

IRRIGATION DISTRICT CANAL AUTOMATION - CARDD

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The first rule regarding irrigation district canal automation is that there is no single "best" method of automation. As an example, the cost of automating a small lateral structure with a computerized gate is similar to the cost of automating a regulating gate on a large canal, although the respective justifiable budgets may be \$1000 versus \$100,000 per structure. The locations of buffer reservoirs, the ability to allow water to spill at the ends of canals, the storage capacity of canal pools, and the topography will also play key roles in deciding if automation is desirable, and what type of automation should be used. These typical engineering considerations must also be coupled with recognition of the limitations and abilities of irrigation district staff regarding maintenance and troubleshooting of sophisticated controls.

On the other hand, there is no doubt that the flexibility and reliability of irrigation district water deliveries to the farm turnout must improve. Environmental pressures and the increased competition for the scarce water resources make on-farm irrigation management changes inevitable. There is a definite limit to on-farm improvements unless the main item, water, arrives in a flexible and farmer-controllable fashion.

There are many ways to improve water delivery flexibility and reliability. On steep canal laterals, the optimum solution may be to use simple long-crested weirs as check structures, and pick up lateral outflow with a lateral interceptor canal for later use in another location. While this may be a relatively inexpensive in-lateral solution, its effectiveness will ultimately depend upon the ease of control of flow rates into the lateral itself. This brings up the importance of making the conveyance canals (which are usually medium to large in size) more flexible in operation.

The conveyance canals which supply the laterals are typically on flatter slopes than the laterals. The kilometers of conveyance canals within a district are generally only a fraction of the total kilometers of lateral canal lengths. Main canal structures are often already supplied with electricity, there are fewer cross-regulators than on lateral canals, and there is generally easy access to structures by vehicles and communications equipment.

CARDD is a gate control algorithm (Canal Automation for Rapid Demand Deliveries) for medium to large irrigation district canals. It was developed to provide responsive, automatic downstream control. CARDD uses independent controllers, does not measure or compute flow rates, and controls a target depth at the downstream (d/s) end of each pool. The only inputs to the controller are water levels and gate opening.

To date, CARDD has been implemented on a large physical canal model at the Water Delivery Facility of the Irrigation Training and Research Center at California Polytechnic State University (Cal Poly), San Luis Obispo. The development of CARDD, its implementation at Cal Poly, and its limitations are discussed in this paper.

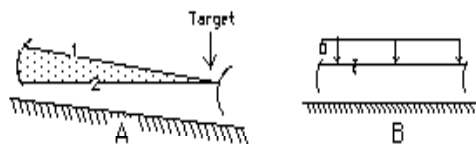


Figure 1. (A) Water surface profiles for CARDD at different flow rates. Shaded area represents wedge storage. Surface "1" is at maximum flow rate. Surface "2" is at zero flow rate. The water level at the downstream end of each pool is controlled. (B) Location and number of water level sensors for CARDD; water flows from left to right.

Computer Modeling Development

Original research on CARDD was done using the USM (unsteady model) program development of the USBR. Over the past two years, CARDD has been streamlined. Recent modifications to CARDD were done as a subroutine within an unsteady hydraulic model called CARIMA, developed by CEFRHYG/SOGREAH in France. Results from the latest computer and physical model research, funded in part by the USGS, are available in a technical report through NTIS (Burt and Parrish, 1989).

The differences between the Original CARDD and the present CARDD are:

1. Calculations are based upon dimensionless values; the Original CARDD made gate changes based upon numerous indicators which were tied to specific depths or deviations, regardless of the canal size.
2. CARDD now has no "deadband" or zone in which no gate movement is allowed.
3. The magnitude of almost all the gate movements depends upon the relative opening of the gate.
4. Rapid gate movement depends upon the speed of water level divergence in addition to the amount of divergence.
5. There are now 5 logic "cases", rather than 14 as in the Original CARDD.
6. Continuous equations for gate movement were developed as a function of water level deviation from the target depth. The Original CARDD utilized step functions which dictated a specific gate movement within a range of deviation of water level.

The determination of CARDD constants was done in a trial-and-error, looping procedure. That procedure was cumbersome; a better procedure should be found.

Physical Modeling

After the computer simulations were completed, the gate control algorithm was tested on a physical canal model constructed at the Water Delivery Facility. The physical canal consists of 6 - 33.5 m long pools. Each pool consists of 4 - 7.62 m concrete sections and one 3.05 m steel gate section. The gate section includes an adjustable side weir (for emergency spills), the gate itself, a turnout, and the gate movement and control mechanism. The canal itself was designed with a distorted vertical scale, having a slope of .00364, bottom width of 67 mm, side slope of .165, Manning's n of .0134, and a target depth of .61 m.

