WATER PROJECT MANAGEMENT

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WATER PROJECT MANAGEMENT

MISSION

To develop tools for the management and augmentation of water supplies in arid-region water projects, particularly those associated with irrigation. This includes methodologies for measuring and monitoring water fluxes with natural and man-made systems, methods for improving control of water within distribution networks, conjunctive management of groundwater and surface water supplies, artificial recharge of groundwater, natural water treatment systems (e.g., soil-aquifer treatment), and methods for assessing the performance of water projects in terms of water quality and quantity management.

A new float-operated valve that can be used in combination with a water inflated bag is proposed to be inserted under a gate, made to raise a weir, or fitted into the pipeline from a main canal to a secondary canal to maintain a desired flow level at locations. The objectives are to develop hydraulic flow control devices applicable where access to electricity may not be convenient and to evaluate the effectiveness of their function. This is an extension of the previously developed DACL (Dual Acting Controlled Leak) systems.

Methods to condition flow profiles in pipe outlets will include insertion of minimum contraction orifices and sidewall vanes. A special 30-inch diameter pipe facility is now ready for conducting these tests.

A meter builder in Fair Oaks, California, (Global Water) constructed and furnished two industrial propeller meter prototypes following our debris shedding design proposals. They will be tested in the 30-inch diameter pipe facility mentioned above. An ultrasonic velocity probe will be used to define this flow field.

FINDINGS: End-cap Orifice: The orifice system calibrated as expected from theory, and is more repeatable than corner tappings on a pipe of uncertain end quality. The convenience aspects of the system were demonstrated. (No new data acquisition is planned.)

Flap Gate: We expected that, as the flow in the pipe increased, the change in the pressure grade line should decrease because there would be more kinetic energy used to keep the flap gate open. However, no distinct pattern could be seen from the data. Low flows and high flows produces back pressures on the order of only 4 mm to 6 mm of water column. (No new data acquisition is planned.)

Flow Profile Conditioning: There are no new findings to report.

Propeller Meter: This has been delayed for higher priority studies. There are no new findings to report.

Pipe Flow Control System: A new DACL valving system was developed because a commercial version did not provide the needed functions. The new valve appears to be capable of all required functions but needs to be laboratory and field proven. A variety of low-cost bag products has been collected. The bag concept was tried on a small model and appeared to function well. Scaling problems have not been ruled out. Progress includes designing and building the low-cost valving system and companion pipe flow obstruction method that is ready to be tested (Fig. 1 & 2). A small model of the concept operated as hoped. The new valving equipment was not used in these tests, but had to be simulated by other means. The test facility has been modified to allow testing of the control concept.

INTERPRETATION: End-Cap Orifice: This version of the end-cap orifice can be installed on well pipe outfalls without any specially drilled holes. The corner tap locations of the original version, which also did not require pipe drilling, are somewhat sensitive to poor pipe-end conditions. While this version cannot be used if the pipe is in badly eroded condition, it is somewhat forgiving. The orifice still requires the installation to provide standard lengths of straight pipe from the last pipe bend.

Flap Gate: While the analysis is still incomplete, preliminary findings are that flap gates cause negligible back pressure on pipelines that are flowing full. No new interpretations have been developed, pending reactivation to complete the technical note. The difference between low and high speed flow was not significant.

Pipe Flow Control System: Stable flows in secondary canals permit low-cost totalization of flow deliveries to farms because time clocks will suffice instead of complex recorder systems. Known constant flows allow more precise management of irrigation systems. Preliminary indications are that the concept can be made to work. If this proves out, then we should be able to provide economical flow stabilization from main canals to lateral canals.

FUTURE PLANS: End-Cap Orifice: Prepare report.

Flap Gate: Prepare a technical note on the findings that the effects are usually negligible.

Flow Profile Conditioning: Start laboratory study phase and refine test facility, and conduct this study in conjunction with the flow profile study.

Pitot System: The Pitot System reported last year has been completed and one report has been published. A report on the complete data collection and interpretation is still in technical review, and we will continue to follow through to anticipated publication. The control system for constant flow delivery from main canals to lateral canals through pipes will be studied.

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REFERENCE:

Replogle, J.A. 1999. Measuring irrigation well discharges. Journal of Irrigation and Drainage Engineering. 125(4): 223-229.

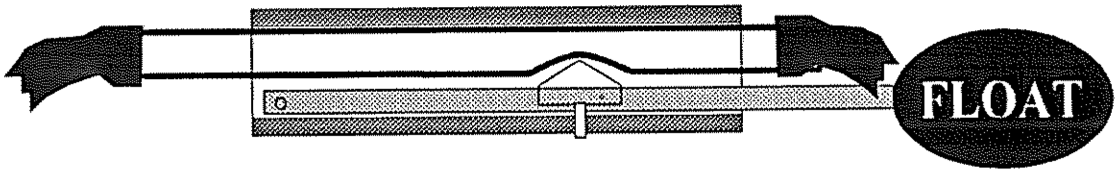

Figure 1. Low-cost valve scheme. Two valves required per system.

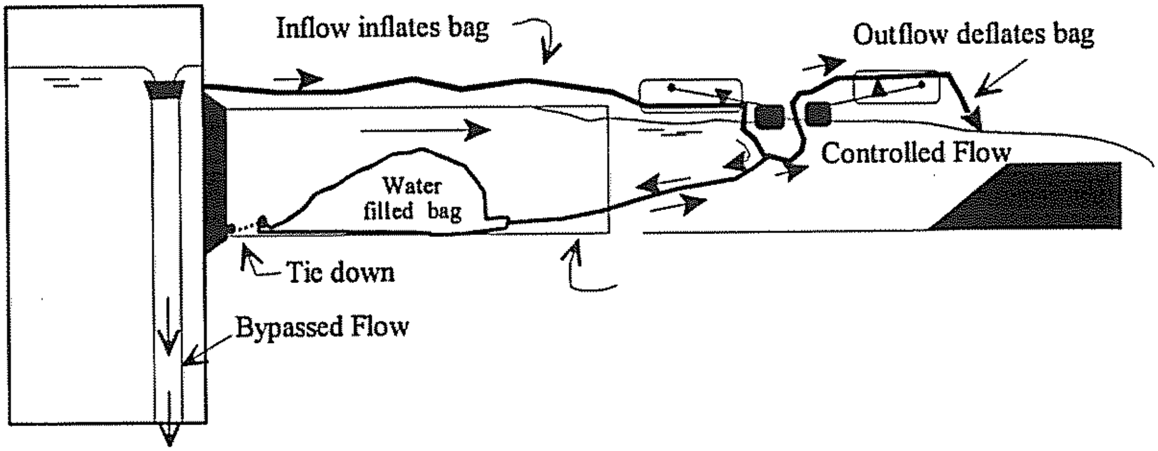

Figure 2. General laboratory set-up for evaluating valve and bag system for flow level control.

