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Considerations for Modeling Flow Control Structures in ADaptive Hydraulics (ADH)

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PURPOSE: This System-Wide Water Resources Program (SWWRP) technical note presents the incorporation of reversible flow-control structures to the two-dimensional (2-D) Shallow-Water (SW2) module of ADaptive Hydraulics (ADH). The SW2 module can model the obstruction to flow directly; however, the grid detail required for evaluating flow field impacts is cumbersome for the user to readily generate. This technical note details a quick and easy method to describe the structure and model the hydraulics.

BACKGROUND: A weir is a regular obstruction placed across the flow path of an open channel to regulate the flow in the channel. One can actually construct a mesh to represent this feature in detail and depend upon the shallow-water equations to represent the flow. However, one could use the weir equations to empirically capture the aggregate contribution to the flow when one's interest is elsewhere in the domain without the exhaustive effort required in modifying the meshed domain.

Ogee-type, weir-controlled flow has been incorporated into the 2-D shallow-water module of ADaptive Hydraulics (ADH). The development of weir boundary conditions in ADH required the application of the weir equation developed by Horton (1907):

$$Q = CLFH^{\frac{3}{2}} \tag{1}$$

where:

C = weir coefficient for flow over the unsubmerged weir
L = length of the weir
F = correction coefficient for submergence of the weir
H = $Z_{up} - Z_{weir}$ = upstream head over the weir crest elevation
Q = flow over the weir.

The weir coefficient C is defined as:

$$C = \frac{2}{3} C_d \sqrt{2g} \tag{2}$$

where:

C_d = discharge coefficient for flow over the unsubmerged weir
g = acceleration due to gravity.

The discharge coefficient was defined by Rehbock (1929) as follows:

$$C_d = 0.611 + 0.075\frac{H}{H_w} \tag{3}$$

where:

$H = Z_{up} - Z_{weir}$
H_w = weir height (Figure 1).

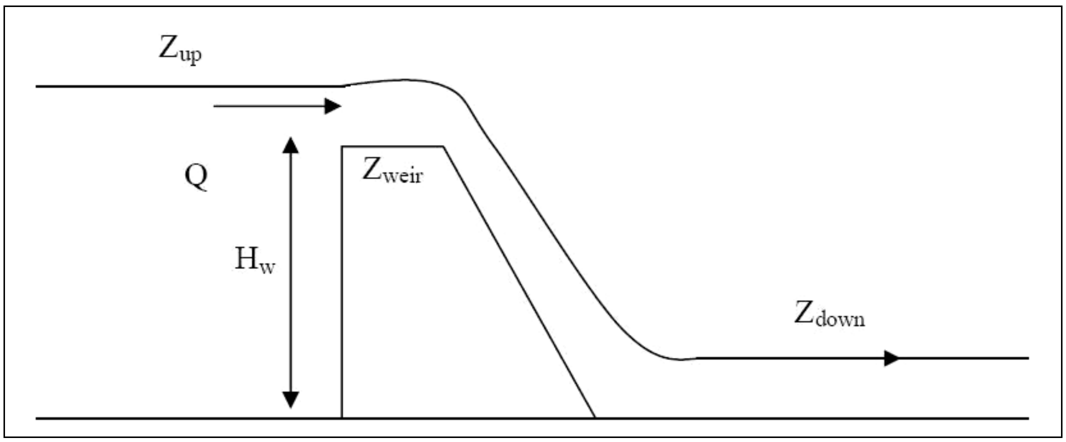

Figure 1. Weir schematic showing relevant quantities.

If the tailwater elevation is greater than the weir crest elevation, the weir is called a submerged weir and the correction coefficient *F* is applied to account for the reduction in flow over the weir. This correction coefficient is calculated as follows (Brater and King 1976):

$$F = \left[1 - \left(\frac{Z_{down} - Z_{weir}}{Z_{Up} - Z_{weir}}\right)^{3/2}\right]^{0.385} \tag{4}$$

The correction coefficient has a value of one if the tailwater elevation is lower than the weir crest elevation.

APPROACH: The 2-D shallow water module of the ADH flow solver is used to model the velocities and water-surface elevations (WSE) in the vicinity of the structure. The flow rate over the structure is calculated using Equation 1.

Using the weir equations instead of SW2 equations requires the velocities and WSE from the previous time-step. Using information from a previous time-step implies that the results pertaining to flow over the structure lag the other flow quantities (WSE and velocity) in time by the length of the time-step.

