FINAL REPORT

Canal Modernization Study for the Evans Ditch

Prepared for the City of Evans

June 20, 2006

Aqua Engineering, Inc.
4803 Innovation Drive
Fort Collins, Colorado 80525
970.229.9668
www.aquaengineering.com

Table of Contents

List of Tables 2

List of Figures 3

Introduction 4

Canal System Overview 4

Canal System Inventory 6

Canal Structure Improvements 8

- Regulation Structures 8
- Measurement Structures 12
- Sedimentation Structures 22
- Canal Lining and Piping Options 25
- Storage and Equalizer Reservoirs 31
- Pressurized Secondary Supply 33

Supervisory Control and Data Acquisition 34

- General SCADA Concept 34
- Evans Ditch Conceptual SCADA Plan 41

Summary 44

Appendix A 45

List of Tables

Table 1. Regulation Structure Recommendations for Evans Ditch 11
Table 2. Measurement Structure Recommendations for Evans Ditch 21
Table 3. Sedimentation Structure Recommendations for Evans Ditch 24
Table 4. Lining and Piping Recommendations for Evans Ditch 29
Table 5. Typical cost for pipe and lining applications 30
Table 6. SCADA Recommendations for Evans Ditch 42

List of Figures

Figure 1. Canal Inventory for Evans Ditch 5

Figure 2. Example of query performed in structure inventory database 7

Figure 3. Rubicon gate installation with SCADA 10

Figure 4. Rubicon gate installation near Lucerne, CO 10

Figure 5. Prefabricated Parshall flume 14

Figure 6. Concrete Parshall flume constructed in field 15

Figure 7. Conceptual layout of a long-throated flume 16

Figure 8. Long-throated flume under construction 16

Figure 9. Long-throated flume in operation 17

Figure 10. Long-throated flume installed in pipe section 17

Figure 11. Eastech Manhole Badger Flume 18

Figure 12. TRACOM Packaged Metering Manhole with a Palmer-Bowlus flume 19

Figure 13. Plasti-Fab Packaged Metering Manhole 19

Figure 14. Rated section measurement structure for Evans Ditch 20

Figure 15. Sand trap on Evans Ditch at Empire Street Tube 23

Figure 16. Preparation of site and completed concrete ditch 27

Figure 17. An equalizer reservoir captures excess flows for Subsequent release to make up shortages 31

Figure 18. Example pump station that transfers water from an equalizer reservoir 32

Figure 19. SCADA system example 35

Figure 20. CAIDD SCADA system 37

Figure 21. Dolores Project SCADA system 37

Figure 22. Automata RTU complete with Auto/Manual Control Panel 38

Figure 23. Preliminary SCADA locations for Evans Ditch 43

Introduction

The purpose of this study is to provide the City of Evans with an evaluation of improvements and recommendations for the future modernization of the Evans Ditch. Aqua Engineering, Inc. was commissioned by the City of Evans to examine a full spectrum of canal modernization options for the Evans Ditch including:

- Conceptualization of structural improvements including control, regulation, measurement, and sedimentation structures in addition to lining and piping options.
- Conceptualization of a pressurized water delivery system
- Conceptualization of a master plan for Supervisory Control and Data Acquisition (SCADA)

In addition, an inventory of existing structures was also completed and incorporated into mapping format compatible with the City's mapping system.

A majority of the canal modernization options presented in this report were identified in conjunction with City of Evans' staff. The project approach was to first evaluate all aspects of the canal system by touring, inventorying, and mapping structural components. This initial step was important for two reasons: (1) to provide a consistent base level of information for discussing modernization options, and (2) to provide Evans with a working canal structure database for future canal management.

The second step in the project approach was to identify, in conjunction with City staff, the primary structural improvement options for the canal. These ideas are discussed and prioritized in this study. Some general level cost estimates are also provided for these options. One element of work that was originally identified in the scope of this study was to consider options related to canal pressurization. During our discussions with City staff, it became apparent that pressurization is not a preferred option for the Evans Ditch at this time. For reasons that will be further elaborated below, pressurization is not given significant consideration in this study. The primary outcome of this element of the work was a further evaluation of improvements already identified by City staff.

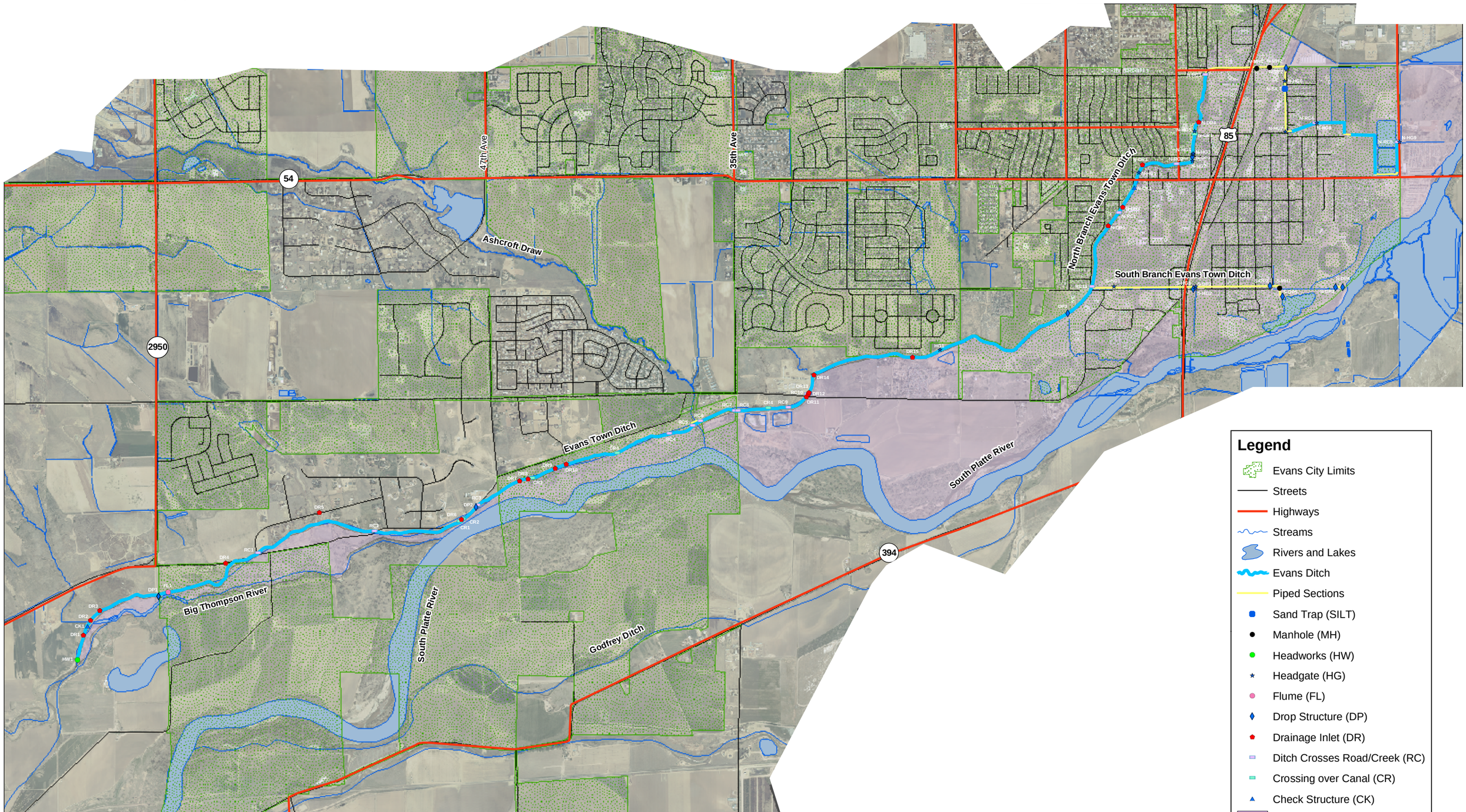
It became apparent through our efforts that the primary canal modernization option of interest to City staff was planning and implementation of SCADA. As such, more detail and discussion is given to this topic in this study. Detailed conceptualization of future SCADA sites, prioritization, phasing and cost estimates are provided. The primary outcome of this element of work was detailed recommendations for implementing SCADA for the Evans Ditch.

Canal System Overview

The Evans Town Ditch (referred to hereinafter as Evans Ditch) originates from the north bank of the Big Thompson River about 1.75 miles upstream of the confluence with the South Platte River. The ditch is an open, earthen ditch until 42nd and Belmont, where it splits into a south branch (which is a piped section that runs east and discharges into Riverside Lake near the South Platte River) and north branch (which is an open ditch that meanders north and east where it discharges into the South Platte River just east of the City of Evans). Refer to Figure 1.

Figure 1. Canal Inventory for Evans Ditch

Canal Modernization Study for the Evans Ditch



Aqua Engineering, Inc.
4803 Innovation Drive
Fort Collins, Colorado 80525
970.229.9668 Phone
970.226.3855 Fax

Plotted Date: June 2006

The Evans Ditch was historically used to irrigate farm land in and around the City of Evans. Over the last several decades, the City of Evans has made extensive use of the water from the ditch for purposes of landscape irrigation at City facilities, including parks, public buildings, schools, open space, as well as residential developments and traditional irrigated agricultural lands. The Evans Ditch is and has been a primary source of non-potable water supply for the City's extensive non-potable irrigation system. Water use from the canal for urban and suburban landscapes is anticipated into the future as the City of Evans continues to preserve their treated water for domestic demands.

The water rights associated with the Evans Ditch only include direct flow (no storage), but the decree is quite senior in the water rights priority system. Even during the severe drought in 2002, the Evans Ditch did not experience a significant reduction in the amount of water diverted and delivered.

For the most part, water supply availability from the ditch is not a significant concern for the City. Because the area in and around the ditch is urbanizing, storm water runoff is of most concern to the City (urbanization tends to increase the magnitude and timing of runoff during storm events). In addition to urbanization, the western half of the Evans Ditch transverses a naturally steep slope. During significant storm events, and in the future as some of the open space areas to the north of the ditch are urbanized, the Evans Ditch serves as a flood water catchment. In some sense, the ditch is a concern for the City because it is the catchment of flood water and there is concern regarding the ability of the ditch to safely convey and discharge this water.

Canal System Inventory

An inventory of the existing structures along the Evans Ditch system was completed as a component of this work. Locations of existing structures were mapped using a handheld GPS device. Appendix A includes Geographical Information System (GIS) based maps, associated inventory database, and a data CD including all electronic GIS files, database files, and structure photos.

