Case Study: West Stanislaus Irrigation District Modernization

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ABSTRACT

West Stanislaus Irrigation District (WSID) provides agricultural irrigation water to about 22,000 acres in the San Joaquin Valley. The majority of WSID's water is diverted directly from the San Joaquin River, with supplemental water obtained from the Delta-Mendota Canal (DMC), groundwater wells, and a variety of other sources.

WSID operates a series of pumping plants that lift water from the San Joaquin River sequentially into six short canal reaches. Each main canal pool supplies one or two laterals along the valley contour. Water from the DMC enters the district via a gravity pipeline at the tail end of the main canal.

Water supply curtailments, regulatory changes, and significant increases in drip/micro irrigated acreage have steered the district and its board members towards modernization of its original 1920's-era infrastructure. To that end, the Cal Poly Irrigation Training and Research Center (ITRC) has worked in cooperation with WSID since the early 2000's on a phased modernization planning and implementation process. Following a Main Canal Modernization Study, significant improvements have been executed along the main canal including the automation of all original pumping plants and lateral headings as well as the construction of two new, automated pumping plants. An industrial-grade Supervisory Control and Data Acquisition (SCADA) system has also been commissioned. Further project planning is underway at the San Joaquin River diversion and throughout the lateral canal system.

This paper describes the modernization process and results. Lessons learned throughout the various projects are also discussed.

DISTRICT BACKGROUND

West Stanislaus Irrigation District (WSID) was formed in May 1920 to provide irrigation water to local farmers. The WSID boundaries, as shown in Figure 1, encompass about 24,000 acres between the cities of Patterson and Tracy on the west side of the San Joaquin Valley. On average WSID services about 22,000 acres of irrigated agriculture with about 300 delivery points, or turnouts. WSID is also obligated to execute an ongoing agreement to deliver Riparian water to roughly 2,200 acres.

