CEE:3371 Principles of Hydraulics and Hydrology
Project #2
Flow Measurement with a Weir

Problem Statement

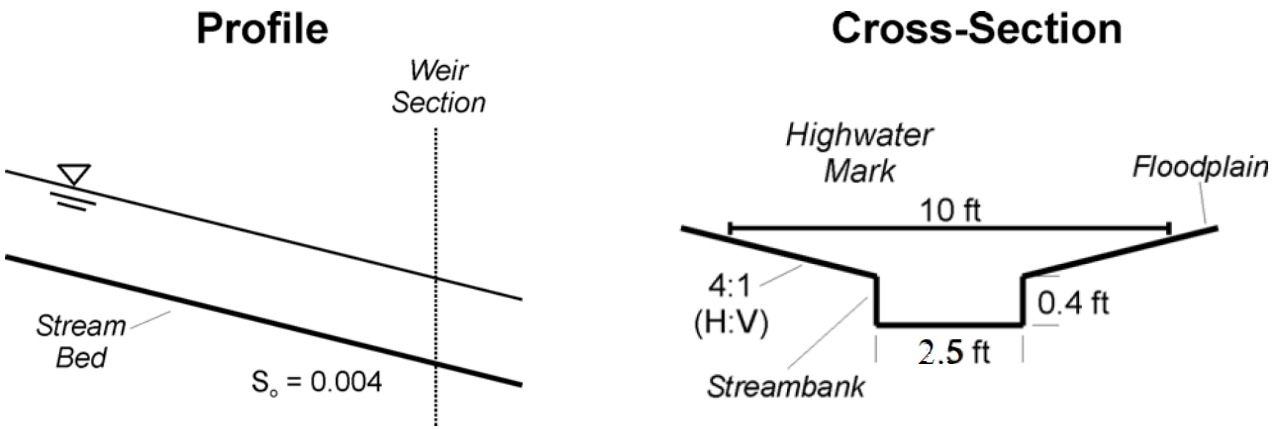
The Iowa DNR plans to monitor a proposed prairie restoration project in eastern Iowa as an experiment. The site is currently in row crops, and will be returned to a tallgrass prairie landscape in a few years. A small ephemeral stream drains the site. The Iowa DNR wishes to find out how the runoff from the site changes over time. You have been hired as a consultant on the project.

Project Objective

Design a weir flow control structure to continuously measure discharge at the site.

Site Information

The site for the flow measurement weir, and the representative channel cross-section at the site, are shown below:



Stream profile and cross-section

A photograph of the stream at the proposed weir site is shown on the following page.

Design Criteria

Although the flow in the stream is usually contained within the streambanks, during times of high flow, the water will spread over the floodplain. The highwater mark for the largest observed flood is shown above. The Iowa DNR requires that the weir be able to measure flows as large as the largest observed flood. In addition, the DNR would like to know the extent of ponded water behind the weir (e.g., the water surface profile) for this design flood.

Photograph showing the stream near the proposed weir site.

A Global Water Instrumentation Inc. WL 400 Water Level Sensor will be used to measure water levels upstream of the weir site. The Iowa DNR requires that estimates of the uncertainty (ΔQ) of the discharge measurements be made for conditions of (1) bankfull flow and (2) the design flood.

Weir Options

One of two weir geometries may be selected for the site. One is a rectangular sharp-crested weir. The other is a V-notch sharp-crested weir. The two weirs have been delivered to the IIHR laboratory facilities for testing. Your project team will run tests to determine the weir head-discharge relation ($Q = kh^n$).

Details of the experimental methods to be used to test the weirs are available in the attached appendix.

Project Report

Your project team must submit a final project report to the Iowa DNR Restoration Project Director. The report should be concise and focused on answering the project objectives. Minimum required components are:

The recommended weir geometry and head-discharge relationship.

Profile and cross-section specs for the weir site (sketch). This should include the height of the weir (H_w) above the stream bed, the maximum height of the weir, and the proposed placement of the water level sensor [Note: The construction manager will be directed to build to these specs].

The required water level measurement range (e.g., 0 to ? feet) for the water level sensor (in order to purchase the correct WL400 Water Level Sensor).

The estimated uncertainty (ΔQ) of the discharge measurement (in cfs) for the two cases mentioned in the Design Criteria. [Note: This will depend on the uncertainty (or accuracy) of the water level measurement (ΔH), as reported in the manufacturer's specifications for the water level sensor].

An estimate of the extent of ponded water behind the weir for the design flood condition [Note: A plot of the water surface profile calculation based the direct-step method would provide this information].

Any other recommended design and operation considerations for the site.

The report should also contain technical information necessary to support your recommendations and conclusion; however, this information needs to be written at a level appropriate to the audience (i.e., the Project Director, who has an MS in Biological Sciences).

Consultation with the CTC is not required, but is recommended (and will be rewarded with extra credit).

Report Format (See appendix B)

APPENDIX A

WEIR CALIBRATION

Principle
The discharge over a weir is a function of the weir geometry and of the head on the weir.

Introduction
A weir is an obstruction in an open channel over which liquid flows. The purpose of this calibration is to determine the head-discharge relationship of two different shapes of weirs, and to compare the experimental results with their corresponding analytical expressions.

Consider a weir with an irregular cross-section, as shown in Figure 1.

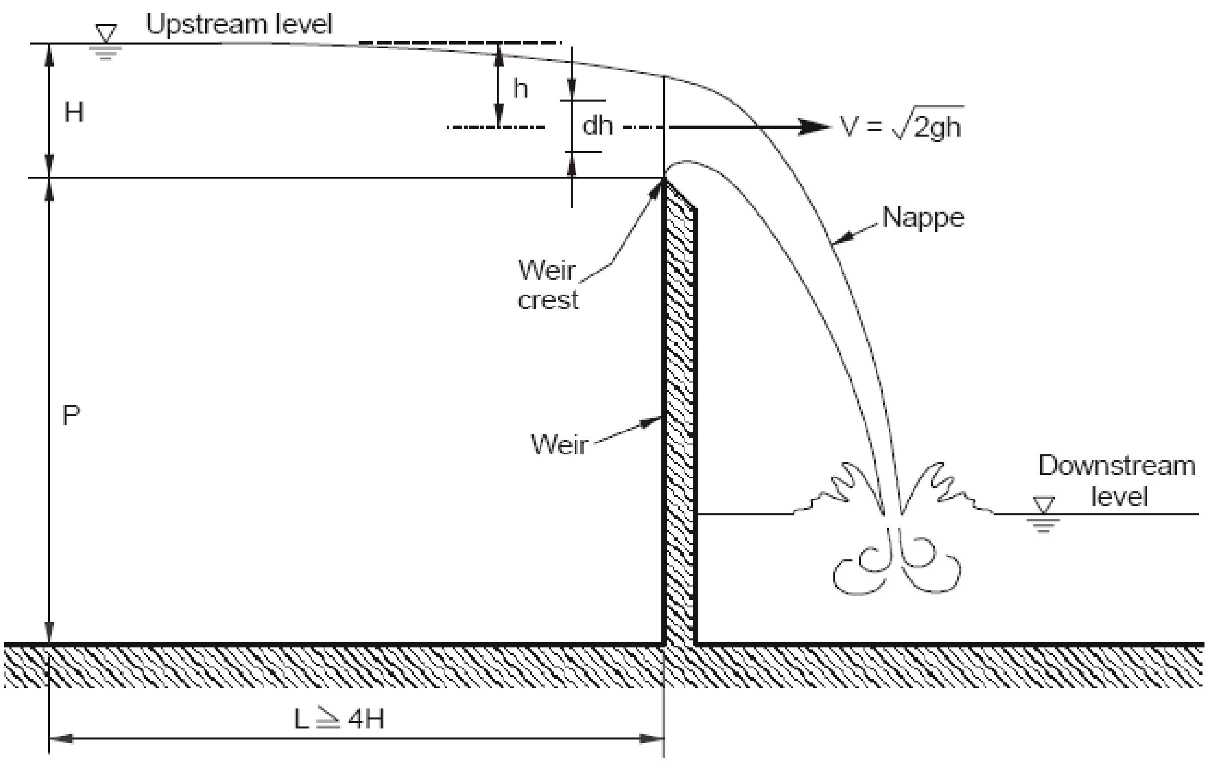


Figure 1. Definition sketch for a weir

Applying Bernoulli's equation along a streamline between a point upstream of the weir (where the velocity head is neglected) and a point in the plane of the weir, the velocity, V, at the weir is:

$$V(h) = \sqrt{2gh} \tag{1}$$

where g is the gravitational acceleration and h is the elevation of the streamline below the free surface. Assuming that the velocity is constant throughout the cross-section of the weir, the expression for the discharge, Q, over the weir becomes:

$$Q = \int_A dQ = \int_A V(h)\, dA = \int_0^H \sqrt{2gh}\, b(h)\, dh = \sqrt{2g}\int_0^H b(h)\, \sqrt{h}\, dh \qquad \textbf{(2)}$$

where A is the cross-section of the weir and b(h) is the width of the weir at elevation, h.

Thus, the general expression for the weir head-discharge relationship is:

$$Q = kh^n \qquad \textbf{(3)}$$

where *k* is a flow coefficient and *n* is an exponent. Both *k* and *n* are dependent on the shape of the weir (e.g., rectangular, triangular, trapezoidal or parabolic) and the flow conditions (velocity distribution in the approach section, fluid viscosity, surface-tension effects, and the contraction coefficient).

Apparatus

The experiment is conducted in 2-foot open channel flume facility located in the Seamans Center. The weir shapes subjected to measurements in this experiment are rectangular and triangular. The geometry of these weirs is sketched in the Figure 2. The weir shapes are cut from stainless steel sheets and can be considered as being sharp-edged.

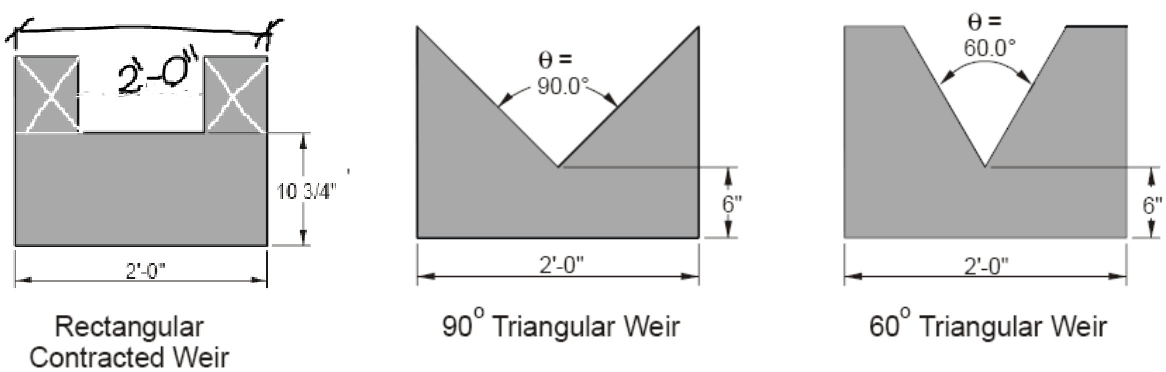


Figure 2. Geometry for typical weirs

The water in the flume is recirculated using a pump. The flume entrance is conditioned with baffles and screens to ensure smooth entry of water in the flume. Slots in the sidewalls are located in the middle section of the flume, between which the weir plates can be inserted. The slope of the flume is such that no submergence of the weir occurs. Water is returned to the headbox through a pipe.

A magnetic induction flowmeter is used to measure the flow entering the flume. The flow can be read via a meter on the wall or using the computer.

A point gauge attached to the flume is provided to enable measurement of the head on the weir. The weir reference point is measured when the flume is empty and the weir plate is in place. The tip of the point gauge has to be lowered so that it is at the same level with the weir reference point. Subsequently, when the desired steady discharge is established in the flume, the point gauge is set so that it slightly touches the water surface, upstream of the weir. Subtracting the reference point elevation from that of the water-surface upstream the weir, the head on the weir (in feet of water) is obtained.

Procedures

The experiment involves setting the pump to produce a series of different discharges (at least five for each weir shape). Set the discharges approximately by setting the pump speed to values suggested by the TA. Using the head measured on the weir and the corresponding discharge measured by the flowmeter, a head-discharge relationship is determined and subsequently compared with the derived analytical expression. The coefficient of discharge for each weir is determined by comparing the theoretical and measured results. Proceed with the following sequence:

1. Insert the weir of the desired shape in the slots.
2. Read the reference point of the weir.
3. Set the pump speed on the pump motor controller to the desired value to obtain a given discharge in the flume. First, read the flow rate, Q, through the flume.
4. Read the point gauge set on the water surface upstream of the weir.
5. Repeat steps 2 - 4 four each of the three weir shapes.

Measurements

Following the procedures described above, measure the quantities specified in the following table:

Discharge	**Rectangular**			**Discharge**	**Triangular 90°**		
Q (cfs)	**Ref Pt (ft)**	**W.S. Elev. (ft)**	**Weir Head (ft)**	**Q (cfs)**	**Ref Pt (ft)**	**W.S. Elev. (ft)**	**Weir Head (ft)**

Data Analysis

1. Plot log Q vs. log H. From the best-fit line to the experimental points determine the n_{exp} (i.e., the slope of the best-fit line) and k_{exp} (i.e., the intercept of the best-fit line with the ordinate).

2. Compare the experimental (n_{exp}) and analytical (n_t) values of the exponent , n.

3. Compare k_{exp} with values indicated in the literature.

Further Considerations

1. Derive, analytically, the head-discharge relationship for each of the weir shapes given in Figure 2. The analytical head-discharge relationship for the rectangular and the triangular weirs are given in standard textbooks.

2. If data seem to imply, $n_{exp} \neq n_t$, why this difference?

References

Gupta, R. S. (1989). *Hydrology and Hydraulic Systems*, Waveland Press, NY

Hwang, N.H. and Houghtalen, R.J. (1996). *Fundamentals of Hydraulic Engineering Systems*, 3rd edition, Prentice Hall, NJ

Rouse, H. (1967). *Engineering Hydraulics*, 6th Edition, John Wiley and Sons, NY

APPENDIX B
Report Format

Section 1: Title Page

- Course name
- Title for the report
- Submitted to "Your clients"
- Your names
- Your affiliation (lab section, group number)
- Date

Section 2: Executive Summary

- A brief, concise paragraph summarizes your project within 200 words.
- At the end of the summary, clearly state your recommendations to your clients.

Section 3: Introduction

- Statement of the problem
- Project objectives

Section 4: Background Information

- Background information for the project including site and operational information etc.

Section 5: Methodology (or Approach)

- Describe and justify the methodology (or approach) you used to achieve the goals.

Section 6: Results and Discussion

- Present the results from the work.
- Discuss the possible factors that may affect the outcomes.
- Justify your suggestions.

Section 7: Conclusions and Recommendations

- Restate the scope of the work and how the objectives were achieved.
- Summarize the major results from the work.
- Provide your recommendations to your clients.

Section 8: Appendices

- This is the only part in the report that is written to professionals in case that second opinion needs to be consulted. Therefore, it needs to be prepared in a scientific manner.
- Attach your technical analysis including:
    * Table or plot of raw data with units and caption (as appropriate).
    * Explain procedures for computed derived data.
    * Table or plot of derived data with units and caption (as appropriate).

Note:

1. The main report needs to be written at a level appropriate to the audience.
2. If tables and figures are included in the report, proper numbering and captions are required. Figures should follow conventional scientific presentation; axes should be properly labeled; variable's name and unit should be specified. If multiple curves are plotted in the same figure, different symbols and line patterns should be used; legend should be shown.