WATER PROJECT MANAGEMENT

CONTENTS

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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.

MEASUREMENT AND CONTROL OF WATER FLOW UNDER DIFFICULT CONDITIONS

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

PROBLEMS: Many flow conditions in irrigated agriculture and watershed studies are not amenable to the use of simple flumes and weirs. Other measurement devices and methods are often more expensive, more difficult to use, or less accurate than needed for field applications. Improvements in these other methods would compliment flumes and weirs. Interest continues in flow profile conditioning in pipes, applications of flow meters to irrigation wells, and automatic regulation of flow to lateral canals. More design information is needed for flap gates, which are sometimes used to prevent back flows in lowland situations. Radial gates are frequently used to control flows in canals. Their hydraulic behavior needs to be simplified, perhaps with simple structural changes.

Most delivery canal systems use pipes through the canal banks to deliver flows to farm canals. Propeller meters, end-cap orifices, Pitot systems and ultrasonic meters placed in these pipes frequently are subjected to poorly conditioned flow profiles that compromise the meters' operation. All of these are affected by upstream pipe bends and valves. Methods to condition flows and improve the flow profiles would allow the application of many flow metering methods now restricted by these limitations, particularly when short lengths of straight pipe precede the meter.

Even with conditioned flow profiles, some methods experience other limitations. For example, propeller meters readily clog in debris-laden flows and usually can be inserted into trashy flows for only a few minutes. Portable end-cap orifice meters do not attach easily to rusted pipe ends. Pitot systems are considered difficult to apply to discharges from wells without special wall taps and insertion ports. Although effective in solving some pipe and open channel flow measuring problems, ultrasonic flow meters remain too expensive for most irrigation applications.

Fluctuating flow-rate deliveries from a main canal to a secondary canal increase the difficulty of effective irrigation and may require expensive means to monitor total delivered water volume. Mechanical-hydraulic mechanisms hopefully can be developed to stabilize the discharge rate through them, regardless of changes in the level of the source canal. Fluctuating flow-rate deliveries increase the difficulty of effective irrigation and may require expensive means to monitor total delivered water volume. Steady flows can use simple time clocks for total volume.

The several ongoing objectives associated with pipe system flows are: (a) to complete papers and technical notes regarding simplifying the use of portable end-cap orifices (previous Annual Reports); (b) to develop practical methods to achieve effective flow conditioning for flow meters installed in difficult short-pipe situations; (c) to evaluate prototypes of clog-resistant propeller meters that have been manufactured to our suggestions; (d) to place current study of the rubberized flap gates into historical perspective with previous flap gate designs, and (e) to modify the edge of a radial gate in attempts to simplify its hydraulic behavior.

APPROACH: Flow-profile conditioning in pipes will include insertion of orifices and sidewall vanes. A special 30-inch diameter pipe facility is being used for conducting these tests. The same pipe system has been modified to allow testing of a pipe flow control concept using the proposed new valving and bag obstruction system.

Testing will continue on the new design of float-operated valves that can be used in combination with a water inflated bag to maintain a desired flow level in a receiving canal. These are cross-referenced to the related "Pipe-Flow" project report for the pipe flow situations. These modifications for channels will be reported herein. The objective is to develop applicable hydraulic flow control devices 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 with a view to generalize the applications and to reduce cost.

Tests on the end-cap orifice system are complete. An alternate pressure tapping method was studied that used a small static pressure tube (with holes drilled through its walls), similar to that used for the Pitot system described last year, to detect the pressure in the approach pipe upstream from the orifice. The tube was inserted through a grommet-sealed hole in the face of the orifice plate near the pipe wall so that the pressure sensed was that for one pipe diameter upstream from the face of the orifice. No further lab data was gathered.

A plastic pipe, O.D.= 1 3/8 inches, was fastened to the closing edge of the radial gate model (Fig. 1) in an attempt to make it less sensitive to the angle of the gate face at different gate openings.

FINDINGS: Flap Gate: The rise of the hydraulic grade line for velocities of approximately 5 feet per second was only 0.01 inches of head even with added weights to the gate. The velocity head (h_v) was calculated to be 0.4 feet. For the higher velocity of about 10 feet per second, the difference was even less, about 0.008 inches, for an h_v of 1.5 feet.

Pipe Flow Control System: The new DACL valving system that was developed, because a commercial version did not provide the needed functions, has only been partly evaluated. The new valve appears to be capable of all required functions but needs further laboratory and field evaluation. A small model of the concept operated as hoped. While the bag concept worked on a small model and appeared to function well, a variety of low-cost bag products tried on the full scale resulted in failures from ripping. Different bag materials are on hand but not yet tested.

End-cap Orifice: The end-cap orifice data have been examined and the data appear consistent. The orifice system calibrated as expected from theory and is more repeatable than corner-taps on a pipe of uncertain end quality. The convenience aspects of the system were demonstrated.

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.

Pitot-tube system for irrigation wells: Second report has been published (Reference.)

Radial Gate: Laboratory testing on the first edge modification involving attachment of a round pipe on the gate edge are completed, but the data have not been fully evaluated.

INTERPRETATION: Flap Gate: While the analysis is still incomplete, preliminary findings are that free discharging flap gates cause negligible increased back pressure on pipelines that are flowing full. This is in contrast to their presence if submerged. Mathematical analysis from historical literature has been only partly successful in describing their behavior. Because design information is not readily available for the free outfall or the submerged gate situations, the current results are being reported in the historical context of some limited previous studies in order to make the information more readily available to designers.

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.

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. Indications from limited test runs 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 (Fig. 2 and 3).

Pitot System: The rugged compact system can be constructed using common shop techniques and standard small pipe fittings, is portable, and disassembles to fit into a standard business brief case. The device can be quickly attached to the flowing well pipe to determine well discharges to within plus or minus 3 to 5 percent. This research facilitates the measurement and management of irrigation wells, providing needed tools for irrigation project technicians worldwide to measure flow from wells and to check the condition of existing meters.

FUTURE PLANS: A report on End-Cap Orifice will be prepared and a technical note on the Flap Gate to make it more available to designers in water resources incorporating some limited historical data. We will continue the laboratory study phase and improve instrumentation for faster data collection on flow velocity distribution and evaluate current data on the Radial Gate to assist in redesigning the lip attachment to a structural angle.

COOPERATORS: Robert Gooch, Salt River Project, Phoenix AZ; John Dickerman, Global Water, Fair Oaks CA ; and John Vitas, Plasti-Fab, Inc., Tualatin OR.

REFERENCE: Replogle, J.A. and Wahlin, B. 2000. Measuring irrigation well discharges. Journal of Hydraulic Engineering, ASCE. 126(5) 335-346.

