Enhanced Canal Recharge Feasibility Report

Yolo County Flood Control and Water Conservation District
Woodland, California USA

August 2012

This report is part of an AB303 grant funded project from the Local Groundwater Assistance program of the California Department of Water Resources. This report is a combined report including both Enhanced Canal Recharge and Gravel Pit Recharge tasks.

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Introduction

Since the original construction of the District's canal system in 1914, it was known that some canal reaches were very "leak prone" and that other areas lost less to groundwater. At the time, a few of the leaky canal stretches were lined with concrete, but 95% of the canals were left as dirt lined. Presumably, this was done to save money, as lining canals is very expensive. However, today it is the policy of the District to leave the canals unlined, to promote groundwater recharge during times when there is water in the canals (summer).

"Losses from this system, as seepage and evaporation, vary from year to year, but have ranged from 15 to 65 percent from 1970 to 1996… The greatest part of the losses is the result of seepage and percolation along the canals and laterals. It is important to note, however, that the major part of these losses are recoverable from the groundwater basin. Over the years, various parties have suggested that the District should concrete-line its water delivery system to minimize seepage losses.

From the standpoint of managing the water supply available from the Cache Creek system, lining the District's water delivery system is not deemed to be a prudent water management measure." (YCFCWCD WMP 2000)

For most of the winter, between storms, the canals are dry. If during the winter, water could be diverted from Cache Creek, increased recharge could be realized.

For this study, infiltration was measured or summarized using the following methods:

1. Delivery amount by volume minus sales and spills. The difference is loss to groundwater.
2. Instantaneous flow rate measurement upstream and downstream of two points. The difference is loss to groundwater.
3. Percolation tests. Water was ponded in more than 6,600 linear feet of canal. The rate of drop in water level can be converted to a volumetric infiltration rate.

A map was also made showing SURRGO Soil Survey infiltration rates on all reaches of the canal system. Historical recharge rates and measurements were also summarized and compared to current findings. Infiltration measurements in sections of canal were scaled up to the entire canal system. Of note are 1914 infiltration date included as an appendix. Original data are available in the District Archives.

In addition to groundwater recharge from the bottom of unlined canals, winter water can be applied to land areas to promote recharge also. An original grant task of delivering winter water for groundwater recharge to a nearby gravel pit near the town of Capay, CA, would have provided groundwater recharge in an area off of the canal system. However, this task was modified. Instead of delivering water to the gravel pit, losses from a stretch of canal near the pit were very closely measured. The losses from the canal entered the pit through an underground path. Water levels in the canal, the pond in the pit, and nearby monitoring wells were measured. The responsiveness of the pond to water losses in the canal was analyzed.

Background Information: Inflatable Dam on Cache Creek at Capay

In 1994, a 500 foot long inflatable bladder was installed on the top of Capay Dam. This dam raises the water level 5 feet during the irrigation season. Previously, wooden boards had to be installed at the beginning of each summer, taking 9 workers two days to accomplish. The process was repeated to remove the boards each fall. Today, the bladder can be raised or lowered in 20 minutes at the touch of a button. The bladder can also be operated remotely during storms and safely observed w/ video camera surveillance.

The bladder was installed for safety reasons, but the District also wanted to have the ability to inflate the dam in winter or early spring, when water is still flowing in the Creek. Inflating the bladder in the winter allows the diversion of water in to the canals for recharge purposes. This operation of the dam could facilitate implementing the District's proposed groundwater recharge / recovery projects in the canal system.

Map of soil infiltration rates by canal reach

Soil map data from Soil Survey Geographic (SSURGO) Database from the NRCS, showing infiltration rate of the upper horizon layer of soil, was overlaid on the canal system. SSURGO data presents a high and low infiltration rate for each soil horizon and the low infiltration rate was used for the map. The lowest rate should be the limiting rate for overall infiltration rate and therefore this low rate was used. A new map, titled *Soil Permeability*, was created showing the infiltration rate along all sections of the canal. The *Soil Permeability* map is attached.

SSURGO: Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO). Available online at http://soildatamart.nrcs.usda.gov. Accessed June 2010.

Table 1. below shows a summary of canal lengths by infiltration rate as shown in the attached *Soil Permeability* map. The majority of the canals have an infiltration rate of 0.57 in/hr or less, while only 4 percent of the canals have an infiltration rate of 1.98 in/hr or higher.

Table 1. Summary of canal length by infiltration rate as presented in the attached *Soil Permeability Map.*

Infiltration Rate in/hr ksat	Canal Length Miles	Percent Length	Infiltration Category
0	0.0	0.08%	Low
0.06	45.3	27%	Low
0.2	51.2	31%	Low
0.57	64.5	39%	Med
1.98	2.6	2%	High
5.95	3.1	2%	High
total	166.9 total miles		

The *Soil Permeability* map was used to plan and identify good areas for measurement of ponded infiltration rate: high, medium, and low flow rates. The map can also be used to identify promising sections of canal for future recharge projects. Areas of higher recharge, in red and orange, are more promising that green areas, with lower infiltration rates. Short sections of red canal areas near the Capay Dam historically have been lined with concrete and are not available for recharge activities today.

The map was also used to scale up the pond tests on each canal section (low, med, high) to the infiltration rate of the entire District. The percent of high, medium, and low infiltration rate areas was calculated from the map, and the results of the high, medium, and low pond test were used to multiply up to the entire District canal system. The results are presented in the Canal Infiltration section.

Canal Infiltration Rates in Ponded Sections (Percolation Tests)

At the end of the 2010 irrigation a large construction repair project necessitated ending the irrigation season early, Sept 15, 2010. Usually the season ends as irrigation demand tapers off, but with the quick drawdown in the canals, we were able to “pond up” sections of the canal and block all inflow and outflow to these sections. With our SCADA flow monitoring system, the drop in water level was automatically measured and logged by the data collection system. In this way, static pond infiltration rates were measured on more the 6,600 feet of canal.

Twenty-two canal sites were evaluated for possible inclusion in the ponding tests (Table 2). Fourteen sites were eliminated right away, as they were located in sloughs, did not have a downstream check to pond water, or were concrete lined and were likely to have a very low infiltration rate. The remaining 8 sites were considered in depth. One major concern was the ability to stop all incoming water into the ponding area during the test. This meant that any remaining water draining out of the canal system, and any drain water from nearby fields, had to be diverted out of the ponding area. Only 4 sites were able to be configured this way; West Adams @ Granite, the Chapman Reservoir Inlet, the Yolo Central Spill, and the Winters Canal @ the Fredericks Flume. The Fredericks Flume site was tested, but no data was collected. The steepness of the canal and the position of the water level sensor was too far upstream of the check, so no water was beneath the sensor during the test and no measurements could be made.

