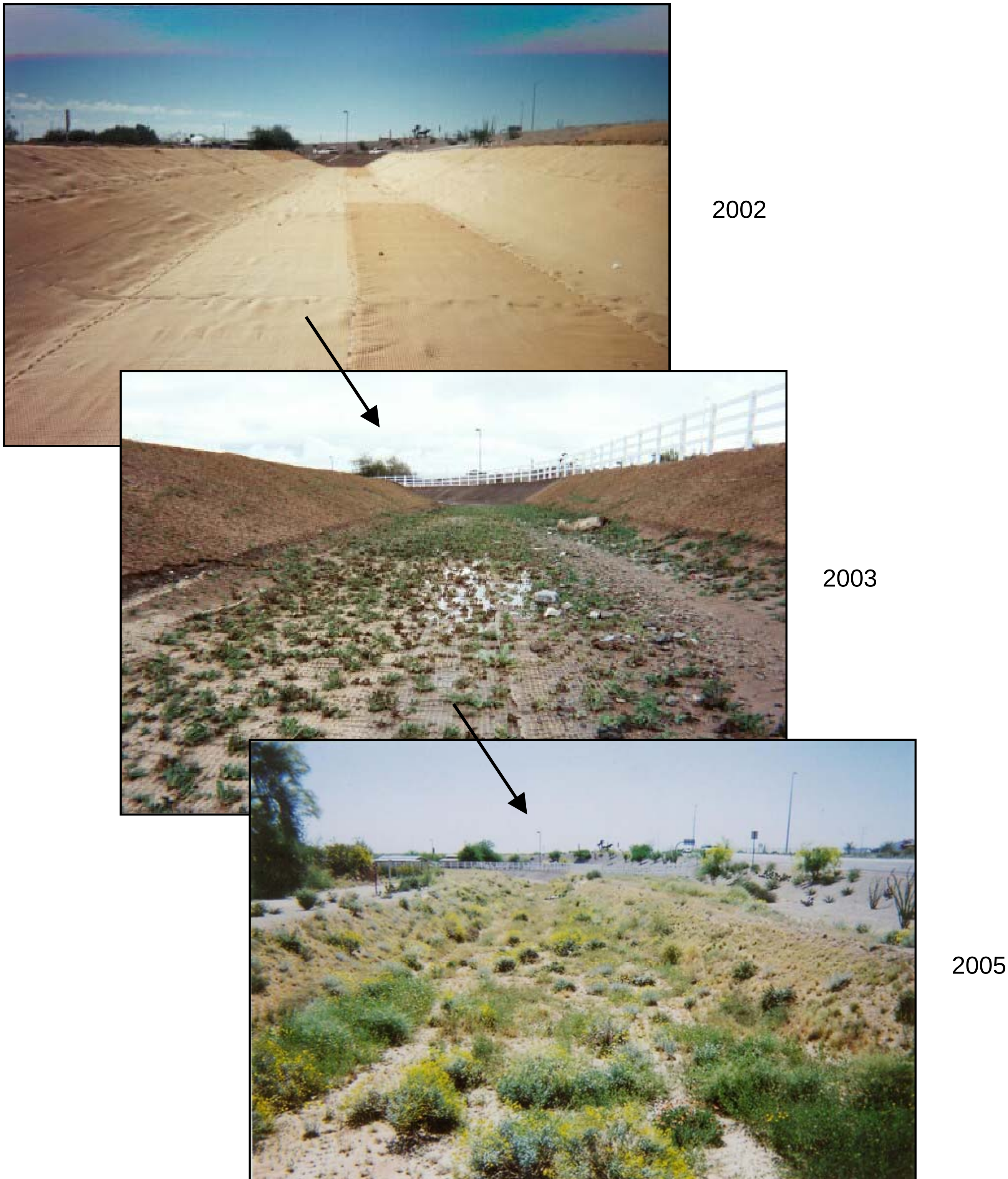


Figure 11.19. (continued).

