RECLAMATION *Managing Water in the West*

Incorporating Sharp-Crested Weirs into Irrigation SCADA Systems

Tony L. Wahl, Water Resources Research Laboratory, Denver, Colorado

Background

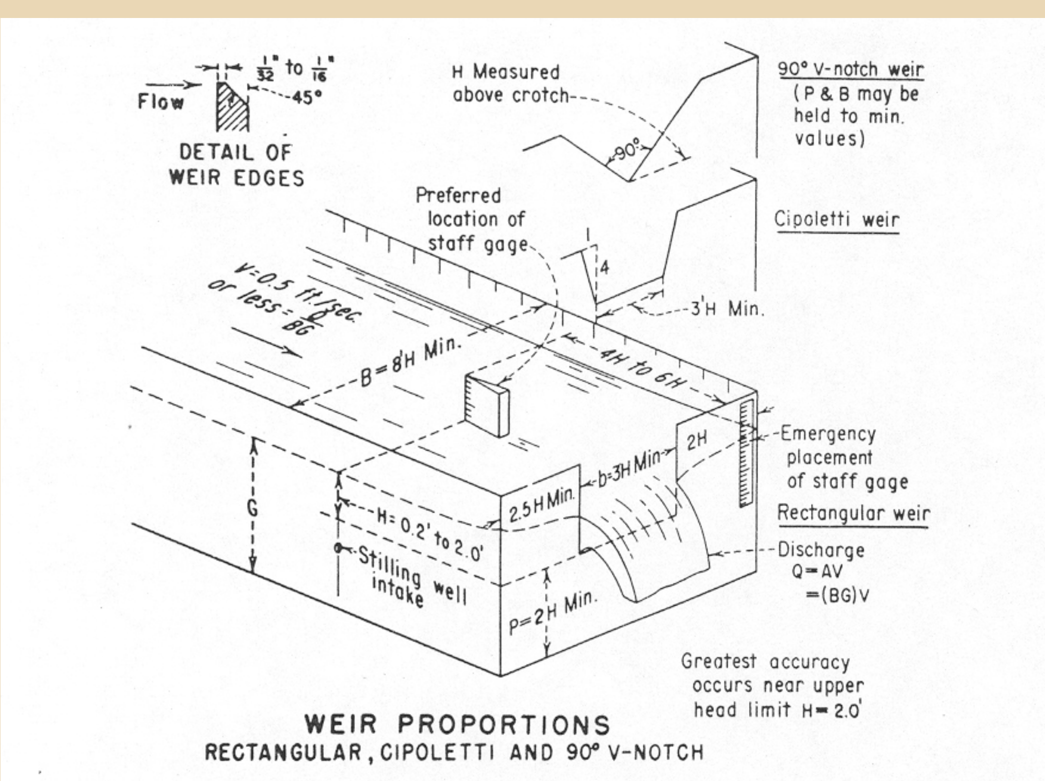
Partially contracted sharp-crested weirs have been difficult to integrate into SCADA systems

Automated flow measurement and monitoring are key elements of modern irrigation SCADA systems. Many newer flow measurement technologies are developed with easy SCADA integration in mind, but older devices still make up a significant part of most district's flow monitoring network.

Sharp-crested weirs of many types are common water measurement structures throughout the world. When they are installed in a fully contracted flow condition, most have simple rating equations, so with the addition of a water level sensor they can be easily incorporated into a SCADA system.

Fully contracted flow occurs when the approach channel is sufficiently large that the floor and sidewalls of the approach do not influence the flow through the weir opening (i.e., the flow contraction is the same as it would be if the box were of infinite size).

Sharp-crested weirs that have a restricted approach channel (weir box is too narrow or too shallow) experience "partially contracted" flow. This changes the discharge coefficient of the weir, making standard laboratory calibrations inaccurate, because they assume fully contracted flow. The weir will deliver more water than the amount that is measured.