The data collected and inventoried in the GIS database include the following:

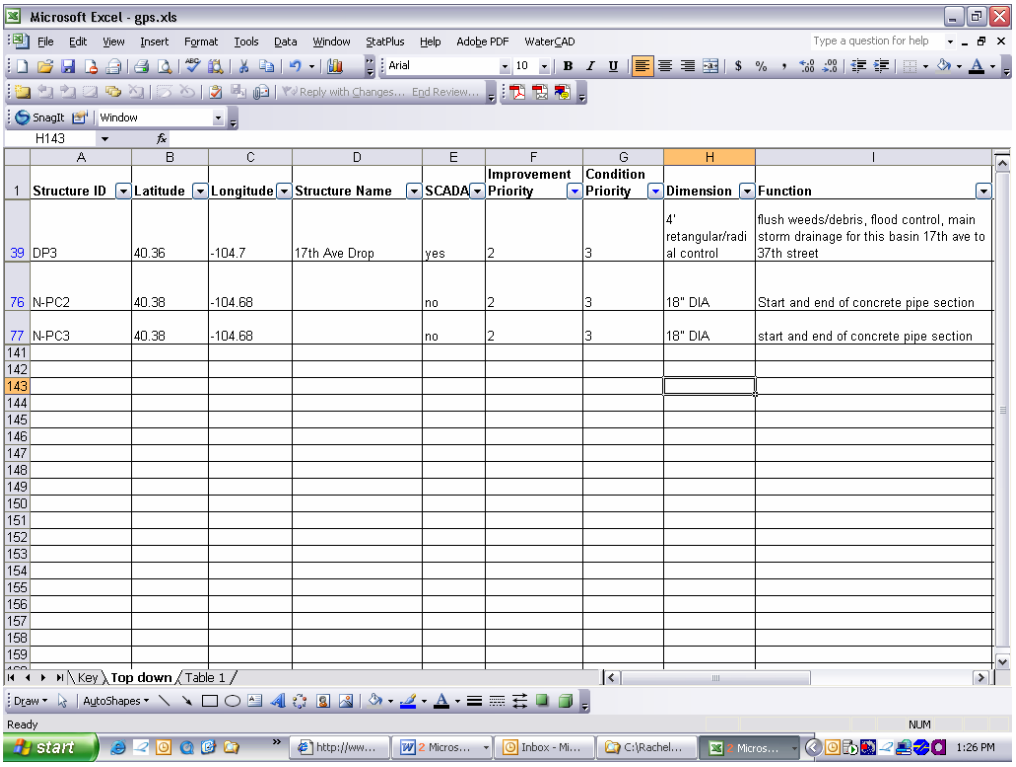
- Structure Name
- Improvement Priority
    - Rank 1: immediate
    - Rank 2: soon
    - Rank 3: not a priority
- Condition
    - Rank 1: excellent
    - Rank 2: adequate
    - Rank 3: minor repairs
    - Rank 4: not used / not applicable
- Critical Dimension (e.g. diameter, width)
- Function Description
- General Notes
- Problem Description
- SCADA Priority
- Site photos
- GPS location (longitude and latitude)

Inventory development is a mechanism that can be used to better manage all aspects of an irrigation system: from an inventory of the historical construction upgrades to accounting for water deliveries to users. Inventories can be as complex as an interactive GIS database with spatial links to a multitude of irrigation system attributes, or as simple as a paper database and map that will hang in the office.

Because the City of Evans has access to GIS, we recommend that the information collected in this inventory be used as the base for an interactive GIS database inventory system. Under this approach, a user would “click” on a structure point on the map and an associated database with information about that structure would display on the screen. Because the data fields in the database can be edited and updated over time, GIS can be a very useful information and data warehouse tool.

Another advantage to using an inventory database is that a user can quickly query data to find particular information, such as all structures that are in need of prioritized improvements. The database can also be used as a planning tool because it is an easy way to keep track of when each of the structures are slated for improvement or construction.

Figure 2 shows an example of how the Evans Ditch inventory can be used to query structures so prioritization can be determined. The query shows there are three structures that have a Rank 2 (soon) in the *Improvement Priority* category and a Rank 3 (minor repairs needed) in the *Condition* category. Appendix A includes a copy of the database that has the structures ordered from top of the canal to the bottom. The electronic version of the database (included in Appendix A) can be queried directly in Microsoft Excel by using filter commands.



	Structure ID	Latitude	Longitude	Structure Name	SCADA	Improvement Priority	Condition Priority	Dimension	Function
39	DP3	40.36	-104.7	17th Ave Drop	yes	2	3	4' retangular/radial control	flush weeds/debris, flood control, main storm drainage for this basin 17th ave to 37th street
76	N-PC2	40.38	-104.68		no	2	3	18" DIA	Start and end of concrete pipe section
77	N-PC3	40.38	-104.68		no	2	3	18" DIA	start and end of concrete pipe section

Figure 2. Example of query performed in structure inventory database

The data collected during this work effort should only be used as the base for future database upgrades. Our work effort was intended to take the base level GPS locations for each structure. This information is the root of the GIS database and will only need to be updated as structures are removed or relocated. The detailed information that is linked to these structural points is the information that Evans should update and use on a regular basis.

Canal Structural Improvements

A multitude of canal structural improvements were discussed with City of Evans' staff during this study including regulation structures, measurement structures, sedimentation structures, and canal lining and piping. These improvement ideas were primarily identified by staff and are discussed in detail in this section.

Regulation Structures

General Overview

Regulation structures are used to control the conveyance of water through an irrigation canal system, starting with the control of inflow to the canal through a diversion dam for example, and ending with the discharge from the canal into laterals or individual headgates. The primary function of regulation structures is to control water. For example, check structures are used to raise the water surface higher than would normally exist in the canal to provide adequate head for delivery to headgates and water users. Spillways are also used to control water in a canal, but they are more commonly referred to as a protective structure because their primary function is to discharge excess water from the canal when needed, such as during a storm event.

Spillway structures are of most interest in this study because there are very few check structures in the Evans Ditch system and the structural integrity of the diversion headworks and individual headgates is adequate. For this reason, the emphasis of discussion in this section is on the application of overshot gates at spillways and at points of bifurcation in the Evans Ditch.

There are many types of gates that can be used for spillways, including radial gates, sluice or slide gates, and overshot gates. We recommend using overshot gates for a spillway application. These gates are likened to a draw bridge – the canal is fully open when the gate is horizontal and the canal is fully closed when the gate sits at 60 degrees from the ground. The following describes several advantages to using an overshot gate in a spillway application:

- Overshot gates can be used to effectively achieve a target upstream water level. The adjustments needed to achieve a desired change in direction and amount of flow are intuitive and predictable. In contrast, adjustments made to an underflow gate depend on the water level on both sides of the gate, thus control of these structures is less intuitive[1].

[1] Underflow gates or orifices are more sensitive than rectangular or weir type gates. A structure with lower sensitivity is better able to resolve small differences in flow, as is the case with an overshot gate.

- The precision of adjustment is very high in overshot gates - small changes can be made to allow for exact position and flow conditions.
- Overshot gates more effectively pass floating debris and high water flows. This is very important for a flood spillway because debris and high surges of water flow can damage the canal if not easily passed through the spillway gate.
- Compared to other gate types, the overshot gate does not submerge as easily (upstream control only).
- Measurement capabilities are easier and more accurate with this type of gate than with other gates.

Rubicon Global Pty. Ltd. offers overshot design gates that incorporate control, regulation, SCADA integration, and measurement into a single, convenient package. These gates can be installed in existing concrete check structures or at new locations (Figures 3 and 4)[2]. Each gate includes a robust remote terminal unit (RTU) and four pressure transducers (two on the upstream side of the gate and two downstream of the gate). The advantage of having four pressure transducers is to provide redundancy and increased accuracy. A $\pm$ 2% accuracy has been reported by a third party group. Additional advantages to the Rubicon solution come from its flexibility. For example, it can be installed in both wet and dry conditions and can be powered either by AC or 12 volt DC (solar panel). For locations where both control and flow measurement are desired, a Rubicon gate may be the most feasible and lowest cost structure rather than installing a separate long-throated flume and a separate check and gate structure.

Recommendations for Evans Ditch

The City of Evans currently has two Armtec overshot gates at the primary diversion and the Measurement Adjustment. The controller in these Armtec gates is not a SCADA compatible unit. In order to make these gates SCADA compatible, it will be necessary to remove and replace the gate controller with a suitable RTU compatible with the RTUs used throughout the SCADA system. If SCADA is desirable throughout the system, we recommend using a SCADA compatible overshot gate for all future installations and possibly retrofitting or replacing existing overshot gates that are not SCADA compatible (i.e., the Armtec gates).

The Evans Ditch staff would like to install overshot gates at all major spillway locations on the ditch. These sites include, in order from highest to lowest priority: Flume at Ashcroft Draw, Purneys, 17th Drop, North-South Split, 31st/Empire Box, 42nd/Golden Box, and 36th Ave Drop. The details of these improvements are summarized in Table 1.

[2] The Greeley #2 Canal north of Evans has Rubicon gates and the site with these gates could be toured.

Figure 3. Rubicon gate installation with SCADA

Figure 4. Rubicon gate installation near Lucerne, CO

Table 1. Regulation Structure Recommendations for Evans Ditch

Site Name	Project Priority	Condition Rank	Current Condition	Recommended Approach	Notable Cost Elements
Flume at Ashcroft Draw	1	3	Site was recently reconstructed but did not include an emergency spillway gate to Ashcroft Draw. This is a logical location to spill water because there are no spillway capabilities between Purneys and 17th Drop.	An overshot gate is recommended for purposes of control and measurement. This gate will be used to flush debris from the canal during the spring and waste water during a flood.	Cast-in-place concrete structure with floor and wingwalls, riprap, 1-96 inch Rubicon gate, site preparation. **$73,500 - 80,000**
Purneys	2	3	The primary function of the current structure is an emergency spillway to the river. The current gate consists of two manual control sluice gates that are difficult to operate and often catch debris where the two gates interface.	An overshot gate is recommended for purposes of control and measurement. This gate will primarily be used as an emergency spill way. The current location (at a low point in the canal) is desirable to drain the ditch when it is turned off. It may be desirable to increase the overall width of the gate.	Cast-in-place concrete structure with floor and wingwalls, riprap, 1-60 inch Rubicon gate, site preparation. **$86,000 - 92,000**
17th Drop	3	3	The primary function of the current structure is an emergency spillway to the river and a head and flow adjustment for downstream delivery. The current sluice gate is manual control and releases water from below the sluice gate which tends to decrease the flexibility to adjust head for downstream use.	An overshot gate is recommended for purposes of control and measurement. This structure will primarily be used to adjust the amount of flow delivered to the rest of the canal. The next location on the ditch that flow can be adjusted is the North-South Branch.	Cast-in-place concrete structure with floor and wingwalls, riprap, 1-48 inch Rubicon gate, site preparation. **$64,500 - 71,000**
North-South Split	4	2	Currently there is no easy way to adjust the amount of flow that is allocated between the North and South Branch (boards at the entrance to the South Branch are currently used to make manual adjustments). Major concern is the amount of water that is allocated to the South Branch because there is a significant elevation drop between head of branch and the 31st/Empire Box - this is the only point of release for the South Branch aside from delivery directly to users.	An overshot gate is recommended on the South Branch for purposes of control. Measurement is not necessarily needed at the location, but the overshot gate is also capable of providing this. The overshot gate could be placed at the entrance of the South Branch and could route water into the existing pipeline.	Cast-in-place concrete structure with floor and wingwalls, riprap, 1-24 inch Rubicon gate, site preparation. **$52,000 - $67,600**
31st/Empire Box	5	2	Provided a control structure is placed at the North-South Split and improvements are made to the 17th Drop, it will probably not be necessary to control the amount of water discharged from this box to river. However, measurement is desirable at this location and the ability to better control and distribute water is desired. Function and condition of structure is mostly adequate.	Because this structure is old, it may be necessary to make improvements or rebuild the structure in the near term. It will not be posssible to retrofit the existing diversion box to include overshot gates. If overshot gates are desirable for water control, structure should be redesigned and reconstructed.	For reconstruction and incorporation of slide gates: cast-in-place concrete structure, 3-18 inch diameter slide gates. **$26,000 - 31,500** For reconstruction and incorporation of Rubicon overshot gates: cast-in-place concrete structure, 3-24 inch Rubicon gates. **$78,000 - 98,800**
42nd/Golden Box	6	2	Provided a control structure is placed at the North-South Split, it will not be necessary to control the amount of water discharged from this box to the Riverside Pond at the tailend of the South Branch. However, measurement is desirable at this location and the ability to better control and distribute water is desired. Function and condition of structure is mostly adequate.	Because this structure is old, it may be necessary to make improvements or rebuild the structure in the near term. It will not be posssible to retrofit the existing diversion box to include overshot gates. If overshot gates are desirable for water control, structure should be redesigned and reconstructed.	For reconstruction and incorporation of slide gates: cast-in-place concrete structure, 3-18 inch diameter slide gates. **$26,000 - 31,500** For reconstruction and incorporation of Rubicon overshot gates: cast-in-place concrete structure, 3-24 inch Rubicon gates. **$88,500 - 109,500**
36th Ave. Drop	7	2	This manual control sluice gate is rarely used, but has been used in the past occasionally for an emergency spillway to a neighborhood wastewater pond. Improvement to this structure is not a high priority.	An overshot gate is recommended at this location to control and measure spills during flood events and emergencies.	Cast-in-place concrete structure with floor and wingwalls, riprap, 1-48 inch Rubicon gate, site preparation. **$64,500 - 71,000**

