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Performance assessment of H Flumes under extreme approach flow conditions

by

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Pioneer Farms, UW Platteville

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Background

H Flumes were designed by the Soil Conservation Service group of the U.S. Department of Agriculture and came into widespread use in the 1930s to measure runoff in small agricultural watersheds and experimental plots. Rating tables for the head-discharge relationships were prepared based on the calibration of these devices, and calibration equations were subsequently developed.

The H Flume is specified to have an opening with sloping sides in the lateral and upstream direction. Laterally the opening has a 6 to 1 slope, and in the flow direction the opening has a 2 to 1 slope. See Figure 1 below.

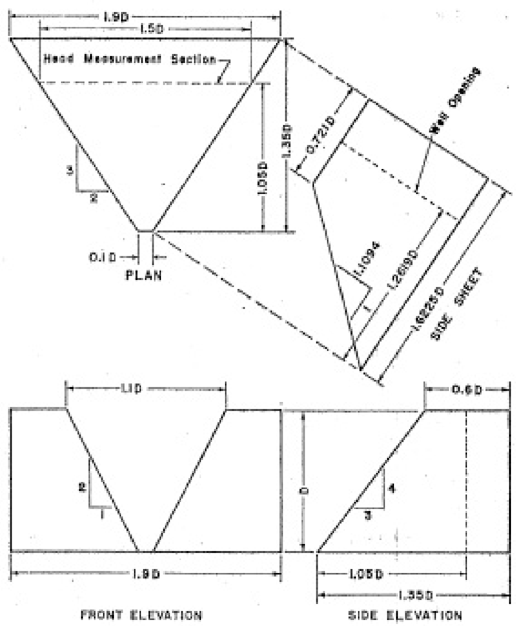


Figure 1. Proportions of H Flume (from Gwinn and Parsons, 1976)

Because these devices are installed in ditches that carry vegetal waste and silt, they were designed to converge toward the bottom so that a higher velocity is maintained at a low flow, and so that the device can be self-cleaning. Specifications for installation of the H Flume include a flat and level floor that is free of sediment deposits, and a uniform and tranquil approach velocity distribution. Flow must be able to exit the flume in an unimpeded manner. As specified in the literature, the H Flume design includes an approach that is to have a length between 2- and 5-times the depth, depending on the source. Some sources also specify that the flume and approach be recessed into the bank up to 70% of its depth.

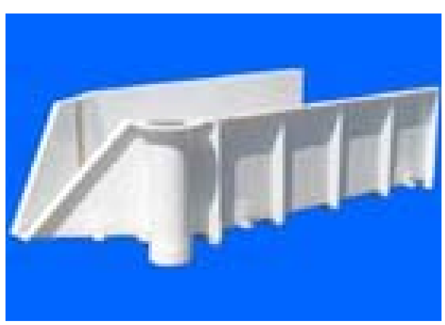


Figure 2. H Flume schematic (from www.inmtn.com).

HS and HL Flumes

In addition to the H Flume, larger and smaller field versions exist to measure flows from ditches of different sizes. The H Flume measures discharges from 0.347 cubic feet per second (cfs) to 84.5 cfs. The HS flume measures lower discharges, from 0.085 to 0.821 cfs, and the HL flume measures higher discharges, from 20.7 cfs to 117 cfs. While the designs are mostly the same, the proportions vary slightly in depth and the side-slope of the nozzle pieces.

Motivation for Research

This experimental series explored H Flume installations for which the specified design requirements are not met. In particular, a number of these devices were installed with little or no approach section and/or are not recessed into the bank, and it was of interest to determine the quality and repeatability of measurements from a flume lacking these features. In addition, tests were performed for situations in which the approach flow is non-uniform because of high slopes or obstacles in the flow, with the intention of exploring performance under these extreme conditions that challenge the ability to make a steady and repeatable measurement.

Figure 3. H Flume without approach section. (Photo by Dennis Busch).

Experimental Setup

The H Flume testing was conducted in the Main Channel at the St. Anthony Falls Laboratory (SAFL). The Main Channel is a rectangular concrete channel with a width of 9 feet, depth of 6 feet, and length of 270 feet. The Channel sources water from the Mississippi River and has a maximum capacity of 300 cubic feet per second (cfs).

Physical setup

A full-scale research facility was constructed out of wood in the SAFL Main Channel. The facility was made up of three distinct sections: the approach slope, the approach section, and the H Flume. All configurations included the same approach slope and the H Flume. The length and vertical position of the approach section were primary independent variables in the study.

A wooden bulkhead wall was constructed at the upstream end of the channel. This wall served to impound water and was the entrance to the approach slope. Far upstream of the wall was the water source to the facility, which was provided via a 12 inch pipe and/or the Main Channel gate. The approach slope was a steeply graded slope that served to deliver water to the approach section and H

Flume. The approach slope was 45 inches wide, 48 inches deep, and 16 feet long with a 6% slope. The slope was constructed out of plywood. Because the objective was to examine the performance of the H Flume under extreme flow conditions, a triangular wedge was added to the downstream section of the approach slope to serve as an obstacle (Figure 4). The wedge was 8 feet long, 6 inches high, and 40 inches wide at its base, leaving a gap of 5 inches between the end of the wedge and the approach slope wall. The terminal end of the approach slope was a finished wall that spanned the entire cross-section of the main channel and served as an attachment point for the various approach section arrangements.

Figure 4. Wedge in approach slope.

Downstream of the approach slope was the approach section. The length of the approach section was one of the main independent variables in the study; 4 foot and 6 foot sections were constructed and could be arranged to give three configurations: 4 foot, 6 foot, and 10 foot approaches. These lengths corresponded to 2-times, 3-times, and 5-times the depth of the 2 foot H Flume and were based on published recommendations that suggest approach lengths should be 2- to 5-times the H Flume depth. The approach sections were constructed by UW Pioneer Farms staff and delivered to SAFL for testing. These lengths were tested with the approach section attached to the end wall of the approach slope at three positions;1) flush with the approach slope, 2) 35% recessed, and 3) 70% recessed. The latter two distances corresponded to a drop of 8.4 inches and 16.8 inches below the floor of the end of the approach slope.

The 2-foot H Flume used to conduct the series of tests was manufactured by Tracom, Inc and supplied to SAFL by UW Pioneer Farms. The order number on the device was 6281. In all cases, the H Flume was attached to the downstream end of the approach section such that the floor of the approach section and H Flume were flush, i.e. no recess. An image of the H Flume, approach section, and approach slope is shown in Figure 5.

Figure 5. Image of test setup in Main Channel with the 4 foot approach section and 2 foot H Flume attached at downstream end, recessed from the approach slope by 35%.

Data Collection

Several types of data were collected to evaluate the H Flume's performance, including carefully calibrated water discharge measurements, and detailed velocity and stage measurements. These data and the acquisition systems are described below.

Water Discharge

The primary water source for the tests was a 12" pipe plumbed from SAFL's supply channel. A 10.5" orifice plate was installed to measure discharge. Differential pressure across the orifice plate was recorded with a Rosemount differential pressure flow meter. The orifice plate system was calibrated using the SAFL weigh tank facility, which is calibrated and has an error of <1%. The maximum capacity of the 12” line was 8.5 cfs, so larger flows were supplemented using flow from the Main Channel gate and measured using the weigh tank facility.

The procedure for setting flows is described below:

For flows over 8.5 cfs:

- Tare SAFL weigh tanks.
- Open main gate to convey flow approximately 4-5 cfs.
- Verify precise discharge using weigh tanks.
- Open 12” supply line until flow measured with differential pressure flow meter output and calibration curve equals the difference between the desired flow and that supplied by the main gate.

For flows under 8.5 cfs:

- Determine discharge required.
- Open 12” supply line to desired flow determined by differential pressure flow meter output and calibration curve.

Water surface (Stage)

The Main Channel data acquisition carriage was used to collect topographic and water surface data during the testing. The carriage has an extremely accurate programmable positioning system that allows three-axis positioning and is equipped with a sonic range finder that is capable of making distance measurements with an error of <1mm. Elevations of the water surface were recorded using this sensor. Also attached to the carriage is a Keyence laser range finder that was used to measure the elevations of the flume bottom. The difference between this measurement and the water surface measurement was used to calculate flow depth. All horizontal positions were recorded using the carriage.

Velocity

The Main Channel carriage was also used to position an Acoustic Doppler Velocimeter (ADV) within the flow. The Sontek ADV is capable of making single-point velocity measurements with a frequency of 50 Hz. The ADV outputs the three Cartesian components of velocity measured 5 cm from the probe tip. The ADV was inserted into the flow at 0.4 times the flow depth (measured from the bottom), a depth which gives a reasonable approximation of average velocity for fully developed flow. At each measurement location, 120 seconds of data were recorded in order to capture various scales of fluctuations and allowing for calculation of statistics (mean, standard deviation) of the velocity at each location.

Photographic and video documentation

Digital photographs were taken from various vantage points during each testing configuration for qualitative understanding of flow characteristics. Two minutes of video were taken for each setup from a downstream vantage point.

