Development of a Discharge-Stage Rating Curve for Strawberry Creek
Lisa Hunt

LA 222 Term Project
Lisa Hunt
May 16, 2011

Abstract

I developed a hydrological rating curve for Strawberry Creek on the University California campus, so that estimated flow rates could be calculated from stage records. Since 2007, water stage levels have been automatically recorded every 15 minutes based on pressure transducers that are located on the North Fork, the South Fork, and on the Main Stem just below the confluence. I used current meters to collect flow measurements six times on the Main Stem, five times on the North Fork, and four times on the South Fork and used these data along with recorded stage data to develop a rating curve for each location. The rating curves developed for the Main Stem, South Fork and North Fork are: $y = 9.5668x^{2.7479}$, $y = 34.061x - 273.35$, and $y = 15.498x^2 - 19.768x + 6.2605$, where y is streamflow in cubic feet per second (ft^3/s) and x is stage in feet. All these rating curves have very good overall correlations for the relationship between stage and flow (r^2 greater than 0.92), and therefore are likely to provide reasonably accurate flow estimates for most all but the highest flow levels. A considerable amount of uncertainty exists for the high flow estimates on the Main Stem and the North Fork. This uncertainty may be due to limited data for high flows, error in flow measurements, unsteady flow conditions, extrapolation to higher flows rates than those measured, and/or stage shift where the pressure transducers are located. The main sources of uncertainty are likely to be the unsteady flow conditions (due to rapid rate of change in flow) and potential stage shift due to erosion and/or deposition. The rating curve equations are sufficient for rough estimates at high flows, but would be improved with additional data collection.

Development of a Discharge-Stage Rating Curve for Strawberry Creek
Lisa Hunt

Introduction

Strawberry Creek runs through the campus of the University of California at Berkeley and has been used for educational and research purposes for many decades. Several classes, including Introduction to Environmental Science (Environmental Sciences 10), Hydrology for Planners (Landscape Architecture 222) and Fish Ecology (Environmental Science, Policy and Management 115C) include Strawberry Creek in field exercises and research projects. A student led class (Environmental Science, Policy and Management 98/198) focuses on restoration of Strawberry Creek. In 2006, the UC Berkeley Environmental Health and Safety Department funded the installation of three automatic stage gauges in Strawberry Creek. These gauges have recorded water level in 15 minute intervals since 2007. However, there was not sufficient funding to develop the relationships necessary so that the stage measurements could be used to estimate flow rates.

The purpose of my project was to develop those relationships, termed rating curves, so that the recorded stage data could be used to estimate flow rates for various research projects where streamflow data on Strawberry Creek would be useful. A rating curve is an equation that expresses the relationship between the discharge of a stream and the water level (stage or water surface elevation) at a given location. The stage measurements recorded by instream instrumentation are relative to the depth of the sensor rather than the actual water depth; the critical feature is the change that occurs with changing streamflow. Rating curves are intended to provide the best-fit relationship for the stage and streamflow data collected during the study period.

Materials and Methods

Study Location

The headwaters of Strawberry Creek are located above the University of California, Berkeley campus and the watershed drains an area of 1,977 acres, with 1,163 acres under the jurisdiction of the university (University of California, Berkeley 2006). The two forks (North Fork and South Fork) converge at the Eucalyptus Grove in the Grinnell Nature Area on the central campus (Charbonneau and Resh 1992; Charbonneau 1987; Figure 1). This study was conducted in three locations on the central campus (Figure 1): one on the Main Stem just downstream of the confluence (Figure 2), one on the South Fork (Figure 3), and one on the North Fork (Figure 4). The South Fork has a subwatershed of 759 acres and the North Fork has a subwatershed of 388 acres (Charbonneau 1987). Stormwater routing, culverts, and channel confinement have altered the natural drainage courses, and the watershed is approximately 40% urbanized (Charbonneau 1987). The upper canyon portion of the watershed is primarily undeveloped (Charbonneau 1987). Flashiness has increased with urbanization, and the lag time between peak rainfall and peak discharge is approximately 15 minutes for the North Fork and 25 minutes for the South Fork, both about 3 times faster than expected under natural conditions (Charbonneau 1987).

Mediterranean climate streams such as Strawberry Creek are characterized by distinct seasonal patterns in precipitation and annual cycles consisting of floods during the wet season followed by reduction in flows, creation of fragmented pools, and sometimes drying of the stream bed during the dry season (Gasith and Resh 1999). In Strawberry

Creek, streamflow is highly seasonal; high flows correspond with rainfall that occurs primarily from October to March (Charbonneau 1987).