Condition Rank:
1 - excellent
2 - adequate
3 - minor repairs
4 - not used/not applicable

Measurement Structures

General Overview

Water measurement is an important component to consider when evaluating the potential for canal modernization. External and internal pressures on irrigation systems are increasing the need for better water measurement, including:

- Shortage and competition of water supplies
- Increased number of smaller water users in urban areas
- Urban storm water runoff
- Environmental problems or impositions
- Accountability
- Increased desire for operation and customer service flexibility

Fortunately, increased pressure to measure is accompanied by the increased accuracy and affordability of water measurement options. Water measurement also has many direct benefits and incentives for irrigation, including:

- Improved canal management
- Improved water use management
- Establishment of historical patterns of water use
- Reporting and accountability
- Securing the water right and decree
- Alarm conditions (example: storm inflows)

Selection

The selection of flow measurement devices is based on several factors:

- accuracy
- cost
- flow range
- head loss
- adaptability to site conditions
- ability to pass sediment
- maintenance requirements
- construction and installation requirements

These many different considerations must be factored into the selection and design of a measurement device to achieve an effective and economical installation. Consideration should be given to the operational demands of each device and how it will fit with the existing operation of the canal. Some of the different devices that can be used for water measurement are:

- weirs
- flumes
- submerged orifices
- current meters
- acoustic flow meters

Each one of these devices has advantages and disadvantages that must be considered when choosing a device that is most appropriate for the Evans Ditch. For purposes of

this report, we only discuss flumes since these are the most common measurement structures currently installed in the Evans Ditch.

First, the desired accuracy must be determined because it may limit the type of devices that are available. In open channel flow of canals, it is common and acceptable practice to target an accuracy between ± 5% and ± 10% in the field. Some devices have accuracies as great as ± 1% in laboratory conditions. The ± 1% accuracies can also be achieved in the field, but with additional cost and effort due to special construction, recalibration, and maintenance. The site for the measurement must be scrutinized since the site could require a non-standard design and installation of the device, causing the accuracy to approach ± 10% or more. The most accurate installed open channel flow device is the long-throated flume at ± 2%.

Cost is often the most important factor in choosing a device. The total costs to consider include the measurement device, the construction installation, and the long-term maintenance and operations. In addition to the initial capital cost of the structure, the life span, durability of the device, and desired accuracy should also be considered.

The flow range is an important consideration since certain devices require specific flow conditions in the calibration and measurement of water. If the flow is outside of the requirements of the structure, then the accuracy of measurement could be significantly affected. One example given by the U.S. Bureau of Reclamation in the *Water Measurement Manual* (1997) states that “sharp-edged devices typically do not give good results with large flows, which are better measured with large flumes or broad-crested weirs”. The device should be chosen to cover the entire flow range of the canal, understanding that different levels of accuracy may be achieved for the high flow and low flow scenarios.

Another consideration is the amount of head loss that results from the measurement device. Canal sections that are relatively flat may not permit a structure that requires significant head loss. The combination of the cost and amount of head loss should be considered. It is possible to have very little head loss, but the cost of installation and construction is usually much higher.

The ability of a structure to pass sediment is often a critical component in the selection process since many irrigation canals carry a significant amount of sediment. Sediment is typically deposited in areas of lower velocities, which is often around flow measurement structures. Whether this sediment causes problems is dependent on the amount of sediment in the system and the type of measurement device used. In some cases the deposition of sediment means routine maintenance to remove the buildup. In other instances the sediment buildup can change the approach conditions and cause the device to be inoperative. In addition, floating debris such as plants, trees, branches, leaves, and trash can plug some flow measurement devices, which causes them to be inaccurate. The debris caught in the device could also block the flow in the canal.

Another important issue is the amount of maintenance required to keep the flow measurement device working at the desired accuracy and to extend the lifetime of the structure. For example, the sharp crested weirs might require more maintenance to remove sediment and debris than the long-throated flume. It is also recommended that maintenance programs be developed for each structure to ensure prolonged measurement quality.

Some final considerations are the construction and installation requirements of the selected flow measurement device. This consideration must include the difficulty of installation and how many components must be modified to fit the existing canal. If the device is easily retrofitted to the existing canal, there will be less time for installation, less down time for the canal, and fewer unforeseen problems.

Parshall Flumes

Parshall flumes can be purchased pre-fabricated (Figure 5) in several sizes or can be constructed in the field (Figure 6). However, this flume must be constructed within very stringent tolerances in order for the laboratory generated and empirical rating curves to be correct. Accuracies are typically between ± 3% and ± 5% assuming proper installation. Many ditch companies are familiar with and standardize using the Parshall flume.

The Parshall flume controls the flow in an angled section to create a three dimensional curvilinear flow. Although this type of flume is called a short throated flume, they usually have a large overall length. Some of the advantages to this type of structure are its ability to “self clean” since it can pass sediment and debris. Therefore, the reduced maintenance concerns are an advantage. It requires about the same head loss as long-throated flumes, discussed later in this section. The approach velocity of the channel has little effect on the structure’s accuracy of measurement. Parshall flumes can have large flow regimes with a trapezoidal design and can measure super critical flows.

These structures can be difficult and expensive to construct since they must be built to specific dimensions and angles of the floor. The structure may have to be larger or smaller than the existing channel which may result in higher installation costs and reworking of the canal section. They also have a tendency to be insensitive to low flows. Similar to other types of flumes, Parshall flumes must be constructed in channel sections that are without turbulence, surging, unbalanced flow, or poor distributed velocity patterns. Increased bank depth may be required to accommodate the backwater associated with the installation of this flume.

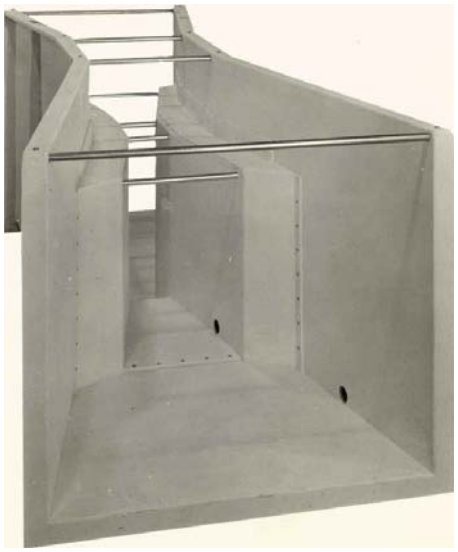


Figure 5. Prefabricated Parshall flume

Figure 6. Concrete Parshall flume constructed in field

Long-Throated Flume

Long-throated flumes have many advantages over more traditional water measurement structures, as discussed below.

The long-throated flume controls the discharge over the structure throat or a sufficient length to create uniform and parallel flow lines. The flume forces the flow to pass through critical depth. This allows for accurate ratings based on hydraulic theory. The long-throated flume can be adapted for any desired cross section shape and custom fit into any channel geometry.

Due to the flexibility to match to existing channel conditions, these flumes usually have simplified construction techniques and are economical. The accuracy of long-throated flumes can be assumed to be ± 2% due to the capability for computer calibration. This accuracy also includes submergence up to 95% (higher allowable submergence than the Parshall flume) with only one upstream head measurement.

Some additional advantages of long-throated flumes are that they are also self cleaning and have the ability to pass sediment and debris through the structure. This means less maintenance for canal staff. They require little head loss across the control section to achieve accurate flow measurement and may even allow a reduction in the number of checks in the canal. They may be constructed in-situ within the canal.

Like Parshall flumes, these flumes must be constructed in channel sections that have little turbulence, surging, unbalanced flow, and poor distributed velocity patterns. They require the upstream banks to be high enough to contain the backwater from the flume installation.

For new installations, the long-throated flume is recommended by the USBR over the Parshall flume. Where the Parshall flume has been established as standard, new installations could be Parshall flumes; however, the long-throated flume is the preferred

measuring device for open channel flows in similar situations. See Figure 7 for a concept drawing of a long-throated flume. See Figure 8 for a photograph of a flume under construction and Figure 9 for a photograph of an operating long-throated flume.

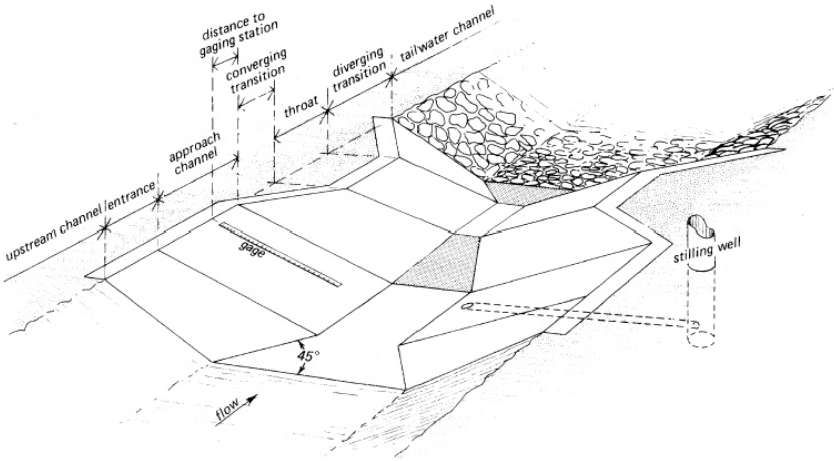


Figure 7. Conceptual layout of a long-throated flume

Figure 8. Long-throated flume under construction

Figure 9. Long-throated flume in operation

Another advantage to using a long-throated flume approach is that they can easily be incorporated into a gravity pipe for flow measurement. Where it may not be practical to have an open channel section for installing the flume, a long-throated flume approach can be highly cost effective. Figure 10 shows a typical installation of a long-throated flume in a pipe.