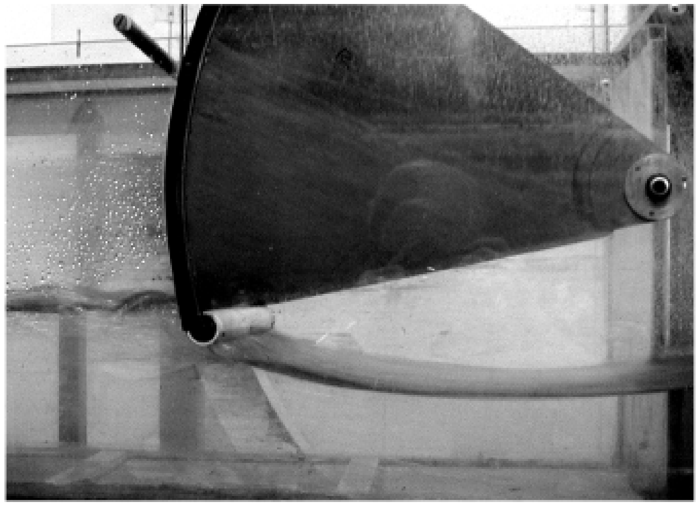

Figure 1. Radial gate with the gate-closure edge modified by attaching a pipe along the edge.

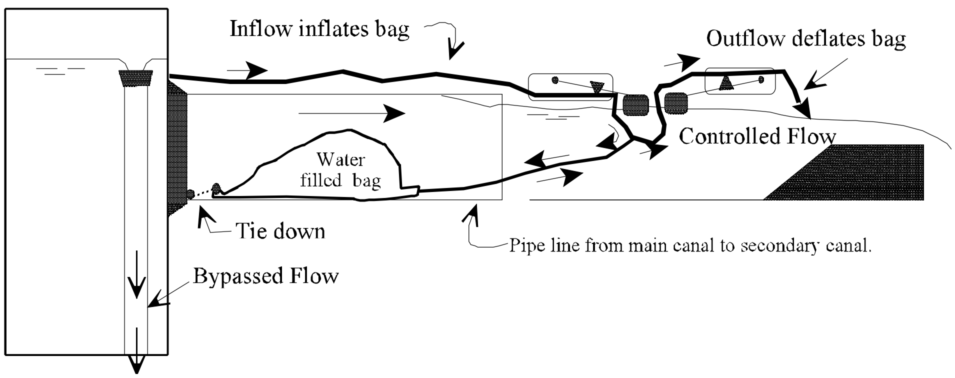

Figure 2. General laboratory set-up for evaluating valve and bag system for flow level control.

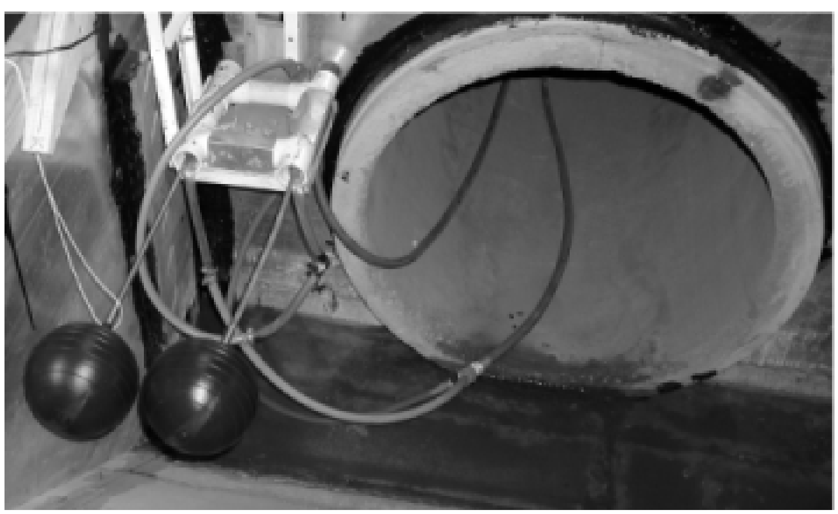

Figure 3. Low-cost float valve system in a pipe outlet channel.

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 connected 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.

- 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 did not run well with computer systems using Windows operating systems. A revision of the original flume book is needed and should include experiences and construction techniques accumulated over the last decade.

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) and has been in operation for over 3 years. The objective was to evaluate the idea of the self-calibrating flume system and to determine its operational limitations in situations where sediment flows ordinarily spoil measurement attempts. 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 was 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.

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 previously reported, the California Water Quality Control Board used the flume data from last year to demonstrate the severity of the cinibar (mercury ore) tailings problem to EPA.

Based on that, emergency super-fund money ($2.5 million) to stabilize the mine tailings was authorized. More data have been collected to verify the initial findings and to evaluate progress in the effectiveness of the clean-up.

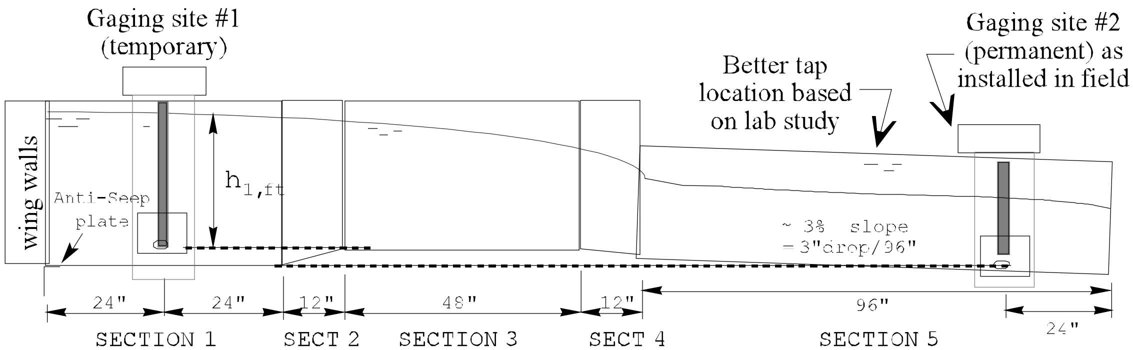

Figure 1. General layout of sediment resistant flume as installed.

The model study of the system showed that 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 of 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. The speculation is that the chute will need to transition gently to its final slope in order to provide a smooth surface drop. The slight drop provided in the original design caused undulations that made depth measurements difficult. This has not been tested.

As previously reported, 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 continue to find the devices easy to install and able to meet their operating requirements. Widespread acceptance appears to be growing, as is interest in 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 final versions to over 490 users from 40 countries.

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.

FUTURE PLANS: Design, installation and application changes for adjustable flumes, including evaluation of field performance, will continue. Recent design assistance included changes to accommodate stilling wells to be attached to the smallest flume size. Kits of a possible recording instrumentation system have not been selected or assembled in any kind of final design format. Such a system seems economical and feasible. This system will continue to be investigated to see if it indeed can be demonstrated and evaluated.

Because the WinFlume program has been distributed, we will write a new book/users manual for the WinFlume Program.

COOPERATORS: Informal cooperation exists among: Tony Wahl and Cliff Pugh, US 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 Steward, 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.

Figure 1. Flow in discharge chute attached to a long-throated flume. The flow calibration is stable despite the rough flow appearance.