Streamflow Measurements

I collected data for this study at all three sites during February to April 2011, targeting a range of stage levels to represent various conditions. For each reach I selected a cross section based on uniformity of flow, and divided it into intervals of approximately one foot. I took velocity and depth measurements at the midpoint of .each interval. Velocity was measured at six tenths of the distance from the water surface to the bed using either a standard (high flow) or pygmy (low flow) current meter. In cases where I could not measure velocity at a depth of six tenths due to obstruction of shallow flow, I measured velocity at the surface and used a correction factor of 0.8 to estimate depth-averaged velocity. Velocity at each point was measured for approximately 60 seconds. Discharge for each interval was calculated by multiplying velocity by depth by interval width, and values for all intervals were summed to obtain total discharge.

Stage Measurements

Electronically recorded stage measurements at the same three sites were obtained from Balance Hydrologics, of Berkeley, California, the consulting firm that installed and maintains the stage gauges. These recorded measurements based on pressure transducers are different than the stage measurements obtained visually from the staff plates at the sites. For each location there are two pressure transducers and hence two stage values. The most recent data can be viewed at Balance Hydrologics' website:

http://www.balancehydro.com/onlinegaging.php. Both values were always identical except for the North Fork; in the case of the North Fork I always used the first reported value.

Rating Curve

For each site I plotted the measured flow rates against the recorded stage values in MS Excel and experimented to find the best-fitting curve using trend lines in Excel.

Results

I measured streamflow 6 times on the Main Stem, 5 times on the North Fork, and 4 times on the South Fork. I also attempted to collect streamflow data an additional time on March 24, when stage was very high, but was unable to due to equipment problems, and because the water level came above my hip waders and conditions were dangerous.

Main Stem

For the Main Stem, there were a total of six data points (Table 1). I found the best fit using the power function in Excel (Figure 5A), with a very good correlation for the rating curve equation (r^2 value of 0.92). The lower values appear the fit the curve best, while the two highest values are further off the curve. The equation of best fit (highest r^2) is:

$$y = 9.5668x^{2.7479}$$

where y is streamflow in ft^3/s and x is stage in feet.

South Fork

For the South Fork, there were a total of four data points. I found the best fit using the linear function in Excel (Figure 5B). There was a very good correlation for the rating curve equation, with an R^2 value of 0.95. The lower values appear the fit the line best, while the two highest values are further off. The equation of best fit is:

$$y = 34.061x - 273.35$$

where y is streamflow in ft^3/s and x is stage in feet.

North Fork

For the North Fork, there were a total of five data points. I found the best fit using the polynomial function in Excel (Figure 5C). There was a very good correlation for the rating curve equation, with an R^2 value of 0.99. Unlike the other two rating curves, there appears to be more variation from the curve for the lower flow values. The equation of best fit is:

$$y = 15.498x^2 - 19.768x + 6.2605$$

where y is streamflow in ft^3/s and x is stage in feet.

Discussion and Conclusions

For both the South Fork and the Main Stem, there appears to be error and/or stage shift for the higher flows. For the South Fork, the two highest data points had recorded stage values that were exactly the same (8.43 ft), but the measured flow differed by almost 4 ft^3/s (Figure 5B). For the Main Stem, the two highest data points had measured flow values that were very similar, but recorded stage values that were very different (Figure 5A). Additional flow measurements at high stage would be helpful to reduce uncertainty in stage estimates at high flow. However, if the differences are due to stage shift and the streambed continues to shift over time, it may be difficult to accurately estimate the flow at high stage levels.

For the Main Stem, the stage values included in the data set ranged from 0.53 ft to 1.48 ft. Since the stage data have been recorded in 2007, the minimum stage recorded was 0.465 ft (2011) and the maximum was 2.909 ft (2010). As shown in Figure 6, the highest stage that occurred during water year 2011 was 2.657 ft. The highest stage value for which we measured flow in the Main Stem (1.59 ft) , which is higher than 99.8 percent of the stage values recording during this wet season (October 2010 – April 2011). Additional data at higher stages (greater than 1.59 ft in the Main Stem) would help to reduce uncertainty in extrapolating the curve to higher values. The low flow conditions appear to be well represented in the data collected for all three sites, and the data points fit the curves well, with the exception of the lowest flow data point for the North Fork.