Figure 10. Long-throated flume installed in a pipe section, with stilling well included for measurement capabilities

Manhole Flumes

Manhole flumes are another flow measurement device alternative when flow measurement is needed at a location that is not open for other types of flumes to be installed. In the case of the existing Evans Ditch system, much of the distribution system is conveyed in pipes and manholes exist throughout the system already. Rather than day-lighting the existing pipe and flow, a manhole flume can be used to measure flow in the pipelines. Staff gages or ultrasonic flow meters can be used to read the flow through these types of devices.

Several types of manhole flumes are available. Eastech Badger manufactures the Manhole Flume™ which is an insert measurement device that is a variation of the Parshall flume and can be installed in standard manholes. This is a low headloss, self-cleaning flow measurement device. Flumes from 4-inch through 12-inch are available and correspond to maximum flow rates of 90 GPM to 1,500 GPM, respectively. The maximum head rise of the 12-inch flume is 18-inches.

Figure 11. Eastech Badger Manhole Flume™

Rather than installing an insert device such as the Eastech Badger flume described above, a complete package could be installed. These packaged systems include a variety of flow measurement devices installed in a fiberglass manhole. For instance, TRACOM offers several fiberglass Packaged Metering Manholes (PPM). These "packaged metering manholes are lightweight, corrosion resistant, watertight, structurally strong, and built to meet the stringent ANSI / ASTM D-3753-99 "Standard Specifications for Fiber-Reinforced Manholes"." The package includes the integral flume, pipe adapters, fiberglass manhole and cover, and access ladder. Several types and sizes of flumes can be included in the packaged system, including: Parshall, Palmer-Bowlus, and Trapezoidal.

Figure 12. TRACOM Packaged Metering Manhole with a Palmer-Bowlus flume

Plasti-Fab is another manufacturer of the Packaged Metering Manhole. Their product is similar to the TRACOM package described above. They advertise that their system is watertight, one piece construction that eliminates infiltration, lightweight, corrosion resistant, and strong and very durable.

Figure 13. Plasti-Fab Packaged Metering Manhole: 48-inch diameter manhole with 6-inch Parshall Flume

Recommendations for Evans Ditch

Table 2 summarizes the specific measurement improvements for the Evans Ditch.

The only point of measurement on the Evans Ditch currently is the measurement or gaging station, which is located near the head of the ditch and is used to record and measure the amount of water diverted under the Evans Ditch decree (Figure 14). This gaging station consists of a Steven's recorder and on what is commonly referred to as a "rated section."

A rated section is a clearly defined canal cross section area (in this case of Evans Ditch a concrete rectangular opening) that is used to estimate the flow in the canal by multiplying an approximate flow velocity by the canal cross section (width of canal multiplied by water depth). The rated section is calibrated and includes a chart that relates water depth to flow rate. These structures are quite common in ditch systems in northern Colorado, but they are definitely less preferred than flumes and weirs because they are substantially less accurate. A rated section may have an accuracy of ± 10%, compared to a Parshall flume with an accuracy of ± 5% or a long-throated flume with an accuracy of ± 2%.

Figure 14. Rated section measurement structure for the Evans Ditch

Table 2. Measurement Structure Recommendations for Evans Ditch

Site Name	Project Priority	Condition Rank	Current Condition	Recommended Approach	Notable Cost Elements
Flume at Ashcroft Draw	1	4	No current measurement capability.	Install an overshot gate that is capable of providing for desired control and measurement.	If an overshot gate and SCADA are installed at this location, no additional cost will be required to measure flow.
Measurement Adjustment	2	4	This site includes an Armtec overshot gate that is currently used for control only (flow not measured).	Install a pressure transducer in the existing wet well and use the existing overshot gate to measure flow.	Install pressure transducer for water level measurement, data logger, solar panel, and installation. **$1,750 - $3,500**
Purneys	3	4	No current measurement capability.	Install an overshot gate that is capable of providing for desired control and measurement.	If an overshot gate and SCADA are installed at this location, no additional cost will be required to measure flow.
17th Drop	4	4	No current measurement capability.	Install an overshot gate that is capable of providing for desired control and measurement.	If an overshot gate and SCADA are installed at this location, no additional cost will be required to measure flow.
31st/Empire Box	5	4	No current measurement capability. Spillway from box currently discharges through a pipe, under 31st Street, and into an open ditch on the north side of 31st Street and Empire.	(1) Install a long-throated flume in the open ditch just north of the diversion box. (2) Install a long-throated flume in the end of the pipe as it discharges to the open ditch.	Includes tree removal, upstream and downstream channel rehabilitation and stabilization, structure, and wet well. **$8,000 - 8,500** Pipe access might be a problem if pipe diameter is less than 24-inch. **$1,300 - 1,600**
42nd/Golden Box	6	4	No current measurement capability. Spillway from box currently discharges through a pipe, under 42nd Street and into Riverside Pond.	Install a long-throated flume in the discharge pipe at a location where pipe is accessible via a manhole. Alternatively, install a pre-fabricated manhole flume.	Pipe access might be a problem if pipe diameter is less than 24-inch. **$1,300 - 1,600**
Rated Measurement Section	7	2	Current station consists of Steven's recorder and rated section. Measurement at this site is currently adequate, but not likely to be highly accurate.	Design and calibrate a long-throated flume by placing a sill in the current rated section.	Includes installing concrete sill within existing rated section a placement of new wet well for water level reading. **$1,750 - 2,000**
North-South Split	8	4	Flow is not currently measured at this location and is not a major concern at this point.	If overshot control structure is installed at the South Branch, flow into the South Branch can easily be measured if necessary.	If an overshot gate and SCADA are installed at this location, no additional cost will be required to measure flow.

Condition Rank:
1 - excellent
2 - adequate
3 - minor repairs

Because the Division of Water Resources accepts the use of rated sections, it is probably not a priority for the City of Evans to replace this structure. However, if the structure is measuring water inaccurately, the water right and decree could be impacted because this structure provides the only historical record of water diversions for the ditch.

If the City is interested in improving the accuracy of this structure, we recommend installing a sill in the bottom of the existing rated section. A computer program called WinFlume, which was created by the U.S. Bureau of Reclamation for the design of long-throated flumes, can be used to design the sill within the existing rated section and the rated section in essence becomes a much more accurate flume. This approach to measuring will be far more accurate than the rated section and is highly affordable because it will not require that the existing structure be removed nor an additional structure be purchased.

The City of Evans staff would like to measure the five major discharge points from the Evans Ditch to the river (Measurement Adjustment, Purneys, 17th Drop, 31st Box, 42nd Box). The City would also like to construct another discharge point from the ditch to the river at the Flume Site at Ashcroft Draw. Because the City is pleased with the overshot gate that was recently installed at the Measurement Adjustment structure, we recommend incorporating overshot gates at these discharge locations for reasons discussed in the previous section, but also because they can be used to measure flow without construction of additional structures.

Water that discharges from the 31st and 42nd boxes does so through pipes. In the case of the 31st Box, the pipe conveys water just north under 31st Street to an open ditch. If flow measurement is desired at this location, the simplest approach would be to install a measurement structure on the north side of the road in the open ditch. Another solution, which is probably more cumbersome, but that also applies to the situation at the 42nd Box, is to install a long-throated flume in the pipe that carries the discharge back to the river. WinFlume can be used to design the flume that would be needed to accurately measure flow through these pipes.

Sedimentation Structures

General Overview

Excessive canal sedimentation can affect the performance of an irrigation system. There are several causes of canal sedimentation including:

- Excessive sediment intake at the canal entrance or other inflow points
- Re-entry of sediment from storms and wind
- Haphazard sediment excavation
- Incorrect channel regulation
- Constrictions, and thus slow water velocities at control points
- Shallow slopes and thus slow water velocities

Excess sedimentation can be caused by poor water quality, defective canal design, insufficient maintenance, or improper channel operation. For example, in shallow sloped canals, water velocities tend to decrease to the point that sediment drops out. If it is not possible to increase the velocity of flow, a sediment structure may need to be designed

or sediment must be removed on a continual basis. Sediment structures are often used to slow water flow and collect sediment particles at an accessible location so sediment may be removed on a continual basis. Proper maintenance and operation may also be used to reduce sedimentation. As a rule of thumb, canals that carry a significant amount of sediment should not be operated at less than three-quarters of their capacity to maintain adequate velocities and thus sediment transport. Similarly, control structures in earthen canals should be operated so that rapid changes in water velocity do not increase canal erosion and thus the sediment load in the irrigation water.

Recommendations for Evans Ditch

The Evans Ditch currently has one sediment trap on the Empire Street tube (Figure 15). This trap is designed so that the water velocity slows enough to allow sediment particles to drop in an open basin. The basin is highly accessible so that Evans staff can easily remove accumulated sediment. Table 3 indicates the sedimentation structural improvements that Evans would like to incorporate. We recommend installing a protective cover on the Empire trap to prohibit easy access by the public. Evans would also like to develop three additional sedimentation structures just north of the diversion structure to the Chappelow Pond, west of the 17th Drop, and north of 42nd Street and east of Belmont. These structures should be designed to a capacity that will allow water to slow and drop unwanted sediment.

A typical design of a sediment trap includes a concrete lined basin that is larger than the earthen ditch (to slow flow and allow sediment to drop out). The structure should be designed to be accessible by machinery that will periodically clean accumulated sediment in the structure. An earthen basin may also be used, and preferred in some cases, because it is less likely to be damaged by cleaning machinery.

