Appendix D
Flow Calibration

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Abbreviations and Acronyms

cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
DMC	Delta-Mendota Canal
ft/s	feet per second
MP	mile post
psig	pounds per square inch, gauge

Appendix D
Flow Calibration

Flow through Newman Wasteway during the 2008 Pilot Study was monitored at the Easton Road Bridge (Mile Post [MP] 1.14 from the head gates) and the final siphon along the Wasteway (MP 6.88 from the head gates). This appendix presents the methods used to calibrate the flow monitoring equipment and discusses the operational obstacles to monitoring faced during the pilot study.

D1 Easton Road Bridge (Mile Post 1.14) Calibration

Flow rating at the Easton Road Bridge was based on the manual flow measurements that the San Luis & Delta Mendota Water Authority's hydrologist collected during previous years (Mark Walsh, personnel communication, 2008). The data were collected using a Marsh-McBirney electromagnetic flow meter mounted on a torpedo weight suspended from a bridge crane. Depth and velocity were recorded as the weight was placed in the stream at several regularly spaced horizontal and vertical intervals, and the results were integrated (multiplied by the corresponding area and summed) across the channel to calculate total flow. The data collected during the 2004 and 2007 pilot studies are listed in Table D-1.

Table D-1. MP 1.14 Flow Measurements by Mark Walsh

Date and Time	Torpedo Weight (lb)	Depth (ft)	Flow (cfs)
August 7, 2007,11:30	30	0.6	31.42
August 7, 2007, 15:00	30	1	87.32
August 30, 2004, 8:00	50	1.7	251.64

cfs = cubic feet per second
ft = foot or feet
lb = pound(s)

These data are plotted on Figure D-1.

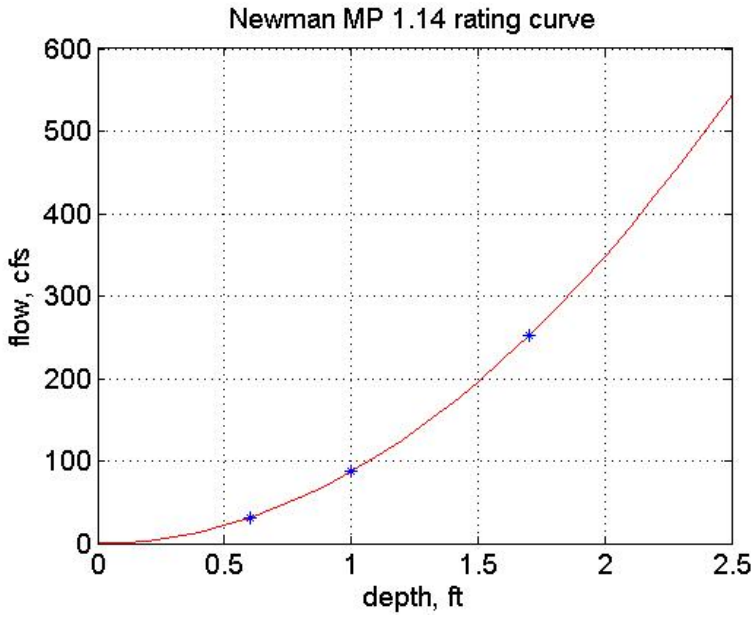

Figure D-1. Rating Curve Used for Mile Post 1.14
Asterisks represent measurement points; the curve represents a power-law fit.

The rating curve takes the form

$$flow(cfs) = 87.2247 \times depth(ft)^{1.9977} \quad \text{(D-1)}$$

D2 Easton Road Bridge (Mile Post 1.14) Flow Results

Due to issues related to debris, the high-resolution 5 pounds per square inch gauge (psig) pressure range In-Situ AquaTroll 200 pressure sensor deployed during the entire 2008 pilot study did not record trustworthy data. The sensor did not respond correctly to changing water levels, likely due to the mat of debris that accumulated on the sensor's upstream face, which caused the sensor to reside in an eddy with lower water surface than the surrounding flow. The streaming flow at this site prevented safe human entry into and debris removal from the sensor, so its data are considered corrupted and are not used in this report. However, between August 4, 2008, and August 11, 2008, a lower-resolution 15 psig pressure range Troll was deployed at the site, and this instrument recorded reliable data, as its deployment configuration did not result in the accumulation of much debris. Furthermore, because this instrument was deployed after the initial flush of debris down the Wasteway, it wasn't exposed to as much debris as the 5 psig Troll, which was deployed before flow was