Baldassarre and Mananari (2009) described common sources of uncertainty in discharge rating curves. They include: errors in stage and flow measurements; interpolation and extrapolation error; presence of unsteady flow conditions; and variations in roughness over time. Pelletier (1987) estimated that the uncertainty in a given flow measurement can vary from about 8 to 20 percent. Uncertainty in stage observations are usually small (about 1 to 2 cm) (Baldassarre and Mananari 2009). The uncertainty due to variations in river geometry is heavily dependent on the site-specific conditions (Baldassarre and Mananari 2009).

In the case of high flows in Strawberry Creek, I suspect that unsteady flows may contribute substantially to uncertainties in the rating curve. Because the time of concentration (time between peak precipitation and peak streamflow) is so short (about fifteen to thirty minutes), flow at a given location can change dramatically just during the ten to twenty minutes that is required to complete a flow measurement for the cross-section. This is illustrated by Figure 7 which depicts the stage levels before, during and after the first flow measurement on Feb 17, 2011, when the highest flow measurement was captured. The stage dropped considerably between the peak flow and fifteen minutes later when we collected the flow measurement. For the two next highest flow measurement on the Main Stem, the stage levels were changing at lower rates (Figures 8 and 9). The phenomenon is likely to be even more important on the North Fork and South Fork, where flows are flashier than on the Main Stem due to the smaller watershed sizes.

Another potential source of error at high flows results from problems due to inaccurate readings from the pressure transducers. This may result from non-uniform flow conditions, including conditions such as hydraulic jumps (J. Liquori, Sound Watersheds, personal communication, May 2011). If pressure transducers are recording correct measurements, the difference between the stage recorded by the pressure transducers and the stage read manually from the staff plate at the same location should always be the same, whether flows are high or low. I could not check this at the North Fork because I did not have access to the staff plate, but I compared measurements for the Main Stem and the South Fork under low flow and high flow conditions. For the Main Stem, the staff plate reading at 12:52pm on May 11, 2011 was 4.64 ft, and the pressure transducer reading was 0.50 ft, with a difference of 4.14 ft. On February 17, 2011at 1:54 pm, the staff plate reading was 5.30 ft. The pressure transducer reading was 1.59 ft at 1:45 pm and 1.48 at 2:00 pm; the interpolated value for 1:54pm is 1.52 ft, resulting in a difference of 3.78 ft, a bit lower than the low flow difference of 4.14 ft. For the South Fork, the staff plate reading at 12:40pm on May 11, 2011 was 7.92 ft, and the pressure transducer reading was 7.96 ft, with a difference of 0.04 ft. On February 17, 2011at 2:30 pm, the staff plate reading was 8.33 ft, and the pressure transducer reading was 8.55 ft, with a difference of 0.22 ft, a bit higher than the low flow difference of 0.04 ft. Therefore, it appears that error in the pressure transducer readings at high flows may be a significant source of error in the rating curves for these two locations. In the future, it would good to always record staff plate readings when taking flow measurements in order to evaluate the error in the automated data.

The rating curves presented in this paper provide reasonable estimates of flow rates based on stage data posted on the website. Additional data should be collected in future years to reduce uncertainty in the peak flow estimates and to evaluate stage shift. Attempts should be made to collect more data at high flows, although this is difficult given the very short time of concentration. At flows higher than a stage level of about 2 ft in the Main Stem (based on pressure transducer measurements reported on the website), alternative measurement collection methods should be considered as it may be dangerous to wade across the stream at high water levels (especially for a small person).

References

Charbonneau, R. 1987. Strawberry Creek Management Plan, Office of Environmental Health and Safety, University of California, Berkeley, California.

Charbonneau, R. and V.H. Resh. 1992. Strawberry Creek on the University of California, Berkeley campus: A case history of urban stream restoration. Aquatic Conservation: Marine and Freshwater Ecosystems. 2: 293-307.

Di Baldasarre, G. and A. Mantanari. 2009. Uncertainty in river discharge observations: a quatitative analysis. Hydrol. Earth Syst. Sci. 13: 913-921.

Gasith, A. and Resh, V.H. 1999. Streams in Mediterranean climate regions: abiotic influences and biotic responses to predictable seasonal events. Annu. Rev. Ecol. Syst. 30: 51-81.

Pelletier, M. P. 1987. Uncertainties in the determination of river discharge: a literature review, Can. J. Civ. Eng., 15, 834–850.