Figure 15. Sand trap on Evans Ditch at the Empire Street tube

Table 3. Sedimentation Structure Recommendations for Evans Ditch

Site Name	Improvement Priority	Condition Rank	Current Condition	Recommended Approach	Notable Cost Elements
Empire Sand Trap	1	3	The current structure is used to slow the velocity of the water so sediment can be removed from irrigation water. Sediment collected in the trap is routinely removed by City staff. There is currently no cover or fencing around the sand trap which is of concern because it is in a residential neighborhood. Access for routine cleaning must be possible.	A protective cover (such as a fabricated steel rack or mesh) on top of the sand trap is recommended to protect the structure. The cover should be designed in a way so it can lock, but also be opened easily for routine maintenance.	For 4 - 5FT x 5FT aluminum grating planks installed with hinges and locks to cover the entire sand trap. **$5,000 - 6,000**
West of 17th Drop	2	4	There is currently no sand trap at this location.	Install a concrete sand trap to the west of the 17th Drop structure.	For a 5FT x 5FT x 18FT concrete structure with riprap and aluminum cover. **$7,750- 8,250**
Chappelow Pond Sand Trap	2	4	There is currently no sand trap at this location.	Install a concrete sand trap near the diversion structure that provides water to the Chappelow Pond.	For a 5FT x 5FT x 18FT concrete structure with riprap and aluminum cover. **$7,750- 8,250**
North of 42nd Street and East of Belmont	2	4	There is currently no sand trap at this location.	Install a concrete sand trap north of 42nd St and east of Belmont.	For a 5FT x 5FT x 18FT concrete structure with riprap and aluminum cover. **$7,250- 8,250**

Improvement Priority:
1 - immediate
2 - soon
3 - not a priority

Condition Rank:
1 - excellent
2 - adequate
3 - minor repairs
4 - not used/not applicable

Canal Lining and Piping Options

General Overview

Under certain circumstances, it may be beneficial to line or pipe the sections of the canal that do not efficiently convey water. Such circumstances may include long stretches of canal that do not service water users or sections of canal in highly permeable soils. It is not always cost effective or desirable to line or pipe entire canal systems so significant consideration should be given to proposed locations. Following are several key considerations for lining and piping canal:

- Piping canals that have historically intercepted overland flow and runoff may create a safety issue because the pipe will no longer intercept this water.
- Use of heavy equipment for maintenance on lined canals may be limited to insure the lining material is not damaged.
- Earthen canals, particularly in urban areas, are considered to be an aesthetic amenity to the community. Piping will eliminate this amenity. However, lining options may help to maintain this amenity while simultaneously decreasing seepage.
- Canal lining and piping can be expensive. May canals have effectively opted to phase in lining and piping costs to help eliminate cost burden.

This section discusses several options for improving canal conveyance systems. The advantages and disadvantages of five types of lining systems are discussed in this section. The general types of lining discussed are: (1) soil sealants, (2) buried impermeable membrane, (3) exposed impermeable membrane, (4) concrete hard surface, and (5) and pipe. Many factors should be considered when choosing a liner system including: climate (freeze and thaw cycles), terrain, water velocity, side slopes, drainage, soil stability, periods of operation, and canal capacity.

Soil Sealants

Polyacrylamide (PAM) has traditionally been used to decrease soil erosion in furrow irrigation systems. The anionic version of PAM is an environmentally safe flocculent and is available in dry granular, tablet, or liquid form. PAM increases soil cohesion and aggregation, which causes sediment to drop out of the water, thereby reducing erosion. In addition to reducing erosion, some studies have shown that the inflow rates can be doubled with the application of PAM thus achieving greater overall field uniformity while still reducing sediment loss.

More recently, PAM has been shown to reduce seepage losses in earthen canals. In a U.S. Bureau of Reclamation study on Colorado's western slope, adding PAM reduced canal seepage by as much as 60% (studies conducted by Jim Valliant, 1999). PAM causes sediment aggregates to precipitate out of the water and coat the bottom of the canal, thereby reducing seepage. The longevity of a single application is highly variable among canal systems and is often applied up to several times during an irrigation season. However, it has been very feasible for many canal companies, including the Grand Valley Irrigation Company in Grand Junction.

Buried Impermeable Membranes

Buried impermeable membranes include PVC and geotextile fabric. PVC is not rated for exposure to UV light from the sun and therefore needs a geotextile fabric installed above it for protection. The geotextile fabric not only provides UV protection for the liner, it also provides a surface for the soil backfill to adhere to. Typically a 12-inch layer of soil is recommended to cover this type of lining system. The liner can be attached to concrete structures such as headwalls with batten strips, and pipe boots are available for installations around pipe. A concrete cover can also be used on top of the impermeable membrane to protect the membrane from damage and weathering – the membrane serves as an added water barrier protection.

A 20 mil (millimeter thickness) PVC liner and 8-ounce geotextile fabric system is not recommended for slopes greater than 3:1 because the soil cover may not be maintained on the side slopes of the canal. Additionally, the PVC liner may tend to creep down the slope.

In order to install the lining system without reducing the existing capacity of the canal, excavation may be required. The excavated material should be placed above the liner after installation and should be compacted. It should be noted that even with compaction, erosion of the newly placed soil may occur.

Exposed Impermeable Membranes

Reinforced polypropylene includes a nylon scrim that provides dimensional stability and strength to the liner. The seams are heat welded for watertight connections between panels. However, because heat fusion welding requires special machinery, alternative installations may be preferred for economic reasons. One manufacturer of this material has seen successful polypropylene installation in canal systems with overlapping panels instead of heat welding. Although overlapping on the down gradient can be effective, heat welding is the recommended installation technique.

There is no sag or creep associated with this liner on 1:1 slopes. The liner can be attached to concrete structures such as headwalls with batten strips, and pipe boots are available for installations around pipe. Again, heat fusion welding would be used to join the liner panels around the pipes. A 45 mil polypropylene liner would be recommended for this particular application.

Concrete Hard Surface

Soil cement is a compacted mixture of native soil, Portland cement, and water. It has many construction applications including canal or stream lining for reduced seepage and bank stability. Typical installation includes preparing the bottom of the canal with a 6-inch layer of sand to allow for drainage and prevent trapped water from pushing up on the soil cement liner. A 12-inch thick layer of soil cement is then poured in place. Slopes of 3:1 are the maximum recommended slope with soil cement because it is hard to compact the mixture properly at greater slopes. Canals are often lined on the bottom only because of the difficulty in lining the slopes. This method of lining may be most economical when native soils are available near the project. If material has to be imported, the costs can increase significantly. Freeze and thaw cycles do not typically

affect soil cement. Soil cement is delivered in concrete dump trucks and then spread with a bull dozer.

Traditional concrete canal lining systems are more costly than soil cement. To line the canal system with 4 to 6-inch thick concrete, a slip form must be created. Vegetation along the canal banks would have to be removed in order to make a road adjacent to the canal for construction purposes. The entire canal would essentially be reconstructed because the bottom and side slopes have to be properly compacted prior to pouring the concrete slip form (Figure 16). The life expectancy of concrete lining is about 20 years.

Figure 16. Preparation of site and completed concrete ditch

Pipe

Pipe can also be used to reduce seepage losses in a canal system. In a pressurized system, the pipe size is based on acceptable velocity ranges and friction losses rather than flow rate and slope because the pump can “push” the water through the pipe. However, in a gravity flow scenario, the pipe has to be sized based on the capacity of the system and the given slope of the existing canal system.

An advantage of piped systems over other canal lining options is that the enclosed pipe would also eliminate evaporation losses. The decision to either line or pipe canals will most likely depend on which provides the lowest cost solution; however, advantages and disadvantages of each may also influence the final choice. Lined canals are a convenient and economical means for conveying large quantities of water. However, water flow velocity can be much higher in pipes because there is no risk of erosion. A partially flowing pipe will behave like an open channel but a full flowing pipe comes under a pressure head which increases flow velocity and capacity.

Another approach to repairing or upgrading existing pipelines is to slip line the existing pipe in place rather than completely removing and replacing pipe. Some pipe manufacturers make liner systems that can be pulled into an existing pipe to seal leaks and cracks. This type of application is typical for sewer and municipal pipeline applications, but can also be used in agricultural settings. One advantage of slip lining is that repairs to existing pipe can be made relatively quickly because the pipe does not necessarily have to be excavated.

Recommendations for Evans Ditch

Table 4 summarizes several areas in the Evans Ditch system that the City of Evans would like to line or pipe.

If it is desirable for the City of Evans to pipe a significant portion of the ditch, a concept that might be considered is pressurization. There are many canal systems that have converted to or are considering converting to complete pressurized water delivery. There are many water users, including the City of Evans, on the ditch that currently pressurize water with individual pump systems for landscape irrigation purposes. Because the City of Evans and other users have already invested financially in pressurizing the individual uses of water, they are not currently interested in piping and pressurizing the entire canal system. Therefore the piped locations that are listed in Table 4 refer to gravity pipe only. Table 5 includes unit costs for typical pipe and lining applications.

31st Street Manhole Repair

Two existing manholes on the Evans Ditch piped section that crosses Highway 85 in 31st Street experience pressure and air problems which cause the lids to detach. Both manholes are located east of Highway 85 in 31st Street. The City has bolted these lids down and installed plugs that can manually be loosened to release the air. However, a long term air release system is desired to prevent future problems.

Two possible solutions come to mind for this problem. First, a pipe could be inserted into the manhole, by way of core drilling the concrete section, and routed south out of the street where a vent tube, approximately 3 or 4-ft tall would be installed. Air would exit through the tube; however, if water in the manhole exceeded the pressure equal to the height of the vent tube, water would also exit the tube. Pressure readings in the manhole should be taken to determine the maximum pressure which would allow the height of the vent tubes to be set.

A second option is to install a pipe in the manhole and route it to the south side of the street where an air-vacuum release valve would be located below grade. This type of valve is designed to be open to the atmosphere to prevent air buildup or vacuum situations in the pipe and when the air is gone and the pipe is full of water, the valve will shut, so no water exits the valve. Again, the pressure and elevation of the water in the manhole should be determined prior to designing this system to be sure that the elevation of the valve will allow for proper operation.

Table 4. Lining and Piping Recommendations for Evans Ditch

Site Name	Improvement Priority	Condition Rank	Current Condition	Recommended Approach
31st Street Manholes	1	3	Two existing manholes east of Highway 85 and 31st Street experience pressure and air problems that cause lids to detach. A long term air release system is desired to prevent future problems and to eliminate the need for manual adjustment of existing air plugs.	(1) Insert pipe in manhole and route air through an air vent. **$2,500 (per manhole)** (2) Insert pipe in manhole and route air to an air vacuum release valve. **$3,800 (per manhole)**
Central: 40th to 39th Street (both sides of street)	2	4	Earthen open ditch	New construction of pipeline
Idaho: 42nd to 40th Street (west side of street)	2	4	Earthen open ditch	New construction of pipeline
Golden Street: 40th to 37th Street (both sides of street)	3	4	24 inch non-reinforced concrete pipe	Replace and enlarge piping with options discussed in study
North of 2675 49th Street	3	4	Earthen open ditch	Replace open ditch with lining or piping options discussed in study
North of 35th Street: Empire to Trinidad	3	4	Earthen open ditch	Replace open ditch with lining or piping options discussed in study
East of Pueblo (Parkers): Pueblo to Structure	3	4	Earthen open ditch	Replace open ditch with lining or piping options discussed in study
Empire Street: Sand Trap to 35th Street	3	4	30-inch reinforced concrete pipe	Slip lining desired
Boulder between 38th and alley to the south	3	4	Currently there is a broken pipe with root intrusion.	Repair or replace pipe
East of 11th Ave: 36th to 32nd Street	3	4	Earthen open ditch	Replace open ditch with lining or piping options discussed in study
North of 37th St: 37th Street to 11th Ave	3	4	Earthen open ditch	Replace open ditch with lining or piping options discussed in study
North of 37th St: 11th Ave to 36th Street	3	4	Earthen open ditch	Replace open ditch with lining or piping options discussed in study
East of Belmont: 42nd Street to Burlington	3	4	Earthen open ditch	Replace open ditch with lining or piping options discussed in study

Improvement Priority:
1 - immediate
2 - soon
3 - not a priority

Condition Rank:
1 - excellent
2 - adequate
3 - minor repairs
4 - not used/not applicable

Table 5. Typical cost for pipe and lining applications

Cost per linear foot of application

Type of Pipe	Pipe Diameter					
	36-inch	42-inch	48-inch	54-inch	60-inch	72-inch
PVC Low Head Irrigation Pipe - 50 PSI	$106	$146	$195	$249	$288	NA
Corrugated Metal Pipe - Aluminized Type 2 UltraFlow	$52	$61	$69	$108	$117	$161
HDPE - Class 50 DR 32.5	$110	$150	$216	$258	N/A	N/A
Circular Concrete Pipe - Class 3 Reinforcement	$51	$78	$95	$125	$161	$228

Type of Lining	Unit Cost Installed
PAM	$63 / acre (not applied)
Buried Impermeable Membrane (concrete cover)	$63
Exposed Impermeable Membrane	$40
Concrete	$125
Sliplining	
24-inch	$74
30-inch	$102
36-inch	$150

Storage and Equalizer Reservoirs

The concept of an equalizer (often called re-regulating) reservoir is rather simple; the intent is to capture excess canal flows in the reservoir and hold water for subsequent release when canal flows drop below downstream water orders. This type of reservoir is generally not intended to hold water for long periods or to capture early season water for late season release, but some reservoirs can serve both purposes.