SEEPAGE CONTROL WITH MUDDY WATER

H. Bouwer, Research Hydraulic Engineer

PROBLEM: Seepage from ponds, reservoirs, lagoons, wetlands, or other water impoundments often needs to be controlled, usually with earth or plastic linings. Where earth linings are used, the soil material is placed on the bottom and banks and mechanically compacted when the impoundment is dry. However, the soil can also be applied dry or as a slurry to the water itself. The question then is: what gives more seepage control, a compacted soil layer placed on the bottom where the soil is thoroughly mixed, or a soil slurry applied to the water where the coarser particles sink faster than the finer particles, thus creating a lining layer on the bottom that is coarser at the bottom and finer at the top? Another question is: can additional seepage reduction be obtained by applying sodium carbonate or other chemicals that will disperse the clay in the liner?

APPROACH: The effect of placement of an earth lining in an impoundment for seepage control was evaluated in four laboratory columns in 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 carefully 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 in which they reached well-defined final values. After the slurries had been applied and the infiltration rates had become essentially constant for at least 20 days, a solution of sodium carbonate was applied to see if further infiltration rate reductions could be obtained by the clay dispersing action of the sodium. Earlier work at the U.S. Water Conservation Laboratory (USWCL) showed that sodium carbonate additions to the water were effective in reducing seepage rates in stock ponds. Using the dose recommendations resulting from that work, each column received 17 grams of sodium carbonate dissolved in 500 ml water. The salt solutions were placed deep into the water so that they would be close to the infiltrating soil surface.

FINDINGS: Table 1 shows the final infiltration rates at about 40 days after the soil liners had been placed. The rates ranged from 0.85 cm/day for the 15 split slurry applications to 2.7 cm/day for the compacted soil. The infiltration rate for column 1 (compacted earth layer) started at about 3.7 cm/day for the first 10 days then decreased gradually to about 2.7 cm/day in the next 20 days, where it remained for the duration of the test (next 15 days). The split slurry applications produced continued declines, as shown in Figure 1. Since the seepage rate for the silica sand alone was 9.6 to 11.1 m/day, 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 reductions 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 achieved with slurry applications gave better seepage control than a uniform compacted liner. In practice, slurry applications can be repeated until an acceptable seepage level is reached.

After the sodium carbonate solutions had been placed in columns 1, 3, and 4 (column 2 was not used because the soil lining had cracked), infiltration rates began to decrease very slowly. After 150 days, they had reached values of 0.49 cm/day for column 1, 0.25 cm/day for column 3, and 0.19 cm/day for column 4. This amounts to additional infiltration reductions of 82%, 75%, and 78%, respectively.
Because of the slowness of the process, the continued reduction must have been caused mainly by clay dispersion rather than by microbiological action. Regardless, the final infiltration rates of about 0.2 cm/day in columns 3 and 4 were much less than the infiltration rate of about 1000 cm/day for the silica sand alone before the soil liners were placed. This is a very significant seepage reduction which may well be a lot less expensive than plastic or other artificial liners.

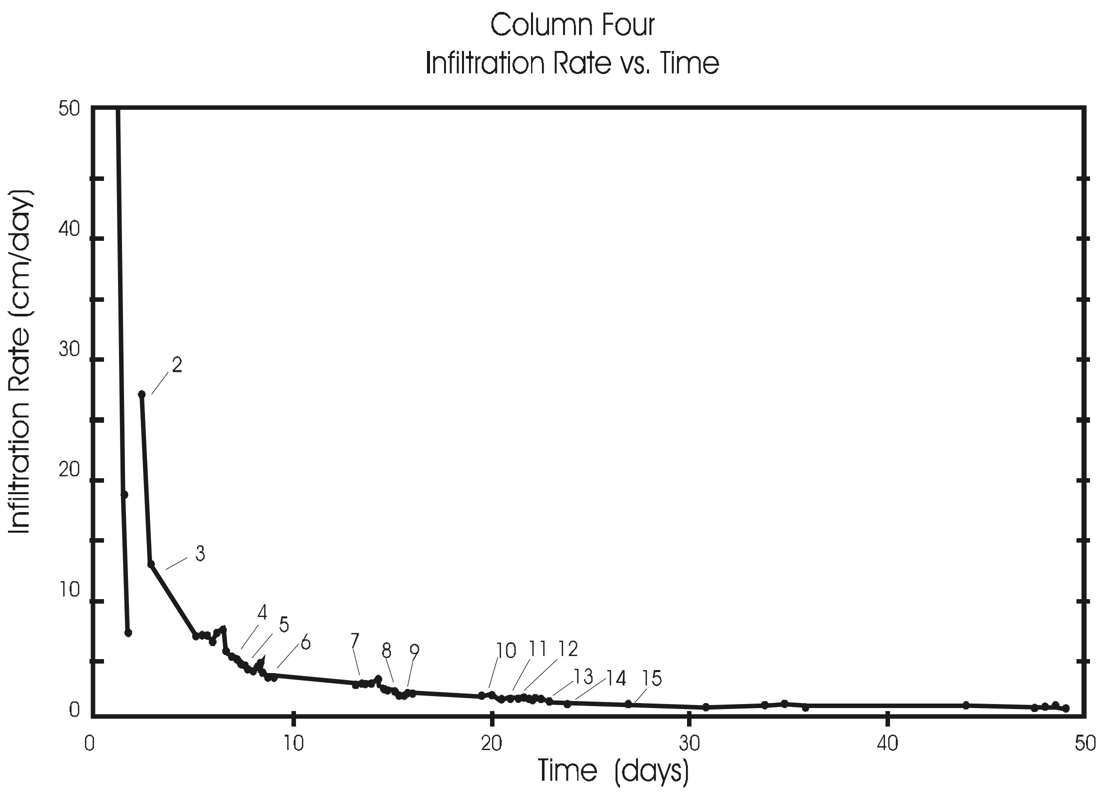

Figure 1. Infiltration rates for column 4 with 15 split slurry applications (indicated on curve).

Table 1. Effects of earth liners and sodium carbonate on seepage rates in soil columns.

	Column 1	Column 2	Column 3	Column 4
	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
Infiltration rate in cm/day after sodium carbonate addition	0.49		0.25	0.19

INTERPRETATION: For the same amount of soil used, earth linings gave lower infiltration rates and, hence, better seepage control when applied as a slurry in split applications to a water filled pond than when applied dry on the bottom of an empty pond and mechanically compacted. Further reductions in seepage losses were obtained by applying sodium carbonate to the water. Repeated slurry applications are naturally achieved in wetlands or other impoundments that receive periodic inflows of muddy water. This is beneficial where seepage losses are to be minimized, but undesirable in infiltration basins for artificial recharge of groundwater. Such basins should then be designed and managed for minimum erosion or other introduction of fine particles into the water.

FUTURE PLANS: The results will be used in interpreting infiltration behavior of impoundments to see what best management practices should be used to maximize infiltration rates (recharge basins) or to minimize infiltration rates (wetlands, ponds, etc.).

FORMATION OF CLOGGING LAYERS IN RECHARGE BASINS

H. Bouwer, Research Hydraulic Engineer; and N.L. Duran, Microbiologist

PROBLEM: Clogging of soil surfaces in infiltration systems for artificial recharge of groundwater or for soil-aquifer treatment is the main problem in maintaining adequate infiltration rates. Even if all clogging parameters like suspended solids, nutrients, and organic carbon are removed, clogging layers may still form on the infiltrating surfaces due to growth of chemotrophic microorganisms. Also, dissolved air in the water may come out of solution as water pressures decrease when the water moves into and through the soil. Other gases, like nitrogen, methane, and hydrogen sulfide may also accumulate due to microbiological processes in the soil.

APPROACH: To evaluate these processes, four plastic columns 10.4 cm in diameter and 90 cm in length were set up in the laboratory. They were packed with four different soils: flint sand, #90 sand, loamy sand of the old Flushing Meadows project in the Salt River bed, and the Mohall-Laveen soil used in the 1 ft x 8 ft stainless steel columns in the greenhouse for studying effects of irrigation and recharge with sewage effluent on groundwater. A coarse sand and gravel layer for drainage was placed at the bottom of the column. Each column was packed with 30 cm of soil. The soil was flooded with Phoenix tap water to a constant depth of 60 cm. The pressure head at the bottom of the soil column was maintained at 60 cm water, thus creating an initial hydraulic gradient of one in the soil column to represent the gravity flow that dominates in actual field systems. The bulk density and saturated hydraulic conductivity of the soils as packed in the column and determined from dry weight and soil volume, and flow rate and head loss, respectively, are shown below.

Soil	Bulk Density, g/cm^3	K, m/day
flint sand	1.50	53.0
#90 sand	1.50	8.5
Flushing Meadows soil	1.54	2.0
Mohall-Laveen	1.74	0.3

RESULTS: Infiltration rates as a function of time for the four columns receiving tap water are shown in figure 1. The infiltration rate started to decrease almost immediately in the two sand columns. The relative infiltration rates (infiltration divided by the initial infiltration rate) are shown in figure 2. The rate at which the infiltration decreased was much faster with the coarser sand columns. The infiltration rate for the fastest three soils approached a common value of about 1 m/day after 45 days. After 95 days, the three columns had an infiltration rate of about 0.7 to 0.8 m/day. The initial rate for the least permeable, Mohall-Laveen soil, was 0.3 m/day and decreased to 0.12 m/day after 95 days. The reduction in infiltration rates could be caused by autotrophic bacteria and/or by formation of entrapped air. Tapping the columns and disturbing the soil surfaces with a rod did not produce ebullition (release of air bubbles) from the soil material, indicating that formation of entrapped air did not contribute to the decline of infiltration rates. However, the soil surface in all four columns was covered with a brown, soft organic layer about 1 mm thick. Stirring up this layer with a rod produced small, sludge-like flocs which, for a while, remained suspended in the water. Undoubtedly, these were flocs of a brown mat of bacteria that grew on the soil surface and their metabolic products like polysaccharides, despite the fact that the water was regular drinking water with some residual chlorine that was given in the water treatment plant to prevent regrowth of microorganisms in the water distribution system. The clogging layer was disturbed for only a small area (about 0.5 cm^2). Nevertheless, infiltration rates immediately increased, but decreased rapidly to the low values before the columns were checked for ebullition (air bubbling). A similar loose, brown deposit of bacterial growth accumulated on the plastic bottom of the constant head reservoir used to maintain constant water levels in the columns, indicating that soil and infiltration played no essential role in the microbiological activity.

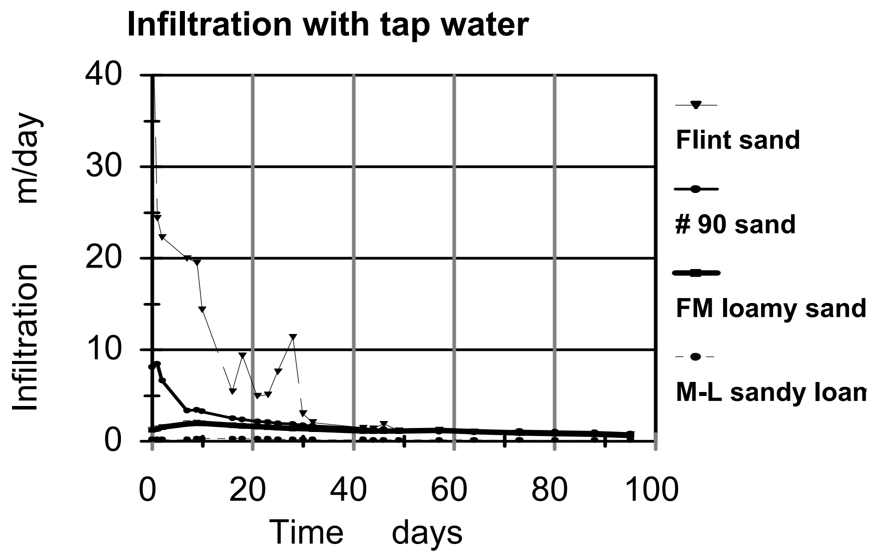

Figure 1. Infiltration with time for columns irrigated with tap water.

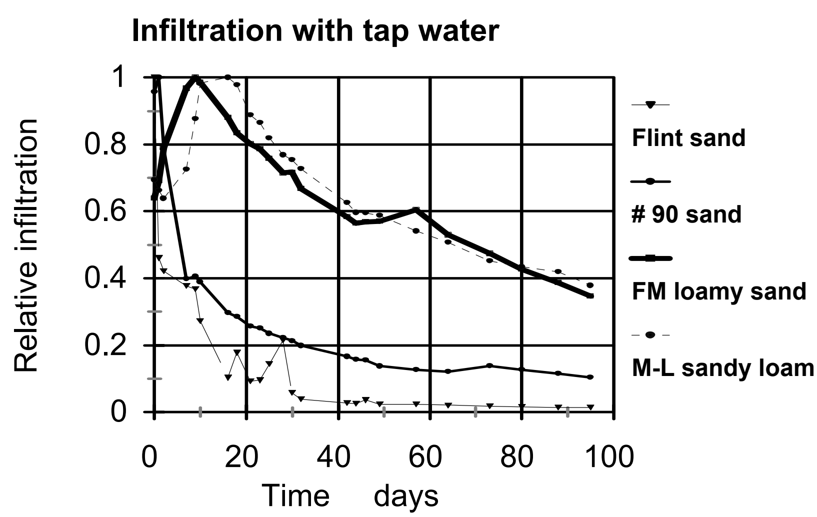

Figure 2. Relative infiltration with time.

Samples were taken from the clogging layer at the top of the columns and analyzed by direct epifluorescent microscopic counts using the nucleic acid fluorochrome stain, acridine orange (AO). Samples were stained with 0.1% acridine orange, filtered through a 0.2μm polycarbonate black filter, and examined with a Nikon epifluorescent microscope equipped with a 410-485 nm excitation filter, an auxiliary excitation filter at 460nm and an absorption filter at 515nm at 100 times magnifications. The biofilm observed on top of the columns appeared to be composed of bacterial cells, dead cell debris and large round cells, possibly aquatic protists. Photomicrographs of spirochetes and bacilli morphologies were taken.

