

RECLAMATION

Managing Water in the West

Water Conservation Verification of Buena Vista Water Storage District Canal Piping Project

Kern County, CA near Buttonwillow, CA
Mid-Pacific Region



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Water, Environmental, & Ecosystems Division
Water Resources Planning & Operations Support Group

March 2017

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Acronyms and Abbreviations

%	percent
°	degrees
AFY	acre-feet per year [L^3/T]
BVWSD	Buena Vista Water Storage District
cfs	cubic feet per second [L^3/T]
ET	Evapotranspiration
ft	feet [L]
HDPE	High-Density Polyethylene
hr	hour [T]
in	inch/inches [L]
mi	mile/miles [L]
PVC	Polyvinyl Chloride
Reclamation	Bureau of Reclamation
SMART	Sustain and Manage America's Resources for Tomorrow
TSC	Technical Service Center
WEEG	Water and Energy Efficiency Grant

List of Variables

A	Cross-sectional area of the change in storage [L^2]
ET	Evapotranspiration outflow [L^3/T]
I	Inflow [L^3/T]
LG	Discharge from leaky gates [L^3/T]
n_{LG}	Number of data points in discharge from leaky gates data set
$n_{\Delta S}$	Number of data points in change in storage data set
O	Outflow [L^3/T]
S_{LG}	Standard deviation of the discharge for leaky gates
Sp	Seepage outflow [L^3/T]
$S_{\Delta h}$	Standard deviation of the water surface elevation decline
$S_{\Delta S}$	Standard deviation of the temporal change in storage
t_c	t distribution critical value
w_0	Initial width of water in the canal [L]
w_f	Final width of water in the canal [L]
Δh	Rate of water surface elevation decline [L/T]
ΔS	Temporal change in storage [L^3/T]

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Introduction

Buena Vista Water Storage District (BVWSD) received funds for a surface water conservation project from the Bureau of Reclamation's (Reclamation) FY16 WaterSMART Water and Energy Efficiency Grants (WEEG) cost-share program under funding opportunity number R16-FOA-DO-004 – reference code WEEG-30. BVWSD is located near the southern end of California's Central Valley, 30 miles (mi) west of Bakersfield, CA and 90 mi south of Fresno, CA (Figure 1).

BVWSD will use the funds to remove 10.5 mi of open, earthen-lined canal from service by installing 3.1 mi of High-Density Polyethylene and Polyvinyl Chloride (PVC) pipe (Figure 2). BVWSD estimates that the project will conserve 9,440 acre-feet per year (AFY) of surface water – 6,100 AFY from eliminating canal transmission losses and 3,340 AFY from improved flow measurement and control ("water better managed" conservation).