initiated in the Wasteway. Using the rating curve from equation D-1, the resulting flow at MP 1.14 is shown on Figure D-2.

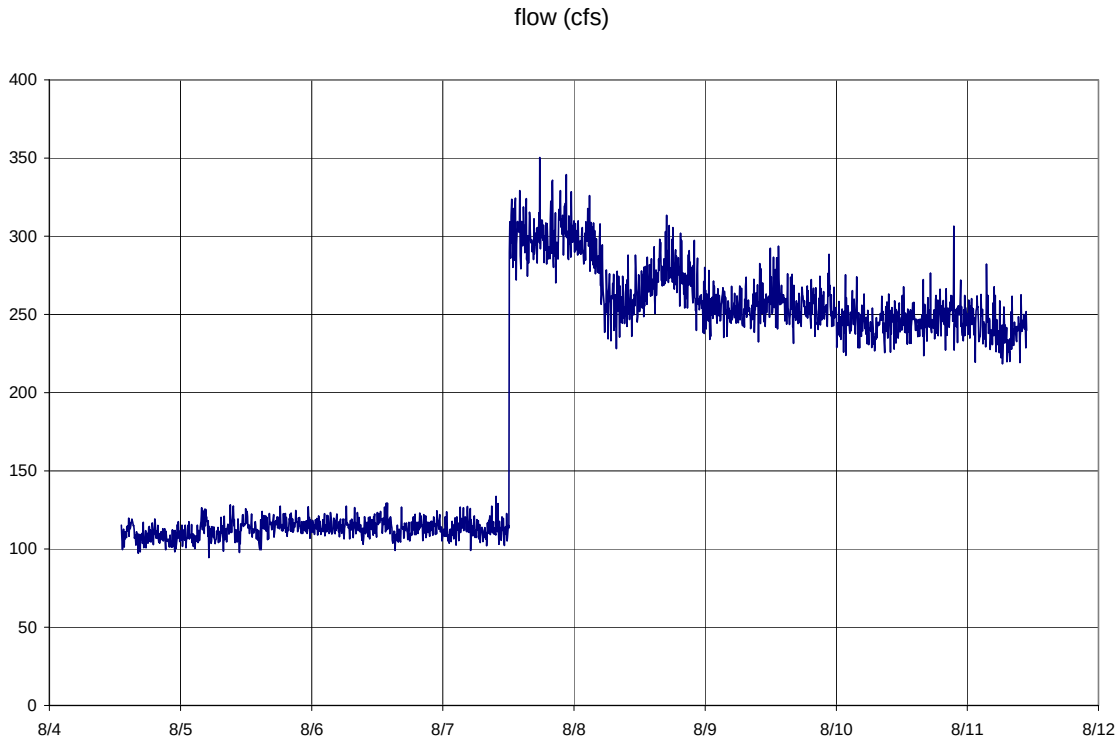

Figure D-2. Flow at Mile Post 1.14, as Recorded by the 15 psig Troll Pressure Sensor and Rated by Equation D-1

D3 Mile Post 6.88 Calibration

A Marsh-McBirney FloDar was deployed at MP 6.88 from July 24, 2008, to August 11, 2008. The FloDar meter records water velocity and distance to the water surface. By measuring the distance from the meter to the channel invert, the water depth can be calculated. The water depth was measured to be 1.5 feet when the instrument was installed on July 24, 2008 (Mark Walsh, personnel communication, 2008). This depth was entered into the FloDar software so that the water level that the instrument recorded thereafter was the actual water depth (absent any scouring or deepening of the bed). Flow as recorded by the FloDar was then determined by equation D-2:

$$Flow = velocity \times depth \times width \times adjustment \qquad \text{(D-2)}$$

