GIS-Based Irrigation District Flow Routing/Scheduling

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ABSTRACT

In 2007, the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo undertook to develop a prototype of an intelligent and scalable real-time GIS-based water scheduling and routing software system for irrigation districts, capable of integrating multiple data sources into an information access and management facility featuring collaborative tools with automatic reasoning and analytical capabilities. Improving the infrastructure and management capabilities of irrigation districts in order to provide flexible delivery schedules and increase participation in peak demand reduction programs has been identified as having a significant potential to achieve energy conservation and resource efficiencies.

The results of this study highlight a number of important lessons that will be applied towards future modernization efforts in the state’s irrigation districts. These key lessons are outlined in this report, showing a significant progression in the conceptualization, organization, and execution of irrigation district-level DSS tools.

Keywords: California Energy Commission, energy, irrigation, agriculture, drip irrigation, microirrigation, geographic information systems, GIS, software

Please use the following citation for this report:

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EXECUTIVE SUMMARY

In 2007, the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo undertook to develop a prototype of an intelligent and scalable real-time GIS-based water scheduling and routing software system for irrigation districts, capable of integrating multiple data sources into an information access and management facility featuring collaborative tools with automatic reasoning and analytical capabilities.

This project was undertaken on behalf of the California Energy Commission (CEC) Public Interest Energy Research (PIER) Program with support provided by the California State University Agricultural Research Initiative (ARI). Improving the infrastructure and management capabilities of irrigation districts in order to provide flexible delivery schedules and increase participation in peak demand reduction programs has been identified as having a significant potential to achieve energy conservation and resource efficiencies.

Development of the Decision Support Systems (DSSs) covered in this final report was led by ITRC with cooperation from the Imperial Irrigation District (IID) where the DSSs were piloted in real-world conditions. A number of experts and consultants, primarily from Keller-Bliesner Engineering (Logan, UT) and Davids Engineering (Davis, CA), were extensively involved with the project, including complex programming across multiple software platforms. This project benefitted significantly from the fact that it was part of the design and planning for a major ($200 million) water conservation program in IID.

The results of this study highlight a number of important lessons that will be applied towards future modernization efforts in the state’s irrigation districts. These key lessons are outlined in this report, showing a significant progression in the conceptualization, organization, and execution of irrigation district-level DSS tools. As expected, the project was partly a mission of discovery – even though some of the individual components related to DSS for irrigation districts are already used in various places for various purposes, this was the first serious effort to integrate them into a workable package. It was also realized that some of the original ideas were either too difficult in practice to be realistic, or that they could be better accomplished by other means, which were only identified as a result of attempting such an effort.
CHAPTER 1: Introduction

The Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo was contracted through the Public Interest Energy Research (PIER) program of the California Energy Commission (CEC) to research the development and implementation of a GIS-based water scheduling and routing software system to aid California’s irrigation districts in achieving their water management objectives. Additional funding for this research was provided by the California State University Agricultural Research Initiative (ARI).

Research Problem

There is typically a large amount of “art” (non-transferrable logic) involved in the decision-making of the managers/supervisors and field operations staff at a typical irrigation district regarding the approval of water requests, and the proper timing of flow changes at various control points in the canal system to ensure that flow changes arrive at farmer turnouts when promised. The intricacies of the district’s operations are learned over many years by long-term staff members, who develop their own personal ways to manipulate water in the canal system. When those employees retire or leave, new employees usually need at least a year to learn how to properly operate canals. Furthermore, each new canal presents a new learning experience.

The research was proposed to evaluate the possibility of formalizing the experienced human decision-making process into a pragmatic software program to aid in the scheduling and routing of flows through canal irrigation distribution and delivery systems. It was recognized that there are complexities such as variable canal roughnesses, inaccuracies in flow measurement, unanticipated behavior of users, different types of canal structures that pass a flow change along the canal in different hydraulic manners, capacity limitations, etc. The conditions also change depending on the time of year.

Most irrigation districts are investing in GIS mapping of their distribution systems and combining their database systems to make information organization and analysis more efficient. GIS integrates spatial information about canal and pipeline infrastructure; facilities such as pumping plants and automated control gates; land use; customer accounts; time-series records; and other geographic data. GIS programs allow detailed characterization of a canal distribution system covering each node and segment (check structure and canal pool) in information (database) layers. However, there has been a technology gap in terms of enabling GIS-based databases to become fully coordinated with real-time decision-making within workflows for: (i) the scheduling deliveries of irrigation water (before the event), and (ii) dynamic, continuous adjustment and monitoring of various control structures and measurement facilities.
Project Goals

The objective of this project was to develop a prototype of GIS-based Decision Support System (DSS) software for scheduling and routing irrigation water in irrigation districts that would consider all information that is currently used by experienced personnel to:

- Receive water orders
- Decide if sufficient total flow is available in the system to provide the requested orders
- Decide if the canal system has sufficient capacity to convey the flow changes at the requested times
- Determine when the water can be delivered
- Create a “run sheet” that tells field operations staff when to make flow rate changes at different control points throughout the system.
- Transfer new setpoints directly to a SCADA system so that flow changes can be automatically made at the appropriate times.

Anticipated project benefits of the new software included:

- Conserved water – reduced operational spills
- Conserved energy – less recirculation pumping through better timing and control of the water
- Less reliance on “art” – less dependence on operators’ historical experience, and more focus on a computer-oriented, knowledge-based decision-making system
- Improved water delivery flexibility – better service provided to the customers

Final Products

There were two distinct DSS software programs developed through this project:

1. **Irrigation District Scheduling** – Water Coordinator DSS (WCDSS). The WCDSS is a platform to assist office staff that receive water orders from customers, approve those orders, and then schedule flows in the main canal system to reach various off-takes for delivery laterals and direct turnouts at the designated times.

2. **Irrigation District Routing** – Lateral Decision Support System (LDSS). The LDSS is a platform to assist field operations staff that make physical manipulations to numerous control structures, monitor conditions on a real-time basis, maintain water records, and interface with customers.
Project Organization

Project Team
The role of ITRC in this research project was to define the conceptual framework, identify collaborators, coordinate project management, and provide irrigation-related technical expertise. Throughout the process of software development, demonstration, and evaluation, ITRC worked with several key cooperators:

- Imperial Irrigation District (IID) – provided the test location for piloting the software
- Davids Engineering – provided core datasets and IT support as the lead agency in the Efficiency Conservation Definite Team
- Keller-Bliesner Engineering – provided software application development, computer programming, and assistance with field trial evaluations
- TruePoint Solutions – consulted to aid in database compatibility

Development Plan
The original work plan for this research project is depicted by the flow chart shown in Figure 1.
Several irrigation districts were initially identified as possible collaborators. As the project progressed, two of the three proposed districts (Modesto and Turlock Irrigation Districts) determined that it would be several years until completion of their planned SCADA system and modernization upgrades. Imperial Irrigation District (IID) was selected as the appropriate agency for cooperating with the development and testing of the DSS software because IID had the prerequisite IT and SCADA backbone systems, and the research fit well with their water transfer program.

The actual sequence of work tasks carried out during this study is summarized by the flow chart shown in Figure 2. Refer to the following sections for a project schedule and decision timeline.