Experiments

The independent variables for this study include: the approach section length, the recessed depth of the approach section, and water discharge. In this study we considered three lengths, three recessed depths, and three discharges, resulting in 27 test conditions, plus a setup with no approach section and the H Flume mounted flush to the approach slope, for a total of 30 tests. Table 1 summarizes the research program.

For each test, the lab-calibrated flow rate was recorded and the stage was evaluated at the measurement point in the H Flume for comparison. Additional water surface measurements were taken along the length of the approach slope, approach section, and H Flume, and velocity measurements were made in the H Flume. Photographic and video documentation of the run was also captured.

Table 1. Experimental Matrix. Three discharges were tested for each setup.

		Approach Length (multiple of flume depth)			
		0	2	3	5
Recessed Depth (fraction of flume depth)	0	1.1 4.7 11.0	1.1 4.7 11.0	1.1 4.7 11.0	1.1 4.7 11.0
	0.35		1.1 4.7 11.0	1.1 4.7 11.0	1.1 4.7 11.0
	0.7		1.1 4.7 11.0	1.1 4.7 11.0	1.1 4.7 11.0

Discharge units are in cubic feet per second

Results

Results of the testing are presented in this section. For each of the three recessed depths examined, three approach section lengths and three discharges were considered. The results are organized by recessed depth.

Zero recessed depth results

Twelve tests were conducted for the condition in which the approach section was not recessed Water surface measurement results are shown in Figures 6 through 13. Each approach length has two associated plots. The first plot is a summary of all water surface and bed surface elevations measured for the three discharges. The second plot is a cross-section of water surfaces measured at the most downstream point within the H Flume for the three discharges. The position is the same as specified in the literature for measuring stage in an H Flume. This plot includes a center elevation as well as two side measurements, and provides information on water surface elevation variance in the H Flume over the two minute sampling period.

Table 2. Summary of results for zero recessed depth trials.

recess depth (relative)	approach length (relative)	discharge (cfs)	expected reading (mm)	river left reading (mm)	percent error (%)
0	0	1	0.72	0.685	4.9
		5	1.39	1.427	-2.7
		11	2	1.978	1.1
0	2	1	0.72	0.631	12.4
		5	1.39	1.348	3.0
		11	2	1.892	5.4
0	3	1	0.72	0.712	1.1
		5	1.39	1.411	-1.5
		11	2	1.984	0.8
0	5	1	0.72	0.739	-2.6
		5	1.39	1.417	-1.9
		11	2	1.984	0.8

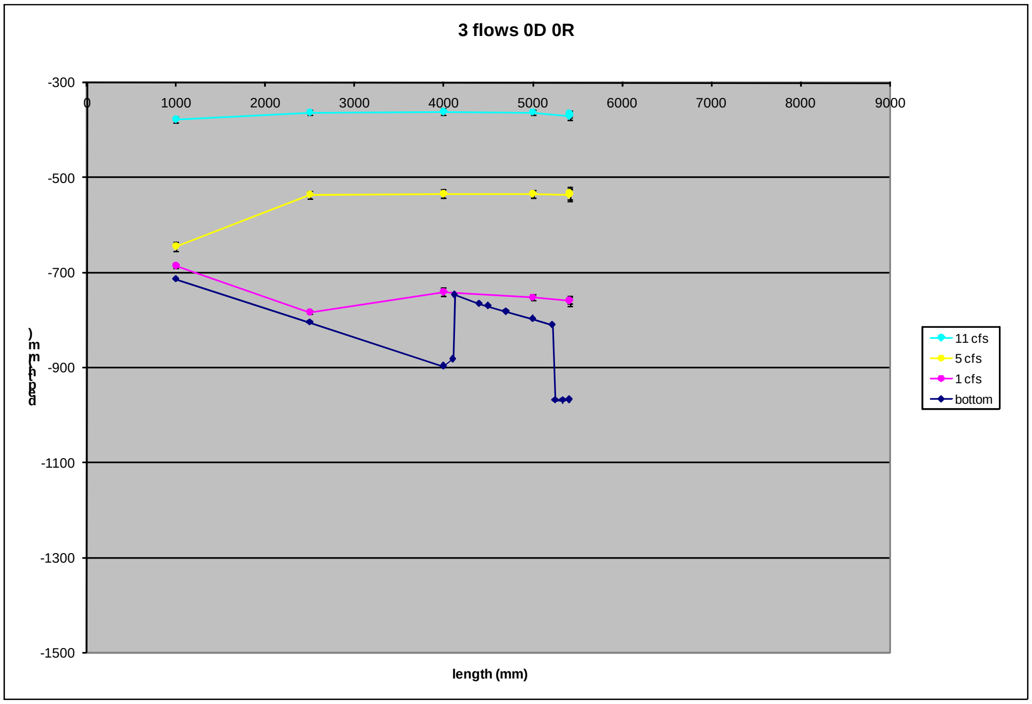


Figure 6. Water surface profiles for the zero approach length and zero recessed depth trials.

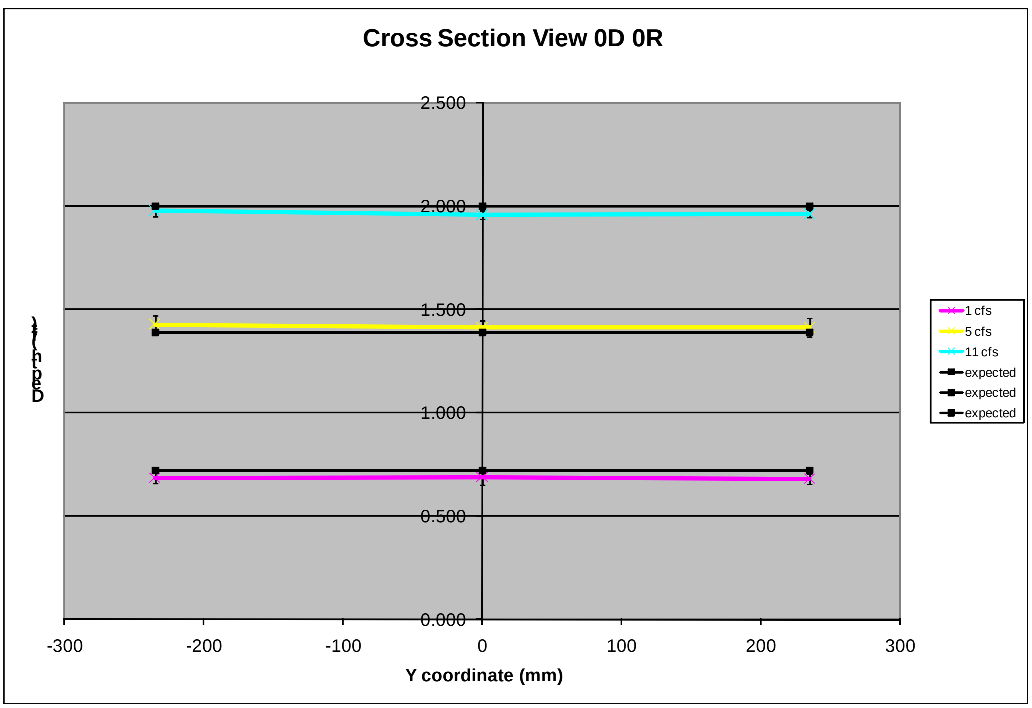


Figure 7. Cross sectional view of water surface measured within the H Flume. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

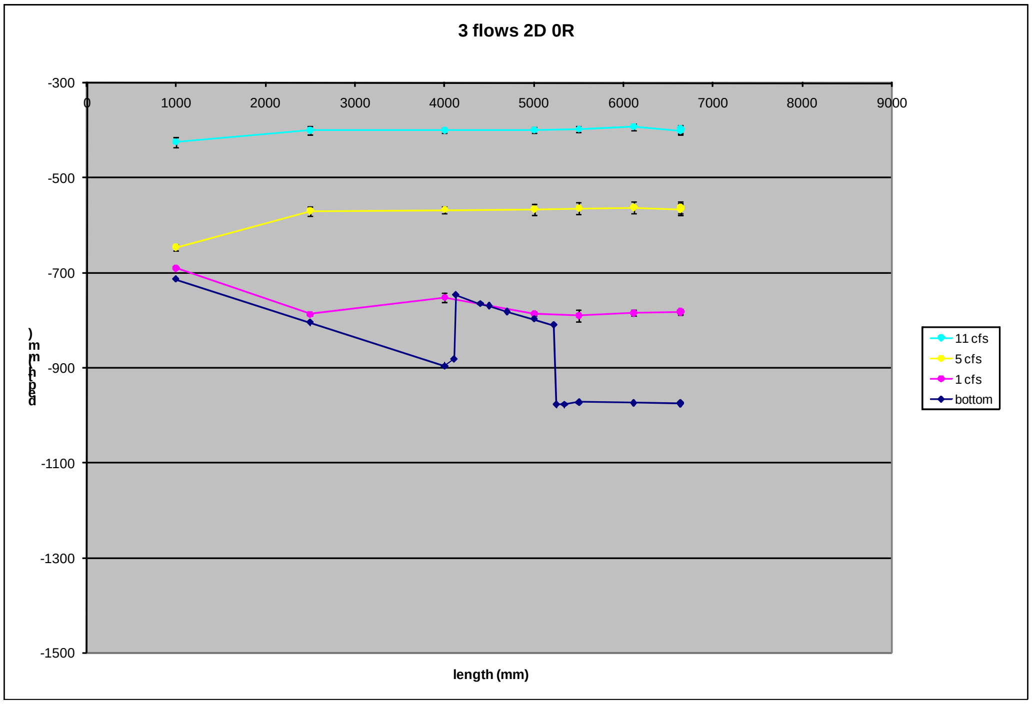


Figure 8. Water surface profiles for the 2d approach section length and zero recessed depth trials.