University of California, Berkeley Office of Environment, Health & Safety (EH&S). 2006. Strawberry Creek Water Quality 2006 Status Report.

Table 1. Streamflow Measurements and Recorded Stage

Main Stem

Date and Time	**Stage**	**Streamflow**
	feet	ft^3/s
2/25/11 14:47	0.79	5.69
2/25/11 15:04	0.78	4.90
2/17/11 13:45	1.59	23.05
3/26/11 12:28	1.16	22.62
4/1/11 13:45	0.62	3.06
4/14/11 0:00	0.53	1.18

South Fork

Date and Time	**Stage**	**Streamflow**
	feet	ft^3/s
2/25/11 14:20	8.14	3.83
2/17/11 13:00	8.43	11.96
3/26/11 13:15	8.43	15.59
4/1/11 13:43	8.05	0.77

North Fork

Date and Time	**Stage**	**Streamflow**
	feet	ft^3/s
2/25/11 14:00	0.86	1.00
2/17/11 13:54	1.38	8.44
3/26/11 12:00	1.16	4.03
4/1/11 13:00	0.89	1.12
4/14/11 12:00		0.11

Figure 1. Study Location and Measurement Sites

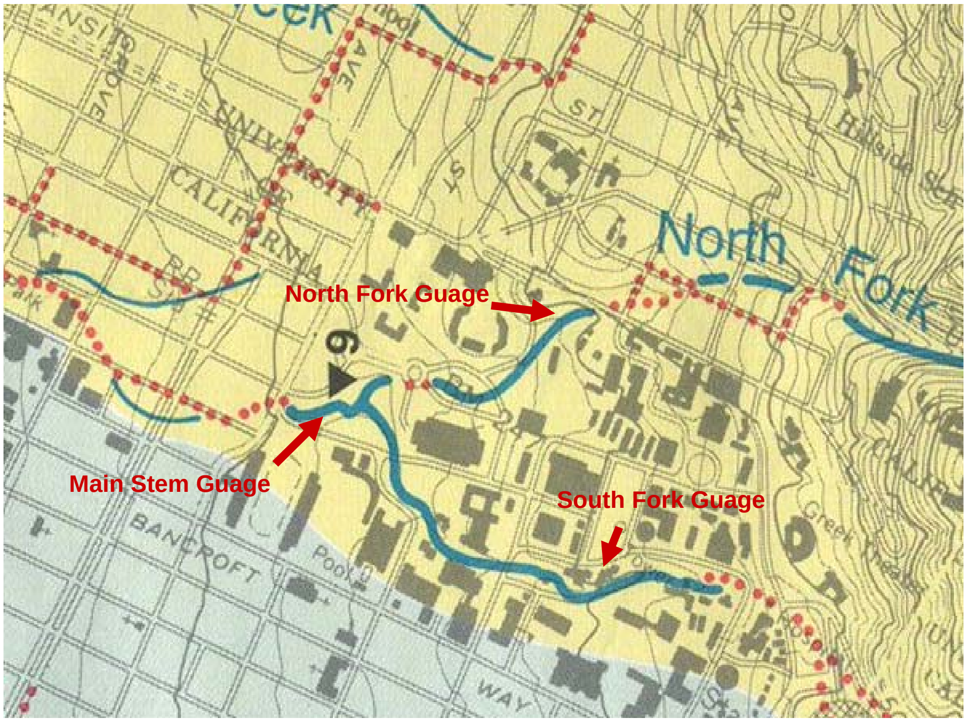
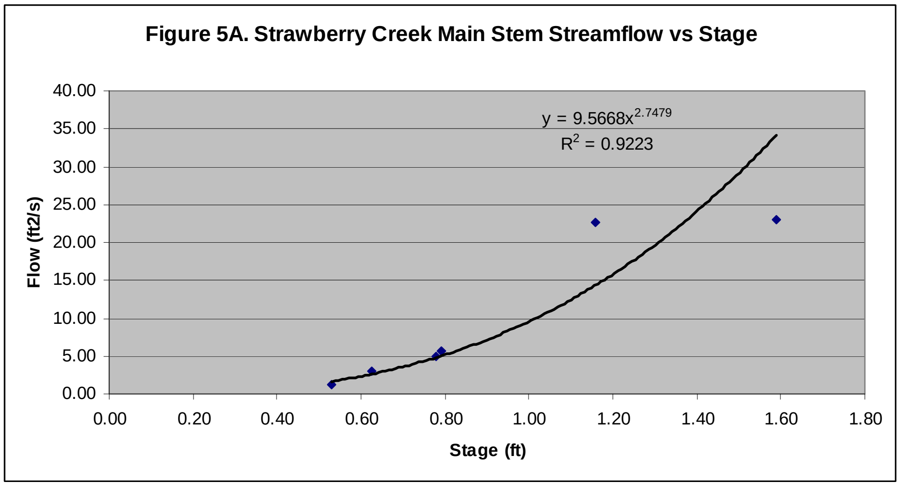