Figure 2: Flow chart of research steps in the development of WCDSS and LDSS
Project Schedule and Decision Timeline

In order to review the tasks that were accomplished for this project, the project timeline in Table 1 covers the major milestones within the framework of ITRC’s initial conceptual brainstorming in 2003 through to the implementation in 2010 of various DSS components in IID’s Efficiency Conservation Definite Plan program. As is the case with most long-term projects as complex as this one, there was a significant amount of trial-and-error involved, meaning that numerous ideas were brainstormed and then tried out until the failed options could be eliminated.

Table 1: Project development and implementation timeline (2003-2010)

<table>
<thead>
<tr>
<th>Date</th>
<th>Project Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>ITRC begins initial development of the concept of water routing/scheduling software. The original concept involves integrating a routing/scheduling module into an industry standard GIS database.</td>
</tr>
<tr>
<td>2006</td>
<td>ITRC is part of the Definite Plan consultant team in Imperial Irrigation District (IID). ITRC has overall responsibility for developing strategic automation and modernization options for capturing canal spill and improving flexibility. The planning and demonstration efforts continue through 2009, eventually leading to the development of the System Conservation Plan (SCP), which incorporates various types of DSSs.</td>
</tr>
<tr>
<td>Jan 2006</td>
<td>ITRC holds discussions with computer modeling and water control experts from Holland on GIS-based DSS technologies for water management in irrigation districts.</td>
</tr>
<tr>
<td>Feb 2006</td>
<td>ITRC begins literature search for GIS-based water scheduling/routing projects and other DSS-related technologies that could have an impact on this project.</td>
</tr>
<tr>
<td>April 2006</td>
<td>ITRC reviews Colorado State University’s use of MODSIM (a network solver for canal modeling purposes).</td>
</tr>
<tr>
<td>Oct 2006</td>
<td>ITRC conducts testing of magnetic flow meters (including the SeaMetrics AG2000 magmeter) in severely turbulent flow conditions. This SCADA-compatible technology was being considered for installation at all customer turnouts in IID.</td>
</tr>
<tr>
<td>Nov 2006</td>
<td>ITRC investigates specific commercially-available GIS extensions that may be applicable to the project, with assistance from a Cal Poly GIS instructor and industry experts.</td>
</tr>
<tr>
<td>Feb 2007</td>
<td>ITRC submits project proposals to ARI and CEC (PIER) for development of GIS-based software for scheduling and routing irrigation water distribution systems.</td>
</tr>
</tbody>
</table>
| Spring 2007 | - ITRC brainstorms about software functional requirements and visual/diagram formats.  
- ITRC contacts various irrigation districts to obtain feedback on what type/format of information would best help them regarding scheduling/routing.  
- ITRC contacts Modesto ID and Imperial ID to determine the willingness of each one to participate, and assesses the potential application for a new DSS in conjunction with on-going modernization programs.  
- ITRC develops preliminary flow charts for information flow and decision-making logic. |
| May 2007 | The Definite Plan team releases the final report for the IID Efficiency Conservation Definite Plan. The recommended package of system conservation improvements and management enhancements is collectively referred to as “Integrated Information Management” (IIM). A recommended short-term action is to pilot test IIM at the scale of at least one zanjero run. |
| Aug 2007 | - ITRC continues to research software options, including ArcGIS extensions, and contacts GIS experts and database experts for feedback.  
- Initial contact with TruePoint representative about the feasibility of using their software as a basis for integrating scheduling/routing DSS components.  
- ITRC selects IID as the cooperating district due to synergies involved with their efforts in support of infrastructure improvements and management enhancements for a large water transfer program.  
- ITRC obtains permission from IID to utilize a lateral for testing and implementation of the scheduling/routing software.  
- ITRC creates a preliminary dataset to test anticipated program functionality using the family of ArcGIS programs and extensions.  
- ITRC studies building windows applications within the .NET framework.  
- ITRC re-evaluates the computational speed requirements of the proposed software in light of the high number of hydraulic and other types of calculations involved with each water request. |
Table 1: Project development and implementation timeline (2003-2010) - continued

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<thead>
<tr>
<th>Date</th>
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</thead>
</table>
| Sept 2007  | - ITRC reviews a similar on-going program in Texas; meetings with project manager to assess their efforts.  
- ITRC brainstorms about programming, rules, database structure, inputs/outputs, etc.  
- ITRC compiles list of software options available with a detailed review of each option.  
- ITRC researches SQL server performance tuning.  
- IID implements TruePoint Solutions software for water ordering management, water billing, etc.  
- At the instruction of IID, the Definite Plan Team adds a new component to the IIM program to upgrade the existing SCADA system, including delivery scheduling and routing software.  
- CEC and ITRC decide to continue in project in order to document efforts and the lessons learned.  
- The Definite Plan Team decides to utilize TruePoint’s database as a foundation for the DSS programs.  
- A survey is carried out among IID division coordinators to define their priorities for making carryover decisions based on various times of the year.  
- Brainstorming meeting at Davis with all consultants involved with IIM.  
- Delivery and spill records are analyzed from a variety of canals in IID in order to select a canal for the pilot demonstration of various planned DSS software packages.  
- IID suggests several laterals within the Orchid Run for the test location. |
| Mar 2008   | - IID implements TruePoint Solutions software for water ordering management, water billing, etc.  
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- CEC and ITRC decide to continue in project in order to document efforts and the lessons learned.  
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- Delivery and spill records are analyzed from a variety of canals in IID in order to select a canal for the pilot demonstration of various planned DSS software packages.  
- IID suggests several laterals within the Orchid Run for the test location. |
| Apr 2008   | - IID and Davids Engineering ride with zanjeros to learn about operational rules/procedures.  
- The Orchid and Holt zanjero runs are selected for testing of improved lateral operation.  
- The Orange Lateral is selected for delivery gate (turnout) automation and improved measurement.  
- ITRC begins field testing various options for laptops, SCADA HMI software, etc. |
| May 2008   | - Links refined between TruePoint database and proposed scheduling/routing databases.  
- Data requested from IID in order to begin testing/programming.  
- TruePoint hired as programming consultants to help with database compatibility (between their existing database and our proposed project).  
- ITRC proposes “Human SCADA”. Zanjeros would function as the information collectors/updaters to provide current real-time information on gate position changes, etc. This would save money but would rely heavily on accurate timely information from zanjeros.  
- Keller-Bliesner Engineering creates an initial version of a flow chart for WCDSS software and the water ordering/scheduling process.  
- Major Decision: the project is formally organized into two distinct DSS components:  
  - LDSS software – to be used by field operations staff  
  - WCDSS software – to be used by office staff |
| June 2008  | - ITRC personnel ride along with zanjeros in the Orchid run.  
- Final versions of flow chart of WCDSS software and water ordering/scheduling process decided on by Definite Plan Team.  
- Remote internet options researched.  
- Literature search for other channel automation projects performed.  
- Installation of the SCADA hardware for the pilot automated turnouts starts in the Orange Lateral.  
- ITRC personnel spend time with Water Coordinators to ascertain how water orders are received and processed in the office.  
- Keller-Bliesner Engineering starts formal programming of WCDSS software.  
- Keller-Bliesner Engineering and Davids Engineering visit water coordinators to discuss WCDSS work in progress and observe/document the current process used in determining carryovers. |
| Aug 2008   | - ITRC begins research to solve data entry issues for water orders.  
- Cal Poly Computer Science student hired to work on the optimization problem for WCDSS decision making.  
- ITRC organizes information on wave travel time for LDSS software.  
- ITRC develops several prototype ClearSCADA screens for LDSS software.  
- ITRC obtains tablet PC and Active Ink software for testing.  
- Active Ink hired to customize water ordering form.  
- IID Water SCADA Dept. begins work on creating LDSS ClearSCADA screen and programming logic.  
- Phase 1 of the evaluation of the Orange Lateral pilot is carried out.  
- Keller-Bliesner Engineering pilots the draft version of the WCDSS software with the IID office staff at Division offices. |
| Sep 2008   | - Keller-Bliesner Engineering pilots the draft version of the WCDSS software with the IID office staff at Division offices.  
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| Dec 2008   | - Keller-Bliesner Engineering pilots the draft version of the WCDSS software with the IID office staff at Division offices.  
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| Feb 2009   | - Keller-Bliesner Engineering pilots the draft version of the WCDSS software with the IID office staff at Division offices.  
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<tbody>
<tr>
<td>Oct 2009</td>
<td>IID suspends implementation of the WCDSS based on negative feedback from Water Coordinators.</td>
</tr>
<tr>
<td>Nov 2009</td>
<td>ITRC hosts a SCADA tour for IID water managers to visit irrigation districts in the San Joaquin Valley to learn about different approaches to automation, using various DSS tools, and implementing SCADA.</td>
</tr>
<tr>
<td>Dec 2009</td>
<td>The Definite Plan finishes the System Conservation Plan. The series of final reports include: conceptual engineering designs for $215 million of infrastructure improvements; a district-level operations plan; SCADA system specifications; specifications for turnout flow measurement devices; and a development plan for the Water Operations DSS.</td>
</tr>
<tr>
<td>Spring 2010</td>
<td>The LDSS components continue to be incrementally improved and used for operation of the Orange Lateral.</td>
</tr>
<tr>
<td>July 2010</td>
<td>Keller-Bliesner Engineering begins to pilot test the Water Operations DSS for the main canal system.</td>
</tr>
<tr>
<td>Sept 2010</td>
<td>ITRC prepares this final report for CEC/ARI.</td>
</tr>
</tbody>
</table>