FLOW MEASUREMENT WITH FLUMES AND WEIRS

J.A. Replogle, Research Hydraulic Engineer; B.T. Wahlin, Civil Engineer; and A.J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEMS: Continuing concerns involve needs related to open channel flow measurement and control. These include:

Sediment-laden discharges in natural streams are difficult to measure because of sediment movements and accumulations.

Parshall flumes have been popular flow measurement devices for open channels since their introduction in 1926. Traditionally, problems have arisen in Parshall flumes if they are not constructed to specifications. For example, a large Parshall flume installed in California has a field-verified calibration that differs by 10% to 20% from the historical calibrations for that size. This determined difference may or may not be structural.

One of the most important factors in installing a broad-crested weir is vertical placement of the sill. If the sill is too low, the flume may exceed its limit of submergence. If the sill is too high, upstream canal banks may be breached. While this has been partly addressed with the Adjust-A-Flume, simplifications in its construction and adaptation to economical recorders are still needed.

The FLUME3 program does not run well with Windows 95. Cooperative efforts with the USBR to re-code the program for Windows, while nearly complete, have generated some follow-through ideas.

APPROACH: The general objective is to address these problems economically and practically with user-friendly technology.

A prototype self-calibrating flume for sediment-laden flows was designed and installed in northern California (Fig. 1). The objective is to evaluate the idea of the self-calibrating flume system and to determine its operational limitations. The design was based on estimated hydraulic behavior of a chute outlet attached to a "computable" trapezoidal long-throated flume. Two stilling wells, one on the main flume and one on the chute, are expected to provide field calibration for the chute after the main flume no longer can function because of sediment deposits. A laboratory model is part of a thesis study at the University of Arizona to check the limits of sediment handling, the best slope for the chute, and whether the calibration of the chute remains stable after the sediment fills the main flume.

The historical calibrations of a one-fourth scale model of an eight-foot Parshall flume were previously verified. The objective is to develop methods to modify wrongly constructed Parshall flumes to recover their function for accurate flow measurement and to identify construction anomalies that can cause large calibration shifts. The same model will be fitted with a modified entrance and other changes in an attempt to identify causes of calibration shifts that have been noted in a larger Parshall flume.

Compilation of field experiences by users of the commercialized version of the patented adjustable-sill, long-throated flume will be used to advise on expansion of the product line and to evaluate field durability and vulnerability to damage from frost and animals. The objective is to evaluate field installations and to assist in design and materials changes that may be needed to hasten technology transfer.

New software being written to make flume calibration and design software compatible with the computer Windows environment will be user tested, and supplemented with a user manual, either in paper copy, on-line, or CD versions.

FINDINGS: As reported last year, the California Water Quality Control Board used the flume data from last year to demonstrate the severity of the cinibar tailings (mercury ore) problem to EPA. Based on that, emergency super-fund money ($2.5 million) to stabilize the mine tailings was authorized. More data has been collected to verify the initial findings and to evaluate progress in the effectiveness of the clean-up.

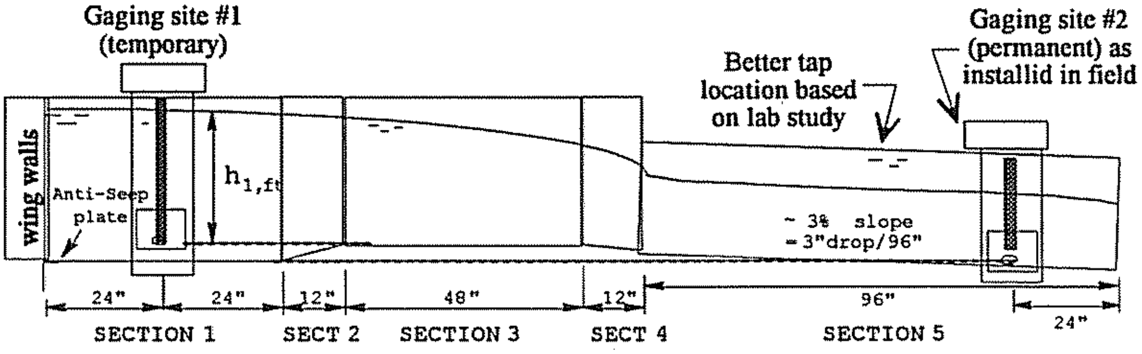

Figure 1. General layout of sediment-resistant flume as installed.

With the laboratory model study completed, the Ph.D. student study was successfully submitted to final exam on September 28, 1999. Basically, the sediment (sand) altered the upstream (subcritical) stilling well as predicted. The model indicated that the detection in the chute will provide discharge rates with errors less than 5%. The downstream stilling well in the chute (supercritical) has about the same response with and without sand, as postulated. Findings include that the midpoint of the chute is a more reliable point of depth detection than the point shown on figure 1.

A 50-foot Parshall flume, whose calibration differs from published calibrations by 10% to 20%, has been in operation for nearly 20 years. It has a modified entrance flare that differs from the published rounded entrance. This modification was suspected of causing the calibration difference. Laboratory studies to verify this on a model of a related eight-foot Parshall flume failed to implicate this type of construction anomalies as a cause. Distorted flow entry also was ruled out. Attention now is centered on the published calibration for this size.