The adjustment term in equation D-2 arises because the instrument measures velocity only in the center of the channel, where the velocity is at its maximum. The adjustment term also accounts for the fact that the instrument measures the water surface flow velocity, not the depth-averaged velocity. The adjustment to the measurement was determined based on the flow and stage data collected by DWR (Mark Walsh, personnel communication, 2008). A single flow and stage value was collected on July 30, 2008, at 8:00 A.M. with a 30-pound torpedo weight and a Marsh-McBirney electromagnetic flow meter. At that time, the depth was 4.0 feet, the width 32 feet, and the total flow 223 cubic feet per second (cfs). The adjustment term was determined to be 0.77.

D4 FloDar Wind Correction

The Wasteway is oriented towards the northeast at MP 6.88. Wind from this direction blowing in the canal can induce an upstream surface flow. Because the FloDar records water speed only at the surface of the flow (see above), wind can have a significant effect on the measured flow rate. Figure D-3 shows the velocity recorded by the FloDar (blue line) and an estimation of the water surface speed induced by wind (pink line), For purposes of comparison between wind speed and the velocity recorded by the FloDar, the wind data are shifted upward by 0.5 feet per second (ft/s) before July 29, and then by 1.4 ft/s after July 29. The wind-induced water surface speed is approximated as 3 percent of the wind speed. The wind data are from the California Irrigation Management Information System (CIMIS) gauge number 161, located at Patterson, about 11 miles northwest of the FloDar site. The wind speed closely follows the diurnal fluctuations in the water surface speed recorded by the FloDar (Figure D-3). The winds at Patterson were out of the north during the period of FloDar deployment. Therefore, the winds caused the FloDar to record a water speed that was too slow during the pilot study, because the downstream flow in the canal was retarded at the surface by the wind blowing upstream. To minimize this error, FloDar data were only considered accurate during the times of calmest winds, between 3:00 A.M. and 7:00 A.M. each day. The FloDar-recorded flow from equation D-2 was averaged over these 4 hours for each morning. Figure D-4 shows the resulting flow.

A data gap exists for the period August 3, 2008, to August 6, 2008, due to vandalism of the instrument. The instrument was replaced after August 6. After August 11, 2008, the replacement FloDar was removed because of fear of further vandalism, and the 15 psig In-Situ Troll from MP 1.14 was moved to MP 6.88 and used for water level measurement.

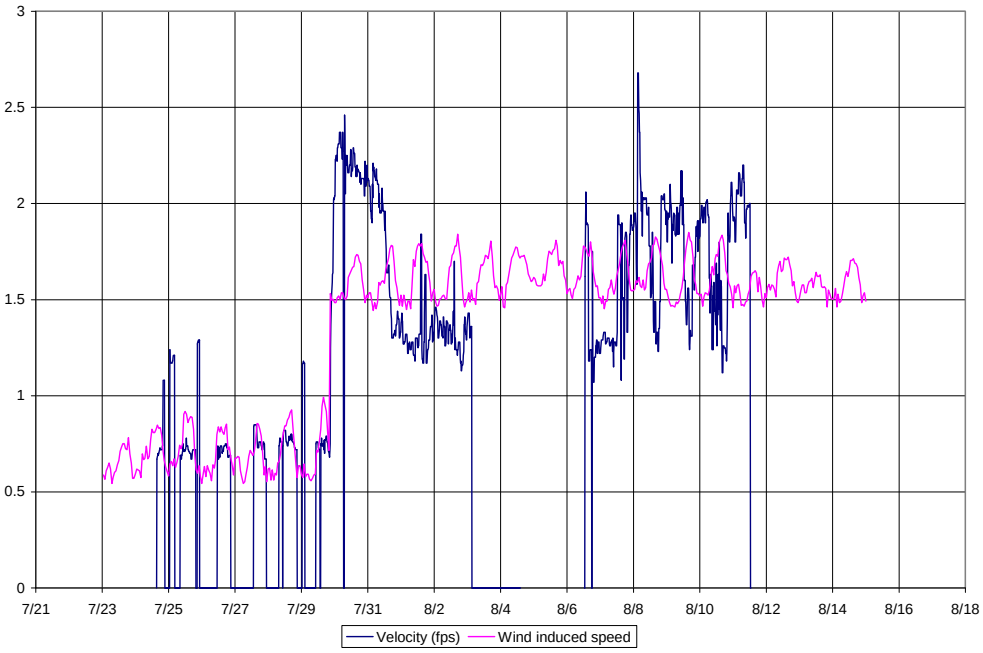

Figure D-3. Water Speed as Recorded by the FloDar Instrument (Blue Line) and Approximate Wind-Induced Water Surface Speed (Pink Line)

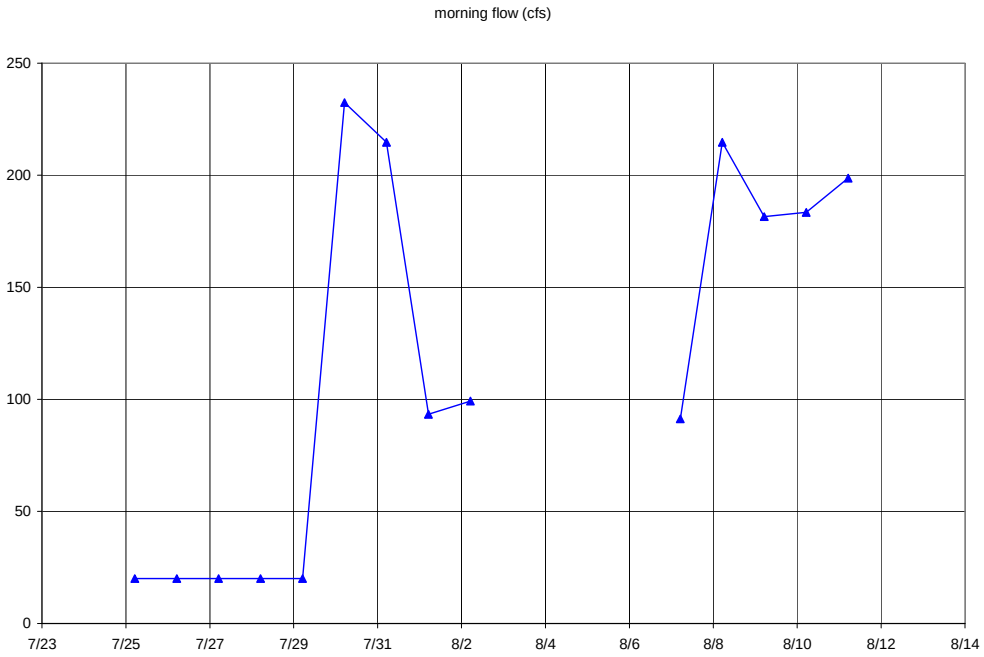

Figure D-4. Flow at Mile Post 6.88 as Recorded by the FloDar Instrument and Corrected for Wind Effects

Values before the pilot study are an assumed 20 cfs due to agricultural tail water. Missing data from 8/3/2008 until 8/6/2008 is due to vandalism of the instrument.

D5 Troll Rating to FloDar

To prevent further vandalism of the FloDar instrument, the instrument was replaced on August 11, 2008, with an In-Situ 15 psig AquaTroll 200 pressure sensor. This instrument is small and is placed underwater, so it is less prone to vandalism than the FloDar. However, the Troll only measures pressure (water level), and therefore a rating curve relating water level to flow (rating curve) needs to be developed. Using the FloDar wind-corrected data, the rating curve takes the form of Figure D-5.