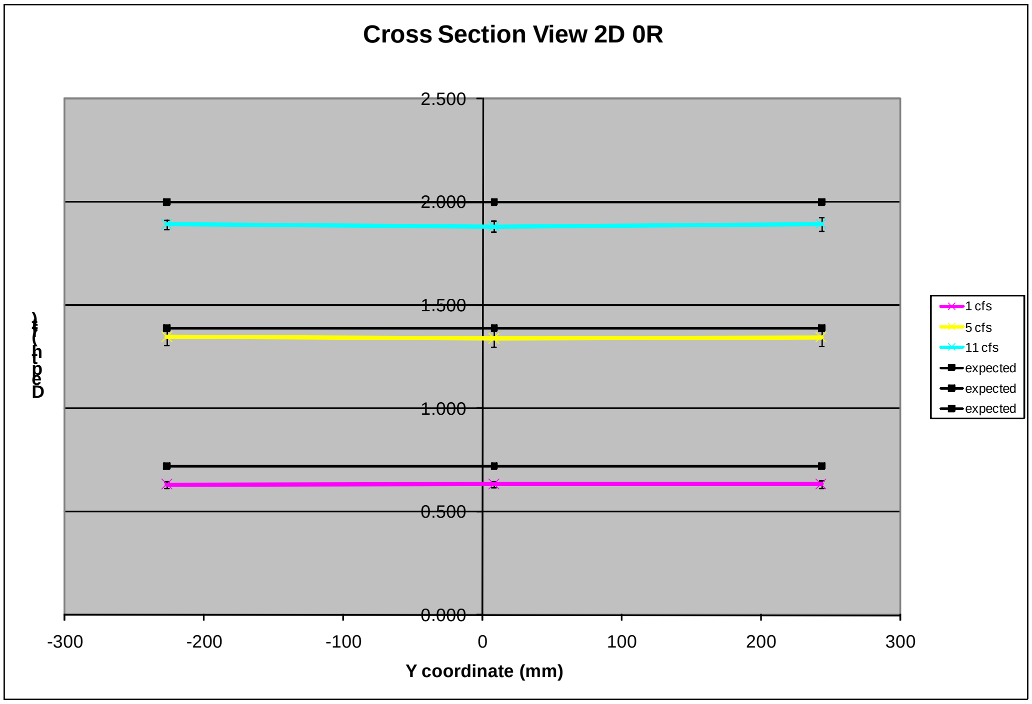


Figure 9. Cross sectional view of water surface measured within the H Flume for the 2d approach section length and zero recessed depth. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

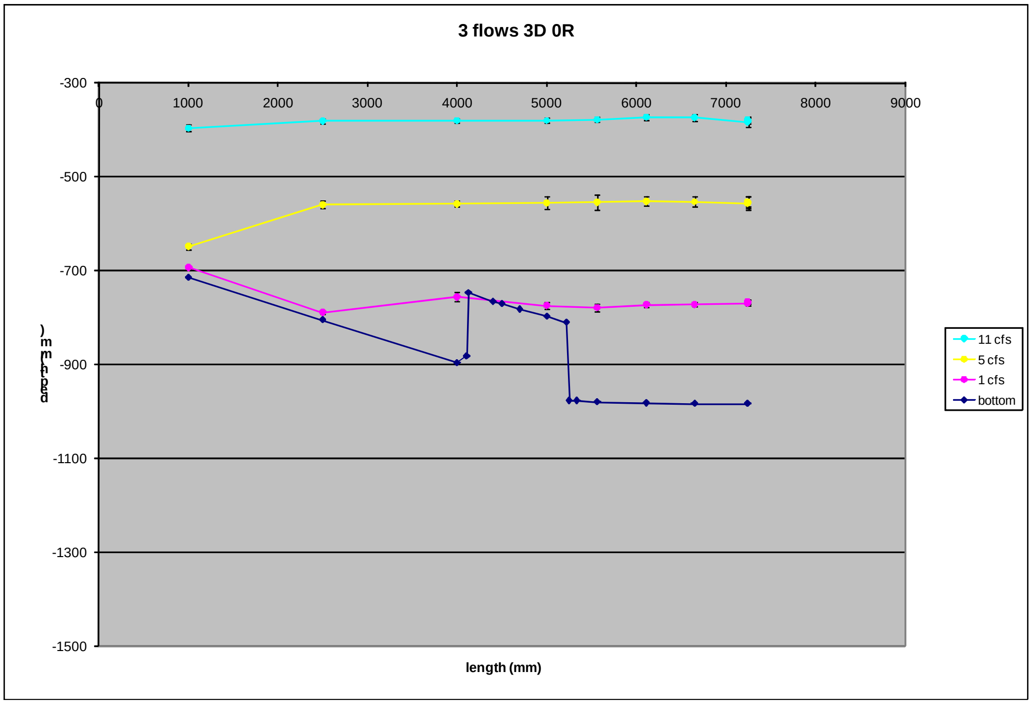


Figure 10. Water surface profiles for the 3d approach section length and zero recessed depth trials.

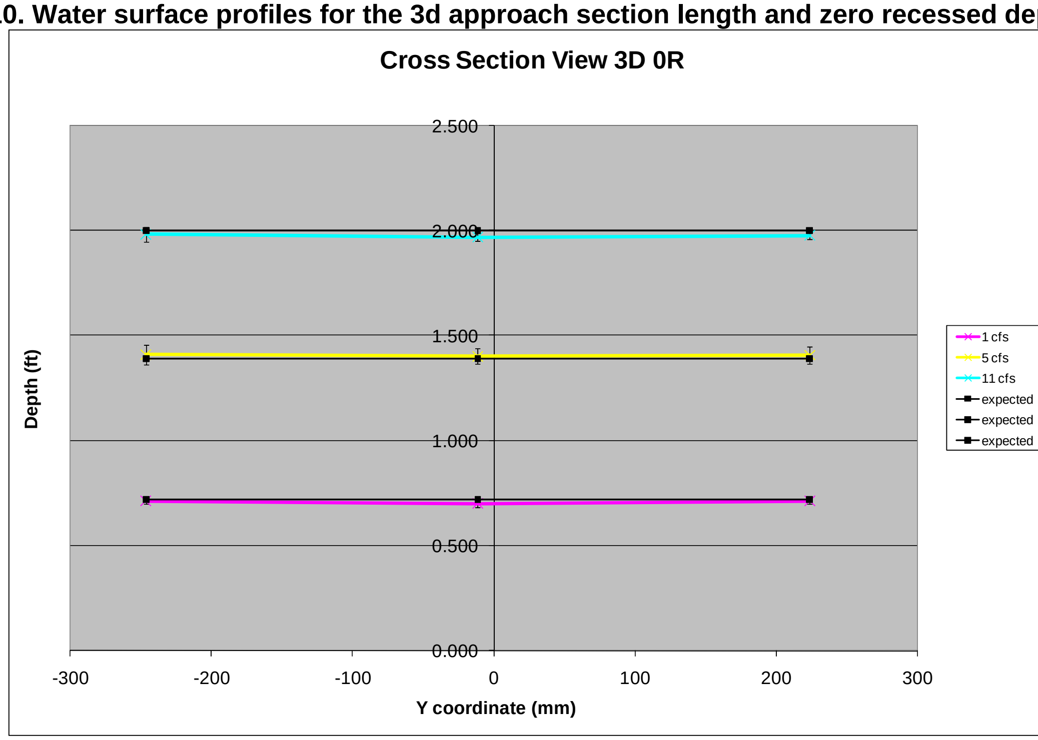


Figure 11. Cross sectional view of water surface measured within the H Flume for the 3d approach section length and zero recessed depth. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

