

PIPELINE AND CANAL DOWNSTREAM CONTROL SYSTEM FOR RECIRCULATION – PATTERSON ID CASE STUDY

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ABSTRACT

Patterson ID in Central California has five long, along-the-contour lateral canals that flow northward from a main canal. The main canal operates on downstream control, providing excellent flexibility to heads of the laterals. The lateral canals operate with manual upstream control and have little storage. The classic tail-ender problem existed; spill from the tail end was necessary to avoid under-supplying tail-end customers.

To eliminate the spill and to provide better flexibility, a system was designed and constructed to tie the ends of the five laterals together with pipes and pumps, with one central regulating reservoir. The automatic control system allows water to exit a lateral pool by gravity if that particular lateral end has too high a water level. Conversely, if the most downstream pool on a lateral canal drops, a VFD-equipped pump from a downhill lateral automatically supplies the correct flow rate to re-establish a constant water level. The same pipe is used for flow in both directions.

Any excess flow from the system as a whole is automatically routed to the reservoir. Any deficit from the system as a whole is removed from the reservoir. The complete system is monitored by SCADA, so operators know where excesses or deficits occur, and can adjust flows at the heads of the laterals to compensate for mismatches at the ends of the laterals.

The system has worked successfully for three irrigation seasons. The paper describes the control philosophy, design, costs, challenges, and benefits.

INTRODUCTION

Patterson ID - Background

Patterson Irrigation District (District) is located in Stanislaus County on the west side of California's San Joaquin Valley. The District provides irrigation water service to nearly 13,500 acres of farmland situated between the City of Patterson, CA and the San Joaquin

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River. The region produces a variety of crops including hay and forage crops, tomatoes, beans, vegetables, almonds, walnuts, and stone fruits. The District's customer base is predominately small family farms and ranchettes, with most parcels ranging between 10-40 acres in size. Because forage crops account for approximately 55 percent of the acreage within the District, furrow and border strip irrigation is the primary method of irrigation. Over the past six years, however, the District has seen a 40 percent increase in acreage utilizing drip/microsprayer and sprinkler irrigation systems, corresponding with a similar increase in almond and walnut orchard establishment.

The District supplies water through the operation of four miles of main canal lift system and over 50 miles of along-the-contour lateral canals which convey water to lands north and south of the main canal. The main canal includes six pump stations with 33 pumps to deliver water to thirteen laterals. Each pump station utilizes downstream control with a Proportional Integral Derivative with Filter (PID-F) algorithm to maintain the water level in the canal pool within ± 0.10 feet. At least one variable frequency drive is used at each station to provide infinite flow rate possibilities for more precise canal control. A map of the District is provided as Figure 1.

