Surface Water Data Assessment

Prepared for:

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1 INTRODUCTION

A series of stream gauges is located within the upper Queen Creek, Devil's Canyon, and Mineral Creek watersheds, located near Superior, AZ (**Figure 1**). These gauges are owned and maintained by Resolution Copper Mining (RCM). The historical stream gauge records were analyzed by JE Fuller Hydrology & Geomorphology, Inc. (JEF) in order provide an assessment of the quantity and quality of the surface water data. These data were also used to characterize and quantify volumetric surface water discharge characteristics in the three watersheds.

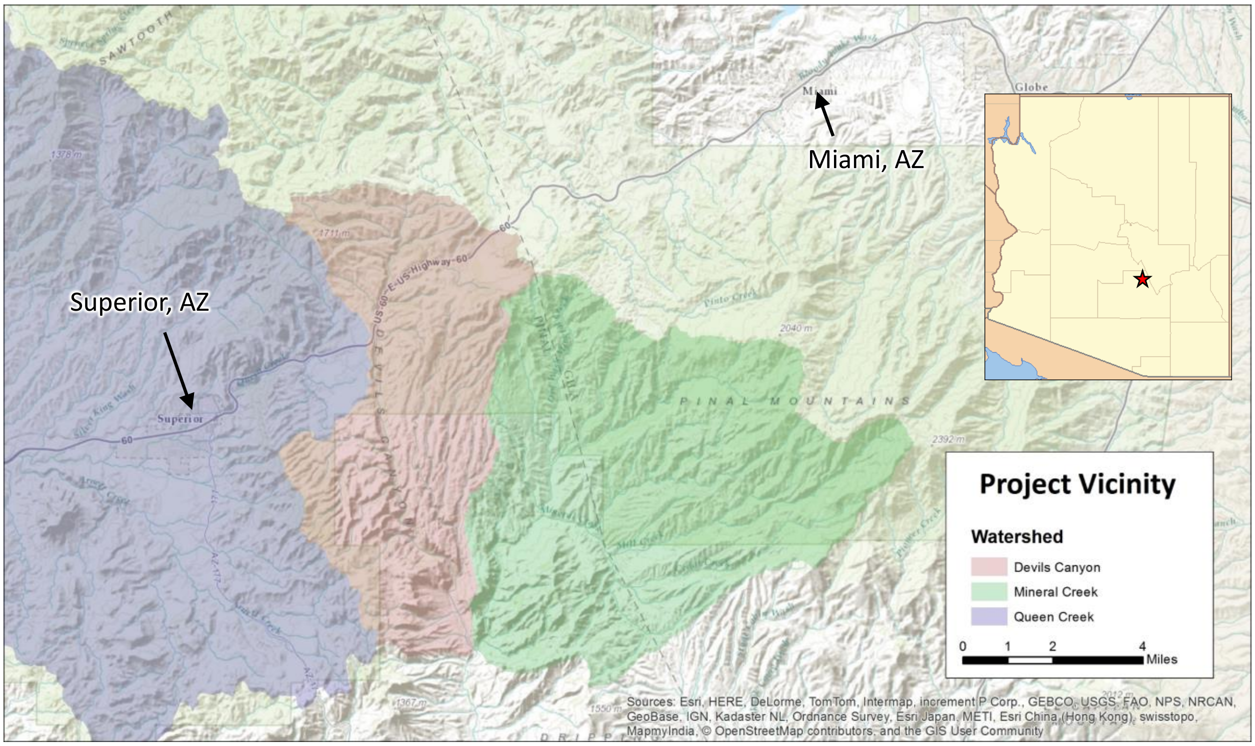

Figure 1. Project Vicinity Map.

2 DATA REVIEW

Data included in the present project are discussed below.

2.1 STREAM GAUGE

Data provided by twelve stream stage gauges (**Figure 2**) were included in the present analysis. Eleven of the twelve analyzed gauges are owned and operated by RCM, and the other gauge is owned and operated by the Pinal County Public Works Department. All RCM stage gauges are pressure transducers (PTs), and the Pinal County gauge is a radar gauge. The pressure transducers owned by RCM log the data internally; these logged data must be retrieved manually. A review of records has indicated consistent field visits to the gauges where the data were downloaded and batteries replaced (for relevant gauges). All stream gauge data for gauges owned by RCM were provided by RCM for this analysis. The radar gauge owned by Pinal County was installed in February 2015, and has been maintained on an annual basis. This gauge is part of the Pinal County flood warning system and transmits data via VHF using the ALERT (Automated Local Evaluation in Real Time) protocol. Data from this gauge were collected for this analysis from the JEF base station database located in Tempe, Arizona where data are collected in real time.