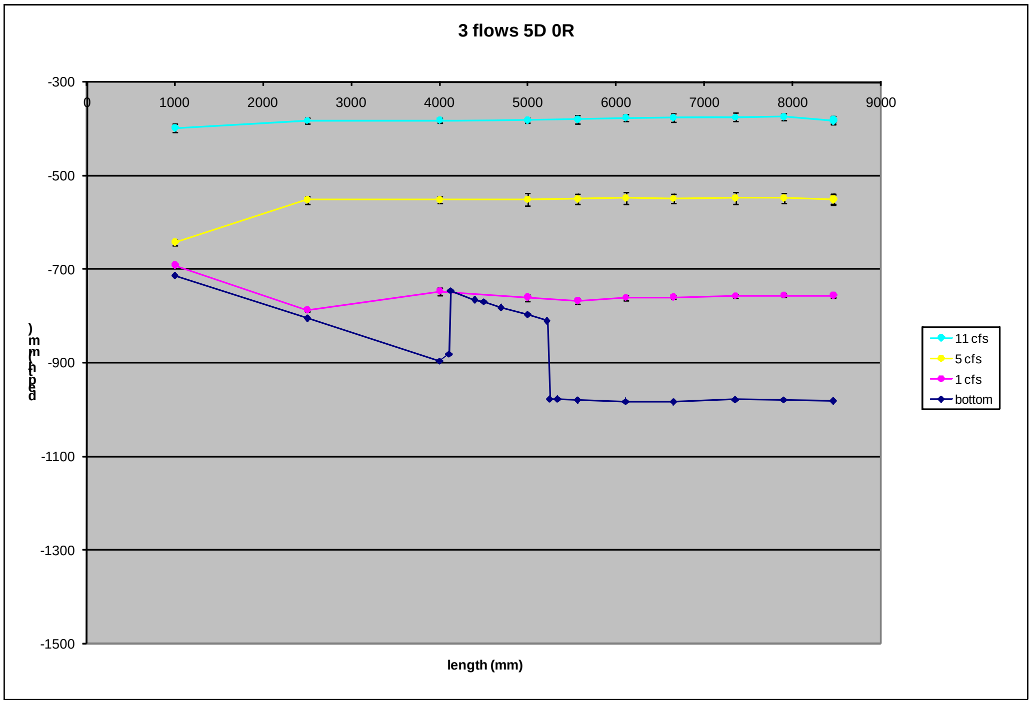


Figure 12. Water surface profiles for the 5d approach section length and zero recessed depth trials.

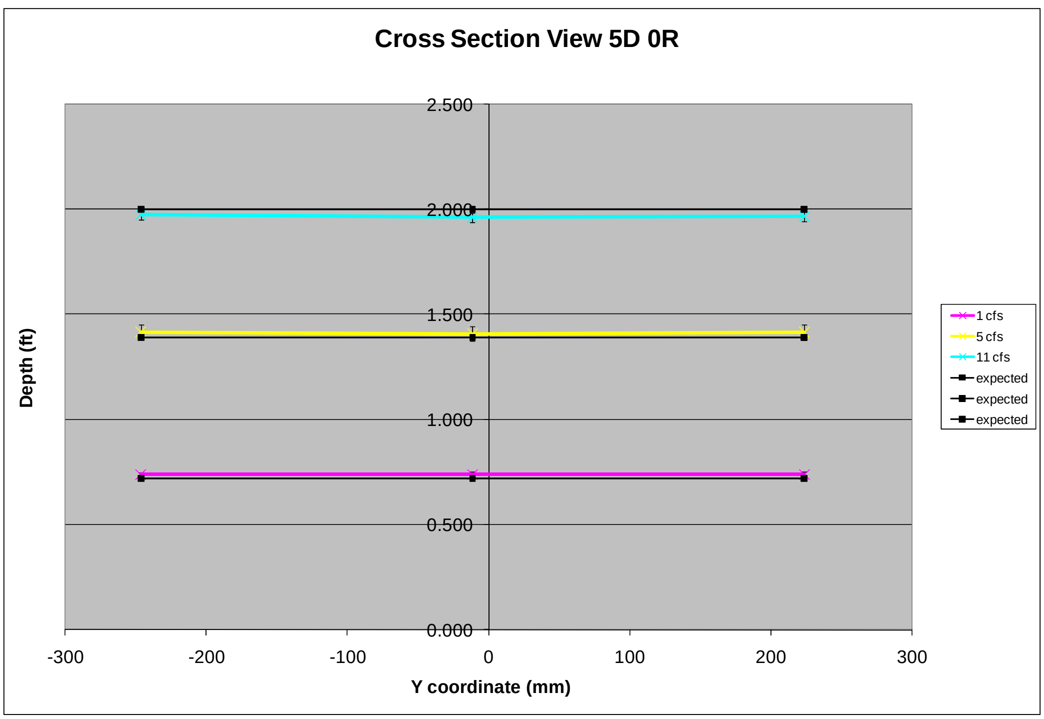


Figure 13. Cross sectional view of water surface measured within the H Flume for the 3d approach section length and zero recessed depth. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

0.35d recessed depth results

Nine tests were conducted with the approach section and H Flume recessed 0.35d below the approach slope. For this configuration, three approach lengths were examined: 2d, 3d, and 5d. The 0d configuration was not examined. Water surface measurement results are shown in Figures 14 through 19. Each approach length has two plots associated. The first is a summary of all water surface and bed surface elevations measured for the three discharges. The second plot is a cross-section plot of water surfaces measured at the most downstream point within the H Flume for the three discharges. This position is the same position as specified in the literature for measuring stage in an H Flume. The plot includes a center elevation as well as two side measurements and provides information on water surface elevation variance in the H Flume over the two minute sampling period.

Table 3. Summary of results for 0.35d recess depth tests.

recess depth (relative)	approach length (relative)	discharge (cfs)	expected reading (mm)	river left reading (mm)	percent error (%)
0.35	2	1	0.72	0.643	10.7
		5	1.39	1.393	-0.2
		11	2	2.066	-3.3
0.35	3	1	0.72	0.682	5.3
		5	1.39	1.393	-0.2
		11	2	2.042	-2.1
0.35	5	1	0.72	0.685	4.9
		5	1.39	1.372	1.3
		11	2	1.967	1.7

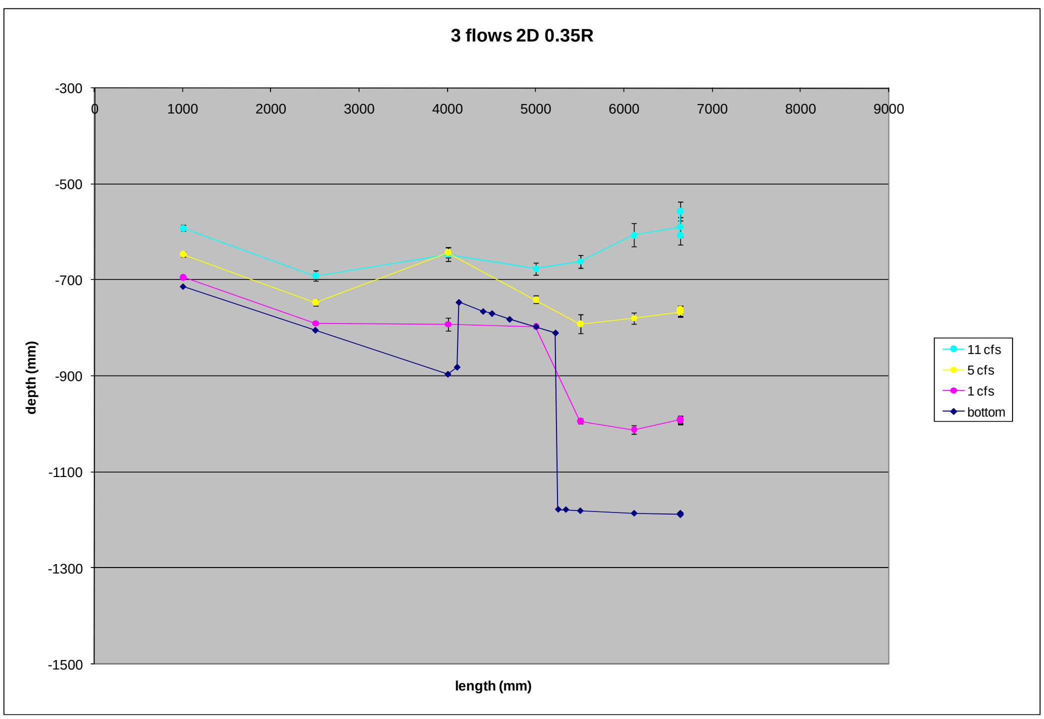


Figure 14. Water surface profiles for the 2d approach section length and 0.35d recessed depth trials.