Several points can be made from the project timeline outlined in Table 1 above including:

- ITRC had been brainstorming and investigating the concepts of a DSS package for irrigation districts for several years before this project started.
- A rough estimate is that there were at least 100 working meetings held since 2007.
- The development of the DSS software components involved a multi-disciplinary team of engineers and scientists with expertise in irrigation districts, advanced automation technologies, database programming, GIS, operation of canal systems, and mathematical optimization, as well as numerous staff of a large irrigation district.
- It took over a year of active brainstorming to define the desired functionality and performance requirements of the proposed DSS software.
- Field evaluations of the piloted LDSS were conducted for over a year.
- The development of the package of DSS tools proceeded in tandem with the design and planning of infrastructure projects that involve a large amount of SCADA and automation.
- The formulation of the DSS software components benefitted from the extensive interaction with field operations staff, who helped greatly to tailor the usability of the tools.
- Despite a long-planning effort and extensive consultation with IID staff during the development of the WCDSS, it only took several weeks of an unsuccessful trial by the Water Coordinators for the district to indefinitely suspend use of the program.
- Even though the core of the DSS effort was a software-centered exercise, the actual work tasks were heavily based around hardware components (turnout gates, laptops, flow measurement, canal hydraulics, etc.).
CHAPTER 2: Water Coordinator Decision Support System

Purpose and Background

ITRC initially envisioned DSS software tools that would assist irrigation districts with two basic tasks: (1) scheduling water orders in the office based on requests from customers, and (2) routing irrigation water through a complex network of canals, reservoirs, recirculation pumping plants, etc. This chapter covers the first task – irrigation district scheduling – and how that led to the development and testing of the Water Coordinator DSS (WCDSS) at IID.

Water Coordinators in the Division offices are the primary people responsible for interacting with IID’s customers who call the office to place an order for water or to make changes to an order that has already been placed. The main decisions that the Water Coordinators must make are which water orders to fill, and which to carry over (a “carryover” is a water order that could not be delivered on the requested date due to unavailable capacity in the system, water supply shortages, or other reasons).

If there were enough water and enough capacity to fill every order, then there would be no decision to make. Unfortunately, this is rarely the case. The majority of the time, the Water Coordinator must rely on his/her experience and personal interpretation of a set of standard criteria to make these decisions. For example, the type of crop being irrigated is one criterion that is considered by the Water Coordinators – certain crops such as vegetables get a higher priority because they are more sensitive to stress if the timing of irrigation is delayed. Some of the carryover variables to be considered when scheduling water orders include:

- Capacity constraints (related to time of year)
- Basic information
  - Number of days of delivery requested
  - Has it already been carried over?
  - Crop type
- Shifting on/off sequence for achieving a semi-rough hydraulic balance (is someone turning off at approximately the same time someone else wants to turn on?)
- Number of days that each farmer has been carried over this year

When these variables have to be manually analyzed for each individual water order, considering the vast number of delivery gates and customer accounts in IID, the decision-making process is cumbersome and prone to uneven execution. None of the water ordering decisions could be made instantaneously because Water Coordinators only have enough time when speaking with the customer to jot down information about the order and then answer the next telephone request. Therefore, the district has to use a batch ordering process, meaning that

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1 There are approximately 30 Water Coordinators for all of IID’s Division offices.
2 There are approximately 5,000 customer water accounts in IID.
the distribution of carryovers has had to be analyzed manually after a designated period in the morning.

In addition, even though the district has invested heavily in various IT and SCADA technologies over the years, many of the steps in the water ordering process, before this project, were done manually, and almost all the information between IID staff in different offices was shared via telephone.

During the duration of this study, IID was relying on several different practices:

- The Division offices already had access to real-time and historical data from the district’s extensive SCADA system and other core databases such as the Water Information System (WIS)
- In 2008, IID purchased and implemented the TruePoint Solutions package of water ordering and billing software. IID began using TruePoint as its central database software platform for water scheduling in March 2008 as part of an effort to streamline water ordering and billing. However, TruePoint software does not include any explicit functionality for handling carryovers.
- Even after the implementation of TruePoint, office staff still had to manually check canal capacities and compare them to requests for water in different amounts and at different times, and then manually rank each water order relative to a number of other criteria.

The objective of the WCDSS, therefore, was to create a new software tool that could be tightly integrated with TruePoint in order provide specific information related to carryovers. The purposes of the new DSS tool were defined as:

1. Provide a list of “approved” water orders
2. Provide a list of carryover water orders

Thus, while water orders would continue to be entered into TruePoint, the new DSS tool would be a stand-alone software package that would compare the quantity (CFS) and timing of the water order with three (3) different sets of parameters that reside in different places within the greater IT system(s) at the district:

1. Design canal capacity
2. Current flows in the system
3. Carryover rules

This is especially challenging because actual water deliveries (as opposed to orders) do not usually follow the pre-programmed schedule for a variety of reasons. Changes are being made continually, 24 hours a day. This means that the actual flow rates in various canal pools at the time of allocation decisions may not be what the people in the office think they are. Because of this, the Water Coordinators had the authority to intervene and give final approval to the scheduled line-up of orders.