Canal flows fluctuate due to diurnal variations in river flows and river diversions, day-to-day changes in total water orders, significant changes to orders in a specific canal reach, dramatic on-off headgate or lateral delivery variations, and storm inflows. The primary benefit of an equalizer reservoir is to improve the consistency of flows at the headgate, thereby allowing an individual irrigator to improve on-farm application efficiency.

Many canals are managed by diverting more water than required by orders and then releasing excess flows back to the river at points tending to be at or near the end of the canal. This approach is functional but it may also be desirable to capture as much of the excess as possible within the canal's service area to improve canal operational efficiency and increase beneficial use of the decree under the prior appropriation system.

Figure 17 shows the concept of an equalizer reservoir. Using the slope of the canal to advantage, water is gravity fed into the reservoir and gravity fed back out. The inflow can be controlled by a gate or a long crested weir. The outflow is best controlled by a gate or gates suitable to both small and large outflows. Remote control of actuated gates with SCADA allows for the greatest reservoir use potential and operational flexibility; however, gates can also be controlled manually.

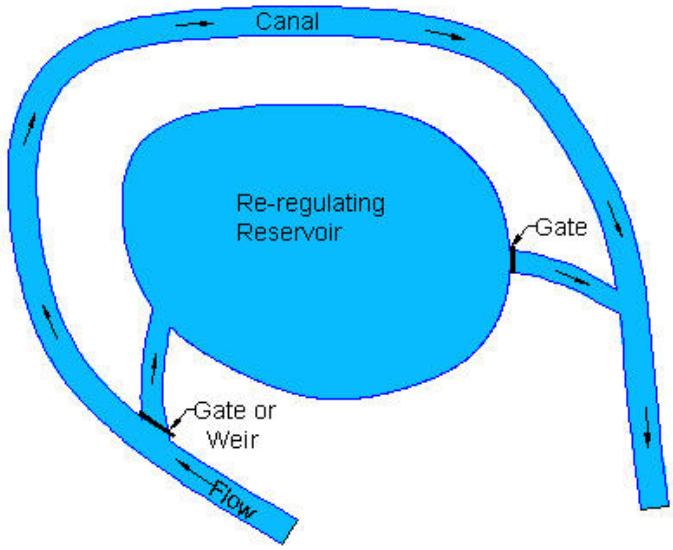


Figure 17. An equalizer (re-regulating) reservoir captures excess flows for subsequent release to make up shortages

It should be noted that SCADA and remotely actuated gates can provide some of the benefits of an equalizer reservoir by using excess capacity in the canal itself for short term water storage. Assuming the canal has adequate freeboard, a downstream check can be used to bring the canal water surface level up, while still maintaining a minimum freeboard, and thereby hold a proportional amount of water at the surface. This approach can be thought of as treating the excess capacity in the canal as a pencil-thin reservoir and might be most appropriate for the short term capture of flow variations due to the more minor delivery changes and diurnal fluctuations.

Pumps can be used to pump water into or out of the reservoir or both. The primary disadvantages of pumping are the costs -- initial and annual operating costs -- but pumps can also provide for a suitably high outflow delivery rate which can be highly varied as required and accurately measured. Pumping systems may have dual purposes as well. For example, a pump station may be used for outflow makeup water at one time of the year and pumping into a storage reservoir at another time of the year (see Figure 18).

Figure 18. Example pump station that transfers water from an equalizer reservoir

Reservoir depth should be as large as possible in order to decrease surface area, for a given storage volume, and thereby minimize evaporative losses. Some equalizer reservoirs are lined to prevent loss due to seepage while the seepage in other situations is viewed positively as contributing to ground water storage and potentially credited to a well augmentation plan.

Equalizer reservoir design issues are:

- Discrepancy (prediction of the volume discrepancy).
- Transient time under normal operational conditions.
- Land area available.
- Operational strategy considering gravity flows, pumped flows, or a combination.
- Implementation budget.

The volume of a re-regulation reservoir is most likely budget driven. Otherwise, the reservoir size generally wants to be as large as is practical and possible.

Pressurized Secondary Supply

A secondary supply or dual system is basically a utility that provides raw water for irrigation purposes. A secondary water supply system can be a good water management strategy for canal companies in urbanizing areas because it has the potential to mutually benefit ditch companies in the form of continued operation as well as the state, municipalities, and residential water users in the form of more strategic water use.

Under a typical secondary water supply scenario, a ditch company becomes the primary raw water provider for urban development in the historical service area of the canal. The canal company would acquire the water shares associated with the lands under development, and retain these shares as treasury stock in the company. Through the continuation of the beneficial use of water rights within the canal service area, a change in use and subsequent devaluation of the rights would not occur. Therefore water rights and their associated value would not be impacted through the secondary supply process.

The City of Evans is in essence already acting as a secondary water company by providing raw water from the Evans Ditch directly to residential developments and City facilities and common spaces. The Evans Ditch is quite unique as far as canal companies in the region are concerned because the City has and continues to deliver raw water to residences and agriculture alike. The institutional base for a secondary supply system in the Evans Ditch is presently in place.

Secondary supply systems can vary in design and operational advancement. They can be as simple as the maintenance of the existing irrigation system with improvements in basic canal infrastructure to as complex as the complete replacement of the canal with pressurized piping. Key design elements for the former may include the maintenance of the existing canal (i.e. open ditch) with water pressurization at each point of delivery such as a park or residential development. Key design elements for that latter may include a consolidated storage facility and pump station as well as transmission and distribution pipeline to deliver pressurized water to each point-of-connection. Although these two approaches essentially accomplish the same task, pressurized water supply at the point of use, the engineering design approaches are quite different. There are real implications to selecting one approach over the other.

Supervisory Control and Data Acquisition (SCADA)

The primary emphasis of this study was to develop a conceptual SCADA plan for the Evans Ditch. The City of Evans staff identified several sites, primarily spillways, during the course of this study where they would like to incorporate SCADA. In this section of the report, we discuss the general SCADA concept including an historical overview, a general description of operation, discussion regarding communication, field and office equipment, and water level sensors.

General SCADA Concept

Overview

The term SCADA stands for Supervisory Control and Data Acquisition. SCADA is a technology that can be used for both monitoring and control of canal operations from a centralized location. Some of the primary benefits to using SCADA systems include:

- Centralized monitoring and/or control of real-time canal operations.
- Sharing and access to real-time data via the Internet.
- Because of decreasing hardware costs, this technology is becoming more affordable for use in agricultural situations.
- Canal automation, both remote manual operation and full canal automation, is possible under SCADA.

SCADA costs are reasonable for canal systems and the costs have decreased in recent years. The payback of the system is achieved through labor savings, water conservation, improved operations, and reduced operational liability. Irrigation, for many years, was not an industry that warranted the hardware and software costs until some irrigation manufacturers began to adapt their own proprietary hardware, and software, into a specialized type of SCADA. For example, in the mid 1980's we began to see adapted SCADA systems that were specifically made for irrigation projects that could afford this technology, such as golf course irrigation. In landscape irrigation, these systems are generally referred to as "centralized irrigation control." These early control systems were further adapted to accommodate distributed sites such as school districts or municipal park departments. In 1986, the City of Pueblo became the first city in the country to have centralized irrigation control for distributed park sites.

There were very few irrigation central control systems to be found in irrigated agriculture at the time this technology was being developed for landscape uses. Agriculture could not afford the rather steep cost of SCADA. During the early 1990's, the cost of implementing SCADA on a per site basis was generally in the range of $5,000 to $10,000 per site without gate actuation hardware. This cost was simply too high in comparison to the cost of a chart recorder installation on a weir or flume, or for that matter, the cost of manual actuation of gates by canal staff. The current cost of SCADA implementation has come down in recent years to a point where SCADA is affordable to irrigated agriculture. For instance, the Central Arizona Irrigation and Drainage District upgraded 108 sites for a hardware cost of only $150,000 a few years ago. SCADA can provide smaller canals cost effective improvements to canal operations.

SCADA can also be phased in over time. For example, a smaller canal may justify SCADA for the primary river diversion or for a particular flume that needs to be read often. A decrease in driving time alone may justify SCADA at that particular site. After implementation on one site, it is easy to imagine additional sites that will benefit the canal and overall operations. Once the computer and interface are in place, the addition of more sites is understandable and cost predictable.

SCADA systems may also be phased per the primary need for the system based on "monitoring" versus "control". If data acquisition is the overriding goal for SCADA, then sensors such as liquid level sensors (pressure transducers) are used to simply allow flow measurement structures to be monitored and a database created. Later, gate actuators may be added to adjust checks or gates from a central location.

Figure 19. Example of a remotely monitored rated section using a SCADA system. Equipment is 12-volt DC powered from a solar panel that maintains a charge on a battery. Communication with the site is via radio.

Operation

SCADA systems are operated from a microcomputer installation which is usually located at a centralized location relative to the canal system (for example the City's Operations Facilities). A computer chip at a remote location is programmed for sensor interrogation, process and calculation, and communication. The remote location hardware is called a Remote Terminal Unit or RTU. Communication can be by telephone, cell phone, or radio, whichever is most convenient, cost effective, or reliable.

SCADA can be described in terms of four differentiating levels of implementation: (1) remote monitoring, (2) remote manual operations, (3) local control operations, and (4) fully automated operations.

Monitoring with a SCADA system allows an operator at the office to see the status of selected elements from a remote location. For example, using a monitoring SCADA system, an operator can see what the water level is behind a specific check structure, what the flow rate is in a metered pipeline, or what pump is on or off. With a monitoring system, if something doesn't look right or needs to be changed, the operator must send someone to the site to investigate or to make adjustments.

When structures are operated under remote manual control, the operator can see all the key values like water level upstream of the check and can use this to make an immediate operational decision. With this information, the operator can remotely make adjustments to the position of the gates or other control device to correct or change conditions as necessary. At a flow rate control structure, if the downstream flow rate is too low or too high, the operator can lift and lower the gate to increase and decrease the flow rate. The change that the operator makes would be displayed on the SCADA office computer immediately so that additional, fine tune adjustments can be made.