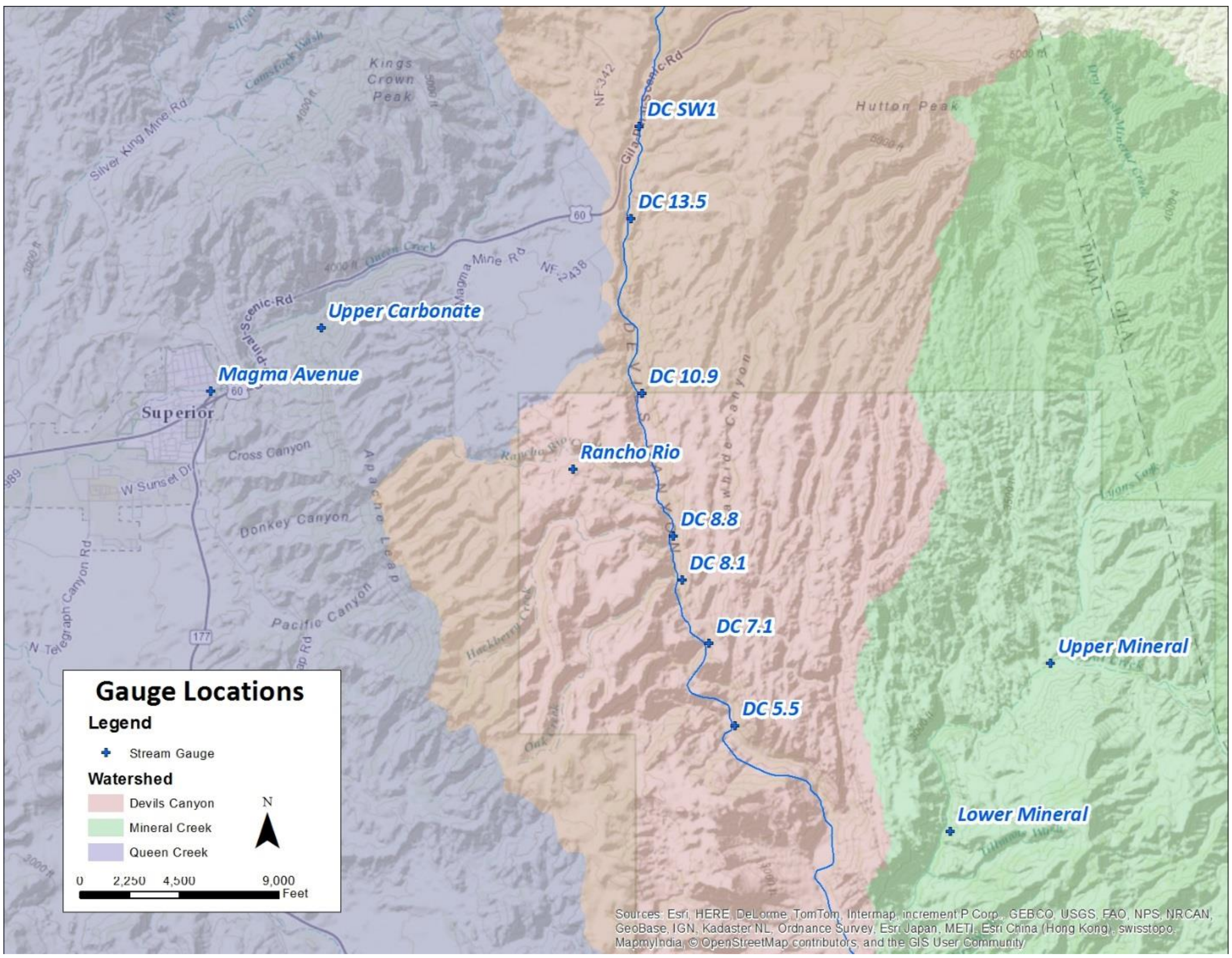

Figure 2. Stream Locations.

As seen in **Table 1** below, both pressure transducers (un-vented and vented) as well as radar gauges were used. Un-vented pressure transducers measure the absolute pressure (both air and hydrostatic pressure) surrounding the sensor. Determination of the hydrostatic pressure for this type of PT requires a coincident record of atmospheric pressure. This type of PT is easy to install and may simply be bolted to bedrock located in the streams' low flow channels. A vented PT measures gauge pressure of the water only, where a vent tube connects the sensor with the open atmosphere. No atmospheric pressure correction is required for this type of sensor. Installation of this type of gauge is more complicated than an un-vented gauge, as relatively greater effort and disturbance are required to provide protection for the vent tube which must extend higher than the expected maximum stage. Radar stream flow gauges measure the water surface elevation without coming into contact with flood waters and associated debris. This type of gauge can only be installed where direct overhead access to the stream thalweg is provided (e.g., bridges).

Hourly data were collected by the unvented pressure transducer logger, and a 5-minute resolution in depth readings were provided by the SW1 gauge (a vented pressure transducer). A twice-daily measurement was provided by the Magma Ave. radar gauge when no changes in water surface elevation were present. The data logger at this location is programmed to report at a finer resolution (15 minutes) when changes in water surface elevation are detected.

The elevation of each gauge was provided by RCM. Available 2015 LiDAR data (also provided by RCM) was used to verify the elevation of each gauge within the LiDAR mapping range. Differential RTK-GPS surveys were performed as part of the initial gauge installation of DC SW1 and Queen Creek at Magma Avenue to determine the gauge elevations.

Table 1. Stream Gauge Descriptions.

Gauge	Northing (ft)	Easting (ft)	Elevation (ft)	Installed	Gauge Type	Owner
DC 5.5	820,864	974,410	2,959[a]	2003	PT - Unvented	RCM
DC 7.1	824,582	973,202	3,389[a]	2004	PT - Unvented	RCM
DC 8.1	827,401	971,973	3,520[a]	2011	PT - Unvented	RCM
DC 8.8	829,399	972,558	3,579[a]	2003	PT - Unvented	RCM
DC 10.9	835,910	970,080	3,730	2003	PT - Unvented	RCM
DC 13.5	843,685	969,516	3,900	2003	PT - Unvented	RCM
DC SW1	847,857	969,845	3,990[b]	2013	PT - Vented	RCM
Rancho Rio	832,379	967,008	3,881	2011	PT - Unvented	RCM
Upper Mineral	823,115	988,878	2,788	2011	PT - Unvented	RCM
Lower Mineral	816,174	984,179	2,516	2011	PT - Unvented	RCM
Upper Carbonate	838,643	955,554	3,175[a]	2010	PT - Unvented	RCM
Magma Ave.	835,762	950,585	2,804[b]	2015	Radar	Pinal County

[a]Verified using 2015 LiDAR Dataset
[b]Determined using GPS-RTK surveying with adjacent benchmark on bridge

2.2 ATMOSPHERIC PRESSURE

As noted, most of the pressure transducers producing the data for this analysis are un-vented. Therefore, those data require post processing in order to extract the hydrostatic pressure from the atmospheric pressure. Data from twelve barometers (**Table 2**) were aggregated and analyzed in order to provide a continuous record of atmospheric pressure for the project area. Most atmospheric data used in this analysis were provided by RCM.

Table 2. Barometer Descriptions.

Barometer	Elevation (ft)	Owner
KC 1	4,166	RCM
KC 2	2,978	RCM
DC 5.5	2,959	RCM
DC 7.1	3,389	RCM
DC 8.1	3,520	RCM
DC 8.8	3,579	RCM
DC 10.9	3,730	RCM
DC 13.5	3,900	RCM
Lower Mineral	2,516	RCM
Upper Mineral	2,788	RCM
Upper Carbonate	3,175	RCM
Rancho Rio	3,881	RCM

In addition to the barometric data record provided by RCM, supplemental data were obtained to fill gaps in barometric data. The largest gap in RCM data spanned 21 months of 2007 and 2008. Supplemental data was also applied to January through March of 2010, as the barometric data obtained from KC1 (the only data record for that period of time) was highly suspect. The supplemental barometric data was sourced from nearby gauges operated by the Flood Control District of Maricopa and the National Weather Service.

2.3 HISTORICAL DATA RECORD

The stream stage and barometric pressure data provided to JEF by RCM were initially reviewed to establish the time span covered for each sensor. **Figure** 3 below depicts the period of coverage for which data are present for each sensor. This depiction does not include gaps in data that are less than a few months, rather it serves to show significant data gaps. Further, it does not distinguish whether the data, if present for a particular time period, are of good quality and included in this analysis.

Datasets from two barometric pressure sensors span from 2003 to late 2010. Starting in late 2010 additional barometers were installed by RCM at six existing un-vented pressure transducer locations. Additional data sources were used to supplement the gaps and more discussion is provided in Section 3.2.