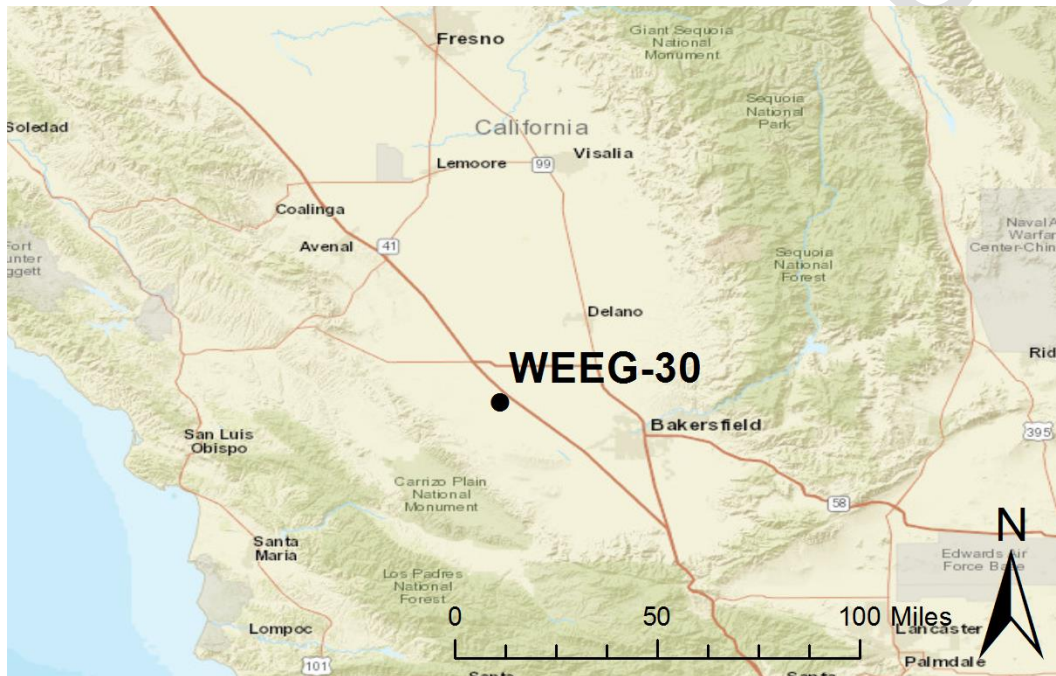


Figure 1 – Vicinity of BVWSD's piping project in the arid Central Valley of CA.

Every year after WEEG recipient selection is completed, several recipients are selected to have a Reclamation representative visit the recipient and verify the amount of water expected to be conserved by the project. Verification is done to improve WEEG selection criteria for future funding opportunities, and the results do not affect receipt of funds from current or future grants.

This work will focus on verification of surface water conservation from eliminating canal transmission losses (6,100 AFY) as verification of "water better managed" conservation is beyond the scope. Piping canals is known to conserve surface water by (1) eliminating evapotranspiration (ET) from the canal water surface and from plants near the canal and (2) eliminating seepage of water from the canal into the material surrounding the canal [Jensen *et al.*, 1967].

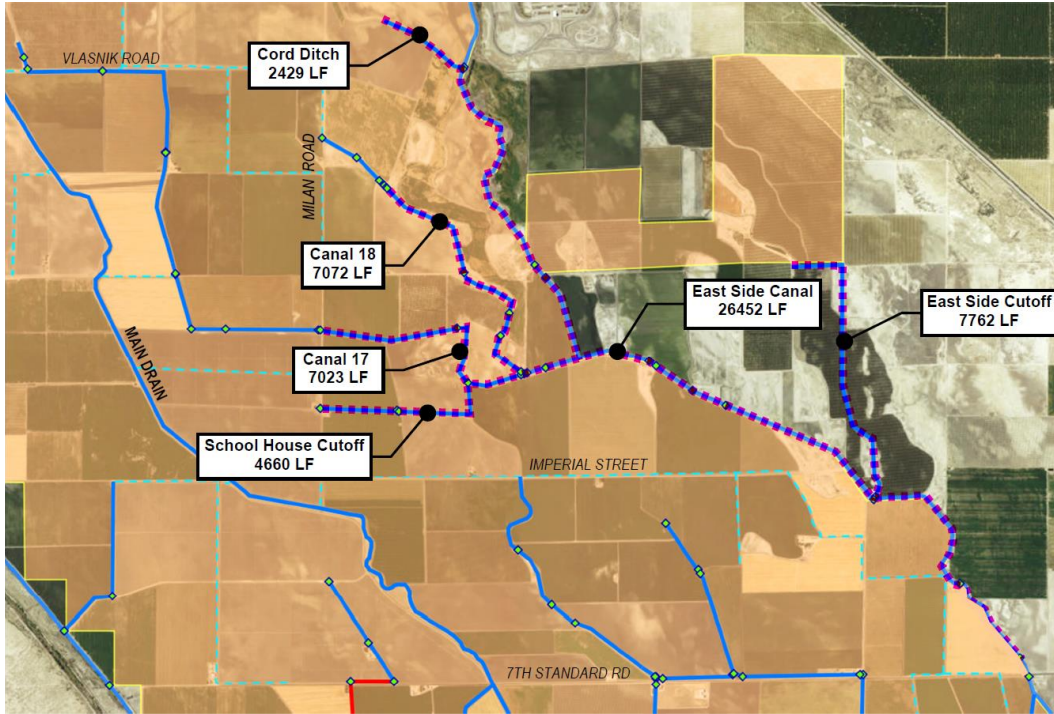


Figure 2 – Map of open, earthen lined canal which will be removed from service by the piping project – decommissioned canals. Canal lengths sum to 10.5 mi. Map courtesy of BVWSD.