INTERPRETATION: The results show that permeable soils with initially high infiltration rates of finished municipal drinking water clogged faster than less permeable soils, and that eventually all four soils had about the same infiltration rates as controlled by the clogging layer which consisted primarily of bacterial cells and cell debris. Thus, pretreatment of natural water for recharge to remove suspended solids, nutrients, and organic carbon as the main clogging agents will not eliminate clogging problems. Regular drying, cleaning, and disking of the infiltration basins will still be necessary to maintain high infiltration rates. The challenge then is to find the optimum combination of pretreatment of the water and basin maintenance procedures (drying, cleaning, disking) to give the best combination of recharge capacity and operating costs. Where land is scarce, maximizing recharge capacity will be the dominating objective.

FUTURE PLANS: The results of the column studies will be used in developing design and management plans for existing and planned groundwater recharge basins.

WATER REUSE

H. Bouwer, Research Hydraulic Engineer

PROBLEM: Increasing populations and finite water resources necessitate more water reuse. Also, increasingly stringent treatment requirements for discharge of sewage effluent into surface water make water reuse more attractive. The aim of this research is to develop technology for optimum water reuse and the role that groundwater recharge and 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 to treat sewage for reuse. These methods include lagooning, groundwater recharge, and intermittent sand filtration.

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 in soils of phosphate, metals, and strongly adsorbed organic compounds, and in groundwater of salts, nitrate, toxic refractory organic compounds, and pathogenic microorganisms. Water reuse for irrigation is a good practice, but it should not ruin the groundwater. Long-term salt build-up in groundwater will occur 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 can damage buildings, pipelines, landfills, cemeteries, parks, landscaping, etc. The salty water removed from the underground environment must be properly managed to avoid problems. Solutions include disposal into evaporation lakes, membrane filtration for water reuse, and disposal of the salty groundwater and reject brines in the ocean. The latter option is feasible only for areas not too far from a coast.

APPROACH: Technologies based on previous research at the U. S. Water Conservation Laboratory (USWCL) and more recent other 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. Ten soil columns in 8 ft x 1 ft stainless steel pipes have been set up in a laboratory greenhouse at the USWCL to study movement of pathogens and chemicals (including trace organics) in systems involving irrigation with sewage effluent, artificial recharge with sewage effluent, and recharge and irrigation with Colorado River water. The columns were filled with a sandy loam from the McMicken Flood Control reservoir northwest of the City of Surprise. This is a desert soil in the Mohall-Laveen Association that has had no agricultural use. The hydraulic conductivity of the soil was determined with a laboratory permeameter test as 28 cm/day, using a disturbed sample. To avoid particle segregation, the soil was placed in the columns in air-dry condition, lowering it in a container and tipping the container when it rested on the bottom of the pipe and then on the top of the soil as the column was filled. The new soil was then compacted with a rod.

Arrangements were made with the Central Arizona Water Conservation District to obtain Colorado River water from the Central Arizona Project (CAP) Aqueduct at a point where the canal has 100% Colorado River water. The CAP water was applied in a recharge mode to one column, starting February 10, 2000.

The sewage effluent to be used in the column studies should be representative of typical treatment for irrigation. As a minimum, the effluent should have had primary and secondary treatment followed by chlorination. Coagulation and granular medium filtration before chlorination removes essentially all microorganisms and makes this so-called tertiary effluent essentially pathogen free and, hence, suitable for unrestricted irrigation. This includes irrigation of lettuce and other crops consumed raw or brought raw into the kitchen, and of parks, playgrounds, golf courses and residential yards. Also, the effluent should primarily be of residential origin with not much industrial input. Proposed irrigation and recharge studies of the 10 columns are shown in Table 1.

Since the U.S. Water Conservation Laboratory does not have analytical capability for the detection of trace amounts of synthetic organics such as pharmaceuticals and other pharmaceutically active chemicals contributed to the effluent by human and industrial waste, samples of sewage effluent were sent to the laboratory of the Civil and Environmental Engineering Department at the University of California at Berkeley, California, where Dr. David L. Sedlak has an active research program on pharmaceuticals in sewage effluent. The first sample was taken from the Goodyear treatment plant because the effluent there was also used for landscape irrigation and artificial recharge of groundwater. The treatment train consisted of primary and secondary treatment, nitrification-denitrification, filtration, and UV disinfection. The sample was taken in mid-August in the late morning when the sewage flow was still relatively small. The results showed very low concentrations of pharmaceuticals, about an order of magnitude less than what is found in San Francisco Bay area sewage effluents, and close to detection limits, which are normally in the 5-10 ng/L range. A better effluent for the column studies may be from the Tolleson sewage treatment plant, which also receives mostly residential sewage and gives only conventional primary and secondary treatment and chlorination. A sample has been sent to the University of California Berkeley for analysis of pharmaceuticals.

FINDINGS: Flooding of the Colorado River water recharge column was started on February 10, 2000, with a 2-week inundation period during which the infiltration rate dropped from 20 to 11 cm/day. The water depth in the column was maintained at 10 cm. When water was first applied to the dry-soil column, it took the wetting front two days to reach the bottom of the column and for outflow to commence. The accumulated infiltration at the time was 75.3 cm, so that the fillable porosity of the air-dry soil in the column was 0.33. This is 84% of the total porosity of the soil, which was calculated as 0.39 from volume and weight of the dry soil in the column. After the first flooding period, drying of the column caused further settlement of the soil. This reduced the length of the column by 11 cm, which decreased the porosity to 0.36. Further settling was not observed. Subsequent infiltration rates were taken as the outflow rates at the bottom of the column. The decline in infiltration rates during the first flooding period may be due to the advance of the wetting front in the column, at least during the first few days of the flooding period. The continued decline may be due to the formation of a clogging layer on the soil surface.

Table 1. Proposed schedule for irrigation and artificial recharge simulation with sewage effluent and Colorado River water for the 10 soil columns in the greenhouse.

Irrigation with Effluent		
COLUMN	**COVER**	**IRRIGATION EFFICIENCY**
1	grass	50%
2	grass	70%
3	grass	90%
4	alfalfa	50%
5	alfalfa	70%
6	alfalfa	90%
7	bare soil	70%[1]
Irrigation with Colorado River Water		
8	grass	70%
	Groundwater Recharge	**Water**
9	bare soil	effluent
10	bare soil	Colorado River water

During the first drying period, the surface soil shrank enough laterally to separate from the pipe, so that it was carefully packed against the pipe again. The second and third flooding periods, which were 21 and 30 days, respectively, showed infiltration rates of around 7 cm/day; but at the end of the third flooding period, an increasing trend developed which continued in the fourth flooding period until infiltration rates reached about 15 cm/day and leveled off at that value. The length of the fourth flooding period was 50 days. During all inundation periods, the Colorado River water above the soil column remained quite clear. A brown mat developed on the bottom, especially in the fourth flooding period, but apparently had no clogging effect. A sustainable infiltration rate of about 15 cm/day is typically achieved in infiltration recharge basins in desert or light agricultural soils. Considering the many factors that affect the relation between infiltration rates and time, the results of the column study did not come as a surprise. The total infiltration amount for the four flooding periods was 12.1 m. Samples of the inflow and outflow were taken for analysis of DOC (dissolved organic carbon) by the Environmental Engineering and Water Resources Department of Arizona State University.