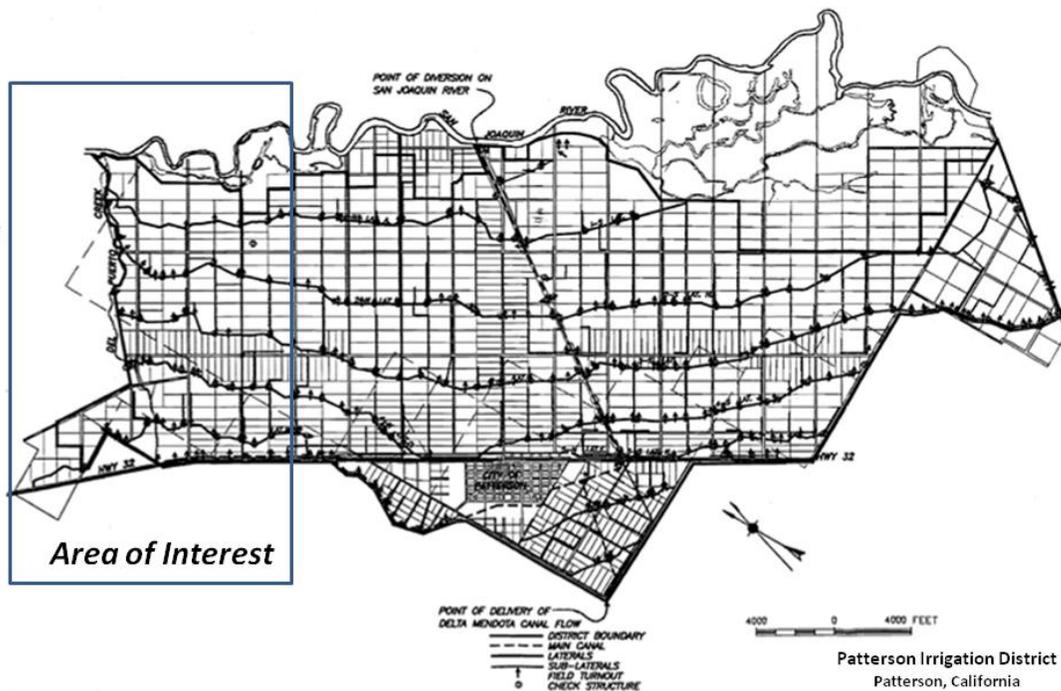


Figure 1. Patterson Irrigation District delivery system.

The majority of the laterals off of the main canal are operated with manual upstream control, although the District recently installed two automated flow control structures at the heads of two laterals on the main canal. Operators typically use a flume at the head of each lateral to set the desired flow rate, based on the orders for the day on each lateral. A typical flow structure is shown in Figure 2. The automated flow structures utilize level transducers, a gate actuator, and orifice flow equations to set and maintain flow rates into two laterals off of the main canal. For both manual and automated control structures, the

main canal responds to level changes on the system and automatically determines pump flow changes to maintain the desired levels in each pool.



Figure 2. Head of Lateral 2N.

Over the past 14 years, the District has implemented an aggressive modernization program which has included the following: main canal automation; Supervisory Control and Data Acquisition (SCADA) and radio communications for remote monitoring and operation of District facilities; standardization of all pump motor control center installations; construction of regulatory reservoirs to capture and recirculate operational spill and agricultural drain water; and most recently, completion of a California Department of Fish and Game/National Marine Fisheries Service-approved fish screen on the district's San Joaquin River diversion. These improvements have increased conservation and efficient use of water supplies, which include the San Joaquin River, groundwater, and gravity-fed Central Valley Project water from the Delta-Mendota Canal. They have also added flexibility to the operation and ordering within the District. The District generally requires 24-hour advanced notice for water deliveries and two to three hours for water shut-offs. If capacity is available, however, water orders can be accommodated immediately and shut-offs can be accommodated within 1-2 hours of advanced notice.

Lands within the District are generally irrigated from west to east, following the natural contour of the area. Water is delivered to a field from the westernmost lateral, and drains into the next easterly lateral. As a result, operators typically estimate an amount of anticipated drainage to expect when setting flow into each lateral. Additionally, the laterals were designed with little additional capacity to meet peak season demand, and no storage. These factors made it difficult to set the correct flow to minimize operational spill and meet grower demands at the end of each lateral for years. Any agricultural

drainage and operational spill would historically outfall into the Marshall Road Drain to the south or the Del Puerto Creek to the north, both tributaries to the San Joaquin River.

Project Concept

The District, in trying to address CALFED's targeted benefits on the San Joaquin River, completed the first phase of a master plan to reduce contaminant loading to the San Joaquin River by improving the operation of the Marshall Road Drain, situated in the southwest corner of the Patterson Irrigation District in 2002. The objectives of this modification were to: reduce the silt loading to the San Joaquin River; reduce Organophosphorus (OP) pesticide levels in the drainage water discharged to the San Joaquin River; reduce constituents adversely affecting the dissolved oxygen level within the San Joaquin River; and develop new water supplies through construction of operational spill and tailwater recovery systems to further improve the local efficiency of water management.

This effort necessitated the cooperation of various local agencies since the watershed tributary to Marshall Drain consists of approximately 6,800 irrigated acres located within Central California Irrigation District, Del Puerto Water District and Patterson Irrigation District, with a smaller area independent of local agencies. Silt-laden upslope surface drainage and operational spill water historically discharges from these areas into the Marshall Road drain and then into the San Joaquin River.

A surface tailwater collection reservoir was constructed with a surface area of 14 acres and usable storage capacity of 42 acre-feet. The operation plan for the reservoir was to divert as much of the watershed surface tailwater drainage as possible and use it as an irrigation supply for approximately 850 acres downstream of the reservoir on Lateral 3-South. The implementation of the project reduced direct discharges of constituents to the San Joaquin River and allowed opportunities for improved water management by recycling this drain water back into the local irrigation supply.