With WCDSS, Water Coordinators can do the following:

- Select rules for making decisions about carryovers
• Over-ride suggested water schedule line-ups, if necessary
• View canal capacities (based on roughness at different times of year and channel dimensions)
• View a GIS model of the district/lateral
• Automatically update the TruePoint database so that an order sheet can be printed for the zanjeros

ITRC was closely involved with formulating the decisions and rules that were used to develop the WCDSS software. Keller-Bliesner Engineering was responsible for programming this software package. The *WCDSS Software Documentation and User’s Manual* is provided in Appendix A.

**Integration with TruePoint Software**

Given the sophisticated nature of IID’s existing IT system(s) and database structure(s), in addition to the advanced database that resides within the TruePoint software, the integration of the WCDSS tools had to be carefully tailored considering factors such as the very large number of discrete data points, multiple users who are distributed among offices in different locations, the required computational speed, security, and networking topology (refer to Figure 3).

***Figure 3: IID Water Management System showing inter-connections of TruePoint software***
The operational flow chart of the WCDSS integrated within IID’s IT database systems is shown in Figure 4.

Figure 4: WCDSS flow chart (Keller-Bliesner Engineering)
The TruePoint software accepts daily water orders and assigns them by geographic location. The program contains a GIS map that keeps track of which turnouts are located upstream and downstream; where laterals connect with each other or a main supply canal, etc., so that the new water order information can be combined with the existing delivery information and positioned within a GIS network representing the entire water distribution system.

About 20 irrigation districts in California have implemented various components of the TruePoint software package as of the time of this report. However, the TruePoint software is a standardized program and is not customized for applications at each irrigation district. This means that in the case of IID, even though the Water Coordinators had the ability to enter water orders into the system with a date/time scheduled in the future, they still had to follow the same manual process for determining which orders were to be carried over.

**Operation of the WCDSS**

WCDSS is a stand-alone Microsoft Windows® application based on .NET Framework technology. The WCDSS is installed on a user’s workstation (office desktop computer), and accesses external data sources such as the TruePoint database via SQL Server and SQL Server Express. The process of retrieving water order information from TruePoint and bringing it into the WCDSS environment is called “transactional replication.” These SQL tools and other networking tools provide a seamless mechanism for synchronizing water ordering information back and forth between the TruePoint database and WCDSS.

Water Coordinators still enter water orders into TruePoint. This information is stored within TruePoint’s internal database (SQL compliant). When a WCDSS session is initiated by a Water Coordinator, the WCDSS software automatically retrieves the current water orders and temporarily saves a copy in a local database running on the WCDSS work station. In addition, through the SQL Server Express application, the current water orders are updated when changes are made in TruePoint, including new water orders. Depending on the number of records retrieved and the connection speed, this replication process can take several minutes.

The main user interface is shown in Figure 5 on the following page. Once the user is in the “Water Order” tab (on the Ribbon Bar), he/she can select the appropriate Division and Area from the drop-down menus. The corresponding zanjero runs are displayed in a hierarchical tree. For the complete canal hierarchy tree, updated information is displayed for the following:

- **Allotted** – the total flow rate (cfs) allotted to the selected area
- **Demand** – the total flow rate (cfs) demand for the selected area
- **Variance** – the difference between the allotted flow rate and the demand flow rate

If the Variance is a negative number – the demand exceeds the allotted amount of water – the basic objective is to carry over enough water orders to bring the variance close to zero. Because the WCDSS automatically calculates an estimated flow at each of the delivery gates with a running order, the system is able to flag water orders that would exceed the canal capacity with the current line-up. These water orders are highlighted in yellow in the Orders Grid.
To carry over a new water order, the user toggles the check box in the CO column in the Orders Grid next to each water order in the line-up. Once the user has checked for canal capacity violations and determined which new water orders are to be carried over (by bringing the variance close to zero), he/she clicks the Update TP button and this selection is updated in the TruePoint database.

Additional information to aid the user in making this selection of carryovers includes:

- Running orders
- New orders
- Carryovers
- Order count
- Crop type

There is also a built-in simplified GIS component that can be accessed by clicking the Show GIS button. A high-resolution map is displayed in a new window and current information about each water order is displayed along with the locations of all the delivery gates in the canal network (refer to Figure 6). Information is also shown in the GIS for estimated canal flow rate and the design channel capacity.
Computerized Data Entry of Water Orders

A separate issue was identified by observing how Water Coordinators manually take down water order information during telephone calls with customers. As is typical of many large irrigation districts, there is a short time-window of a few hours when many people try to call to quickly place a new water order (or cancel an existing one), which means that district staff only have the time necessary to quickly jot down the information and then batch process all the water orders later.

As part of the WCDSS effort, this project conducted an extensive evaluation of tablet PC technology and handwriting recognition software programs in an attempt to create a digital water order form to streamline the office processing of water orders. The effort did not succeed. The best commercially available software tools were not able to provide the required speed and accuracy required for this process. Because the combined hardware and software tools were not robust enough, the approach was not incorporated into the pilot of the WCDSS. Refer to Appendix B for a detailed discussion of this part of the investigation.
CHAPTER 3: Lateral Decision Support System

Purpose and Background

The basic purpose of developing Irrigation District Routing software was to assist field operations staff with determining the timing and amount of flow changes at various control points in a canal system. In other words, once a schedule of water deliveries is established through a water ordering process, operators still have a major challenge in figuring out what specific control structures need to be adjusted in order to meet the corresponding demands. As operators gain more and more experience as a result of dealing with this on a daily basis, more and more of that experience becomes part of the “art” used to operate the system.

The hydraulics of a large canal network and accounting of flows are so complex that these experienced people can only provide deliveries in an inflexible manner; any more flexibility is too difficult to deal with. The existing infrastructure of many irrigation districts is part of the problem, but this lack of water delivery flexibility created by the limitations of the operators is a serious impediment to how effectively and efficiently growers can utilize the state’s resources for agricultural irrigation. Thus, at the practical level of irrigation district operations, improving efficiency is a matter of being able to determine how to route a flow change efficiently through the canal network so that it arrives at the desired point at the correct time.

As explained in the Project Timeline section of this report, the routing software program was formulated in tandem with the System Conservation Plan (SCP) at IID. This provided an excellent opportunity for the research team to not only utilize real-world information within existing IT systems, but also to pilot the DSS software in actual field conditions and thoroughly evaluate the results.

Initially, the proposed concept of a routing software program to be applied at IID was quite wide-ranging, with several different stages of planned/possible implementation including:

**Level 1 – Enhanced SCADA Data for Field Operations Staff**

- Data available
  - Heading, spill and delivery (cfs)
  - Lateral head at each gate
  - Allowable lateral head
- Computed values
  - Lateral pool elevation change and timing to thresholds

**Level 2 – SCADA + Revised Operating Rules**

- Management of operating ponds for storage
- Guidance on check settings
- Timing of gate opening and closing
- Using indicator checks for spill

---

3 The specifics of the water ordering and scheduling processes used by irrigation districts in California vary considerably. Regardless of whether or not a DSS is available for the ordering/scheduling component, the routing component is a separate and distinct function.
Level 3 – DSS component to manage pool storage

- Screen reminder to improve pool management
- Accesses TrueCanal, SCADA, GIS, etc. for additional non-SCADA information
- Pop-up module overlaying basic SCADA screen

Level 4 – DSS component to support early shutoff

- Module 1 – zanjero enters gate, change in flow, intermediate re-heading (undershot upstream check). Output provides lag-time from heading to re-heading (if used) and re-heading to gate
- Module 2 – Recommendations for heading changes and check changes to best meet orders and reduce spill
- Stand-alone modules that pop up over SCADA and access SCADA, TrueCanal, GIS database, etc.