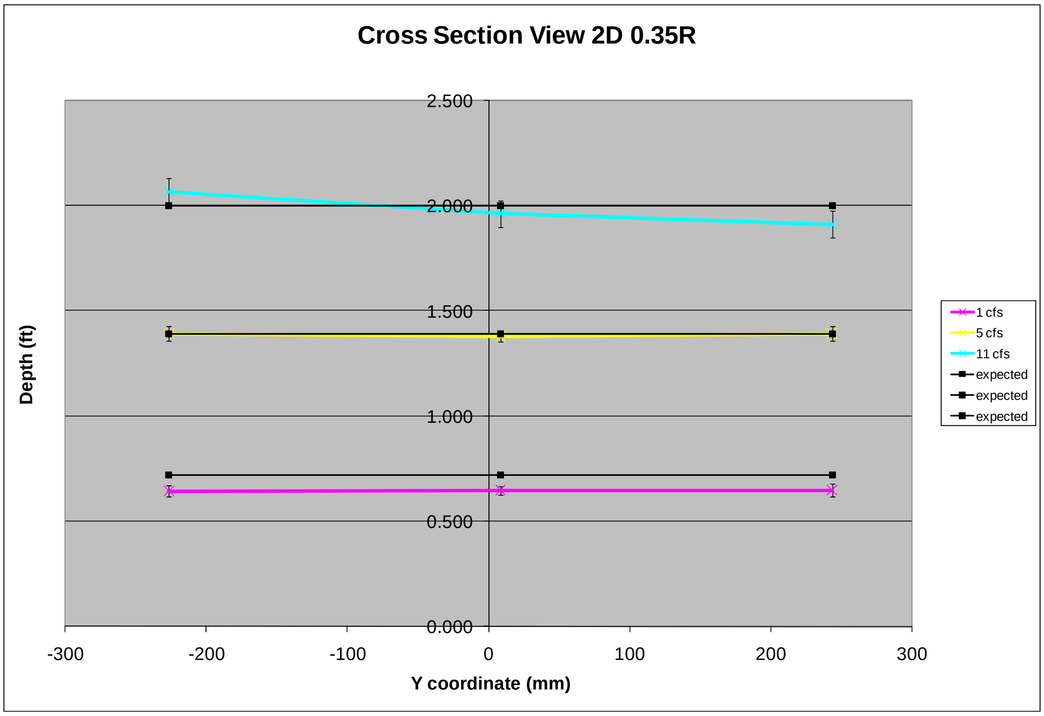


Figure 15. Cross sectional view of water surface measured within the H Flume for the 2d approach section length and 0.35d recessed depth. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

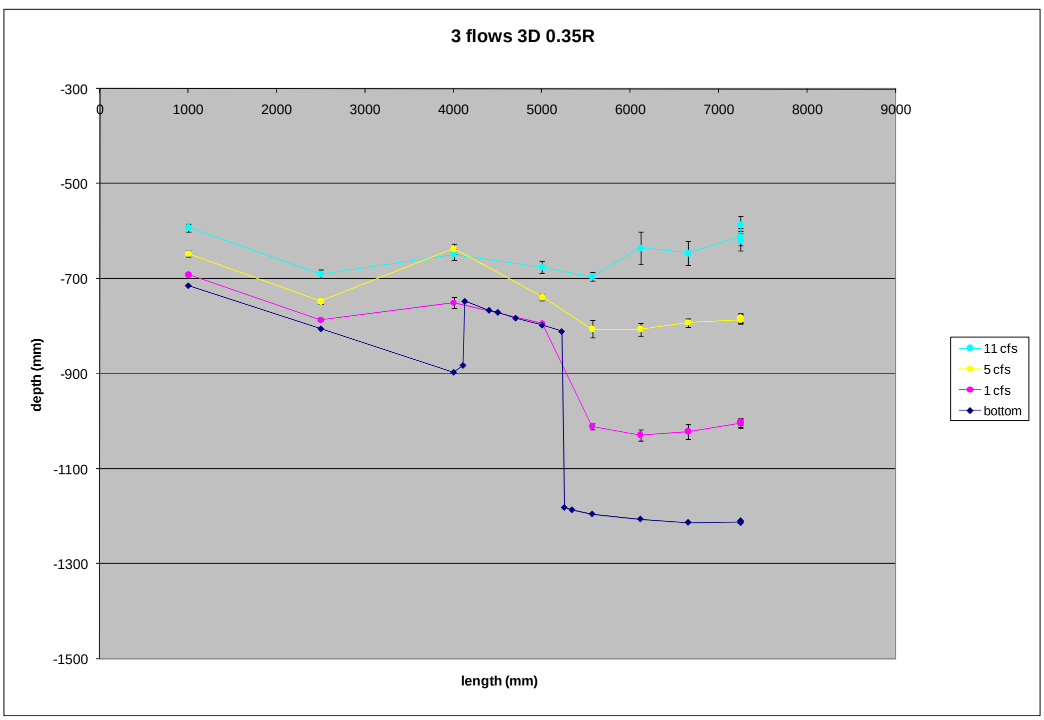


Figure 16. Water surface profiles for the 3d approach section length and 0.35d recessed depth trials.

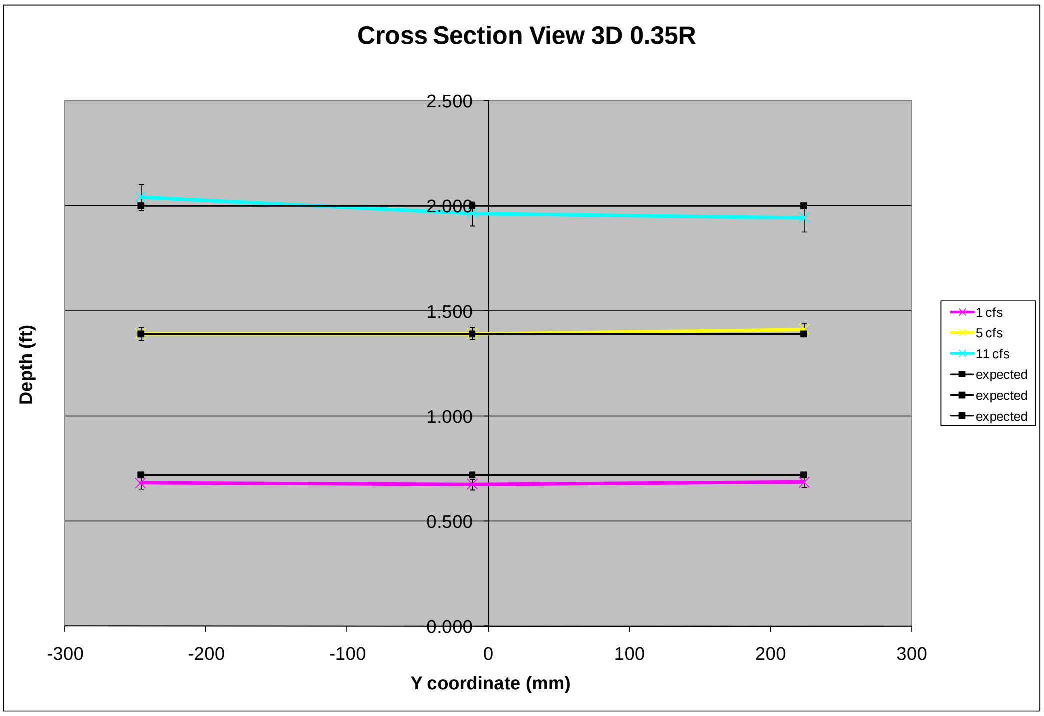


Figure 17. Cross sectional view of water surface measured within the H Flume for the 3d approach section length and 0.35d recessed depth. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

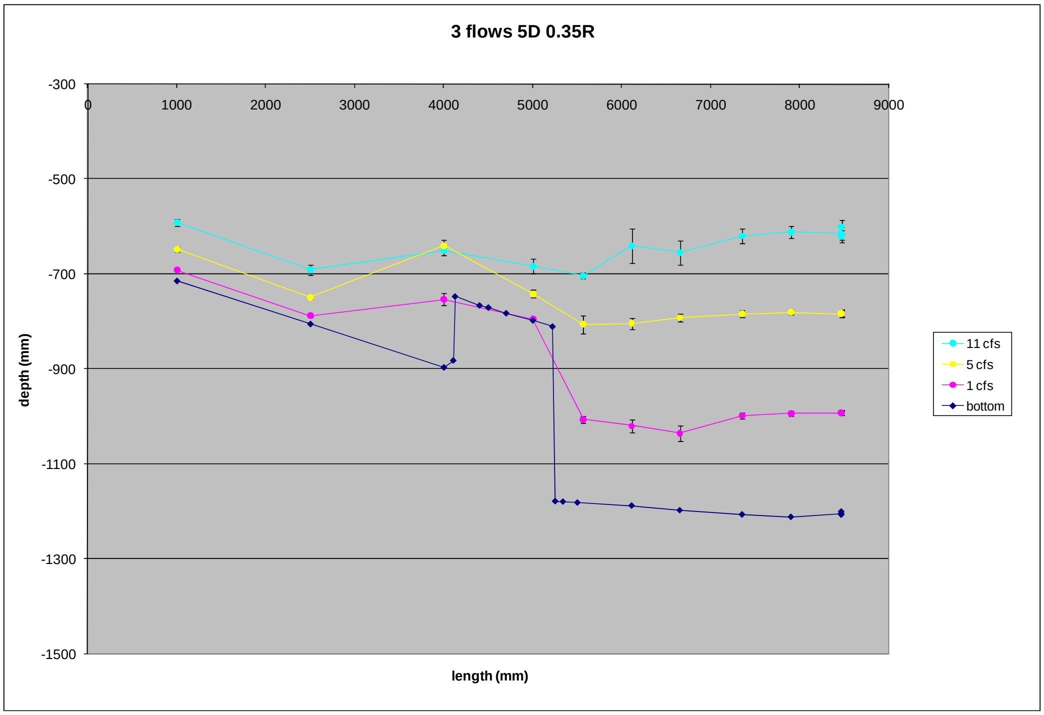


Figure 18. Water surface profiles for the 5d approach section length and 0.35d recessed depth trials.