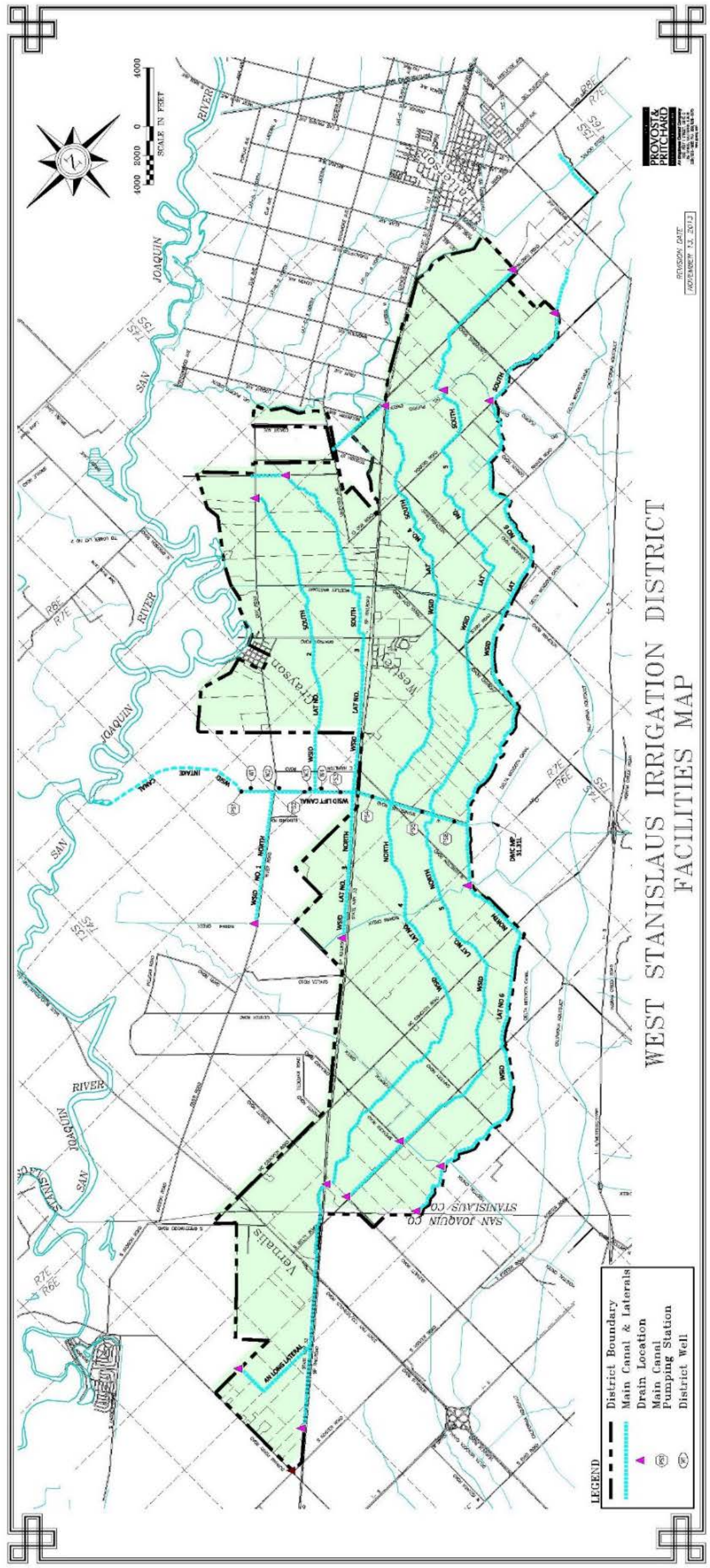

Figure 1. WSID service area. (WSID, 2011)

WSID currently utilizes three sources of water, each with unique constraints, as listed in Table 1.

Table 1. Current WSID water supplies

Source description	Typical diversion rate or volume	Constraints of Use	Water Use
San Joaquin River	307 CFS	Pumping is reduced during low river stage Periods of low water quality	Riparian Irrigation
Delta-Mendota Canal	50,000 AF	Supply volume and timing fluctuates	Irrigation
Groundwater wells	Variable	Limited number of wells Variable water quality	

ORIGINAL INFRASTRUCTURE

As shown in **Figure** 1, San Joaquin River water enters the district via an approximately 2.2 mile long Intake Channel. Without any check structures, the Intake Channel water level fluctuates with changes in river stage. Water is pumped into the WSID Main Canal at Pumping Plant 1 from the intake channel.

The Main Canal is a series of six short pools that flow in a southwesterly direction, roughly perpendicular to the contour. Main Canal pool lengths are short and varied. Each pool is supplied by a pumping plant, consisting of a group of single speed pumps at the upstream end. Water is diverted into two laterals at roughly the mid-point of each Main Canal pool.

Each lateral is identified by its Main Canal pool number and direction of flow, north or south (e.g. 1 North, 2 South) along the valley contour. The Main Canal pools, pumping plants and laterals are summarized in Table 2.

Table 2. Main canal and lateral summary

Pool Number	Approximate pool length (mi)	Upstream pumping plant ID	Upstream pumping plant capacity (CFS)	2011 Total irrigable acres served by pool laterals	Pool supplies two lateral canals
1	0.75	1	310	818	All
2	0.5	2	280	3,211	
3	1.0	3	280	2,123	
4	0.55	4	257	7,364	
5	0.45	5	117	4,662	
6	0.33**	6	102	4,184	

** Pool 6 is a tee pool

A gravity pipeline from the DMC was brought online in 1953 to provide supplemental water to the district. DMC water entered the district at the downstream end of Pool 6.

Each lateral heading was equipped with a Danaidean gate and a downstream suppressed weir. The weir was used for lateral canal flow measurement. The lateral canals are relatively long with periodic check structures consisting of either flashboard weirs or undershot gates used to raise the upstream water levels for irrigation deliveries. Typical lateral flow rates range from 15 to 90 CFS.

ORIGINAL OPERATIONS

Relative to many other districts, the original operations within WSID were unique:

1. Various combinations of single speed pumps at each Main Canal pump station were turned on to meet the accumulated downstream flow demand. Excess flow was usually pumped because there was no mechanism to fine tune the pumped flow rate. Any excess flow was returned to the lower, upstream Main Canal Pool using a manually adjusted bypass canal gate.
2. At the head of each lateral canal, the Danaidean gates were configured to automatically maintain a target water level over the downstream suppressed weir.
3. During the irrigation season, two operation crews staffed the district continuously:
    a. Main canal (pump) operators
    b. Lateral canal ditch tenders

DRIVERS FOR MODERNIZATION

WSID operated and maintained infrastructure as described above for more than six decades without major changes since original construction in the early 1900's. Within the past two decades, forward thinking WSID board members and management have shifted priorities. Realizing that standard maintenance would not overcome recent external and internal pressures, WSID began to focus on modernization.