Each undershot gate is controlled independently of the other gates. TESCO controllers have been programmed with the CARDD logic to control the gates. Three water levels are measured in each pool with pressure transducers, and the gates are moved with linear actuators equipped with potentiometers to measure the gate positions.

The canal receives water from an upstream reservoir of a fairly constant water height. Water is available "on demand"; whenever the upstream gate of the canal opens or closes, the inflow to the canal is immediately and automatically changed.

RESULTS AND DISCUSSION

CARIMA

Seven canals were studied under CARIMA simulation. The canal dimensions were from hypothetical canals which spanned a range of flow rates, lengths, and slopes. Each canal had six pools, which was

considered important because of harmonics problems which can develop in multiple pools (as a side note - almost any control algorithm will work for downstream control on a single pool; it is a completely different matter to have one work on a series of pools).

At first the modeling work was frustrating because of a lack of rules which could develop transferrable knowledge. Discovery of several simple yet essential rules in modeling marked the turning point toward rapid results in CARIMA studies. Those rules are:

1. Good control is identified by four factors:
 - a. Minimal initial YS3 (water level at the downstream end of a pool) deviation from the desired setpoint (STP).
 - b. Rapid achievement of stability (i.e., rapid dampening of cycling).
 - c. Minimal amplification of disturbances in upstream pools.
 - d. The YS3 water level in Pool6 should remain almost constant, regardless of upstream turnout flow rate changes.
2. The best result is the one in which turnout flow change results in a small YS3 disturbance in Pool1, along with almost no disturbance in Pool6.
3. The rule of "goodness" used in selecting the "best" constant and STP values was that the deviation in YS3 for Pool1 must be close to 5% when a flow rate change of 25% was introduced in the canal.
4. The sensitivity of the gate commands will depend upon the initial opening of the gate. For logic transferability purposes it was decided to have the canal gates at 50% open during the initial maximum flow conditions.
5. Stability of downstream control is very sensitive to the water depth. The proper STP may be greater than the normal depth at the design flow rate.

Final Results from CARIMA: A total of 11 constants were used in the CARDD algorithm. The "best" values for each of the constants were first determined on one canal. Only one of the constants (CNSTM) needed to be modified to obtain the best results on any of the other canals. CNSTM acts as a speed-of-gate-movement controller.

The canal responses to flow rate changes for the canals were almost identical. Results from one of the canal simulations are shown in Figure 2. It should be noted that a 25% instantaneous flow rate change is much larger than what is normally encountered on a real canal; however, the recoveries are excellent.

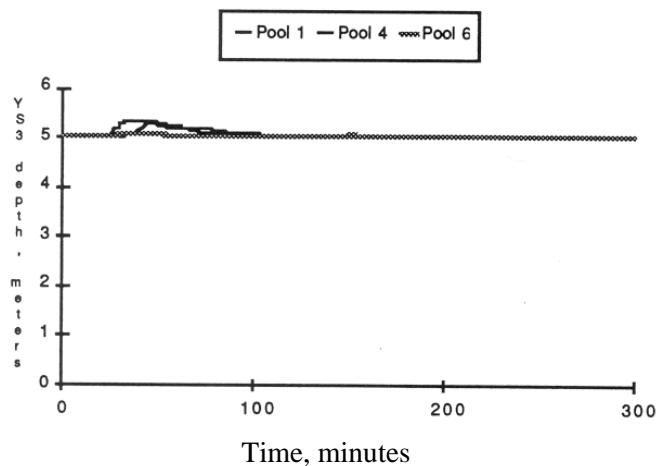


Figure 2. Variation in YS3 due to immediate shutoff of 25% of the total canal flow (Turnout4) at 30 minutes. Canal 3120B. CARIMA results.

Other simulations were run with the entire flow rate passing the complete length of the canal. At a simulated time of 30 minutes, the exit flow was increased. All trials were begun with an initial flow rate of 50% of the design flow rate. Figure 3 shows the results from a "Canal 450F". The results of this canal were considered representative of the range of all the canals.

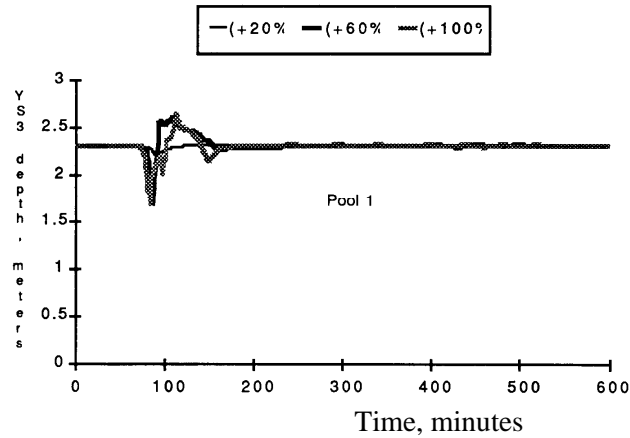


Figure 3. YS3 values in canal 450F with **instantaneous** flow rate increases from the d/s end of the canal. Initial flow rate in all cases = $22927 \text{ m}^3\text{h}^{-1}$. CARIMA results.