Field observations and reports have been compiled for flumes ranging in maximum capacity from 200 gpm (12 l/s) to 35 cfs (1 m^3/s). The users find the devices easy to install and able to meet their operating requirements. The standard versions are now commercially available under the name "Adjust-a-Flume" (Nu-Way Flume and Equipment Company). Widespread acceptance appears to be growing, as is interest to adding recording instrumentation to the product line that is complicated by the movable reference throat level. Commercial components have been identified that hold the possibility for developing a "kit" to field adjust to many sizes of flumes.

The WinFlume program has been distributed in trial versions to many users, and bugs are corrected when they are found. Current thoughts are for a CD version of a users manual. The format for this has not been firmly decided.

INTERPRETATIONS: The ability to measure flows in heavy sediment carrying flows is important to studies of erosion, runoff, and the effectiveness of best management practices on watersheds. This system expands the range and flume shapes available for such use.

Parshall flumes may not behave as originally specified if installation differs from the standard, or if the flow is distorted at the flume entry. Effects of these problems were evaluated and appear to be of too small a consequence to account for the large errors noted. Therefore, the original calibration may be in question and more definitive model studies may be needed to resolve the questions concerning calibration.

The field problems involving the vertical placement of flumes and broad-crested weirs are greatly reduced for farm-sized earthen channels by the commercialization of a series of semi-portable, long-throated flumes with adjustable throat sills and maximum capacities ranging from 200 gpm (12 l/s) to 35 cfs (1 m^3/s). Sizes above 6 cfs are not intended to be portable. The addition of an instrumentation package will extend the use of the flume systems.

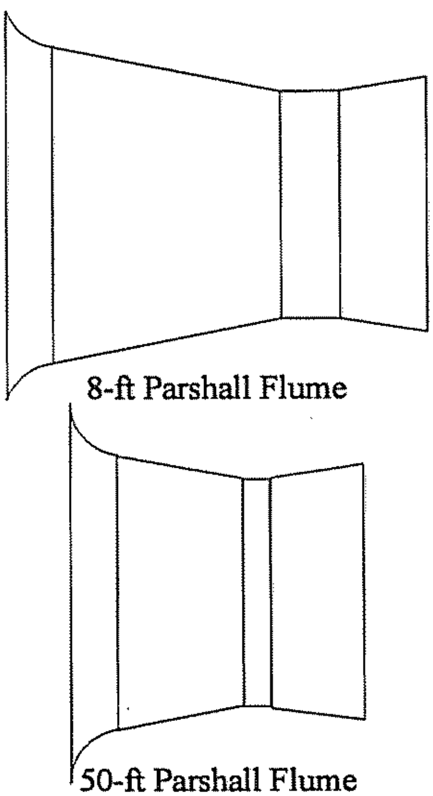

Figure 2. Relative proportions of 8-ft and 50-ft Parshall flumes.

The new flume program will hasten the technology transfer of good flow measuring and monitoring for irrigation management.

FUTURE PLANS: The sediment resistant flume in California will continue to collect data from storm events. The laboratory model study may be "mothballed" for possible extension studies by another student, which may include development of sediment sampling equipment attached beyond the chute. A second, clear-plastic model is being considered so that sediment movements can be observed more readily in future studies.

The new DACL valve will be laboratory and field evaluated for desired control functions. Further laboratory and field evaluations for function and durability of assembled control systems using the concepts will be reinitiated.

The findings for the field installation of the 50-foot Parshall flume will be further evaluated to see if a calibration shift can be produced, even though the 8-foot Parshall flume, which is not a scale model of the 50-ft version, showed little effects from the usual suspected sources (Fig. 2).

Advice on design changes for adjustable flumes and evaluation of field performance will continue. "Kits" of a possible recording instrumentation system have been sketched that involve minor modifications to commercial equipment and should be available for under $500. This will be continued to see if it can indeed be demonstrated and evaluated.

Write a new book/users manual for the WinFlume Program.

COOPERATORS: Informal cooperation exists among: Tony Wahl and Cliff Pugh, U.S. Bureau of Reclamation, Hydraulics Laboratory, Denver CO; Harold Bloom, Natural Resources Conservation Service, Phoenix AZ; Anisa Divine, Imperial Irrigation District, Imperial CA; Joe Kissel and Kirk Kennedy, Salt River Project, Phoenix AZ; Charles Slokum, Wellton Mohawk Irrigation and Drainage District, Wellton AZ; Brian Betcher, Maricopa-Stanfield Irrigation and Drainage District, Stanfield AZ; Jackie Mack, Buckeye Irrigation District, Buckeye AZ; Randy Stewart, Plasti-Fab, Inc., Tualatin OR; Don Slack, The University of Arizona, Tucson AZ; Dyan White, California Water Quality Control Board, Sacramento CA; and Charles Overbay, Nu-way Flume and Equipment Company, Raymond WA.

WATER REUSE AND GROUNDWATER RECHARGE

H. Bouwer, Research Hydraulic Engineer

PROBLEM: Increasing populations and finite water resources necessitate more water reuse, as do increasingly stringent treatment requirements for discharge of sewage effluent into surface water. The aim of this research is to develop technology for optimum water reuse and the role that soil-aquifer treatment can play in the potable and nonpotable use of sewage effluent. Present focus in the U.S. is on sustainability of soil-aquifer treatment, particularly the long-term fate of synthetic organic compounds (including pharmaceutically active chemicals and disinfection byproducts) in the underground environment. The fate of pathogens and nitrogen also needs to be better understood. In Third World countries, simple, low-tech methods must be used, including lagooning, groundwater recharge, and sand filtration to treat the sewage.

Artificial recharge with infiltration basins for storing fresh water underground as part of integrated water management and conjunctive use of surface water and groundwater, or for underground storage and soil-aquifer treatment (SAT) of sewage effluent for water reuse, is still rapidly increasing. The permeable soils that such systems require are not always available, so that less permeable soils like the loamy sands, sandy loams, and even light loams of agricultural and desert areas are increasingly used to obtain recharge and SAT benefits. Such soils require reliable techniques for infiltration measurements and other pre-investigations to assess the feasibility of the project, and for management of recharge basins to maintain maximum infiltration rates. Climate change is going to be an important factor in future management of water supplies. Because it is impossible to predict it with any accuracy on a local or regional scale, managers increasingly must develop flexible water management schemes so that they can handle excessive as well as inadequate water supplies. This requires more long-term (years to decades) storage of water or "water banking," which is best achieved via artificial recharge of groundwater to avoid the evaporation losses that occur with long-term surface storage behind dams. SAT principles can be extended to river bank filtration systems where wells are drilled at some distance from the river so that river water is "pulled" through the aquifer and receives SAT before it goes to the water treatment plant.