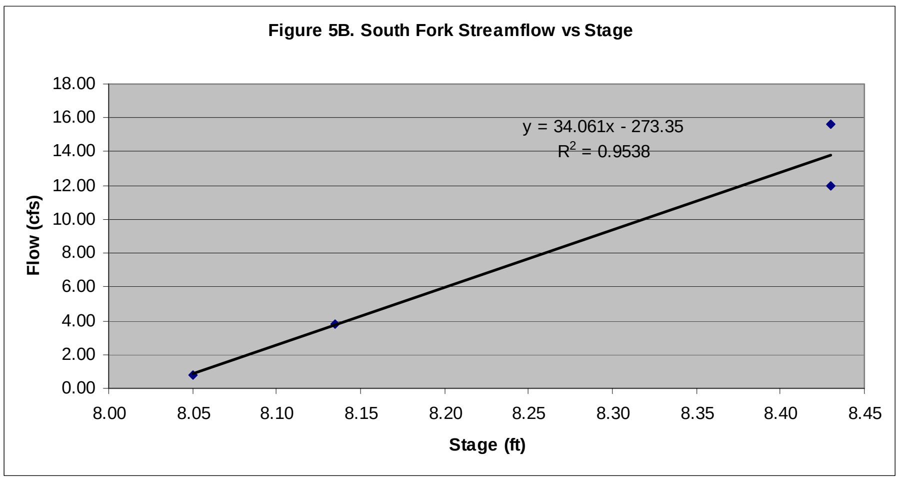
Figure 2. Main Stem Flow Measurement Location on February 17, 2011

Figure 3 South Fork Flow Measurement Location on February 17, 2011

Figure 4. North Fork Flow Measurement Location on February 17, 2011

Figure 5A-C. Rating Curves for main stem, south fork, and north fork of Strawberry Creek.