Background

BVWSD presents their method for estimating current transmission surface water losses from the canals which will be removed from service (the decommissioned canals) in their grant application. The annual losses for a subset (Group C) of BVWSD's canals, of which the decommissioned canals are a subset, is stated to be 10,365 AFY. Per canal rates of loss for Group C sum to 69.8 cubic feet per second (cfs). Per canal rates of loss for those canals which will be decommissioned by the project sum to 41.1 cfs. Therefore, the decommissioned canals account for 59% of the total annual losses from Group C canals (41.1 cfs / 69.8 cfs). BVWSD assumes that current surface water losses will be fully mitigated by the piping project; therefore, total surface water conservation expected to be realized by the piping project is estimated to be 6,100 AFY (10,365 AFY * 59%)

Methods

To estimate the amount of surface water expected to be conserved by the piping project through the decommissioned canals, Reclamation used a method based on the continuity equation. The continuity equation states that the difference between the volumetric flow rate (discharge) of water entering a system (inflow, $I [L^3/T]$) and the discharge of water exiting the system (outflow, $O [L^3/T]$) is equal to the temporal change in the volume of water stored in the system ($\Delta S [L^3/T]$) [Dingman, 2015]. That is:

$$I - O = \Delta S \quad \text{Equation 1}$$

If we assume that no water is entering the system, ($I = 0$), then Equation 1 reduces to:

$$O = \Delta S \quad \text{Equation 2}$$

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Error! Reference source not found. Equation 2 indicates that the temporal decrease in the volume of water stored in a system with no inflows, is equal to the outflow from the system. This forms the basis of the ponding method for estimating canal surface water losses. For the ponding method, a reach of canal is isolated from inflows with either watertight dikes or gates – the reach of interest. The reach of interest is then filled to some depth with water and waves generated by filling allowed to stabilize (Figure 3). A time-series of change in water surface elevation data is collected [Bureau of Reclamation, 1976]. Using the canal geometry and rate of water surface elevation decline, the temporal change in storage of the reach of interest (ΔS) can be calculated. By Equation 2 this is equal to the outflows from the reach of interest. It is typically reasonable to assume the only outflows from the reach of interest are seepage (Sp [L^3/T]) and ET (ET [L^3/T]) (Figure 3). Equation 2 can then be modified to:

$$Sp + ET = \Delta S \quad \text{Equation 3}$$

Other possible outflows are leaky containment structures and/or direct pumping of impounded water. Pumping groundwater near the reach of interest could also artificially increase the seepage outflow. As stated above, piping projects are assumed to eliminate both seepage and ET [Jensen et al., 1967]; therefore, for verification of the water conservation expected to be realized by this project, the outflows of seepage and ET can be lumped.

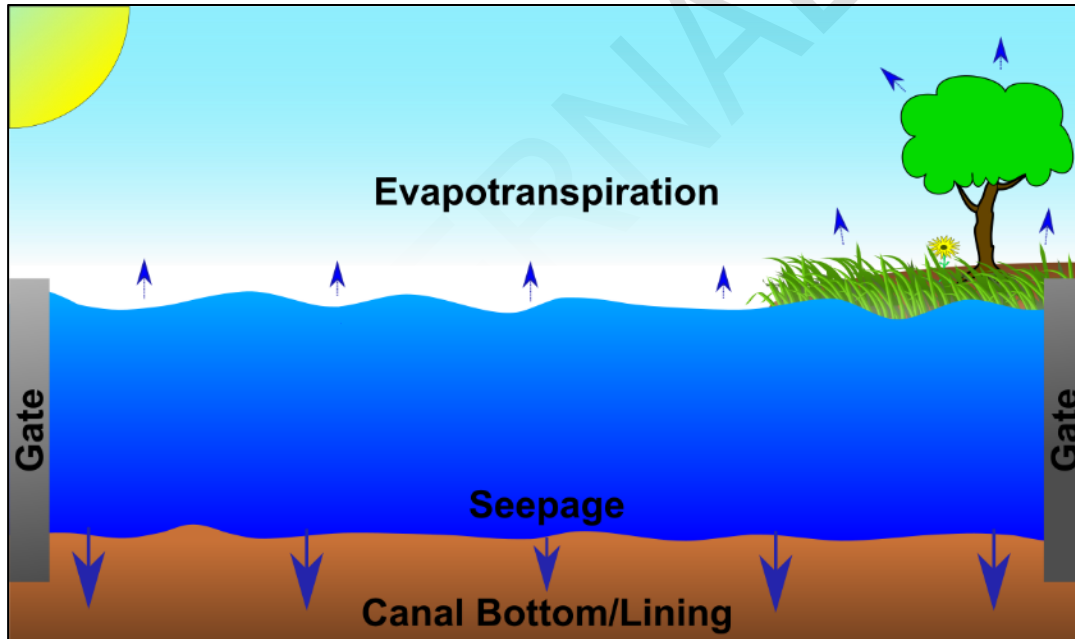


Figure 3 – Schematic depiction of a ponding test where inflows to the reach of interest are eliminated leaving only outflows. The lumped outflows of seepage and evapotranspiration can be estimated by measuring the change in storage in the reach of interest throughout the duration of the ponding test.