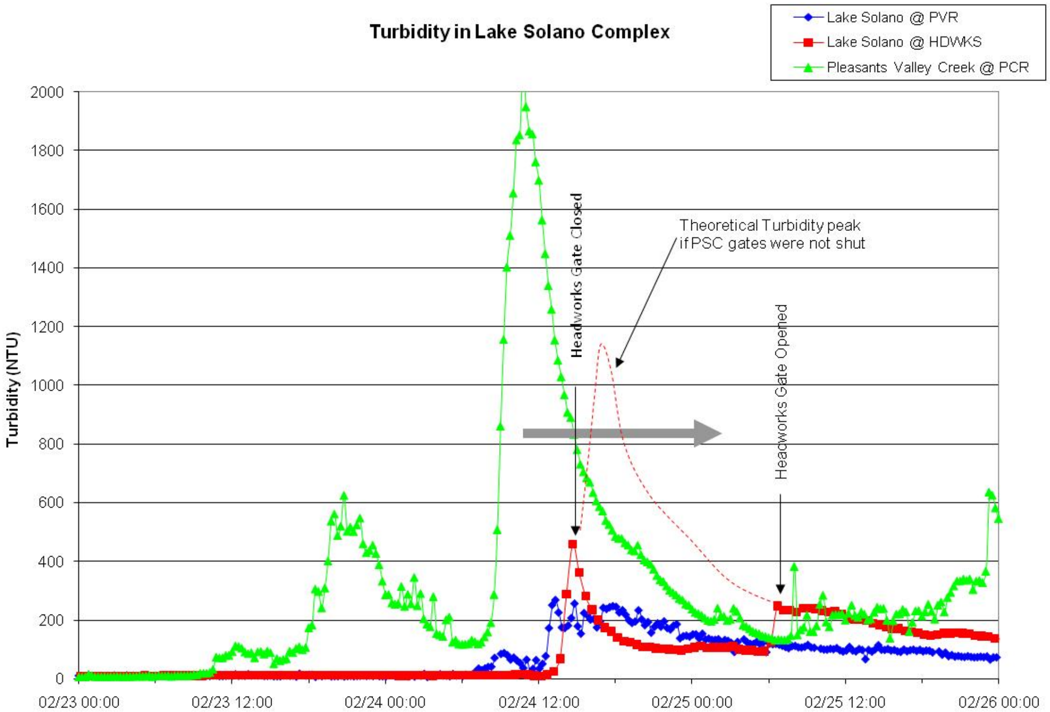
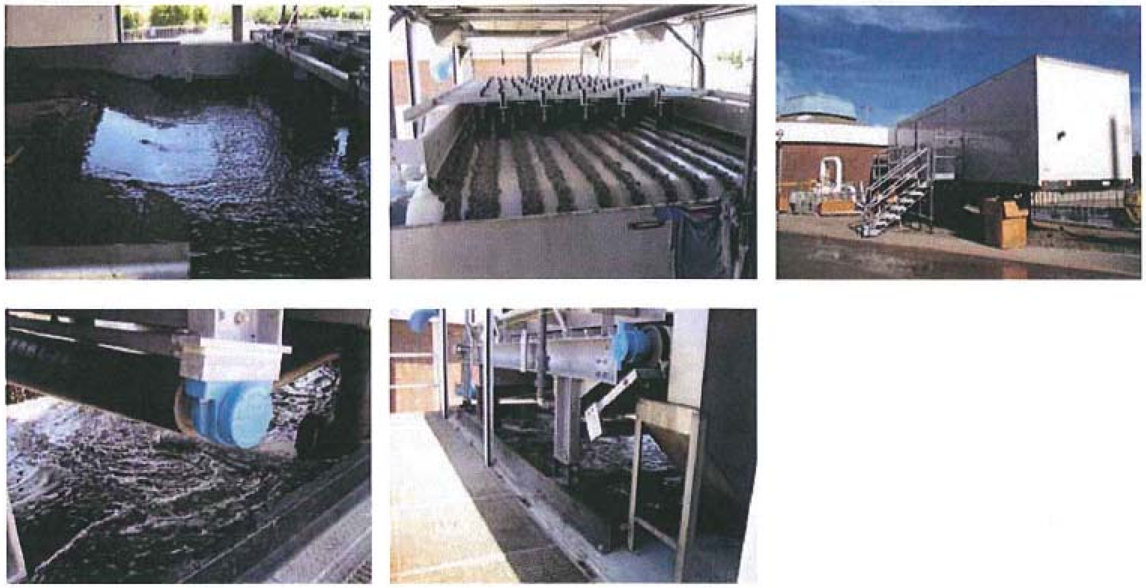


Figure 11.20. Turbidity records from SCWA stations during December 24, 2008 storm event. Note 4-6 hrs lag between turbidity increases in Pleasants Creek and at Headworks and 1-2 hrs lag between Putah Creek at Pleasants Valley Road (called here Lake Solano at PVR) and Headworks. Figure provided by SCWA.

Figure 11.21. De-watering of isolated section of Union Canal, Edinburgh, Scotland. Photo of January 13, 2008. Water is pumped around isolated section. View downstream.

Figure 11.22. Mechanical removal of sediment from isolated section of Union Canal, Edinburgh, Scotland. View downstream. Photo of February 12, 2008.

Gravity Belt Thickener for Rent



Available for rent at $4,500/month (half the usual rate)
It is mounted on a 1.7 METER TRAILER (for easy transport)

This Gravity Belt Thickener -- model RB 817.3 manufactured by Roediger Pittsburgh, Inc. – is rated to thicken a feed rate of 300 GPM of Raw or Mixed Liquor sludges and has been used for co-thickening, as well. The unit can thicken sludges to a concentration of four to eight percent. The unit comes with a Roediger model No. L-2 polymer system. Discharge sludge thickness is determined by adjustment of sludge feed, belt speed, and polymer dosage.

The unit contains a 55-gallon stainless steel cake hopper, a progressive cavity discharge pump with a Variable Frequency Drive (VFD) to vary speed

The Unit has the following features:
- In line venture mixer
- 100 gallon stainless steel flocculation tank
- Belt gravity zone has an area of 76 square feet
- 14 rows of individually adjustable plows
- Pneumatically adjusted belt tensioning
- Pneumatically adjusted belt tracking
- Automatic belt washing, with a wash water booster pump
- Polyester monofilament wovenware belt with 316 SS seams
- VFD Thickener Drive with AC motor

The unit is mounted on a DOT approved 42' x 8.5' trailer. The unit can be easily transported via highways to facilities anywhere in the continental United States and has been leased to treatment plants as far away as Indiana.