To close this separation in the solution schemes, the structure is modeled as both an inflow boundary as well as an outflow boundary. To create the boundary conditions, the weir equation is solved prior to the ADH SW2 solver and flows are calculated based on the upstream and downstream WSE. These flows are then applied as boundary conditions to ADH at the weir boundary. The WSE and velocities used to calculate the boundaries are obtained through a node string on the upstream and the downstream sides of the structure. Using a node string prevents oscillations in flows over the weir between the time-steps.

IMPLEMENTATION: The user must provide certain cards (listed in the following paragraphs) in the ADH boundary conditions (*.bc) file to activate flow calculations involving weirs.

1. The user must specify a WER card, described in Table 1, to indicate that weirs have been specified for the simulation.

2. Further, the user must specify the properties for each weir indicated in the WRS card, described in Table 2.

3. The last card that the user must include is the OFF card, described in Table 3. The material designated as the weir must be turned off. For instance, if the weir is designated Material 2, then Material 2 must be turned off using the OFF card. By turning off a material, the user is removing that material from the 2-D hydrodynamic calculations.

Table 1
WER Card Description

Field	Type	Value	Description
1	Character	WER	Card type
2	Integer	> 0	Number of weirs to be modeled

Table 2
WRS Card Description

Field	Type	Value	Description
1	Character	WRS	Card type
2	Integer	> 0	Weir number
3	Integer	> 0	String on the upstream of weir
4	Integer	> 0	String on the downstream of weir
5	Integer	> 0	String defining the upstream of weir
6	Integer	> 0	String defining the downstream of weir
7	Real	#	Width of the weir
8	Real	#	Weir crest elevation
9	Real	#	Weir height

Table 3 OFF Card Description			
Field	**Type**	**Value**	**Description**
1	Character	OFF	Card type
2	Integer	> 0	Material to be turned off

EXAMPLES:

1. **Non-submerged weir.** Consider the case shown in Figure 2 – a 1,000 × 50-m-wide rectangular flume with the flow dropping 1.5 m over a weir. The weir material is the green section of the flume. The starting upstream and downstream depths are 2.5 and 1 m respectively, with the weir height specified as 2.3 m.

   Table 4 summarizes the values obtained from hand calculations of Equations 1–3 and by ADH for this non-submerged weir.

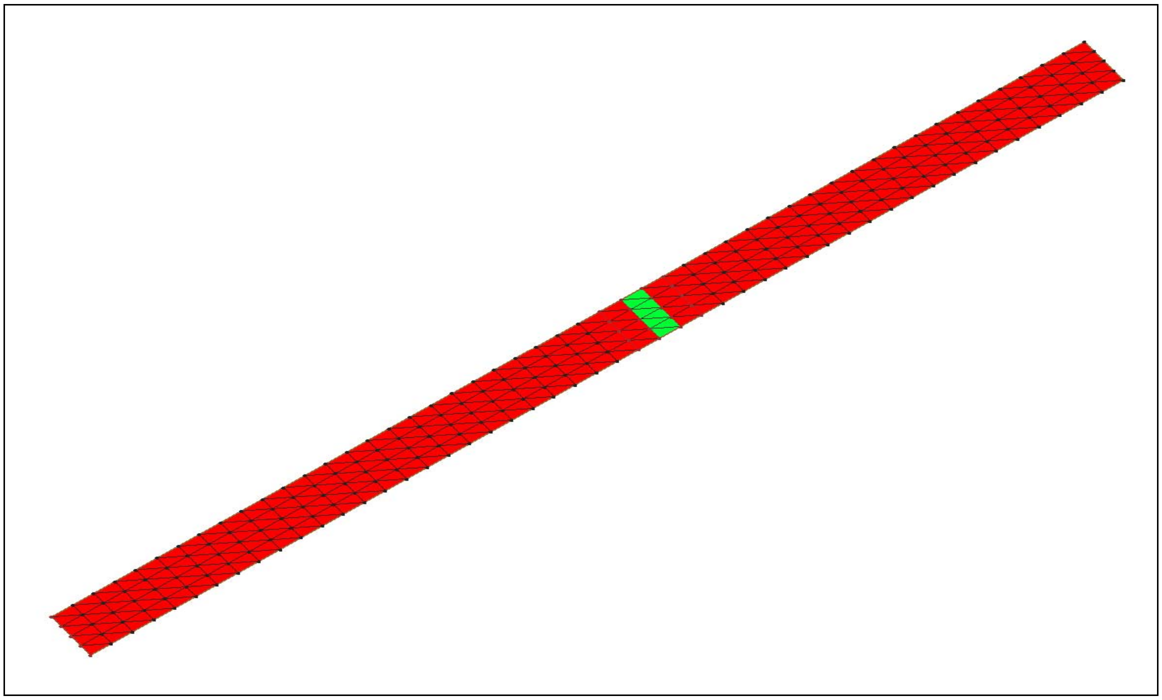

Figure 2. Test flume.