To estimate the temporal change in storage of the reach of interest, the canal geometry must be used. Typically, the canal has been filled prior to the start of the ponding test, so submerged canal geometry must be obtained from the canal owner or operator. Field measurement of some parameters can be collected. The canal cross section can typically be idealized as a trapezoid (Figure 4). Using the rate (or average rate) of water surface elevation decline (Δh), the cross sectional area of the change in storage of the reach of interest can be approximated as the area of a trapezoid (A):

$$A = \frac{w_0 + w_f}{2} * \Delta h \quad \text{Equation 4}$$

where w_0 is the initial width of water and w_f is the final width of water in the reach of interest (Figure 4). The initial water width can be measured on site at the start of the ponding test. w_f can be calculated using Δh , the side slope, and the base width or measured. This area can then be multiplied by the length of the reach of interest to calculate the temporal change in storage (ΔS). By Equation 2, this is equal to the outflow from the reach of interest (O), which, in most cases, can be assumed to be equal to surface water lost to seepage and ET (Equation 3).

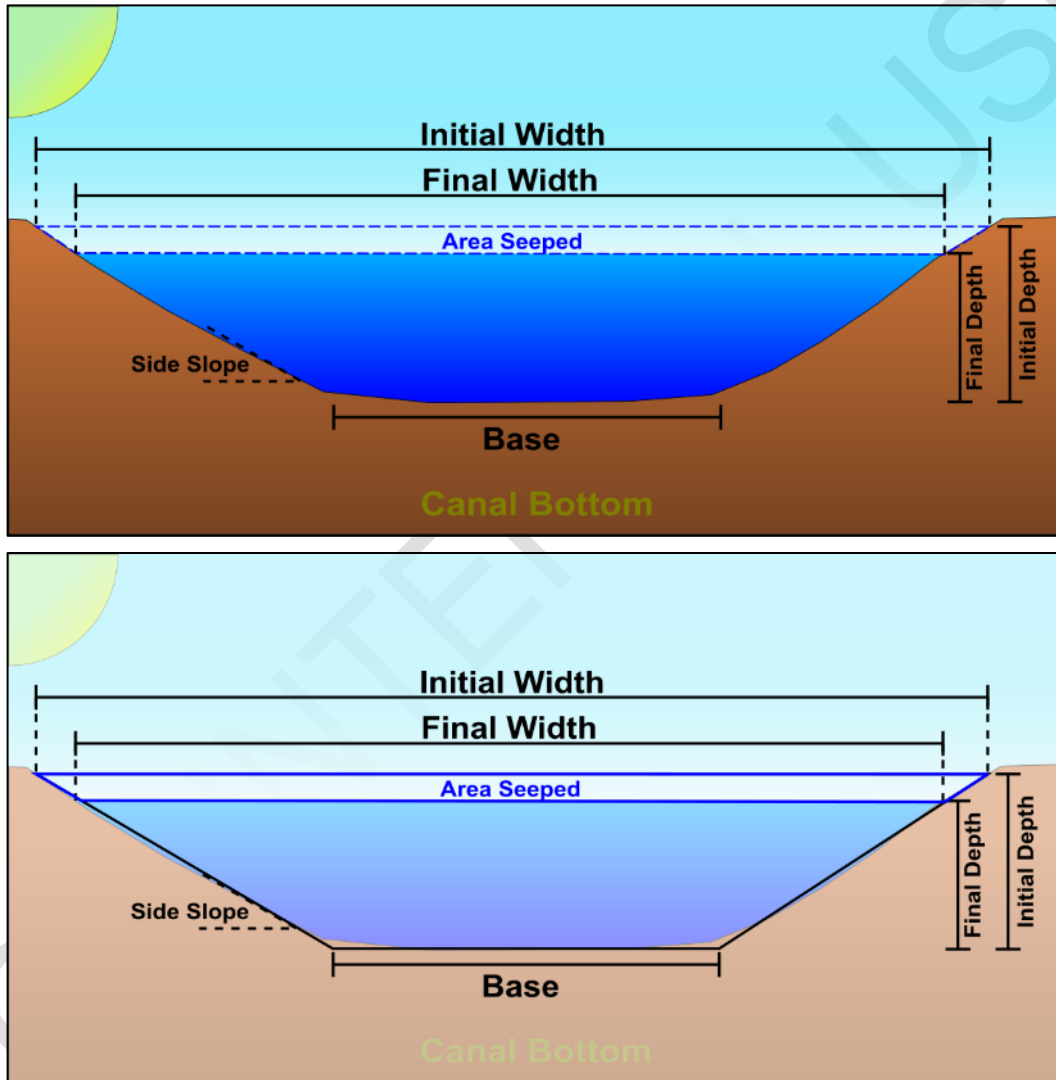


Figure 4 – Schematic depiction of reach of interest canal cross section. Top figure shows a more realistic representation, while the bottom figure shows an idealized, trapezoidal approximation.

Data Collection

Reclamation Hydrologic Engineer, Brandon House, visited BVWSD the morning of March

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23rd, 2017 to estimate surface water losses using a ponding test. A canal near the decommissioned canals (Angelo Canal – the reach of interest) was available for this work, and BVWSD began diverting water into this canal at the southern end early that morning (Figure 5). Approximately 0.2 inches (in) of precipitation occurred the previous day and none during the ponding test (GHCN Station ID: USC00041244). Once filled to a normal operating depth, water diversion into Angelo Canal was stopped and data collection began. Water depth was collected using a foldable, wooden measuring stick. Measurements were collected on a canal gate structure at the north end of the reach of interest. The structure had a concrete base and walls allowing for repeatable measurements (Figure 6) Depth of water data was collected for 4.5 hours (hrs) at approximately 0.5 hr intervals (Table 1).

Arrangements were made to receive canal geometry dimensions from BVWSD once the canal was drained and the earthen lining exposed (Figure 7). The length of the canal was provided by BVWSD and verified using ArcMap (*Esri*).

A second canal was also identified as a prospect for an additional ponding test – the School House Canal (Figure 5). This canal began being filled several hours after Angelo Canal. The gate separating the School House Canal from a small reservoir could not be sealed (Figure 5). The decision was made to fill the reservoir and open the gate to allow hydraulic connection between the two. Due to reservoir seepage rates not necessarily being similar to canal seepage rates, data from the School House Canal was not used for this work.