The remaining three sites were successfully measured during the pond test. These sites are listed in bold in Table 2.

Table 2. Twenty two canal sites were evaluated for the end of season percolation test. The three sites highlighted in bold were selected.						
Canal Monitoring Site	Operational?	Site Notes	Possible Infiltration site	U/S Check	D/S Check	Measured?
Clover Spill	X	earthen lined	x	CLV 0543	CLV 0601	No
PLP Spill #1	x	earthen lined	x	PLP 0965	PLP 1013	No
PLP @ Gayle Check	broken	earthen lined	x	PLP 0534	PLP 0593	No
West Adams Canal @ Granite	**x**	**earthen lined**	**x**	**WEA 0170**	**WEA 0240**	**Sept. 18, 2010**
Alder Canal @ Gordon Slough Heading	x	earthen lined	x	WEA 0970	ALD 0009	No
Winters Canal @ Fredricks	x	earthen lined	x	WIN 1119	WIN 1313	attempted
Chapman Inlet	**x**	**earthen lined**	**x**	**WIN 1536**	**WIN 1603**	**Sept. 14-15, 2010**
Yolo Central Spill	**x**	**earthen lined**	**x**	**YOC 0970**	**YOC 1008**	**Sept. 28-29, 2010**
Alder Drop	x	concrete lined				
Chapman Outlet	x	concrete lined				
Cottonwood Spill	x	in slough				
Fairfield Ditch Heading	no sensors	earthen lined				
Gordon Slough Heading	x	in slough				
Hungry Hollow Spill	x	in slough				
PLP Spill #2	x	concrete lined				
Salisbury Spill	x	in slough				
University Spill	x	concrete lined				
West Adams Canal Heading	x	concrete lined				
Willow Slough @ 98	x	in slough				
Willow Slough Bypass	x	in slough				
Winters Canal Heading	x	concrete lined				
Yolo Central Heading	x	no d/s check				

Percolation Tests: Field Data Acquisition Methods

Water depth in the canals is measured constantly with a network of telemeterized non-contact ultrasonic sensors. These data are logged on a server at District HQ running the ClearSCADA database. A duplicate “hot standby” server is simultaneously running at a remote location to ensure no lost data. The main use of this system is to monitor canal flows and to manage irrigation deliveries. For the pond infiltration test, this system was used to monitor dropping water levels in sections of ponded canal. Canals were visually monitored periodically during the test to check for leaks or water entering to ensure that changes in water level were due to losses to groundwater only (evaporation over the few hours of the test were estimated and found to be very small and were ignored).

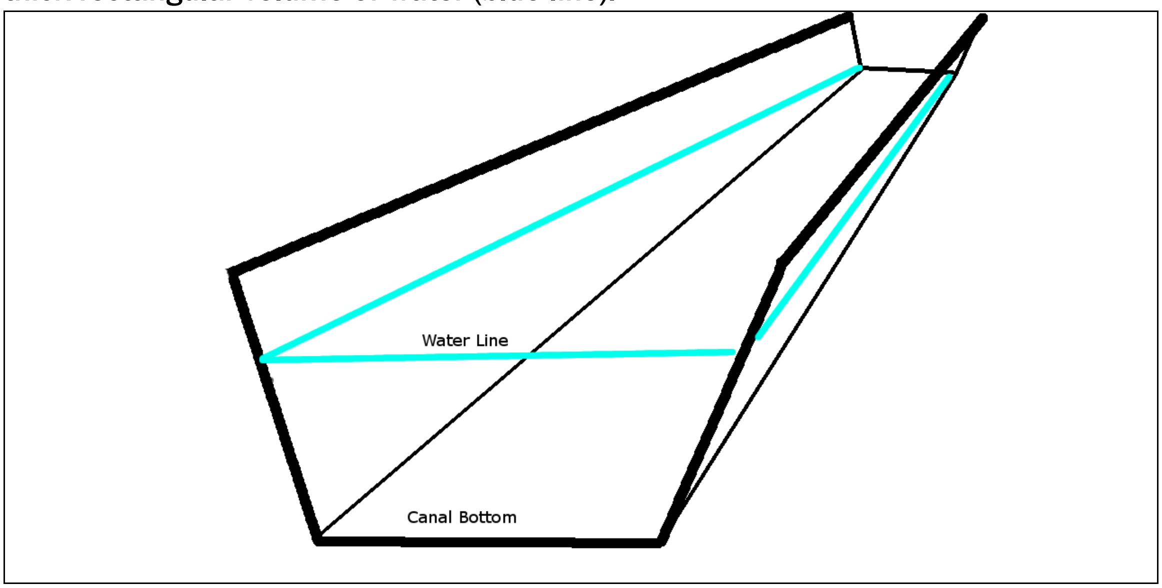
Hydrographs showing the water level were printed out and the slope of the line during the ponding test was measured and converted to infiltration in inches/hour. Table 3 shows the date and duration of the ponding test for each location.

Table 3. Dates and time of ponding tests in three sections of canal during September 2011

Canal section name	Date of Pond Test	Length of time used for level drop measurement (hours)
WEA @ Granite	9-18-2010	8
WIN Chapman inlet	9-14-2010	12
YOC Spill	9-29-2010	15

After the canals dried out, the canal cross section dimensions were measured with a tag line stretched across the canal and a measuring tape was used to measure canal depth at each station along the tag line. The beginning and end of each ponded canal section was measured and a minimum of 5 intermediate cross sections were used to model the geometry and volume of the canal. Figure 1 shows how the top one inch of water surface in the canal can be modeled as long thin slab, or volume, of water. The upstream depth of water eventually reaches zero, as the canal drops over its length while the water surface stays level (Figure 1).

Figure 1. The top surface of the ponded canal water was modeled as a one inch thick rectangular volume of water (blue line).



Percolation Tests: Results

Table 4 shows the results of the percolation test in inches/hour. The results are compared to SSURGO database values. The infiltration rates are also converted to losses in CFS/mile and acre feet/day mile. These loss data can be used to “scale up” and estimate losses for the entire District canal system (Table 4).

Ponded canal versus full flow infiltration rate is presented in Figure 1. The water surface during the pond test was level, while the canal floor drops along its length (Figure 1.) Therefore, the dimension of the modeled “thin slab of water” is a different size at the ponded water surface, versus a full flowing canal. The difference in these dimension are reflected in “ponded” versus “full flow” volumes in Table 4.