Improvement goals were identified in the following areas:

1. Much of the district infrastructure was in disrepair. For example, the Danaidean gates at many of the lateral headings were no longer working. The complex mechanisms that normally provide automatic gate controls were overridden by manual chain hoists.
2. Decreasing operational costs.
   a. Maintaining multiple operations crews 24/7 during the irrigation season was no longer sustainable. In addition to labor overhead increases, training new operators takes years – operations were more of an "art" than a science, which is difficult to transfer.
   b. Eliminating bypassed flow at each Pumping Plant could reduce power costs by more precisely matching internal Main Canal pool supply and demand
3. Keeping pace with on-farm irrigation practices. As local growers shifted to sprinkler and micro-irrigation, lower flows and increased operational flexibility were required (Burt and Styles, 2000).
4. Water supply uncertainty. The frequency of drought conditions further constrained WSID water supplies.
5. Regulatory compliance. Increased performance and reporting obligations necessitated new and enhanced monitoring, water delivery equity and record keeping. Examples include US Bureau of Reclamation Water Conservation Criteria, SBx7-7, various Central Valley Water Quality Control Board regulations regarding drainage water standards, etc.

The following tools and services were found to help facilitate modernization:
1. State and federal financial assistance. A variety of financial assistance programs have lowered the barriers to entry for smaller districts to participate in more substantial infrastructure projects.
2. Technical assistance from key consulting, project management and engineering firms
3. Advances in automatic canal control have facilitated more complex and well-performing control schemes (Burt and Piao, 2004).
4. New technology. New hardware and software tools have enabled the proliferation of robust supervisory control and data acquisition (SCADA).

MODERNIZATION EFFORTS

WSID has embarked on the following modernization projects:
1. Early infrastructure improvements completed by 2001.
2. New Pumping Plant and lateral heading automation and renovation. Completed in 2011.
3. Main Canal Modernization started in 2011. Implemented in three phases:
   a. Pumping Plant 1A (PP1A) completed in 2012
   b. Pumping Plant 5A (PP5A) completed in 2014
   c. Pumping Plant 3A (PP3A) planning started in 2015
4. A sequence of Fish Screen Feasibility Studies, starting in 2010. Project final design, environmental compliance and permitting is ongoing and scheduled to be complete in 2017.
5. Lateral Modernization Plan began in 2015

EARLY IMPROVEMENTS

Beginning around the year 2000, WSID started its first major Main Canal improvement project. The project involved:

1. Automating Pumping Plants 1 through 4 using programmable logic controllers (PLC) as the primary downstream control scheme. As designed:
    a. One pump in each of the Pumping Plants received a variable frequency drive (VFD) to provide fine flow adjustment.
    b. The pumps would be controlled to maintain a relatively constant downstream target water level. Based on canal modeling and simulation, the Cal Poly Irrigation Training and Research Center (ITRC) provided the project integrator with tuned control constants and core control logic flow charts, which is perhaps 10% of the complete PLC code required for typical projects. The integrator used these work products to develop the complete PLC code.
    c. A backup automatic control system using mechanical floats was also in-place for each Pumping Plant.
2. A new SCADA base station was installed to provide remote control and monitoring capabilities for the four Pumping Plants, from the WSID office. The SCADA system featured the following major components:
    a. Lookout Human Machine Interface (HMI) software
    b. MDS 900 MHz serial radios
    c. Modbus communications protocol
    d. Control Microsystems PLCs
    e. An operator interface terminal (OIT) with keypad and two line display
    f. Industrial sensors

By 2009, a new district manager was hired. It quickly became evident that:

1. The automation was not working, despite the previous manager's testimony to the contrary.
2. Many of the components were already outdated or obsolete including the HMI, radios, PLC programming software and the OIT
3. Almost no documentation was provided on the SCADA system

Based on these realizations, a complete SCADA and Main Canal Automation replacement was necessary and an easy management decision. A modular upgrade would not be feasible. Lessons learned from this experience regarding automation and SCADA were:

1. Extensive SCADA specifications are important.
2. District expectations need to be present, reasonable and clear.
3. Contracting an integration firm to transpose core control algorithm instructions into PLC code will likely not succeed. The instructions will never be a replacement for controls expertise.
4. Quality control and performance verification is critical
5. The assured obsolescence of SCADA components should be planned and budgeted for.
6. Good documentation can help decrease unnecessary, future SCADA upgrade or maintenance costs

Taking from the lessons above, future modernization projects followed a different process.