The period of record for stream stage data collection spans from 2003 to 2015. All stream stage gauges shown in **Figure** 3 (below) are currently collecting stage data. Five gauges were installed during the period from 2003 through 2004, and an additional five gauges were installed during the period from 2010 through 2011. The DCSW1 gauge was installed by JEF in May 2013. The newest gauge to be constructed in the project study area was also installed by JEF in February 2015 on Queen Creek at Magma Avenue in Superior, Arizona.

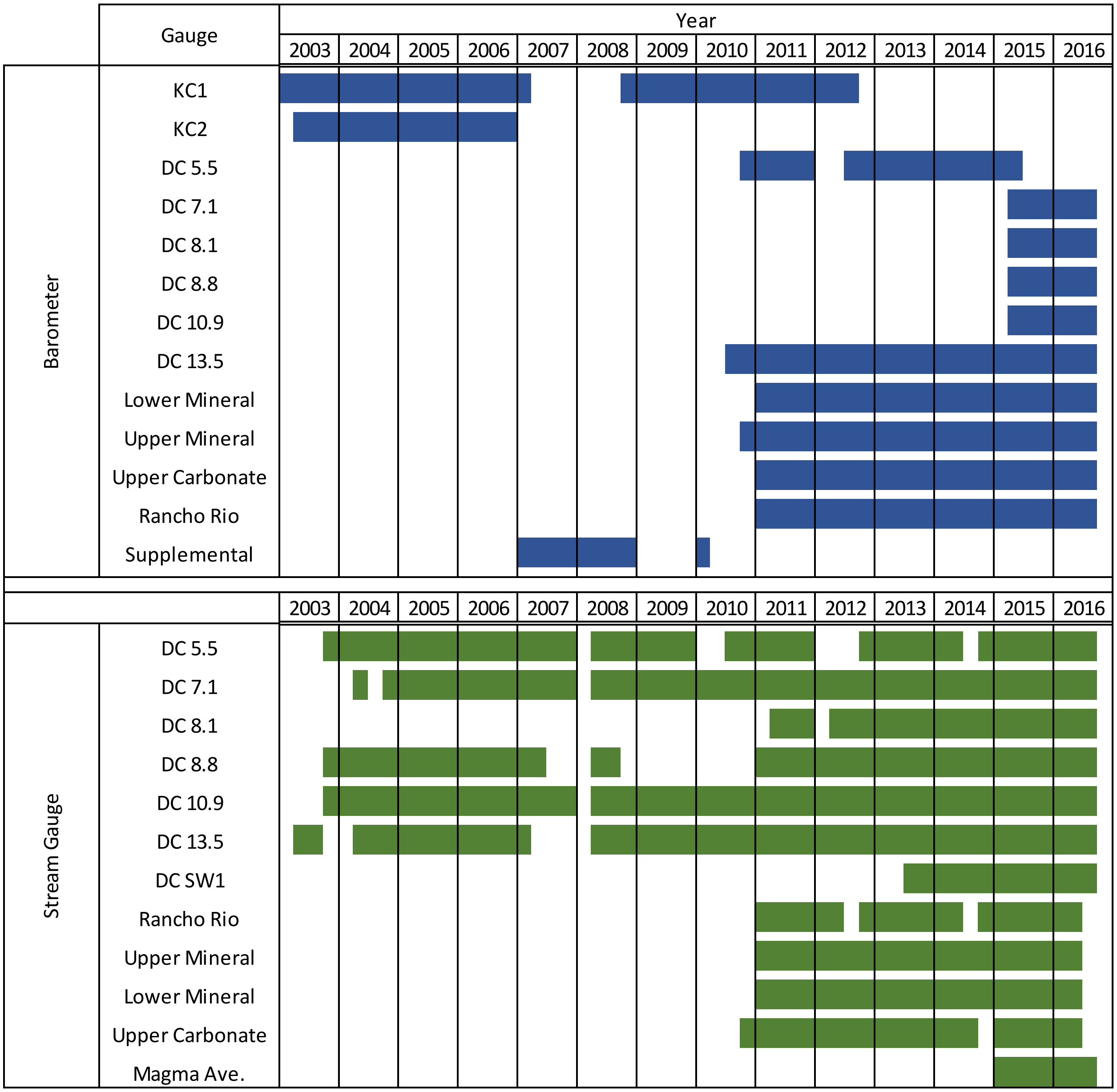

Figure 3. Data Record by Sensor.