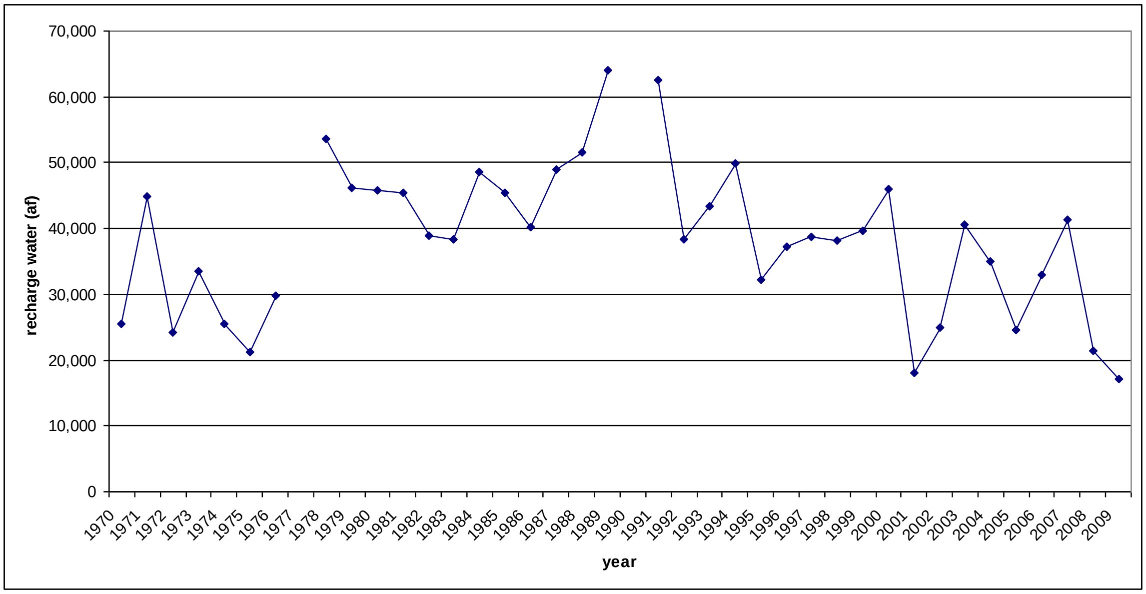
Table 4. Results of ponding tests in three sections of canal during September 2010								
Canal section name	Length of section (ft)	Average width full flow (ft)	Volume of top one inch ponded (cf)	Volume of top one inch full flow (cf)	K_{sat} inches/hr Measured	K_{sat} inches/hr SSURGO	cfs/ mile	acre feet / day mile
WEA @ Granite	1,440	30.6	3,336	3,675	0.50	.32 - 20	1.87	3.7
WIN Chapman inlet	3,552	18.66	5,523	5,523	0.29	.12 - 1.2	0.66	1.3
YOC Spill	1,640	12	1,367	1,640	0.25	.12 - .50	0.31	0.62

Note: Ksat from SSURGO does not match the *Soil Infiltration* map exactly because the map used low values from the uppermost soil horizon, where depth is variable depending on location, and this table uses the low value for the top 20 cm of the soil profile, regardless of the depth to the first horizon.

Potential for Increased Groundwater Storage

The farms and cities within the District depend on the groundwater recharge that occurs because of the unlined canals. The amount of recharge has been quantified over the years and is presented Figure 2. The additional amount of recharge available from winter water diversion (Table 5) into the canals will be compared to the current amount of recharge that occurs.

Figure 2. YCFCWCD Annual losses to recharge. These losses are calculated as the total releases from storage, minus the sales. The result is losses and the total is assumed to be losses to groundwater, although small amount of evaporation and spill occur. In 1977 and 1990 there were no deliveries of irrigation water and hence zero losses.



The water lost from the canal system is mostly recoverable from the groundwater. Figure 2 shows the amount lost to range from ~18,000 af in 2009 to a maximum of ~64,000 af in 1989 and on average 38,264 af of water is lost. Other data, for example, Table 3 of the 2000 Water Management Plan (http://www.archive.org/download/watermanagementp00borcrich/watermanagementp00borcrich.pdf), show that on average 28,500 af are lost to recharge each year from the District's system.

Table 5. Recharge estimates using pond test infiltration data

Category	Canal	length (mi)	af/day mile	af/ day	days	af
Large Main Canal	Winters Canal	16.05	1.3	21	212	4,423
Medium Main Canal	West Adams Canal	10.55	3.7	39	212	8,275
Small Lateral	Canal Laterals (using YOC Spill as average loss rate)	140.3	0.62	87	212	18,441
	Total	166.9				31,140

In Table 5, estimates of losses from the pond infiltration tests were multiplied by total length of the canal and an assumed 212 day season. Two hundred and twelve days is the average season length between 1981 and 2009 (with minimum length of 171 and maximum of 280 days). This analysis of pond infiltration data shows that 31,140 af would be lost in an average length season. This amount is in between the two estimates of losses from sales data discussed above (Figure 2).

Promising Canal Stretches for Recharge

There are two main canals in the District's system: the Winters Canal, which diverts water south of Cache Creek at Capay, and the West Adams which diverts waters on the north and opposite side of the Creek. All other canals in the system branch off of one of these two main canals (*Soil Permeability* map attached which shows the canal system).

Any winter time diversions into the canal system will, by design, pass first into the Winters or West Adams Canals.

The volume of recharge water depends on both the infiltration rate and the size of the canal. Two stretches of canal can have a similar infiltration rate, for example canal sections 'WIN Chapman inlet' and "YOC Spill' from Table 3, but very different recharge rates due to differences in overall size of the canal.

In any particular stretch of canal, the infiltration rate is not that high. But because there are so many miles of canal (166.9) the total infiltration rate for the system can be significant. In other words, there are no particularly promising sections of canal, most of the system must be used to achieve significant amounts of recharge.

Wintertime Canal Recharge Feasibility: Administrative Costs and Other Factors

The main factor limiting wintertime recharge is that the canal system has dual modes: summer-mode and winter-mode. During summer-mode the canals are full for irrigation deliveries. During winter-mode the canals are empty to accept storm runoff. Changing the canal configuration from summer-mode (irrigation) to winter-mode typically requires a crew of 10 people to work one week. If a storm comes in the winter and the canal system is in summer mode to recharge groundwater, flooding and damage could result.