[1] Since evaporation from bare soil will be less than evapotranspiration from a vegetated surface, the bare soil column will be irrigated to give the same volume of leachate as the grass column with 70% irrigation efficiency.

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. The column studies on underground fate and transport of pharmaceuticals and other organic compounds will shed more light on possible effects of both irrigation and artificial recharge on groundwater quality.

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.

COOPERATORS: Dr. P. Fox, Dr. P. Westerhoff, and Dr. J. Drewes, Arizona State University, Department of Civil and Environmental Engineering and National Center for Renewable Water Supplies, Tempe AZ; Dr. R. Arnold and Dr. M. Conklin, The University of Arizona, Tucson AZ; Dr. David Sedlak, University of California, Berkeley CA; J. Swanson, The City of Surprise, Surprise AZ; Fort Huachuca AZ, United States Army Garrison through ASU, Tempe AZ; M. Milczarec of GeoSystems Inc., Tucson AZ; and the City of Tolleson AZ.

IRRIGATION CANAL AUTOMATION

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

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 may 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. Computer models of unsteady canal flow are very complex and expensive because they are 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.

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 are currently using a commercial SCADA package, FIX Dynamics from Intellution, Inc. Originally, standard MODBUS communication protocol was used to communicate between FIX Dynamics and Automata's Base Station, and the base station communicated with the field equipment using Automata's proprietary protocol. All communications in the system now use MODBUS. The USWCL canal control scheme logic (USWCL controller) is interfaced with FIX Dynamics. The research approach will be to use simulation models to test and further develop various control schemes for the proposed automation system. The combined hardware and software automation system will be field tested on the WM lateral canal of the Maricopa Stanfield Irrigation and Drainage District (MSIDD).

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 the 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 family of controllers, including a series of simple local PI controllers. Selections of controllers to test on the WM canal are based on simulation tests of controller performance on the American Society of Civil Engineers (ASCE) test cases and simulation of the WM canal itself.

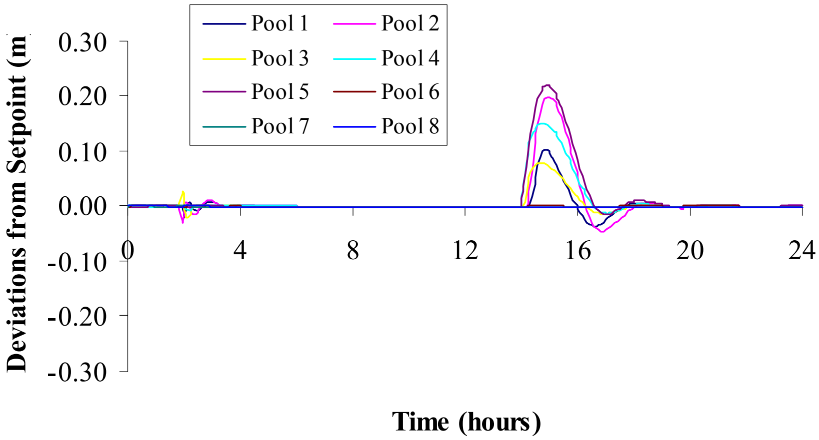

Figure 1. Setpoint deviations for a series of PI controllers on ASCE test case 1-1 (no gate constraints and tuned conditions).

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.

<u>Simulation studies of downstream-water-level feedback controllers</u>: Last year a comprehensive set of simulation tests was performed on the ASCE test canal 1. The feedback controllers used ranged from a series of simple, local downstream PI controllers to a fully centralized downstream PI controller. These controllers were tuned using optimization techniques and the integrator-delay model. This year focus shifted slightly, and the tuning method was examined more

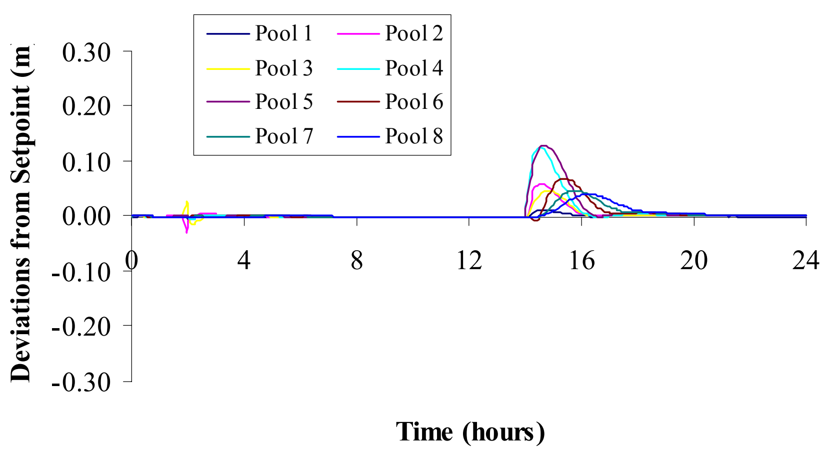

Figure 2. Setpoint deviations for the fully centralized PI controller on ASCE test case 1-1 (no gate constraints and tuned conditions).

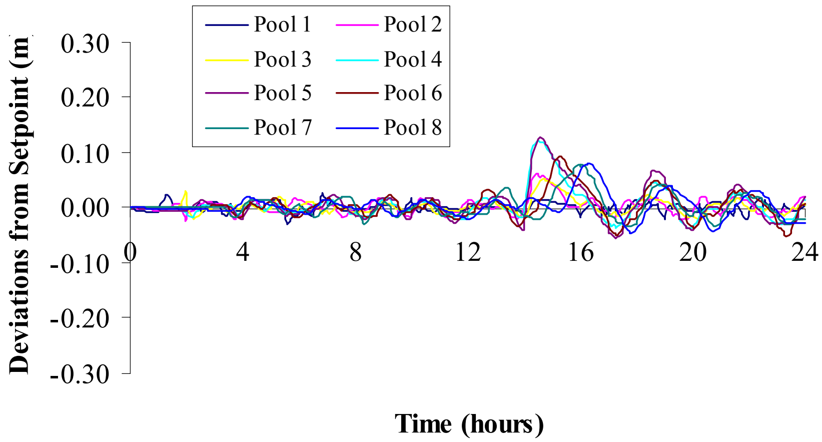

Figure 3. Setpoint deviations for the fully centralized PI controller on ASCE test case 1-1 (gate constraints and tuned conditions).

closely. Specifically, the weights used to penalize water level errors and control actions in the optimization routine were examined. In the initial simulation studies, some of the feedback controllers became unstable when they were run under untuned conditions. This poor performance arose because the controller was fairly aggressive and because of uncertainties in the wave travel time prediction. To avoid this problem, the controller was made less aggressive by increasing the penalty for control actions in the tuning process. Figure 1 shows the simulation results for a series of local PI controllers for the ASCE test case 1-1, while Figure 2 shows the results for the fully centralized PI controller. The minimum gate movement constraints introduced sustained low amplitude oscillations in the water levels (Fig. 3). Most of these optimal controllers were robust enough to handle the untuned conditions without much degradation in performance (Fig. 4).