Physical Model Results: The use of CARDD on the physical canal was modeled using CARIMA, and the best CNSTM value was determined. All other algorithm constants remained the same as for the other modeled canals. When CARDD was actually implemented on the physical canal, it was found that very good stability was not achieved. Further work was done, and it was found that three other constants needed to be varied slightly. Specifically, these were constants which affected the "brakes" which were activated when the water level was converging rapidly upon the setpoint. Once those constants were adjusted, good stability was achieved at the downstream end of the canal. A test was devised to determine the ability of CARDD to control the canal with multiple changes. Table 3 and Figure 4 provide information regarding this test.

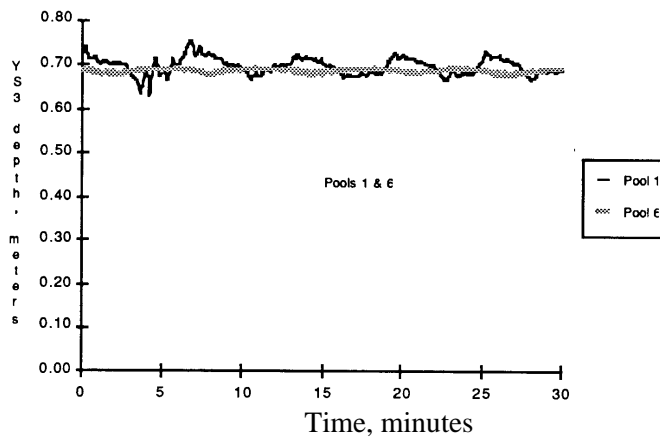


Figure 4. Results of a test with multiple turnout flow rate changes. Conducted on the physical canal.

Table 3. Flow rate requirements for multiple turnout changes. Flow rates are in m^3h^{-1}

<u>Location</u>	<u>Initial Condition</u>	<u>T= 3 min</u>	<u>T= 4 min</u>	<u>T= 5min</u>
Inlet	170	227	227	170
Turnout3	23	23	0	0
Turnout4	0	57	57	57
Turnout5	34	34	57	0
Downstream End	113	113	113	113

Another test gauged the ability of CARDD to enable operators to automatically start up the model canal from an empty condition. Figure 5 shows the results of this test. The initial water level of 0.23 m is not a true reading, as the transducers were calibrated to that depth when the canal had any water level between 0 and 0.23 m. The results show that the complete canal stabilized in a relatively short time. The only significant fluctuations after 15 minutes occurred in Pool1, and they continued to dampen out as long as the test was run.

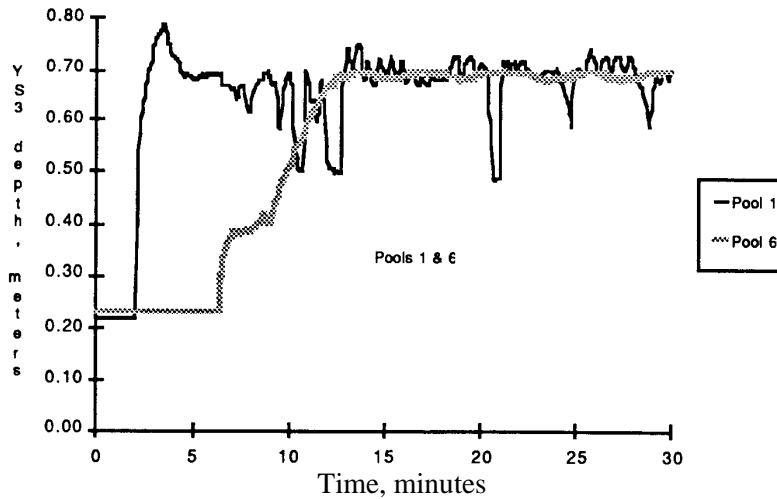


Figure 5. Startup of the physical model canal from a dry condition.

The final design test involved an almost catastrophic instantaneous flow rate change at the downstream end of the canal. The final case began with an initial flow rate of $113 \text{ m}^3\text{h}^{-1}$ through the complete length of the canal. At a time of 4 minutes, the downstream end gate was opened to draw an additional $227 \text{ m}^3\text{h}^{-1}$, resulting in a total demand of $340 \text{ m}^3\text{h}^{-1}$. Figure 6 shows that CARDD maintained very good control.