SCADA REPLACEMENT AND LATERAL HEAD GATE AUTOMATION

In 2010 through 2011 WSID, began two major improvement projects:

1. Complete replacement of the SCADA and automation systems for Pumping Plant 1-4
2. Adding new automated lateral headings to the new system

The new SCADA system deviated from the previous version in the following major ways:

1. Different hardware and software:
    a. New, redundant base station servers running ClearSCADA HMI software and an automatic alarm dial out system to alert operators of unexpected system conditions and faults.
    b. 2.4 GHz Ethernet radios for secure access to PLCs installed in the field for remote code updates
    c. Large 10 inch operator interface terminal (OIT) touchscreens
    d. Redundant industrial sensors. Redundant sensors have proven a critical component of robust automation systems. (Burt and Piao, 2004)
2. Cal Poly ITRC developed the new PLC control code in-house by building off of the previous tuned control constants and new logic. This single entity was also responsible for developing the SCADA specifications, and programming the PLCs with the control code. This ensured a single organization held responsibility throughout the entire project.

At the lateral headings, the old Danaidean gates were replaced with standard radial gates and electronic actuators. New RTUs and sensors were installed. Additionally, a variety of modifications were made to the lateral heading weirs to improve flow measurement accuracy.

Results. There are several very important considerations when examining the control accuracy of the Main Canal:

1. The control is automated downstream control. In other words, there are no pre-programmed flow changes at each Pumping Plant.
2. Only one pump at each Pumping Plant was equipped with a variable frequency drive (VFD) control.
3. The canal pools have very little storage and are relatively short, which creates a very difficult situation for designing stable downstream control.
4. The river stage and subsequently the Intake Channel water levels on the supply side of the first Pumping Plant can fluctuate up to 20 feet (compared to a minimum total dynamic head of 21 feet). This meant that special control logic was necessary to account for how pump flows changed not only with varying speed, but with different total dynamic heads.

In general, the new SCADA and automation system performance has been excellent. However like many modernization projects, the realized benefits of the interventions have not been precisely quantified. This is mainly due to the lack of prior, continuous monitoring of key performance indicators such as flow rates and water levels for comparison. As such, some benefits to WSID include:

1. Improved Main Canal Pool water level (refer to Figure 2) and lateral flow rate stability.
2. Excess pumping between canal pools has been eliminated
3. Shifting labor from operations to customer service and maintenance

4. Minimizing operations and management staff anxiety during and after regular business hours
5. Reducing operational spill at the lateral canals by approximately 5-10%. Lateral flow rate changes can be preprogrammed and scheduled with more precision.