Building upon the success of the south reservoir program, the District proposed construction of another reservoir/impoundment on the northern end of the District to prevent/reduce operational spill, improve service to landowners on the tail-end of the system, and to also meet the following objectives:

1. Develop cooperative and coordinated real-time salt and nutrient drainage load reduction strategies through enhancements to existing flow and water quality monitoring networks.
2. Plan, design, construct and operate a drainage detention pond within the District to meet CRWQCB objectives of salt and nutrient load reduction to the San Joaquin River while enhancing water supply reliability in the District.
3. Enhance effectiveness and efficiency of operation of on-farm irrigation and drainage facilities and practices in neighboring West Stanislaus Irrigation District through design and application of a real-time monitoring and diversion control system and associated irrigation and drainage best management practices (BMP's).

4. Monitor, evaluate and contrast the performance of irrigation district-owned and privately-owned drainage detention facilities and operational strategies. Develop BMP's for real-time operation of similar projects and on the west side of the San Joaquin Basin.

The initial project concept included a series of pump stations and interconnecting pipelines that would convey excess agricultural drainage and operational spill between laterals and into a reservoir on the northern end of the District. The reservoir would store water that was historically spilled to Del Puerto Creek and the conveyance system would recycle this water to the laterals to meet crop demands at the tail end of the system. This concept is illustrated in Figure 3.

PID was awarded two grants for development and construction of this project: a Proposition 50 Agricultural Water Quality Grant through the California State Water Resources Control Board in 2004, and a CALFED Water Use Efficiency Grant in 2005. Both grants totaled approximately \$1.7M toward design and construction of this project, with the District originally pledging approximately \$1.3M in funds toward the project.

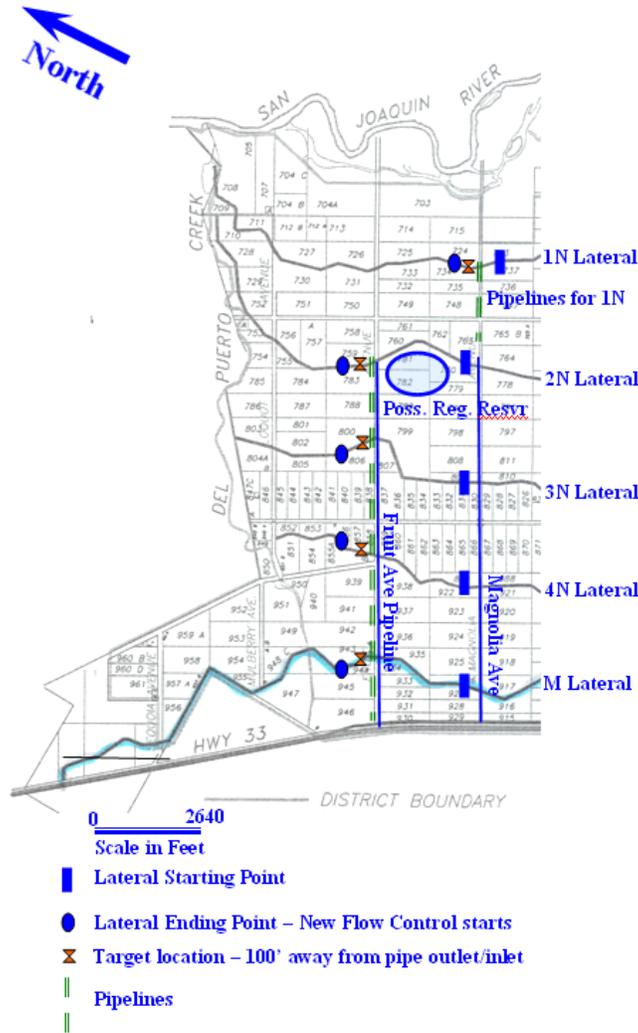


Figure 3. Early conceptual sketch for the project.