Standards for Fully Contracted Weirs

Fully contracted flow occurs when the approach channel is large enough that the presence of the bottom and side walls does not affect the flow contraction through the opening. The drawing shows minimum approach channel dimensions for fully contracted flow.

Partially contracted sharp-crested weirs can be calibrated (i.e., rating equations determined) by use of the Kindsvater-Carter procedure, introduced in 1957. The method is relatively straightforward, but tedious because several charts and tables must be consulted for each flow rate of interest. Developing a complete rating table or rating curve requires significant effort, and the end result is still not easily integrated into a SCADA system until the rating table is converted to a curve-fit equation by regression analysis. The spreadsheet presented here is the first tool that simplifies each of these steps.

Kindsvater-Carter Calibration Method

Method accounts for changes in weir performance caused by partial contraction

The Kindsvater-Carter method is based on straightforward rating equations that incorporate three factors, C_e, K_b, and K_h, which are determined graphically from charts showing their variation as a function of various dimensionless ratios of weir parameters. The method has been adopted by several organizations as the most accurate method for calibrating sharp-crested weirs with full or partial contraction. The method is described in Reclamation's ***Water Measurement Manual***, and in many other flow measurement texts and standards.

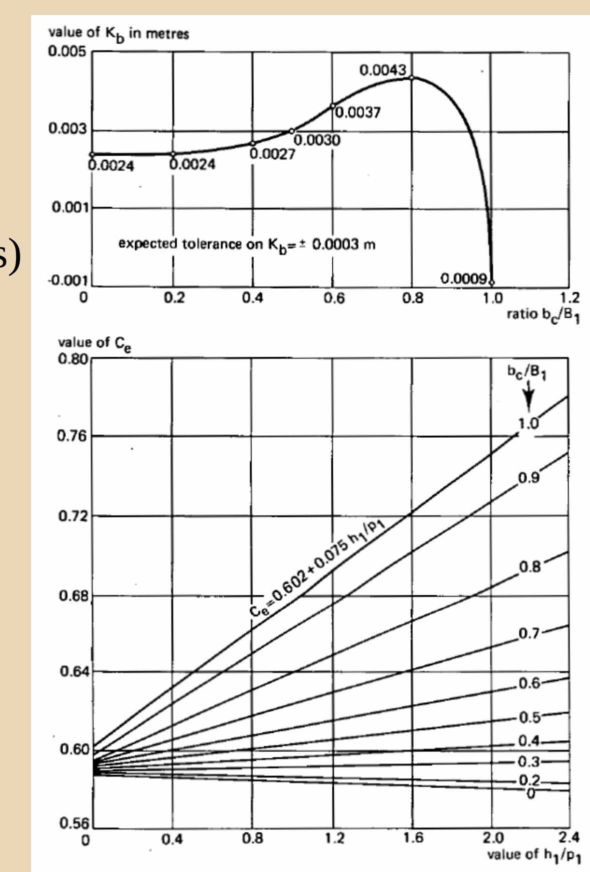