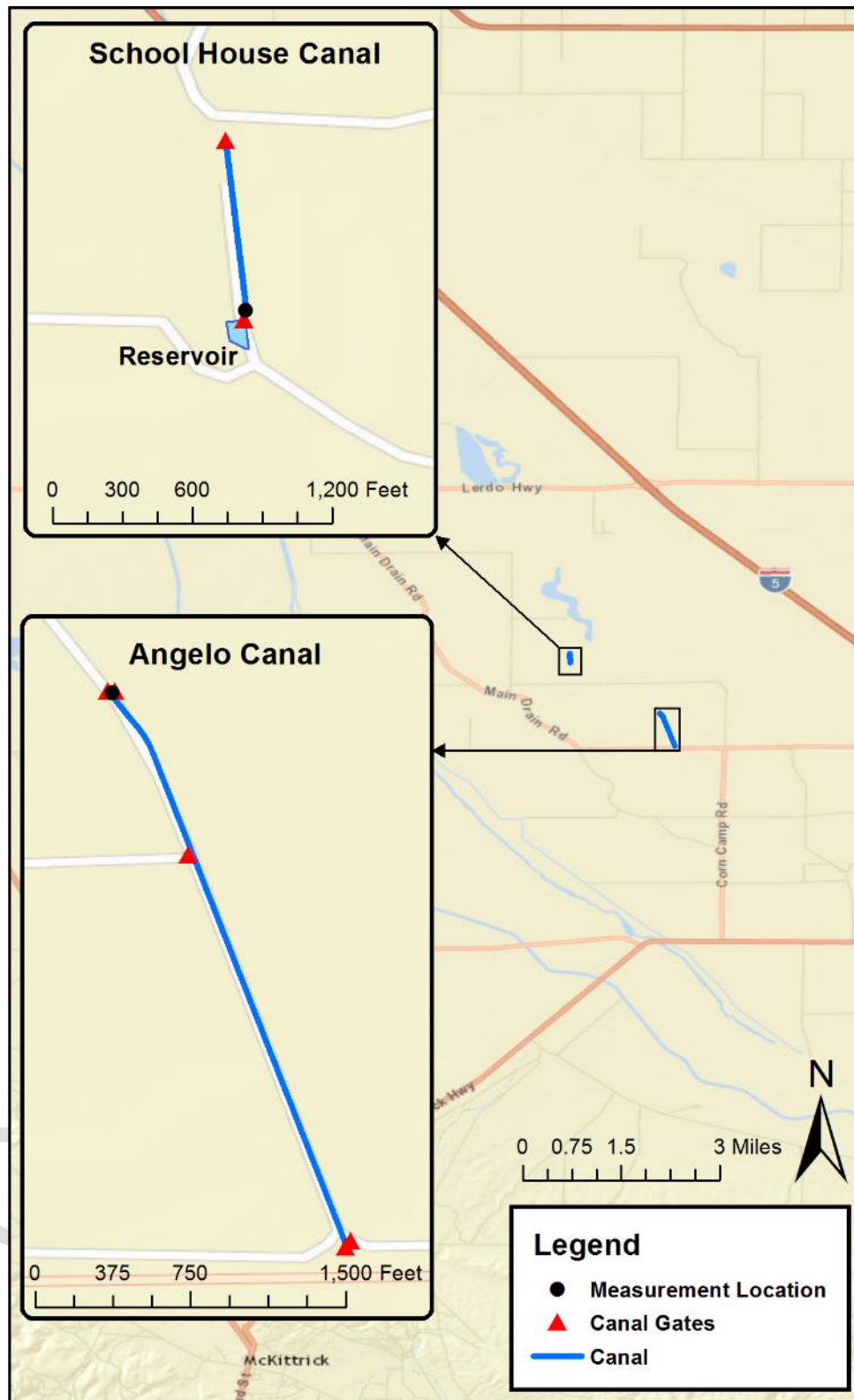


Figure 5 – Location of verification work. The blue line represents the reach of canal where water was impounded for the ponding test. School House Canal data was collected but not used in surface water loss analysis. Angelo Canal is 0.53 mi long. Angelo Canal was filled from the southernmost gate.

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Figure 6 – Angelo Canal looking southeast from northern end. Note two canal gates, both with slow leaks, and measurement location.