Seepage from ponds, reservoirs, lagoons, wetlands, or other water impoundments often needs to be controlled using earth or plastic linings. Where earth linings are used, the soil material can be placed on the bottom and banks and mechanically compacted when the impoundment is dry, or it can be applied dry or as a slurry to the water itself. The question then is: what gives more seepage control, a compacted soil layer on the bottom where the soil is thoroughly mixed, or a slurry applied to the water where the coarser particles sink faster than the finer particles to create a lining layer that is coarser at the bottom and finer at the top?

Long-term effects of irrigation with sewage effluent on soil and underlying groundwater must be better understood so that future problems of soil and groundwater contamination can be avoided. Potential problems include accumulation of phosphate and metals in the soil and of salts, nitrate, toxic refractory organic compounds, and pathogenic microorganisms in the groundwater. Water reuse is a good practice, but it should not ruin the groundwater. Long-term salt build-up in groundwater will occur in groundwater below any irrigated area (agricultural or urban), regardless of the source water, if there is no drainage, groundwater pumping, or other removal and export of water and salt from the underground environment. Groundwater levels then also will rise, which eventually requires drainage or groundwater pumping to avoid waterlogging of surface soils and formation of salt flats. In urban areas, such groundwater rises will damage buildings, pipelines, landfills, cemeteries, parks, landscaping, etc. The salty water removed from the underground environment must be properly managed to avoid problems.

APPROACH: Technology based on previous research at the U. S. Water Conservation Laboratory (USWCL) and more recent research are applied to new and existing groundwater recharge and water reuse projects here and abroad. Main purposes of the reuse projects range from protecting water quality and aquatic life in surface water to reuse of sewage effluent for nonpotable (mostly urban and agricultural irrigation) and potable purposes. Soil columns in 8 ft x 1 ft stainless steel pipes have been set up in a laboratory greenhouse to study movement of pathogens and chemicals (including exotic organics) in systems involving irrigation with sewage effluent, artificial recharge with sewage effluent, and Colorado River water. Various scenarios of rising groundwater levels and salt buildups due to irrigation were considered and compared with field data to get an idea of rates of rise in groundwater levels and salt content of the upper groundwater, and how to handle this water (i.e., disposal in salt lakes, sequential irrigation of increasingly salt tolerant crops ending with halophytes to concentrate the salts in smaller volumes of water, membrane filtration to remove the salts and allow municipal or agricultural use of the water, and disposal of the reject brines).

The effect of placement of an earth lining in an impoundment for seepage control was evaluated in a laboratory column study using 4-inch diameter clear plastic tubing. At the bottom of each column was an 11 cm layer of silica sand. In column 1, the silica sand was covered with a 16 cm layer of Avondale silt loam at optimum water content to give maximum compaction when packed with a rod. The column was then filled with water and a constant water level was maintained to give a water depth of about 160 cm. The other three columns also were filled with water with the same constant level at the top. Column 2 received the same amount (dry weight) of soil as column 1 but it was poured in as a thick slurry at the top of the column. Column 3 also received the same amount of soil as a thick slurry, but it was poured in 5 split applications at least 24 hours apart so that the water in the column had become completely clear when the next slurry was applied. Column 4 received the same amount of soil in the same way but in 15 split applications. Seepage rates were then monitored for about 40 days to reach well-defined final values.

FINDINGS: Field and laboratory tests continued to show the usefulness of recharge and soil-aquifer treatment in water reuse. Main issues still are sustainability of soil-aquifer treatment and fate of recalcitrant organic compounds, including disinfection byproducts, pharmaceutically active chemicals, and humic and fulvic acids and other organic compounds that react with chlorine to create new disinfection byproducts. Calculation of the water and chemical balance (including salts) indicates that the drainage or deep-percolation water from sewage irrigated fields will be seriously polluted, especially in dry climates.

The slurry applied earth liners had a fine, slowly permeable layer at the top of each layer. Thus, the integranular pressure below the fine top layers was relatively high since the fine layers "carried" the weight of the water. This produced considerable compaction of the liner for about 2 weeks as evidenced by reduced thickness of the layer and reduced infiltration rates until both became constant at the following values.

	Compacted soil	1 slurry application	5 slurry applications	15 slurry applications
Final thickness in cm	16	21	21	19
Final infiltration rate in cm/day	2.7	1.2	1.0	0.85

The seepage rate for the silica sand alone was 9.6 to 11.1 m/day. Thus, the earth lining was very effective in reducing the seepage rate, especially when applied as a slurry. The biggest percentage of reduction from compacted earth to slurry applied soil was achieved when the total amount of soil was given in one slurry application (56%). Five split slurry applications gave further seepage reduction and so did the fifteen split applications. However, the additional seepage reductions (i.e., 17% and 15%) were not as high as the 56% reduction obtained from a compacted lining to a one-application slurry-applied lining. Thus, segregation of soil particles in the earth lining due to slurry application gave better seepage control than a uniform compacted liner. In practice, slurry applications can be repeated until an acceptable seepage level is reached.

INTERPRETATION: The developments of better technologies or concepts for predicting infiltration rates with cylinder infiltrometers, estimating volumes of water that can be stored underground for water banking, and managing relatively fine textured soils to achieve maximum infiltration for recharge will extend the use of artificial recharge of groundwater to "challenging" soil and aquifer conditions. This will enable water resources planners and managers to benefit from the advantages that artificial recharge offers in conjunctive use of surface water and groundwater, in water reuse, and in integrated water management.

