IRRIGATION SYSTEM REGULATING (BUFFER) RESERVOIRS

Charles M. Burt, Ph.D., P.E.
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ABSTRACT

Regulating reservoirs (also known as "balancing" or "buffer" reservoirs) are very commonly used in western US irrigation district modernization projects with canal systems. Some districts have a dozen or more reservoirs within total service areas of 20,000 – 40,000 ha. This paper presents details of sizing and control of flows into and out of the reservoirs.

INTRODUCTION

"Feast or Famine" Effects

Most irrigation canal systems are designed with upstream control. Under this method of control, the flow rate into the head of a canal system is set to the anticipated demand downstream. If the flow rate into the head of the canal is too high, there is operational spill at the tail end (most downstream end) of the canal. If the flow rate into the canal is lower than the demands, there is a deficit at the tail end. This phenomenon is often called "feast or famine" at the tail end.

The causes of "feast or famine" are many, but include:
1. As more drip/micro systems are used, and as other field irrigation practices are improved, there is a demand by farmers for more flexibility of water delivery.
2. A flow rate change made almost instantaneously at the head of a canal will arrive at a point several miles downstream after a considerable amount of time. Moreover, the flow rate change arrives gradually.
3. Flow rate measurement is imprecise. In the field, +/- 6% accuracy is often considered very good.
4. There are numerous reasons that turnout (delivery gate) flows will change unexpectedly, including fluctuations in the canal water level, or fluctuations in the pressure or water level downstream of the turnout.

Without regulating reservoirs, the "feast or famine" is typically handled in one of three ways:
1. It just exists. Farmers at the tail ends of canals receive the worst service.
2. The irrigation district makes a point to always deliver more water than is needed. Therefore, spill occurs all the time. This is a convenient way to provide excellent flexibility to users in a very simple manner.
3. Spill is minimized by using canal pool storage for the excesses or deficits. This means that the canal water levels constantly fluctuate and provide a fluctuating flow rate to the turnouts. These fluctuations also contribute to canal breaks and rodent damage to canal banks.

REGULATING RESERVOIRS

Advantages of Regulating Reservoirs

Reservoirs (Figure 1) have a classic location of two-thirds of the distance down a canal.

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1 Modified from Chapter 2 of “Canal Automation Manual” being developed by a Task Committee of American Society of Civil Engineers, EWRI.
2 Chairman, Irrigation Training and Research Center (ITRC). California Polytechnic State University (Cal Poly). San Luis Obispo, California 93407-0730. USA. 805-748-3863. cburt@calpoly.edu www.itrc.org
Regulating reservoirs offer the following advantages:
1. They greatly reduce canal spillage.
2. The canal operation becomes much simpler. The watermaster determines the change in water orders and looks at the water level in the reservoir. There is no need to constantly adjust inlet flow rates to match flow rates; once or twice a day at the canal head is often sufficient.
3. Reservoirs allow for flexibility of water delivery upstream, while the canal pool water levels upstream can be maintained fairly constant. All of the fluctuations in flow rate show up at the regulating reservoir.
4. Reservoirs allow for more flexibility of water delivery downstream, in one of two ways:
   a. If the canal downstream of the regulating reservoir is operated on downstream control, the flow rate entering downstream of the reservoir will precisely match the actual user demands.
   b. If the canal downstream of the regulating reservoir is operated on upstream control, the downstream canal sections, for purposes of control, are only about one-third as long as without a reservoir.

Regulating Reservoir Volumes
The volume of a regulating reservoir depends upon three primary factors:
1. Availability of land. An irrigation district must find a willing seller of land in about the correct location.
2. Cost of land and construction. A regulating reservoir may easily cost $US 1-3 million.
3. Hydraulic requirements. In theory, the required reservoir volume is calculated based on the following assumptions:
   a. The discrepancy of actual flow rate in the canal, versus the total flow rate being delivered. This discrepancy pertains to the canal sections both upstream and downstream of the reservoir. For purposes of illustration, assume it is decided that this is 5% of a total of 35 CMS.
   b. The time required for a compensating flow rate change at the head of the canal to travel to the reservoir. For illustration, assume this "travel time" is 6 hours.
   c. The time required for operators to notice the flow rate discrepancy and react. Because discrepancies often occur during the evening, this "reaction time" may easily be 12 hours.
   d. The reservoir would ideally be half full before any flow discrepancy begins. It could either supply a deficit or excess discrepancy. The "plus/minus" factor is therefore 2.0.

