

## **THE MYTH OF A “TURNKEY” SCADA SYSTEM AND OTHER LESSONS LEARNED**

Robert E. Norman<sup>1</sup>  
Ram Dhan Khalsa<sup>2</sup>

### **ABSTRACT**

The Bureau of Reclamation’s Western Colorado Area Office has been working on a canal modernization project on the Grand Valley Project for roughly 11 years. During that period we have built seven new check structures, a pumping plant, made several modifications to structures along the canal and, finally installed a SCADA system to accompany automation of check structures and pumps. The cast of characters in implementing our SCADA system was the water user organization, the Cal Poly Irrigation Training and Research Center (ITRC), the SCADA “integrator,” and the Bureau of Reclamation. The concept of a turnkey SCADA system is that you outline what you want your SCADA system to be able to do, write technical specifications to achieve that objective, and then hire a SCADA integrator to make it happen. Is it plausible that the technical specifications can explain the existing system to the extent an integrator can accurately estimate the cost of the SCADA system? Did the person writing the technical specifications understand what SCADA can and cannot do? Did that person understand what the water users wanted the system to be able to do? There are many steps to implementing a SCADA system. The next step of often guided by what happened on the last step. We would like to share our experience for having this cast produce a final product and what steps we took along the way. Hopefully, your path to a final product will be more direct than ours.

This paper will discuss the process used to implement a canal modernization program, which included a SCADA system, and more importantly some of the lessons learned. But before discussing “turnkey” SCADA it is important to provide a brief background.

### **BACKGROUND**

Although we have been working on the canal modernization project for 11 years we are not yet done. This project was pursued to reduce river diversions and leave more water in the river to benefit endangered fish. There are several non-endangered fish benefits, but ultimately, the goal is to help recover endangered fish. The fact that there are other beneficiaries made the project politically possible. The modernization project was funded by an endangered species program. The improvements were a one-time shot so it was in our interest to make sure we did the job as well as we could. While this is true for any project,

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<sup>1</sup> Planning Team Leader, Bureau of Reclamation, Western Colorado Area Office, 2764 Compass Drive, Suite 106, Grand Junction, CO 81506, rnorman@uc.usbr.gov.

<sup>2</sup> Civil Engineer, Bureau of Reclamation, Western Colorado Area Office, 2764 Compass Drive, Suite 106, Grand Junction, CO 81506, rkhalsa@uc.usbr.gov.

since the endangered species program was more interested in saving water than they were the cost of saving water, we had the funds to take a thorough look at the project and select what we thought would be the best strategy both in water savings and a robust system.

The 55-mile long canal, 70 laterals, and diversion dam are part of the Bureau of Reclamation's (Reclamation) Grand Valley Project. It is Reclamation's project number 8 and celebrated its 100 year anniversary this year. Our project canal had few existing check structures, very limited local automation, and no system storage. There were radial gates, slide gates and a few stoplog check structures.

We used the term "our project" because that is the way we see it. The project is technically owned by Reclamation and operated by the Grand Valley Water Users' Association (GVWUA). So the "our" is the combination of GVWUA and Reclamation. This perception is both interesting and important. It is interesting because it is not even shared throughout the Western Colorado Area Office much less Reclamation. While we have a wide range of relationships between the Western Colorado Area Office and our projects operators, there is even a broader range in other Reclamation offices. At some locations and times, these relationships even become adversarial.

In implementing the canal modernization program on the Grand Valley Project the relationship between GVWUA and Reclamation is important because of the nature of both organizations. The project serves about 24,000 acres with an annual budget of about \$1.2 million. Grand Valley Water Users' Association is run by a manager and a staff of 12. The manager oversees the daily operation of the canal and gives orders to his operation staff. The Board of Directors of the GVWUA are more concerned that the manager understand irrigation and farming practices and do not require, and maybe, do not even prefer that the manager have an engineering background. The Association does not have an engineer on staff, but it does have a lot of experience of what does and what does not work. Reclamation staff, in general, have a more technical background but, for the most part, are not strong on the understanding of minute-to-minute canal operations - especially how those operations interface with irrigation and farming practices. As we sought the application of SCADA to our canal system it was imperative that we maintained a close relationship with the GVWUA, specifically the manager, to make sure that the improvements are compatible with their operation.