To explain in more detail the difference between summer-mode and winter-mode: If the canals are used for wintertime recharge, and are in summer-mode, the capacity for flood flows are greatly limited. For wintertime recharge the canals must be in summer-mode. However, since storms cannot be predicted much more than a few days in advance, it is currently not possible to switch from summer to winter mode quickly enough in the advance of a predicted storm. Therefore the canals must remain in the wintertime configuration for the duration of the winter season. To solve this issue, a system of automated gates could allow the canals to switch from winter to summer mode in minutes, instead of days, allowing wintertime recharge to occur, while still preserving the ability of the canals to carry flood flows.

Even with an automated gate system, the system must be managed in such a way to monitor for approaching storms, protect against localized flooding, and protect the headgates and diversion works at Capay from flood damage. There will be an incremental increase in administrative costs for these activities. Additionally, the financing of a capital improvement program to install automated gates will incur additional administrative overhead.

Gravel Pit Recharge

The use of existing gravel pits for active groundwater recharge has been discussed for many years in Yolo County (YCFCWCD Water Management Plan 2000). Active recharge allows the opportunity to increase groundwater storage and optimize conjunctive use of both surface and groundwater resources. Optimized conjunctive use can provide more water for all uses, without creating new surface water reservoirs.

In 2006, the Yolo County Flood Control and Water Conservation District (the District) completed a Countywide groundwater simulation model, which specifically looked at using gravel pits in a groundwater recharge and recovery scenario.

For this grant project, the was modified for the following reasons. Certain aspects of the District's irrigation system made it difficult or impossible to deliver the water and plans were changed. Infrastructure improvements of more than $25,000 were needed to deliver the water, but were not part of the original budget. Additionally, the road to the canal heading is dirt and not passable at times during wet winter weather and the control gates could not be reached. After the end of the study, the District installed remote control on these gates, but this feature was not available for the gravel pit test.

The gravel pit at the Granite Capay Facility is a 10 acre hole in the ground left over from extraction of aggregate resources (gravel).

Aggregate Industry Partnerships

Both aggregate mining and the District (or predecessor water companies) have a long history in Yolo County, starting with the first white settlements in the 1850's. The aggregate industry along Cache Creek has been mining for high quality aggregate resources since the late 1800's. (Irrigation diversions started in 1856 with the Moore Dam with a water right currently held by the District.) Historically, gravel mining was generally in the main Creek channel itself, but off-stream mining is documented starting around 1981.Yolo County began regulating mining in 1936, but this was inconsistently applied until 1960 or so.

For the current study, Granite Construction agreed to provide access to their mining facility, the pond, monitoring wells, and other monitoring data in exchange for a copy of the report, when completed.

Infiltration Rate near the Gravel Pit from Canal Flow Measurement: Field Data Acquisition

During normal canal operations, losses to groundwater must be taken into account. For example, if a canal has sales for a particular day of 75 cfs, 100 cfs of water must be delivered to the canal heading, to account for losses. By carefully measuring flows upstream and downstream of a particular point along the canal, losses can be quantified.

From April 30, 2012 to June 17, 2010, canal flows were manually measured daily at 6 locations in the West Adams Canal system near the Granite Capay aggregate mining facility (Figure 3). The weir stick overpour method was used (http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/). The flows after June 17, 2010 became too high for use of the weir stick method and those measurements were stopped. Also displayed in Figure 3, are the acre feet of water lost per day in that section of canal. Approximately 20 acre feet were lost per day along that 1.81 mile section of canal.

Two sites, the uppermost WEA0170 and the lowermost WEA0240 were equipped with continuous flow measurement sensor and telemetry allowing real-time collection of flow data at these two sites (Figure 4). Figure 4 is a screen shot from the District's Real-time SCADA system. For each day shown in Figure 4, a single value for daily average difference in flow was estimated and used to make the hydrograph shown in Figure 5. Figure 5 shows the losses in cfs between the two sites.

Infiltration Rate Estimates from Canal Flow Measurement: Results

Figure 5 shows the losses from the canal nearby the Granite gravel mining facility, between the WEA0170 and the WEA0240, a distance of 0.7 miles. The water that was leaving the canal due to infiltration was moving into the ground and percolating to the groundwater surface, "filling the profile" and raising the groundwater. The daily average losses from the data in Figure 24 is 9.4 cfs, or 13.4 cfs/mile, and compares well with the manual weir stick method measurements (Figure 3).

Gravel Pit Water Level and nearby Groundwater Levels: Field Data Acquisition

The monitoring wells surrounding the pit were surveyed during installation by Granite Construction Inc an unknown number of years ago and this elevation data was supplied to District. For this current study, a GPS Total Station survey instrument, with sub centimeter accuracy, was used to tie the canal water and pond water levels in with the monitoring well elevations. A U-10 Hobo waterlevel data logger was deployed in each of the wells and the pond, while the previously constructed SCADA station at WEA0240 measured the water levels in the canal. Water level monitoring locations are summarized in Table 6 and shown on Map 1.

Table 6. recharge amounts using current infiltration data				
Location name	**Reference Elevation ft msl (NGV27)**	**UTM 10 S Easting**	**UTM Northing**	**Notes**
MW1	204.02	582888.54	4285410.24	Monitoring Well #1 (MW1)
MW2	198.29	583698.40	4285985.65	Monitoring Well #2 (MW2)
MW3	194.22	583963.88	4285390.20	Monitoring Well #3 (MW3)
Pond 1A	Pond surface variable	--	--	Pond size and surface elevation is variable, for location please see Map #1
WEA0240CK	201.715	583033.94	4285899.23	West Adams Canal 0240 Check

Figure 3. Daily flow at 6 locations on the West Adams Canal near the Granite Capay facility. The difference in flow between the uppermost location (WEA0170) and the most downstream location (WEA0351CK) is converted to af/day.