Project Design

The District worked with staff from Summers Engineering out of Hanford, CA, Berkeley National Laboratories, the Irrigation Training and Research Center at Cal Poly, San Luis Obispo, and neighboring West Stanislaus Irrigation District to develop a regional, multi-benefit project to meet the project objectives. This project included the design, installation, and operation of a regional reservoir within PID to store and divert excess drainage water and operational spill flows for reuse within the PID system. As part of the SWRCB grant agreement, a local field-level drainage recirculation system was also constructed and installed so that the costs/benefits of the various drainage-storage and reuse strategies within the local region could be computed. The project was broken into two separate project components: (1) a Northside Recovery System (Northside Reservoir), which includes a regional reservoir within PID and interconnecting pipeline and pump facilities between laterals; and (2) the Westley Tailwater Return System.

The Northside Reservoir project design was unique and challenging. Design objectives included:

1. No spill from the ends of any of the five laterals during normal operation.
2. Provision for emergency spill from the lateral ends in case of power failure or errors in control.
3. Only one reservoir, due to the costs of reservoir construction and land purchase.
4. No flow rate shortage at the ends of any of the five laterals during normal operation.
5. Completely automatic operation.
6. Remote monitoring of the status of the pumps, valves, and lateral reservoir water levels.
7. Ability to remotely change target depths of water in the laterals, or to over-ride automation and be able to remotely manually control the operation.
8. Stable and rapid control.
9. Fairly constant water levels at the ends of the laterals, regardless of the flow.
10. Operation without knowing any of the turnout flow rates.
11. Distributed control.

Figure 4 shows the general control concept. Lateral 4N will be used as an example for discussion. The logic was the same or very similar for all other laterals.

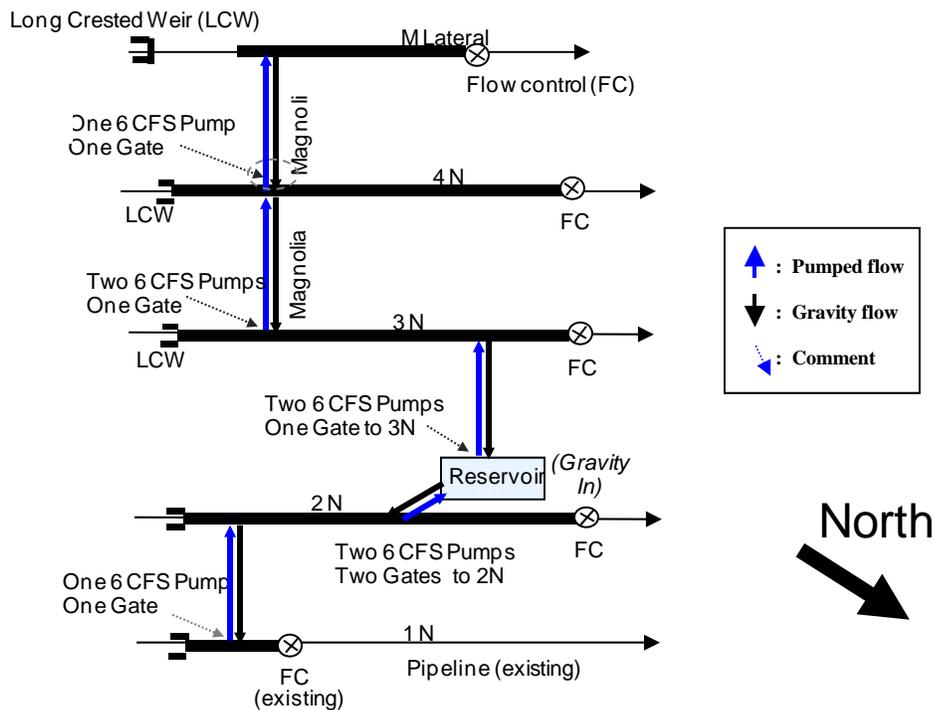


Figure 4. Final configuration. Note that "North" is oriented differently than in the previous figures.