With local control, the RTU at a particular site is programmed to maintain a set point for upstream water surface elevation. This set point is maintained at that site for an indeterminate period until the set point is changed.

Finally, a canal component like a check structure can be operated under fully automatic control. Instead of an operator viewing the parameters and making changes, an algorithm residing at the central computer is used to analyze gate positions, canal reach storage, and water surface elevations in order to make the anticipated deliveries. Of course, the operator still has complete oversight control. The operator can still see all the information to make evaluations, can change set points and can even override the automatic control if necessary. For example, the Maricopa Stanfield Irrigation and Drainage District (MSIDD) near Phoenix operates 12 miles of their canal system using software that was developed by the Agricultural Research Service, Water Conservation Laboratory (Figure 9). When SCADA systems are fully implemented and fully operational, some have argued that ditch operations can be just as fully automated as piped and pressurized water distribution systems. The advantages in full monitoring and full automation are enormous.

Communications

Communications is the backbone of every SCADA system. Communications used for SCADA must be reliable, free from interference, inexpensive, and easily maintained. Communications options include radio, "dial-up" telephone lines, leased telephone lines, dedicated cables, and satellite. At remote locations, radio is a logical communication choice. The newest radio systems, such as spread spectrum radios, can "store and forward" which means that several radios are "daisy chained" along the length of the ditch to reach a remote location. A 900 MHz spread-spectrum radio solution is recommended for sites that are in close proximity to each other because this approach is inexpensive and low maintenance and does not require FAA licensing. However, a radio check is typically needed to determine whether repeaters are necessary between selected sites.

Many sites of interest for SCADA do not have power available. RTUs at these sites are easily powered by solar panels and 12-volt DC equipment. Gate actuators (12-volt DC) can reliably power even sluice and radial gates on the canal or ditch.

Figure 20. An operator at the Central Arizona Irrigation and Drainage District near Phoenix monitors primary flows and water surface elevations in the 60 mile canal. This SCADA system was implemented at very low cost using affordable RTU equipment and spread spectrum radios for communication.

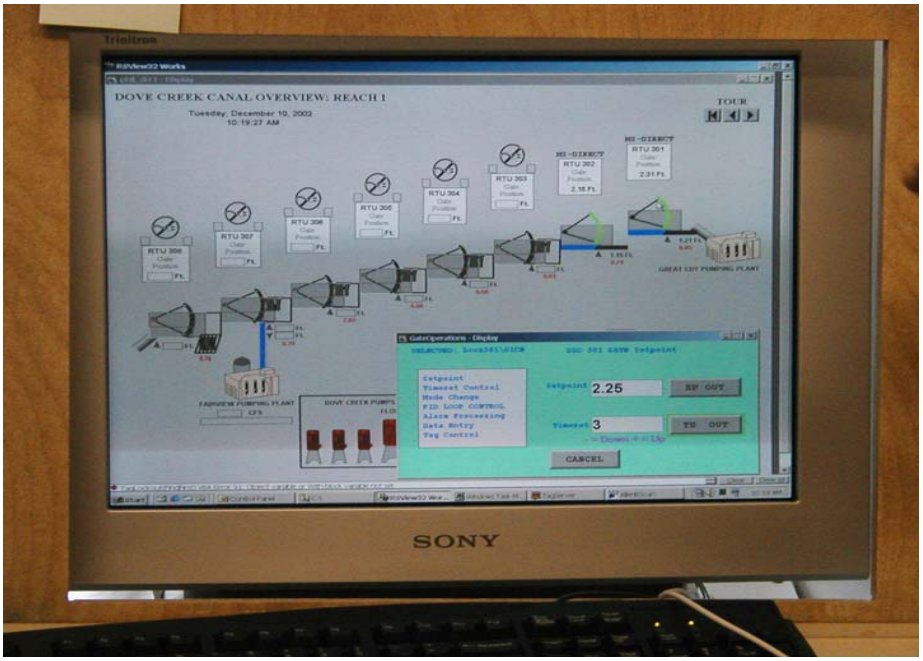


Figure 21. Example of SCADA computer interface used by the Dolores Project

SCADA Field Equipment

The RTUs used for monitoring and remote manual control are nearly identical packages. The only difference is that an RTU used for remote manual control has more extensive programming, as well as relay hardware, to implement the control functions.

The SCADA equipment located at a remote manual control includes sensors to measure the necessary parameters, an RTU, a gate actuator, the radio and antenna to communicate with the office SCADA system, and provision of power.

The SCADA equipment located at a monitoring site is identical to the SCADA equipment used for remote manual control except that the hardware required to move gates or make other adjustments necessary for control are not required. A typical RTU is shown in the photo below. The RTU is contained in a vandalism resistant enclosure.

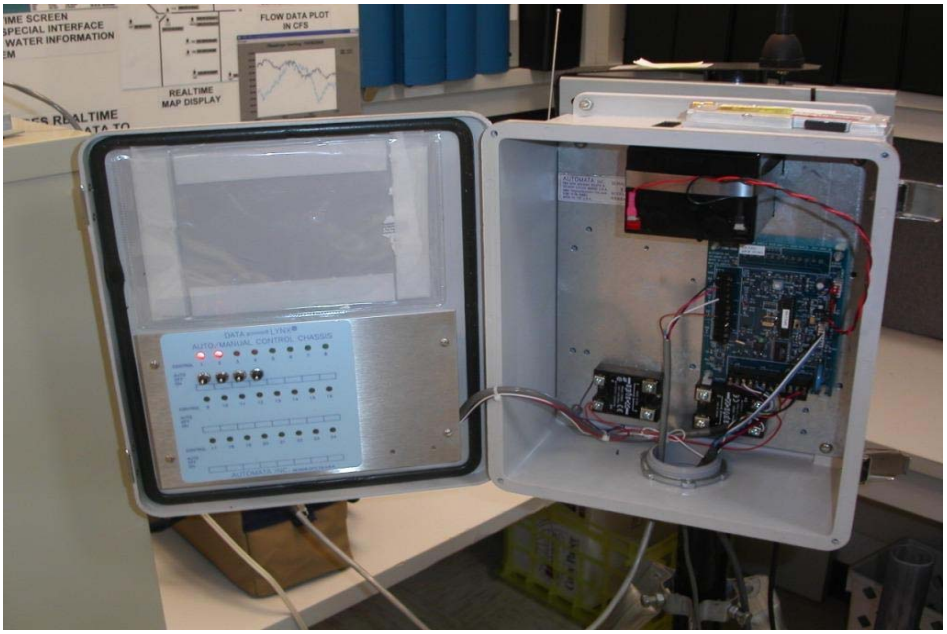


Figure 22. Automata RTU complete with Auto/Manual control panel

Office SCADA Equipment

The office needs to be equipped to receive the communications from the remote terminal units, display the necessary information to the operator, and provide a way for operators to make adjustments and change set points. This is accomplished using a desktop computer running specialized Human-Machine-Interface (HMI) software. This software is all available off-the-shelf, but needs to be configured to display and communicate the needed information to the user. Example brands of software commonly used by irrigation districts are SCADAConnect®, Lookout®, and Intellution®.

The HMI software presents the information in both graphic and numeric formats to the operator. The operator can make changes to any control component in the system by changing appropriate values on the computer screen.

Finally, the operator's computer is used to display and archive operational data. The data can be flow rates, accumulated flow volume, water levels, or any of the other parameters measured by the SCADA system or that can be calculated from the measured values. The data can be presented in graphical form (trend charts) or in numerical form. Data files compatible with spreadsheets or other software can be created through the HMI software. The archived (stored) data can be used to study system operations, for billing purposes, or for reporting to interested parties.

The office computer should be a contemporary desktop computer with a high speed processor, 256 MB of RAM, two serial ports, one parallel port, a large hard drive (larger than 10 GB), a compact disk recording drive, and a large screen (19" minimum) monitor. Dual monitors are often quite helpful and functional for the operator. The computer should be equipped with appropriate HMI, and a complete office software suite (MS-Office is highly recommended) that includes a word processor, spreadsheet software, and database software. A good quality color printer is also recommended to generate reports and facilitate operations.

Water Surface Level Sensors

Water surface level sensors are required at every level of SCADA implementation including monitoring, control, and automation. There are three basic sensors to consider: ultrasonic flow sensors, float sensors, and submersible pressure transducers. Monitoring water surface levels is critical to the successful operation of a SCADA system, so proper consideration should be given to the type of sensor used.

Ultrasonic Sensors

Ultrasonic sensors transmit a series of cone-shaped sound waves through the air. These sound pulses reflect off of the liquid surface and are in turn received by the sensor, which measures the time interval between the transmitted and received signal. Electronics then convert the time interval into a distance measurement using the speed of sound. No part of the sensor ever touches the water, a distinct advantage of this sensor type.

General ultrasonic advantages:

- Non-contacting, so they are not affected by dirty water, floating debris, or aquatic wildlife
- Not affected by fluctuating water temperatures
- Not affected by high flow rates
- Easy to calibrate
- Low maintenance
- Can withstand freezing temperatures
- Long term reliability

General ultrasonic disadvantages:

- Affected by temperature fluctuations (air)
- May reflect off floating foam or debris
- Must be aligned precisely
- May be affected by turbulent water (a stilling well may be required)
- If echo is lost, may display a misleading reading

- Large beam angles cannot be used in restricted spaces
- Some sensors can be damaged by flooding (if they are not waterproof)
- Some sensors delay between the time when power is first applied and the first output

Float Sensors

There are two basic types of float sensors, one which involves a pulley and a counterweight, and the other which utilizes a spring to produce an upward force on the float cable.

General Float Device Advantages:

- Not affected by dirty water
- Not affected by water temperature
- Not affected by foam
- Low affect of changing air temperatures
- Low maintenance
- Low cost
- Can withstand freezing temperatures
- No delay between the time when power is first applied and the first output

General Float Device Disadvantages:

- Stilling well required
- Cable may slip (pulley and counterweight type only)
- Easily vandalized unless enclosed
- May wear if the water level remains at one position for extended periods
- Salt build-up may freeze the pulley

Submersible Pressure Sensors

At any given water level, both liquids and gases exert an equal pressure in all directions. Water pressure increases linearly with depth of submergence. For every 70 cm (2.31 ft) of water, pressure increases by 1 PSI. The pressure difference between the atmosphere and the water around the sensor head produces a force on a flexible diaphragm. Electronics convert the force on the diaphragm into a proportional electric signal, which is then produces a water level.