Table 1 – Ponding test field data. All data collected on March 23rd, 2017. Water depth does not represent depth of water in the canal as a whole but is used to calculate the change in water surface elevation with time.

Time of Measurement (hh:mm)	Water Depth at Measurement Location (in)	Rate Decline in Water Surface Elevation (in/hr)
10:45	42.4	N/A
11:25	42.3	0.19
11:45	41.5	2.25
12:08	41.0	1.30
13:20	39.8	1.04
13:50	39.3	1.00
14:20	38.8	1.00
15:14	38.0	0.83

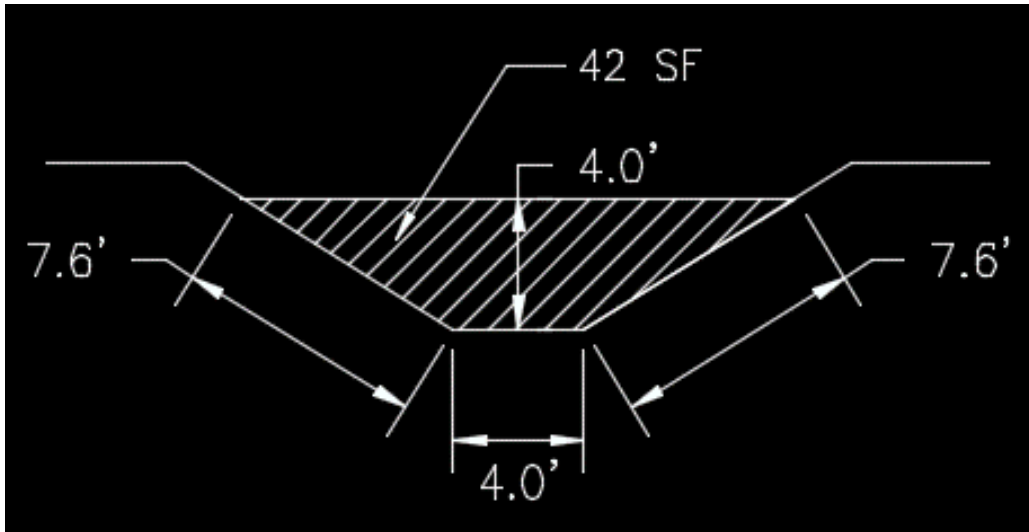


Figure 7 – Angelo Canal cross section dimensions received from BVWSD.