Application to Rectangular Weirs

$$Q = C_e \frac{2}{3}\sqrt{2g}\, b_e h_e^{1.5}$$

$$b_e = b_c + K_b$$

$$h_e = h_1 + K_h$$

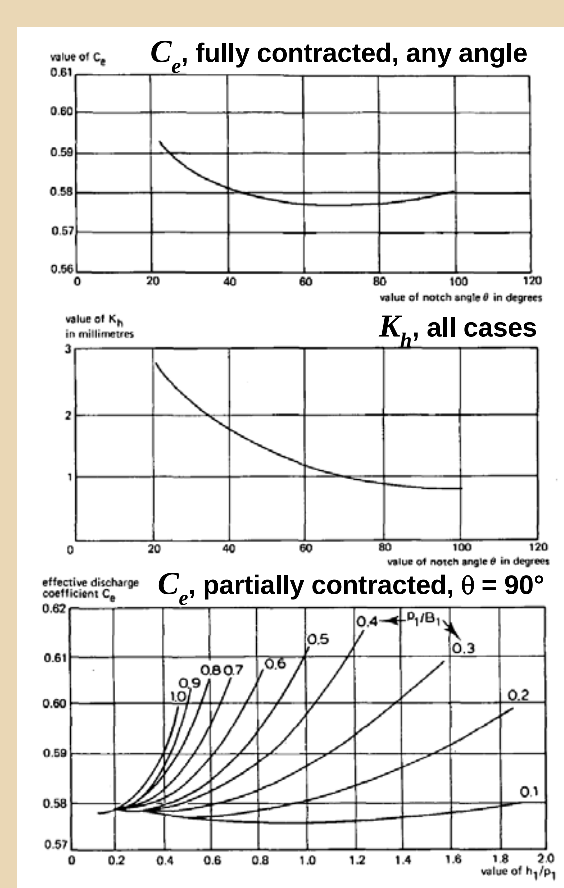
$$(K_h = 0.001\,\text{m for all cases})$$



Application to V-Notch Weirs

$$Q = C_e \frac{8}{15}\sqrt{2g}\tan\frac{\theta}{2} h_e^{2.5}$$

$$h_e = h_1 + K_h$$



USBRWeir.xls

Spreadsheet automates application of the Kindsvater-Carter calibration procedure

To simplify the application of the Kindsvater-Carter method and facilitate the incorporation of sharp-crested weirs into irrigation SCADA systems, a spreadsheet application was developed. The spreadsheet offered a good environment for creating the desired user-interface, and promoted rapid initial development of the application.

The spreadsheet can determine calibration tables, rating curves, and rating equations for 5 different types of weirs:

- 90° V-notch weir
- Rectangular suppressed weir
- Rectangular contracted weir
- Cipoletti weir
- V-notch weir (25° to 100°)

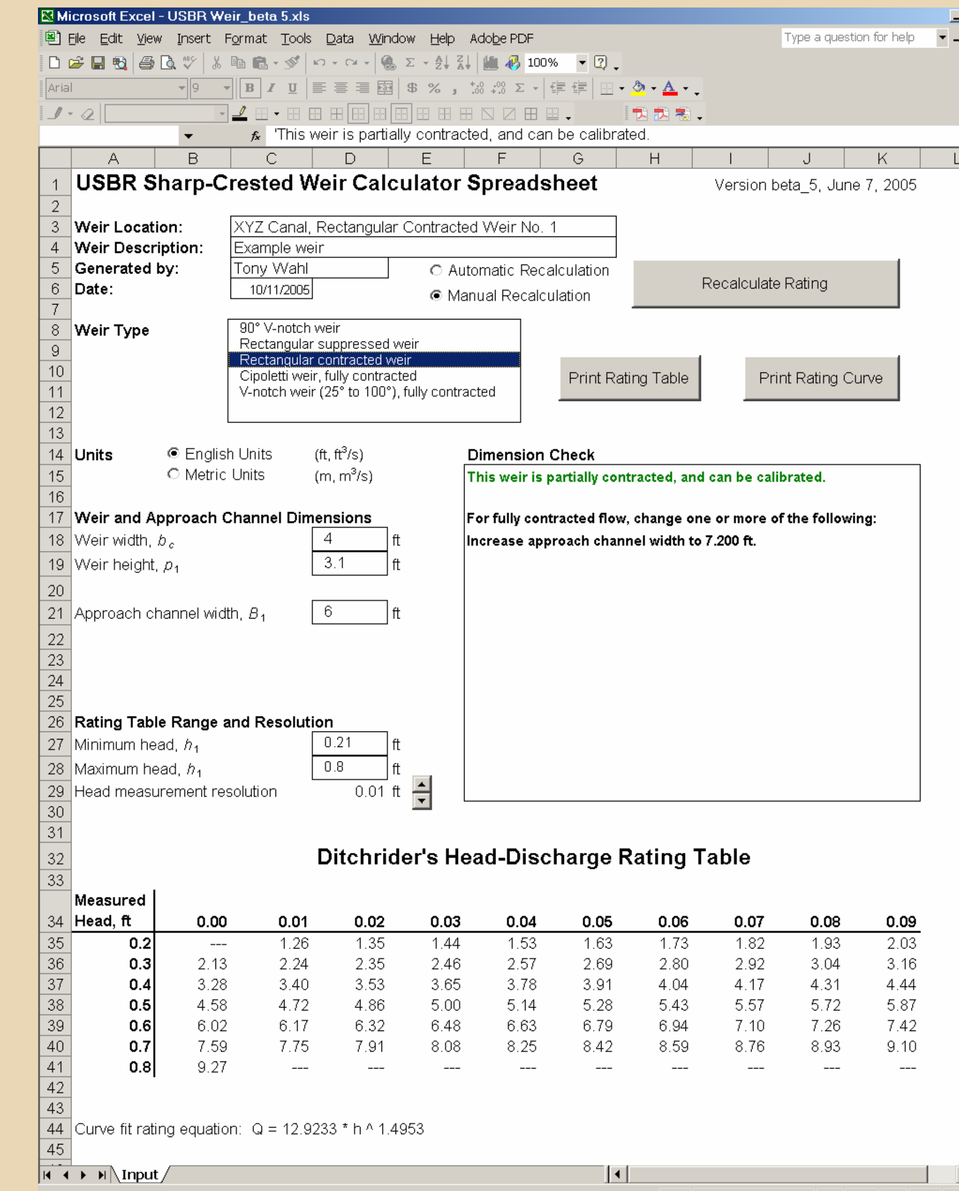
The first three types of weirs can be calibrated for either fully or partially contracted flow (Kindsvater and Carter 1957). The last two can only calibrated for fully contracted flow. Although Cipoletti weirs are not addressed by the Kindsvater-Carter procedure, the spreadsheet does adjust Cipoletti weir calibrations for velocity of approach using a procedure described by Bos (1989). V-notch weirs with included angles other than 90° can only be calibrated in fully contracted conditions, because there is little laboratory data on partially contracted flow through these weirs.