### **THE SCADA TEAM**

This relationship and the abilities of GVWUA and Reclamation staff significantly contributed to the approach for accomplishing the modernization and SCADA project. A district with engineering staff would likely approach the project quite differently as would a district without the technical resources of an agency like Reclamation.

As part of our modernization project we hired Cal Poly's Irrigation Training and Research Center (ITRC) in San Luis Obispo, California. One of their tasks included computer modeling of our canal hydraulics. Through the use of this

model they determined the best location and design for 7 new canal check structures. In addition, ITRC determined the correct algorithm and appropriate constants to use in the gate control algorithm using the model. Simply put, the algorithm is the logic behind how to open or close a gate and how far to move the gate. We hired an integrator to write the program to implement the algorithm within the Programmable Logic Controller (PLC) and to install the SCADA system hardware and HMI.

With four players, GVVUA, Reclamation, ITRC, and an integrator, coordination was essential. We feel that one of the key requirements in having a successful SCADA system is that one of the team members have a working knowledge of what the other team members contribute. Since GVVUA had very little SCADA experience, and Reclamation had worked with ITRC on the canal study, the project oversight role was filled by Reclamation.

### **THE MYTH**

Why do we call turnkey a myth? We think we had one of the strongest SCADA teams you could assemble when we put our system together. At the start, we did not know much, but our knowledge grew as we proceeded through the project. The ITRC has a lot of technical and hands on experience with SCADA implementation and we hired what we feel is one of the best integrators around. But even with this team, there were problems. Sometimes the “key” in the turnkey did not turn. The good news is that all of the problems were solved.

### **WHERE TO START?**

In the beginning, the Association had no SCADA experience and Reclamation at Grand Junction had a rudimentary understanding. So we needed to develop an understanding of what SCADA is and how to implement it. One of our first steps was an ITRC SCADA short course, plus and a Canal Modernization Class conducted by Reclamation’s Denver Office. What we quickly learned is that there are a lot of experts with both technical and practical expertise with a wide range of opinions. Two key areas that the experts do not agree on are, the location of the “Supervisor,” and the gate control algorithm. We are not going to attempt to resolve these issues here. The point is that it is necessary to understand the different strategies and make the decision that is best for your project.

### **SUPERVISORY CONTROL**

The phrase “Supervisory Control and Data Acquisition” sounds simple enough. But who is the Supervisor, where does the supervisor reside in relation to the canal structures, just what is the supervisor controlling, and how is he communicating? On our canal system our goal was to control the water level in the canal in some places, and to control flows at other locations. This is done by adjusting the amount of water entering into the canal and then by opening and closing the 15 check structures along the canal.

### **Central Control**

One school of thought is that a central decision making computer should make all control decisions. In most canal automation literature, it is assumed that the algorithm is running on a central computer. Using the algorithm, the central site would calculate the required gate movements and convey that information to each site. Control computations happen in a central location. With this form of communication, it is possible to operate the canal as a whole. As an example, if water is needed at a location far downstream, all of the gates upstream from that point could in theory be opened in unison thus using some of the canal storage potential to move a change quickly through a canal. This type of control requires very reliable communication between the central site to the remote sites. In selecting this type of control, it is necessary to assess the reliability of your communications as well as the consequences of failed communication.

### **Central Guidance - Local Control**

Another school of thought is to provide targets from a central location to the PLC at each canal structure. The central location should maintain and disseminate that information to each site. For us the disseminated information is the upstream target water level, downstream water level or target flow. Guidance can happen from an operator panel at each site or from a central location via some form of electronic communication. The algorithm actually runs on a PLC at each site. Therefore, the local computer or PLC would decide whether to open or close a gate and then issue those commands to the gate. The sites along a canal are hydraulically connected. That is, if a gate upstream opens, it would allow more water through. Eventually a downstream gate would sense this increased flow by an increase in water level. This “hydraulic” communication is slow but it is reliable. Of course, there are situations when the speed of the control is more than adequate, and other situations when it is not.

The decision for what type of control to use on our project was largely based by what happens if the communication between the supervisor and control site fails. The discussion about the best method of communication is another debatable topic but for several reasons we opted for licensed radio communication. On our sites, if the communication is lost for prolonged periods of time it is possible to provide a new target or guidance through the operator panel at each site. How likely it is that communications will be lost? In the “Other Lessons Learned” portion of this paper will discuss one of the challenges we have experienced with our radio system.