Utility requirements:
Electrical 460 volt, 3 phase, 60 Hz is standard, 2.0 Horsepower Drive units
Washwater @ 85psi (min.)
Pneumatics (instrument air) 1 cfm at 80 psi min, 250 psi max

Figure 11.23. Example of a trailer mounted gravity belt thickener for rent that can be used to test how well polymer-aided sludge enhancement equipment perform to separate bottom sludge materials from residual water following traditional canal cleanout (www.dsrsd.com/construction_projects_section/GBT_sludge_thickeners).

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Appendices

Following are Appendices A through E that are referred to in the body of this report.

APPENDIX A

Appendix A-4.1
Erosion Hazard Rating Methodology

Erosion Hazard Analysis Rating System

Erosion hazard ratings were developed for each reach of Putah South Canal, based on five characteristics found to most significantly affect erosion hazard. These are ground cover, slope length, slope angle, toe characteristics, and existing erosion sites. The selection of these characteristics is based on detailed field investigations conducted in 2007 where these and other field measurements were collected along the 33 mile length of Putah South Canal. A detailed description of each characteristic used in the rating system is provided below. Hazard ratings for each characteristic are summed to yield a reach erosion hazard rank for each reach ranging from no erosion hazard to severe erosion hazard.

Data Layer: Ground Cover (%)

Ground Cover	Hazard Rating
0 – 29%	5
30% - 49%	2
50% - 69%	1
70% - 89%	0
90%+	-1

Notes: Ground cover has the greatest impact on erosion hazard rating. Bare soil exposed to surface runoff and rainfall can exhibit erosion rates one or two orders of magnitude (10 to 100 times) higher than grass or gravel covered slopes.

Data Layer: Slope Length (ft)

Slope Length	Hazard Rating
0 – 3	-3
3 – 5.9	-1
6 – 9.9	1
10 – 19.9	2
20+	3
If upper slope present, add 2 to score	

Notes: Slope length is the prerequisite for erosion. If there is no slope, there can be no hillslope erosion along the canal. This is represented by the -3 rating for slope lengths in the 0 – 3 ft range. The negative rating prevents areas with little or no ground cover and with little or no slope from having a 'high' erosion hazard rating. Conversely, long slopes have greater potential to produce eroded material than do shorter slopes, particularly in the case of upper slope sediment delivery to the canal where the upper slope refers to a hillslope above the canal access road. This is represented by the higher hazard ratings associated with longer slope lengths.

Data Layer: Slope Angle (degrees)

Slope Angle	Hazard Rating
less than 28	-1
28 – 35.9	0
36+	1

Notes: Although slopes along the canal were generally in the 30 – 34 degree range, some areas were present with significantly more gradual or steeper slopes. In order to account for these areas and the increased or decreased erosion potential they present, the above slope angle hazard rating adjustments are provided. Slope angles of 28 and 36 were chosen based on field observations – very few areas have slopes less than 28 or greater than 36 degrees. This rating is meant to distinguish these few areas with unusually high or low slopes from other reaches.

Data Layer: Toe Characteristics[1]

Toe Characteristics	Hazard Rating
0 – 159	0
160 – 239	-1
240+	-2

[1]Calculated by multiplying toe width (ft) by toe cover (%).

Notes: Many areas of the canal exhibit a relatively flat, narrow toe at the base of the slope. This toe can reduce overall reach erosion by acting as a sediment trap where eroded sediment is deposited and stored. Field observations revealed that for the toe to act as a significant sediment trap it must be both substantial in width (2 ft or more) and have excellent vegetation cover (80%+), or some combination thereof that yields a minimum toe characteristic value of 160. Many reaches exhibit a narrow, poorly unvegetated toe that provides no sediment trapping benefit. These do not reduce reach erosion hazard and are assigned a zero rating.

Data Layer: Erosion Sites

No. of Erosion Sites per unit length[1]	Hazard Rating
0	0
1	1
2 – 4	2
4+	4

[1]The number of discrete erosion sites mapped in the reach during the Sept – Oct 2007 field work multiplied by the ratio of (’typical’ reach length / reach length) where the ‘typical’ reach length is 850 ft (determined by obtaining the mean and median of the LB and RB reaches and averaging them to obtain a ‘typical’ reach length). This provides a common denominator for comparison of erosion sites per unit length between reaches.

Notes: The presence of discrete erosion sites in a reach is a primary indicator for more of the same in future, assuming no significant change in other reach characteristics.

Erosion Hazard Analysis Ranking

Summation of Hazard Ratings from all Data Layers	Erosion Hazard Rank
Zero or less	No significant hazard
1 – 2	Low
3 – 4	Moderate
5 – 6	High
7+	Severe

Notes: Sum hazard ratings from the five previous data layers and identify the reach erosion hazard rank from this table.