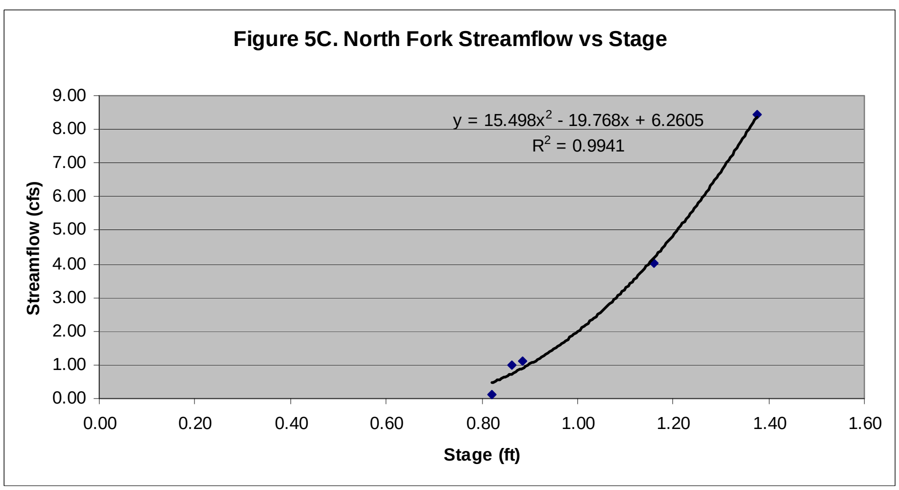


Figure 6. Main Stem Hydrograph and Flow Measurement Dates - Water Year 2011

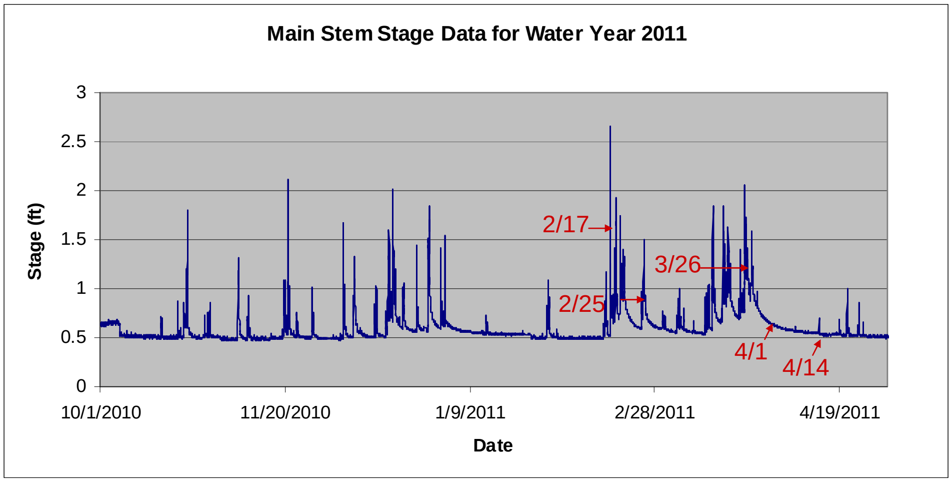


Figure 7. Main Stem Hydrograph Feb 17, 2011

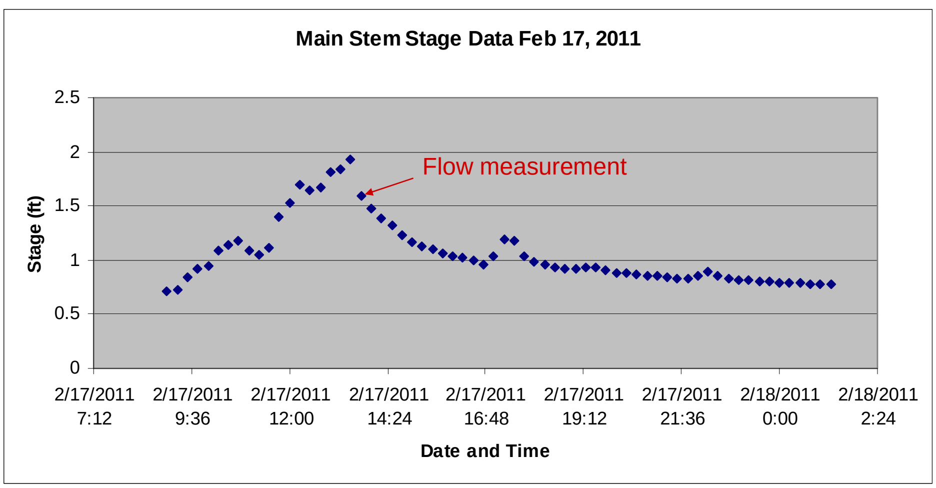


Figure 8. Main Stem Hydrograph Feb 25, 2011

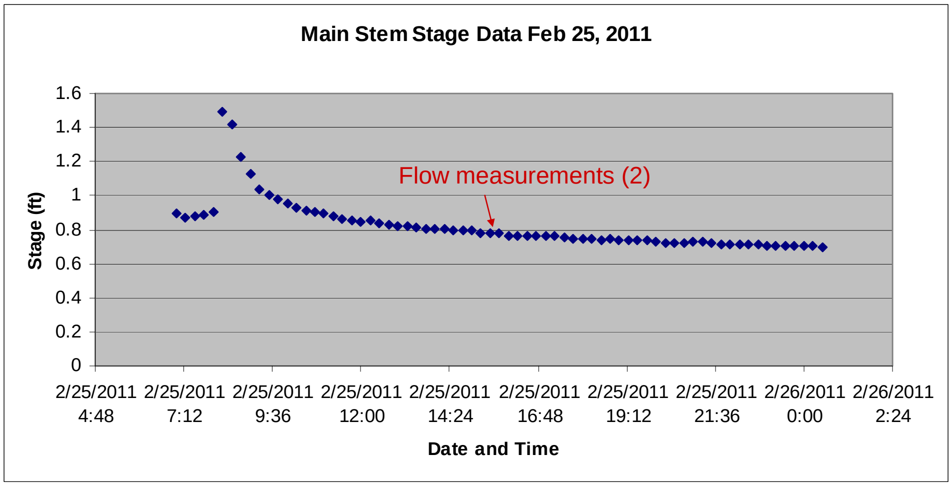


Figure 9. Main Stem Hydrograph March 26, 2011