The DSS for zanjeros was supposed to tell them when and by how much to adjust flows at the headings of laterals in their zone of responsibility so that when a zanjero arrived at the delivery gate to fulfill a scheduled water order, the flow change would have just arrived. In order to accomplish this, the DSS would need to figure out the hydraulics of each the laterals, such as the travel times between delivery gates and operating flow capacities. Knowing that the travel time would depend on the configuration of the check structures (whether it was overpour or undershot or a combination), achieving complete understanding of the lateral’s actual hydraulics became an important area of concern.

Implicit in the concept of a DSS for field staff is the requirement that the operator have the ability in real-time to control flows in his/her area of responsibility. Given the size and extent of zanjero runs (their designated zone of responsibility), this basically meant that SCADA and automation were essential components for the LDSS in IID. Specifically, there are three key places where the zanjero needed to have real-time monitoring of conditions and/or the ability to remotely make adjustments to automated structures:

1. At the headgate(s) of the canal
2. At the delivery gate(s)
3. At the spill(s)

Thus, in order to pilot the LDSS and use it operationally, installing an advanced SCADA and automation system was a prerequisite, as described in the following section.

In the spring of 2008, ITRC began doing extensive ride-alongs in IID with zanjeros in order to:

- Learn about the specifics of their routine practices, infrastructure/management constraints, daily hassles, etc.
- Identify suitable areas within IID to pilot the LDSS

Once the pilot area had been determined – the Orange Lateral – and the appropriate SCADA system installed, including several dozen trials of automated delivery gates, the LDSS was tested in the field for over a year. The results of the field trial led to adjustments in the concept of a workable DSS for field operations as described in the following sections.
SCADA

SCADA is a valuable tool with tremendous potential for enhancing water management in irrigation districts. Many irrigation districts have invested in SCADA as part of the major modernization programs that are underway throughout the state. SCADA systems are widely used for the measurement and control of water. The experience with the LDSS in IID pushed the SCADA frontier even further and demonstrated how smart SCADA technologies can be tailored to provide knowledge-driven tools for operators.

Prior to the development of the LDSS, there was already an existing SCADA system in IID that included several hundred field sites, as well as sophisticated communications and IT networks. Various types of canal and pump automation have been used successfully in IID for many years. As a result, there were core backbone systems in place upon which the SCADA upgrades for the pilot in the Orange Lateral could be built. For example, Table 2 shows the amount and types of information that is available from the SCADA system at spill sites.

Information from spill sites is important for three distinct reasons:

1. Real-time information is needed by the zanjero to help manage the lateral.
2. Spill volumes, and their trends, must be archived for purposes of:
   a. Verification of spill savings
   b. Management (division and district) decisions on where problems lie, and making recommendations for reducing spill
   c. Setting realistic targets for spill
3. Maintenance, repair, and evaluation of automatic structures by water control and maintenance staff.

The role of SCADA in terms of the required interaction with and support for the LDSS evolved through the development period. As mentioned previously, it was realized that in order for the software to provide meaningful guidance on the adjustments to water control structures, the hydraulics of a given lateral had to be worked on the level that the representative mathematical computations closely matched actual conditions in the field.

To evaluate the possibilities for estimating travel times in actual field conditions, ITRC collected data for several weeks by placing water level sensors in a few active laterals, specifically in canal pools where deliveries were being made. (Note: zanjeros will typically pull check structures completely out of the water unless a delivery is being made in that pool in order to minimize silt build-up and algae growth.) The conclusion drawn from this very important analysis was that it was not possible to predict any relationships regarding travel times, water levels, and deliveries.

The reasoning, however, was fairly straightforward. Zanjeros utilize pool storage to effectively control the movement and speed of water down their canals. In fact, this is a common strategy that almost all operators utilize in canal systems where check structures can be manipulated. For example, by moving a check structure gate down to temporarily hold water back (raising the water level in that particular pool), operators can delay when flows will arrive at a downstream location, which may be needed for a variety of reasons. Add in unauthorized flow changes that can and do also occur at any time, and it was impossible to completely figure out the complex hydraulics of a single lateral even with extensive datasets.
The next step in the process was the idea of using real-time data from the SCADA system, which is GIS-based, about delivery flow rates and times, combined with pool levels in order to predict changes. There were various ideas of looking at the rate of rise in a pool and figuring out when it would overtop. Included in this concept was the idea that each zanjero would have a portable, hardened laptop in his pickup connected to the SCADA system.

An extensive field trial was begun on the Orange Lateral in 2008, in which automated delivery gates were installed along the canal (refer to Figure 7) and connected to an upgraded IID SCADA system. The heading of the canal was automated and an electronic flow meter was installed to remotely monitor canal spill. The zanjeros had portable, hardened laptops installed in their pickups that were connected to the SCADA system.

<table>
<thead>
<tr>
<th>Type of Site</th>
<th>PLC Parameter</th>
<th>Units</th>
<th>Sig. Digits</th>
<th>Real-Time Alarms Generated by PLC</th>
<th>WIS (Archived?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Transducer on Weir</td>
<td>Battery Voltage</td>
<td>Volts</td>
<td>0.0</td>
<td>Low battery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>U/S water level in canal (sensor 1)</td>
<td>Feet</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Flow Rate</td>
<td>CFS</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>AF</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>PLC Time</td>
<td>Date, 00:00:00</td>
<td></td>
<td>Flat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLC Program</td>
<td></td>
<td></td>
<td>Intrusion Radio fail</td>
<td></td>
</tr>
<tr>
<td>Automated Gate</td>
<td>Battery Voltage</td>
<td>Volts</td>
<td>0.0</td>
<td>Low battery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>U/S water level in canal (sensor 1)</td>
<td>Feet</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>U/S water level in canal (sensor 2)</td>
<td>Feet</td>
<td>0.00</td>
<td>Sensor fail Low water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>D/S water level in canal (sensor 1)*</td>
<td>Feet</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>D/S water level in canal (sensor 2)*</td>
<td>Feet</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Gate position sensor (sensor 1)</td>
<td>Feet</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Gate position sensor (sensor 2)</td>
<td>Feet</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Target water level</td>
<td>Feet</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Flow Rate</td>
<td>CFS</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>AF</td>
<td>0.00</td>
<td>Sensor fail High water level</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>PLC Time</td>
<td>Date, 00:00:00</td>
<td></td>
<td>Flat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLC Program</td>
<td></td>
<td></td>
<td>Intrusion Radio fail</td>
<td></td>
</tr>
<tr>
<td>Electronic Flow Meter</td>
<td>Battery Voltage</td>
<td>Volts</td>
<td>0.0</td>
<td>Low battery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>U/S water level in canal (sensor 1)</td>
<td>Feet</td>
<td>0.00</td>
<td>Sensor fail</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Flow Rate</td>
<td>CFS</td>
<td>0.00</td>
<td>Sensor fail</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>AF</td>
<td>0.00</td>
<td>Sensor fail</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>PLC Time</td>
<td>Date, 00:00:00</td>
<td></td>
<td>Flat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLC Program</td>
<td></td>
<td></td>
<td>Flow meter fail</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Intrusion Radio fail</td>
<td></td>
</tr>
</tbody>
</table>

* only for spills sites with automated gates that do not always have free flow conditions
It was a major effort to get this LDSS pilot installed and operational. There were numerous technical issues that had to be addressed, including what specific hardware/software was suitable for:

- **Design of the automated delivery gates**
  - As part of this LDSS pilot, IID conducted an extensive field evaluation of about a dozen different gate designs from different manufacturers using various types and complexities of control logic.
  - There were many, many details related to the gate design and operation that had to be designed, specified, programmed, installed, calibrated, tested, evaluated, adjusted, etc. This was done at 26 delivery gates.