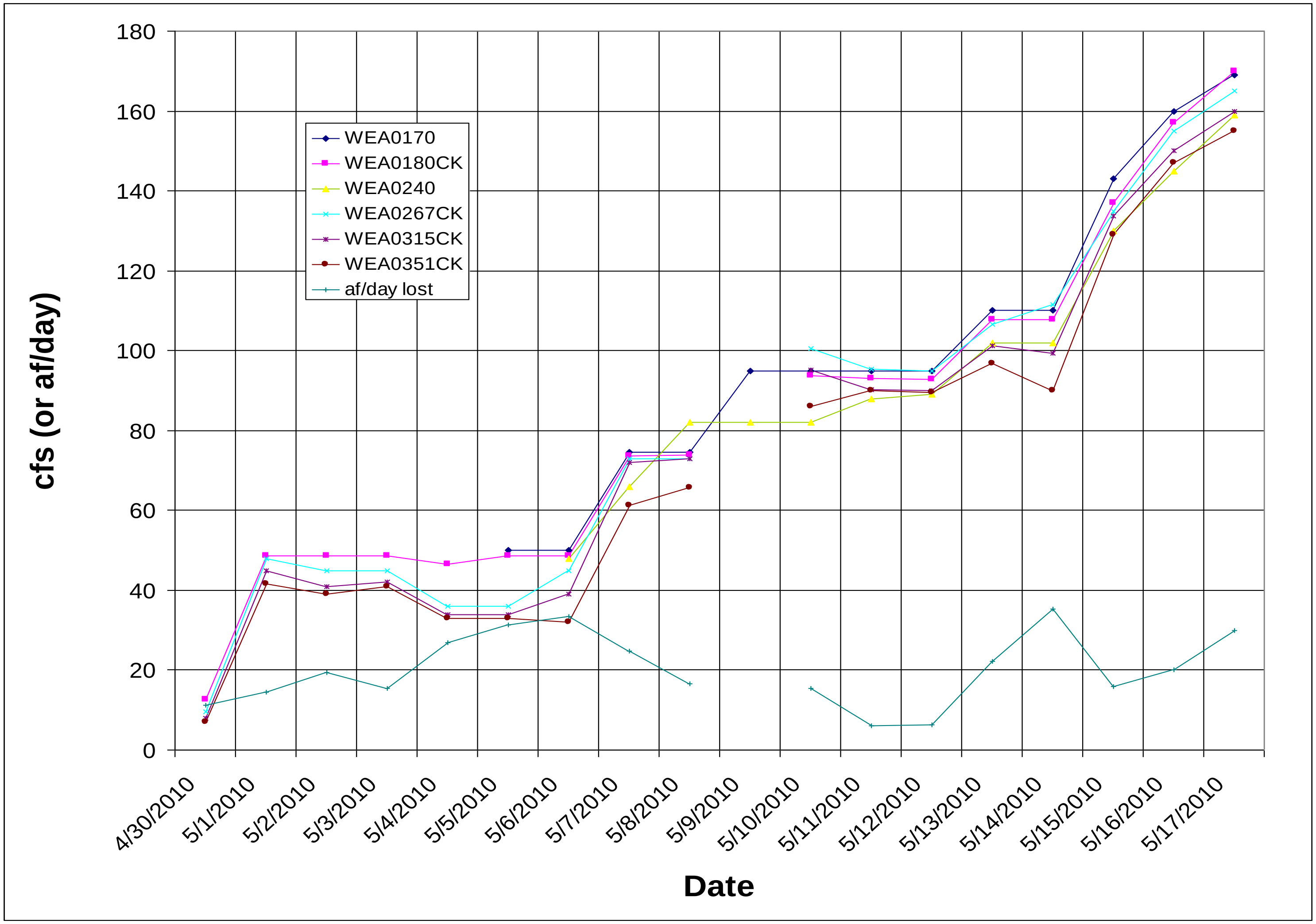


Figure 4. Screenshot showing upstream and downstream flows at two locations. The difference in flow between the green (upstream) and blue (downstream) lines is loss to groundwater.

