Methods for Collection of Rating Curve Calibration Points

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Background:

Rating curve calibration points are taken at the small watershed stream gaging stations at the H. J. Andrews Experimental Forest. These calibration points are collections of stream stage height values with an associated discharge calculated for each point. Calibration points are used to build rating curves or check existing curves for each watershed. Rating curves translate stream stage height to discharge. Beginning in water year 1997 a program to systematically collect calibration points was initiated. Stream stage height, flume area and velocity measurements are used to calculate stream discharge for each calibration point.

Four methods for calculating discharge were used. The method selected was determined by several factors. These factors were:

> Flume/weir type, stream stage, number of velocity measurements taken, and location of measurements within the stream channel or flume.

U.S.G.S. Method:

The USGS method is a version of the current-meter method of measuring discharge as described in "Measurement and Computation of Streamflow: Volume1. Measurement of Stage and Discharge" (Rantz, S. E., Geological Survey Water-Supply Paper 2175, 1982, pg. 79 –183) for measurements of discharge in irregular shaped channels.

The width of the sampled stream cross-section is measured. Water depth, and velocity measurements are taken at measured intervals along the cross-section. Velocity measurements are taken at .6 of the water depth at each sample point using a top-setting wading rod and Model 200 Flo-Mate velocity meter.

Areas (Width X Depth) for each velocity measurement point are calculated by averaging the depths of the previous, current, and following sample points. The width is the sum of 1/2 the distance between the previous point and 1/2 the distance to the following point. Discharge (Velocity X Area) are calculated for each velocity sampling point and then summed to calculate total discharge for the stream.

This method was used when measurements were taken in irregular shaped sections of the stream channels, and measurements taken in "H" style flumes (WS's #6 & #7).

This method was altered for 4 points taken on the Mack Creek flume in 1994. In these cases, a velocity head rod was used instead of a velocity meter. 3 of these 4 points were later discarded and not used in the rating curve because the flow was deemed too high.

Area Method:

The Area method was developed to accurately calculate areas within stable/fixed form trapezoidal flumes. It takes advantage of known dimensions and angles of the flumes and very accurate measurements of depth from hookgages. (Note that areas are calculated somewhat differently at Mack Creek due to the uneven nature - flattening of the slope - of the flume construction. This variation of the method is the cumulative slope method and is described below.)

The width of the sampled stream cross-section is measured using a tape. Velocity measurements and depths were taken at measured intervals across the section using a top-setting wading rod and Model 200 Flo-Mate velocity meter. All velocity measurements were taken at 0.6 of the water depth. Hookgage measurements were taken before and after the velocity measurements.

Areas are not calculated for each velocity sample point, but instead are calculated for 5 distinct zones within the flume trapezoid in which the sample points are located singly or as a group. Two of the zones are "edge" zones. These zones are the small triangular areas on each side of the flume in which the first and last sampling points occur. Velocities within these zones tend to be significantly lower than the other zones. The width of the edge zone is the distance from the edge of the water to the velocity sample point plus 1/2 the distance to the following or previous sample point. The depth is calculated by dividing the width of the zone by the tangent of the flume side slope angle from vertical. The area is then calculated using the area formula for triangles ([W x D] /2).

Two of the remaining three zones are "intermediate slope" (IS) zones. IS zones are the areas covering the sloped sides of the flume between the edge zones and the edge of the level or flat bottom portion of the flume. Area calculation for IS zones are a 3 step process. First a width for the entire triangular area from the edge of water to the edge of the level/flat bottom section of the flume is calculated by multiplying the starting hookgage measurement by the tangent of the flume side slope angle from vertical. Next, using the calculated width and starting hookgage measurement for depth, area is calculated using the triangle area formula. Finally the area of the adjacent edge zone is subtracted from the calculated area to arrive at the area for the IS zone.

The final zone or "center" zone is the rectangular area above the level/flat bottom portion of the flume. The known or documented width of the level/flat bottom is multiplied by the median hookgage depth to calculate the area of the center zone.

Discharge for all zones are calculated by multiplying the area of the zone by the average of all velocity measurements taken within the zone. Discharges for each zone were summed to calculate total discharge thru the flume.

This method was used at sites with trapezoidal flumes with consistent side slope angles and known dimensions (WS's# 1, 2, 3, 6, 7, 8, 9 & 10), and an adequate distribution of velocity sampling points along the measurement cross-section.

Tangent angles used by site were:

30 degrees - WS# 6, 7, 8, 9 & 10

65 degrees - WS# 1, 2, & 3

Cumulative Slope Method:

The "Cumulative Slope" method is a version of the Area Method designed specifically for the trapezoidal flume at Mack Creek. Initial attempts to apply the Area method to the Mack Creek resulted in large differences between the measured and calculated cross-section widths. This indicated that the documented flume side slope angle was not correct. A precision survey of the sampled cross-section was done, and verified the documented angle was incorrect. The survey data showed that the side slope angle increased with increased distance away from the edge of the level/flat bottom of the flume.