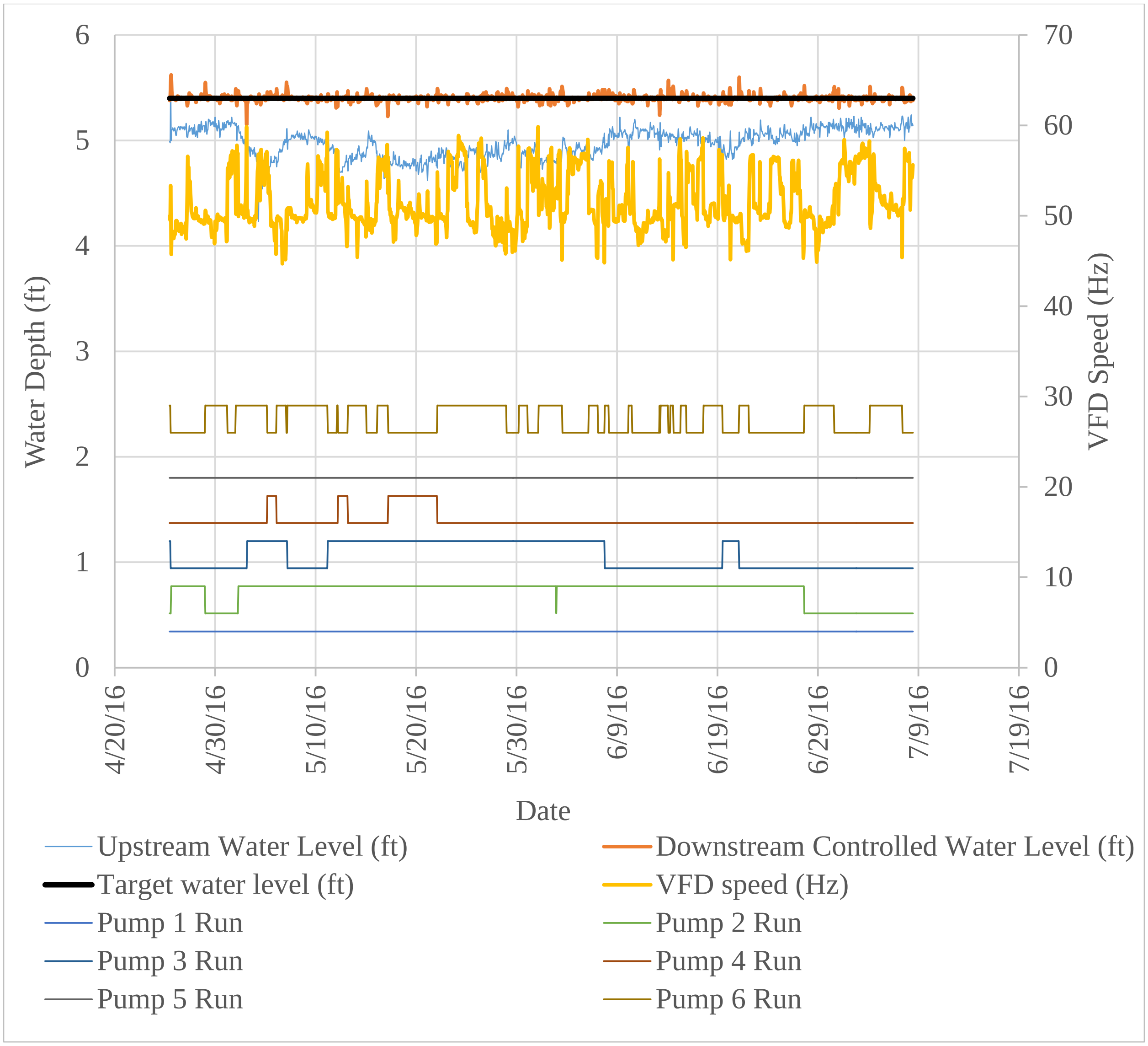

Figure 2. Typical performance trending from Pumping Plant 4 under automatic downstream control, during peak irrigation season. Notice the VFD and single speed reactions required to maintain a relatively constant downstream water level. Individual pump capacities are roughly 40 CFS. Also, the "jumps" in *Pump Run* trends indicate pump starts/stops.

The data set above was analyzed using basic statistics. The results are provided in Table 3.

Table 3. Typical performance values for the automated Pumping Plants during peak irrigation season. Data from Pumping Plant 4, May to July of 2016

Performance statistic	Value
Average controlled water level error (ft)	<0.01
Standard deviation of controlled water level (ft)	0.028
Coefficient of variation (standard deviation / mean)	0.006
Maximum percent of time controlled water level is less than the target minus 0.1 feet (%)	0.21
Maximum percent of time controlled water level is greater than target plus 0.1 feet (%)	0.86

The time period selected was not the best or the worst. An attempt was made to select a sufficient duration to highlight normal operating conditions without uncontrolled events such as maintenance or power outages.

It is also important to note that the project also experienced issues, mostly dealing with intermittent radio communication failures that have been resolved.

MAIN CANAL MODERNIZATION

WSID conceptualized a major Main Canal modernization project and developed a strategic plan, along the way contracting with consultants and engineers to fill in some of the details. The key component of the strategic plan was to construct a new intertie with the DMC to improve operational flexibility and water supply reliability.

The modernization project was also focused on resolving the following issues:

1. The distribution of DMC water was limited to a single Main Canal pool because:
    a. The manual bypass gates at each Pumping Plant were the only mechanisms available to distribute DMC water.
    b. Main Canal pool capacities hindered the expanded distribution of DMC water to other pools
2. The original Pumping Plants were not satisfactorily maintained over the years resulting in severe structural integrity issues.
3. WSID was still operating with the original pumps and motors. Overall pumping plant efficiencies ranged from 50% to 65%.