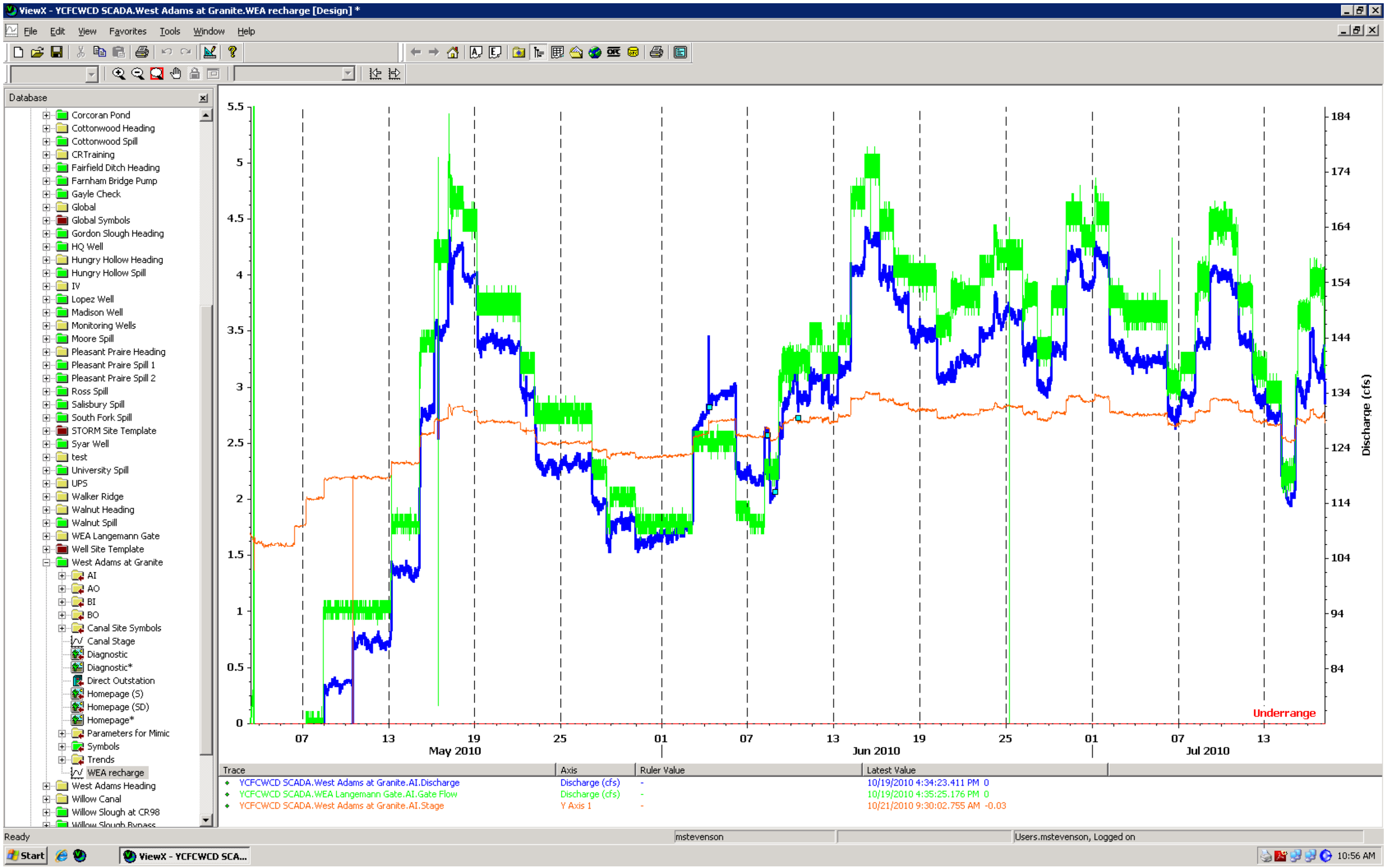
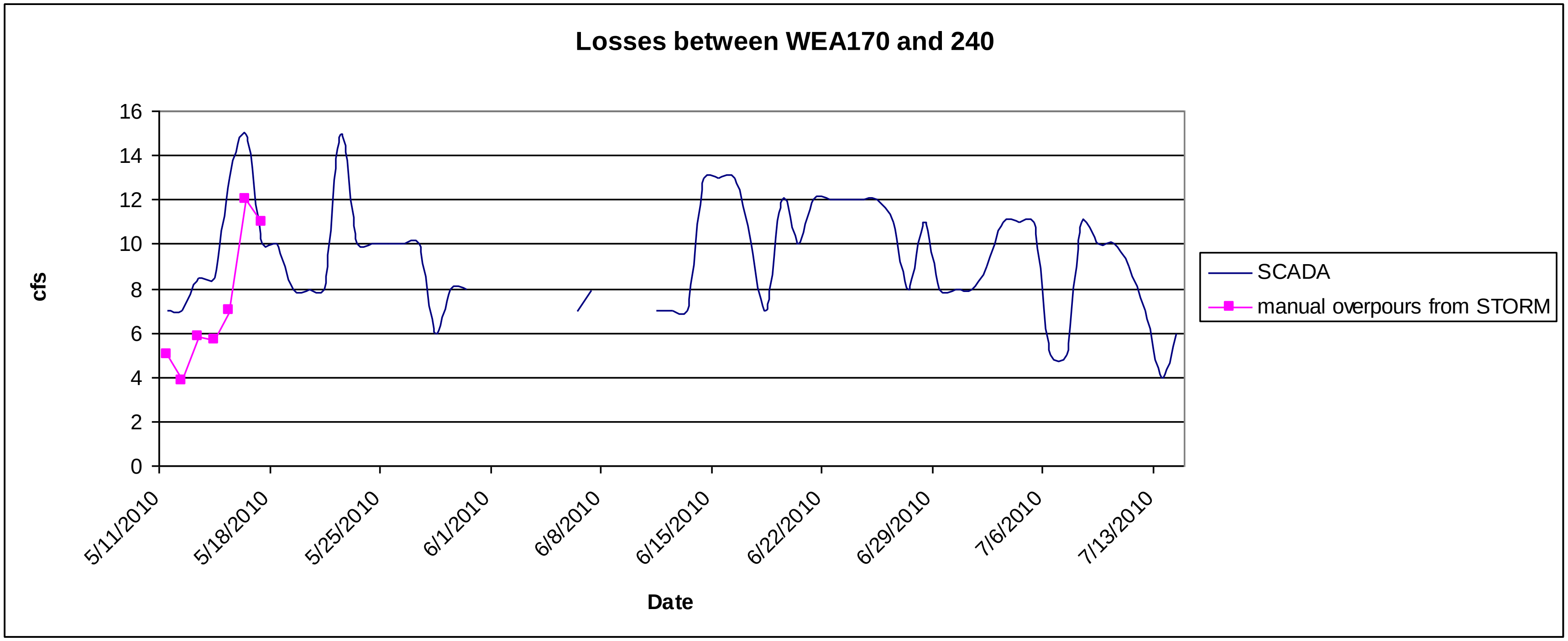
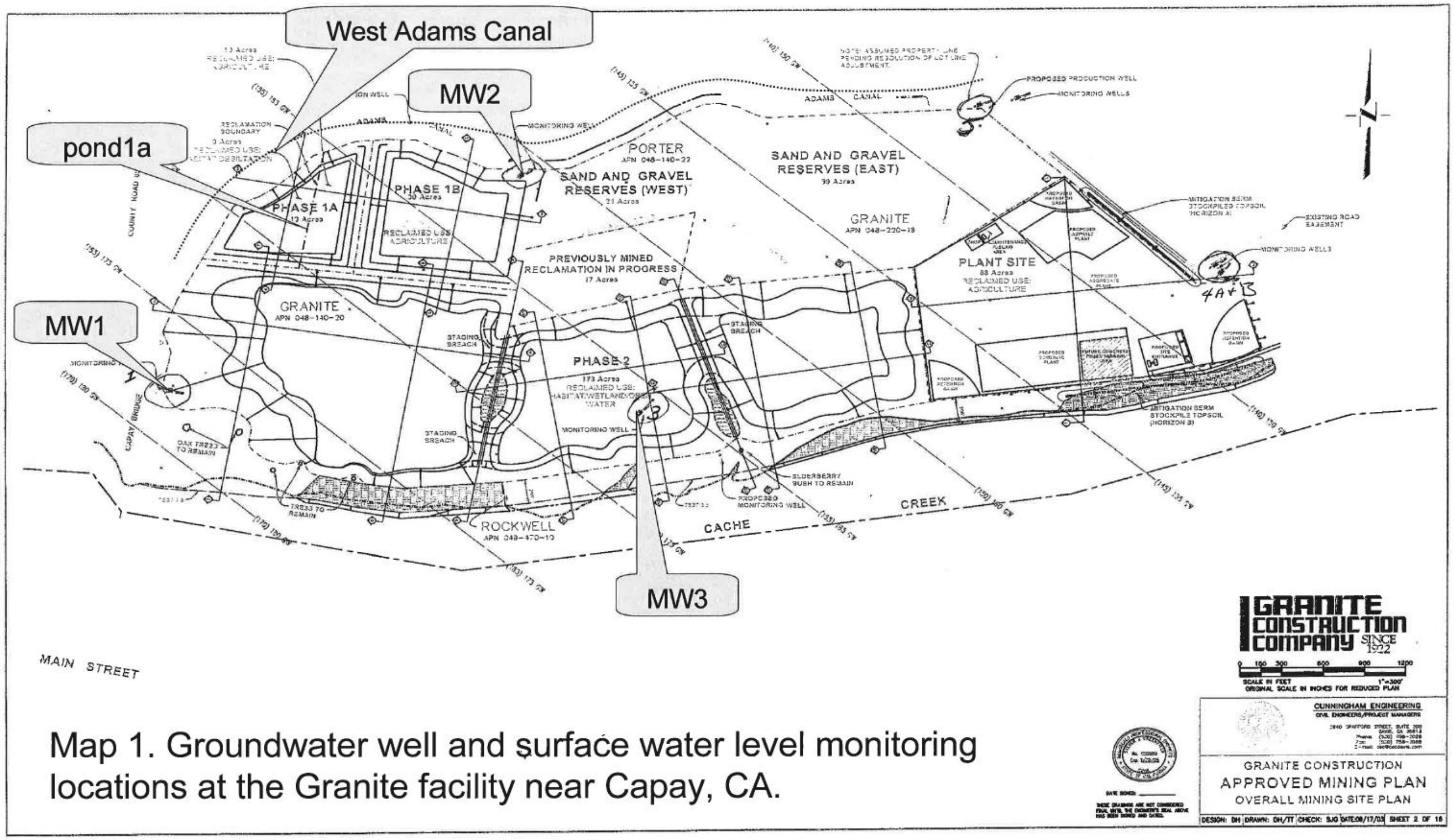