FUTURE PLANS: These plans consist primarily of continuing existing research and of developing new field and laboratory research projects, mostly with universities and water districts, on long-term effects of irrigation with sewage effluent on soil and groundwater. Also, infiltration test plots will be installed to verify concepts of recharge basin management developed for finer textured soils where clogging, crusting, fine particle movement or wash-out wash-in, hard setting, and erosion and deposition can seriously reduce infiltration rates.

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IRRIGATION CANAL AUTOMATION

A.J. Clemmens, Supervisory Research Hydraulic Engineer; R.J. Strand, Electrical Engineer; B.T. Wahlin, Civil Engineer; B. Schmidt, Computer Programmer; and E. Bautista, Research Hydraulic Engineer

PROBLEM: Modern, high-efficiency irrigation systems require a flexible and stable water supply. Typically, open-channel water delivery distribution networks are controlled manually and are not capable of providing this high level of service. Stable flows can be achieved when little flexibility is allowed since canal operators can force canals flows to be relatively steady. Allowing more flexibility increases the amount of unsteady flow and leads to more flow fluctuations to users.

Most canal systems operate with manual upstream control. With this approach, all flow errors end up at the tail end of the system and result in water shortages or spills. In some canals, supervisory control systems are used to try to match inflows with the expected outflows. Because this adjustment is done by trial-and-error, pool volumes and water levels can oscillate until a balance is achieved. In canals with large storage volumes, these fluctuations may have little impact on deliveries. Smaller canals with insufficient storage need more precise downstream control methods than are currently available. Development of improved canal control methods requires convenient simulation of unsteady flow by computer. Many computer models of unsteady canal flow have been built in the last twenty years, some very complex and expensive, designed to model very complicated systems. Only recently have these programs allowed simulation of control algorithms for canal automation.

The objective of this research is to develop technology for the automatic control of canals as a means of improving canal operations. This includes development and testing of canal control algorithms, development of necessary sensors and hardware, development of centralized and local control protocols, refinement of simulation models needed for testing these methods, and field testing of algorithms, hardware, and control protocol.

APPROACH: A Cooperative Research and Development Agreement between ARS and Automata, Inc., was established for the purpose of developing off-the-shelf hardware and software for canal automation; i.e., plug-and-play. We will work closely with Automata in the application and testing of this new hardware and software. The core of this system is the U.S. Water Conservation Laboratory (USWCL) canal automation system that consists of

- feedforward routing of scheduled flow changes (similar to gate stroking),
- feedback control of downstream water levels (to balance canal inflow and outflow), and
- flow control at check structures.

The system is controlled from a personal computer at the irrigation district office. A Supervisory Control and Data Acquisition system (SCADA) is used by operators to monitor the irrigation system and to control gates remotely through radio communications. We plan to use a commercial SCADA package, FIX Dynamics from Intellution, Inc. Standard MODBUS communication protocol will be used to communicate between FIX Dynamics and Automata's Base Station. Eventually all communications in the system will use MODBUS. The USWCL canal control scheme logic (USCWL controller) will be interfaced with FIX Dynamics. The research approach will be to use simulation models to test and further develop various control schemes that can be used within the proposed automation system. The hardware and software components will be assembled and made compatible in the field. Finally, the combined hardware and software automation system will be tested in the field on the WM lateral canal of the Maricopa Stanfield Irrigation and Drainage District.

Simulation of unsteady flow in canals is needed to understand canal pool properties. We routinely use the unsteady-flow simulation package CanalCAD to study canal properties and to test controller performance. The canal properties taken from CanalCAD tests are used within a mathematical analysis software package, MATLAB, to design various controllers. We have been using a centralized proportional-integral (PI) controller that accounts for system delays. This format allows selection from a series of controllers, including a series of simple local PI controllers. Selection of controllers for testing on the WM canal are based on simulation tests of controller performance on the American Socity of Civil Engineers (ASCE) test cases and simulation of the WM canal itself.

FINDINGS: Poor canal control performance is caused by a mismatch between pool inflows and outflows and/or incorrect pool volumes. Thus, canal controller methods must address control of both flow rates and pool volumes. An understanding of (1) wave travel times and (2) pool volume as a function of flow rate are necessary and sufficient for the development of feedforward control logic, while for feedback control (1) wave travel times and (2) pool backwater surface area can be used.

Simulation studies of downstream-water-level feedback controllers: A comprehensive set of simulation tests was made for ASCE test canal 1. First, for a series of local PI controllers of pool downstream water level, there was little difference between control of gate position or control of flow rate at each check structure. However, use of flow rate control separates control of pools from control of structures. Second, better control was obtained when control actions from one pool were passed upstream to other check structures, invoking the so-called decoupler I. In general, the completely centralized PI controller provided the best performance. Accounting for the system delays led to mixed results. If our estimate of the delays was poor, then including the delays in the controller hurt the overall performance. If our estimate of the delays was accurate, then including the delays in the controller improved performance. A reasonable compromise between controller performance and complexity is to pass a portion of the PI control actions one pool upstream and one downstream. Finally, the integrator-delay model of Schuurmans for defining canal pool properties appears to work very well for controller design.

Development of accurate gate position controller: The canal automation system was installed on the WM canal at MSIDD using Automata hardware, including Remote Terminal Units (RTUs), gateposition sensors, and a base station. The RTUs were programmed to move the gate according to the number of pulses requested by the controller and the number of pulses sent from the gate position sensor. This system is functioning very well. Run-on, or gate movement after the motor is turned off, is usually zero and occasionally one pulse. Each pulse represents roughly 0.95 mm, thus we are able to position these gates to within 1 mm. Automata programmed their base station to translate from the MODBUS protocol of the SCADA system to Automata's protocol which is communicated with the RTUs by radio. This communication is functioning, but needs some improvement.

SCADA implementation: The WM canal was set up within the FIX Dynamics SCADA system. Digital photographs of the canal and the check structures were used as background screens for the

SCADA control functions (See Figures 1 and 2). The system was set up to monitor continuously the headgate, all check structures, water levels above two flumes, and water levels at the downstream end of all canal pools. Within FIX, digital signals are sent to the RTU indicating how many pulses to move a gate, and in what direction.