- **Communications link between the remote sites and the office**
  - High-speed data radios from different manufacturers were evaluated.
  - Since the field radios had to be incorporated into IID’s existing radio network, which actually consists of about four different radio systems (licensed, unlicensed, microwave, etc.), and then put onto a fiber-optics backbone, IID’s SCADA technicians had to create a new IP-based Ethernet radio network using a new protocol that was not being used elsewhere in the district (DNP)

- **Communications link between the office and the field laptops**
  - Several options were tested including mobile broadband cards (from Verizon) and a commercial wireless DSL service
  - Once the broadband card method was selected, there were still significant challenges providing them with reliable and secure internet access to the central SCADA server computers housed at the district’s headquarters
- **HMI**
  - IID made the determination, for other reasons in addition to this pilot, to upgrade to a new SCADA host software platform and incrementally switch all remote sites (existing and future) away from FactoryLink.
  - ClearSCADA (by Control Microsystems) was selected as the replacement HMI software, which meant that instead of adding the pilot SCADA sites to an existing, well-tested and developed HMI, the programmers at IID were starting basically from scratch.

- **Laptops**
  - The first decision was whether to use semi-rugged or normal laptops, which involved an analysis of cost vs. performance and durability.
  - Once the semi-rugged option was selected, several brands/models were evaluated (e.g., Panasonic ToughBook, Dell ATG, Itronix and others).

During the field trial, the information that the zanjeros would see via the SCADA system was finessed considerably based on their feedback. There was an initial tendency to want to add more and more information to the screens. However, ITRC quickly found out that zanjeros can get overloaded with information very easily.

### Operation of the LDSS

The LDSS tools fall into several categories:

1. **Real-time SCADA information.** For example, current water levels and flow rates are measured and reported at strategic locations along the laterals. Special HMI screens were developed for the zanjeros’ laptops. The zanjeros used these screens to:
   - View the present status of flows and water levels in their runs
   - Remotely change target flows at reservoirs and lateral headings

2. **Historical SCADA information.** The zanjeros have access, through their laptops, to historical trend screens of flows and water levels in their run. These screens are standard screens developed within the HMI that can be “called up” occasionally on demand by the zanjeros. These are also particularly useful for the zanjeros to settle disputes with irrigators that might be due to a low lateral water level, or to identify where and when water may have been inappropriately diverted.

3. **Notepad information.** Zanjeros are able to write notes on their laptops during their work hours. These notes are accessible as a historical record, but most importantly they are available to the zanjer on the next shift. A note may, for example, state that irrigator “A” on Turnout J15 will probably shut off early - at 3 a.m. rather than at 5 a.m.
An example of a final LDSS screen from ClearSCADA is shown in Figure 8.

Figure 8: Example LDSS screen for the Orchid Run in IID

The information available on the LDSS SCADA screen in the figure includes:

- Turnout flow rate – There is an alarm if the flow rate varies by more than some assigned amount from the target. The green color indicates a turnout is open.
- The spill flow rate
- The canal head flow rate
- Pool water level, with different colors to indicate if it is low, high, or OK

IID has plans to consider further modifications to the LDSS screens including:

- Color schemes and the fonts used for the captions and legends
- Adding links to the main screen so that zanjeros can easily navigate to other DSS tools, such as the updated run sheets in TruePoint
- Adding more detailed site location screens (e.g., clicking on a flow control site in the main screen takes the user to a new screen that allows a change to target)
- Adding special screens for in-line reservoirs and other facilities
- Rearranging the layout and number of laterals on a single main screen to improve readability on the laptops

In addition to the primary LDSS interface on the laptops running client versions of ClearSCADA, other tools organized and developed as part of this projects are summarized in Table 3. These DSS tools will be a fundamental part of the implementation of the SCP in IID over the next decade.
Table 3: Field operations decisions and associated DSS tools