General pressure sensor advantages:

- Easy to install
- Electronics are hidden from view
- Low power draw
- Not usually affected by air temperature fluctuations
- Not affected by foam
- Almost no time lag
- No delay between the time when power is first applied and the first output

General pressure sensor disadvantages:

- Damaged by ice
- Can clog in dirty water

- Susceptible to malfunction if allowed to dry (some sensors)
- May hang up debris
- Adversely affected by water temperature fluctuations
- Range is not adjustable
- Desiccant must be periodically replaced
- Stilling well often required
- Lightning protection recommended
- Damaged if submerged beyond its range
- Easily damaged by aquatic life

Evans Ditch Conceptual SCADA Plan

Table 6 summarizes the recommendations for each of the primary SCADA sites of interest for the Evans Ditch. These elements will be discussed in detail below. Figure 23 includes a map that shows the potential locations for SCADA implementation. The following sites were identified by Evans staff for potential SCADA implementation, in the order of highest to lowest priority:

- Flume at Ashcroft Draw
- Head of Ditch
- Purneys
- 17th Drop
- North-South Split
- 31st/Empire Box
- 42nd/Golden Diversion Box

Three basic solutions or approaches to implementing SCADA within the Evans Ditch were identified in this study. These approaches are as follows:

- Approach #1: Remote Monitor Only
- Approach #2: Remote Monitor and Control – Existing gate solution
- Approach #3: Remote Monitor and Control – New gate solution

SCADA can be as simple as monitoring water levels from a remote location. Using this approach (Approach #1), manual operation of canal structures are still necessary; the monitoring only serves as an indicator for what changes must be made manually.

As previously discussed, the Evans Ditch has two Armtec overshot gates at the primary diversion and the Measurement Adjustment. Because the controller in these gates is not SCADA compatible unit, it will be necessary to remove and replace the gate controller with an RTU that is compatible with a SCADA system. Under Approach #2, we present a recommended SCADA approach that would involve replacing the Armtec gate controllers and actuating all existing manual gates, as opposed to purchasing new gates.

Under Approach #3, we recommend installing the Rubicon FlumeGate at all locations, including those sites that currently have Armtec gates and manual gates installed.

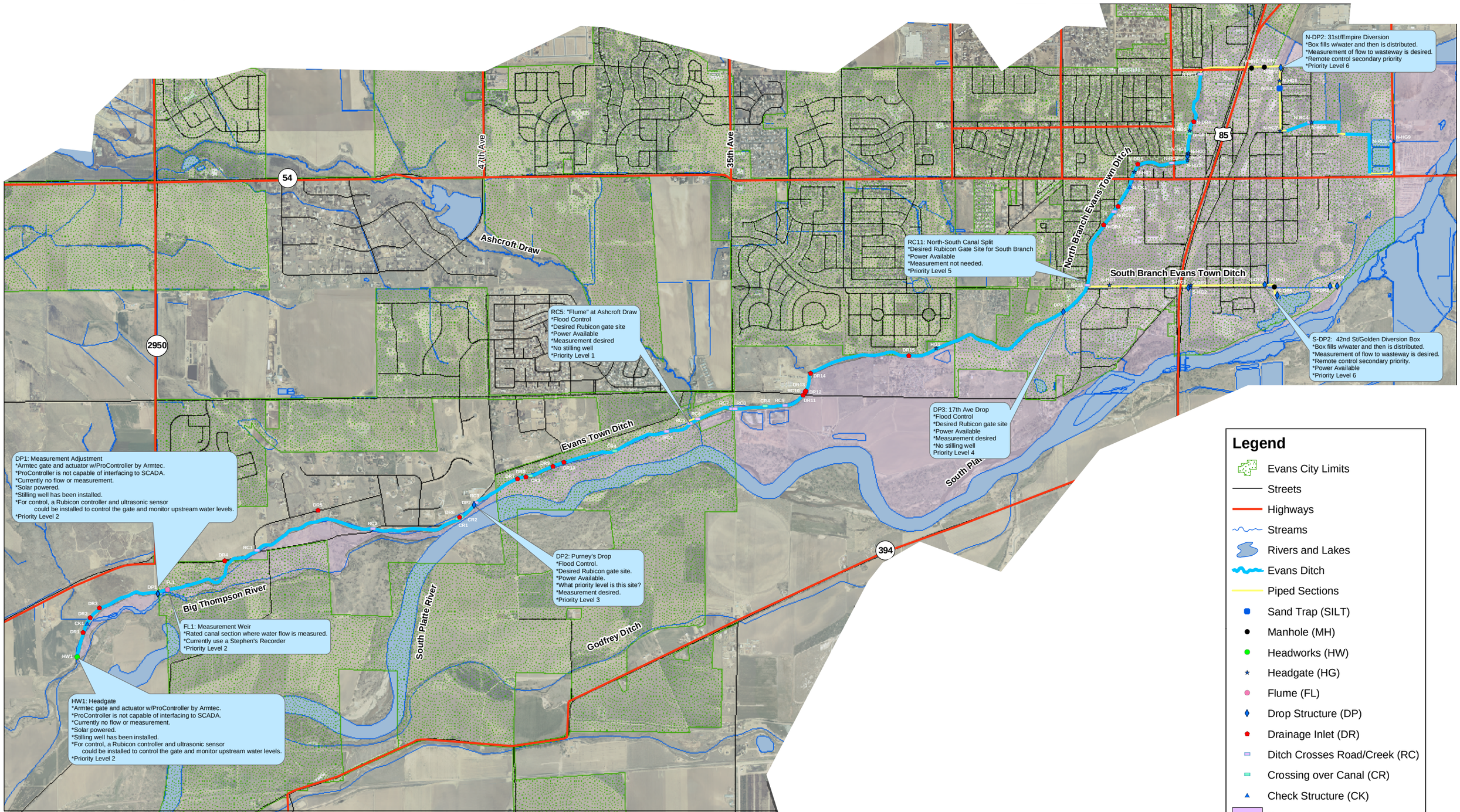
Table 6. SCADA Recommendations/Costs for Evans Ditch

This table reflects costs for SCADA equipment only - see other tables for additional cost elements

Site Name	Project Priority	Current Condition	Approach #1 (remote monitor only)	Approach #2 (remote monitor & control)	Approach #3 (remote monitor & control)
			Monitor water levels: manual control still necessary on all existing structures.	**Monitor and control: Existing Gate Solution***	**Monitor and control: New Gate Solution****
Flume at Ashcroft Draw	**1**	There is currently no spillway capabilities at the Flume site. An overshot gate with SCADA is desired at the site for future spill capabilities.	Install pressure transducer in wet well. Install RTU/radio for monitoring flows/levels at site from office. **$6,500**	There is no existing spillway gate at this location so an existing gate SCADA solution is not applicable.	Install a Rubicon overshot gate. Install radio for communications, adjusting flows/levels by controlling gate at site from office. **$32,750**
Head of Ditch	**2**	(2) Obermeyer gates & (1) Armtec overshot gate. Controller on Armtec is not SCADA compatible. Used to make large adjustments at the river (Obermeyer) and to control the water directly diverted into ditch (overshot).	Install pressure transducer in wet well. Install RTU/radio for monitoring flows/levels at site from office. **$6,500**	Replace controller on Armtec gate. Install RTU. Install pressure transducer in wet well. Install radio for communications, adjusting flows/levels by controlling gate at site from office. **$8,000**	Remove Armtec gate and replace with Rubicon overshot gate. Control levels/flows remotely from office. **$32,750**
Measurement Adjustment / Rated Section	**3**	Measurement Adjustment structure is an Armtec overshot gate that is used to make fine tuned adjustments to flow in the canal before it is measured at the rated section. The overshot gate serves as a spillway to the river.	Install pressure transducer in wet well. Install RTU/radio for monitoring flows/levels at site from office. **$6,500**	Replace controller on Armtec gate. Install RTU. Install pressure transducer in wet well. Install radio for communications, adjusting flows/levels by controlling gate at site from office. **$8,000**	Remove Armtec gate and replace with Rubicon overshot gate. Control levels/flows remotely from office. **$32,750**
Purneys	**4**	Manual controlled gate used for emergency spillway to river.	Install pressure transducer in wet well. Install RTU/radio for monitoring flows/levels at site from office. **$6,500**	Add actuator to existing manual gate. Install RTU. Install pressure transducer in wet well. Install radio for communications, adjusting flows/levels by controlling gate at site from office. **$13,500**	Remove manual gate and replace with Rubicon overshot gate. Control levels/flows remotely from office. **$32,750**
17th Drop	**5**	Sluice gate used for emergency spillway to river and head adjustment for downstream users. This site is currently used to monitor the amount of water delivered to rest of canal.	Install pressure transducer in wet well. Install RTU/radio for monitoring flows/levels at site from office. **$6,500**	Add actuator to existing manual gate. Install RTU. Install pressure transducer in wet well. Install radio for communications, adjusting flows/levels by controlling gate at site from office. **$13,500**	Remove sluice gate and replace with Rubicon overshot gate. Control levels/flows remotely from office. **$32,750**
North-South Split	**6**	Site used to divert water to North and South Branches of ditch. Check boards at the entrance to the South Branch are currently used to make manual adjustments.	Install pressure transducer in wet well (South Branch only). Install RTU/radio for monitoring flows/levels at site from office. **$6,500**	N/A	(1) Replace with Rubicon overshot gate. Control levels/flows remotely from office. (2) Replace with single Rubicon gate and compare levels at gate with a gate upstream to determine level of non-gated structure (north or south)
31st/Empire Box	**7**	Diversion box that is used to divert water in several directions for several uses including an open ditch spillway to the river and delivery to water users via laterals and headgates. Water measurement and SCADA are desirable for spillway water only.	Install ultrasonic or pressure transducer in box. Install RTU/radio for monitoring water level in box from office. **$6,250** for pressure transducer or **$6,500** for Ultrasonic sensor. (See Table 2 for additional flume costs).	Install actuators on all existing gates. Install flow meters in all outlet pipes. One RTU/radio for monitoring flows at site from office. **$17,000**	N/A
42nd/Golden Box	**8**	Diversion box that is used to divert water in several directions for several uses including spillway to a pond (end of south branch) and delivery to water users via laterals and headgates. Water measurement and SCADA are desirable for spillway water.	Install ultrasonic or pressure transducer in box. Install RTU/radio for monitoring water level in box from office. **$6,250** for pressure transducer or **$6,500** for Ultrasonic sensor. (See Table 2 for additional flume costs).	Install actuators on all existing gates. Install flow meters in all outlet pipes. One RTU/radio for monitoring flows at site from office. **$17,000**	N/A

Figure 23. Recommended SCADA Locations for Evans Ditch

Canal Modernization Study for the Evans Ditch



Aqua Engineering, Inc.
4803 Innovation Drive
Fort Collins, Colorado 80525
970.229.9668 Phone
970.226.3855 Fax

Plotted Date: 5/06

Summary

The purpose of this study was to provide a general overview of canal modernization elements the City of Evans may consider for future improvements in their ditch system. The GIS inventory provided the City with a tool that can be used to prioritize and plan for improvements over the next several years. The report has also provided recommendations for upgrading control and regulation structures, measurement structures, sedimentation structures, and canal sections of interest for either piping or lining. A general discussion on equalizer reservoirs and secondary supply systems was also included.

Of particular interest to the City was the conceptualization of a SCADA system for several key structures. Recent improvements made on the canal system include the incorporation of control gates that do not come equipped with SCADA compatible controllers from the manufacturer. As such, these structures will require some sort of retrofit or replacement. Control gates that are SCADA compatible are discussed in detail in the report and may be more desirable to the City for future improvements.

Appendix A