For lateral 4N, the only Programmable Logic Controller (PLC) that examines the water levels in 4N is located between it and the reservoir – at the pump station located on

lateral 4N. If the water level in lateral 4N drops below the target, there are two types of action possible:

1. Reduce the flow out of 4N. Control-wise for "demand" operation, this can only be accomplished if water is flowing from 4N to 3N. In this case, water would be flowing downhill from 4N through the single pipeline. A modulated valve adjacent to the pumps on 3N would be closed the appropriate amount, reducing the flow from 4N.
2. Increase the flow into 4N. If the modulated valve on the pipeline between 4N and 3N is completely closed, the pumps would be turned on. Water would flow through the same single pipeline as in (1) above, but this time it would be pumped uphill from 3N to 4N. The pumps are equipped with variable frequency drive controllers, so the speed is carefully adjusted by the PLC to provide exactly the change in flow rate needed to stabilize the water level in pool 4N.

The cause of water level fluctuations in 4N could be an increase or decrease in turnout flows directly from the 4N lateral, or from flow rate changes to/from lateral 5N.

Prior to the construction, the laterals and pipelines were simulated for unsteady control conditions associated with downstream control. It was found that some of the canal pool banks needed to be slightly raised to achieve the required control stability. The pools were physically modified as part of the modernization process.

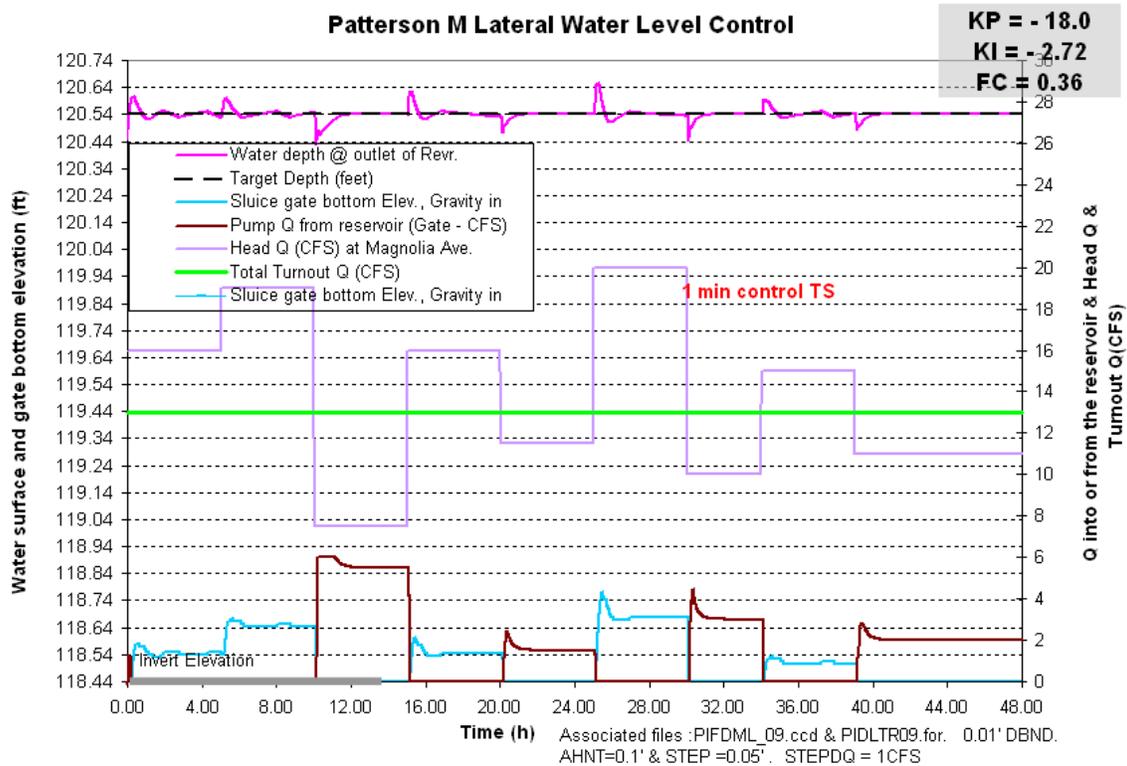


Figure 5. Example simulation results prior to final implementation.

Simulation procedures such those illustrated in Figure 5 assume that when the control requires an increased flow of 0.23 CFS, for example, that precise flow rate is available. Actually achieving that desired change in flow rate in the field control requires excellent knowledge of the characteristics of the valves and pumps. Figure 6 shows how one pump curve at multiple speeds reacts with the system curve. The problem becomes somewhat more complex in some of the pipelines because two pumps are used on the same pipeline, rather than just a single pump.

