WATER CONSERVATION AND IRRIGATION EFFICIENCY: A CASE STUDY OF TURLOCK IRRIGATION DISTRICT'S DATA MANAGEMENT SYSTEM FOR IRRIGATION OPERATIONS, ENVIRONMENTAL MONITORING, AND ENERGY PRODUCTION

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ABSTRACT

Current efforts in water conservation and irrigation efficiency illustrate the need for modern data management systems that that can consume, validate, calculate, manage and automate the reporting of real-time and historical water data with ease. Managing the vast amounts of data being collected along with the ability to dynamically link to water resource management models, are key requirements for irrigation districts. The problem presented in this paper is the availability of Commercial Off-The-Shelf (COTS) solutions that provide a stable decision support platform for water conservation and irrigation efficiency efforts while offering additional capabilities in the areas of environmental monitoring and energy production. The Turlock Irrigation's approach to solving this problem is based on WISKI: a comprehensive COTS solution that manages and automates the entire process of data collection, import, validation, editing, reporting, and exporting with advanced editing capabilities. The KISTERS WISKI (**W**ater **I**nformation **S**ystem **KI**STERS) solution can integrate with all in-house data collection systems, including water resource management models and offers users a wide range of tools for water data management. Automation of the routine data management tasks performed by District staff reduces the lag time between data collection and decision-making, thus increasing their overall operational efficiency. Streamlining the entire process from data collection to reporting in one solution has also improved the District's ability to conserve water and focus on revenue generating opportunities like energy production. WISKI makes information available in near real-time to District staff, thereby reducing the amount of time and money spent generating good data for decision-making. The use of cumbersome and error-prone spreadsheets, as well as custom in-house developed data management solutions have been phased out as COTS solutions like those from KISTERS offer a viable alternative without the hassle. Without a solution like WISKI, that accommodates all the District's interests, in addition to saving its engineers and hydrologists valuable time and money, the District would not be as efficient as it is today.

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INTRODUCTION

Integrated water management of both surface and ground water has become an important concept in the management of this precious natural resource. The proper management of water resources requires a well defined monitoring program that includes the collection, analysis, reporting and overall management of water quantity and water quality data.

Processes and programs for data collection have been well defined over the past 50+ years, and there are many public and private agencies meeting this segment of the data management process. However, effectively converting the massive amounts of data being collected into usable and actionable information for decision-making purposes has been limited to only a handful of private and public agencies around the world. Prior to the 1990's, only government agencies could afford the investment in time and money required to develop robust data management systems capable of handling the volumes of data being collected. Even at that, the majority of systems being developed were limited in scope and capability due to the agency's specific focus. It was not until the 1990's that private consultants started investing in the development of data management systems at the request of government agencies needing to replace their aging, limited capability, "homegrown" solutions. Some of these consultants recognized a need to develop a commercial "off-the-shelf" (COTS) data management system and designed a business model around this niche industry. As computer and monitoring technologies have rapidly progressed in complexity, and others have retired from industry, several data management solutions have fallen by the wayside and are no longer viable options for organizations. Today there are a limited number of entrepreneurs that have survived and provide excellent systems for water data management.

Most current systems on the market today can store vast quantities of data. However, the key to a comprehensive data management solution is the ability to capture and ensure a high level of data quality while maintaining an efficient flow of data to decision-makers. The solution to achieving this high level of data quality is to provide an integrated system that takes title of the data from the initial import of raw data to the export of quality processed data. Only a few solutions meeting these criteria exist in the world today. The desirable solution must also be able to meet the stringent requirements and policies of the Federal, State and Local agencies. In addition, organizations are requiring that the COTS systems be delivered and configured in a minimal amount of time, flexible enough to manage all their data, and not require ongoing consulting and support from the provider to be able to maintain it.

This paper discusses the need for a comprehensive data management solution that can perform a host of tasks: collect, validate, calculate, manage, and report real-time and archived data; integrate with existing applications like water resource management models; provide a decision support platform for water conservation and irrigation efficiency; monitor diverse inputs from environmental to energy production parameters; and provide the scalability to serve the data management needs of both small and large organizations alike. Along with the discussion for the need of a comprehensive data management system, this paper presents Turlock irrigation district's use of WISKI

(Water Information System KISTERS) as their comprehensive data management solution and decision making platform.

TURLOCK IRRIGATION DISTRICT COMPANY PROFILE

Established in 1887, the Turlock Irrigation District (TID) was the first publicly owned irrigation district in the state and is one of only four in California today that also provides electric retail energy directly to homes, farms and businesses

Since 1923, TID has been providing safe, affordable and reliable electricity to a growing retail customer base that now numbers in excess of 98,000 residential, farm, business, industrial and municipal accounts in an electric service area that encompasses 662 square-miles in portions of Stanislaus, Merced, Tuolumne and Mariposa counties.

TID provides irrigation water to more than 5,800 growers in a 307 square-mile service area that incorporates 149,500 acres of Central Valley farmland. The District has been delivering irrigation water to growers since completing its gravity-fed water conveyance system of canals and laterals in 1900.

The Tuolumne River is the District's primary source of water, originating at Mt. Lyell in Yosemite National Park. Water for irrigation and hydroelectric power production is kept at Don Pedro Reservoir about 50 miles east of Turlock in the Sierra Nevada foothills near the historic gold rush era town of La Grange.

Business focus:

Optimization of Reservoir Management

- Minimize Flood Threat
- Maximize Energy production
- Manage Water Accounting/Rights
- Manage Energy Dispatch
- Manage Renewable Energy
- Manage Environmental Releases to Tuolumne; flows, temperatures
- Manage Financial Risk Analysis
- Manage Irrigation Demands

Technical situation:

TID recognized a need for a central data hub to manage the massive amounts of data necessary to optimize the operations of Don Pedro Reservoir as well as downstream facilities without spilling, causing potential down stream flooding. The data hub must have the capability to automatically collect, validate, calculate, manage, and report real-time and archived data; integrate with existing applications like water resource management models; provide a decision support platform for water conservation and

irrigation efficiency and monitor diverse inputs from environmental to energy production parameters.

Import data from:

- SCADA
- CDEC
- USGS
- NWS
- Financial systems

Export data to:

- Excel sheets
- Operations Models
- Hydrological Models

OVERVIEW OF WISKI

WISKI is a leading environmental data management software solution developed by KISTERS that has grown over the last 25 years into a mature solution that allows organizations to keep up with global advancements in technology and data management requirements. WISKI can be applied to many different applications as well as integrated into automated process management and control. WISKI can be used to manage all the tasks related to data management, from data importing through to final reporting. The WISKI solution uses advanced relational database management platforms such as ORACLE, or MSSQL to manage the data and is proven in both small and large installations around the world.

APPLICATION INTEGRATION

Resource management organizations often utilize a myriad of different data collection devices and presentation applications that are vital to their data management procedures, such as data loggers, Laboratory Information Management Systems (LIMS), SCADA, Geographical Information Systems (GIS), and spreadsheets. These all need to be taken into consideration and their data feeds integrated into a central data management system. The replacement of these applications by a single “mega” solution would be incredibly cost prohibitive and unnecessary if a data management solution that could integrate all the existing applications into a single solution was not commercially available. Without a comprehensive and integrated system, organizations may spend much of their time and energy simply transferring data from one application to another, greatly reducing efficiencies and potentially introducing unwanted error. Integration of the data collection and presentation applications inherently provides greater system efficiencies since data could be easily transferred from one application to another. Data quality resulting from validation routines performed in each application could also be preserved using this approach.

The availability of a COTS data management solution that has the ability to perform all the processes of data management, from collection to reporting, including the integration with other applications is limited. This type of system is much needed by irrigation districts and water resource managers, in general. Many data management systems offer only a single component of a comprehensive data management solution. This often leads to a combination of many different data management systems coupled together to try to solve the problem, often leading to errors and system instability issues.

Manufacturers of data loggers and other data collection equipment have greatly improved the software offerings that accompany their devices, as well as increased the amount of data they can store. Many of these device-specific data management solutions only have the ability to perform limited tasks concerning data records management. Organizations are routinely faced with collecting data with one type of data collection software/telemetry system, performing statistical calculations with a specific statistical software package, performing any data conversions or calculations within coupled spreadsheets, managing quality control within another management system, and then performing report generations through yet another software application. These loosely coupled systems always require reformatting of the data from one application to another, providing yet another potential opportunity for error. This type of data management system requires not only the need to keep track of the data processing workflow from one software application to another, but also to employ staff with the knowledge of how to operate the many different applications being used.