Use of the Spreadsheet

The user chooses the weir type and enters basic weir and approach channel dimensions into the spreadsheet, along with the expected range of operating heads. After each entry is made, the spreadsheet determines whether the weir can be calibrated, and whether it is fully or partially contracted. The user is given suggestions to assist them in achieving a design that can be calibrated.

Once the dimensions are entered, the rating table can be generated by clicking the **Recalculate Rating** button. The spreadsheet also uses the rating table data to generate a power-curve type rating equation by regression analysis. The rating tables, rating curves and rating equation can all be printed easily.

Unlike typical compiled stand-alone applications, the working parts of a spreadsheet model are usually fully accessible to the user. To prevent accidental modification of its computational algorithms, the spreadsheet has been protected using standard security features in Microsoft® Excel. A complete description of the procedure used to apply this protection is given in the paper included in the conference proceedings.


Microsoft Excel - USBR Weir_beta 5.xls

'This weir is partially contracted, and can be calibrated.

USBR Sharp-Crested Weir Calculator Spreadsheet Version beta_5, June 7, 2005

Weir Location: XYZ Canal, Rectangular Contracted Weir No. 1
Weir Description: Example weir
Generated by: Tony Wahl
Date: 10/11/2005

Automatic Recalculation / Manual Recalculation — Recalculate Rating

Weir Type
90° V-notch weir
Rectangular suppressed weir
Rectangular contracted weir
Cipoletti weir, fully contracted
V-notch weir (25° to 100°), fully contracted

Print Rating Table — Print Rating Curve

Units English Units (ft, ft³/s) / Metric Units (m, m³/s)

Dimension Check
This weir is partially contracted, and can be calibrated.
For fully contracted flow, change one or more of the following:
Increase approach channel width to 7.200 ft.

