Andrews Forest Streamflow Calculation and Rating Curve Summary

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Contents:

I. Steps involved in transforming raw streamflow data into discharge data

A. Raw gage height data are summarized using a computer program that identifies "key (turning) points" that is, points where the slope or trajectory of streamflow height changes. This program is analogous to the process of hand digitizing in which these key points are identified. A critical aspect of this approach is that the gage height data summaries are a set of points spaced irregularly in time, i.e. more points for periods of more rapid change such as during storms or during wet periods.
B. The data summaries are corrected by a program that adjusts measured gage height to be consistent with a set of concurrent, independent observations from the hook gages located adjacent to each gage house. When hook gages are not installed, direct measurement of gage height is made in the flume with a rule.
C. The corrected gage heights are converted to discharge using rating curves.
D. If discharge data are desired for a particular period (e.g. hourly, 15 minute, etc.), discharges from these time periods are determined by interpolating between the key stage height points and re-converted to discharge using the rating curves. This process is now handled interactively on the web-based FLOW program (first launched 18 Nov 2002).

II. Summary of history and current status of rating curves, by gage

A. Background on rating curves

1. A rating curve is developed for every flume within the Andrews Forest. Changes in the flume configuration require a change in the rating curve. Typically a rating curve is a single log-linear equation or multiple piecewise log-linear equations that each operate over a specified water depth interval. The equation form is a power curve:

$$Y = a\, b^{x} \quad \text{or} \quad \ln y = \ln a + b \ln x$$

(where y= flow as cfs and x = stage height in ft.

2. Each rating curve is fitted to a set of calibration points. The calibration points relate a specific stage height (either measured using a hook gage in a stilling well, or directly measured with a rule in the flume) to a determined measure of streamflow (calculated from velocity). Some of the early flumes (e.g. pre-built H-flumes installed at WS 6,7,8,9,10) came with a manufacturer's rating curve; the concrete trapezoidal flumes in use today at all Andrews gages and all of the v-notches installed in summer have required the development of custom-built rating equations.

3. The technology for taking calibration points, and hence, possibly, their accuracy and precision, has changed over time at the Andrews. Calibration points consist of synchronous measures of stage height and velocity. These measurements were taken by a velocity-head rod in the early years (1953-1973). While hook gages had been installed, only the flume measurements had been recorded with velocity measurements from 1953-1957. The dye dilution method was used to develop the WS 9 & 10 trapezoidal flume rating curves from 1975-1977. In more recent years (1983-present) velocity measurements have been taken with a velocity meter. Volumetric or "bucket" samples have also been used to measure velocity during low flows since 1973 for the calibration of the v-notch weirs.

4. The technology for fitting curves also has changed over time. In the early days (prior to computerized statistical packages) curves were fitted by eye and rating tables were developed (WS 1, 2, and 3). Subsequently curves have been fitted using regression techniques, typically with a log-linear or piecewise log-linear function. However, in some cases other functional forms were used (e.g. a reverse sigmoidal (cubic) curve for Watersheds 9 and 10 in the 1970s). Piecewise functions have been used to account for bends in an otherwise straight log-linear relationship inferred from the calibration points; some rating curves have as many as seven segments (e.g., WS1). Rating curves for all Andrews flumes are now in log-linear or piecewise log-linear functional form (Dec 2002). The USGS- maintained Lookout Creek gauge is still calibrated with surveys of cross-sectional channel area and velocity and streamflow is calculated with rating tables.

B. Rating curve history and status

1. Watersheds 1, 2 and 3. Rating curves for these basins were developed based on velocity-head rod measurements taken in the 1950s. The original data points for these exist, but it is not clear which points were used to fit the original curves. It is clear that early rating tables were developed and based on flume measurements. In the 1960's, the USFS in Portland replaced the rating tables with rating equations based on hook gage measurements, and these curves are still in use.
    a. The original flume for WS 1 was replaced in 1956. The curve used to calculate discharge for WS 1 (1953-1956) was based on the early rating table derived from flume measurements and velocity-head rod points.
    b. Watershed 3 has two periods in which no hook gage data are available to correct the discharge data (step I.B. above), and data are corrected to flume measurements: these are Nov 1964 to Sept 1966 and Oct 1996 to October 1998 (the hook gages were destroyed by the floods). Post 1964 flood streamflow is calculated with a rating curve of unknown origin, but based on flume (rather than hook gage) measurements. Post 1996 streamflow has been calculated with the original hook gage-based equations to date.
    c. V-notch weirs in Watersheds 1, 2, 3 have been in place since July, 1999 with curves based on volumetric samples.

2. Watersheds 6, 7, and 8. These basins were originally instrumented with purchased H-flumes, and the accompanying manufacturer's rating curves were used without any attempt at validation. The H-flume at Watershed 8 was replaced with a trapezoidal flume in 1988. During the 1990s questions about

the accuracy of the H-flume rating curves led to calibration measurements being taken at Watersheds 6 and 7 in 1996-1997 prior to the removal of the H-flumes and their replacement with trapezoidal flumes in 1998.

a. These original manufacturer rating curves used for the 1963-1997 periods can still be validated at Watersheds 6 (18 calibration points) and 7 (22 calibration points). Overlay of these points on the manufacturer's curve indicates that high and low discharges may be being overestimated at WS 6, and low discharges may be being underestimated at WS 7.
b. Since the installation of the trapezoidal flumes, rating curves have been developed based on velocity meter calibration points (22 at WS 6, 19 at WS 7, and 27 at WS 8).
c. V-notch weirs in Watersheds 6, 7, and 8 have been in place since 1997 (WS 8) or 1998 (WS 6 and 7) with curves based on volumetric samples.

3. Watersheds 9 and 10. Like WS 6, 7, and 8, these basins were originally instrumented with purchased H-flumes, and the accompanying manufacturer's rating curves were used without any attempt at validation from 1968 to August of 1973, when they were replaced with trapezoidal flumes.
   a. The rating curves for the trapezoidal flumes were originally based upon a reverse sigmoidal (cubic) curve, and were used until December 2002. The calibration points were collected with a dye dilution method and obtained between Nov 1975 and Dec 1977. Additional calibration points were obtained from 1996 to 1999, and the overlay of these points on the cubic rating curve indicated that low discharges in Watersheds 9 and 10 were being greatly underestimated, and apparently peak flows were over-estimated. Consequently, the rating curves for WS 9 and 10 were redeveloped in December 2002 and based on the dye dilution and velocity meter calibration points in log-linear form.
   b. V-notch weirs in Watersheds 9 and 10 were originally in place in summers 1973 to 1979. Calibration points were collected (volumetric samples) for the early v-notch at both watersheds. For unknown reasons, the rating curve developed for Watershed 10 was used for both Watershed 9 and 10, and the WS 9 calibration points were never used. In 2002, the original WS 9 volumetric sampling points were combined with derived points (based on calculated flows from the new regular flume equation at times when the v-notch was added or removed) and a new curve developed.
   c. V-notch weirs in Watersheds 9 and 10 have been in place since 1997 with curves based on volumetric samples.

4. Mack Creek. Mack Creek was instrumented with a trapezoidal flume in 1980. At present, the discharge record is calculated from a piecewise log-linear rating curve based upon 52 calibration points collected between 1983 and 2002.
   a. Earlier versions of this rating curve were developed in 1994 and 2001. Data made available before 1994 had been run using a linear curve and are now invalid.
   b. In 1996, when the Mack culvert was removed and replaced with a bridge, a fish ladder was added to the Mack Gage. The rating curve for the fish ladder's compound weir (there is a rectangular cross-section above a v-notch) was originally derived using theoretical relationships. The fish ladder rating equations were recreated with additional rating points in 2001.

III. HJA Flume Rating Curve Summary – April 2006 Update

WS	Eqn. Set	Years	Description	Status
1	A	1953-1956	Original trapezoidal flume (18" floor) - Damaged and replaced in 1956	Rating curve based on a rating table developed from flume measurement calibration points with velocity-head rod method
1	B	1956-Present	Rebuilt trapezoidal flume (9" floor)	Exact set of points used to fit curve unknown. Low flows may be over-estimated. Consider building new curve.
1	C	1999-Present (summers only)	Trapezoidal flume with v-notch	Curve based on volumetric sampling points
2	A	1953-Present	Trapezoidal flume	Exact set of points used to fit curve unknown.
2	B	1999-Present (summers only)	Trapezoidal flume with v-notch	Curve based on volumetric sampling points
3	A	1953-Present	Trapezoidal flume	Exact set of points used to fit curve unknown. Low flows may be over-estimated. Consider building new curve.
3	A	Post-1996 flood	Trapezoidal flume -channel changes may alter existing curve	Original hook gage-based equations still used. Consider building new curve
3	B	Post-1964 flood (1+ year)	Same flume with only flume measurements and no hook gage measures	Curve origin unknown, but is based on flume measurements –used because no hook gage
3	C	1999-Present (summers only)	Trapezoidal flume with v-notch	Curve based on volumetric sampling points
6	A	1964-1997	Factory H-flume	Manufacturer's equation used
6	B	1998-Present	Trapezoidal flume	Curve based on velocity meter sampling points
6	C	1998-Present (summers only)	Trapezoidal flume with v-notch	Curve based on volumetric sampling points
7	A	1964-1997	Factory H-flume	Manufacturer's equation used
7	B	1998-Present	Trapezoidal flume	Curve based on velocity meter sampling points
7	C	1998-Present (summers only)	Trapezoidal flume with v-notch	Curve based on volumetric sampling points
8	A	1964-1987	Factory H-flume	Manufacturer's equation used
8	B	1988-Present	Trapezoidal flume	Curve based on velocity meter sampling points
8	C	1997-Present (summers only)	Trapezoidal flume with v-notch	Curve based on volumetric sampling points
9	A	1969-1973	Factory H-flume	Manufacturer's equation used
9	B	1973-1979 (summers only)	Trapezoidal flume with v-notch (early style)	Curve based on volumetric sampling and derived points
9	C	1973-Present	Trapezoidal flume	Curve based on dye-dilution and velocity meter sampling points
9	D	1997-Present (summers only)	Trapezoidal flume with v-notch	Curve based on volumetric sampling points
10	A	1969-1973	Factory H-flume	Manufacturer's equation used
10	B	1973-1979 (summers only)	Trapezoidal flume with v-notch (early style)	Curve based on volumetric sampling and derived points
10	C	1973-Present	Trapezoidal flume	Curve based on dye-dilution and velocity meter sampling points
10	D	1997-Present (summers only)	Trapezoidal flume with v-notch	Curve based on volumetric sampling points
Mack Main	A	1980-Present	Trapezoidal flume	Curve based on velocity meter sampling points
Mack Fish	A	1996-Present	Compound weir: V-notch w/ rectangular section above	Curve based on volumetric sampling points and theoretical points (rectangular section)