Typically, organizations either pay an outside software development firm to develop a customized system that incorporates the features and functions of the many different applications needed for data management procedures, or they are forced to continuously pass data files from one application to another to perform specific tasks. This type of data management system is an extremely inefficient use of both the data manager's time, as well as the organization's IT infrastructure. Many data management systems may be able to handle and process a small organization's data requirements, but they often have difficulty when dealing with the massive amount of data large organizations are mandated to manage.

Most organizations that are tasked with water resource management do not have a comprehensive and integrated data management system, yet require such a system to efficiently manage their data and the much valued data quality associated with it. The ability to manage all of an organization's needs, from the integration of data collection devices to reporting in a single software application would greatly increase efficiencies in time and reduce errors.

DATA COLLECTION

Data collection and environmental monitoring is becoming increasingly easier with technological advances in monitoring devices and reduction in data storage costs. This is accompanied by the request for more frequent data collection and the desire for real-time or near real-time systems. Not so long ago, simple monthly, weekly or daily mean

readings of water level and flow was sufficient for the operation of an irrigation district and reporting to governing bodies. Nowadays, hourly and 15-minute readings are becoming the normal time resolution for data, with some moving towards collecting 5-minute data. The increase in data resolution is occurring for a number of reasons, including changing model input requirements, the desire to gain greater knowledge of monitored parameters and their trends, and the desire to gain a faster response to resource changes that require mitigating actions.

New models are emerging that allow organizations to predict the future of parameter states. With these models comes a greater need to collect data on, or near, a real-time basis so the models can produce a faster result of the future parameter conditions (Bigelow and David, 2003; Gerts and Linacre, 1998). These models are able to utilize high data resolutions (5 minute or less) to increase the probability of correctly predicting the future state of parameter conditions. Many models require an exact data raster (data at specific time intervals), with no missing values. Newer data loggers can support these high data resolutions and allow the models to operate directly on raw data coming in from the field. This eliminates the need for data to be interpolated to fit the strict data raster requirements of data models. However, models that run on raw data, without first adjusting for errors like spikes or sensor drift, can be problematic. This is especially so if alarm notifications and critical operation decisions are being based on this raw, unchecked data. Systems, like WISKI, has allowed Turlock Irrigation District to perform automated QA/QC on high resolution incoming data and pass it to models in near-real time, thus greatly reducing the possibility of costly errors.

DATA IMPORTING

As noted previously, the data logger industry is growing rapidly as technology improves to better serve the water resources community. The number of new data collection devices is growing each year, and so is the number of new data file formats produced by these devices. Even though some have the ability to configure certain aspects of their output data file format, nearly all data collection devices produce their own specific file format. With this flexibility in data file output formats comes increased complexities for data management systems as configurations for the same device may change from one organization to another. The nearly unlimited number of file formats and format variations illustrates the need for a data management solution to contain a fully configurable data file importing capability that can handle data from any collection device.

Irrigation districts that do not have a comprehensive data management system spend much of their time simply formatting data so that it can be imported into their existing system. Any organization would be able to increase their total data management efficiency by utilizing an automated data import process. Time saved by an automated import process could instead be spent on developing information from the data and making decisions based on this information. At the Turlock Irrigation District, savings in data processing time has exceeded 40% during normal non-flood control operating times

(38 labor hours per week savings) and upwards of 70% (73 labor hours per week savings) during flood control operation times since the introduction of the WISKI system.

Often irrigation districts are interconnected with other water delivery systems and thus are required to import data from different data sources other than their own into their data management solution. An important requirement of any data management solution is to be able to accommodate these various data sources in their system as they may need to validate or correct their data with it. With many data management organizations needing to perform data corrections or validation with data from other organizations, data management solutions must have the ability to contain multiple import time series locations to accommodate for the various data sources. With WISKI, the irrigation district is able to do so with ease.