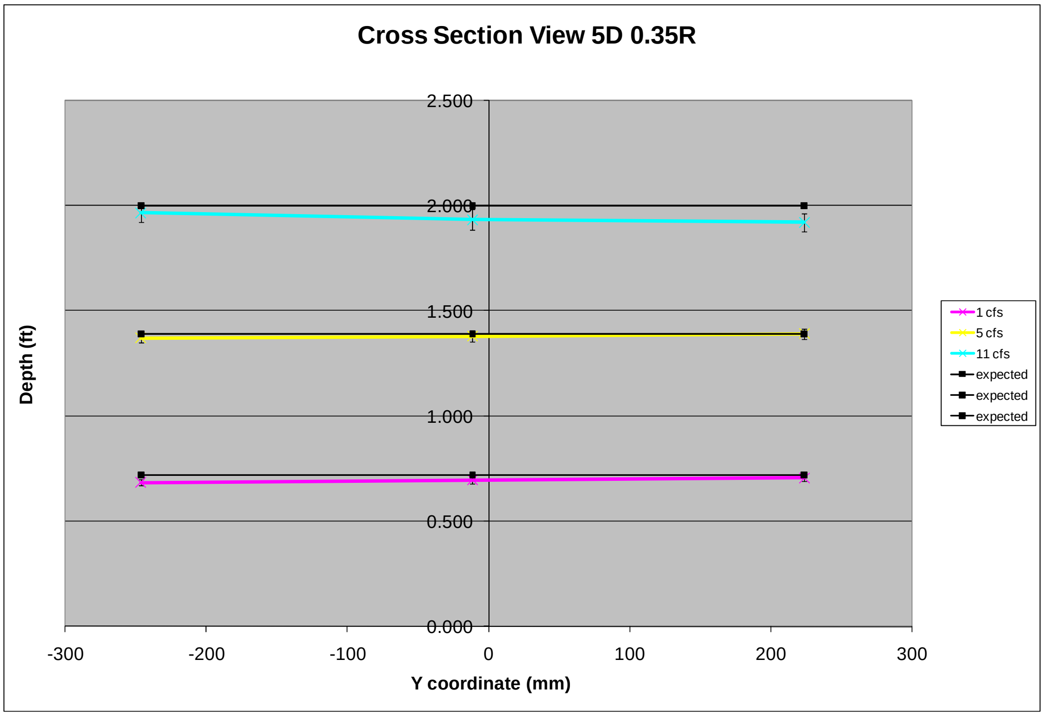


Figure 19. Cross sectional view of water surface measured within the H Flume for the 5d approach section length and 0.35d recessed depth. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

0.7d recess depth results

Nine tests were conducted with the approach section and H Flume recessed 0.7d below the approach slope. For this configuration, three approach lengths were examined: 2d, 3d, and 5d. The 0d configuration was not examined. Water surface measurement results are shown in Figures 20 through 25. Each approach length has two plots associated. The first is a summary of all water surface and bed surface elevations measured for the three discharges. The second plot is a cross-section plot of water surfaces measured at the most downstream point within the H Flume for the three discharges. This position is the same position as specified in the literature for measuring stage in an H Flume. The plot includes a center elevation as well as two side measurements and provides information on water surface elevation variance in the H Flume over the two minute sampling period.

Table 4. Summary of results for 0.7d recess depth tests.

recess depth (relative)	approach length (relative)	discharge (cfs)	expected reading (mm)	river left reading (mm)	percent error (%)
0.7	2	1	0.72	0.617	14.3
		5	1.39	1.375	1.1
		11	2	1.881	6.0
0.7	3	1	0.72	0.689	4.3
		5	1.39	1.392	-0.1
		11	2	1.927	3.7
0.7	5	1	0.72	0.671	6.8
		5	1.39	1.368	1.6
		11	2	1.929	3.6

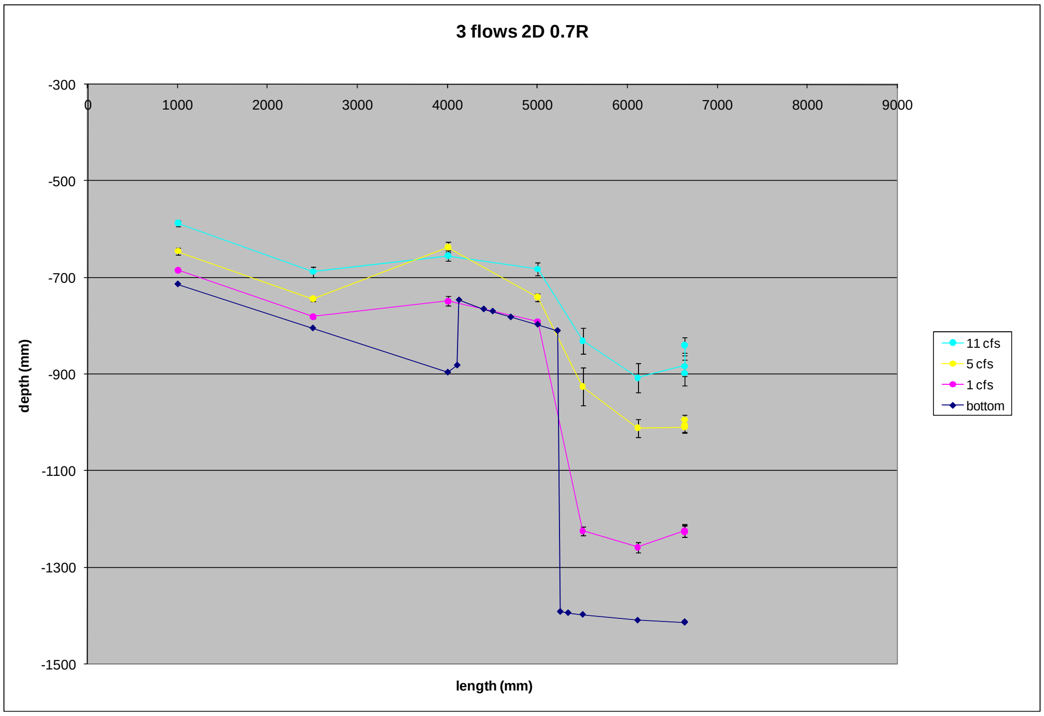


Figure 20. Water surface profiles for the 2d approach section length and 0.7d recessed depth trials.

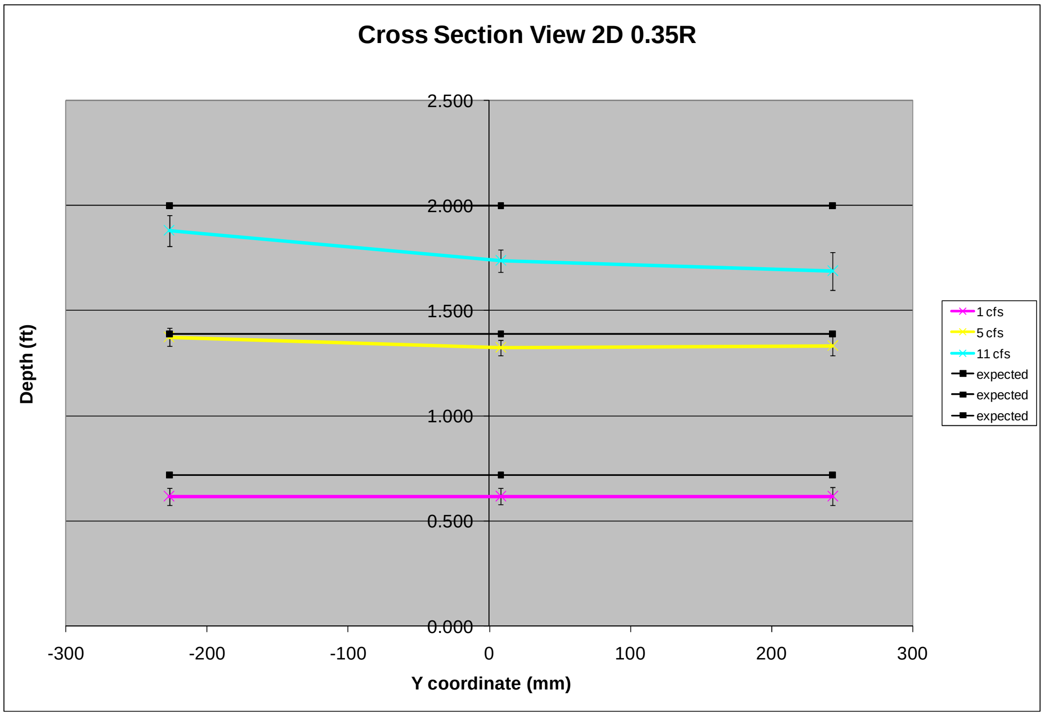


Figure 21. Cross sectional view of water surface measured within the H Flume for the 2d approach section length and 0.75d recessed depth. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