Table 4 Discharge and Weir Flow Validation for a Non-Submerged Weir		
	Hand calculation	**ADH**
Discharge coefficient	0.6175	0.6175
Flow over weir (cms)	8.1508	8.1505

Figure 3 illustrates the test flume and the water-surface elevation (WSE) over the test domain. The WSE plot (top half of Figure 3) shows the 1.5-m drop in water surface caused by the weir.

2. **Submerged weir.** In certain cases the tailwater is higher than the weir crest elevation. In such cases the weir is called a submerged weir, and the weir submergence causes a flow reduction over the weir. The weir equation used in ADH includes the correction coefficient *F* defined in Equation 4 to account for weir submergence.

   This test comprised the flume in Figure 2, with upstream and downstream depths of 2.5 and 2.4 m, respectively. The weir height was 2.3 m, so the weir was submerged by 0.1 m.

   Table 5 summarizes the values obtained from hand calculations of Equations 1-3 and by ADH for this submerged weir.

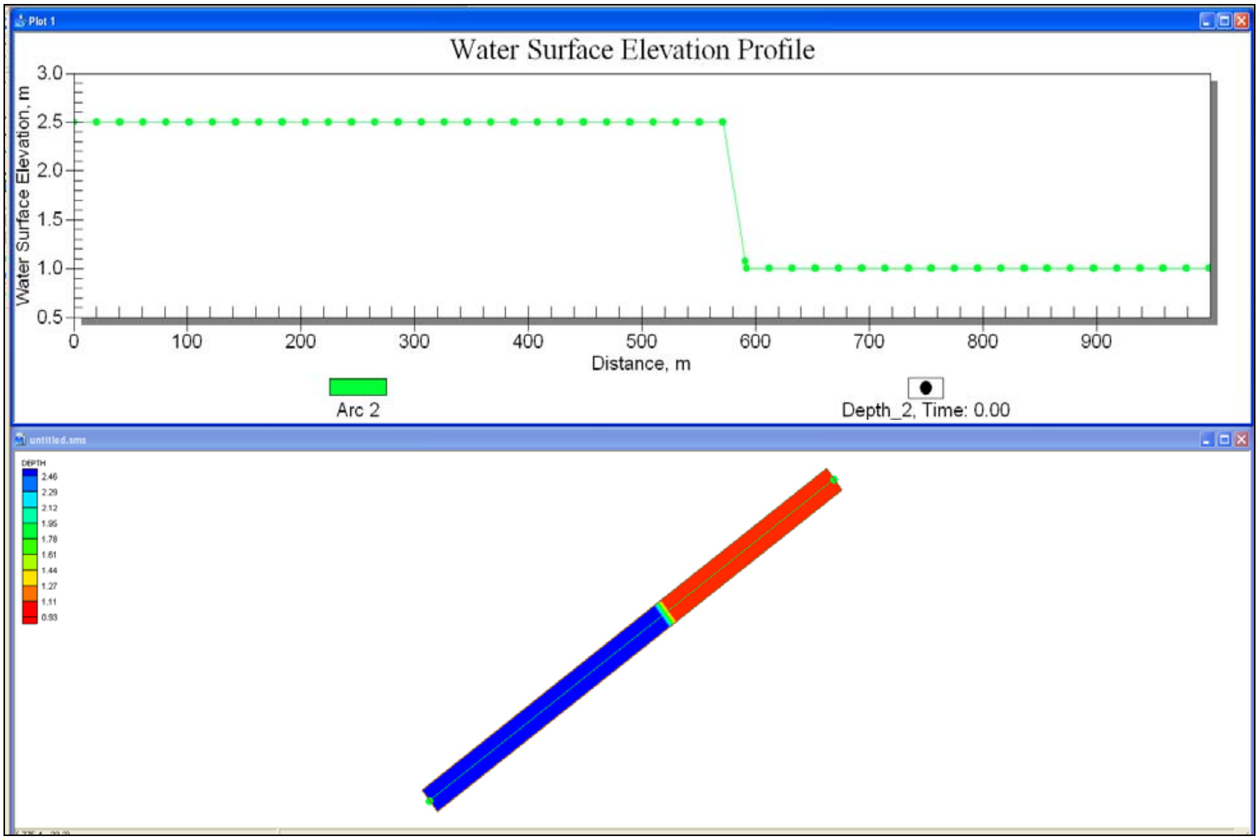

Figure 3. Water-surface elevation, 1.5-m drop.