DATA VALIDATION

Having the ability to record and track the quality of any data point is an essential criterion in deciding which data management system to use. Given the massive amounts of data these systems are now required to handle, a key feature a system should have is the automation of data validation procedures. Automated data validation is imperative to quality assurance and quality control (QA/QC) of field data. Data from the field may include a number of erroneous values for many different reasons, including low battery voltage, sensor fouling, sensor malfunction, improper installation, etc. Without proper data validation routines these erroneous values are often imported and could be incorporated into the final results that decision makers utilize. Along with erroneous data, gaps in the data may also be introduced by data loggers that have failed, been destroyed by flooding, removed by vandals, or simply had battery failure. These data gaps must either be filled or marked with a certain quality to ensure the correct processing of dependent calculations, such as stage to flow rating curves. The many sources of data errors need to be managed, controlled, and either corrected or validated to make sure that irrigation managers are not mislead by incorrect data when they are making important decisions. An efficient data management solution must therefore be able to automate data validation and correction routines to preserve good quality data and correctly qualify bad quality data.

A robust data QA/QC methodology is an essential part of any system to keep track of data quality throughout the entire data management process. A data management system must not only be able to track data quality throughout the validation process, but also be able to automate data quality changes based on specific validation routines, write remarks based on validation routines, keep track of who has edited the data, as well as keep track of remarks associated with each data value. The system should also contain a range of data qualities that may be customized by an organization to conform to their specific data management requirements. For instance, WISKI allows our irrigation district to establish up to 254 user-defined data quality levels. Although we do not utilize all of the levels, we have implemented a meaningful set of five quality levels in the system that includes good, estimated, suspect, unchecked, and missing.

Standardization of data quality values in an organization is necessary to preserve the same meaning throughout a data management system. Standardized data validation practices across all monitored parameters ensures consistent data quality through a data management solution. The District has been able to utilize several validation routines in WISKI in its day-to-day operations - threshold validation to change the data quality if the values are above or below specified set point, or compared to another time series, rate of change validation to change the data quality when values change at or beyond a specified rate over time, delta validation to change data quality when values change beyond a specified range, and distance validation to change the data quality when the time between two data points exceeds a specified time interval.

As the amount of data entering data management systems increases, validation processes must be automated to make them efficient and effective decision-support tools. Manual data validation processes take vast quantities of time that could be better used making critical operation decisions. The automation of data validation routines increases the efficiency of data management systems by reducing the amount of time hydrologists, engineers, and data managers spend on the QA/QC processing. A system with a robust and flexible QA/QC methodology that offers multiple automated validation routines enables our District to focus on making informed decisions with quality data.

DATA EDITING

Data collection devices are becoming more and more efficient, but nearly all data collection devices at some point log incorrect values for many different reasons. To be efficient, organizations must utilize data management systems that allow their managers to revise and edit incorrect data with ease. No two managers edit their data in the same exact way. Some prefer to edit data in tabular format, while others prefer a graphical format. Data management systems must be flexible enough to allow users to edit their data both graphically and within tables, as well as keep track of who, why and when the edits were made.

To determine who, why and when edits were made, an audit trail of edits becomes a necessary component of a data management system. Irrigation districts, as well as other public sector agencies require this component of data editing as they are often required to adhere to quality assurance oversight guidelines. The importance of an audit trail is paramount when there are multiple people working with the same data set. Organizations can then determine accountability and enforce internal guidelines if necessary.

When editing is being done both automatically by the system, and manually by different staff, having a way to visually inspect data qualities and comments for large ranges of data is imperative. WISKI includes an intuitive graphical control bar for reviewing data qualities and comments made by the system and users. By simply moving the mouse cursor over a particular part of the control bar, the entire audit trail of edits and comments can be visually inspected by the District staff. The unique color coding defined for each of the quality codes used in the system enables staff to quickly and efficiently understand

the quality of the data, who has edited it, and any specific comments that were made along the way.

SCALABILITY

Irrigation districts have been collecting data on their operations for decades. With data collection devices becoming more and more proficient, organizations are moving towards collecting and storing higher resolution data sets. In parallel, more monitoring stations are currently being deployed at a fraction of the cost compared to a decade ago. Each of these stations can typically support the collection of 2-10 parameters, or more. With higher resolution data sets, an increasing number of monitoring stations, and multiple parameters being measured at each station, the scale of data collection is growing exponentially. For a typical irrigation district that collects five minute data, from ten parameters, at 50 different stations, it would result in collecting 17,520,000 data points every year! Some organizations may collect much more data, but a COTS data management system must be scalable to accommodate for both large and small organizations and the continuously growing amount of data these organizations collect.