Using the survey data a table of flume side slope angles for ranges of stream stage heights was developed to use in the Area Method of discharge calculations for Mack Creek. Each angle in the table is a mean of cumulative angles from both sides of the flume. Cumulative angles are defined as the calculated angle from measurements of cumulative change in elevation over a cumulative distance.

Table of Cumulative Angles by Stage for Mack Creek

Stage Range	Horz. Angle	Vert. Angle (Area Method)
0.000 - 0.491 ft.	14.04 degrees	75.96 degrees
0.492 - 0.714	13.77	76.23
0.715 - 0.923	13.13	76.87
0.924 - 1.144	13.12	76.88
1.145 - 1.368	13.08	76.92
1.369 - 1.593	13.03	76.97
1.594 - 1.816	12.99	77.01
1.817 - 2.031	12.91	77.09
2.032 - 2.244	12.89	77.11
2.245 - 2.471	12.86	77.14
2.472 - 2.500	10.45*	79.55*

*Side slopes change greatly from cumulative angle trends in this range. Recommend calculating discharge for area below 2.472 using table values then calculating area above 2.472 using table values. Add the two to get total area.

Average Method:

The "Average" method of discharge calculation is simply multiplying the average of all velocity measurements taken in the stream channel or flume by the total area of flow. This method was used when a good measure of area existed, but due to the location, configuration, or number of velocity measurements the alternative methods could not be used.

Velocities were taken at varied positions and depths using velocity meters mounted on a top-setting wading rod or hand held wand. Two Model 200 Flo-Mate velocity meters with top-setting wading rods were purchased and used beginning October 1996.

(Note that areas are calculated somewhat differently at Mack Creek due to the uneven nature - flattening of the slope - of the flume construction. This variation of the method is the cumulative slope method and is described under the AREA method.)

Bucket Method:

The "Bucket" method of discharge calculation is the process of measuring the time to fill a container of known volume. This is repeated 3 times. The times are then averaged and divided into the volume of the container to produce a per second discharge rate.

This method was used mostly during the low flow periods at sites where water depths did not allow use of a velocity meter, and had a physical configuration such that allowed for a good catch of the flow in a container. This method was also used at sites where v-notch weir plates were used, since attempts at using a velocity meter for measuring discharge provided inconsistent results when compared to the bucket method.

Difference Discharge Method:

The Difference Discharge method was used to develop a discharge rating curve for the fish ladder weir located at the Mack Creek gaging station where other methods of discharge measurement were not possible or provided inconsistent results.

The Difference Discharge method uses the change in discharge in the trapezoidal (main) flume of Mack Creek as the flow gate to the fish ladder is opened and adjusted as the discharge for the fish ladder.

The method begins with the flow gate to the fish ladder closed, so no water is entering the fish ladder weir. The stage of the (main) flume is recorded, and discharge calculated from existing equations for the main flume. The flow gate to the fish ladder is then opened, and after a period of flow stabilization the stage of the fish ladder and main flume are recorded. Using the existing equations the after opening discharge for the main flume is calculated, and subtracted from the before opening value. The difference in the before and after discharges in the main flume is recorded as the discharge for the fish ladder weir (use with after-opening stage of the fish ladder).

To check the accuracy of this method velocity measurements were taken in the main flume before and after opening the fish ladder gate. Discharges for the main flume were calculated using the cumulative slope method, and compared to the discharge values from the existing equations.

Calculation Method:

Extra rating points for the v-notch were derived when the v-notch is removed/replaced by calculating flow using the main flume rating equations immediately preceding/following configuration change with the preceding/following v-notch stage height.

This method was only used for the early v-notch weirs used on WS 9 and 10 during the 1970s.

Derived Method:

Extra rating points for the main flume were derived from v-notch bucket points taken directly before/after the v-notch is removed/installed by using main flume gage height immediately preceding/following configuration change. The assumption here is that the streamflow represented by the bucket sample point does not change before the gage height can be read from the regular flume after v-notch removal (or has not changed since the installation of the v-notch). Also, after v-notch removal we assume the regular flume gage height has stabilized before being measured.

This method is only used at sites where a v-notch weir is removed or installed on a regular basis.

Velocity Head-Rod Method

The velocity head-rod method was used in the 1950s on HJA WS 1, 2 and 3 to build rating tables for these watersheds. These rating tables related stream stage height based on direct flume measurement to the calculated discharge. Once hookgages were installed and adjusted, these rating tables were used to build rating curves based on stage height from the hookgages (See flume-hookgage method). The exception is the original flume at WS1 which was operative 1953-1956. This period is still represented by these original flume stage height-discharge points as there was no hookgage operative at this time.

The following excerpt on velocity-head rod measurements is from:
Wilm, H.G., & Storey, H.C., November 1944. Velocity-Head Rod Calibrated for Measuring Stream Flow, Civil Engineering, vol. 14 no. 11, page 475-476.