Also, most of the simulation studies done to this point have been for downstream control of sloping canal systems that are not completely under
backwater. Initial work was done with Jan Schuurmans, Peter-Jules van Overloop, and Charles Burt to convert the downstream tuning procedure into an upstream tuning procedure. The initial work indicates that upstream and downstream control require quite different weighting factors on the control actions. In addition, work was also done on adding a high frequency filter to the tuning procedure to account for the resonance problems that may occur in pools that are completely under backwater. Schuurmans and van Overloop have written an initial optimal tuning method in MATLAB that will add a filter to a series of local PI controllers and allow the user to choose either upstream or downstream control. We are in the process of reviewing that code now, and no simulation tests have been performed yet.

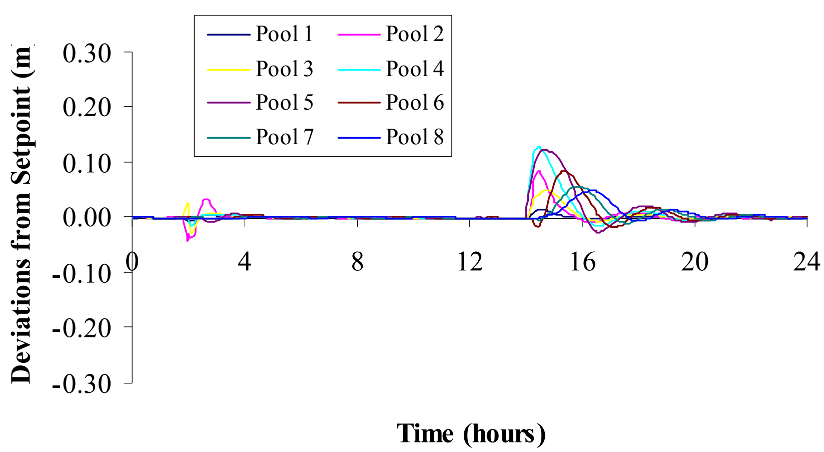

Figure 4. Setpoint deviations for the fully centralized PI controller on ASCE test canal 1-1 (no gate constraints and untuned conditions).

One of the drawbacks to the USWCL controller is that it is applicable only to a single inline canal system. In other words, it cannot be applied to branching canal networks. In reality, canal operators would desire to automate an entire canal network and not just a single branch of that network. Work was done on the USWCL controller to modify it to be able to handle branching canal networks. The method has been developed and it appears to give reasonable controller constants; however, no simulation test has been performed because CanalCAD cannot handle branching canal networks. To overcome this obstacle, the hydraulic simulation package SOBEK was obtained from Delft Hydraulics in the Netherlands. This Windows-based program is capable of handling branching canal networks and the USWCL controller can be programed into it.

<u>MSIDD Field Hardware Modifications and Software Upgrades</u>: As part of the CRADA with Automata, the control sites on the WM lateral were equipped with Automata's "Field Controller" (FC) Remote Terminal Unit (RTU). This unit uses Automata's proprietary communications protocol. To reduce the RTU firmware programming effort, a translator was used at the base station to translate standard MODBUS communications to Automata's protocol. The FC units have been replaced with a new 10-bit version of Automata's Mini RTU. This unit provides functionality similar to that of the FC unit and uses MODBUS as its native communications protocol. This eliminates the need for the intermediate translator. Originally, communication was over narrow-band FM radios. Interference from repeaters in the Phoenix and Casa Grande areas of Arizona have hampered the performance of the control system. To eliminate the interference problem, the FM system has been replaced with a 900 MHz spread-spectrum radio system.

The control software has been upgraded to improve user access to control actions proposed by the system. There are two modes of operation. In "Automatic" mode, control actions are sent automatically to the RTUs. In "Review" mode, the operator is given an opportunity to modify or delete the proposed control actions.

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: Additional simulation studies need to be performed using the controllers developed from Schuurmans and van Overloop's new tuning program. These simulations will include tests to determine the appropriate weighting on the control actions in the tuning program as well as test to determine if the high frequency filter works properly on pools that are completely under backwater. Also, the USWCL controller will be coded into SOBEK and simulation tests will be performed on branching canal networks.

COOPERATORS: Lenny Feuer, Automata, Inc., Nevada City CA; Gary Sloan, MSIDD, Stanfield AZ; Jan Schuurmans, University of Twente, The Netherlands; Peter-Jules van Overloop, van Overloop Consultancy, The Netherlands; Cliff Pugh, USBR, Denver; Charles Burt, California Polytechnic State University, San Luis Obispo CA; Bob Gooch, Salt River Project, Phoenix AZ; Victor Ruiz, IMTA, Cuernavaca, Mexico; Pierre-Olivier Malaterre, CEMAGREF, Montpellier, France.

CANAL AUTOMATION PILOT PROJECT FOR SALT RIVER PROJECT'S 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 and 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 by 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.

As indicated in the 1999 Annual Report (Bautista et al., 2000), SRP has been upgrading their Supervisory Control and Data Acquisition System (SCADA) and their computer systems. Consequently, many aspects of the automation project have been delayed until the upgrade is complete. There are other items on which we have been able to continue our research and development efforts.

(1) A computer program has been under development to carry out the feedforward control calculations. Testing of the program is currently underway.

(2) A study was initiated in 1999 by Jan Tel of Delft University of Technology in cooperation with the USWCL and SRP. The objective of the study was to obtain a more accurate head-discharge relationship for SRP's radial gates. Simulation tests have previously demonstrated that performance of the control system will improve with improved gate flow predictions. These predictions are currently very uncertain, with likely errors of 10% under free-flow conditions and 30% under submerged flow conditions. Even if SRP ultimately does not adopt the proposed automation system, improving gate discharge predictions will improve their canal flow control capabilities.

(3) Prior to field testing, we will need to conduct extensive simulation tests with the automatic control system. The control algorithms were coded into the unsteady flow simulation software Mike 11 during Phase I of this project. That code was developed to handle a specific segment of SRP's delivery system and does not provide the flexibility needed to conduct control tests with the entire Arizona Canal or with other canal systems. Thus, the control algorithms in Mike 11 have been under further development.

FINDINGS: (1) A working version of the canal scheduling program is currently being tested by our cooperators in SRP. The program utilizes water order information compiled through SRP's water accounting database, WTAP. Extensive programming has been required to ensure that WTAP data is properly retrieved and the integrity of all input data is preserved. Also, various elements of the interface have been modified to improve the program's user-friendliness.

