

Response of Ideally Controlled Canals to Downstream Withdrawals

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Most research on downstream control of canals has dealt with the problem of selecting and calibrating a suitable algorithm which can dictate gate movements, with the objectives of achieving a rapid and stable recovery of the downstream water level in the case of any deviation of that water level from a desired target depth. This paper addresses another equally important factor in achieving the desirable control - the influence of the canal characteristics on controllability. This paper will not provide a simple, definitive, and universal formula to predict controllability. However, it will present the problem, along with options which are available to examine the problem further on individual design cases.

There are various types of local, independent downstream control (Burt and Plusquellec, 1990). In all cases, a gate at the upstream end of the pool is modulated in an effort to control the water level at a designated downstream point. The three basic Forms are:

1. Sloping pools with level tops. The control point is immediately downstream of the gate (i.e., at the upstream end of the pool). This is sometimes referred to as "local" downstream control, whereas Forms 2 and 3 are other Forms of "regional" downstream control.
2. Sloping pools with the control point in the middle of the pool. The last half of the pool length requires level tops.
3. Sloping pools with the control point at the downstream end.

Even if a controller were capable of inducing immediate and exact replacement of off take withdrawals for Form #3 (for example), the depth at the point of withdrawal still decreases until the replacements arrive in sufficient quantity. And even after the wave from the upstream arrives, only gradually, over a period of time, does the depth revert to its original level.

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This leads to the conclusion that certain combinations of canal characteristics are required for adequate downstream control, regardless of the algorithm and the Form (1, 2, or 3 above). That leads to a second conclusion which states that before an imperfect canal control algorithm (and all algorithms are imperfect) for downstream control is tested on a canal, the canal pools should first be studied to determine if their response to ideal control (in terms of water level deviation from the target depth) will be acceptable.

The phenomena related to withdrawal replacement and water level recovery are controlled by gravity, resistance, pressure, and inertial forces, the proportions varying with specific circumstances: reach length, slope, roughness, cross section, initial discharge, degree of check-up at the downstream end, and withdrawal rate.

Form #1 - Level Top Pools

The importance of canal geometry in achieving stable control for Form #1 (level top pools) has been identified by various authors. GEC Alstom (no date) states in its literature that in order to achieve stable control, the required volume of wedge storage is:

$$\text{Volume} = \frac{Q \times T}{2}$$

where

$$T = \frac{L}{(gh)^{0.5} + V} + \frac{L}{(gh)^{0.5} - V}$$

in which

Q = maximum flow rate in the reach in question

$$h = \frac{\text{cross-section area}}{\text{width at the water surface}}$$

$$V = \frac{Q}{\text{cross section area}}$$

T = time for a wave to travel both up and down the pool

L = pool length

g = gravitational constant

Hoitink (1990) analyzed the various Forms of downstream control, and concluded that for stability of Form #1, the following must occur:

$$\text{Head loss} > \frac{V^2}{g}$$

where

Head loss = the change in water surface elevations along the length of the pool = (slope x L)

It should be noted that the two equations above can lead to very different conclusions regarding the required pool dimensions for achieving stability. Traditional designs have used the first equation.

A procedure to graphically display canal water volume responses to upstream and downstream control was developed by Deltour (???). It is developed from multiple computer simulations on a single, specific pool, and provides valuable insight into the controllability of that pool. Figure 1 illustrates such a graph by Deltour.

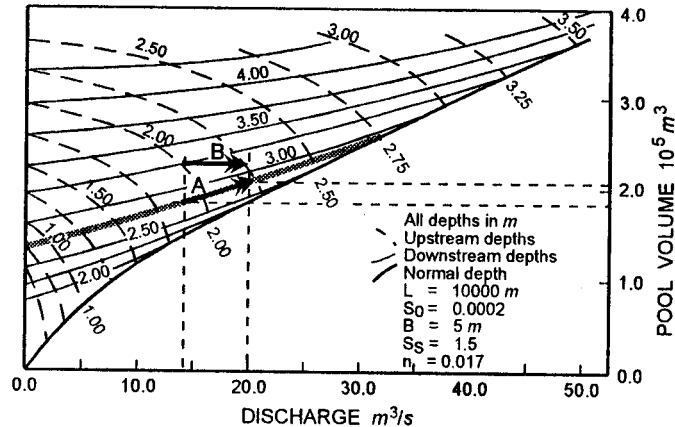


Figure 1. Steady State Characteristic Curves for a specified pool. Stored volume as a function of flow rate and water level

Form #3 - Sloping Pools with Control Point at the Downstream End

Most of the work on this form of downstream control has concentrated on the algorithms themselves. No satisfactory general guidelines appear to be available beyond the recognition that longer and steeper pools are more difficult to control than short and flat pools.

The authors were initially optimistic that a general set of guidelines for design could be developed. The first efforts concentrated upon finding some relationship to wedge storage volume, similar to what had been developed for Form #1 and the work by Hoitink (1990). When those efforts proved unsuccessful, it was recognized that before a simplified rule or formula can be developed for control, a new procedure was required to describe the canal characteristics themselves. The companion paper by Strelkoff, Clemmens, and Gooch (1995) defines a procedure to reduce the number of variables used to describe a canal without loss of generality. This allows the generation of a pattern of solutions blanketing the practical range of interest.

In these terms, all depths and other transverse lengths (breadth, hydraulic radius, etc.) are expressed as a ratio to a reference, normal depth in the canal at the initial flow; all lengths in ratio to a reference length equal to normal depth divided by bottom slope; all times, to the time to traverse the characteristic length at normal velocity. The reference discharge is the initial flow rate divided by the aspect ratio of the normal-flow cross section (the "aspect ratio" is defined as the ratio of the average breadth to depth under normal

conditions, $\frac{A_N/Y_N}{Y_R}$). The relative measure of the inertial forces is provided by the normal Froude number of the initial flow.

A program of variation of dimensionless reach length L^* , degree of check-up, y_D^* , relative withdrawal rate, Q_{off}^* , and initial normal Froude number FN has been undertaken to ascertain the influence of these variables on the draw down at the point of off take (assumed sudden, as is its replacement upstream). The relative cross-sectional shape is expected to play a smaller role. The minimum value of depth, the timing of that minimum, and a measure of its recovery rate are of interest. So far, no simplifications comparable to those for the steady case (Strelkoff, Clemmens, and Gooch, 1995) have emerged.

Typical discharge and depth hydrographs are shown in Fig. 2, for $L^* = 1.6$, $y_D^* = 1.3$, $Q_{off}/Q_N = 0.6$, and $FN = 0.2$. Numbers 1-6 represent hydrograph locations: at the upstream end, at the quarter, half, and three-quarter points, and at reach end on either side of the offtake. Station 6, in the gate structure downstream from the offtake, is shown dot-dash. The appearance of longitudinal profiles of water-surface elevation (Figure 3), concave downward, show that the inertial forces are relatively unimportant. When these are dominant, the profile is concave upward; furthermore, the depth changes for a sudden withdrawal are immediate. The immediate, inertial response is probably that shown in the depth hydrograph at the start of its decline, as it suddenly drops a small amount. The slower, more substantial effects of resistance, pressure, and gravity are shown by the subsequent gradual decline in depth at the off take, until sufficient water has arrived from upstream, at approximately kinematic-wave speed, to reverse the trend, eventually to return the depth to its original value.

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