After the construction, Patterson ID personnel performed trial pump tests to determine the actual pump discharges at various speeds. That refined information was incorporated into the control logic to improve performance, although the initial performance was already very good.

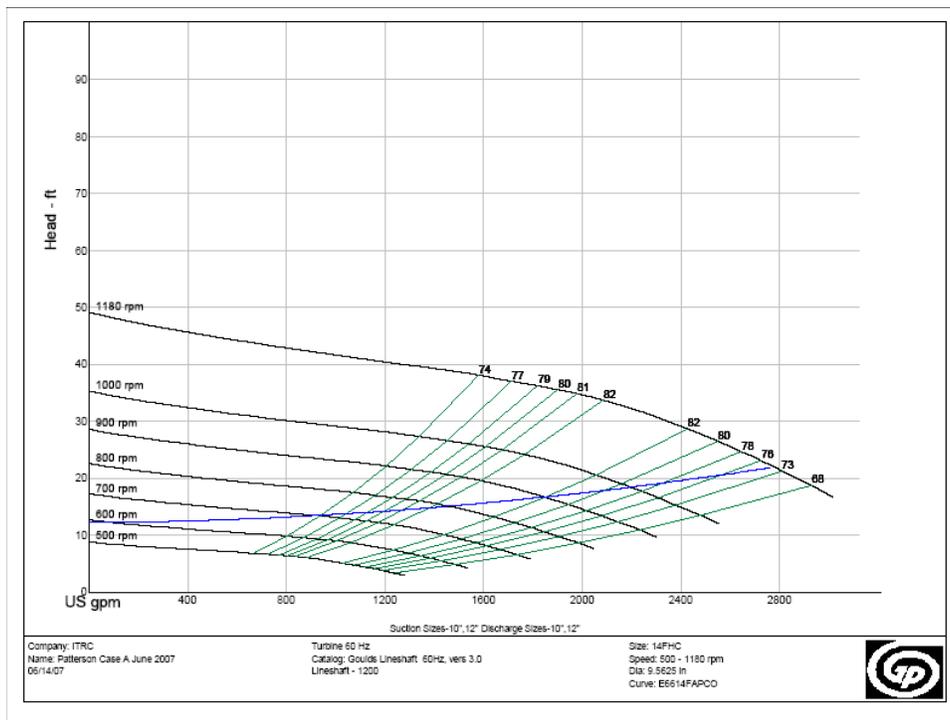


Figure 6. Example pump curves and system curve.

Construction Management

The District took a very hands-on approach to overall construction management for the project. A number of contractors were hired under separate contracts for various aspects of the project including pre-cast concrete products, earthwork, pumps, flow control structures, electrical, and SCADA integration. Throughout the project, District staff, along with engineers from Summers Engineering, managed and coordinated construction schedules between contractors to ensure that the project was completed on time. District staff also coordinated with engineers for regular construction inspection and progress reporting.



Figure 7. Earthwork to establish reservoir levees and rip rap for levee protection.



Figure 8. One flow control structure to the north of Fruit Avenue with weir length designed to pass high flows under system failure conditions.



Figure 9. Pump station and valves to divert water from the reservoir into 3N or vice versa

Upon completion of the construction, the District installed heavy security measures for the overall project in an effort to prevent the vandalism and copper-wire theft that had occurred to local landowner pumps and wells in the region. These measures included concrete vaults to house motor-control centers, burglar alarm panel/PLC's, anti-climb fencing with vibration detection, magnetic locks, sirens, and strobe lights. These improvements were financed directly by the District.

The Westley Project included the construction of a two-stage tailwater collection reservoir and a return pump station and pipeline. The reservoir collected tailwater from a 550-acre field into an initial settling cell. The purpose of the settling cell was to settle out the suspended silt in a relatively small pond that could be cleaned easily. As the initial cell filled, tailwater was decanted into the primary cell through a flashboard riser, where it was stored until it was needed for irrigation. A pump station was constructed on the down-slope end of the primary cell which would pump the stored tailwater through a ½-mile long pipeline, where it was blended with surface water and used for irrigation. This project is shown in Figure 10.



Figure 10. Westley Project tailwater collection and return system.