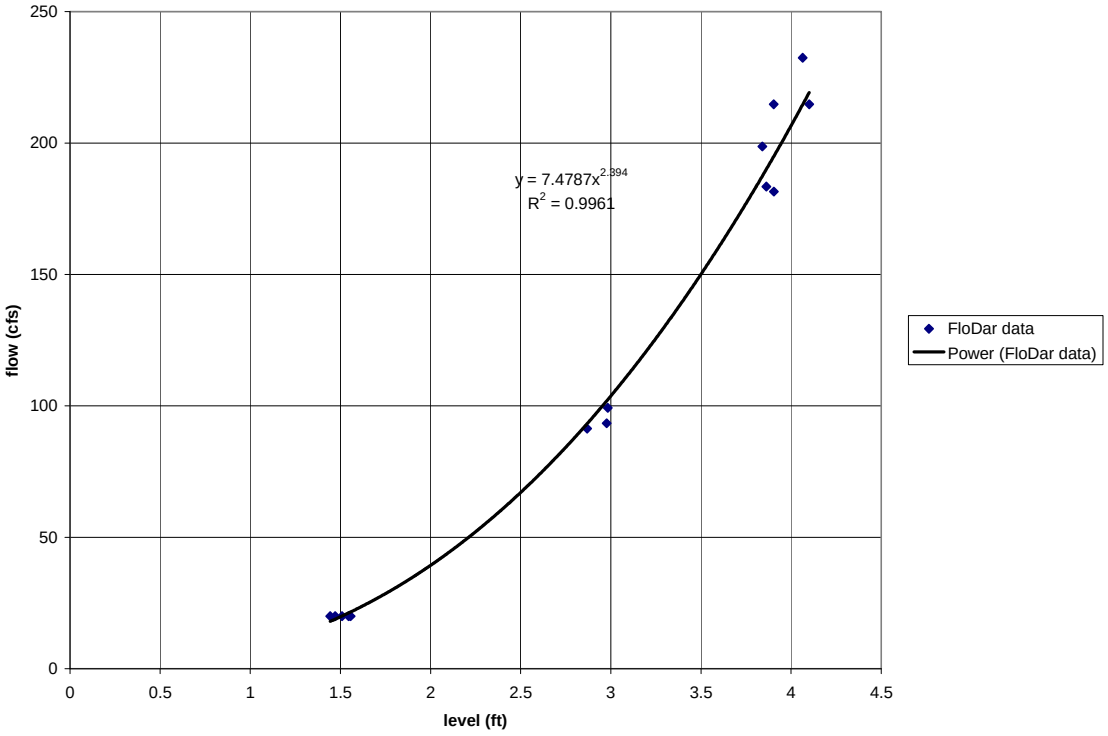

Figure D-5. Flow Versus Water Depth for Wind-Corrected FloDar Measurements Used as Rating Curve for Troll at MP 6.88

However, the pressure read by the Troll is not exactly the same as the water depth, because the Troll doesn't sit exactly on the bed of the stream. For the FloDar-recorded flow and Troll-recorded (rated) flow to match (at 199 cfs) on August 11, 2008, when the FloDar was replaced with the Troll, the Troll must be located 0.6 feet below the bottom initially recorded by the FloDar. This requirement means that either the Troll was sitting in mud or the muddy bed had scoured deeper after the pilot study began. When retrieved, the surface of the Troll did have mud on it, so it is likely that the sensor was sitting in the soft muddy bed.

D6 Removal of Debris-Induced Pole Bending from the Troll Data

A long steel pipe was used to protect the data cable that extended from the Troll to the top of the bridge the Troll was mounted to. The end of the steel pole was submerged in the water and tended to acquire debris, which bent the pole (see Figure D-6). As the pole bent, the Troll rose higher in the water column, because it was clamped to the pole. In the data, this rise appeared to indicate that the water surface was falling. However, the water surface was not falling; rather, the Troll was rising (see Figure D-6).