A dependable yet cheap and rugged measuring stick was developed several years ago at the San Dimas Experimental Forest, in Southern California, to facilitate the calculation of discharges from mountain streams. This device, which has been described in technical publications, is particularly useful in gaging small volumes of flow containing varying amounts of bed-load and silt. Measurement of these flows is made continuously by weirs or measuring flumes, the calibration of which should occasionally be checked in place. The instrument is simple, portable, easy to construct and accurate within practical requirements. Its principle is not new, being simply an application of Bernoulli's theorem somewhat different from that employed in the Pitot tube.

In use, the rod is first placed in the water with its foot on the bottom and the sharp edge facing directly upstream. The stream depth at this point is indicated by the water elevation at the sharp edge, neglecting the slight ripple, or "bow wave." If the rod is now revolved 180 deg, so as to oppose the flat edge to the stream, a hydraulic jump will be formed by the obstruction to the flow of the stream. The average height of this jump measures the total energy content of the stream at this point; the jump height, minus the depth, equals the actual velocity head. Velocity can then be computed by the standard formula,

$$V = \text{sqrt}(2gh) = 8.02\ \text{sqrt}(h)$$

where, V = velocity, in ft. per sec
g = acceleration of gravity (taken as 32.16 feet per sec per sec)
h = velocity head, in ft.

The average discharge for the stream is obtained by taking a number of measurements of depth and velocity throughout its cross section.

In tranquil flow, the jump on the rod is very steady and can be read easily; in turbulent flow, on the other hand, it often fluctuates as much as 0.1 ft. or even more. This fluctuation may be explained by the fact that the column of water impacting on the rod has constantly varying contents of kinetic energy. At one instant, filaments of water may converge upon the rod; at another they may diverge. As indicated by Eq. 1, however, errors in reading give errors in percentage of discharge equal only to one-half the percentage reading error.

For low discharge rates, the flume had already shown satisfactory correspondence with a V-notch weir; the rod data agree within practical limits of error for higher rates of flow.

The rod has obvious limitations; it is inaccurate for velocities much below 1 ft. per sec, and for streams with soft, unstable beds, and it cannot be handled well in streams moving faster than 8 or 9 ft. per sec. It has, however, a very definite and considerable value as the only method usable within this range, where the streams to be measured contain debris and bed-load.

Flume-Hookgage Method:

Velocity measurements were taken with a velocity-head rod in the early years at WS 1, 2, 3 (1953-1958) in association with a direct stage height measurement in the flume. Rating tables were developed based on these measurements (See velocity head-rod method). After new hook gages were installed and properly adjusted, simultaneous direct flume and hook gage measurements (1957-1964) were collected. The original rating tables based on the direct stage height measured in the flume were used to determine discharge. New calibration points were generated using the hookgage stage height reading and discharge determined through these original rating tables from the corresponding flume reading. These generated calibration points were used to fit the long-standing rating curves used at WS 1, 2 and 3. The rating curves were originally generated in 1966 but applied to the entire record.

Dye Dilution Method:

The dye dilution method was used by Dennis Harr on both watershed 9 and 10 in the 1970s. These data points are used today in building rating curves for these watershed main flumes. The following description is excerpted from a Harr white paper:

Flume Calibration using the Dye Dilution Method
by R. Dennis Harr, Research Hydrologist
Forestry Sciences Laboratory
3200 Jefferson Way
Corvallis, Oregon 97331
Revised August 27, 1976
United States Department of Agriculture, Forest Service

Introduction:

The dye dilution technique may be used to calibrate stream gages such as the trapezoidal flumes at Watersheds 9 and 10. A dye solution -- in this case Rhodamine WT, a fluorescent dye -- of known concentration is injected at a constant rate upstream from the flume. The dilution of this dye solution is determined downstream after mixing of the dye has occurred.

Discharge is determined by:

Q=((N1-N2)/(N2-N0))*(i/c)

where Q = discharge (ft /sec)

- N1 = concentration of dye injected into the steam
- N2 = concentration of dye after dilution by streamflow
- N0 = concentration of dye upstream from injection point
- i = injection rate (ml/sec)
- c = constant to convert ml/sec to ft./sec (28,320)

Equipment:

The two major pieces of equipment used in the dye dilution technique are a constant rate dye injection apparatus and a fluorometer. The injection apparatus, shown in figure 1, (see pg. 1a), consists of a sealed tank equipped with an air vent and a nozzle. Using the principle of a Mariotte vessel, the tank injects dye at a constant rate that is proportional to the temperature of the dye solution (see table 1, pg. 1a). The tank is suspended from a tripod erected over the point of injection.

Initial and diluted dye concentrations are determined with a Turner Model III fluorometer. Standard dilutions are used to prepare smaples whose fluorescent properties will be within the measurement range of the flu9ormenter. Because the fluorometer can detect dye in extremely low concentrations, all glassware and other equipment used in sample collection, dilution and fluorometry must be thoroughly clean.

Titles of tables, figures, and procedures: