SEVIER RIVER BASIN

WATER RESOURCE MANAGEMENT NETWORK:

EVOLVING TOWARD SENTIENCE

MAY 2004

Sevier River Water Users Association
StoneFly Technology, Inc.
Utah State University
and
U.S. Bureau of Reclamation

ABSTRACT

This “Sevier River Basin - Water Resource Management Network” final report culminates a 4-year investigation of technological innovations to enhance water management in south-central Utah. The effort involved the development of:

- a river-basin real-time monitoring and control system;
- a river-basin water management website: www.sevierriver.org;
- decision-support software to fine-tune water distribution; and
- software to make the water resource network self-diagnosing

The project demonstrated that new low-cost communication technologies provide cost-effective tools for improving water management and dispensing important information related to the environment in general. This project represents the first furtive step toward developing a sentient water resource telemetry network.

FORWARD

This publication presents a general overview of the “Sevier River Basin - Water Resource Management Network” project. The project involved staff from the following organizations:

- Sevier River Water Users Association (Association)
- StoneFly Technology, Inc. (Stonefly)
- Utah State University (USU)
- U.S. Bureau of Reclamation (Reclamation)

Also involved were: Brigham Young University, Utah Climate Center, and the individual canal companies in the Sevier River Basin.

Major funding was provided by a grant from the Department of Commerce’s Technology Opportunities Program (TOP). The TOP program officers associated with the project were Mark Tibbetts and Judy Sparrow. Reclamation’s participation in the study was funded through its Inter-Regional and Geographically Defined Programs.

Cover: Aerial photograph of Piute Dam and Reservoir.

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The photographs in this report were provided by Stacey Smith, Kelly Bringhurst, Bret Berger, Rachel Jensen, Roger Hansen, Frank Woodward, Arlen Hilton, and the webcams.

CHAPTER I

INTRODUCTION

This report documents the Sevier River Basin (see Figure 1) Water Management Network's first furtive steps toward sentience (definition: having the faculty of perception). It is impossible to predict when the network will become self-aware, but clearly it is developing a life of its own and evolving at a rapid pace.

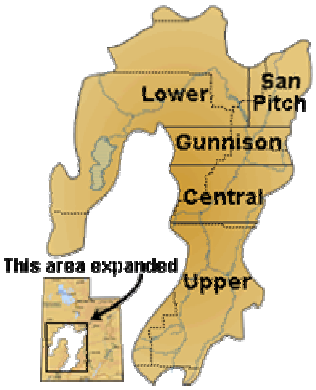


Figure 1
General Location of the Project Area and Its Sub-areas.

Several developments in recent years have made the goal of sentience cost-effective. The convergence of the following technologies has made low-cost automation (and eventual sentience) a viable reality: (1) low-cost datalogger/ controllers; (2) growing variety of inexpensive environmental monitoring sensors; (3) expanding use of solar-energy and battery systems; (4) innovations in communication equipment; (5) rapid advancements in the PC and server industry; (6) increasingly sophisticated decision-support software; and (7) the phenomenal growth of the Internet. One example of how these technologies are being applied is in Utah's Sevier River Basin. This self-contained river basin (no outlet to the ocean) is instrumented with low-cost automation equipment and a SCADA (supervisory control and data acquisition) system which uses the Internet and a web browser for real-time data distribution.

In many respects, the Sevier River Water Users Association's (Association) irrigation distribution and electronic communication systems are analogous to the human body. This comparison will hopefully be a useful tool to understand the nature of the Association's network. Chapter II will start the discussion by comparing the Association's physical water distribution system to the human circulatory system. Chapter III discusses the human skin and how it is similar to the Basin's environmental monitoring system. Chapter IV gets to the core of the issue of sentience by exploring the Basin's evolving central nervous system. Chapter V will speculate on the future of the water resource management network in the Sevier River Basin.

Background

The Sevier River Basin (Basin) in rural south-central Utah is one of the state's major drainages. A closed river basin, it encompasses 12.5 percent of the state's total area. From the headwater, 250 miles south of Salt Lake City, the river flows north and then west 225 miles before reaching Sevier Lake. In John Wesley Powell's seminal report on the Lands of the Arid Region of the United States (1879), a full chapter is devoted to the Basin. Captain C.E. Dutton (Powell, p. 144) marvels that "there is probably no region in the world more admirably suited for easy, cheap, and efficient application of (artificial reservoirs) than this very region drained by the Sevier River." The water users exploited with the construction of Otter Creek and Sevier Bridge Reservoirs and the State of Utah exploited it with the construction of Piute Reservoir. Since the turn of the century, irrigation has depleted the river and the only flows that reach the terminal lake are occasional floods, like those in 1983 and 1984, and some irrigation return flow (see Photograph 1).

Photograph 1 - Sevier Bridge Dam and Reservoir during the flooding of 1983.

The institutional structure for operating the river is relatively straightforward. Operation of the river is overseen by a River Board (an executive committee of the Association) that meets annually to deal with current issues and to make assessments to offset the costs of operating the river. Water rights are administered by two river commissioners (State employees). Other than the two commissioners, there is only one other full-time employee (the office manager for the canals and reservoirs in the lower Basin). Most of the canal companies operate out of the homes of their managers and employees (i.e., ditch riders and/or water masters).

All western water rights are established by legal decree or statute. In Utah, regulation of water rights is an administrative procedure executed by the river commissioners acting under the direction of the State Engineer. In the Basin, the river is managed by two river commissioners using procedures so complex that few people fully understand them. The most difficult aspect of the allocation procedure involves the determination of the primary flow and the segregation of this water from the storage water. Another confusing aspect is the division of the flow into zones.

Water Supply

Most of the surface water runoff comes from snowmelt during the months of April, May, and June. Tributary streams peak at different times depending on the watershed aspect, elevation, and configuration. The peak irrigation season is in July and August. Thus the need for short-term water storage (to match supply and demand). In the lower reaches of the river system, much of the streamflow is made up of return flows from upstream

irrigation. This modifies the river flow even further.

At the present time, the Basin is in a dry cycle (drought). Sevier's large storage reservoirs are critical for leveling the effects of these long-term hydrologic cycles.

The three largest storage reservoirs in the Sevier River Basin, Otter Creek, Piute, and Sevier Bridge, account for about 75 percent of the total water storage capacity (see Table 1 and Figure 2). The combined capacity of the remaining reservoirs is approximately 120,000 acre-feet. These smaller reservoirs are used exclusively to store irrigation water, and some contain water only in years of excess precipitation.

Table 1
Major Reservoirs in the Sevier River Basin

Reservoir	Source of Water	Capacity (acre-feet)	Surface (acres)	Use*
Otter Creek	Sevier River, East Fork	52,660	2,520	IR, R
Piute	Sevier River	71,830	2,508	IR, R
Sevier Bridge	Sevier River	236,150	10,905	IR,I,R

* IR=irrigation; I = industrial; and R=recreation

Water Management Network History

GOES Monitoring System

In the late 1980s, GOES (Geo-synchronous Operational Environmental Satellite) technology was installed on river and canal monitoring stations along the Sevier River. These stations, which provided data on an hourly basis, demonstrated the usefulness of real-time information for improving management of the river. The problems with the Sevier River GOES system were two-fold: (1) the communication system was one way and thus not suitable for most control applications, and (2) the system for distributing the data was primitive, with each river commissioner having his own satellite downlink station, and thus the data was not widely distributed (Association et al., 1994).

Delta Area Canal Automation

In 1991, the Delta Canal and Melville Irrigation Companies in the lower Basin asked Utah State University (USU) and the Bureau of Reclamation (Reclamation) to design and install a system to control the flow of irrigation water through Canal A, which supplies water to the two companies (see Photograph 2). The system was a product of USU's Biological and Irrigation Engineering Department

(Walker, 1993). The canal automation system included: (a) a radio-telemetry network that transmits data and commands; (b) a datalogger/controller that collects data about gate positions and water levels, and raises and lowers gates; and (c) a PC that controls the system.

Photograph 2 - Canal company manager's from around Utah inspecting the USU automation project at Canal A in Delta.

The aim of the Canal A automation project was to reduce losses while maintaining a high degree of on-demand flexibility in the canal's operation. The system was designed to improve regulation through easier and more timely changes in gate openings, better flow measurement as a result of more stable outflows, and automatic regulation during periods when the canal was unattended. The project proved successful, producing a water savings of 3,000 acre-feet (AF) during its first full year of operation.

Richfield Area Canal and Reservoir Automation

After viewing the success of the Canal A project, irrigators in the Richfield area opted to try components of a selective automation system. During 1993, in a joint effort with Reclamation, the Richfield Irrigation Company installed a radio-telemetry monitoring station on the Parshall flume at the head of their canal (see Photograph 3). The station allowed the water manager to observe conditions and improve canal operations. After a year of monitoring canal flows, the company decided to upgrade to real-time control.

During the early Spring of 1994, the telemetry equipment and controller were moved 200 feet from the flume to the diversion structure. Subsequently, the gates on the diversion structure were motorized with solar-powered 12-VDC motors, and the datalogger/controller was reprogrammed for manual remote control. This enabled the water manager to make gate changes from his residence. Richfield's new system proved to be a useful water conservation tool (Pugh and Hansen, 1995).

Photograph 3 - At the Richfield diversion structure, monitoring equipment was initially installed at the measurement flume in the foreground. Ultimately, the three gates in the background were automated.

During 1995, the Richfield diversion structure was equipped with automatic remote control. This was accomplished by installing enhanced software at the diversion. Now, instead of moving the

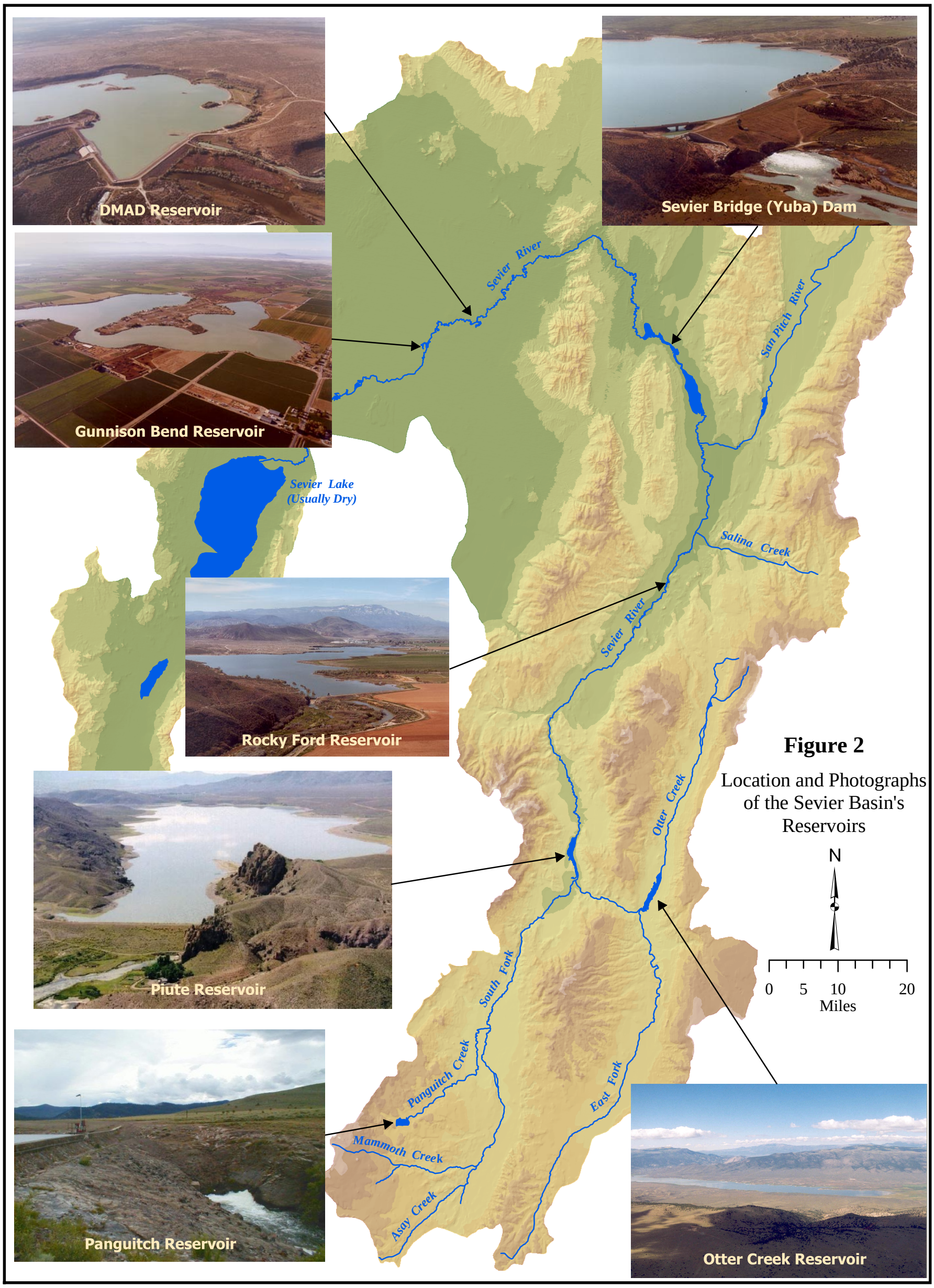


Figure 2

Location and Photographs of the Sevier Basin's Reservoirs

gates by remote control, the water manager could set a canal flow target remotely and the gates would automatically move to maintain the required flow. The canal manager estimates that the system has helped the company conserve approximately 12 percent of its water supply.

After the success of the Richfield Canal automation project, Reclamation assisted seven other canal companies in the Richfield area to automate their structures. Both major reservoirs serving the area, Piute and Otter Creek, were also automated. In addition, 15 real-time river and canal flow monitoring sites were added to the developing network. All data communications in the area were by a combination of VHF radio and telephone (Hansen and Pugh, 1997).

In 1998, the automation equipment on the Richfield diversion structure was remodeled to make it camera friendly, and a webcam was installed. The latter demonstrated the usefulness of having real-time images.

Sevier River Basin Web Site

The various monitoring and automation systems in the Sevier River Basin generated substantial amounts of data, but it was unavailable to all but a few water managers. This was a constant source of frustration to a number of excluded water managers who needed the data to improve their operations.

Meanwhile, the rapid rise in the development and use of the Internet meant that many of the water managers were either getting "on-line" or considering it. It became apparent that getting the real-time data onto the Internet might become a good way to distribute the data to a wide audience without requiring the water users to purchase specialized equipment.

In 1997, StoneFly Technology (StoneFly) approached the water users in the upper Basin with a proposal to connect their real-time database to the Internet (Berger et al, 2001). This proposal was accepted and Reclamation agreed to assist with the project. That fall, a preliminary web site was tested and was well received. The site was enhanced for the 1999 irrigation season and the graphic displays were expanded.

TOP Grant Activities

In 1999, the Association received a grant from the Department of Commerce's Technology Opportunities Program (TOP). The principal goals of the TOP project were to expand the automation/Internet activities to the entire Sevier River Basin and to improve the communications and decision-support software associated with the network (see Table 2). This report provides a description of the current system. Since the network is ever changing and expanding, this is just one snapshot of the system at one moment in time, September 2003, at the conclusion of the TOP project. The grant has enabled the water users to move their water management network toward sentience at an accelerated pace.

Table 2
Specific Goals of the TOP-Funded Project

No.	Goals
1	An integration of all existing real-time systems into one comprehensive network;
2	Enlarging the system to include the entire river basin (at the start of the TOP Project it only encompassed the area around Richfield);
3	Definition and development of a relational database;
4	Software so canal companies can place water orders over the Internet;
5	Real-time water balance to help quality control data and estimate unmeasured inflows;
6	Daily water rights update to provide the current status of individual rights;
7	Secure communication system for Internet control applications;
8	River operations model to optimize water deliveries;
9	Irrigation scheduling program to maximize crop production; and
10	Fine-tune the website to better meet the needs of secondary users.

Source: Technology Opportunities Program (TOP) Grant Proposal dated March 10, 1999.

System Evolution

The nature of the automation/Internet/ decision-support technologies needs a brief discussion. Engineering projects typically have beginnings and ends. For example, a dam is constructed and when completed its turned over to the water users to repay and operate. In the case of automation/Internet/decision-support technologies, it gets more sophisticated and less costly with each passing day. And as the technologies get more complex, so do the needs of the water users. With real-time technologies, you "buy into" a process more than a specific product.

Most of the goals stated in Table 2 are evolving. The TOP Grant provided an excellent starting mechanism for processes that will continue long after the grant is over. The fact that these processes did not stop at the conclusion of the grant is a testimony to the success of the project.

CHAPTER II

THE BASIN'S CIRCULATORY SYSTEM

The human circulatory system consists of the heart and a drainage system of blood vessels. Some of these vessels, the arteries, conduct blood in the tissues and terminate in microscopic branches, the arterioles, which under the control of the central nervous system act as "spigots" and regulate blood flow in various regions according to metabolic demands. Branching from the arterioles are the smallest blood vessels, the capillaries, across the walls of which chemicals diffuse between the blood and the tissue fluids. From the capillaries, blood is carried through the microscopic venules and the veins back to the heart.

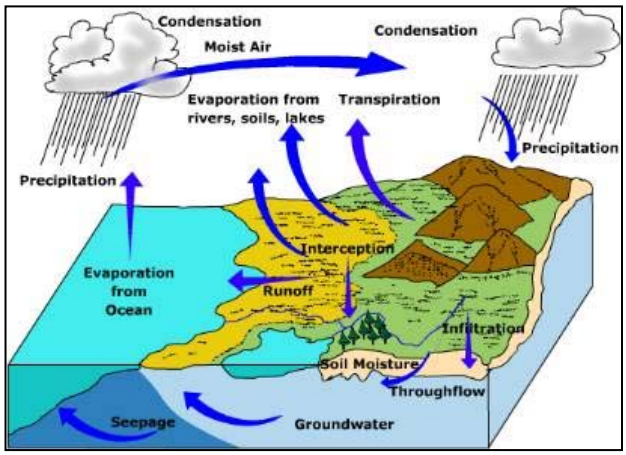


Figure 3
General Schematic of the Hydrologic Cycle.

The water supply for irrigation in the western United States is remarkably similar to the human circulatory system. The process, in a general sense, is referred to as the hydrologic cycle (see Figure 3). Water is released from clouds as precipitation (usually snow or rain) and is collected as runoff by a network of streams and rivers. Water which is not immediately needed is stored in large reservoirs. Water is released from reservoirs to rivers. From the rivers it is diverted into canals and then into smaller laterals (see Photograph 4). From laterals it is used by individual farmers to irrigate their cropland. Surplus water from irrigation flows back into the river in the form of return flow.

Photograph 4 - Water being diverted from the Sevier River into Vermillion Canal for irrigation.

Evaporation and evapotranspiration recycle water to the atmosphere.

(Because this project deals only with surface water, the groundwater portion of the hydrologic cycle is not specifically addressed.)

Figure 4 is a graphical representation of the average annual streamflows, diversions, and return flows in the Sevier River Basin for the period 1941 to 1990 (Utah Board of Water Resources, 1999). The width of the arrows and bands indicates the average annual flow volume. The flow volumes are derived or estimated from stream gauge data, other records, and by correlation. Annual precipitation and runoff varies from year to year and typically runs in cycles (hydrologists call this a stochastic process.). At the present time, the Basin is in a dry cycle (drought).

Water Regulation

In the human body, the distribution of blood is regulated by "spigots" controlled by the central nervous system. Historically, in the Sevier River Basin, water has been controlled by gates operated manually (see Photograph 5). This required the water manager to drive long distances to make gate position changes (to adjust the flow rate at the head of his canal). Because of the inconvenience and difficulty of making flow adjustments, the system was not always as fine-tuned as it needed to be for optimal water management. Additionally, while this type of open-channel system appears to be fairly straightforward to operate, it is not. Typical of the problems encountered were: (1) dealing with the time lags in delivery (i.e., the time it takes for water to move from a storage reservoir to a farm); (2) getting water to the end of a distribution system; and (3) operating a system 24/7.

Photograph 5 - Prior to the mid-1990's, gates like this one on Richfield's diversion dam were operated manually by turning the handwheel.

One of the goals of the TOP project was to begin the process of putting the water distribution system under the control of a "central nervous system." But before this could be accomplished, the gates had to be motorized so they could be remotely controlled. One of the impediments to motorization was the isolation of many of the water control structures; they were well removed from the commercial power grid. It was soon determined that solar powering the gate actuators, in most instances, was a necessity. This required the use of 12- or 24-VDC (volts direct current) systems.

When the Association began designing and installing low-cost remote-controlled gate systems in 1994, there was little enthusiasm among commercial manufacturers to make or sell 12- or 24-VDC gate actuators. For this reason, Reclamation designers developed two prototypes that could be retrofitted onto the slide gates of existing structures.

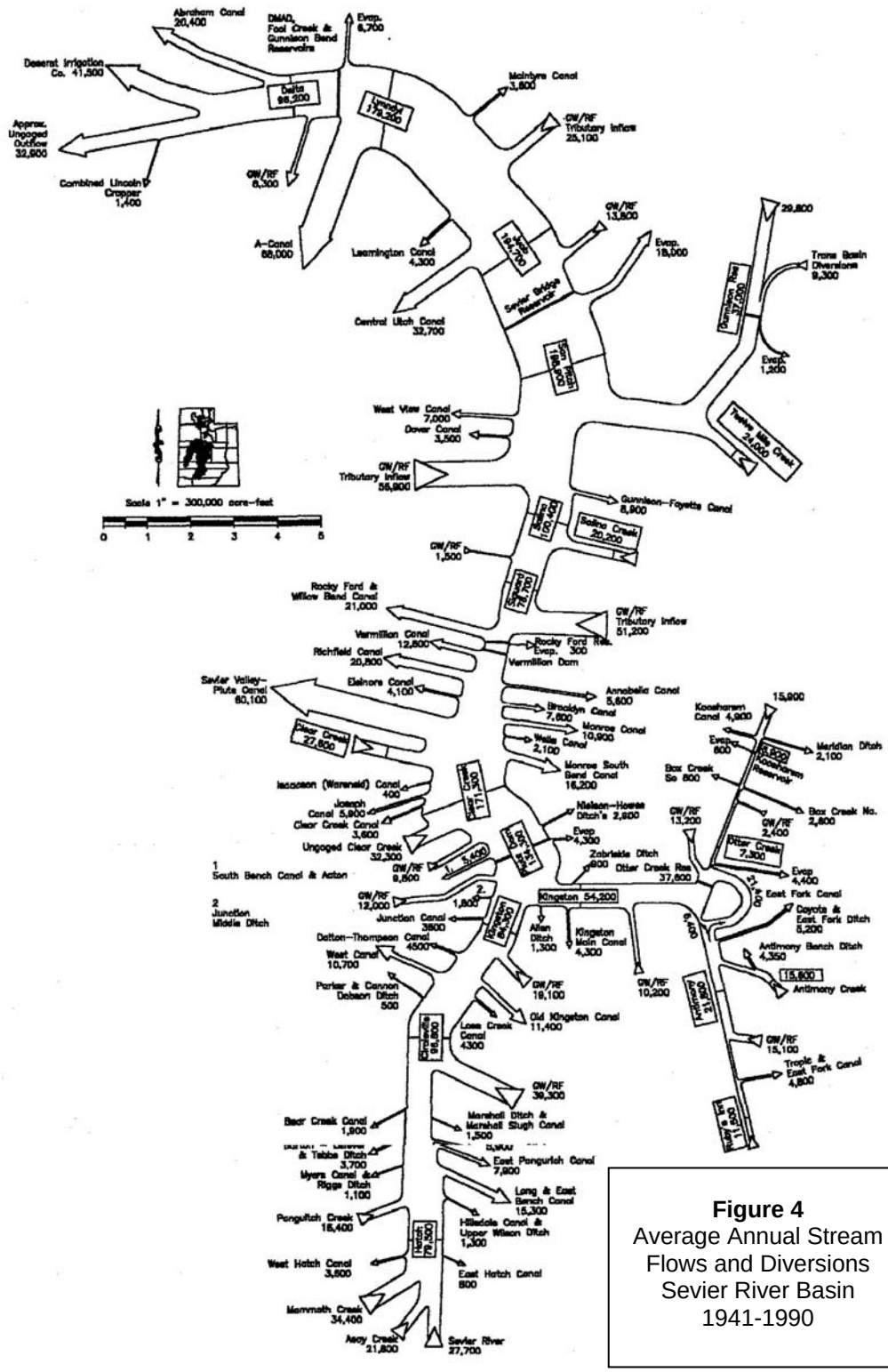


Figure 4
Average Annual Stream Flows and Diversions Sevier River Basin 1941-1990

Solar-Powered Gate Actuators

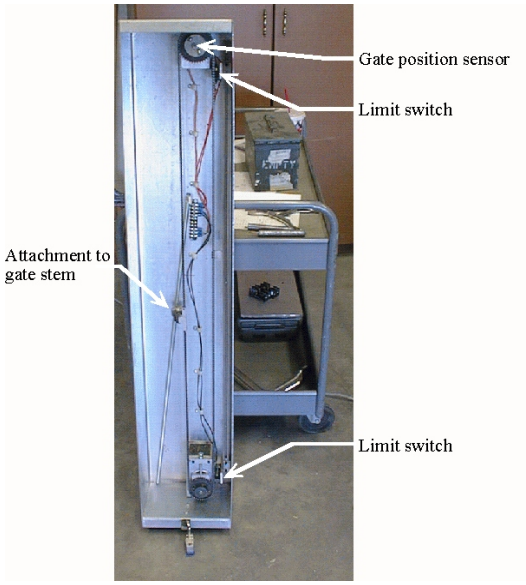
While developing a low-cost solar-powered gate actuator, Reclamation staff determined it that is relatively easy to attach a 12-VDC gear motor to an existing slide gate. This can be accomplished with a chain and sprocket (see Photograph 6). What is more complex is

Photograph 6 - The 12-VDC motor and second prototype are attached to the brass lift nut on the gate stem.

measuring gate position and installing limit switches. Measuring gate position is important because it provides necessary information on the state of the remote-control system (and can also be used to estimate flow). The limit switches are critical because they protect the gate from being closed too tightly or opened too wide.

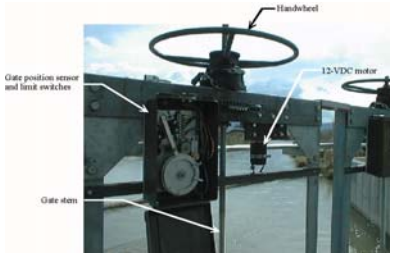
Frank Woodward, of Reclamation's Provo Area Office staff, developed two prototypes which measure gate position and provide limit switches (www.usbr.gov/uc/provo/progact/ca/prototypes.html). The first prototype mounts over the gate stem and is designed for a gate system where the stem moves up and down in sync with the gate (see Photograph 7).

As the gate stem moves, a good potentiometer tracks gate position. The limit switches are triggered as the gate moves toward its extremes.



Photograph 7 – The first prototype is mounted over the gate stem and houses the gate position potentiometer and limit switches.

The second prototype (see Photographs 6 and 8), was designed for gates where the stem does not move up and down. On this unit, a gear box is attached to the gate stem lift nut with a chain and sprocket. The gear box is connected to a disk which activates the potentiometer and triggers the limit switches. Because there is increasing interest for integrating image monitoring into gate control systems, the first prototype (which covers the gate stem, a useful visual monitoring point), it may not be appropriate for



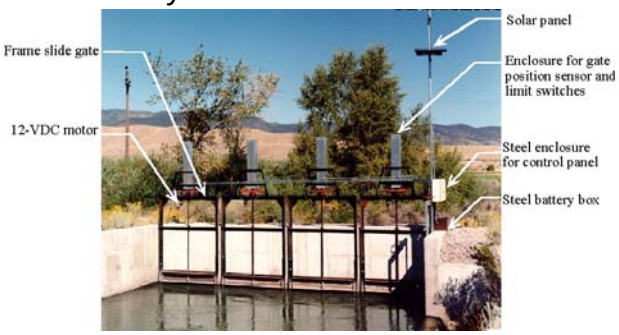
Photograph 8 – The second prototype (center left) attaches to the gate stem lift nut with a chain and sprocket and also includes a gate position sensor and limit switches.

systems which include a camera. In addition, the first prototype is visually obvious and, for this reason, susceptible to vandalism.

The second prototype overcomes these two problems. The diversion structure for the Richfield Canal is an example of the second prototype. A real-time image of this structure can be seen at www.sevierriver.org/webcams (see Photograph 9).

Photograph 9 - This webcam image of the gates on the Richfield diversion structure updates every 10 minutes. Staff gauges are attached next to each gate stem to provide visual confirmation of gate position.

Typical of the solar-powered field sites currently in operation is the diversion structure on the Sevier Valley/Piute Canal, Richfield, Utah (see Photograph 10). The structure has four large slide gates (each is 2-meters square) which are moved up and down by fractional-horsepower 12-VDC motors. A 40-watt solar panel charges two deep-cycle (130 amp-hr) batteries which provide ample power for the system. The solar-powered automation system was retrofitted onto the existing structure using the first prototype described above.



Photograph 10 - The diversion structure for the Sevier Valley/Piute Canal illustrates the successful implementation of a solar-powered canal automation system.

Photograph 11 - 12 VDC Commercial gate actuator installed at the head of Vermillion Canal.

While the example above uses a "do-it-yourself" type gate actuator, purchasing a 12- or 24-VDC commercial gate actuator is now possible. Today, AUMA and Rotork have DC models, as does Limitorque. Reclamation has installed several Limitorque 12-VDC actuators (see Photograph 11). Most have been in operation for several years and have worked well. A typical commercial gate actuator costs between $3,500 and $6,000, excluding installation. The product comes with a manual control box, limit switches, a torque limit, and a gate position sensor. In the Sevier River Basin, commercial gate actuators were typically installed on radial gates and "do-it-yourself" models on vertical slide gates.

Three of the major reservoirs in the Sevier River Basin have existing or retrofitted hydraulic gate actuators which consist of an AC motor, hydraulic pump, and head-control valves. These were upgraded to remote control by the addition of: (1) an electronic solenoid control system installed in parallel with the existing hand valve system, and (2) a gate position sensor.

Table 3 provides a description of each of the gate actuators installed in the Sevier River Basin since 1994.

Table 3
Gate Actuators Installed in the Sevier River Basin

Function/Facility	Type of Actuator	No. of Gates Automated	Date Installed	Power	Notes
Water Storage Dams					
Panguitch Lake	Do-It-Yourself, Type I	1/1	1998	Solar	
Otter Creek Dam	Hydraulic	2/2	2000	Commercial	
Piute Dam	Hydraulic	1/1	2003	Commercial	
Sevier Bridge Dam	Hydraulic	3/3	2004	Commercial	
DMAD Dam	Do-It-Yourself, Type I	3/3	1993	Solar	
Diversion Structures					
Monroe/South Bend	Do-It-Yourself, Type I	1/2	1997	Solar	
Sevier Valley/Piute	Do-It-Yourself, Type I	4/4	1997	Solar	
Joseph	Do-It-Yourself, Type I	1/1	1998	Solar	
Monroe	Do-It-Yourself, Type I	1/2	1999	Solar	
Elsinore	Do-It-Yourself, Type I	1/1	1997	Solar	
Richfield	Do-It-Yourself, Type II	3/3	1994	Solar	Type I until 1996
Annabella	Commercial	1/1	1997	Solar	
Vermillion	Commercial	1/1	1997	Solar	
Westview	Do-It-Yourself, Type I	1/1	2000	Commerical	River gates: Commerical
Gunnison/Fayette	Do-It-Yourself, Type I	1/1	2000	Commerical	River gates, Commercial
Central Utah	Do-It-Yourself, Type I	1/2	1999	Solar	
Vincent	Do-It-Yourself, Type I	1/2	2003	Solar	
Leamington	Do-It-Yourself, Type I	2/2	1999	Solar	
Canal A	Do-It-Yourself, Type I	3/3	1993	Solar	

Solar Power Systems

Solar-energy systems are an important component of the Association's water management network. Typically, the equipment costs for a solar-energy system are less than 10 percent of total field installation costs. A system can be as simple as a small solar panel (10 to 40 watts), a charge controller, and a battery (see Figure 5). The cost can be as little as $200 for a 10-watt system and $500 for a 40-watt system. When comparing this cost to the thousands of dollars which are frequently required to hook up to the utility grid, a solar-energy system can be a very cost-effective alternative. The basic components for the Sevier River system include:

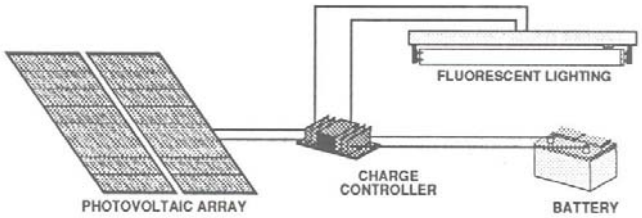


Figure 5
Schematic of a Regulated 12-VDC Solar-Powered System Like That Used on the Association's Gate Control Systems.

- The solar panels (or photovoltaic cells) which generate electric power are widely available and low-cost. The ones used on the Sevier River real-time system are manufactured from silicon, the same material that makes up sand. They are single-crystal type and uniform in color (blue). A specially-designed pole mount is used to fix the solar panel at the correct angle to the sun (see Photograph No. 10). A 10-watt solar panel, enough to power a typical flow monitoring site, costs approximately $100, and the pole mount an additional $25. A 40-watt solar panel, which provides enough energy to power a multiple-gate control system, costs approximately $240 and the pole mount an additional $40. Better quality solar panels have an expected life of 20 years.

- Batteries store the electrical energy generated by the solar panels during sunny periods for delivery whenever the modules cannot supply power. At environmental monitoring sites, captive electrolyte (gel) batteries are used. These 12 amp-hr. batteries cost approximately $40. At control sites, one or more deep-cycle lead-acid battery is used. These 130 amp-hr. batteries cost approximately $70 each and have a 3-year life cycle.

- Charge controllers are used at all sites and cost approximately $40. Their primary function is to protect the battery from overcharge and undercharge. Any system that has unpredictable loads requires a charge controller and/or low-voltage disconnect. The lack of a controller on water resource monitoring and control systems can result in shortened battery life and decreased load availability.

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CHAPTER III

THE BASIN'S SKIN

Millions of measuring devices, including cameras, temperature and rain gauges, water and air quality monitors, and gate position and water-level sensors are popping up everywhere on the earth's surface. Experts predict that by 2010 there will be 10,000 telemetric devices for each human on the planet. This number is not particularly surprising in and of itself – there have been sensors for a long time, ranging from piezometers in earth-fill dams to flow monitoring stations on major rivers. What is surprising is that our planet is evolving into a single vast network made up of billions of interconnected processors and sensors.

What is happening on the earth's surface has been compared to the human skin. Skin is a unique piece of engineering and the human body's largest organ. It has the ability to measure and sense temperature and the movement of air; it can size up objects and identify their structure. It achieves all of this with the help of a huge number of tiny integrated chemical sensors that communicate with each other through the nervous system. As Neil Gross pointed out in *Business Week* (1999), a skin of a similar sensitivity is enfolding the earth right now. Or more to the point of this study, a skin is enfolding the Sevier River Basin.

Environmental Monitoring System

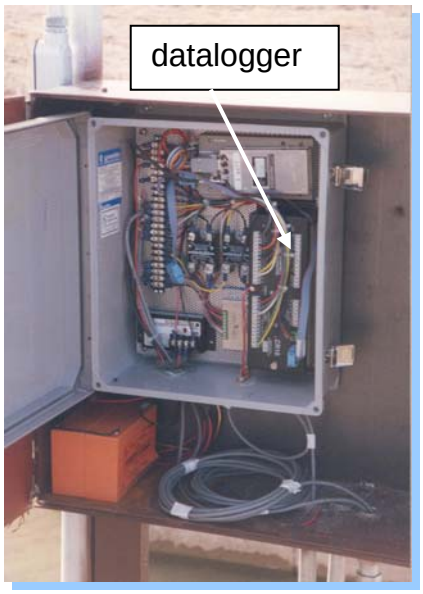
The sensors that monitor the Basin's epidermis are varied and extensive. The Association has its own network in place which compliments systems operated by the U.S. Geological Survey (USGS) and the Natural Resources Conservation Service (NRCS). Also monitoring environmental conditions in the Basin are the Bureau of Land Management (BLM) and the Forest Service (USFS) as part of their weather reporting system. This report will concentrate on the network installed by the Association, but will briefly mention the information available from the USGS. Much of the Sevier system was completed prior to the current TOP-funded project, but major gaps in the system were filled in during the period since 1999. For a current summary of the real-time monitoring system, see Table 4.

A key component of a field monitoring site is the datalogger (see Photographs 12 and 13). This device controls the sensors, and time stamps and logs the data collected from the sensors.

Table 4
Sevier River Basin Real-time Monitoring Sites (Including USGS)
Identified by Type and River Segment (2003)

Type of Site	Segment				Total
	Upper	Central	Gunnison	Lower	
Reservoir	3	0	1	3	7
River	6	3	2	2	13
Canal Diversion	1	9	4	7	21
Canal/Pond	0	10	0	0	10
Weather	0	3	1	0	4
Total	10	25	8	12	55

Photograph 12 - An important component of a field site is the datalogger.



Photograph 13 - Datalogger installed at Vermillion Canal diversion structure. Note the fiberglass enclosure to protect the electronics from the environment and the steel enclosure to protect from vandals.

Environmental Sensors

The Sevier River network uses a variety of sensors to monitor environmental conditions.

River and Canal Flows

The Association currently monitors river and canal flows at over 30 locations along the Sevier River, its tributaries, and its irrigation distribution system. Additionally, the USGS monitors flows at seven (7) locations on the river (this number was reduced to four in 2003). The general location for the various sites is shown in Table 4.

To monitor flow, typically a stilling well is constructed adjacent to: (i) a weir, (ii) a flume, or (iii) a rated section of river or canal. By measuring the height of water in the stilling well and knowing the characteristics of the adjacent channel or structure, a flow can be estimated.

To continuously measure the height of water in the stilling well, a potentiometer geared to a float and pulley is the most commonly used technology in the Basin. This sensor system provides input to a datalogger which records the data at regular intervals. Other sensors used to measure water level include: pressure transducers (see below), incremental shaft encoders, and bubblers.

Reservoir Storage

The Association currently monitors reservoir elevation at seven (7) locations: (a) Panguitch Lake, (b) Otter Creek Reservoir, (c) Piute Reservoir, (d) Rocky Ford Reservoir, (e) Sevier Bridge Reservoir, (f) DMAD Reservoir, and (g) Gunnison Bend Reservoir. The general location of the reservoir monitoring sites is shown in Figure 2. Additionally, water level is measured behind four diversion structures and on one irrigation pond.

To monitor water level at a diversion structure or in a pond, a potentiometer geared to a float and pulley is used. To monitor water level in a large reservoir, typically a pressure transducer is installed. The transducer measures the pressure exerted vertically by the water over the sensor; this can then be converted to a reservoir level. As with a flow monitoring site, the transducer is connected to a datalogger.

Once the elevation of the water in a reservoir is known, the quantity of water stored and its surface area can easily be computed. This is done using area-capacity tables developed at the time a dam is constructed, or as a part of subsequent engineering studies.

Gate Position

An important measurement for computing water flow and assessing the status of automation projects is knowing gate position (how wide a gate is open). This is accomplished by attaching a potentiometer to the gate stem or gate (see Photograph 6).

Water Quality

The Association has a developing network of salinity sensors. Salinity management in the lower Basin is a constant concern. If irrigation water is too saline, it is detrimental to crop yields. To measure salinity, a specific conductance sensor is used. This sensor measures the ability of water to conduct electricity. The better water conducts electricity, the

higher the salinity level in the water. If the salinity sensor is located near a flow monitoring site, the same datalogger can be used for both.

Dam Safety

In 2001/2002, a structural dam safety fix was applied to Otter Creek Dam. As part of this fix, a series of wells and piezometers were installed in the dam. At the recommendation of the Association, the Utah dam safety program funded the installation of electronic sensors in the wells. These sensors were attached to the datalogger already at the damsite. Additionally, starting in 2003, the two major drains from the dam were electronically measuring drainage flow. The information from the piezometers and drains are important measures of the structural integrity of the dam.

Starting in 2003, a similar program was initiated on Piute Dam. And in 2004, it is anticipated that Sevier Bridge Reservoir will be added to the structural dam safety monitoring program.

Weather

The Association currently has five weather stations operational in the Basin (see Figure 5). Each site monitors: (i) air temperature, (ii) wind speed and directions, (iii) relative humidity, and (iv) solar radiation. Each of the four sensors is attached to a datalogger. In addition to the Association's weather network, NRCS operates a snow monitoring system (SNOTEL). This information is complementary to the Association's weather network.

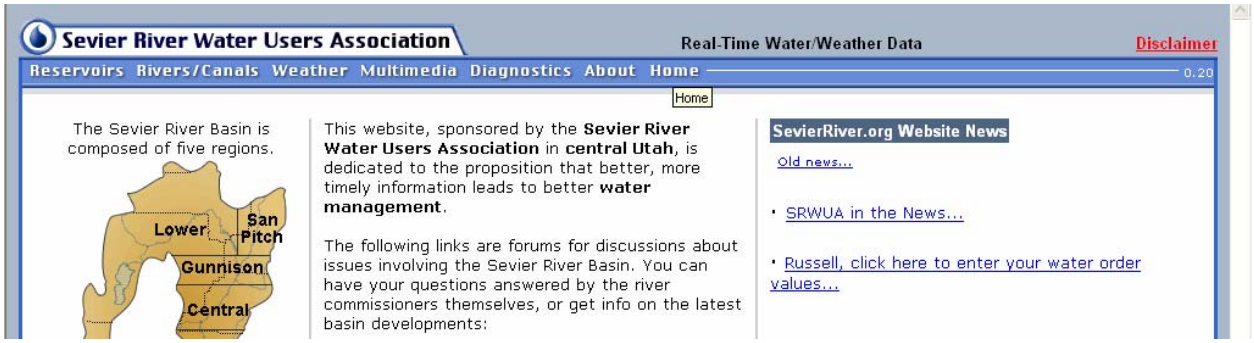
Real-Time Images

The Association also has a developing network of webcams (see Photographs 9 and 13). Cameras are important sensors for critical sites because they (a) provide a redundant reading for parameters like water level and gate position, (b) provide important visual confirmation on the state of the automation system, (c) provide important weather information to forecasters, (d) enhance site security, and (e) help deter vandals.

Controllers

The datalogger used for monitoring (see photograph 12) has eight ports which can be used for gate control. Typically, two ports are used to control one gate (one to move the gate up and the second to move the gate down). The algorithm to move a gate is a modified industrial PID (proportional- integral- derivative) controller. This is a type of feedback controller where output is based on the error between some user-defined set point (i.e., desired flows in a canal) and some measured process variable (i.e., actual flow in a canal). Reclamation research has demonstrated that only the PI elements of the algorithm are required in irrigation applications (Wahl, undated).

Once a motorized gate is wired to the datalogger using relays, a gate system can be programmed to maintain either a constant level in a pond or a constant flow in a canal. Prior to installing gate automation systems in the Sevier River Basin, the flow in a canal would fluctuate as the river fluctuated, frequently providing irrigators with either too much or too little water.



CHAPTER IV

THE BASIN'S CENTRAL NERVOUS SYSTEM

According to Stanley Bolanowski, neuroscientist and associate director of the Institute for Sensory Research at Syracuse University: "When the nerve cells in the human skin are stimulated, physical energy is chemical transformed into energy used by the nervous system and passed from the skin to the spinal cord and brain. It's called transduction, and no one knows exactly how it takes places." Suffice it to say that the process involves the intricate, split-second operation of a complex system of the signals between neurons in the human skin and the brain.

Something analogous to the human nervous system has coalesced in the Sevier water management network. Information collected by the field dataloggers associated with the network's "skin" and "circulatory system" is "transduced" or communicated to the network's "brain" using a variety of radio systems. At the Richfield airport a Datahut is starting to function as the network's brain.

Communication System

Information is communicated between the field sites and the Datahut by line-of-sight radio. This system has been slowly evolving.

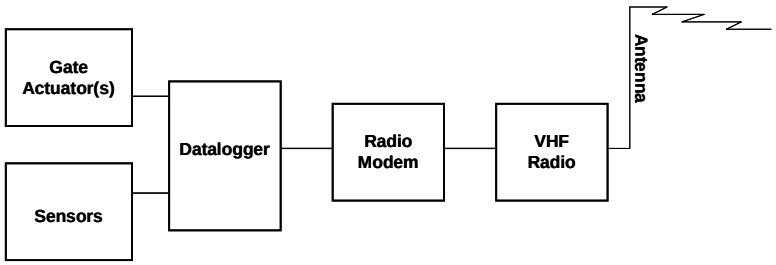


Figure 6
General Configuration for a First-Generation Field installation (i.e., Sevier Valley/Piute Diversion Dam

First- and Second-Generation Field Sites

At the start of the TOP-funded project in 1999, the communication network was largely VHF-radio based (see Figure 6), with a few telephone links to areas too remote to reach by radio. Radio was the preferred method of communication because after installation costs there were no monthly charges. The components for the initial Basin real-time communication system included: (1) VHF telemetry radio, (2) antenna and cable; and (3) a radio modem. The basic cost of the communication equipment for one site is approximately $850. The function of the communication network is to transmit information from field sites to the Datahut or "brain" on an hourly basis.

Because of equipment evolution and changing Association needs, a more complex configuration has been used on recent major installations (see Figure 7). The newer configuration is similar to the one described above except it is designed like a network, with web appliances attached. Communication is by spread-spectrum radios to increase bandwidth. The basic cost of the system is approximately $1,300. Installations of this type have been installed on the Richfield diversion structure.

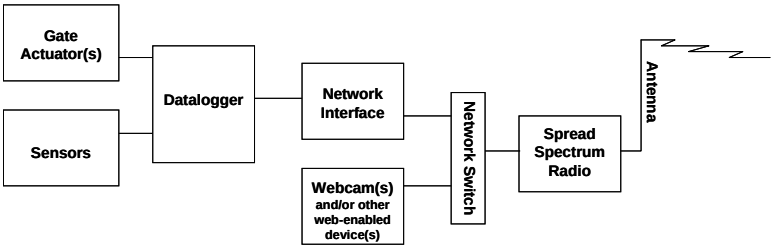


Figure 7
General Configuration for a Second-Generation Field Installation (i.e., Richfield Diversion Dam)

Third-Generation Field Sites

In 2002, the manufacturer of the dataloggers used by the Association started marketing a product that is a combination mini-datalogger and low-wattage spread-spectrum radio. This unit is less than half the cost of the systems described above, thereby making it very attractive for low-cost applications (see Table 4). While the comparison in Table 4 is somewhat misleading for reasons discussed below, it is indicative of future possibilities.

The general configuration currently being used at one location in the Basin is shown in Figure 8. Two low-cost units are networked with a master spread-spectrum system (i.e., second-generation system). At Richfield diversion dam, two nearby monitoring sites (Monroe Canal flume and Sevier River at Elsinore) are networked to the Richfield datalogger.

Table 4

Equipment Cost Comparison
For Three Generations of Field Sites

	Generation		
Equipment	**First**	**Second**	**Third**
Datalogger	$1,200	$1,200	$850
Radio/Coax/Antenna	500	1,300	
Radio Modem/Cable	350		
Network Interface		300	
Totals	$2,050	$2,800	$850

Figure 8
General Configuration for a Third-Generation Field Installation (e.g., Richfield Diversion Dam)

Brain/Base-Station/Datahut

Since 1997, the base station for the Association's water management network has changed considerably. What started out as a personal computer running the DOS operating system in a water manager's home has evolved into a sophisticated data center. At the beginning of the TOP project grant period, it became obvious to the water users and the integration contractor (StoneFly), that a dedicated facility for radios and computers would make the system more reliable and easier to expand. With the help of Reclamation, a 20x8x8 foot steel cargo container was retrofitted as a climate controlled data center. The container, soon coined the Datahut, was located on the outskirts of the Richfield City airport (see Photograph 14).

Photograph 14 - Richfield Airport Datahut as seen from the air.

The Datahut serves as the brain center and the nexus of a radio, telephone and satellite telemetry network that spans six counties. The Datahut is connected to the Internet by a T-1 data line. A firewall/router, running the Linux operating system, secures the Datahut from the Internet. A dual-processor server with triple redundant power supplies and a SCSI RAID storage system hosts a database, Web, DNS and mail services. Additionally this machine, also running the Linux operating systems, runs several real-time models which calculate evapotranspiration data in the Basin and recommended water release schedules. The actual task of communicating with the fifty-plus remote telemetry stations in the Sevier River Basin is handled by a dedicated server running Microsoft Windows 2000 Professional and data collection software provided by the vendor of the telemetry-station/datalogger hardware (see Figure 9).

At present, six water user's homes are connected via wireless links to TCP/IP service in the Datahut. This allows them to have reliable and high-speed access to real-time data and also to the Internet. These links are operated on a variety of frequencies including 900 MHz frequency hopping spread spectrum radio and 2.4 GHz direct sequence spread spectrum. Several of these links are over 10 miles in length. Having the key water users connected directly to the Datahut has proven to be very helpful, and it is expected that additional water users will obtain connections over time.

Diagnostics and emergency backup have been incorporated into the Datahut. All servers and radios can be run for several hours by a battery-powered, backup-power system. Should power not be restored within 30 minutes, a propane powered generator automatically starts and can run the Datahut for 24 hours. Several cameras are mounted on the Datahut and provide remote visual monitoring capabilities (see Photograph 15). The doors and interior are equipped with intrusion sensors. An Open

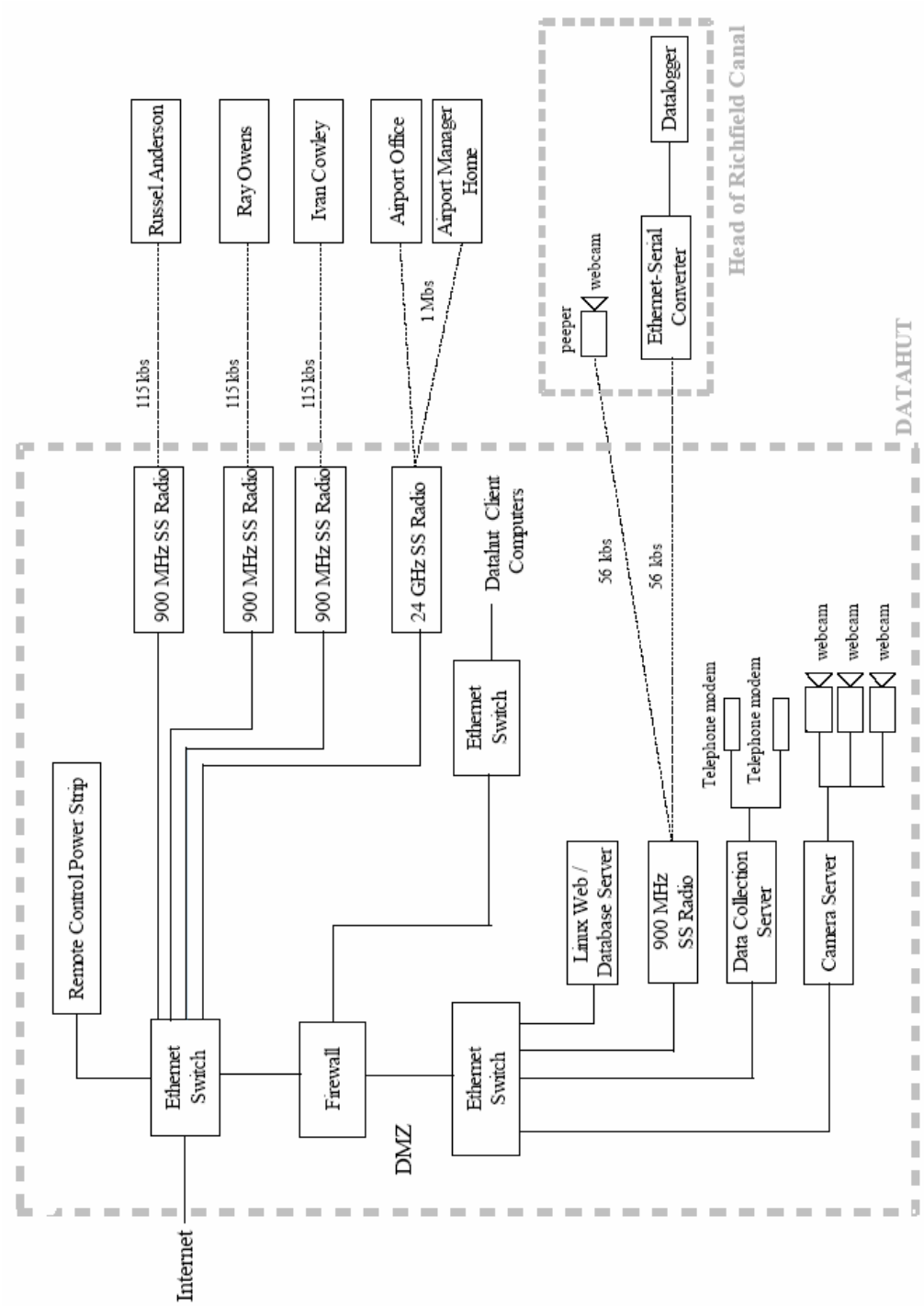


Figure 9
Network Topology for the Richfield Airport Datahut

Source software package call Nagios (www.nagios.org) running on a Linux server is used to monitor the performance and availability of all the computer systems, telemetry stations, and communication links. Nagio will send out email and/or pages when there are failures such as low battery voltages at telemetry stations or failed radio links.

Photograph 15 - The webcam image of the interior of the Richfield Airport Datahut updates every 10 minutes.

At critical locations, far from Richfield, it was determined that adding additional Datahuts was impractical because of cost, security, and other concerns. So a high-speed link to the Internet was developed instead. The topology for a typical secondary site is shown in Figure 10.

The Sevier River Basin real-time monitoring and control network generates a great deal of information. (The general path for the data collection is shown in Figure 11.) Much of the information that is collected is useful to individuals and organizations other than the Association. For example, kayakers can use stream and canal flow data to determine if conditions are right for kayaking (see Photograph 16). However, there was a concern about the best and most efficient method to dispense the data.

Photograph 16 – Kayaker honing his skills on Richfield Canal water measurement flume.

At the recommendation of StoneFly Technology (Berger et al., 2001), it was decided to dynamically connect the environmental monitoring network to the Association's website: www.sevierriver.org. Early efforts at displaying real-time information over the world-wide web proved highly successful. As part of the TOP project, the capabilities of the Association's website were greatly expanded and its scope was extended to include the entire river basin.

The software that runs www.sevierriver.org is based on Open Source packages (Berger and Maxwell, 2004). The Open Source software movement has created many popular, robust, and secure programs, including the Linux operating system and Apache web server. In the spirit of giving back to the open software community, StoneFly started the OpenBasin software project in 2003 (Berger and Maxwell, 2004). At the project's website (www.openbasin.org), software that runs the Association's website is being rewritten and released to the public. It is hoped that a community

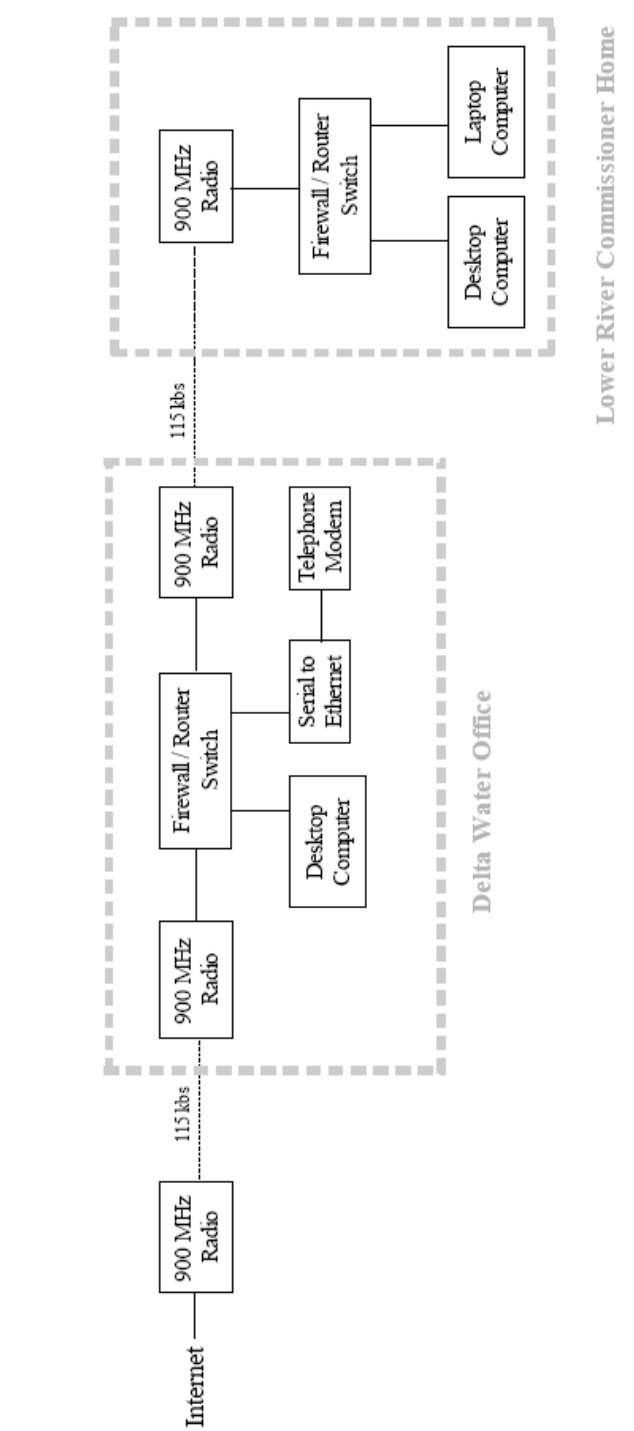


Figure 10
Network Topology for a Secondary (Delta Area) Site

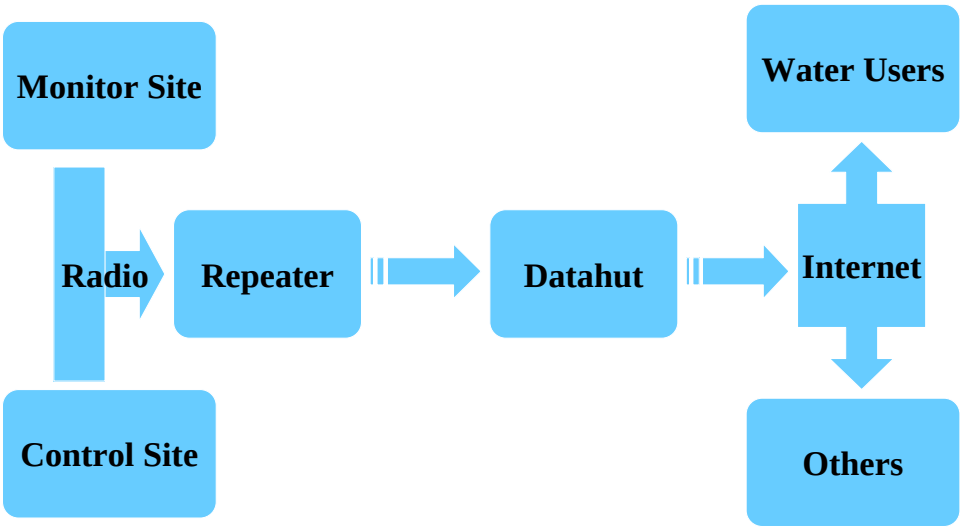


Figure 11
Flow of Information on the Sevier River Basin Water Management Network.

of users will evolve that will use, test, and enhance this software to the benefit of all.

Water Management Website

The real-time web site developed by Stonefly consists of four major data collection categories: reservoirs, rivers/canals, weather, and snow-pack. By clicking on a selection from the navigation bar, the user is taken to a page where specific measurement locations in a given category can be selected. For example, under the "Reservoir" menu, the web page presents the user with a schematic diagram of the reservoirs in the Sevier River Basin (see Figure 12). The relative size of the teacup indicates the storage capacity of the reservoir. The current storage in the reservoir is indicated by the level in the teacup. By clicking on individual teacups, one can get a time-series graph of reservoir elevations. In addition to the teacup diagram, a table showing the reservoir elevations is included on the same page. Since data

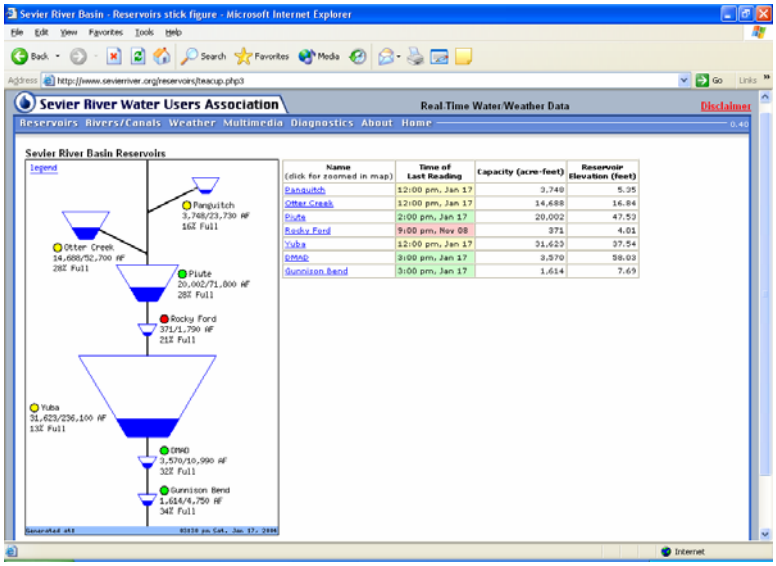


Figure 12
Real-Time States of All Major Water Storage Reservoirs in the Sevier River Basin.

transmission between the reservoir and the web site is not always perfect, each measurement is color coded to indicate how old it is. For example, red indicates a measurement over 24 hours old.

The pages under the "Rivers/Canals" menu item allow the user to select one of six individual sub-basins along the Sevier River. Each sub-basin displays monitoring points along the river. The monitoring points are represented on a schematic map which graphically shows the geographical relationship of the stations on the river (see Figure 13).

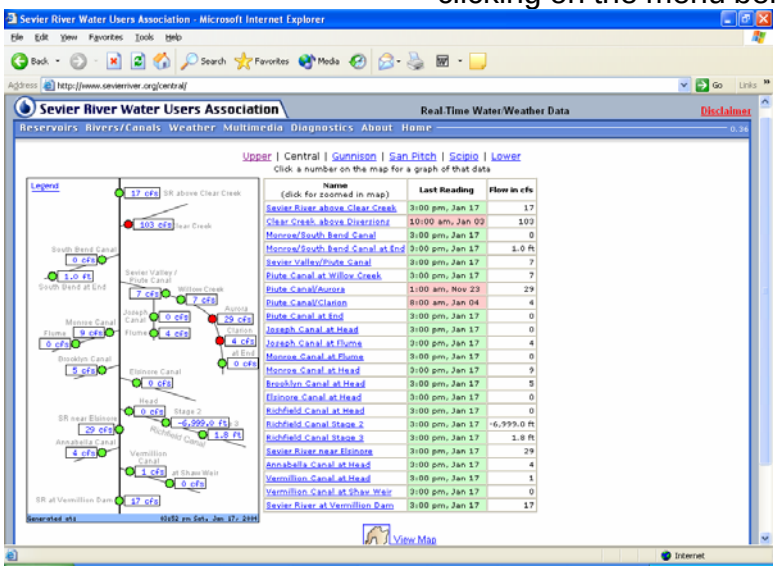


Figure 13
Spatial Diagram Displaying Real-Time Information for a Stretch of the Sevier River

By clicking on the station, the user can "drill down" using the graphing tool to get more detailed data. Figure 14 shows a 7-day time-series graph of streamflow. Figure 15 shows a similar time-series graph for the Sevier Valley/ Piute Canal. There are five flow monitoring sites along the canal and Figure 15 has all five plotted on the same graph. This allows the canal manager to survey the entire canal at a glance. With the time-series graphs, the user can change the time period of the graph by clicking on the menu below the displayed graph. It is also possible to move forwards and backwards in time with the graphing tool. An option for outputting a publication-quality version of the graph in Adobe Acrobat format is possible.

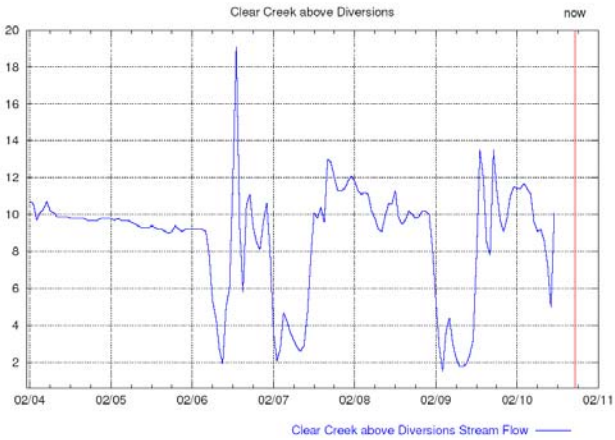


Figure 14
Time-Series Plot Displaying Hourly Flows at a River Gauging Site for the Previous 7 Days.

Weather and snow pack information is accessed by clicking on the "Weather" menu. A basin wide weather overview map is shown in Figure 16. Snow pack information is of great interest to the water users during the winter months. NRGS monitoring stations high in the mountains measure the depth and water content of the snow. After each snow storm, the website is heavily viewed by users who want to see how much snow pack was gained. Figure 17 shows a graphic summary of the snow pack data for a single station.

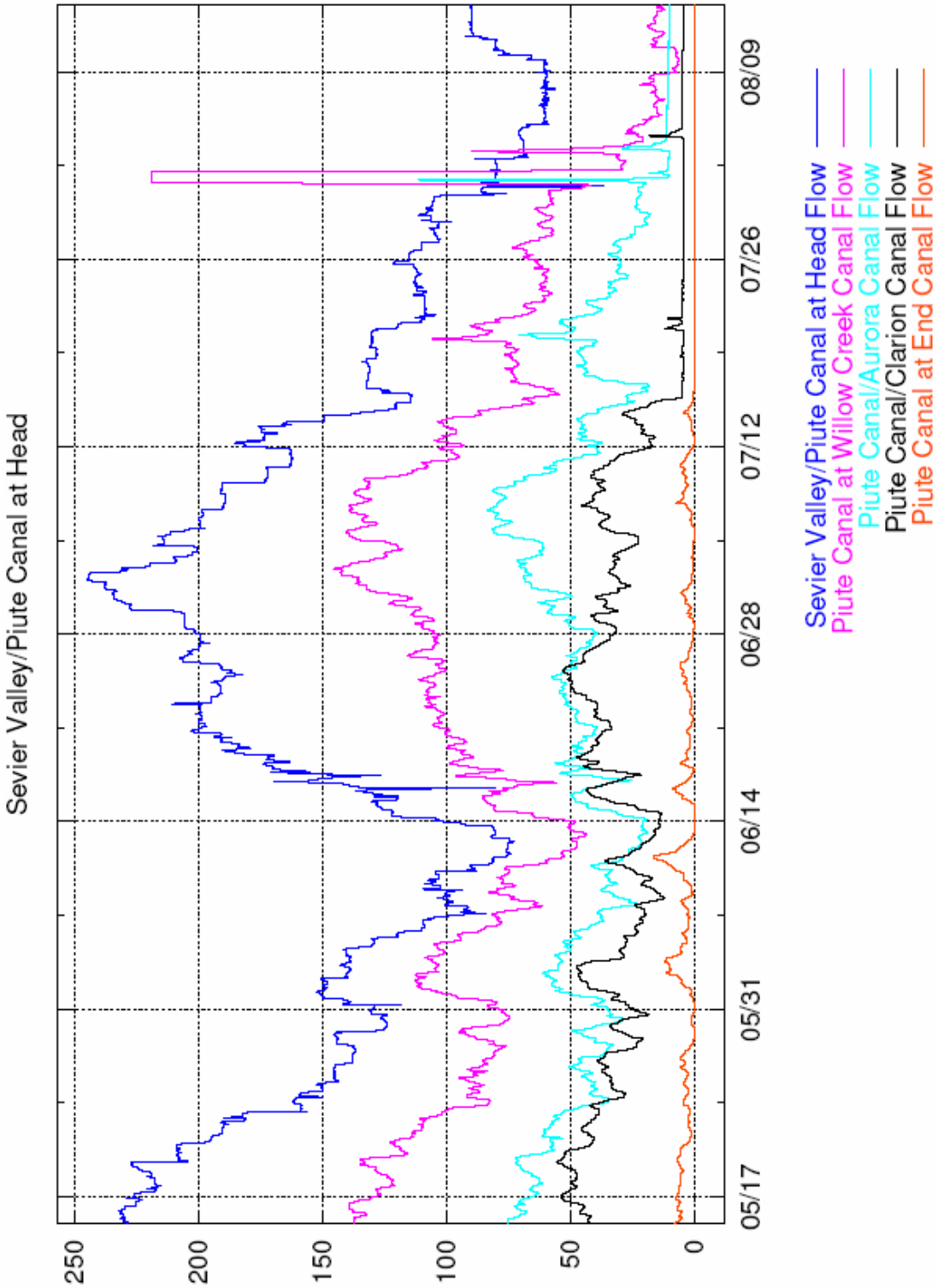


Figure 15
Time-Series Plot (in PDF Format) Displaying Hourly Flows on Five Locations on the Sevier Valley/Piute Canal for a 3- Month period in 2003

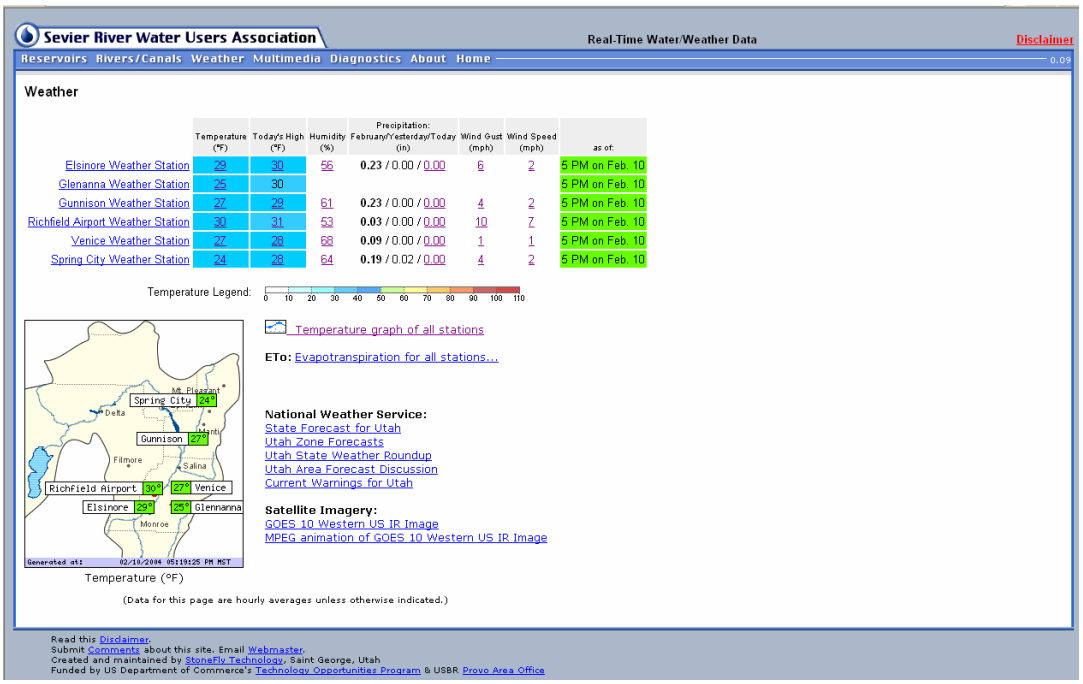


Figure 16
Real-Time Weather Information Summary
for the Sevier River Basin

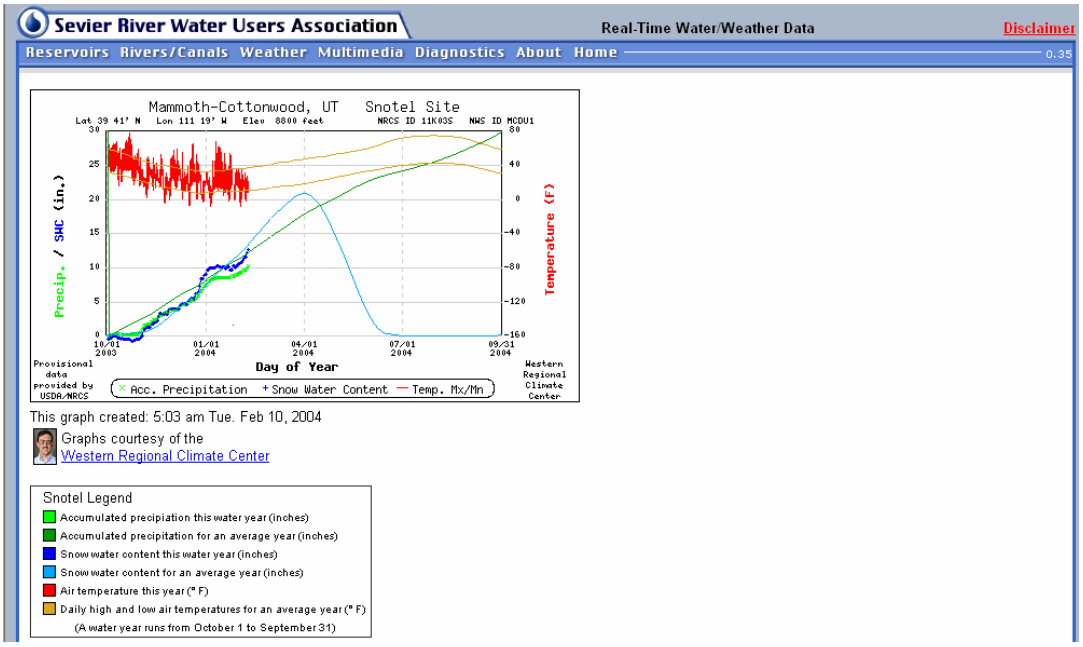
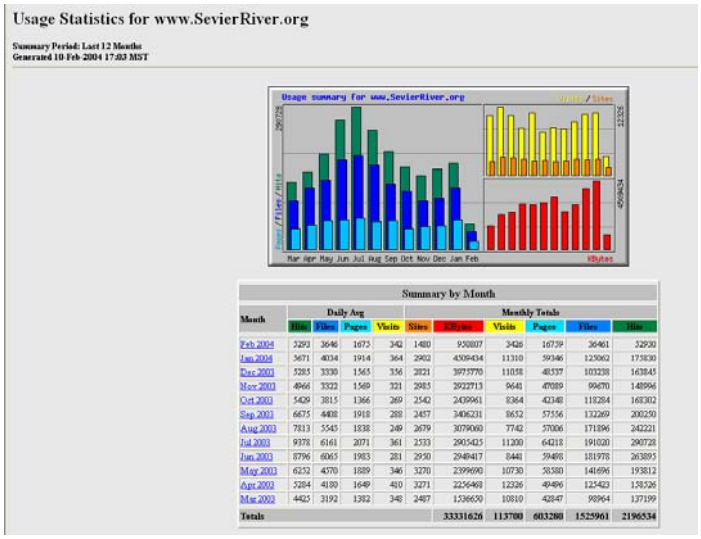


Figure 17
Time-Series Plot of Snow Depth (SNOTEL) Information

Web Cameras

A popular part of the www.sevierriver.org web site is the web camera section. These cameras display live still images taken from a variety of locations including the head of the Richfield Canal and the Richfield Airport Datahut. (see Photograph 9). A website visitor is able to view a current image (taken once every 10 minutes) or an archive of images taken over the past 24 hours. The camera on the Richfield Canal allows the operator to visually confirm the height of the gates and to inspect for trash accumulation. There are three cameras at the Datahut. One monitors the interior of the Datahut, and the other two are pointed at the western and southern skylines. Images from these "weather cameras" are collected and used by the National Weather Service in Salt Lake City to verify on-ground conditions.



Month	Daily Avg Hits	Daily Avg Files	Daily Avg Pages	Daily Avg Visits	Monthly Totals Sites	KBytes	Visits	Pages	Files	Hits
Feb 2004	5293	3646	1673	342	1480	930807	3426	16739	36461	52930
Jan 2004	5671	4034	1914	364	2902	4509434	11310	59346	125062	175830
Dec 2003	5285	3330	1565	356	2821	3975770	11038	48537	103238	163845
Nov 2003	4966	3322	1569	321	2985	3922713	9641	47089	99670	148996
Oct 2003	5429	3815	1366	269	2542	2439961	8364	42348	118284	168302
Sep 2003	6675	4408	1918	288	2457	3406231	8652	57556	132269	200250
Aug 2003	7813	5545	1838	249	2679	3079060	7742	57006	171896	242221
Jul 2003	9378	6161	2071	361	2533	2905425	11200	64218	191020	290728
Jun 2003	8796	6065	1983	281	2950	2949417	8441	59486	181978	263893
May 2003	6252	4570	1889	346	3270	2399690	10730	58380	141696	193812
Apr 2003	5284	4180	1649	410	3271	2256468	12326	49496	125423	158526
Mar 2003	4425	3192	1382	348	2487	1336650	10810	42847	98964	137199
Totals						33331626	113700	603288	1525961	2196534

Figure 18
Usage Statistis for www.sevierriver.org for the period March 2003 to February 2004

Website Usage Statistics

In order to gage the use and popularity of the web site, software was installed on the server which generates reports showing how users interacted with the web site (see Figure 18). Graphs and tables are created, which can themselves be viewed on the web site, which show how many users visited the web site, who these visitors were, what pages were popular, which pages were the first page to be visited, and many other views of how the web site was installed. Study of this data allows the web site creators to concentrate on improving the most popular parts of the web site and gain insight into how the web site is used.

Diagnostics

The canal and reservoir automation system extends over six counties and hundreds of square miles. Early on, the importance of troubleshooting tools was recognized. The website has several data products which allow the operators of the river network system to spot potential trouble with the automation equipment. Almost all of the automated gates are powered by solar-panel/lead-acid battery systems. Seeing a time-series graph of the battery voltage can tell the user a lot about the state of the power system. In Figure 19, a 7-day view of voltage level in a canal head gate system is displayed.

The daily charge/discharge cycle is clearly evident. Also easy to spot is a cloudy day, where the sun was obscured enough to depress the charging voltage. A common failure mode is the loss of one of the six cells in the 12-volt battery. This failure tends to occur after the batteries have been in service for 3 or more years. This type of failure is easy to spot in a

graph showing the battery voltage over time; the average voltage simply drops by about 2 volts. Another failure mode is the loss of a solar panel. Solar panels can be stolen (infrequently), damaged by gunfire, or blown off their mountings by extreme wind. The loss of a solar panel is also easy to spot on the time-series graphs. It shows up as a constantly discharging voltage with no evident charging during the day

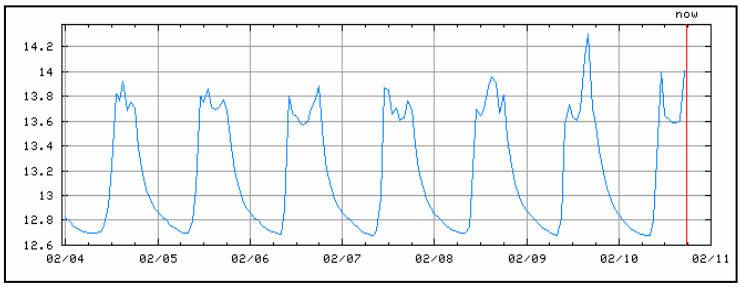


Figure 19
Time-series plot displaying hourly voltage level at a solar-power canal automation site.

The Datahut is instrumented with temperature sensors (see Figure 20). This allows the system operators to observe the operation of the air conditioning system and insure that overheating does not occur. Several times during 2003, the temperature monitoring system helped head off potential equipment damage when the air conditioner had inadvertently been turned off.

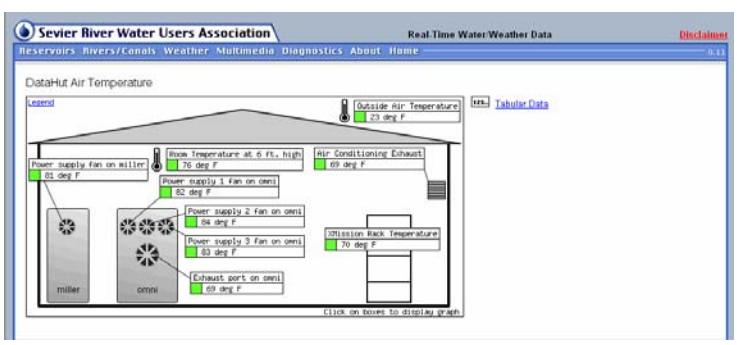


Figure 20
Real-time Temperature Readings Inside and Outside the Richfield Airport Datahut

Diagnostics of a totally different nature are also provided. To track the status of the real-time water measurement system, water balances are computed. The basic computation in hydrology is the Continuity Equation:

$$\Delta S = I - O \quad (1)$$

Where O is outflow, I is inflow, and ΔS is the change in water storage. For the three major reservoirs in the Sevier River Basin, all the major variables are measured or can be estimated:

$$\Delta S = RI + P - RO - E \quad (2)$$

where RI is river inflow, P is precipitation, RO is reservoir outflow, and E is evaporation. With each of these variables known, a daily error term can be computed. If this error term is consistently high or low, then there is a problem with one or more of the water measurement parameters.

Interactive Voice Response System

To allow the water users better access to real-time data, an Interactive Voice Response (IVR) system was added in 2003 (see Figure 21). Often users will need access to data, but are not in the vicinity of an Internet-connected computer. The IVR system allows anyone to call a local telephone number in Richfield, enter a 3-digit station ID, and receive a voice report

Figure 21
Instructions and Site Identification Numbers for the Sevier River Network IVR System

of a current data value (water flow in a canal, for example). The website contains a table with the listings of all the station IDs. A version of the station ID table is also available in Adobe Acrobat (pdf) format which allows a user to print out a single-page, formatted version that can be carried with them for reference.

Weather Banners

To make the data generated by the weather stations more accessible to the general public in 2001, programmers at StoneFly created "weather banners". Weather banners are small graphics files which provide a weather summary for each weather station in the Sevier River Basin. An updated banner is created automatically for each station once per hour. These weather banners may be included by webmasters on local websites. For example, a local radio station in Richfield (KSVC), posts several weather banners on their main webpage (see Figure 22).

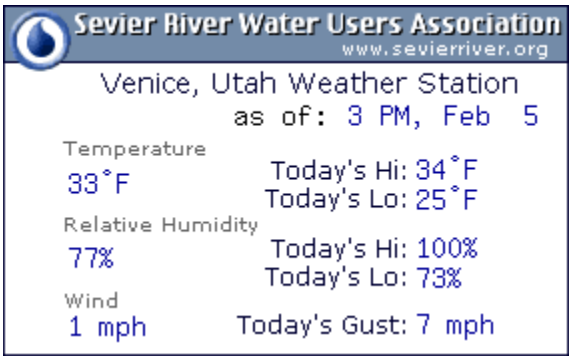


Figure 22
Weather Information Banners Provided by the Association to the Local Media.

This arrangement has reciprocal benefits. The radio station is able to offer its website visitors weather data at no cost to the station. The Association gains additional attention for its website, since each weather banner has the water user's logo and website URL.

Real-time Water Rights

Water users in the Sevier River Basin of central Utah (both individual irrigation companies and local communities) are entirely dependent on controlling, diverting, and using water from the river. River flows are not now, nor have they ever been, sufficient for all local water needs. As a result, an exhaustive system of water right allocations has evolved to divide water resources equitably. Prior to the implementation of the current real-time water management network, individual users found it very difficult to make timely determinations on how much water they had used or had remaining to use. This lack of "real-time" information resulted in either conservative cropping or over-application of water, both with the attendant limitations on farm income and negative impacts on water quality.

Water rights in the Sevier River Basin are defined on daily flows, diversions, and storage accumulations. The conceptual framework for programming the procedures utilized by the Sevier River Commissioners was used as a template to develop a computer-based system to compute primary and storage rights and their

allocation to right classes defined in the river's adjudication. All of the results are available day by day via the Internet at www.sevierriver.org.

Detailed water rights in the Sevier River are modeled by a software package called SEVIER III developed by Dr. Wynn Walker at Utah State University. The various algorithms have been verified and are now in use by the River Commissioners. Real-time data from river, canal, and reservoir gauging stations are now automatically loaded to a server at midnight and then processed by the SEVIER III software to provide real-time information on the varied individual rights (Walker and Hansen, 2004). The accounting system for each water right shows the accrual of the rights as well as the use and balances for each major users.

Figure 23 shows the allocation of water in the river's Section A (Upper Basin) in 2003. This figure allows any water user or manager to determine what components of the overall rights are accruing at any point in time. This information is then allocated to each right holder as shown in Tables 6 and 7. As a result of the real time capabilities in the Sevier River Basin and the data processing capabilities, the entire river system is now operated much like a commercial bank, in this case a water bank.

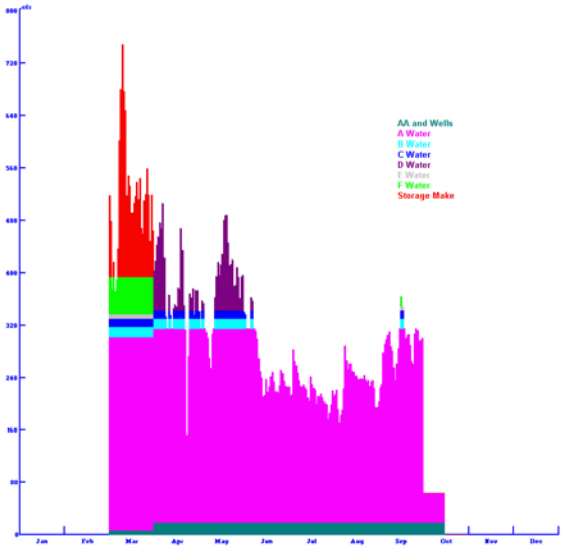


Figure 23
Section A Primary Accruals by Water Right Class in 2003

Artificial Neural Networks

Note: This section is the work of Dr. Mac Makee and Abelalrazq Khalil at Utah State University.

The Sevier River real-time monitoring system provides water managers, with better and more timely information on which to make decisions. Additional improvements can be made through the use of decision-support software. The emphasis in the TOP project was placed on fusing the available real-time data using artificial neural networks (ANNs) to obtain decision-relevant predictions at different time scales. An attempt was made during 2003 to integrate the ANN models into the Basin's information management system and website. This modeling effort is an early step toward sentience.

The ability of the brain to perform difficult operations and to recognize complex patterns has inspired researchers to simulate the functioning of the brain and thereby bypass the need to represent the physical details of systems in the form of complex equations or related empirical relationships. ANNs are practical information processing systems that provide methods for "learning" functions from observations. An ANN roughly replicates the behavior of the organic brain by emulating the operations and connectivity of biological

neurons (see Figure 24). This emulation, is done in a mathematical form that is greatly simplified from the biological prototype. The advantage of ANNs in engineering and other practical applications lies in their ability to learn and capture information from data that describe the behavior of a real system.

Table 6
Typical Account for a
"Primary" Water Right in the Sevier River Basin

Exit Print Year 2003 Month April

Day	AA/Well Water (af)	A Water (af)	B Water (af)	C Water (af)	D Water (af)	E Water (af)	F Water (af)	Total Right (af)	Use (af)	Balance (af)
1	6.71	31.18						37.89	39.67	0.0
2	6.71	28.80						35.51	35.46	0.0
3	6.71	26.56						33.27	33.72	0.0
4	6.71	27.07						33.78	32.65	0.0
5	6.71	25.95						32.66	29.75	0.0
6	6.71	24.94						31.65	29.75	0.0
7	6.71	21.28						27.99	29.75	0.0
8	6.71	10.76						17.47	29.75	0.0
9	6.71	20.64						27.35	29.75	0.0
10	6.71	24.03						30.74	30.08	0.0
11	6.71	29.37						36.08	37.69	0.0
12	6.71	22.53						29.24	35.95	0.0
13	6.71	23.92						30.63	33.72	0.0
14	6.71	23.60						30.31	33.72	0.0
15		25.62						25.62	33.72	0.0
16	6.23	40.70						46.93	11.90	35.0
17	6.23	38.92						45.15		80.2
18	6.23	25.93						32.16		112.3
19	6.23	28.08						34.31		146.7
20	6.23	26.08						32.31		179.0
21	6.23	23.86						30.09		209.1
22	6.23	23.47						29.70		238.8
23	6.23	22.61						28.84		267.6
24	6.23	24.59						30.82		298.4
25	6.23	23.88						30.11		328.5
26	6.23	21.98						28.22		356.8
27	6.23	22.70						28.93		385.7
28	6.23	25.04						31.27		417.0
29	6.23	23.20						29.43		446.4
30	6.23	25.57						31.80		478.2
31										
Total af	187.4	762.9	0.0	0.0	0.0	0.0	0.0	950.3	507.0	

Table 7
Typical Account for a
"Storage" Water Right in the Sevier River Basin

Exit | Print | Year 2003 | Holdover, af 0

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Beginning Credits, af	0.0	7167.1	8385.8	8713.9	7876.0	6812.8	5814.9	6662.2
Primary Credits, af								
AA + Wells, af	0.0	357.0	368.9	357.0	368.9	368.9	357.0	0.0
A Water, af	2243.6	1600.0	2569.3	1680.3	1504.6	1409.4	1185.9	0.0
B Water, af	0.0	0.0	98.2	0.0	0.0	0.0	0.0	0.0
C Water, af	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D Water, af	0.0	0.0	92.0	0.0	0.0	0.0	0.0	0.0
E Water, af	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F Water, af	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Primary	2243.6	1957.0	3128.4	2037.3	1873.6	1778.3	1542.9	0.0
New Storage Credits, af								
1st Increment (104,000)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2nd Increment (132,000)	0.0	0.0	0.0	130.7	129.9	30.2	16.1	0.0
3rd Increment (>236,000)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exchange Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Winter Water	4707.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DMAD Wells	274.0	816.8	754.3	0.0	0.0	0.0	0.0	0.0
Miscellaneous	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Transfers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New Storage	5081.6	816.8	754.3	130.7	129.9	30.2	16.1	0.0
Uses and Losses, af								
Canal Diversions	81.3	1418.0	3789.5	2889.3	2424.0	2365.7	656.5	359.0
IPA Diversions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sevier Bridge Losses	82.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
River Transit Losses	0.0	271.5	92.7	165.4	254.7	-139.2	3.4	0.0
DMAD Losses	2.2	84.5	190.4	459.6	585.4	543.2	214.2	39.1
Gunnision Bend Losses	-7.7	-218.9	-517.9	-508.4	-197.6	36.8	-162.6	-223.9
Total Use & Losses	158.1	1555.1	3554.6	3006.0	3066.5	2806.5	711.6	174.2
Ending Credits, af	7167.1	8385.8	8713.9	7876.0	6812.8	5814.9	6662.2	6488.0

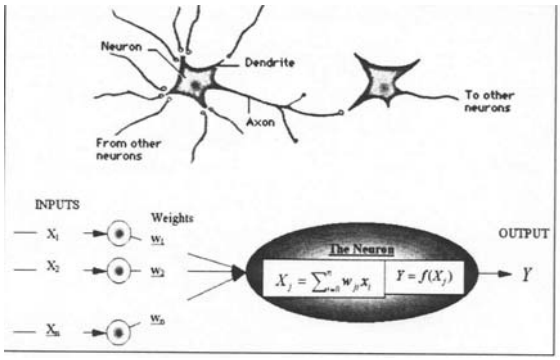


Figure 24
Representation of a Biological Neuron Versus an Artificial Neuron

An interesting property of ANNs is that they often work well even when the training data sets contain noise and measurement errors (Hammerstrom, 1993). Moreover, they have the capability of representing complex behaviors of nonlinear systems (Maier and Dandy, 2000).

Developing an ANN model for a particular application requires designing the network architecture for capturing the behavior of the system being simulated from data that are available to describe the problem domain. The structure of an ANN requires identification of the input and output vectors. The resulting ANN model must be evaluated, or "tested", in terms of the quality of its predictions.

Daily Canal Demands Model

A common requirement for management of an irrigation canal is the anticipation of the quantity of water that must be diverted into the canal that will be needed to meet future water orders. Several factors make the estimation of this required diversion quantity a difficult task. For example, travel times in irrigation canals change from day to day as a function of various hydraulic conditions, including flow rates in the canal, the state of canal maintenance, and the magnitude of seepage losses (or gains). Variations in these factors throughout an irrigation season can generate a high degree of uncertainty for canal operations, especially for long canals that have relatively long travel times. In the face of this uncertainty, the manager of a canal must decide on a near real-time basis how much water to divert into the canal in order to meet water orders along the entire length of the canal over the next few days, while at the same time minimizing the volume of spill that occurs at the end of the canal.

The canal used as a test case for the TOP project was the Sevier Valley/Piute (SVP) Canal. The SVP Canal is approximately 65 miles in length, and travel times from the beginning to the end of the canal range from 2 to 3 days, depending on the quantity of flow in the canal and on antecedent flow conditions. The canal is organized into four reaches. A real-time flow measurement gauge is located at the point of diversion into the canal, and real-time flow gauges are also located at the end of each of the four canal reaches at: Willow Creek, Aurora, Clarion, and the end of the canal where water spills back into the Sevier River. Figure 15 shows the flow readings of these gauges for the 2003 irrigation season.

The SVP Canal operator sets the diversion gates each morning and maintains a constant flow into the canal. Therefore, the desired output of the ANN model is simply the quantity of water that should be diverted from the Sevier River into the canal. The information that

should be made available to the ANN model through the neurons in the input layer should exploit the information available and describe current, and perhaps recent historical, flow conditions in the canal. This information is readily available from www.sevierriver.org. Input to the ANN should also include the orders that have been received by the canal managers for water deliveries along the length of the canal for the next 24-hour period. The relationship between inputs and outputs of the SVP Canal ANN model, then, can be expressed as:

$$O_{D_t} = \Gamma(I) \qquad (3)$$

where O_{D_t} is the quantity of water to be diverted into the canal on day t, I is the vector of inputs to the ANN, and Γ is the ANN nonlinear transformation of inputs to outputs. The input vector can be expressed as

$$I = \left[D_{t-1} \quad \overline{Q}_{t-1} \quad \overline{O}_t \quad \overline{O}_{t+1}\right]^T \qquad (4)$$

where D_{t-1} is the average diversion flow from the previous day, $\overline{Q}_{t-1}$ is a vector composed of the average flows from the previous day at the flow gauges at the end of the four canal reaches, $\overline{O}_t$ is a vector of water orders to be delivered during day t for the first two reaches, and $\overline{O}_{t+1}$ is a vector of water orders at the third and fourth reach of the canal day ahead t (see Figure 25). The use of previous-day canal flow information and orders for next-days water deliveries produces an input layer with nine neurons.

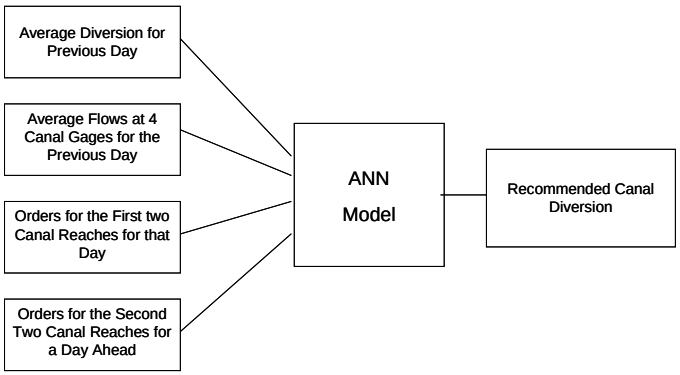
Figure 26 presents a time-series plot comparing the ANN model's diversion forecasts and the actual diversions for the entire 2002 irrigation season. These show good model performance in predicting the diversions into the canal. Figure 27 provides a scatter-plot, together with ±10 percent error bounds, of model predictions versus measured diversions for the 2002 irrigation season testing data. The regression coefficient for this scatter has a value of R=0.984.

Daily Reservoir Release Model

The need for daily prediction is also of great importance for managing reservoir releases. If the river commissioner releases too much water, it is wasted, and if they do not release enough, crop growth is adversely affected. Piute Reservoir was selected to test the applicability of ANNs for supplying information for daily reservoir management.

The Piute Reservoir operator releases water according to the irrigation demands of the downstream canal companies. Modeling all the climatic, hydrologic, and hydraulic physical processes involved in order to provide near real-time forecasts of river and canal flows and, ultimately, required reservoir releases would involve solution of a complex system of non-linear, partial differential equations. Implementation of such a model would need a substantial amount of data, a skilled modeler, and powerful computing devices. There is also uncertainty involved in the reservoir releases owing to the variations in the influencing processes throughout the season and the travel times from the reservoir to the last irrigator on the system.

Figure 25
Input/Output Data Sets for the Canal Diversion Model



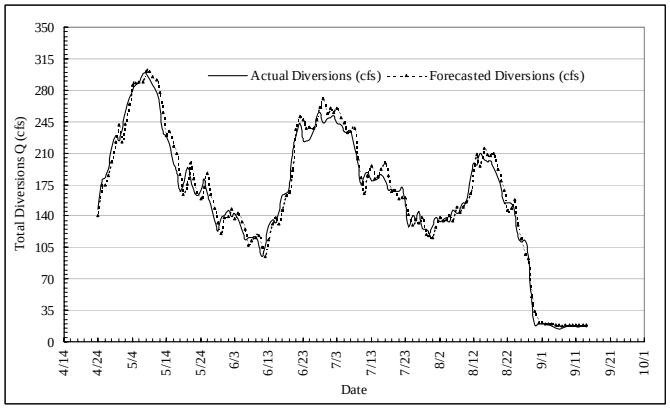


Figure 26
Time-Series Performance of the ANN Canal Model In Predicting the 2002 Irrigation Season Daily Diversions

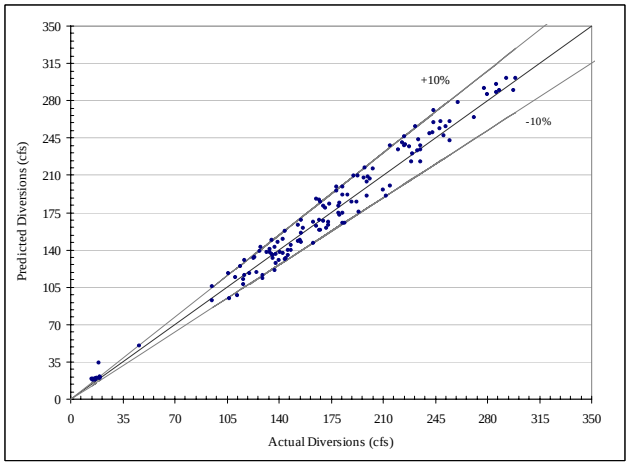


Figure 27
Scatter-Plot of Model Predictions Versus Measured Diversions for the 2002 Irrigation Season (R=0.984)

In the face of this uncertainty, the Piute Reservoir operator needs a tool to help decide on a near real-time basis how much water to release to meet water orders to canal managers located downstream of the reservoir. In other words, a common requirement for managing a reservoir is the anticipation of the quantity of water that must be released while accounting for losses and travel time.

The Piute Reservoir operators desired to set the diversion gates once per day and maintain a constant flow into the river over the following 24-hour period. Therefore, the desired output of the ANN model is simply the daily quantity of water that should be released from the Piute Reservoir. The information that should be made available to the ANN model through the neurons in the input layer should include data that describes current and perhaps recent historical, flow conditions in the river and canals. This information is readily available from the Association's website (www.sevierriver.org). Input to the ANN also needs to include the orders that have been received by the river commissioner for water deliveries along the length of the river. This information is also available from the Association's website. The relationship between inputs and outputs of the daily ANN model, then, can be expressed as equation (3), where O_{Dt} is the quantity of water to be released on day $_t$, I is the vector of inputs to the ANN, and Γ is the ANN nonlinear transformation of inputs to outputs (Khalil et al., 2003). The input vector can be expressed as:

$$I = \left[D_{t-1} \quad \overline{Q}_{t-1} \quad \overline{O} \ \right]^T \qquad (5)$$

where D_{t-1} is the average release flow from the previous day, $\overline{Q}_{t-1}$ is a vector composed of the average flows from the previous day at the flow gauges along the river, and $\overline{O}$ is a vector of water orders to be delivered during day $_t$ (see Figure 28). The use of previous-day canal flow information and orders for next-day water deliveries produces an input layer with 14 neurons.

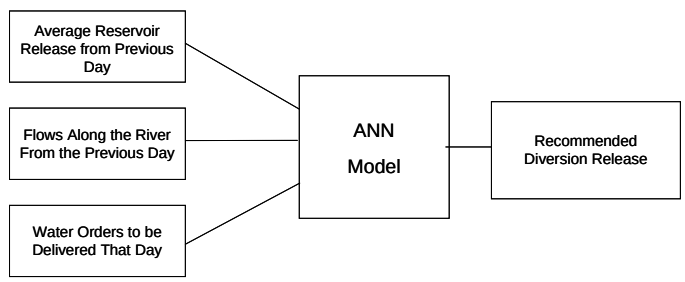


Figure 28
Input/Output Data Sets for Reservoir Release Model

Figure 29 presents a time-series plot comparing the ANN model's release forecasts and the actual releases for the irrigation seasons of 2000, 2001, and 2002. This model shows good performance in predicting the required releases from the reservoir. Figure 30 provides a scatter-plot, together with ±20 percent error bounds, or model predictions versus measured releases for the testing data used in the 2000, 2001, and 2002 irrigation seasons. The regression coefficient for this scatter had a value of R = 0.977. To utilize the model in near real-time, the predicted reservoir releases can be provided to the reservoir operator, and then it is possible for the

operator and experts to analyze, judge, and evaluate the results of the ANN model according to their own knowledge and experience.

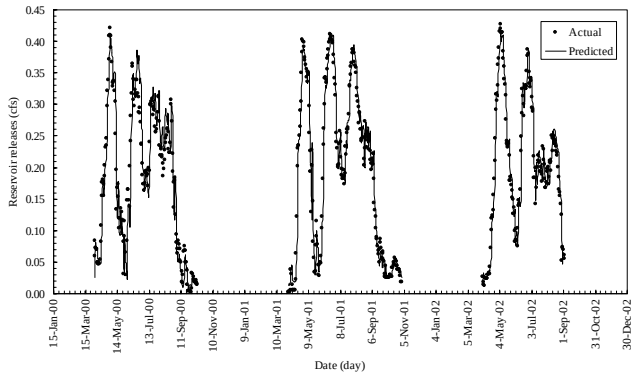


Figure 29
Time-Series Performance of the ANN Reservoir Model in Predicting the 2000, 2001, and 2002 Irrigation Season Daily Releases
(R=0.977 and RMSE = 0.041)

Water Orders

A key input to the ANN models are the daily water orders (forecasted needs for the next 24 and 48 hours). To collect this information from the two major water managers in the central Sevier area, passworded web pages were developed. (Water order information is also useful for comparing the projected water needs to the water actually delivered.)

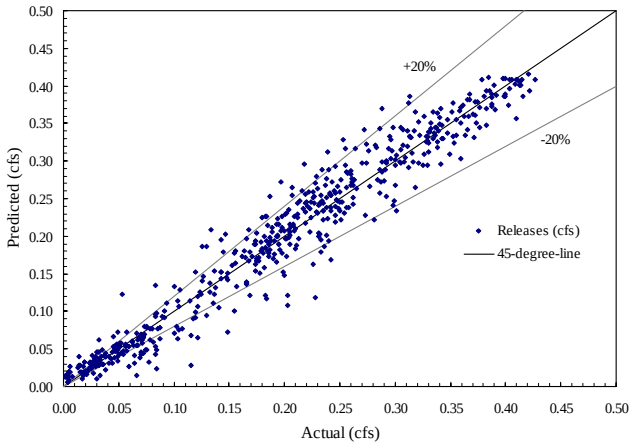


Figure 30
Scatter-Plot of Model Predictions Versus Measured Releases for the 2000, 2001, and 2002 Irrigation Season
(R = 0.977)

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Table 2, on page 6, lists the 10 specific goals outlined in the Association's funding proposal request to TOP. Each of these goals was accomplished as reported in this document. According to interviews conducted by Sydne Jacques, Project Evaluator, the TOP project results met the Association's expectations. The objective of Jacque's interviews was to determine: (1) usage of the system; (2) recommendations for improvements, and (3) specific benefits derived from using the Water Management Network (including the website).

Survey Results

Satisfaction and Use of System

All nine persons interviewed expressed an overwhelming satisfaction with the Sevier River Water Management Network. The amount of use of the website varied by user. Some users reported "logging on" every couple of days, while others stated their use at 4 to 8 times per day and a total of 4 to 6 hours per day. Approximately 50 percent of those interviewed expressed a satisfaction level well beyond what they had originally anticipated going into the project.

Comments made by one interviewee included: "One of our watermasters told me he would quit if we took away the ability to change the water from the computer in his house. Our Board of Directors and the farmers have also been very happy with it." Another person interviewed stated: "For sure my expectations have been met and exceeded! I need to maintain reservoir levels – this way I can add up diversions and know what water to turn. That would only be possible with real-time data. I can also change the water from my home."

Recommendations for Improvements

The biggest concern expressed by the interviews is that they have come to rely on the water management network to help manage their river basin and they are fearful that because of cuts in funding or changes in personnel, they may not always have the support they need to maintain a successful system. Many expressed the sentiment: "Now that we have had the luxury of using this system, we could never go back to the old way of doing things."

Ideas for improvements included continuing to apply newer technologies. One water users want to be able to monitor and control the network over his cellular telephone. Every water user interviewed had ideas for additional areas where real-time technology could be installed to further improve water management.

Benefits from Network

The water users reported that some of the most important benefits were from the amount of water savings that they were able to document. They report losses have dropped in some areas from 6 percent down to 3 percent. One water user stated: "If we need 10 cfs at the bottom, now we can put 11 cfs in at the top. We used to run 20 cfs down just because we couldn't go change it."

Another benefit is the savings of time and transportation costs because water managers have to make fewer trips to field sites. They can also make more timely and frequent water control adjustments, thereby conserving water.

Additional Benefits

In addition to optimizing management of a water distribution system, the Association's evolving automation/ Internet system has: (1) built trust through complete disclosure; (2) encouraged collaboration in water resource management; and (3) allowed for adaptive management practices.

Complete Disclosure

Observers of our evolving global economy claim that the concept of transparency, or complete disclosure, is essential to economies which hope to prosper in the future. They argue that information about financial data and transactions should be available to all in a timely and consistent fashion. This ensures that sound decisions can be made by investors and that financial problems don't fester until they explode with unfavorable consequences.

We believe that the same principle applies in the case of water resources. When all the stakeholder groups—irrigators, municipalities, sports enthusiasts, and boaters—are privy to the same information, no one can hide their actions. While this may be painful to some in the short run, in the long term we believe it to be good for all. When www.sevierriver.org went live, there were concerns voiced about making the information available to everyone. After more than 5 years of operation, however, we have not yet heard of anyone wishing for the days when information was scarce and out of date.

Collaboration

It has been widely reported in the national news media that attitudes are changing in the western United States. For example, a recent edition of Time Magazine (MacCarthy, 2001, p. 21) quoted Patricia Limerick, a history professor at the Center of the American West in Boulder, CO: "There has been a tremendous surge in collaborative conservation groups and watershed alliances in the past 10 years. This evolution toward broader input into decision-making is, in part, the result of over-allocated or over-stressed resources and changing values."

The trend toward collaborative and localized decision-making is well served by real-time monitoring technologies because the latter provides information to everyone with access to the Internet (which is rapidly becoming everyone). Better and timelier data, universally available, is leading to better decision-making and improved water management. Web sites like www.sevierriver.org report real-time conditions throughout the Sevier River Basin (including river and canal

flows, reservoir storage, snow and weather conditions, water quality, etc) for everyone to see. Decisions are made with a better understanding of present (and recent past and historic) conditions.

Adaptive Management

Environmental monitoring web sites can provide timely feedback on important management issues like the effectiveness of reservoir release decisions and the accuracy of canal demand forecast. The benefits of "adaptive management" have long been touted. But adaptive management depends upon carefully monitoring the effects of management actions on the environment, and then using that information to refine our understanding of the system and to adjust our decision-making and management plan (Western Water Policy Review Advisory Commission, 1998, pp 3-30 to 3-31). What better way to assess the effectiveness of management strategies than with real-time monitoring systems coupled with comprehensive decision-support software?

Future

The Association feels that they have only begun to tap the potential of their automated water management network. There is still a great deal to accomplish before anything close to sentience is possible. Future activities being considered include:

- Better and more useful weather information.
- Additional real-time water balances (real-time extensions of Figure 4). These additional balances would better account for water and assist with quality control of data sets.
- More automatic remote-control infrastructure along the individual canals, i.e., at the lateral and spillway headgates.
- Further explore the utility of applying ANN and similar decision-support model to assist water managers.

Conclusions

By any measure, the Sevier River Water Management Network has been a success. According to one water user, "when something goes down and I have to go back to the old way of doing things, it is like being blind after being able to see." But admittedly the process of using low-cost automation/Internet technologies to improve water management is still in its developmental stages.

With their web site, the Association has done several things right: (1) their technological innovations are being applied basin-wide; (2) they are striving to improve the operation of their in-place infrastructure; (3) information is being distributed universally helping to develop trust and empowering a wider range of users; and (4) they are applying technology at the local level where it can do the most good.

With the progress that the Association is making, can Sentience be far away?

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