Figure D-6. Troll Mounting Pole and Debris That Caused Bending of the Pole (Photo Taken on August 18, 2008)

For a pole of length L bent at an angle θ from the vertical, the recorded depth decreases by an amount Δz, where

$$\Delta z = L(1 - \cos\theta) \qquad \text{(D-3)}$$

For a length L of 20 feet, an 8° bend results in a Δz of 0.2 feet, and a 13° bend results in a Δz of 0.5 feet. Figure D-7 shows a nearly linear decrease of recorded depth with time and indicates that the debris were slowly pulling on and bending the mounting pole. By the beginning of August 18, 2008, the depth had decreased by 0.2 feet, which corresponds to a pole bend of 8°, which agrees with the photo (Figure D-6). An anomaly occurred on the afternoon of August 18, 2008, when it appears that a large piece of debris struck the pole and caused it to suddenly bend elastically. However, on the afternoon of August 20, 2008,

the debris was removed from the pole with a grappling hook, after which the pole returned to the state in which it had been 2 days before. By the afternoon of August 25, 2008, the Troll measurements showed a depth that was 0.5 feet less than its initial reading, indicating a pole bend of 13°.

To estimate actual water depth (and flow), it was assumed that the water level did not change significantly during the Troll's deployment. This assumption is reasonable because the position of the Newman head gates were not altered during this period. The water level in the Delta-Mendota Canal (DMC) did change on August 19, 2008, because the flow rate through the DMC was stepped up that day. A similar increase in the DMC flow rate occurred on August 25, 2008. However, these increases in the flow rate should not have caused the head at the Newman head gates to rise significantly, and the flow through the Newman head gates should not have changed greatly during this period. Furthermore, if the flow through the Newman head gates did change, it would be a step change followed by a new constant flow, with the same pattern reflected in the water level. The strategy for removing the pole bending from the data is thus to subtract the linear plastic bending trend from the depth measurements and to remove the elastic bending between August 18, 2008, and August 20, 2008. This same strategy was applied throughout the period of record of this Troll. Figure D-7 shows the removed trend (pink line) and the resulting corrected depth (green line).