### **Gate Control Algorithm**

We find this to be one of the most hotly debated topics of our project. The PIF gate control algorithm we use on our canal is promoted by ITRC. ITRC contends that in order to calibrate the algorithm for a particular canal with multiple gates and intervening pools in series, canal modeling is required. Reclamation’s Denver Office uses a PID algorithm. They contend that calibration of the

algorithm can be accomplished through a software application without canal modeling.

Some gate control algorithms seem to be more focused on tuning a gate. Other algorithms seem to be more focused on tuning the gate to perform in a canal. When the effects of a gate downstream extend to an upstream gate, it is especially important that the algorithm tunes the gate to perform in a canal as well as being customized for individual gate characteristics. This is one of the benefits of using canal modeling to calibrate the gate algorithm. Our canal is set up so that the effect of a downstream gate reaches the next gate upstream. Without this ability, our canal water surfaces would fall to unacceptable levels. If the canal modeling had not been done as part of the modernization project and if we had not had the financial resources to prepare the canal model, we are not certain we would have come to the same conclusion.

The PIF algorithm we are using is able to respond to drastic flow changes. To get a feel for the resilience of the PIF algorithm, we decided to run a test. Late one irrigation season, when there was not much demand, we manually closed both of the radial gates on the most upstream check structures. Then we turned on the logging function for all of the downstream checks (all of which were operating on upstream control). When the pool above the upstream check got as high as we dared, we completely opened both 12-foot radial gates sending a wave downstream. The log files from the next downstream check indicated that the water level never deviated more 0.1 feet. By the time the wave got to subsequent check structures the deviation was even less.

These are not the only two gate control algorithms. Most integrators have one or two they have used with purported success. AquaSystems 2000, a gate manufacturer, has at least two different algorithms for their gates. They tune their algorithm based upon site conditions and expected flow changes.

It appears to us that that as the flexibility of the canal to respond to large flow rate or target depth changes increases, it becomes more important to model the canal system. Said another way, if you move the gates slow enough or if you make small changes in flow, you might not need to model the canal. It should be noted that most existing automation system actually operate with minimal flow rate changes, so we are not convinced that those non-modeled systems are capable of responding to dynamic sudden changes.

## DATA ACQUISITION

### Water Level Sensors

This area of SCADA does not seem as contentious as the control and algorithm issues. Not all hardware for data acquisition is equal. On our SCADA system we needed to measure two different physical parameters: gate position and water level. There are several ways to measure each one of these parameters. If you ask a handful of water districts and a handful of integrators, you would probably end up with two handfuls of options. Our decision on water level measurement was largely influenced by the independent testing performed by the ITRC. Based upon their findings we measured water level using pressure transducers. Our goal is to measure the water level to within the nearest 0.01 feet, which has been possible using the pressure transducers having the proper depth range.

### Gate Position Sensors

As we mentioned before, part of the modernization project included the construction of 7 new check structures. The specifications required the gate manufacturer to provide a gate position sensor. The optical encoder used by the manufacturer has proven to be one of the best pieces of equipment we have seen for gate position. Gate position is calibrated based upon gate shaft rotation. With the optical encoder we are using we are able to calculate the gate position well within the required 0.01 feet.

### Redundancy

The ITRC strongly encourages SCADA systems to include redundancy whenever possible. With the cost of sensors at about \$500 to \$650 we were a bit hesitant to take this step. Our belief was that if you get good quality equipment and have spare parts on the shelf, redundant sensors should not be required and we did not want to “gold plate” the project. In the end, the ITRC convinced us to install redundant sensors. As a result we have two upstream water level sensors, two downstream water level sensors and two gate position sensors on each gate. For the new sites this was eight sensors. We are now on our 4<sup>th</sup> year of operation and the redundant sensors have really paid off. Even with lightning protection hardware, we have had two sensors fail due to nearby lightning strikes. Two other failures occurred when wires in a conduit broke. We think the wire broke due to freezing water in the conduit. Every time the redundant sensors continued to work.

## SCADA INSTALLATION

There are several approaches to installing a SCADA system. For us, we were not only concerned about how to get the SCADA system installed, but we were also concerned about how we were going to maintain the system.