Volume needed = "Plus/minus factor"
   × (% discrepancy)/100
   × (canal flow rate)
   × (travel time + reaction time)
   = 2.0 × .05 × 35 CMS × (6 + 12) hours ≈ 0.2 MCM

Typical regulating reservoir volumes in California vary from about 50,000 cubic meters to 320,000 cubic meters. Before the first reservoir is constructed in a district, the district personnel tend to think the initial volume estimate seems high. After a couple of years, the operators want more and larger reservoirs.
Sizing the Flow Rates for Reservoir Inlets and Outlets
The inlets to reservoirs are typically sized for greater flows than are the outlets, because:
1. The inlet to a reservoir is typically gravity flow, and the outlet often requires a pump. It is relatively inexpensive to “oversize” a gravity inflow structure, as compared to a larger pumping facility.
2. Sudden rainstorms cause farmers to shut off their irrigation deliveries, which creates the requirement of high flow rate capacities into the reservoir.
3. In a modern irrigation system, it is very important to provide farmers with flexibility to shut off their water without advance notice. This allows them to conserve water. It is less important to provide the flexibility to open turnouts at any time without advance notice.

If it is anticipated that there might be a 20% discrepancy in volume during the day; this might translate to a 40% instantaneous change in flow rate.

RESERVOIR CONTROL CONSIDERATIONS
There are numerous configurations of control schemes into and out of reservoirs. The exact scheme used will typically depend upon factors such as:
1. Topography. For example, in a few situations it is possible to use gravity flow both into and out of a reservoir.
2. Depth and height of a reservoir. Some reservoirs can have gravity flow in at times, but the reservoir may also depend on pumping into the reservoir at other times.
3. Simplicity. Programmable logic controllers for pump and gate operation are standard in some projects, but are too complex for others.

The control sketches on the next few pages assume that the canal re-starts with flow control. That is, the canal will continue to operate on upstream control. In some cases, the canal re-starts with downstream water level control rather than flow control. The following symbols will be used in Figure 2 through Figure 11:

- ▶ Upstream Water Level Control Device
- □ Flow Measurement Device
- □ Flow Control Device
- ○ Pump
- ◊ Target Flow Rate
- ● Variable Flow Rate
- ■ Constant Flow Rate

When talking about control considerations, the following are generally true:
1. It is desirable to only have a portion of the canal flow enter a reservoir to minimize the amount of sediment that is deposited in the reservoir.
2. If there is no significant drop available in the canal, the reservoir control is usually designed to maintain a fairly constant water level in the adjacent canal pool (Figure 2). A pump will be needed in at least one direction of flow in/out of the reservoir.

![Figure 2. Reservoir control with no significant drop in the canal](image-url)
3. If there is a significant drop available in the canal, it may be possible to have gravity flow both into and out of the reservoir (Figure 3). This configuration typically has two flow control points; most of the flow rate is controlled at a check structure in the canal. The flow into the reservoir is variable, the flow out of the reservoir is relatively small, and the water level in the reservoir varies. The gravity flow into the reservoir provides automatic upstream water level control in the adjacent pool.

\[ \dot{V}_{\text{res}} = \dot{V}_{\text{in}} - \dot{V}_{\text{out}} \]

**Figure 3. Reservoir control with a significant drop in the canal**

**Passing Excess Canal Flows into a Reservoir**

There are various means of providing "upstream control" of the canal pool that is adjacent to the regulating reservoir when excess flows arrive. These include:

1. Spill into reservoir via a long-crested weir (Figure 4). If the weir is long enough, the rise in water level in the reservoir can be maintained at 8 cm or less. The reservoir can fill to the crest of the long-crested weir.