Technological advances are not limited to the data logger industry. Hardware and hardware operating systems are also subject to continuous change and updates over time. Current COTS data management systems must take advantage of these innovations in order to meet the increasing demands of the environmental monitoring industry. Given the limited operating budgets of most irrigation districts, it is imperative that a COTS system take advantage of new technology, but also insulate the user from the cost of technology change.

WISKI's n-tier system architecture helps the District strike a perfect balance between monopolizing on advances in technology and meeting its environmental monitoring and operational goals. The District's WISKI system is composed of three scalable tiers – a thin desktop client, an application server, and a database server. The desktop client can be loaded directly on our workstations, or hosted via a terminal server or Citrix ©. The application server can be situated on either a virtual machine, or on its own hardware. Lastly, the database can even be split into separate components for high availability systems. With this type of system the District can safely deploy an unlimited number of stations, to collect an unlimited number of parameters and high resolution data sets without worrying about requiring a new data management system to meet these needs.

REPORTING

Reporting is typically the culmination and the ultimate goal of a data management system. They are essential tools that irrigation district managers use to help make their critical operational decisions. Since reports play such a pivotal role in the daily operation of an irrigation district, a high-quality reporting system is fundamental to any data management system. They offer summaries of many different types of information that may include daily, monthly, and yearly resource summaries, system efficiency gains and losses, and data management auditing checks to ensure proper data records management.

In some COTS data management systems the reporting process may be the most time consuming of all the data management processes. The ability to fast-track and automate the reporting process ultimately saves time and money. A system, like WISKI, with automated report generation is invaluable to an irrigation district. All the reports are streamlined in an automated process that allows them to be delivered through various media, such as email, FTP locations, and file sharing sites of our partner organizations. With the reporting capabilities of WISKI the District has experienced approximately a 60% increase in reporting efficiency (approximately 12 labor hours per week savings) during non-flood control operation times and approximately 130% increase in reporting efficiency (approximately 26 labor hours per week savings) during flood operating times compared to our previous system.

DATA EXPORT

The need to export data is often as important as the need for importing. The interconnected nature of the world's hydrologic cycle dictates that outputs from one process become critical inputs to another. The same applies to the operations of an irrigation district where the output from one district is often the input to another. Monitoring data therefore needs to be shared among organizations to facilitate the integrated management of water resources in a region.

Data sharing starts with the export of data from a data management system. This critical functionality must be present in any data management system. The system must also possess the ability to export data in multiple formats to enable the simple import into other applications. Flexible application programmable interfaces (API) provide the required ability to export data in an unlimited number of desired formats.

NECESSARY DATA MANAGEMENT TOOLS

A comprehensive water data management system is not only required to integrate with other applications, collect, import, validate, edit, report and export data, but also provide a suite of specialized tools to manage more complex tasks. Irrigation districts must be able to perform a number of complex calculations and analyses in order to conserve water and optimize their operational efficiency. The following subsections describe some of the data management tools that are necessary for the District.

Rating Curve Conversions

Many environmental parameters must be monitored, however, for some there is no direct method of measurement. In this case, these parameters have to be determined through relationships to another measureable parameter. At the District, rating curves are routinely used to represent the relationship between stage and flow. The relationship of these vital parameters rarely stays constant through time as changes in channel geometry can affect the calculated flows. The relationship between stage and reservoir volume, or stage and surface area also changes due to erosion of the reservoir's banks, sedimentation, or vegetation growth and must be calculated using a rating curve. With

the nearly continuous relational change between some parameters, a data management system must not only be able to handle rating curves, but also be able to manage an unlimited number of rating curve versions to keep track of the changing relationship between the parameters.

Regression Analysis

The relationship between parameters rarely follows a linear pattern, therefore the rating curve manager portion of a data management system must allow for regression analyses to be conducted in multiple sections on observed measurements. Regression analyses in multiple sections allow a system to characterize sharp differences in parameter relations that a single regression analysis may not be able to. Multiple regression sections supply a good fit where sharp changes in channel geometry occur. Relational parameters may follow a specific pattern through one section of relationships, but may follow a completely different relationship pattern in other sections. For this reason, data management systems must be able to perform single and multiple regression analyses to characterize the changing relationship of two parameters.