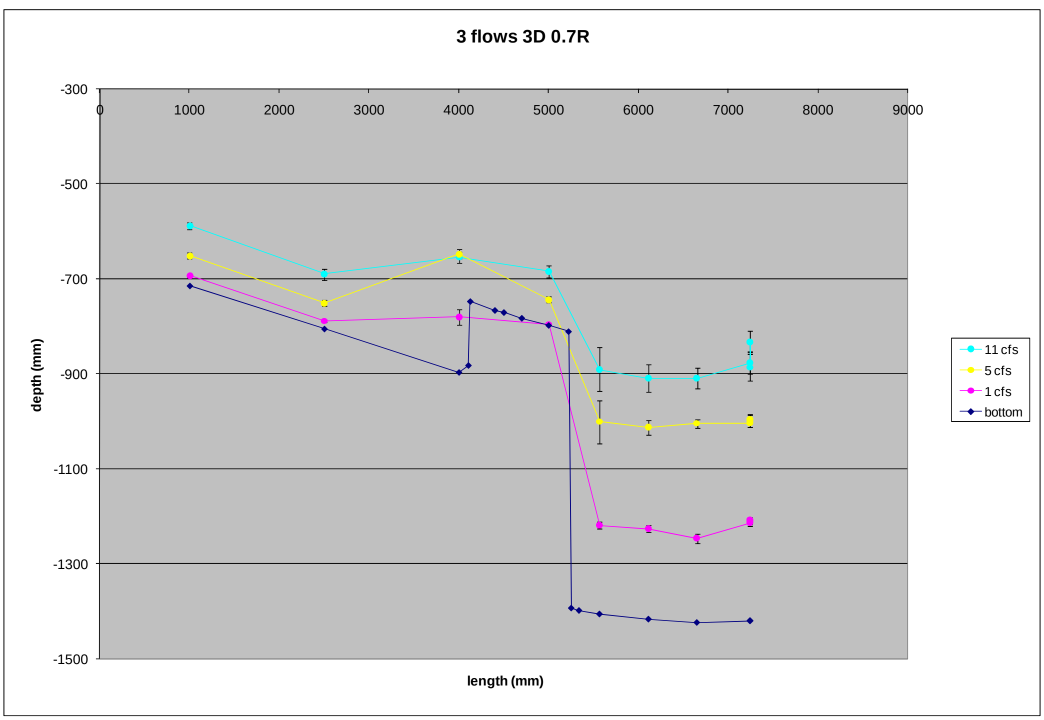


Figure 22. Water surface profiles for the 3d approach section length and 0.7d recessed depth trials.

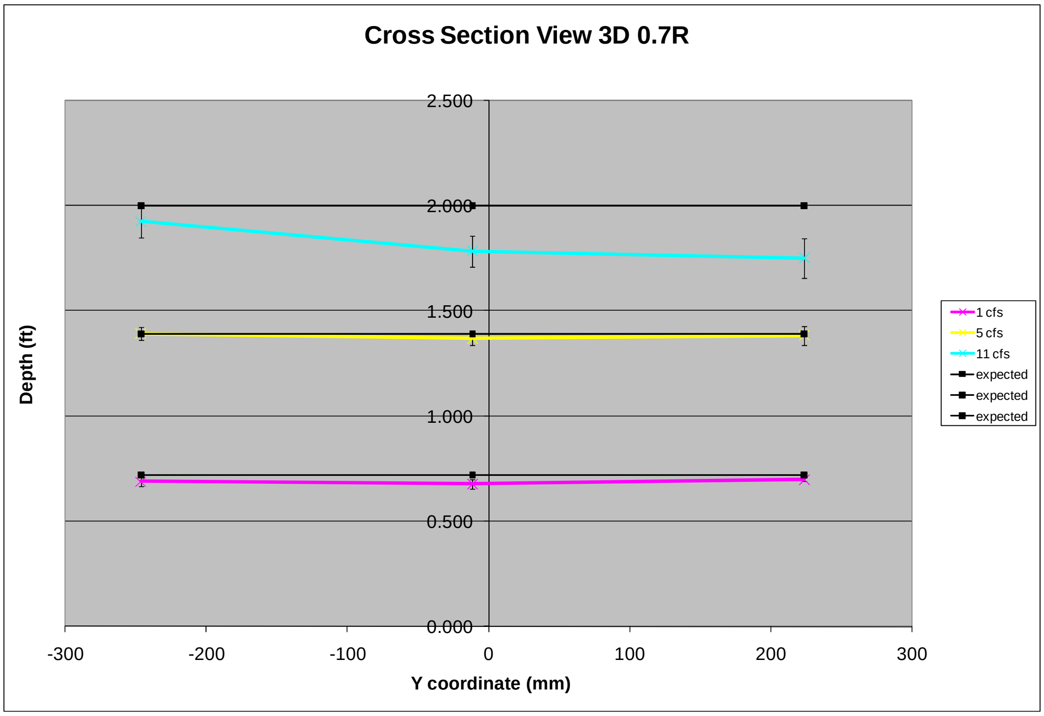


Figure 23. Cross sectional view of water surface measured within the H Flume for the 3d approach section length and 0.7d recessed depth. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

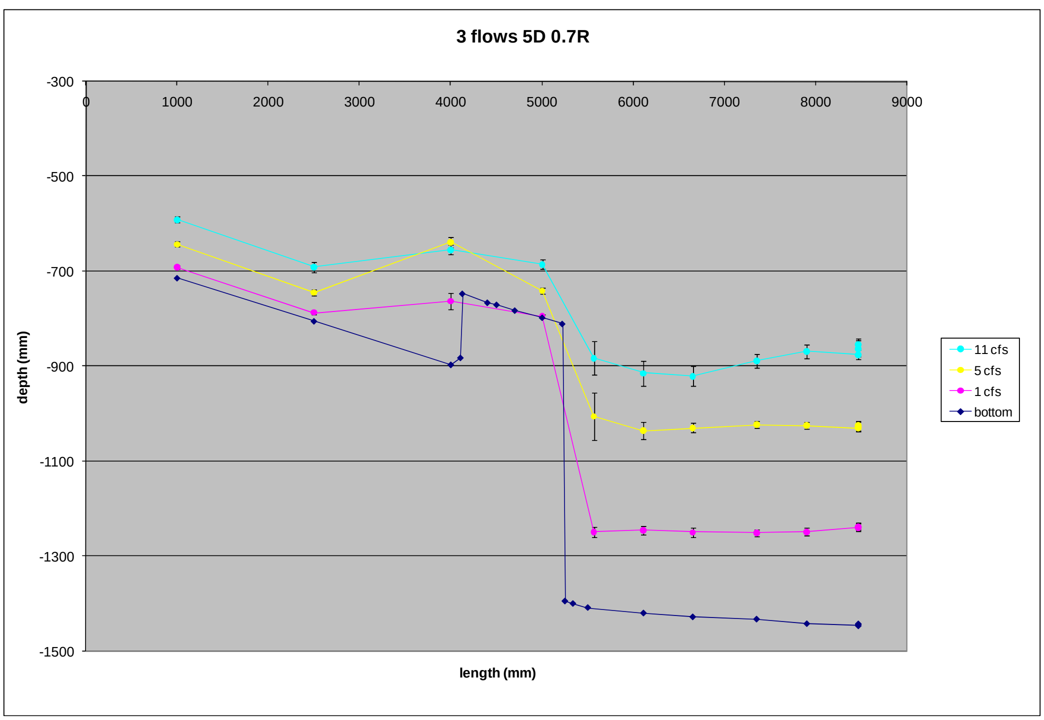


Figure 24. Water surface profiles for the 5d approach section length and 0.7d recessed depth trials.