The original Main Canal and Pumping Plants were not designed for the anticipated capacity for DMC deliveries (see Table 2). Therefore, the following system modifications were formulated:

1. The main canal would be almost completely bypassed with a series of three new Pumping Plants, each discharging into buried eight foot diameter pipelines. Each buried pipeline would terminate at an existing Main Canal pool with a submerged outlet.
2. The buried pipelines would be fitted with automated butterfly valves to serve each Main Canal pool. With the exception of Lateral 1N, all valves would discharge into the existing Main Canal pool near the lateral headings. Lateral 1N would be served directly from the pipeline.

3. All pumps would be fitted with either a VFD or soft-start to minimize starting current and to improve controllability.

A conceptual schematic of the plan is illustrated in Figure 3. Another concern was distributing DMC water to lower canal pools.

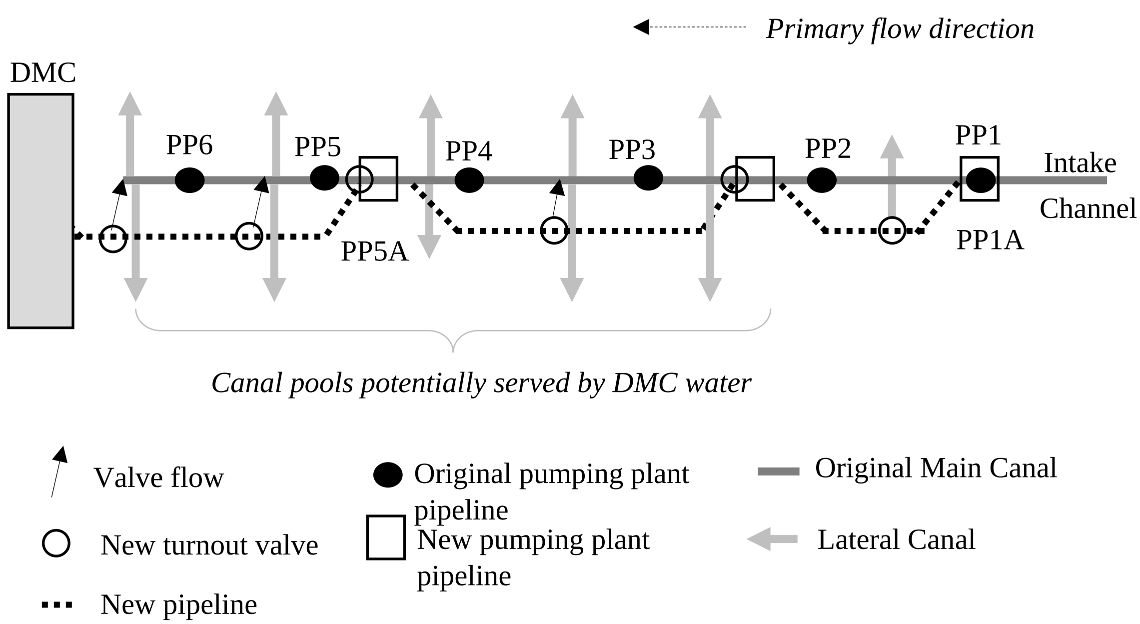

Figure 3. Proposed Main Canal modernization plan. Two remote (manual) controlled sluice gates that operators can close at the DMC intertie are not shown.

Additional Control Discussion. The selection of instrumentation and the eventual control logic focused on increasing operational flexibility. For example, there are three different control types for the pumps at PP5A:

1. Two flow control locations. The pipeline downstream of PP5A was fitted with two flow meters, one at PP5A and one at the new DMC intertie. Control logic was developed to provide operators with the option of maintaining a target flow rate at one location or the other (but not both at the same time).
2. Downstream pressure control. Alternatively operators would remotely close the sluice gates at the DMC and configure the pumps to maintain a target pressure in the (now closed) discharge pipeline.