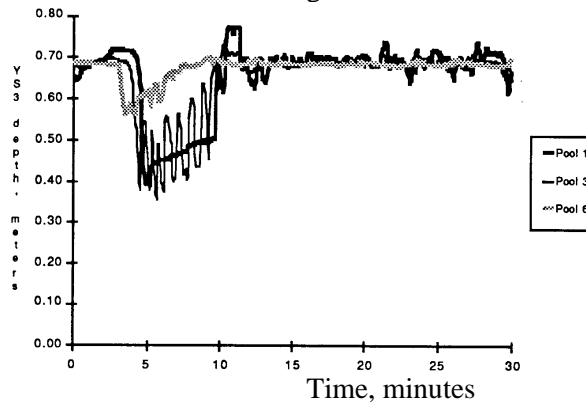


Figure 6. Results of instantaneous flow rate change of $113 \text{ m}^3\text{h}^{-1}$ to $340\text{m}^3\text{h}^{-1}$ at far downstream end of the model canal. Conducted on the physical model canal.

It was noticed that the YS3 water level in Pool1 was not controlled as well as the YS3 levels in the other pools. Upon re-examination of the first gate, it was found that a bushing had loosened on the linear actuator shaft. Any time the linear actuator reversed direction, it had to move approximately 4 cm. before

the gate was engaged. It was concluded that this hardware defect was primarily responsible for the fluctuations found in the YS3 levels of Pool1.

CARDD SUMMARY

The figures and discussion above give a brief glimpse of CARDD research. The points below summarize conclusions from that glimpse, plus provide a few additional insights to CARDD research results. The points include:

1. Procedures for developing a control algorithm on CARIMA have been developed. They include:
 - a. A uniform standard for gate openings.
 - b. Examination of the proper pool depth required (which may be greater than the normal depth).
 - c. A trial and error process to determine best constants.
 - d. Determination of a rule for establishing the "goodness" of a result.
2. The CARDD (Canal Automation for Rapid Demand Deliveries) algorithm successfully provided independent downstream control, both in computer simulations and on a physical model canal.
3. The original CARDD algorithm was considerably modified and streamlined into a dimensionless control routine.
4. CARDD logic could be used on all 6 simulated canals (within CARIMA) without any change in the CNST values.
5. CARDD successfully controlled large multiple changes on a very long (72.4 km) canal simulated with CARIMA, but not with the same high degree of rapid stability achieved on canals with shorter pool lengths.
6. For successful implementation of CARDD on the very long canal, it was necessary to modify one constant (CNSTM), which slowed the gate action to prevent instability.
7. CARDD was not successfully simulated on steep canals.
8. A physical model canal with 6 pools, having a total length of 200 m., was successfully constructed and instrumented.
9. CARDD was successfully implemented on the model canal. Implementation included testing for multiple flow rate changes, huge single flow rate changes, and control during a dry start-up of the canal. CARDD proved to be quite robust.
10. CARIMA did not accurately simulate CARDD performance in the model canal.
 - a. Several constants needed to be modified for successful implementation on the model canal.
 - b. No satisfactory explanation for the discrepancies was determined. It was beyond the scope of this project to examine the simulation programs.
 - c. The discrepancies point out the need to implement new control routines in stages and with caution on actual canals.
12. There is a need for a very user-friendly, accurate, and rapid PC-operable simulation program.
13. Short pools can be more easily controlled than long pools.
14. Increases in the pool storage improve the stability of CARDD control.
 - a. Increases in volume achieved by widening the canal are not very effective.
 - b. Increases in water level depth to obtain more volume are very effective.
15. There is a need to define a rule for achieving stability with downstream control on canals with the target depth at the downstream end of the pool (regardless of the algorithm). Such a rule exists for level top canals having downstream control, but it deals simply with storage volume requirements. This research indicates that the rule for sloping canals must concentrate upon water depth.
16. Water depths must be relatively higher (compared to normal depths) at the tail ends in order to achieve stability. It may be that on some canals, a downstream control technique such as CARDD will only work on level top canals.
17. The single greatest problem with existing control on canals is the "tailender problem", in which the downstream ends of canals suffer from large fluctuations in water level. In all cases, the "tailender problem" was virtually eliminated. Instead, fluctuations in water level moved upstream and were most pronounced at the first pool.

REFERENCES

1. Burt, C.M. 1983. Regulation of Sloping Canals by Automatic Downstream Control. Ph.D. dissertation. College of Engineering. Utah State University. Logan, Utah.
2. Burt, C. M. and J. Parrish. 1989. Canal Automation Providing On-Demand Deliveries for Efficient Irrigation. Final Report to the Water Resources Program of USGS. Grant 14-08-0001-G1280. NTIS Access No. PB90119769/AS