Figure 5. Losses to groundwater as measured by difference in flow between two SCADA stations. Manual overpours from STORM are measurements taken with the weir stick method.





Map 1. Groundwater well and surface water level monitoring locations at the Granite facility near Capay, CA.

Gravel Pit Water Level and nearby Groundwater Levels: Results

Figure 6 shows the response of groundwater level and the pond surface level to rain and irrigation water present in the canal. The water level in the pond rose 10 feet when irrigation water was placed in the canal at the beginning of May, 2010 (Figure 6.) The closest monitoring well to the canal (MW2) rose more than 30 feet. At the end of the irrigation season in September 2010, the groundwater level in MW2 immediately dropped, while the pond dropped very slowly.

The phase 1A pond at the Granite Capay Facility is 10 acres in size. A rise of 10 feet in water level is 100 acrefeet (af). One hundred af is a very small amount of water for the District which delivers over 180,000 af per year. Although the pond looks like a surface water reservoir, it would be very small if so and not much use to the District if it only held 100 af. It is better to think of the pond as a very large diameter well. The water level in the pond reflects the water level in the surrounding aquifer. The water levels for the pond in Figure 6 show that during irrigation season, the pond is intermediate between the canal and MW2, up gradient, and MW3, down gradient. It is apparent that the pond is filling with water from the canal.

During the non-irrigation season, the pond water level stays higher than the surrounding aquifer, as shown in the monitoring wells. If there was a good hydraulic connection between the bottom of the pond and the surrounding aquifer, the pond should quickly drain. This does not appear to happen.

The pond is used at the Granite facility to dispose of ‘fines’ from the gravel washing process. Perhaps the bottom of pond is clogging up with silt. The sides of the pit, above the pond high water level, may not be clogged with silt and high groundwater from the surrounding aquifer can drain into the pond, filling it. However, when the surrounding groundwater levels drop below the level of the pond, the pond drains very slowly. For the 24 days after the end of irrigation season, when no water was present in the canal, the pond level dropped only 6.2 inches, a rate of 0.01 inches per hour. This rate is more than 10 times smaller than any infiltration rate measured in the canals (Table 4). Of note, the water level is MW1 was still high after the end of irrigation season and water could be coming from up gradient to keep the pond high, perhaps lowering the measured infiltration rate.

Gravel Pit Conclusions

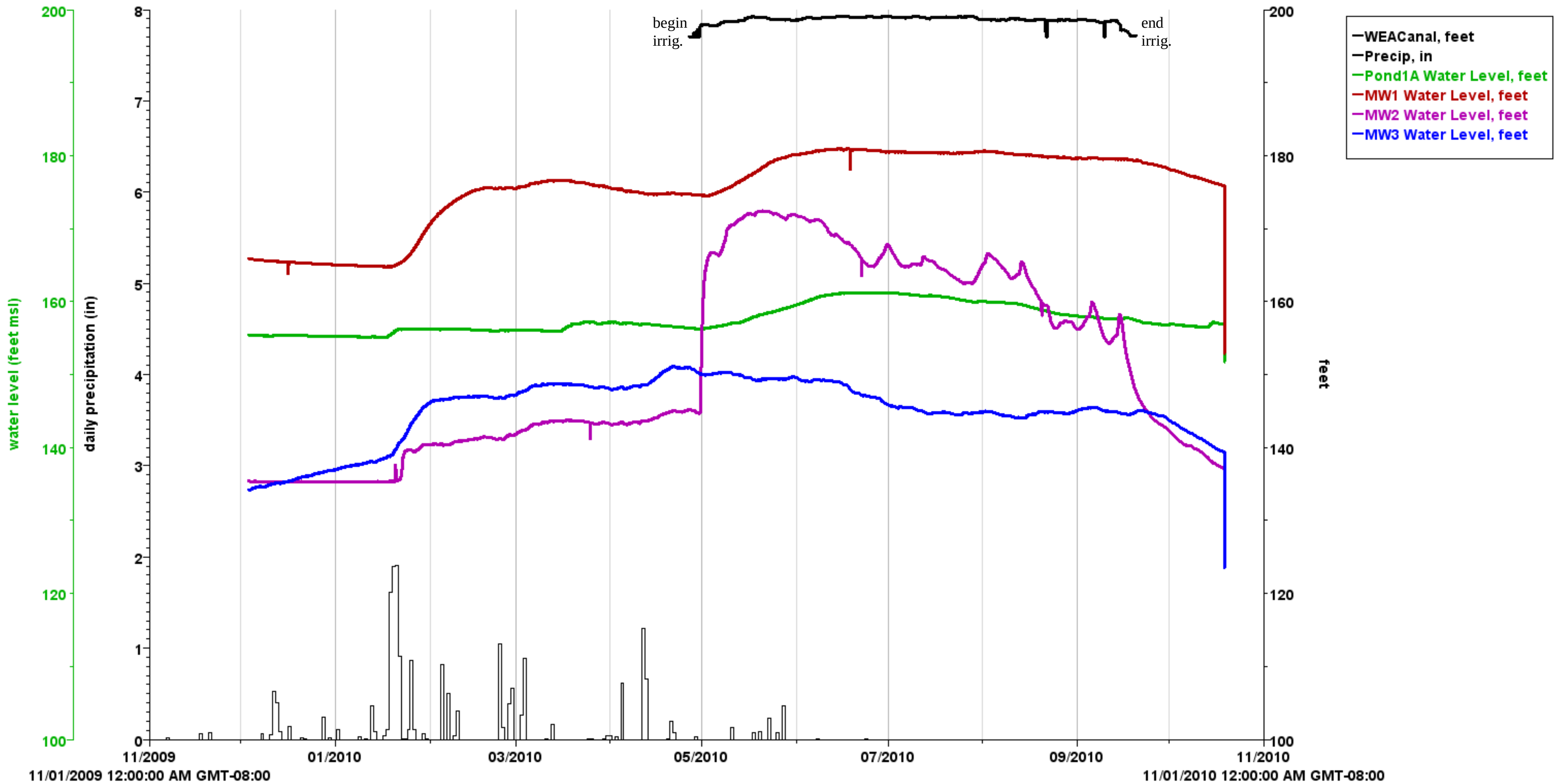
It appears that using the gravel pit pond as a recharge basin would not be very effective, as it drains slowly in its current configuration. If the pond were filled with water, it would remain relatively static and not recharge the aquifer. These are preliminary results. Perhaps if the pond was filled with water above its current level and no fines were added, infiltration rates could be increased. However, the current plan for this particular pond is to eventually fill it completely with fines from the washing process, and reclaim the land. The canal bottoms in the District's system appear to have much higher infiltration rates. The canals and other opportunities in the area for active recharge basin development should be explored.