These options provide WSID operators with the flexibility to select the control type that best suites various operational criteria, including:

1. Deliver a fixed flow rate to the DMC
2. Deliver excess water not directed into any laterals to the DMC
3. Divert DMC water into the district. DMC diversions can range from periodic supplements to significant portions of on-farm demand depending on the flow rate target set at PP5A

4. No flow to or from DMC, all water is supplied by a combination of San Joaquin River water and groundwater

To facilitate these operational criteria, the corresponding control types for the other modernization sites are listed in **Table** 4.

Table 4. Typical control configurations for the completed Main Canal modernization project. This table assumes the original Pumping Plants are not operating.

<table>
<tr><th>Operational Criteria</th><th>PP5A</th><th>PP3A</th><th>Automated butterfly valves at each Main Canal pool not directly served by buried pipeline</th><th>PP1A</th></tr>
<tr><td>Target flow rate delivered to DMC</td><td>Flow control at the DMC intertie</td><td rowspan="4">Downstream water level</td><td rowspan="4">Downstream water level</td><td rowspan="4">Downstream water level</td></tr>
<tr><td>“Excess” water delivered to DMC</td><td>Flow control at PP5A</td></tr>
<tr><td>DMC water diverted to WSID</td><td>Flow control at PP5A</td></tr>
<tr><td>No flow to/from DMC</td><td>Downstream pressure control at PP5A</td></tr>
</table>

Numerous other control schemes are possible if operations at the original Pumping Plants are considered. For example, each automated butterfly valve (serving each Main Canal pool) is also capable of automatic flow control, to be used if the original pumping plants are configured to operate under automatic downstream water level control in an emergency.

Implementation. Due to budget and operational continuity constraints, the project was divided into three phases.

Pumping Plant 1A. Pumping Plant 1A was the first phase of implementing the major Main Canal modernization project. The project included:

- A new pump station and conveyance pipeline set parallel to the original Pumping Plant 1. PP1A was fitted with 5 new, automated vertical turbine pumps. Three of the pumps are controlled by VFDs. The pipeline terminates just downstream of Pumping Plant 2, discharging into Pool 2.
- A new automated trash rack just upstream of the pump intakes
- A new piped turnout at the Lateral 1 North and 1 South lateral headings to replace the existing slide gates.

Pumping Plant 5A. The second phase of the Main Canal modernization project was PP5A, which included:

- The intertie to the DMC. The structure included a new RTU, and two sluice gates integrated for remote manual position control. These gates operate in one of two positions, fully closed or fully open.
- A new pump station (PP5A) in Pool 4 just upstream of the original Pumping Plant 5. PP5A was fitted with four new pumps. Three of the pumps were fitted with VFDs.
- New automated butterfly valves servicing Pool 4, 5 and 6

Pumping Plant 3A. The third phase, which is still in the planning stages will be similar in design and functionality to PP1A.

FISH SCREEN

The Fish Screen project was initially envisaged by WSID and natural resources agencies since 2008. In general the project is designed to provide a screened intake for fish protection and relieve pumping issues at low river stages. The project will likely include the following major components:

1. A new pumping station adjacent to the San Joaquin River with five new VFD-controlled vertical turbine pumps. The pumps will be automated for downstream water level control at a point just upstream of PP1A
2. A buried discharge pipe connecting the Fish Screen pumps with a shortened intake channel
3. Improved access roads
4. Improved flood control structures along the intake channel

LATERAL CANAL MODERNIZATION

The WSID lateral canals are relatively long and are operated under manual upstream control. The result is excessive lag time, operational spill and constant human operations effort. A study to analyze and recommend modernization projects for the lateral canals began in 2015. Anticipated projects under investigation, such as lateral canal interties and regulating reservoir focus on:

a. Capture and reuse of excess lateral canal flows
b. Storage capacity to supplement lateral deficits
c. Decreasing operational spill
d. Decreasing lateral canal lag time

PROJECT COST EXAMPLES

Approximate expenses incurred by WSID for SCADA project components are presented in Table 5. It is important to note that these figures may not be transferrable to other projects, however the values provided tend to reflect the norm for custom SCADA implementations in California.