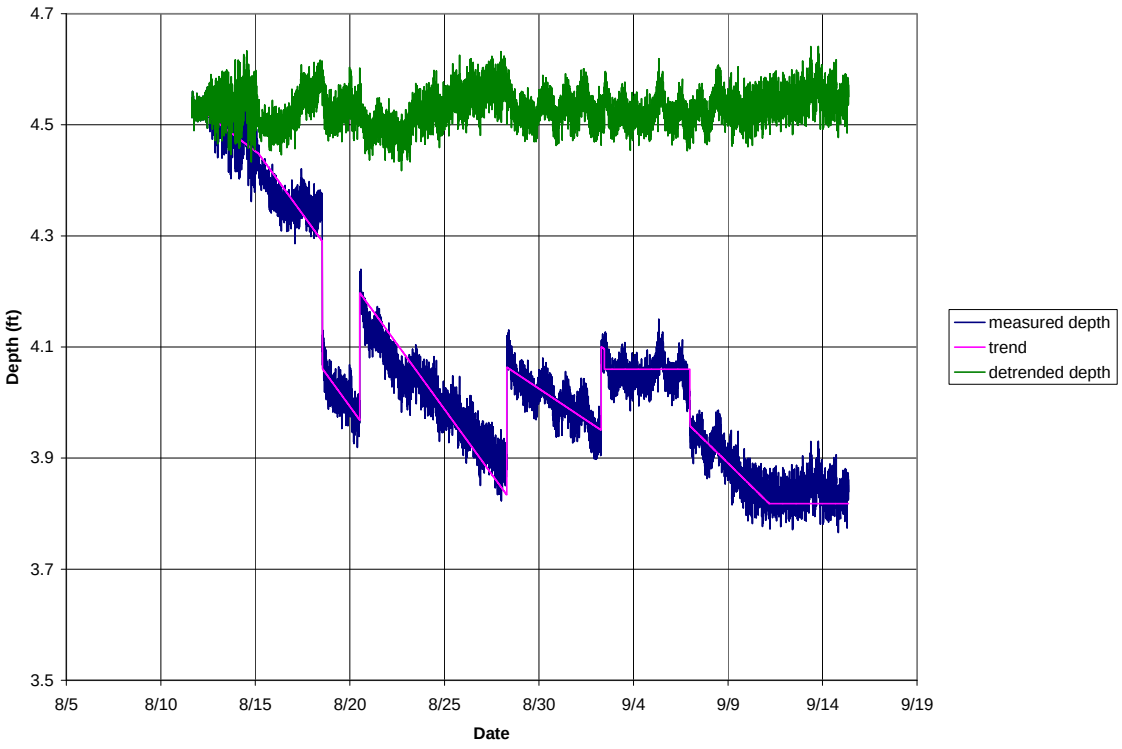

Figure D-7. Troll-Recorded Depth (Blue), Trend (Pink), and De-trended Depth (Green)

Figure D-8 shows the flow recorded by the Troll using the rating curve from Figure D-5.

D7 References

Walsh, Mark. 2008. Written and verbal communications from Mr. Mark Walsh, Hydro Tech II, San Luis & Delta Mendota Water Authority, to Dr. Jeremy Bricker, Water Resources Engineer, URS.

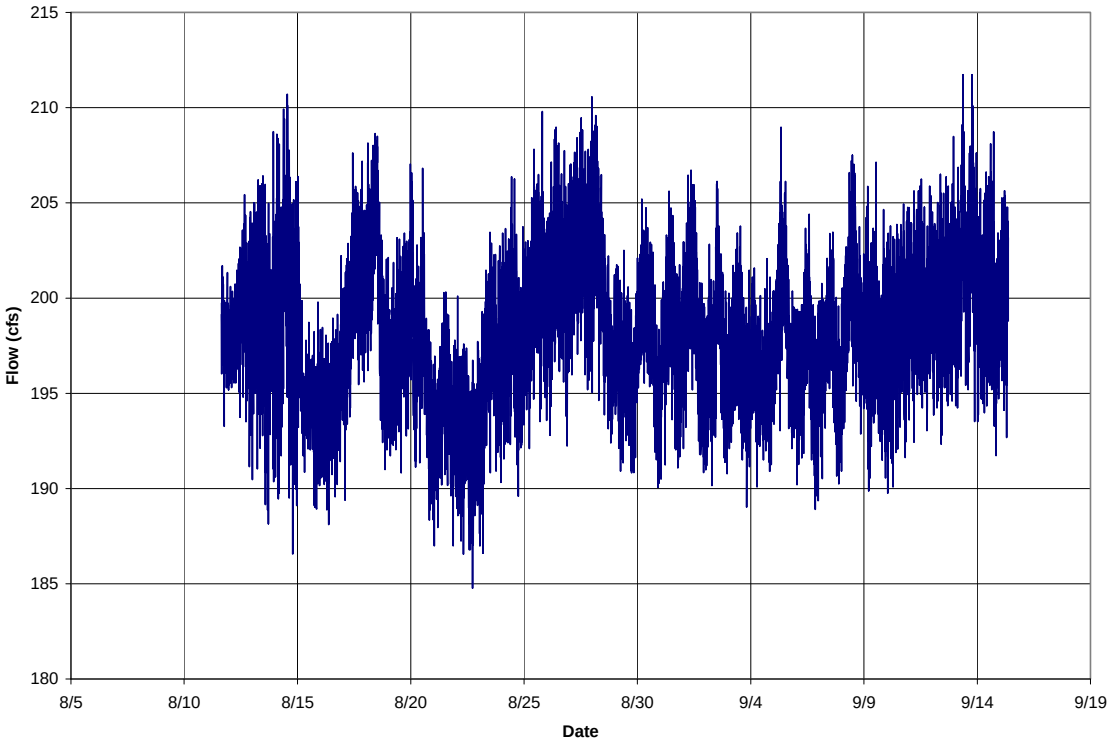

Figure D-8. Flow as Recorded by the Troll at Mile Post 6.88 with Back-Correction of FloDar and Troll Data to Mark Welsh's Manual Measurement