The USWCL canal automation system control program was interfaced to the FIX Dynamics SCADA package. The USWCL control program is a separate program running in parallel with FIX in a Windows NT environment. Information on the state of the system are read from the FIX database by the control program through an ActiveX interface. Control actions determined by the control program are passed to FIX, also through ActiveX. Additional ActiveX elements are used to allow the operator to enter manual changes from FIX screens (for example to move the gate a certain distance rather than a number of pulses (Fig. 2), or to adjust manually water level and check flow setpoints). A first level of error checking was added to the control program so that the controller would not overreact if sensors or communications failed. These were essential during early testing.

Field testing: The control system was made operational and run several times during October 1999. These tests were all run with only the first 5 pools since there were no deliveries downstream. The system functioned as intended. An example of one test run is shown in figure 3. For this test, a series of local PI controllers were used. The test consisted of starting with the initial water level as the setpoint and gradually raising the setpoint to the desired level. The controller and control program were functioning properly, but had not yet stabilized by the end of the test. Numerous communications and other small problems will require additional RTU, base-station, and control programming to clean up.

INTERPRETATION: The feasibility of a plug-and-play type canal automation system looks promising. Ensuring proper functioning of the system for a given canal will still require some engineering analysis to determine hydraulic properties and controller constants so that the automation performs adequately.

FUTURE PLANS: Communication has been the biggest problem. Assuring that the controller will perform appropriately requires that the control program have some control over the obtaining of information from the RTUs. MODBUS allows this, but it is not programmed into the base-station translator. A better solution appears to be programming MODBUS into the RTU software. This will allow the base-station to control the collection of information rather than relying on FIX's periodic querying. The current RTU programming has unneccessary code that is left over from other Automata applications. We plan to eliminate as much of this unnecessary code as possible and to remove the automatic periodic reporting. Additional features need to be added to the RTU and control programs. Work will continue on the development of feedback and disturbance controllers that perform better under unusual circumstances. Finally, a number of controllers will be tested on the WM canal in real time, which also will serve to test the control and RTU programs.

COOPERATORS: Lenny Feuer, Automata, Inc., Nevada City CA; Gary Sloan, MSIDD, Stanfield AZ; Jan Schuurmans, University of Twente, The Netherlands; Dave Rogers, USBR, Denver; Charles Burt, Cal Poly, San Luis Obispo CA; Bob Gooch, Salt River Project, Phoenix AZ; Victor Ruiz, IMTA, Cuernavaca, Mexico; Pierre-Olivier Malaterre, CEMAGREF, Montpellier, France.

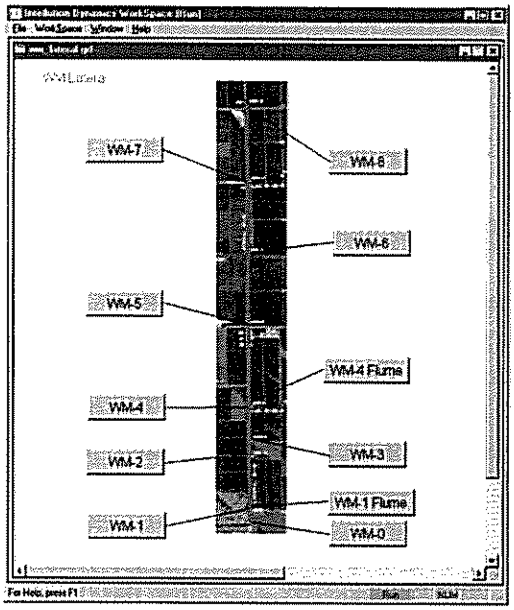

Figure 1. FIX SCADA screen showing WM canal layout.

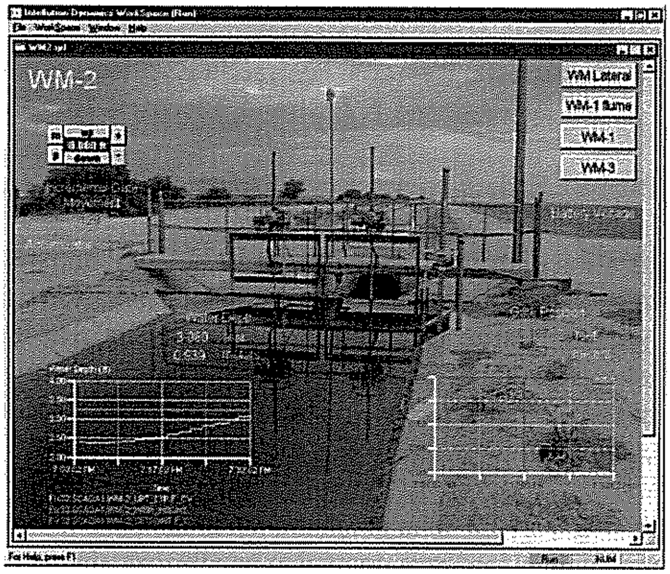

Figure 2. FIX SCADA screen of WM-2 check structure, including graphs of water level and gate position and activeX element for changing gate position.

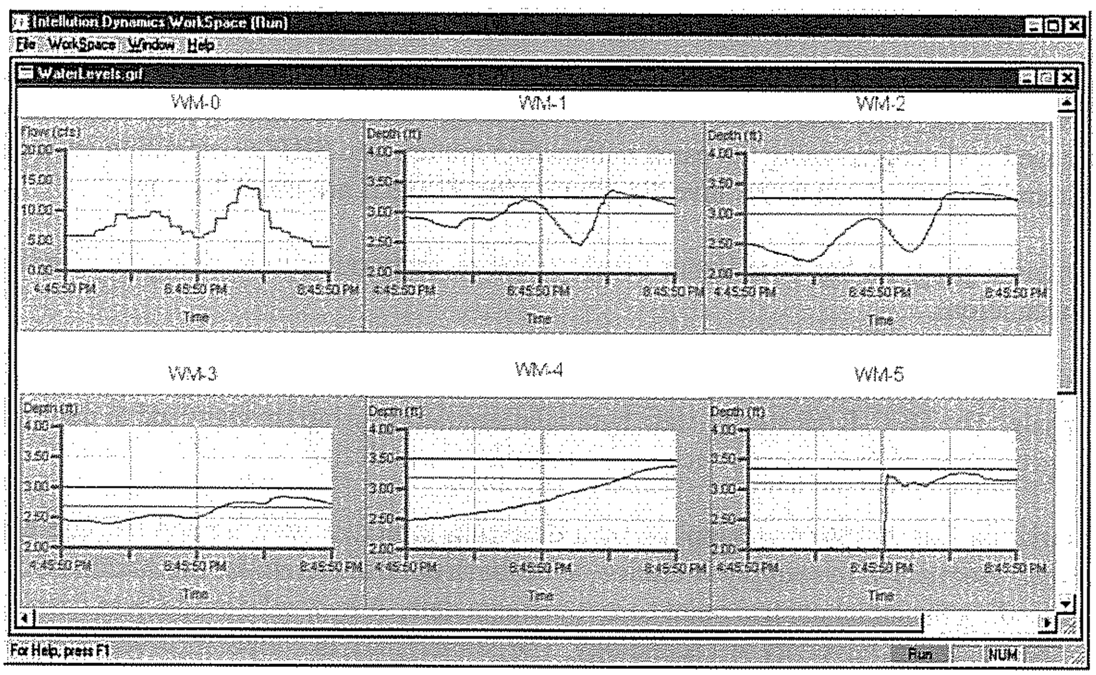

Figure 3. FIX SCADA screen showing results of test on Oct. 19, 1999. Red lines are water level setpoints and green lines are overflow weirs.

CANAL AUTOMATION PILOT PROJECT FOR THE SALT RIVER PROJECT ARIZONA CANAL

E. Bautista, Research Hydraulic Engineer; A.J. Clemmens, Supervisory Research Hydraulic Engineer; R.J. Strand, Electrical Engineer; and B.T. Wahlin, Civil Engineer

PROBLEM: The Salt River Project (SRP) is the largest municipal and agricultural water supplier in the Phoenix valley. The district also has a long history of being progressive in the management of its water distribution system. In 1995, SRP initiated an in-house research and development project, in cooperation with the U.S. Water Conservation Laboratory (USWCL), to determine the feasibility of implementing canal automation within its distribution network. Canal automation is expected to improve service, reduce operating costs, and improve SRP's stewardship of resources. The objective of this project is to develop an automated canal control system that is compatible with SRP's current canal operational strategies and systems.

APPROACH: The proposed canal control scheme has three main components: (1) downstream water-level feedback control to handle disturbances or errors in flow rate, (2) open-loop feedforward routing of scheduled or measured offtake flow changes, and (3) check structure flow-rate control. Phase I of this pilot project consisted of the development of an automatic control system and simulation studies to test its ability to control water levels on an SRP canal system reach. The upper portion of the Arizona Canal was chosen as the study site. This section includes 5 pools, separated by check structures, and a major branch point at the heading of the Grand Canal. Findings of this initial phase were reported in Clemmens et al (1997).

In view of the promising results, SRP decided to continue with the next phase. In Phase II of the pilot project, which is currently underway, we are investigating various control system issues identified during Phase I and programming the canal automation system into SRP's computing environment. Specific items that have been under investigation during Phase II are the following:

(1) A computer program has been under development to carry out automatically the feedforward control calculations.

(2) Analysis of the feedforward control problem was expanded to include the entire Arizona and Grand Canals. The HEC-RAS steady-state hydraulic simulation program was used to determine the hydraulic properties of these canals needed for control system design.

(3) The Arizona Canal system is supplied by a diversion structure with limited storage capacity, Granite Reef. Because of this supply limitation, a feedback control system for the Arizona Canal may require extending the initial control point to an upstream dam. A hydraulic model was developed by Rogier Visser, of Delft University of Technology, The Netherlands, in cooperation with the USWCL, of the river system that supplies water to Granite Reef. The model includes a river reach between Stewart Mountain and Granite Reef on the Salt River and a reach between Bartlett Dam and Granite Reef on the Verde River. Data for the study were provided by SRP, U.S. Geological Survey, and the Maricopa County Flood Control District. Additional field data also were collected by Rogier Visser.

(4) Since the proposed canal control system uses flow rate as a control variable, check gate discharges need to be measured. In practice, these measurements can be inaccurate. This is true for SRP's gates, particularly under submerged flow conditions. While the control system can stabilize water levels even with inaccurate gate discharges, control improves substantially with better flow predictions. Therefore, a laboratory study was initiated to obtain a more accurate head-discharge relationship for radial gates. The study was conducted by Jan Tel of Delft University of Technology, the USWCL, and SRP.

(5) Automated control simulations have been conducted by assuming initial steady-state flow conditions. Steady-state is difficult to achieve in real canal systems. A start-up strategy has been developed that assumes initial unsteady flow and has been tested with simulation.

(6) Currently, the water-masters serve as the interface between the water orders and the main canal check structures. Daily water orders are transmitted by field operators and consolidated in a UNIX-based database. Daily operational schedules are developed manually based on these demands and on the available supplies. Through a VAX-based supervisory control and data acquisition (SCADA) system, watermasters keep track of water levels and gate positions and make necessary adjustments. Work was begun to integrate the proposed control system with SRP's current operations and computer environments.

FINDINGS: (1) A canal scheduling program is being developed in the Windows environment (Bautista and Clemmens, 1999). The program has standard graphical user interface features and is able to communicate with a local database for data input and output. The program will be modified during implementation to be able to interact with SRP's database systems. A beta version of the program has been provided to SRP to test the scheduling procedures under different flow conditions, to debug the software, and to identify needed graphical interface improvements.

(2) Figure 1 is an example of the discharge schedule computed at the head of the Arizona-Grand Canal system, based on actual demand data. The canal system consists of 30 pools and 44 offtakes. The scheduling program allows the user to impose constraints on the frequency and the magnitude of the computed flow rate changes. For example, the schedule of figure 1 was computed by constraining the frequency of changes to a 5-minute interval and the magnitude to multiples of 1 cfs. Programming work is still pending to enable the unsteady simulation software being used in this project, Mike11, to perform automatic control simulations for the entire Arizona-Grand Canal system. Simulation tests will be conducted with the computed schedules when the Mike 11 programming work is completed.

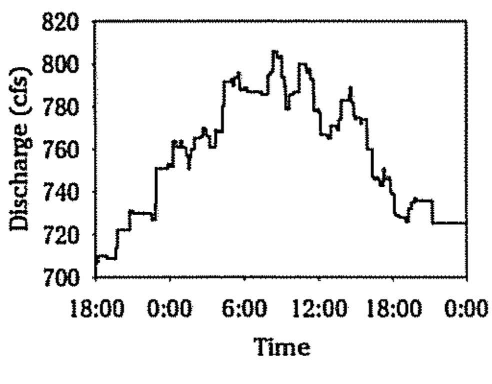

Figure 1. Computed feed forward schedule at the head of the Arizona Canal.

(3) The hydraulic model was developed by extrapolating currently available data cross-sectional and elevation data for the Salt and Verde River. While the model oversimplifies the river's topographical features, simulation results were promising in that predicted water levels at the downstream boundary of the system, Granite Reef Dam, compared relatively well with observed water levels (Fig. 2). Simulation tests have shown that modeling results are most sensitive to water losses in the river bed, which are relatively large on the Verde River, and less sensitive to potential errors in cross-sections and hydraulic roughness. Supercritical flow conditions occur at various locations along the Salt River reach and the unsteady flow model used in this study, SOBEK, can simulate those conditions. However, results computed with and without these supercritical flow reaches were not very different from each other. Detailed results are reported in Visser (1998).

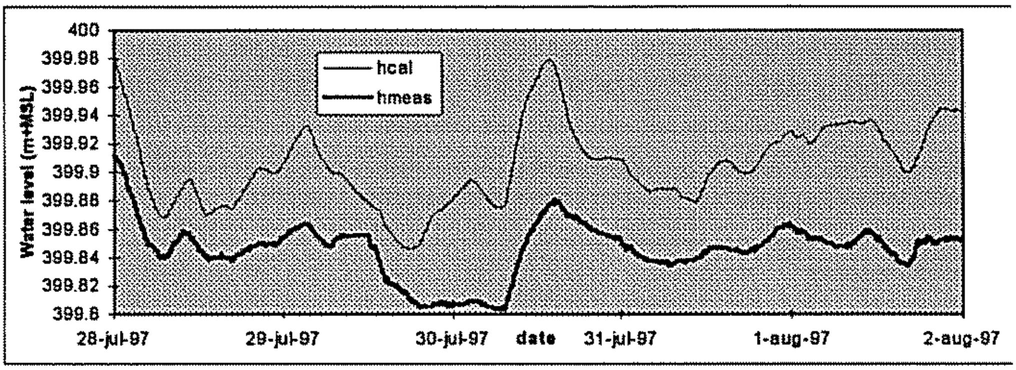

Figure 2. Measured surface water surface elevation at Granite Reef Dam for July 28-August 1, 1997, and values simulated with the Salt-Verde River system model.

(4) A scaled model of an SRP radial gate was installed on a laboratory canal along with pertinent instrumentation. Water depths, pressure distribution, and flow jet contraction were measured as a function of gate opening and flow rate. These measurements are being used to determine the adequacy of the head-discharge equations currently used by SRP and to test alternative head-discharge relationships. SRP uses a relationship that has been documented in the literature (Bos, 1989), but that was modified to reflect a gradual transition from free flow to submerged flow conditions. Data from this study are still being analyzed.

(5) Simulation tests have shown that attempting to start the automation system when the actual water levels are far from the setpoints can result in unstable behavior. To overcome this problem, when the control system is turned on, the water level setpoints are initialized to the actual water levels. Water levels are then gradually adjusted to the desired target by varying the setpoint linearly in time and by using a combination of feedforward and feedback control to make the necessary flow changes. The strategy was programmed into the unsteady flow model, CanalCAD, and tested with the ASCE Task Committee's Test Case 1 (Clemmens et al., 1998). The results of figure 3 show the change in water levels in an eight-pool canal system in which water levels in all pools are required to change simultaneously at 2:00. In combination, the feedforward and feedback control systems are able to maintain a stable control during the transient. Programming of this strategy into the unsteady flow simulation software being used in this project, Mike 11, is still pending.

(6) During most of 1999, SRP has been installing and testing a new SCADA system for Y2K

compliance. This work prevented us from making any significant progress in that area. Late in 1999, SRP decided to replace its VAX operating system, which currently hosts the SCADA system. Therefore, programming of the control system will be postponed until the new operating system and a SCADA package that works under that environment are installed.

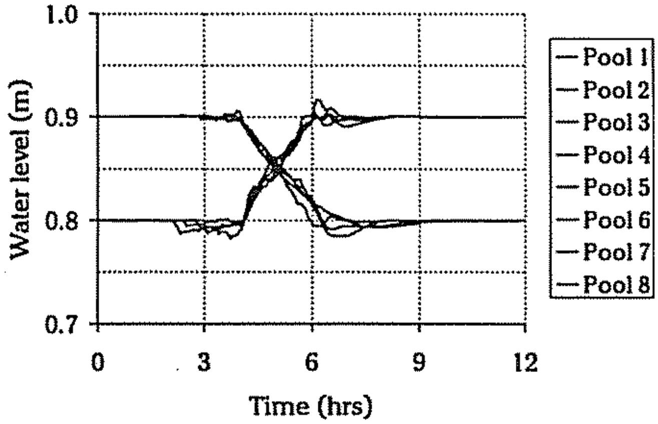

Figure 3. Simulated water levels in ASCE Test Canal 1.

INTERPRETATION: Based on the analysis to date, it appears that canal automation (remote computer control) has some real potential for improving canal operations over supervisory (manual remote) control. The magnitude of unscheduled flow changes that can be allowed is still limited by the canal's hydraulic properties. Automation itself cannot fully overcome these limitations.

FUTURE PLANS: Work will continue to complete the various tasks that were included in the Phase II workplan and a report will be prepared by early next year. During Phase III, if funded, the system will be tested in real time. Although the pilot project's objective testing the feasibility of the control system and not full implementation, to test its potential fully some level of implementation is required.

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