Tests are being conducted to compare the program's output with SRP canal operations. These tests will help us assess the potential for implementation. SRP canal operations are complex. Operators receive next day's orders through WTAP and by phone. Based on these demands, they develop a schedule of flow changes. The scheduling process is based on experience. In addition to the known demands, operators take into account possible canal losses or gains (from canal infiltration, gate leaks, return flows, rainfall etc.) and trends in water levels. For example, if water levels are increasing throughout the canal (i.e., supplies exceed demands), they will service some demand increases without scheduling them in the expectation that those unscheduled changes will compensate the excess flow in the system and stabilize the water levels. Operators realize that flow predictions through their check structures is imprecise and, therefore, they do not attempt to develop very detailed schedules. Furthermore, they seek to minimize the number of scheduled changes, which they perform manually through the SCADA system.

In addition to the scheduled changes, operators often try to respond to same-day requests for flow cuts or increases (so-called red changes because they are not scheduled). Operators try to satisfy these red changes by finding an increase or cut of similar magnitude to counteract the requested change. Also, they may observe increasing or decreasing trends in pool levels and try to use the requested change to balance the flow. In other cases, if pump capacity is available, the operators will try to respond by turning pumps on or off. Still, in other cases operators will borrow from pool storage to accommodate these short-notice demands. In addition to red changes, canal flows are subject to other unanticipated conditions, such as partial or total shutdown in water treatment plant operations, flushing of water treatment plant filters, unexpected opening of turnouts, storm runoff, etc., all of which impact flows and levels. Clearly, there is a lot of guesswork involved in the operation of the canal. Because of all of this uncertainty, the schedule developed during the previous day is used only as a guide and may depart substantially from actual operations.

Testing of the scheduling program will be conducted in three stages. During the present initial stage, we are comparing the program's output with the planned schedules and the actual system flows. These tests will be conducted over several weeks to identify conditions that are not being accounted for by the scheduling program. These tests will also help us determine the extent to which operators' schedules depart from actual daily flows. We expect the program output to bear some similarities to both the operator-computed schedules and the patterns of daily flows. If this assumption proves true, then these tests should also help us convince the operators to test the program-generated schedules as their daily operating plan. The second testing phase will consist, therefore, of manual implementation of the program output. After SRP completes its SCADA upgrade, we will request SRP's approval to implement flow control on their check structures and to automate the execution of the computed schedules. Thus, the last testing phase will consist of automatic control in real time.

Figure 1 is an example of scheduled and actual discharges at the head of the Arizona-Grand Canal system based on data collected for October 13, 2000. Because of water travel time, flow rate changes for a given day need to be initiated the day before. The program and operator schedules are quite similar except for the initial flow condition used by the operators and the magnitude of a major flow cut occurring at midnight. The actual flow through the headgate is less than the scheduled values, and it appears that throughout the day operators were trying to catch up with the requested system flow. These discrepancies are thought to be related to the fact that data were collected following a period of intense rainfall and runoff into the canal. According to the operators, there was excess volume of water in the system that they were trying to eliminate. Water level data for the illustrated test period have not been analyzed to verify this statement.

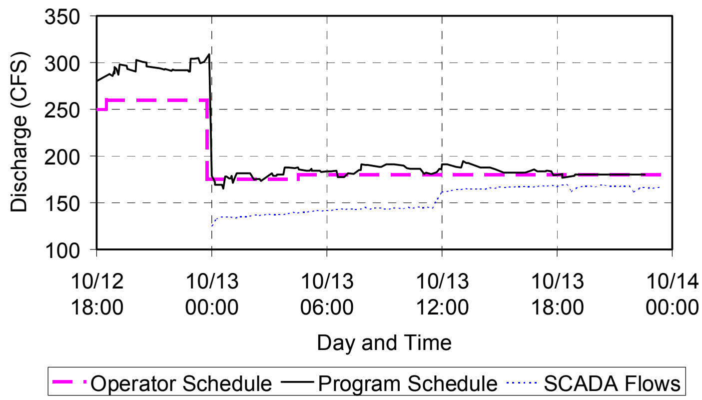

Figure 1. Scheduled and actual flows at the head of the Arizona Canal for schedule date 10/13/2000.

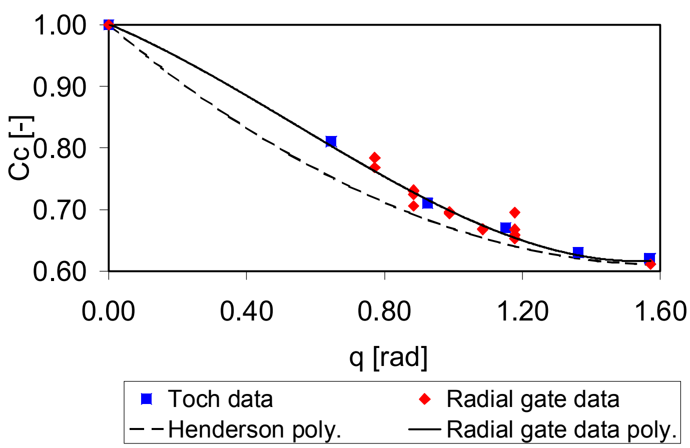

Figure 2. Contraction coefficient for radial gates under free flow conditions; experimental data and best fit polynomials.

(2) Results of the SRP radial gate study were partly inconclusive (Tel, 2000). The analysis under free-flow conditions produced a relationship for the contraction coefficient that fits data from this and previous studies as well or better than a commonly used relationship proposed by Henderson (1966). These results are illustrated in Figure 2. The analysis also concludes that small energy losses occur under free flow. An energy loss coefficient is proposed for discharge calculations but an approach for computing the value of that loss coefficient is not

provided. From the submerged flow analysis it was concluded that important flow parameters could not be measured with sufficient accuracy. Thus, the study did not suggest ways of improving the accuracy of the radial gate head-discharge relationship under submerged flow conditions.

(3) Development of the Mike 11 automatic control code continued intermittently during 2000 and is expected to be completed early in 2001.

INTERPRETATION: Initial testing of the scheduling program suggests that there is some uncertainty in the available data and that operators rely on experience to compensate for this uncertainty. Despite this, results suggest that the computed schedule can assist operators in developing their daily operational plans.

FUTURE PLANS: A report is under preparation summarizing the Phase II activities and accomplishments. At this time and because of the delays with SRP's SCADA system upgrades, the future of Phase III, testing in real time, seems uncertain. SRP operators remain interested in testing the feedforward control program and so we expect to begin manual implementation of schedules in 2001. At the same time, operators have manifested skepticism of the feedback control component and, thus, there is less enthusiasm to test that part of the control system. We plan at least to conclude the control system simulation tests.

COOPERATORS: Robert Brouwer and Jan Tel, Delft University of Technology, The Netherlands; Jan Schuurmans, University of Twente, The Netherlands; Robert Gooch, Joe Rauch and Grant Kavlie, Salt River Project, Phoenix AZ.

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