Control Implementation. The implementation of the automation required careful specifications in advance, as well as close cooperation between the integrator company (Sierra Controls of Carson City, Nevada), the civil engineering firm in charge of the construction drawings (Summers Engineering of Hanford, California), the irrigation district, and ITRC. ITRC was responsible for the control concept, specifying the equipment and logic development, simulation, and programming. The automation was accompanied by a new Supervisory Control and Data and Acquisition (SCADA) system. The integrator was provided, in advance, with all of the tag and register locations for the control logic. The control logic was written in the ISaGRAF language, which is standard for ITRC.

The integrator first established the new, expanded SCADA system by upgrading an older system using Lookout® with newer ClearSCADA® software and associated hardware. All communications use spread-spectrum radios, although the office server can be accessed via the web to perform any functions possible at the office itself.

After the integrator had installed the field sensors, radios, antennas, RTUs, and other equipment, the control software was downloaded. The logic communications with the office were verified, site by site. ITRC and the integrator worked side by side to verify instrument calibration, correct implementation of register assignments, and the other multiple details that must be checked before commissioning a site. The automated logic was then implemented. Due to the simulation testing and control constant tuning that was done in advance of the implementation, only very minor adjustments were needed. As is standard with VFD installation (pump curves and required pressures do not always

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match design assumptions), the actual pump flow rates needed to be verified by the district at various RPMs. The appropriate adjustments were made to the pump flow constants within the PLC.

The system uses redundant water level sensors, and also features emergency weir overflows at the downstream end of each controlled pool. The SCADA system provides alarms in the event of discrepancies between sensors, failures of pumps and valves, high or low water levels, and other critical items.

Magnetic flow meters were installed on the flow control structures, and on each interconnecting pipeline. One of the benefits of utilizing magnetic flow meters in this application is that since the pipelines were designed to convey water in two directions either by pumping or gravity, a single magnetic flow meter can read flows in both directions. A typical flow meter installation is shown in Figure 11. All of the flow meters communicate with the District's SCADA system, allowing staff to monitor and record all flows for the project, trend current and historical data, and troubleshoot operational issues.



Figure 11. 1N pump station magnetic flow meter

Operation

The Northside Reservoir has been in operation now for nearly three full irrigation seasons, and functions as intended, achieving level control in each lateral pool, and flow control downstream of this project. District distribution system operators can set flows for tail-end landowners and water users from the office and in the field, delivering precisely the flow ordered. All conveyance to and from the reservoir and in between the laterals is automated, based strictly on level-control in each lateral pool. The project has met all of the objectives it was designed for, including water conservation, storage and recycling, as well as improved operational flexibility to meet tail-end water demands. Furthermore, various HMI screens created for the reservoir project allow staff to operate, monitor, and troubleshoot nearly all components installed for the project.

Maintenance of the project has primarily involved weed control, rip-rap erosion protection installation, and regular pump and valve maintenance. After two years of operation, the reservoir has not required cleaning and removal of sediment deposits, which can accumulate as sediment-laden drainage water is stored. It is anticipated that this type of activity will be required every three to five years. Minor control calibrations have been performed over the year, although these activities are relatively seamless as SCADA integrators and consultants have the ability to remotely log-in to troubleshoot and modify control parameters.

In order to estimate overall Northside Reservoir conservation and performance over an irrigation season, and to compare the larger regional reservoir project to the landowner-based Westley Project, data from 2010 was reviewed and used to compute conserved water volumes. Flow data for the Northside Reservoir project was downloaded from the District's SCADA system for the months of March through October of 2010. This flow data included flows into and out of the reservoir, as well as flows between laterals. During this time period, approximately 2,300 acre-feet of water were conserved through the operation of this project. This includes approximately 1,500 acre-feet of water that was stored and used directly from the reservoir, and another 800 acre-feet of excess water that was diverted to meet adjacent lateral demands or deficits.

Electrical usage data for the project were also analyzed to determine project use energy, which was then compared with overall District energy consumption. For the same 2010 period, the project utilized approximately 82,400 kW-hrs of power, primarily for the operation of pumps and gate actuators for the project. After applying the District's average monthly power rates, project energy consumption costs are approximately \$2.14 per acre-foot of water conserved. For comparison, the District's average electricity cost to divert water from its various supplies during the 2010 irrigation season was \$7.72 per acre-foot. These conserved supplies allowed the District to augment diversions and pumping by a similar volume, which equated to approximately \$5.58 per acre-foot, a 72 percent cost savings in electricity per acre-foot of conserved water. Given annual maintenance costs of \$13,000, the total cost for reservoir operations, based on conserved quantities, is approximately \$7.80 per acre-foot.