### **SCADA by Bid**

If you plan on asking for bids for a SCADA system, some form of specifications will be required. If you have never done a SCADA system before we think it would be very difficult to prepare a set of specifications to build a turnkey SCADA system. It does not seem possible to anticipate all of the field conditions that will be encountered. For example, sometimes the limit switches on our new radial gates did not work. We also found out that the gate manufacturer wired the gate position sensors backwards.

Without good specifications an integrator has a few choices: 1) bid the job and have a high allowance for unforeseen conditions, 2) bid the job as presented and correct for unforeseen conditions through changes orders, or 3) alert you to the shortcomings of the specifications and resolve the issues before bidding. If an integrator chooses option 1, and since you may not have a good grasp of what goes behind putting a SCADA system together, you will be shocked at the bid price. You will then either think that it is not worth the price or go back and work on understanding SCADA more thoroughly. If an integrator chooses option 2, you will be frustrated by the “nit-picking” changes and additional costs the integrator wants and may end up at odds with each other. Although option 3 may be the best of the 3 options, it is difficult for an integrator. What you essentially would be asking the integrator to do is correct your specifications when the company submits the bid. If your end result was to then re-bid the project, it would be necessary to compensate the integrator for this assistance.

Turnkey SCADA is a lot like building that house - the more you understand the options, processes, and what the end result should look like, the easier it will be to define what you want. For example, you tell a contractor to build a house. You turn the key to get into the house and find that it has no water heater, heating or maybe even no windows. That may sound silly but it sounds silly because everyone knows that all houses have those components. So after your first turnkey house you know to tell the contractor to include windows, a water heater, and heating and air conditioning systems. Only this time, when you turn the key you realize that you forgot the wood trim, carpet and painting. We think the point is clear - we do not think it is possible to specify a “turnkey” SCADA system unless you have a fairly good understanding of what goes into one. And, since all canals are a little different, it will still be a “custom turnkey.”

### **SCADA by Time and Materials**

Another option would be to solicit for integrators based upon their qualifications and experience. Once you have an integrator you are comfortable with, install the system on a time and materials basis. This takes out the risk part of the bidding process for the integrator which can translate to having the project cost what it needs to. There has to be a fair amount of trust and good communication to make this work, but it is worth considering.

### **SCADA by Example**

In our case, there are not any SCADA integrators in the Grand Junction area who have done canal systems. There are a lot of gas and oil field integrators but none with canal experience. In the end we wanted to be more self-sufficient so we opted for a hybrid model. We selected an integrator from out of the area that has a background in canal automation. We then asked that integrator to provide us a bid to build two SCADA boxes, do the necessary programming, develop the operator panel software and then install one of the SCADA boxes at one of our sites, and then make that site fully functional.

After that project was done we paid the integrator on a time and materials basis. Using the second of the two original boxes, we made the remainder of the SCADA boxes. Don't misunderstand me, there was a lot of hand holding at first. But as we built and installed subsequent SCADA boxes, our understanding grew as well as our comfort level. For us, that was one of our objectives – we wanted to be personally involved in a “hands-on” manner.

As a result of that effort we can now make modifications to our system and incorporate new sites. When we get into areas where we are unsure about the correct way to do something, we ask an integrator.

### **OTHER LESSON LEARNED**

#### **Radio Challenges**

During the discussion of supervisory control we mentioned the possibility of losing communication. Communication in our SCADA system is accomplished through a licensed radio system. There are many manufacturers of radios that will work in SCADA systems. Some have a more proven track record than others and some seem willing to tell you anything to sell you a radio. After talking to several SCADA integrators, the ITRC, and our local radio experts, we purchased a Microwave Data Systems (MDS) radios. We chose a frequency that we felt would do the best job due to the terrain and distances on our project. Due to our terrain we needed a repeater station. We contracted through a local company that specializes in repeater sites. Since its repeater site was located on a 10,000 ft mountain peak, about 5,000 feet above our valley floor, lightening is a known problem. Consequently, we took all the precautions we could for lightening protection.

When we first started the system up we were getting interference from a nearby frequency. The radio company installed a filter on the antenna that allowed our radio to see only our frequency. At that point our radios were working nearly flawlessly.

This operation continued for over a year and then in the first week of May 2004, we started losing the ability to talk to our sites as well as get status information from the sites. We initially thought we were trying to get too much information too frequently from our sites, so we spent some time making adjustments to our

software. After this things seemed to be better but not fixed. The next step was to examine some of the radios’ settings which controlled how long the radios would wait for a response before timing out. This seemed like it helped a little but we were still having problems. We then tried upgrading the radio software. They called it the radios’ firmware. Again, the problem did not go away.

It seemed like something was interfering with our system. Our radio experts were fairly sure we were trying to get too much information through the system, thus causing us to interfere with ourselves. This search lasted most of the summer and we never did find the problem. At the end of our irrigation season we turned all of our radios off. With the remote radios off, we were still receiving information at the master station. At this point we knew the interference was coming from another radio system, only we had no idea where.

Our radio license was granted by the Federal Communication Commission (FCC). Supposedly, when they issue a license they will not issue the same frequency within 75 miles. The FCC has a comprehensive web site on which it is possible to check for all licenses within a defined radius. So we asked their system to list anyone who had a license on our frequency within 200 miles of our repeater site. There were 7. We went through the list one by one and mostly for terrain reasons were able to eliminate all but one, Chevron Oil. They have a repeater site 78 miles from our site on the same frequency. With all of our radios off, our radio company went up to the repeater site and was able to listen to the Chevron sites on a hand held radio.

What is even more amazing about this problem is that our radios are MDS model 4710A. They will only talk to other MDS 4710A radios. So not only did Chevron end up on the same frequency, they ended up with the same radios. Chevron tried turning down the power output of their radios but we were still getting interference. The final solution is that Chevron is in the process of getting a new license on a new frequency.

The point I would like to make is that the entire time we were experiencing these problems, since control occurs at each site, the sites continued to run. We were able to communicate often enough to change the water levels if required so the system was still functional.

### **Programming Challenges**

Page 2 of the March 2003 Irrigation Training and Research Center’s SCADA Short Course training manual has the following list of SCADA components: sensors, actuators, the PLC/RTU, communication link and a Master Station. While this is a good list of the hardware required for a SCADA system, it does not include what we found to be the most challenging, the software. In our system we currently have at least 3 different software applications. The program in the PLC/RTU, the operator panel at the site used to interface with the PLC/RTU, and the interface at the Master Station. Of these software applications, the PLC/RTU program was the most challenging.

There are different programming languages that can be used for the PLC program. Some tie you to specific hardware more than others and some may be easier for you to understand. The language we initially used for our SCADA system is an excellent tool for the application but we found it difficult to understand. In addition, the language only worked in the PLC/RTU of one manufacturer. We wanted to understand the PLC program and we wanted to not be tied to specific hardware. So we changed the programming language during our SCADA development. Fortunately, our PLC/RTU did support the alternative programming language.

Some of the programming languages actually look like flow charts. Consequently, they are easier for non-technical people to understand. If you want to be able to be involved at this level, it is worth discussing this aspect during your SCADA development process. We have gotten involved to the point that we do a large portion of the programming (but not the development of the algorithm itself). At the very least, we recommend that you choose a PLC that can be programmed in a non-proprietary language.

### IN SUMMARY

The concept “turnkey” implies that you don’t need to worry about attention to detail, persistence, and cooperation. Alarms should go off if someone says that they will create a turnkey system when they have not taken the time to understand your irrigation system. The reality of the situation is that if you want the system to work well, you have no choice but to get involved at least to some degree. The SCADA implementation process takes persistence and cooperation. There may be minor hurdles along the way but everyone should look at them as learning opportunities. Team work with an identified team coordinator is essential. There are a lot of details that when they work together correctly, create a well working SCADA system. Don’t leave them to chance.

During the drought in the 2002 and 2003 irrigation seasons the canal modernization and SCADA system have proven to be invaluable. The SCADA system and canal improvements have allowed GVVUA to operate the canal during this period of drought and still meet the demands of water users. Without these improvements, all upstream storage would have been depleted. This did not only benefit the Grand Valley Project but all water users throughout Colorado.

To us the success of the system revolved around team work, education, and being willing to get involved with every step of the process, and doing as much of the work as we can. The “Myth” of turnkey SCADA is largely due to the fact that no two canals are the same. Some will have different algorithms, some will have to deal with winter operations, some will have large flow changes and some may be nearly steady state. Maybe you could make a McDonalds turnkey, but you would have a hard time getting them to turn an existing restaurant into a McDonalds.