Weir and Approach Channel Dimensions
Weir width, b_c: 4 ft
Weir height, p_1: 3.1 ft
Approach channel width, B_1: 6 ft

Rating Table Range and Resolution
Minimum head, h_1: 0.21 ft
Maximum head, h_1: 0.8 ft
Head measurement resolution: 0.01 ft

Ditchrider's Head-Discharge Rating Table

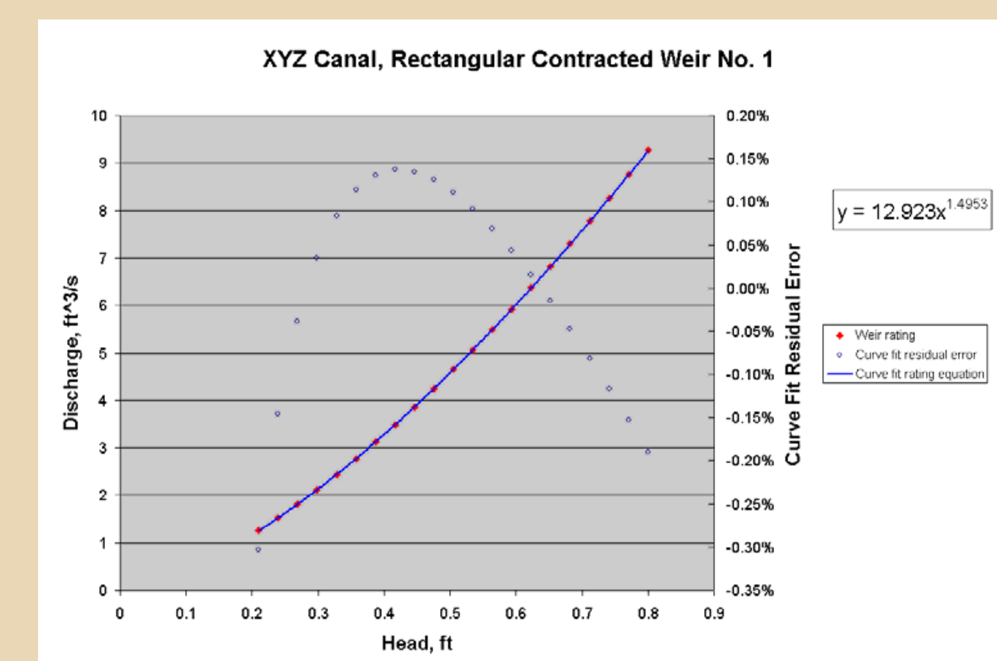
Measured Head, ft	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.2	---	1.26	1.35	1.44	1.53	1.63	1.73	1.82	1.93	2.03
0.3	2.13	2.24	2.35	2.46	2.57	2.69	2.80	2.92	3.04	3.16
0.4	3.28	3.40	3.53	3.65	3.78	3.91	4.04	4.17	4.31	4.44
0.5	4.58	4.72	4.86	5.00	5.14	5.28	5.43	5.57	5.72	5.87
0.6	6.02	6.17	6.32	6.48	6.63	6.79	6.94	7.10	7.26	7.42
0.7	7.59	7.75	7.91	8.08	8.25	8.42	8.59	8.76	8.93	9.10
0.8	9.27	---	---	---	---	---	---	---	---	---

Curve fit rating equation: Q = 12.9233 * h ^ 1.4953

Input

Ready

USBRWeir.xls spreadsheet



Typical Rating Curve Developed with USBRWeir.xls

This rating curve can be used directly in the field, or flows can be computed by a SCADA system using the regression equation shown in the upper right corner of the chart.

Obtaining the Spreadsheet

The USBRWeir.xls spreadsheet is freely available to the public from the Bureau of Reclamation's Water Resources Research Laboratory through our web site, at

http://www.usbr.gov/pmts/hydraulics_lab/usbrweir/index.html

USCID Conference on SCADA and Related Technologies for Irrigation District Modernization
October 26-29, 2005 — Vancouver, Washington