The landowner operating the Westley Tailwater Return Project was interviewed to determine the Westley Project's costs and quantities conserved. According to the landowner, the tailwater return system costs approximately \$6,000 to operate annually, which includes maintenance costs for weed control, electricity, and annual sediment removal and maintenance. During an irrigation season, the grower noted that approximately 400 acre-feet are captured and reused as a result of this project. This equates to approximately \$15/acre-foot, and approximately \$45 dollars in savings when comparing the grower's direct per acre-foot costs from the local irrigation district, or a 75 percent cost reduction for conserved water made available through the tailwater return system. In regards to electrical costs alone, the project costs the landowner approximately \$5 per acre-foot to operate.

CONCLUSION

When comparing the intended results of the district regional drainage recirculation project and the landowner farm drainage recirculation projects to the actual results from operations there are several positive observations as follows:

1. Both projects were able to successfully impound and recirculate surface drainage water for application as consumptive-use irrigation water on crops.
2. Both projects were able to reduce the amount of silt and constituent-laden surface drainage water which otherwise would have ended up in creeks, streams and rivers, thereby meeting the CVRWQCB objectives of salt and nutrient load reduction to the San Joaquin River while enhancing water supply reliability in the District.
3. Both projects resulted in increases in operational efficiency when considering initial diversions in-district or applied water on farm through applying recirculated surface drainage water as opposed to applying water from primary initial sources such as water rights, contract and groundwater diversions.

There appear to be some straight economic advantages when comparing the cost per acre-foot of recirculated water on the landowner project vs. the district project. Including capital amortization and O&M costs, the landowner project's recirculated water comes at an annual present cost of approximately \$26.50 per acre-foot when compared to a cost for the district project's recirculated water of \$63.50 per acre-foot. These are the non-grant capital subsidized costs per acre-foot. If the grant funding is excluded from the true capital cost of the project's the annual cost per acre-foot of recirculated surface drain water is approximately \$16.45 for the landowner project and \$37.40 for the district project. As mentioned previously this is a cost savings per acre-foot for the landowner so the landowner is actually avoiding a higher cost and realizing a savings. In the district case the average true cost of delivering its melded primary water supply sources (water rights, contract water and groundwater) is approximately \$55 per acre-foot. The grant subsidized capital cost yields a cost savings per acre-foot for the district when compared to its alternate water supplies but only when grant funds offset the overall capital cost. Additionally, the district has the option to consider alternate beneficial uses for the water rights and contractual water supplies which otherwise would have been diverted to the project benefit area absent the project, such as water transfers. In general, water transfers have generated revenue for the district to complete these types of multi-benefit projects which generally require significant capital outlays.

There are several non-monetary advantages the District realized by completion of this project:

- An avoided incalculable cost of further regulatory compliance regarding concerns with silt and constituent-laden tailwater reaching natural water bodies
- A drastic improvement in customer service through the implementation of a sophisticated, automated project that has created a new water source at the tail-end of one-half of its distribution system. This new water source allows the system to meet growers' demands for instant turn-ons and shut-offs, eliminating

- the need for tail-end water customers in this area to divert groundwater to make up for the District's inability to meet their full water needs.
- The ability to continue to provide surface drainage capabilities to farms in the affected area, as the project can now easily handle the irregular drainage flows.

Additionally, data continues to be gathered on the amount of silt outflow reduction from both projects. Constant annual estimates from the District's prior recirculation project experiences indicate a fairly consistent annual relationship of one cubic yard of sediment outflow reduction per acre-foot of recirculated water. The landowner project has needed to perform sediment basin removal a minimum of once per year and the district project appears to likely only have to complete sediment removal approximately once every five years.

For both projects the best management practice ultimately implemented was the capture, recirculation and crop-irrigation application of nearly 100% of the surface drainage water in the project areas. The District will continue to gather data on water quality, as well as examine operational costs to further refine cost and water quality benefits of both projects.