<table>
<thead>
<tr>
<th>Decision</th>
<th>Causes for Decision or Explanation</th>
<th>Information Needed</th>
<th>DSS Tools Supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make a flow rate change at the head of the canal</td>
<td>Regularly scheduled delivery gate flow changes (on/off/change) on a lateral without reservoirs or interties</td>
<td>a. Run sheet from division with schedule</td>
<td>a. Improved run sheet from division</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. Knowledge of his physical travel time between canals and delivery gates</td>
<td>b. SCADA real-time status of all pool levels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. Wave travel times at that flow rate and roughness and distance</td>
<td>c. SCADA real-time status of spill</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. Status of various pool levels and storage</td>
<td>d. Improved control of lateral headgates from WCC, with SCADA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. Spill at that moment</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. Interaction between on/off locations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>g. Anticipated behavior by users</td>
<td></td>
</tr>
<tr>
<td>For a lateral reservoir used by one zanjero. No intertie.</td>
<td>How should the potential excess or deficit at the reservoir be considered?</td>
<td>a. AF storage in the reservoir</td>
<td>Appears on zanjero lateral SCADA screen, next to reservoir site</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. Flow rate (CFS) into or out of reservoir – based on rate of rise/fall of the water level</td>
<td></td>
</tr>
<tr>
<td>For a new intertie from an adjacent lateral</td>
<td></td>
<td>a. Flow rate from the intertie</td>
<td>Appears on zanjero lateral SCADA screen, next to the intertie site</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. Adequacy of demand or capacity below intertie (communication with downstream zanjero)</td>
<td></td>
</tr>
<tr>
<td>For an intertie with a reservoir. Exactly who uses this</td>
<td></td>
<td>a. AF storage in the reservoir</td>
<td>Appears on zanjero lateral SCADA screens for both zanjero runs, next to the reservoir site</td>
</tr>
<tr>
<td>information and how will be decided later, but the</td>
<td></td>
<td>b. Flow rate (CFS) into or out of reservoir – based on rate of rise/fall of the water level</td>
<td></td>
</tr>
<tr>
<td>information must be made available.</td>
<td></td>
<td>c. Flow rate measured through the intertie</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. Adequacy of demand below reservoir (communication with downstream zanjero)</td>
<td></td>
</tr>
<tr>
<td>Should a flow change at any automated flow control point</td>
<td>The SCADA system will have the capability to store pre-programmed flow schedules, which will be</td>
<td>a. Total orders downstream of that point now</td>
<td>The best display format will focus on zanjero acceptance. It may be too much</td>
</tr>
<tr>
<td>be pre-scheduled or modified?</td>
<td>automatically executed. Perhaps for 24 hours in advance.</td>
<td>b. Total orders downstream of that point at the time of the next scheduled change</td>
<td>information to display on the zanjero laptop, on the same screen that shows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. Current flow rate thru flow control device</td>
<td>current flows and water levels. May need a sheet that shows a diagram of the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. Target flow rate thru flow control device</td>
<td>system with current and scheduled flows at the flow control points</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. Next scheduled flow rate</td>
<td>(not including delivery gates).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. Time of next scheduled flow rate change</td>
<td></td>
</tr>
<tr>
<td>Intermediate pools filling or emptying more than</td>
<td></td>
<td>a. Real-time spill information</td>
<td></td>
</tr>
<tr>
<td>anticipated</td>
<td></td>
<td>b. Knowledge of impending order changes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. Estimate of irrigator behavior in the next few hours</td>
<td></td>
</tr>
<tr>
<td>Adjust check gates along a lateral</td>
<td>Desire to temporarily store or release water</td>
<td>Experience that this practice will minimize spill or provide quicker reaction to delivery gates.</td>
<td>SCADA status of spill and pool water levels</td>
</tr>
<tr>
<td>Water level is too high or low in a pool</td>
<td>Observation of water level or complaint</td>
<td>SCADA water levels</td>
<td></td>
</tr>
<tr>
<td>Need to set a check to start or stop a delivery in that</td>
<td>Regularly scheduled delivery</td>
<td>Run sheet from TruePoint</td>
<td></td>
</tr>
<tr>
<td>pool</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Record flows and times to delivery gates</td>
<td>Periodic, standard procedure during deliveries, at beginning, and end</td>
<td>a. Gate opening</td>
<td>SCADA historical data of delivery gate information</td>
</tr>
<tr>
<td>Resolve disputed delivery record</td>
<td>Farmer complains</td>
<td>b. Head difference</td>
<td></td>
</tr>
<tr>
<td>Utilize storage from a boundary-crossing reservoir</td>
<td>Hearsay or observations of actual gate positions and water levels</td>
<td>c. Times any changes were made to the gate position or water level</td>
<td>SCADA historical data of delivery gate information</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision</th>
<th>Causes for Decision or Explanation</th>
<th>Information Needed</th>
<th>DSS Tools Supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Should a flow change at any automated flow control point</td>
<td>The SCADA system will have the capability to store pre-programmed flow schedules, which will be</td>
<td>a. Total orders downstream of that point now</td>
<td>The best display format will focus on zanjero acceptance. It may be too much</td>
</tr>
<tr>
<td>be pre-scheduled or modified?</td>
<td>automatically executed. Perhaps for 24 hours in advance.</td>
<td>b. Total orders downstream of that point at the time of the next scheduled change</td>
<td>information to display on the zanjero laptop, on the same screen that shows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. Current flow rate thru flow control device</td>
<td>current flows and water levels. May need a sheet that shows a diagram of the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. Target flow rate thru flow control device</td>
<td>system with current and scheduled flows at the flow control points</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. Next scheduled flow rate</td>
<td>(not including delivery gates).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. Time of next scheduled flow rate change</td>
<td></td>
</tr>
<tr>
<td>Intermediate pools filling or emptying more than</td>
<td></td>
<td>a. Real-time spill information</td>
<td></td>
</tr>
<tr>
<td>anticipated</td>
<td></td>
<td>b. Knowledge of impending order changes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. Estimate of irrigator behavior in the next few hours</td>
<td></td>
</tr>
<tr>
<td>Adjust check gates along a lateral</td>
<td>Desire to temporarily store or release water</td>
<td>Experience that this practice will minimize spill or provide quicker reaction to delivery gates.</td>
<td>SCADA status of spill and pool water levels</td>
</tr>
<tr>
<td>Water level is too high or low in a pool</td>
<td>Observation of water level or complaint</td>
<td>SCADA water levels</td>
<td></td>
</tr>
<tr>
<td>Need to set a check to start or stop a delivery in that</td>
<td>Regularly scheduled delivery</td>
<td>Run sheet from TruePoint</td>
<td></td>
</tr>
<tr>
<td>pool</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Record flows and times to delivery gates</td>
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</tr>
</tbody>
</table>
CONCLUSIONS

This research project successfully developed two prototype irrigation district DSS software systems and put them to use in one the largest irrigation districts in California. This report has summarized the processes leading to their development and highlights important lessons for future efforts.

Lessons Learned

1. Complexity overwhelms operators. Only provide necessary information.

2. The complexity of the dynamic hydraulics cannot be adequately described for real-time use without excellent automatic water level control at all the check structures, automatic flow control at delivery gates (or very hydraulically insensitive deliveries), and SCADA data on actual field conditions that is automatically incorporated into the DSS on a real-time basis. Because IID did not have the first two conditions, the routing DSS could not be developed as originally envisioned.

3. A close examination of existing data management systems can indicate substantial efficiency improvement opportunities without complexity by just simplifying and/or automating some of the procedures (e.g., automatic adding and displaying of information that is now being done manually).

4. If the hardware does not work reliably and accurately, the software has no chance of success. This involves strict attention to detail, use of industrially hardened equipment (e.g., sensors, radios, laptops, etc.), good engineering and design, excellent maintenance, and an appropriate level of capital investment.

5. Real-time SCADA information, available on mobile laptops in the field, can be extremely helpful even without the addition of models and complex calculations.

6. The implementation of new DSS tools for operators and managers at irrigation districts needs to proceed in an incremental manner and the development process must have established opportunities for integrating feedback from users into the development process. This was illustrated by the experience with the WCDSS. The DSS software’s functionality closely adhered to the users’ original specifications, but by the time it was put into use, the users had already discovered other acceptable methods for achieving the same objectives.

7. There are limitations to what can be achieved with software in terms of improved operational efficiency. This project clearly demonstrated that a proper strategic approach for improving operations in an irrigation district has to balance the right mix of hardware and software. Software is no substitute for things like re-regulation reservoirs, flow measurement devices, canal interceptors, etc.

8. It is extremely difficult, if not impossible, to develop usable DSS software unless the underlying databases, communications protocols, etc. are based on open industry standards.
APPENDIX A:
User’s Manual (Sept. 2009)
Water Coordinator DSS
APPENDIX B: Data Entry with Tablet PCs

Figure B-1 shows a flow chart with the specific steps taken for the data entry phase of this project.