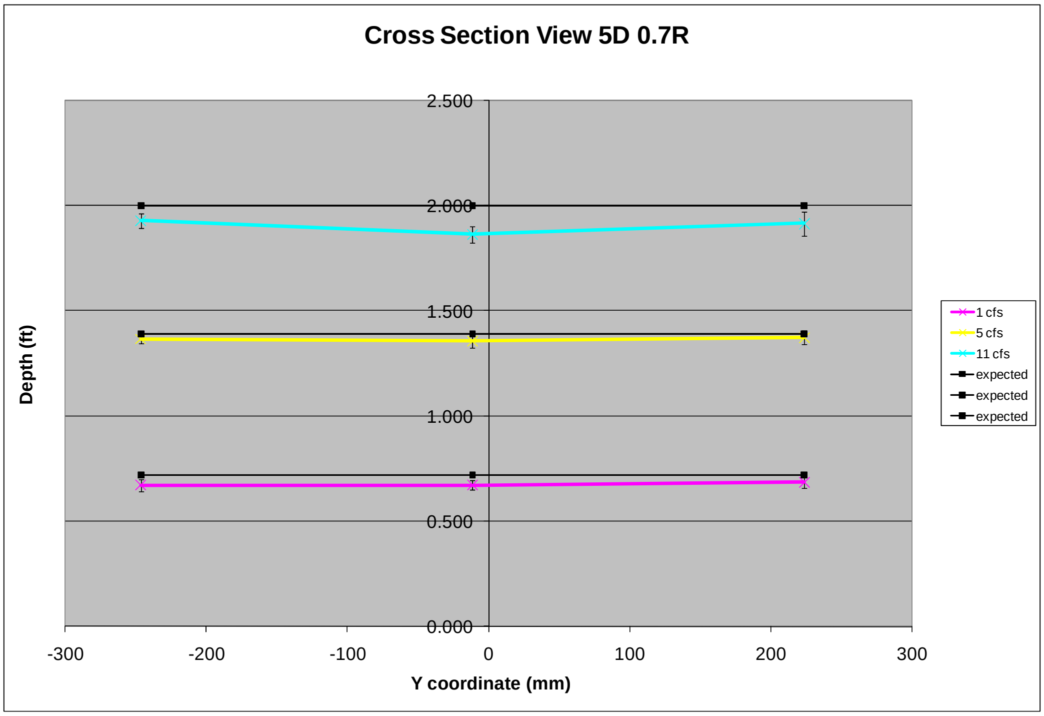


Figure 25. Cross sectional view of water surface measured within the H Flume for the 5d approach section length and 0.7d recessed depth. The point at -250 mm is the location specified by the manufacturer for discharge measurement. The black line is the water surface elevation equivalent to the actual discharge passing through the system as specifed by the manufacturer. Error bars indicate one standard deviation about the mean value.

Conclusions

The triangular wedge placed in the approach slope provided complexity to the flow by concentrating the flow against the river-right wall, which resulted in lateral flow velocity downstream within the approach section and H Flume. The tests reported here examined the performance of the H Flume under a range of flows and under various geometric configurations of approach section length and recessed depth. The following conclusions are identified from the tests:

1. The testing suggests that the error and variability in the discharge reading at the H Flume was lower with a longer approach section that served to “still” the flow. We observed that an approach section longer than 2 times the depth helped dissipate turbulent energy prior to entering the H Flume. It should be noted that discharge readings were better with a longer approach section, but were still fairly accurate with shorter approach sections—adding length to the approach sections improved an already accurate reading. Therefore, for a situation in which it is challenging to incorporate a longer approach section, the trade-off between approach section length and error is worth investigating.

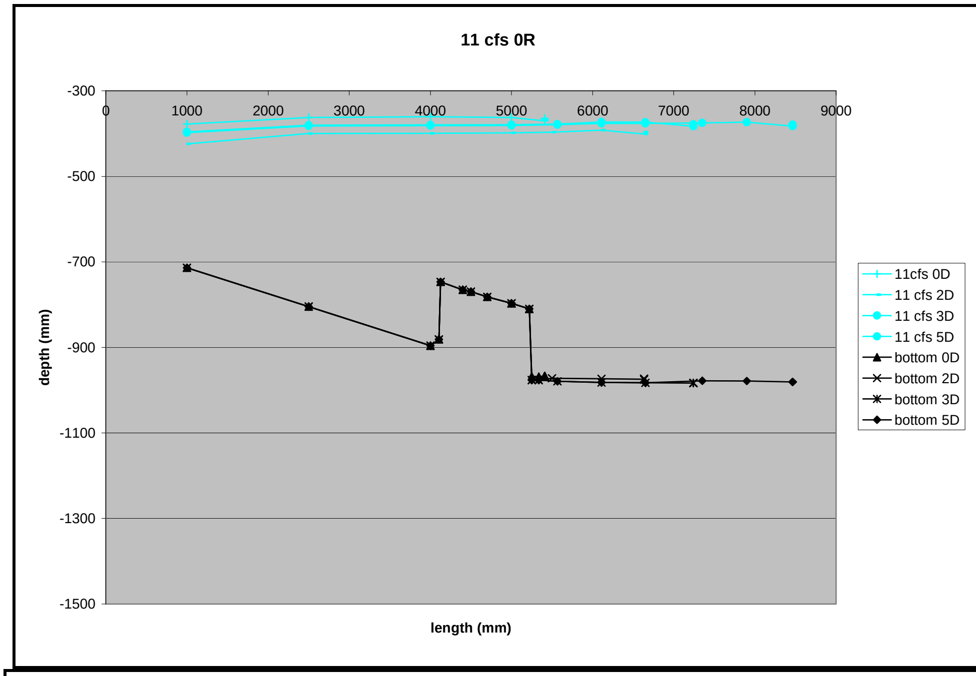
2. The testing revealed that the recessed approach section introduced turbulence into the approach section via a hydraulic drop from the end of the approach slope, which negatively impacted the discharge measurement at the H Flume. The hydraulic drop formed for the 0.35 and 0.7 recessed depths. A longer approach channel helped dissipate the turbulent energy but did not completely remove the effect.

3. The testing confirms that the H Flume causes a backwater effect that can be quite significant at maximum design flow rates. The tests illustrate that by recessing the approach section, the impact of the backwater on the approach slope is minimized. This may have important implications for application in field settings since, without the recess of the approach, the backwater could cause flooding of low gradient environments. The effect is illustrated in Figure 26.

4. The tests suggest that a non-recessed case provided the most accurate and precise measurement of discharge at the H Flume. However, for large flows the backwater effect caused by the H Flume was significant.

In general, the H Flume performs well under the perturbed flow conditions created in the testing. Percent errors were all below 14% and average errors among all trials were:

- Non-recessed case was 3.2%;
- 0.35% recessed case was 3.3%;
- 0.70% recessed case was 4.6%.



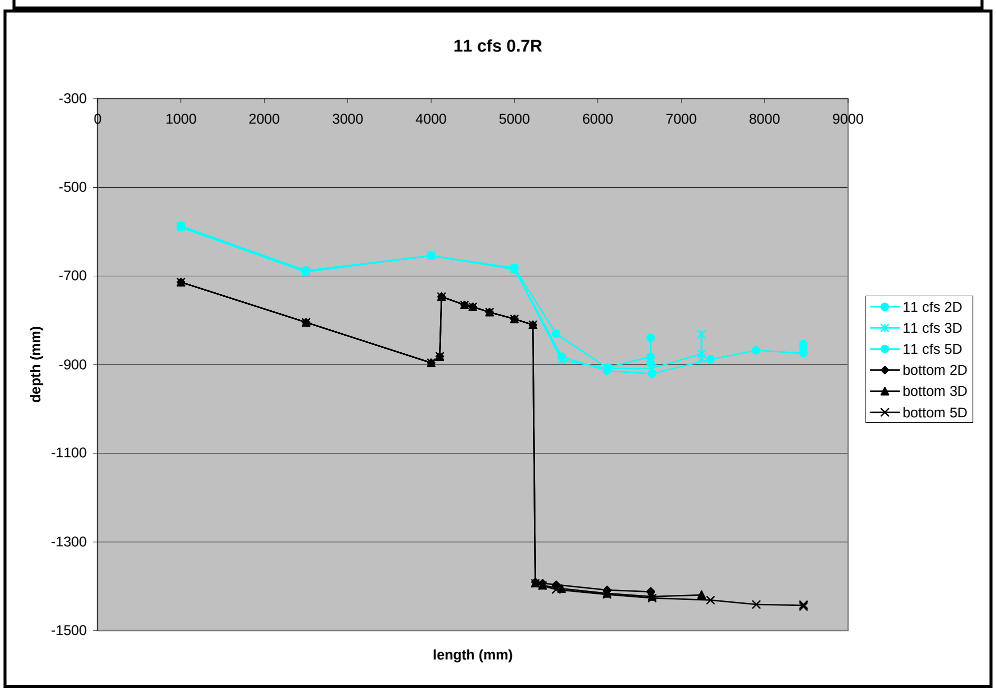


Figure 26. The upper figure shows a backwater effect from the H Flume extending up the approach slope and putting the stage at approximately -400mm at x = 1000 mm for the condition of no recess. The lower figure is recessed to 0.7d and therefore there is no backwater on the approach slope so the stage is approximately -600mm at x = 100.

References

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Gwinn, W.R., and Parsons, D.A. Discharge Equations for HS, H, and HL Flumes. Journal of the Hydraulics Division, ASCE, Vol. 102. January 1976. No. HY1, Proc Paper 11874: 73-88.