Five canal gates are connected to Angelo Canal (Figure 5). All were closed during the ponding test; however, four were observed to be less than watertight (Figure 8). One of the five gates was submerged so it is unknown if it was watertight. These four leaky gates represent an outflow from the reach of interest other than seepage and ET; therefore, Equation 3 must be modified to:

$$Sp + ET + LG = \Delta S \quad \text{Equation 5}$$

where LG is the total discharge from all the leaky gates. It was estimated that a discharge of 0.1 cfs was flowing from each leaky gate with an accuracy of $\pm 50\%$. The total discharge from the leaky gates (LG) must be removed from the temporal change in storage as, for this work, we are interested in calculating the portion of the temporal change in storage which can be attributed to seepage and ET. Equation 5 can then be rewritten as:

$$Sp + ET = \Delta S - LG \quad \text{Equation 6}$$



Figure 8 – Small leak from closed canal gate connected to Angelo Canal. Three other gates with similar leaks were observed from Angelo Canal.

Data Processing

Water surface elevation data collection was initiated immediately following cessation of diverting water into the reach of interest. Water was diverted into the canal from the southern end while data was collected at the northern end (Figure 5). Due to the wave generated by filling the canal, the first several measurements are not reliable for estimating the change in water surface elevation. Over time, the wave dissipates and the rate change in water surface elevation stabilizes. To evaluate when the stabilization occurred, data from Table 1 were plotted and a linear fit calculated using select data points (Figure 9). A good fit was found ($R^2=0.9973$) when the latter five depth measurements were used (Time of Measurement = 12:08 and on). The average (Δh) and sample standard deviation ($S_{\Delta h}$) of the rate of water surface elevation decline for these five measurements is presented in Table 2.

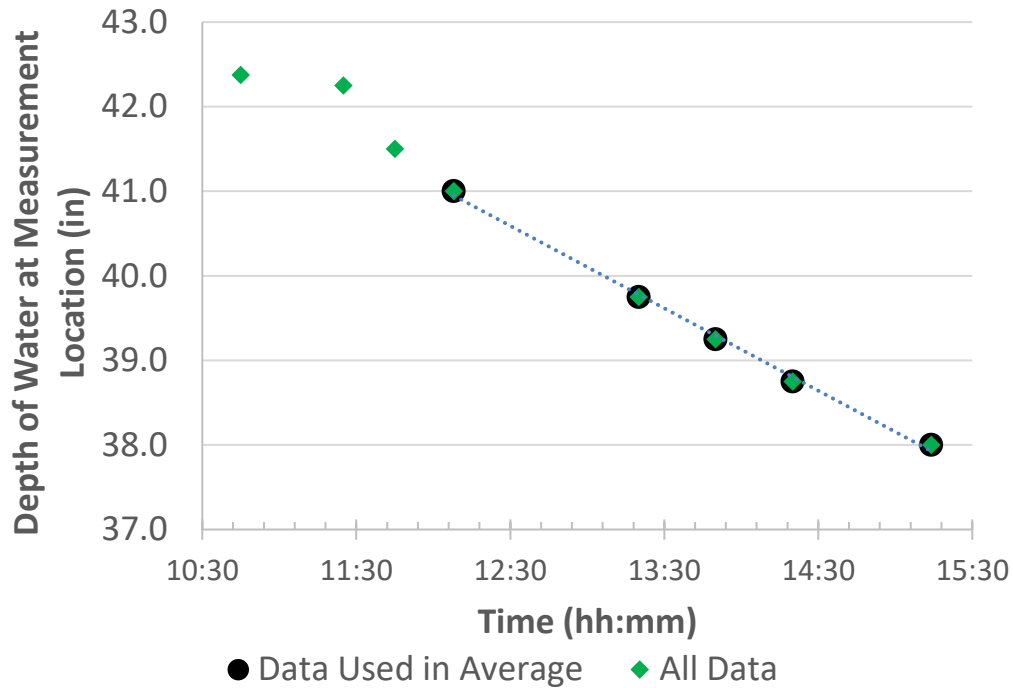


Figure 9 – Plot of depth of water over time at measurement location. Linear best-fit line (blue dotted line, $R^2=0.9973$) is shown for data used to calculate the average rate of surface water elevation decline.