Statistical data calculations

The natural environment is extremely variable. Statistics are one way to describe the variability of a monitored parameter over time. Data management systems must be able to perform statistical analyses on data sets in order to determine if the current state of a parameter is beyond a certain deviation of its mean and warrants alarming and/or action. Statistical calculations are needed at an irrigation district for a vast number of reasons, including mean, minimum, and maximum daily production and efficiency statistics that can be used to optimize system resources. Beyond the standard statistical calculations mentioned above, data management systems must also include sufficient flexibility to configure unique statistical calculations, such as the 30-year 95^{th} percentile of all January values. The District requires these statistical analyses to be automated as new data enters the system. WISKI's automation of statistical calculations has dramatically decreased the time the District's managers spend calculating these values.

System efficiency calculations

Irrigation districts constantly strive to achieve a maximum operating efficiency. However, naturally occurring cracks in drainage canals and pipe networks produce unexpected gains or losses in delivered volumes. Organizations must be able to determine the gains and losses within the system that were not accounted for by the known system inputs and outputs. Unexpected gains and losses may result in many undesired results, including loss of revenue as the system loses resources, or system overload due to unexpected gains. The ability for a data management system to store an unlimited number of data points for an unlimited number of stations would allow organizations to more fully monitor their managed resources. With the increased ability to monitor resources, such as the total flow of a channel throughout a channel network, organizations are able to determine the sections of a system where unexpected inputs or

outputs are located by calculating the difference between the upstream and downstream channel flow. This calculation is described as follows:

$$\Delta flow = Dflow - Uflow$$

Where:
$\Delta flow$ is the change in flow
$Dflow$ is the downstream flow
$Uflow$ is the upstream flow

Any unknown inputs and outputs to a channel system may be detected with this simple water balance equation. This simple water balance equation may be modified to account for further inputs and outputs to a channel system as shown below.

$$\Delta flow = Dflow - Uflow - \Sigma Inputs + \Sigma Outputs$$

Where:
$\Delta flow$ is the change in flow
$Dflow$ is the downstream flow
$Uflow$ is the upstream flow
$\Sigma Inputs$ is the sum of inputs to the system
$\Sigma Outputs$ is the sum of outputs to the system

WISKI provides the District with a flexible and robust framework in which simple or complex system efficiency calculations can be made. These calculations can be performed on an automated basis and the results provided to managers in near real-time. This capability has enabled the District to maintain a tight control over its entire operations and achieve significant efficiencies in operation.

THE SOLUTION

KISTERS has developed a COTS data management system that is able to provide irrigation districts with all the necessary components to successfully and efficiently operate their networks. The KISTERS' WISKI solution is a scalable, flexible and comprehensive data management solution that allows for automation of every step in the data management processes. From data imports, validation, processing, statistical and system efficiency calculations to reporting an organization's standard reports through various media such as email, FTP locations, shared folder locations, etc., WISKI has been the ideal choice for the District.

WISKI's data structure is based on a hierarchical layout of sites, stations, parameters, and time series. An unlimited number of sites may exist within the system, containing an unlimited number of stations, at which an unlimited number of parameters are measured, and an unlimited number of time series stored. The time series provides a place holder for all data values being collected. WISKI also allows for many different versions of time series to be stored. Original data, validated data and production data can exist simultaneously in separate time series in conjunction with others containing statistical

calculations, water balance calculations, key performance indicators (KPI's), and system efficiency calculations. Throughout the entire workflow the quality value for each data point is preserved and an audit trail kept for future reference.

CONCLUSION

There are many necessary components to a data management system that irrigation districts require to provide them with a comprehensive solution. The requirement for a scalable solution that allows for the automation of every step in the data management workflow is critical. The system must also include data import, data validation, data processing, statistical and system efficiency calculations, and reporting capabilities to fulfill the necessary requirements of a district. Lastly, the inclusion of specialized tools necessary for managing water data is a fundamental requirement for any COTS data management system.

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