Table 5 **Discharge and Weir Flow Validation for a Submerged Weir**		
	Hand calculation	**ADH**
Correction coefficient	0.8450	0.8453
Discharge coefficient	0.6175	0.6175
Flow over the weir	6.8899	6.8900

Figure 4 illustrates the test flume and the water-surface elevation (WSE) over the test domain. The WSE plot (top half of Figure 4) shows the drop in water surface achieved as a result weir placement across the path of flow.

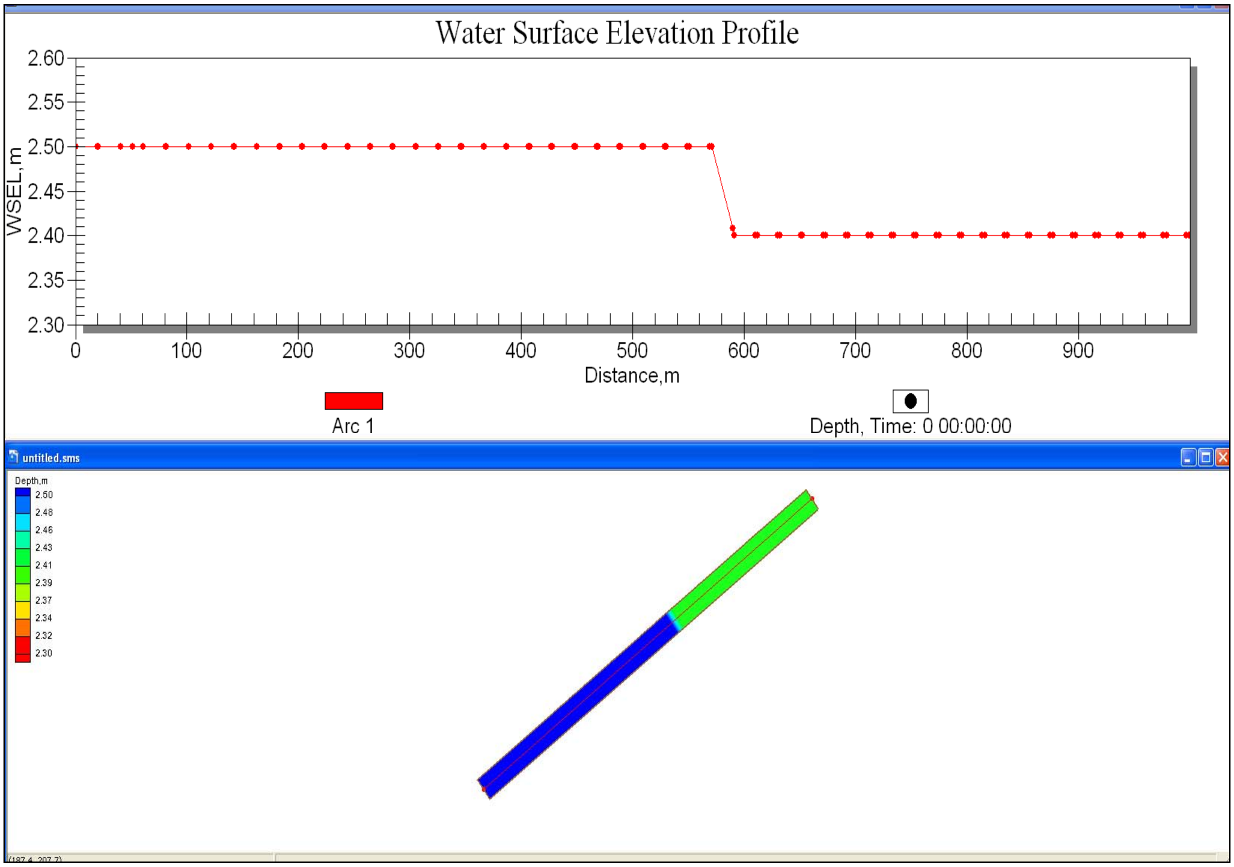

Figure 4. Water Surface elevation, submerged weir.

ADDITIONAL INFORMATION: For additional information, contact Dr. Gaurav Savant, Dynamic Solutions LLC, on-site contractor, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180 at 601-634-3628, e-mail: Gaurav.Savant@usace.army.mil. This effort was funded through the System-Wide Water Resources Program. For information on SWWRP, please consult *https://swwrp.usace.army.mil/* or contact the Program Manager, Dr. Steven L. Ashby: Steven.L.Ashby@usace.army.mil. This SWWRP tech note should be cited as follows:

Savant, G. and C. Berger. 2009. *Considerations for modeling flow control structures in ADaptive Hydraulics (ADH).* ERDC TN-SWWRP-09-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center. An electronic copy of this SWWRP-TN is available from *https://swwrp.usace.army.mil*.

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