**Figure 4. Spill into reservoir via a long-crested weir**

2. Spill into reservoir via an ITRC Flap Gate. This technique will maintain a tighter control of the canal pool water level, but about 70 cm of storage is lost in the regulating reservoir. That is very expensive storage, so this is usually not an acceptable option.

3. Gravity flow into the reservoir using a PLC-controlled gate that provides upstream water level control on the adjacent canal pool (Figure 5). If the control is good, it provides the best combination of good canal pool level control and minimal loss of regulating reservoir storage. It is also much more complicated than a long-crested weir entrance.
Figure 5. Gravity flow into reservoir using PLC-controlled gate

4. Pump into the reservoir. This is necessary if the reservoir water level is higher than that of the canal pool. The control can be complex or very simple. The simplest controls (no VFD, no transducers) provide the most canal pool fluctuation.

Table 1. Simple summary of pump control options

<table>
<thead>
<tr>
<th>Pump Option</th>
<th>Tightness of Water Level</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Best</td>
<td>Most</td>
</tr>
<tr>
<td>B</td>
<td>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td>C</td>
<td>Worst</td>
<td>Least</td>
</tr>
</tbody>
</table>

*Option A:* Electronic level sensor, PLC, VFD, and complex logic (e.g., PI). Pumps are sequenced, one at a time, to maintain target within a close tolerance (3 cm). Figure 6 shows the configuration.

*Option B:* Electronic level sensor, PLC, and single-speed pumps (Figure 7). When water level rises to “on”, one pump turns on. If the flow is sufficient, the water level will drop and the pump shuts off at target. If insufficient, the water level continues to rise above “on” and after 1 minute, turn on 2nd pump, and so on.
Option C: Probe contact sensors (not transducers), no PLC, and single-speed pumps (Figure 8). Each pump has a different "on" and "off" water level. This is an old control technique, but results in large canal water level fluctuations.

Control of Flows out of a Reservoir
Water exits the reservoir to prevent the water level in the adjacent canal pool from dropping below its target. As mentioned earlier, there are two basic control designs:

1. If the water level in the reservoir is at or below the water level in the canal, pump(s) must be used. These can use one of the three pump control options described earlier (A, B, and C).
2. If the water level in the reservoir is at least 8 cm higher than the water level in the canal pool, the flow can be pulled by gravity (using PLC-controlled gates).

Sometimes, as in Figure 9, there may be gravity in/out and pump in/out on the same reservoir, depending upon the water level in the reservoir.
Gravity Outflow. When there is a drop, allowing gravity outflow from the reservoir, there are important details regarding how the flow rate out of the reservoir is computed and controlled. Two common situations are described:

1. There is no good location, or conditions are poor, for an in-channel flow measurement device, downstream of reservoir outlet on the canal. For example, there may not be enough head difference to install a broad-crested weir. Or there may be no good straight section available to install any flow measurement device.

In this case, there must be two excellent flow control and measurement sites (Figure 10). Both $Q_{pool\ out}$ and $Q_{res\ out}$ will have a set flow rate, with the sum of those flows equal to the canal’s target flow rate ($Q_{Tb}$). Note that for this control scheme, $Q_{res\ out}$ must be accurately measured.

2. There is a good location to measure the total channel flow rate in the canal pool downstream of the reservoir discharge point. In this case, the two flow control points do not need to have accurate flow rate measurement. The flow rate through the large canal gate is constant (because it has a constant head on it) but it can be adjusted manually. The gate from the reservoir must typically be automated to adjust for varying reservoir water levels. This reservoir discharge gate will adjust its position to automatically maintain a total target flow across the flow measurement device.

One advantage of this option is that the “total channel flow rate” can be measured downstream of a section with numerous turnouts. The actual discharge from the reservoir plus canal will equal the target flow rate, plus the turnout flow rates. The turnout flow rates can be varied with great flexibility and the reservoir discharge gate will automatically compensate (Figure 11).

CONCLUSION

Modernization of canal networks in the USA frequently involves the construction of new regulating reservoirs. There are many different control schemes available to utilize these reservoirs to re-initialize the flow rate into the downstream sections of the canal. The specific control scheme that is selected will depend upon the topography and familiarity with automation hardware and programming.