Figure B-1: Flow chart of data entry with tablet PC's product development

1. Decide to improve water order process for Water Coordinators
2. Observe water ordering procedures at IID
3. Brainstorm technology options
4. Purchase Lenovo Thinkpad and ActiveInk software
5. Develop ActiveInk water data entry form
6. Attempt to create required features using built-in development tools
7. Hire ActiveInk to provide custom software features that mimic the water order form
8. Extensive testing conducted at ITRC
9. Additional work to develop customized electronic handwriting tools
10. Inaccuracies in handwriting recognition and digital form functionality persist
11. Sub-project abandoned
The third link in the development of irrigation district scheduling and routing DSS tools was an attempt to streamline the data entry process for water orders. ITRC personnel observed the process of how water orders were received by IID Water Coordinators in the division offices. It was very apparent that there was huge room for improvement due to unnecessary duplication of work and the high probability of errors. The following is a brief outline of how the existing water ordering process works:

- A phone call comes in to the IID office for a water order for the next day or to cancel an earlier placed order (before noon)
- A phone operator quickly scribbles the order onto a paper form (or several forms depending on number of orders per customer) and puts it to the side with other forms
- Sometime before the end of the day when the Water Coordinator has some time available, the information gets entered into TruePoint software
- The Water Coordinator determines which orders to fill and which to carry over (and this information is entered into TruePoint)

In order to streamline this process, ITRC felt that an electronic data entry form that could be filled out with electronic handwriting would be a useful tool for Water Coordinators. The potential benefits of utilizing a digital water ordering form via tablet PCs include:

- **Reduction in the number of manual tasks** – By directly inputting the information into the tablet PC, one entire step of the water ordering process is eliminated (handwritten paper forms). Information input to the digital form would be instantly sent to a database linked to IID’s main TruePoint database, speeding up the transfer of information to the water coordinator. Additionally:
  - The tablet PC’s digital form would have the ability to show pull-down menus (“pick lists”), which further reduces the amount of handwriting/typing.
  - Every digital form could be automatically time stamped (again, reducing the amount of handwriting/typing required).

- **Reduction of errors** – These could include typing errors or misreading poor handwriting. With a tablet PC, data that was input into the digital water ordering form by the telephone operator could be immediately viewed in its final form. Therefore, the operator would have the opportunity to immediately verify the accuracy of the information.

Based on these potential benefits it seemed that a tablet PC would be a good solution. ITRC researched various tablet PC manufacturers and models, and eventually selected the Lenovo Thinkpad. ITRC used a software package called Active Ink that provided the platform for building a digital water ordering form. After purchasing the software, a form was created to closely match the paper one used by IID personnel (see Figure B-2).
The next step was to test the data entry function on the tablet PC. Unfortunately, ITRC ran into many problems with both the tablet PC and the Active Ink software. Several of the features that were envisioned were not standard tools in the software, which resulted in expensive customization of the Active Ink software. ITRC worked closely with the Active Ink representatives to get the features that were required. It proved to be expensive and imperfect. Some of the problems that were encountered with both the tablet PC and Active Ink software are listed below:

1. **Handwriting recognition**: Since the handwriting recognition software is relatively sensitive, frequent errors occur during the process of filling out the form. Refer to the example in Figure B-3 showing the software’s inaccuracy recognizing a phone number.
2. **Pull down menus (pick lists):** When a user clicks on a pull-down menu in the data entry form, a drop-down list should appear that would allow rapid data entry with no room for typing error. For some unknown reason(s), occasionally the drop-down menu would come up blank, and sometimes it would appear correctly (see Figure B-4).

![Figure B-4: Pick list error](image)

3. **Speed:** When ITRC attempted to input data as quickly as the office staff at IID do, the tablet PC had trouble keeping up.

4. **Time Stamp:** ITRC found that the time stamp was not such an easy task for the Active Ink program to display. This required an expensive add-on to get the time stamp inserted into the digital form correctly.

5. **Compatibility:** ITRC realized that it would require a large effort from both Active Ink and TruePoint in order to enable the two databases to work together.

6. **Operating System:** There was an operating system incompatibility (64-bit version of Windows Vista had to be downgraded to a 32-bit version in order to work properly).

7. **Erasing Function:** For unknown reason(s), the eraser would not work if the brightness of the screen was set at 100%. If turned down to 99% or lower, it would work.

8. **Computer Crashes:** ITRC found that the tablet PC experienced frequent crashes. This was not acceptable due to the high frequency of phone calls that the IID office receives.

Along the way, ITRC thought that the software problems might be solved with a different software package. Therefore, several comparable software options were reviewed that could serve as an alternative to Active Ink. The various options were:

- Design Universe E-Pen & Forms Builder for tablet PC
- RightScript, Ritepen
- Nuance OmniForm
- Microsoft Infopath
However, it appeared that all of the brands of software were similar in the services that were provided and there appeared to be functionality problems with each one based on user reviews. Therefore, no other brand of software was chosen, due to the high cost of customization and the seemingly small chance of success.

It was found that if either the operator takes the time to write neatly and wait for the pick lists to show up, or if the form was revised to provide a box for each digit to be entered into, it is possible for the form to be correctly filled out. The problem is that IID staff require speed and accuracy above all else. Speed and accuracy are extremely important, because there is a farmer on the other end of the telephone who does not want to wait for the computer to process the information. The farmer wants to give information quickly, and then get off the phone. Since there is a high volume of water orders received every day (plus cancel orders), there is no extra time to wait for the tablet PC to recognize text or restart after a crash.

ITRC realized that it would quickly frustrate both the Water Coordinator and customers to have to slow down and/or retype the information, which would most likely result in them reverting back to their traditional method. Therefore, it was determined that the tablet PC was far too slow and inconsistent.

Other issues that increased the complexity beyond the practical limit of the tablet PC were:

- IID’s naming convention:
  - “Canal name” and/or “gate number” typically consist of a series of numbers and letters. It would most likely be simpler (reducing handwriting recognition errors) if the values were restricted to either only numbers or only letters.
  - The account number is generated internally by the TruePoint software when the operator starts to fill out the form. The “account number” is actually more like a water order number and varies each time that water is ordered for each farmer.

- The same farmer may have several different accounts.

- Several farmers may be served by the same turnout.

- The numbers of days of irrigation requested are not always full calendar days. For example, IID uses letter codes to specify the specific times when to turn water on/off.

- In the end, there were too many variables, which greatly slowed down the process of data entry into the tablet PC.

While it is possible to have the tablet PC trained to recognize a specific person’s writing, it was still not robust enough to satisfy all of the requirements. ITRC personnel went through a lengthy process of teaching the software to recognize a specific person’s handwriting. However, the errors were still too frequent when converting the handwriting to text.
# APPENDIX C: Definitions

Throughout this report and its appendices, the following words and acronyms are used:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Art</td>
<td>Logic/reasoning learned through experience that is non-transferrable to new employees, and usually not detailed in written documentation</td>
</tr>
<tr>
<td>Carryover</td>
<td>A water order that cannot be filled when requested and is postponed for a certain time period (e.g., 1 day) based on district rules/policies</td>
</tr>
<tr>
<td>DSS</td>
<td>Decision Support System</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
</tr>
<tr>
<td>IIM</td>
<td>Integrated Information Management</td>
</tr>
<tr>
<td>LDSS</td>
<td>Lateral Decision Support System</td>
</tr>
<tr>
<td>PLC</td>
<td>Programmable Logic Controller</td>
</tr>
<tr>
<td>RTU</td>
<td>Remote Terminal Unit</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
</tr>
<tr>
<td>WCDSS</td>
<td>Water Coordinator Decision Support System</td>
</tr>
<tr>
<td>WIS</td>
<td>Water Information System</td>
</tr>
<tr>
<td>Zanjero</td>
<td>Irrigation district employee who delivers water to the farmers (basically, a ditch tender)</td>
</tr>
</tbody>
</table>
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