Approximating the canal cross section as a trapezoid, the canal dimensions and the average rate decline in water surface elevation (Δh) were used to calculate the cross sectional area of the change in storage in the reach of interest (Equation 4). This value was multiplied by the length of the reach of interest to calculate the temporal change in storage (ΔS , Table 2). The standard deviation of the temporal rate of storage ($S_{\Delta S}$) was found by following the same procedure but for $S_{\Delta h}$.

Table 2 – Canal dimensions and calculation of volumetric flow rate of the change in water stored in the reach of interest. The rate of decline in the water surface elevation is the average and sample standard deviation calculated from the latter five data points.

Description	Value	Standard Deviation
Reach of Interest Length (ft):	2820	N/A
Reach of Interest Base Width (ft):	4	N/A
Initial Water Width (ft):	17	N/A
Reach of Interest Side Slope (°):	30	N/A
Water Depth (ft):	3.8	N/A
Final Water Width (ft):	16	N/A
Average Rate Decline in Water Surface Elevation, Δh (in/hr):	1.0	0.17
Temporal Change in Storage, ΔS (cfs):	1.1	0.18

Assuming the average rate decline in water surface elevation (Δh) data population is normally distributed, the confidence intervals were calculated using the t distribution,

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standard deviation of the data set (S), and the number of data points used to calculate the mean (n) [Spiegel et al., 2013]. The t distribution was used in place of the Normal distribution since n is less than 30. The confidence intervals are then calculated by:

$$\Delta h \pm t_c \frac{S_{\Delta h}}{\sqrt{n}} \quad \text{Equation 7}$$

where t_c is the t distribution critical value read from a table based on the desired confidence level and the degrees of freedom ($n - 1$). Equation 6 requires the calculation of the difference between ΔS and LG , both of which have uncertainty. The confidence interval for the difference between two values with uncertainty can be calculated by [Spiegel et al., 2013]:

$$\Delta S - LG \pm t_c \sqrt{\frac{S_{\Delta S}^2}{n_{\Delta S}} + \frac{S_{LG}^2}{n_{LG}}} \quad \text{Equation 8}$$

Since discharge measurements from the leaky gates were not collected, n_{LG} was assumed to be infinite ($n_{LG} = 999$) and the uncertainty in the estimate was included in the assumed 50% error. In this case, the difference between these values will be the lumped discharge of seepage and ET from the reach of interest.

Results

Results of the ponding test are summarized in Table 3. The temporal change in storage, adjusted for discharge from the four leaky gates, over the duration of ponding test was 0.7 ± 0.17 cfs for this depth of water (Equation 8). The change in storage was then normalized for the length of the reach of interest to account for the difference in length between it and the decommissioned canals. With 90% confidence, this yields approximate annual surface water loss of 7636 ± 1763 AFY (Table 3).

Table 3 – Calculation of Estimated Surface-Water Losses

Temporal Change in Storage, ΔS (cfs):	1.1 ± 0.17
Estimated Discharge from Gates, LG (cfs):	0.4 ± 0.2
Adjusted Temporal Change in Storage, ΔS (cfs):	0.7 ± 0.17
Irrigation Season Duration (days):	274
Reach of Interest Length (mi):	0.53
Total Length of Decommissioned Canals (mi)	10.5
Annual Surface Water Losses (AFY):	7636 ± 1763

Conclusions

By Equation 6, it is assumed that the adjusted annual surface water losses from the reach of interest are entirely from seepage and ET. By piping the reach of interest it is assumed that these surface water losses will be entirely mitigated. With 90% confidence, the canal piping project will result in a surface water conservation of $7,636 \pm 1,763$ AFY. This is $25\% \pm 29\%$ more than the estimated surface water conservation of 6,100 AFY stated in BVWSD's grant application.

The uncertainty in these results is due to variability between measurements of the rate of water surface elevation decline (Table 1), the number of measurements collected, and

estimating the discharge from the leaky gates. The greater the central tendency of the rate of water surface elevation decline, the less uncertainty in the final average value used. The confidence interval for the rate of water surface elevation decline is relatively low ($\pm 16\%$). However, when the difference of this and the discharge from the leaky gates is calculated, the uncertainty is amplified ($\pm 23\%$). Uncertainty can be reduced by collecting additional measurements; however, this was not deemed necessary to accomplish the project scope.

The scope of this work is to verify that the grant recipient's estimate of surface water conservation realized from the funded project is reasonable. The surface water conservation estimated by BVWSD (6,100 AFY) is within the 90% confidence interval of the estimated surface water conservation resulting from this ponding test. It is recommended that BVWSD's grant application surface water conservation estimate be considered reasonable.

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