Table 5. Approximate expenses for various parts of the new SCADA system prior to the construction of the new pumping plants (PP1A and PP5A), not including external funding or WSID staff time

Item	Major components	Approximate expenses (2011 US dollars)
SCADA Plan	A document outlining the scope and specifications for integration firms to bid, includes tasks and responsibilities for project team	20,000
New SCADA base station	New server, HMI configuration and license, remote access desktop, work station desktop, radio, backup power supply, automatic alarming software, two hardened laptops, installation and commissioning	90,000
Pump Station RTU	PLC, Ethernet radio, 10" touchscreen, security sensors, redundant field sensors (upstream and downstream water levels), installation and commissioning	35,000
Pump Station PLC control code	PLC code for operating about five pumps, one with a VFD; automatic downstream water level control. Three possible control target locations; using optimized control constants (requiring unsteady canal modeling and simulations), field testing and 1 year of support	8,000
North and South Lateral RTU	Single RTU for two laterals: Same as pump station but with different redundant sensors (upstream water level, two downstream water levels and two gate positions), installation and commissioning	35,000
Lateral gate PLC control code	PLC code for operating two canal head gates in automatic flow control, field testing and 1 year of support	6,000
Complete SCADA system and automation	Materials and labor, all-inclusive	1,105,000

MODERNIZATION BENEFITS

The new flexibility provided by the modernization projects have significantly changed WSID operations. The data required to empirically evaluate the effects of modernization projects independent of any changes to operations is not possible at this time. Instead, a comparison of pumping plant efficiencies is provided in Table 6.

Table 6. Pumping efficiencies before and after Main Canal modernization

Category	Irrigation Season	
	2011	2015 – with PP1A, PP5A and DMC intertie
Number of original Pumping Plants in operation	6	2
Pumping plant efficiency of original Pumping Plants (%)	50 - 65	50 - 65
Pumping plant efficiency of new Pumping Plants (%)	N/A	70-78**

**Best estimate based on field measurements

Additional comments:

1. Efficiently distributing DMC water would not be possible without the project. At one point WSID operated rented diesel pumps which required over $500,000 per month of fuel to operate.
2. The new DMC intertie was heavily utilized in the 2015 season. It could be speculated that permanent crop damage would have been a result if the project had not been operational.

MODERNIZATION PROCESS

In this and other cases (Styles et al, 1999), a process of strategic and incremental modernization projects have been successful. Components of the process are described below:

1. Identify the need for holistic improvement. This is a fundamental first step that has not yet been realized by many smaller irrigation districts. In many cases, smaller irrigation districts are overburdened by other issues that monopolize staff effort.
2. Develop a long-term strategic plan, starting with the main canal. In addition to describing various modernization interventions, a strategic plan prioritizes projects and presents a road map for implementation based on a complete irrigation system appraisal. In many cases, re-routing or recirculating water, changing hydraulic control schemes are part of the plan.
3. Meet with the board and other stakeholders to develop acceptance of the project costs, and risks
4. Select the highest priority projects and secure funding.
5. Assemble a project team comprised from an array of key disciplines. Positive attitudes and teamwork are critical.
6. Pay special attention in developing construction sequencing phases to minimize operational disruptions during construction
7. Develop good project specifications for all contractors and services. Focus on field verifications, manufacturer support, training, retention and documentation.
8. Complete the project. When issues arise, focus on the resolution and commit to seeing things through
9. Chaperone staff through the training and familiarization process. Even seasoned operations staff can sometimes struggle to accept rapid changes to an old routine.
10. When things work, actively publicize their effectiveness and benefits to farmers and board members to develop interest in additional projects.

COMMENTARY

Based on the authors' experiences, the following conclusions can be made in regards to recent developments in SCADA and automation over the past 20 years:

1. Rapid advancements in technology have resulted in considerable shifts in SCADA software and hardware.
2. There is a tipping point at which regular operation and maintenance of a growing SCADA and automation system will require at least one full-time district staff member. However, skilled technicians are difficult to find largely because formal SCADA training programs are rare, if not non-existent. Most existing SCADA technicians receive substantial on-the-job training.
3. Good sensors are still expensive. Despite their cost and quality, good sensors still require periodic calibration adjustments.
4. Automation projects are still complex exercises, despite high success rates
5. Although hardware costs have decreased, project costs have remained the same or increased. This is largely due to the interest in new and effective SCADA add-ons such as:
    a. Remote access via tablets and smart phones
    b. Automated voice or text alarm notifications
    c. Automated report creation
    d. Remote power and water quality monitoring
6. Finding quality integrators is difficult. Solid specifications requiring thorough verification and quality control measures are key, for all types of integrators.

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