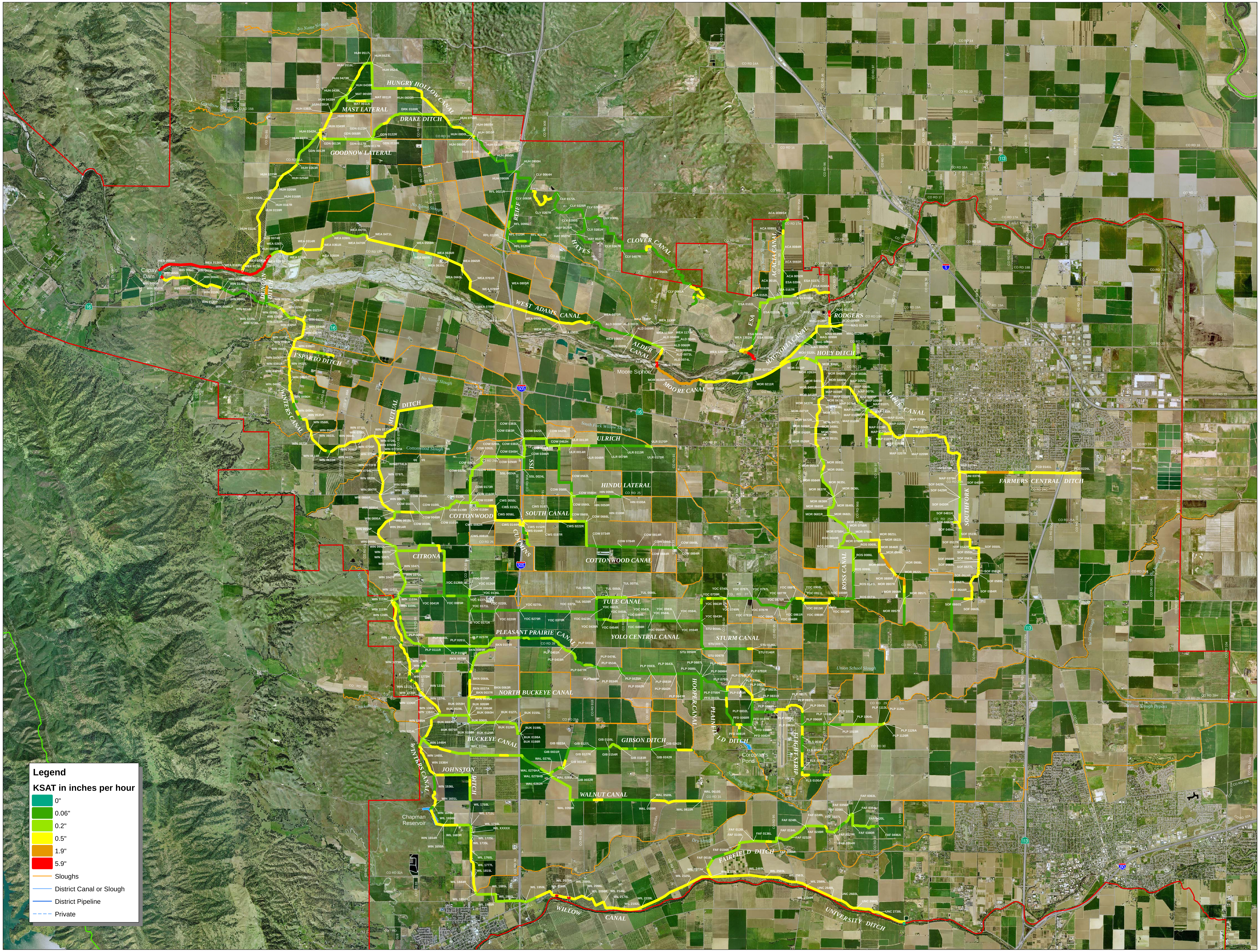
Recommended Action Plan

The Granite Capay facility pond has a low capability as a recharge facility and likely should not be used for an active recharge program, however other gravel mining facilities may be appropriate. The District's canal system should be the focus of future active recharge systems. This is due to higher infiltration rates in the canals versus the gravel pit and the large size overall of the District system. Other gravel pits in the Cache Creek system may be more appropriate for active groundwater recharge.

Although not discussed earlier, but mentioned here, the gravel pits along the Cache Creek system involve large amounts of administrative overhead due to coordination of mining operations and safety, unusual wintertime water delivery systems, and important environmental concerns. In contrast, the District's existing canal system is partially dependant on natural waterways and is efficient with no pumps that can be used for increased wintertime recharge. Over the next decades, the District should focus on upgrading its canal infrastructure for wintertime recharge operations.

Figure 6. Water levels (NGV27) at the Granite Capay Facility during 2010. Rain also shown in vertical bars.





AirPhoto USA Imagery flown March 2004 soil_perm2.pdf
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Soil Permeability

Yolo County Flood Control and Water Conservation District