2.4 FIELD SURVEYS

A series of cross-sections were surveyed in August and September 2015 by RCM personnel at all gauge locations with the exception of DC SW1 and Queen Creek at Magma Avenue, for which survey data had previously been collected by JEF. The 2015 surveys typically included cross sections at each pressure transducer plus cross sections upstream and downstream of the pressure transducers. The basis of elevation for the surveys was relative to the height of the pressure transducers. These surveys were used in this analysis to construct stage – discharge relationships (i.e., rating curves) for each gauge. Field photographs at each gauge location were also provided to JEF to assist in rating curve development as well as the assignment of Manning's roughness coefficients for hydraulic modeling. A more detailed discussion of the hydraulic modeling performed in this analysis is covered in the methodology section of this report.

2.5 STAGE – DISCHARGE RELATIONSHIPS

Rating curves for the gauges installed by JEF (DC SW1, Magma Ave.) had previously been developed as part of the sensor installation project for each gauge. These relationships were based off of field survey performed by JEF at the time of installation. Hydraulic modeling was performed to provide the stage and discharge relationships for each gauge. The DC SW1 (Devils Canyon) rating curve was refined by a zero outflow verification (12/5/2013) and an opportunistic discharge measurement of 0.76 cubic foot per second (cfs) taken on 11/27/2013. While the rating curve developed for the Queen Creek at Magma Avenue gauge[1] was developed primarily for purposes of flood warning, an opportunistic discharge estimate of 1 cfs was made on the day of installation which was used to refine the lower end of the rating curve.

2.6 JEF FIELD INVESTIGATIONS

JEF accompanied RCM staff during the quarterly maintenance and data collection rounds during February and March of 2016. The purpose of this task was to familiarize JEF staff with site-specific hydraulic characteristics, review and observe site-specific best management practices, and to perform instrument calibration checks. The information obtained as part of this task was used to refine the discharge record generated by JEF in 2015. Precise flow measurements were taken at each site, often using more than one method, and these measurements were used to refine the site-specific rating curves.

2.7 SITE PHOTOGRAPHS

The following photographs record the conditions at each of the stream gauge locations (**Figure 4** - **Figure 15**).

[1] Stage/Discharge Rating Curve for Queen Creek at Magma Avenue Bridge (ALERT Station 1360), Prepared for Pinal County Flood Control District by JE Fuller/Hydrology & Geomorphology, Inc., June 30, 2015.

Figure 4. DC 5.5 Field Photograph

Figure 5. DC 7.1 Field Photograph.

Figure 6. DC 8.1 Field Photograph.

Figure 7. DC 8.8 Field Photograph.


Figure 8. DC 10.9 Field Photograph.


Figure 9. DC 13.5 Field Photograph.


Figure 10. DC SW1 Field Photograph.


Figure 11. Rancho Rio Field Photograph.


Figure 12. Upper Mineral Field Photograph.


Figure 13. Lower Mineral Field Photograph.

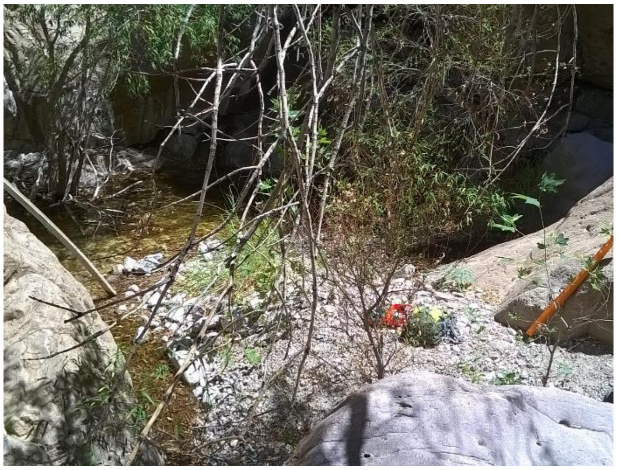

Figure 14. Upper Carbonate Field Photograph.

Figure 15. Magma Avenue Field Photograph.

2.8 HISTORICAL FIELD MEASUREMENTS

Discharge measurements collected by RCM were provided for all un-vented pressure transducers spanning the respective duration for which each gauge had been collecting data. Typically, these measurements took place during quarterly field visits to each gauge site. These measurements were taken using either a cutthroat flume, pygmy meter, stopwatch and flow geometry measurement, or a general estimation. These measurements were used to verify and refine the lower ends of the rating curves developed for this project.

2.9 RAINFALL

Rainfall data were provided by RCM representing monthly measured totals near the East Plant and West Plant sites. The PRISM[2] rainfall dataset spans from January of 1895 to December of 2014. Given the close proximity of the two sites to one another and the close agreement between the two records, measured precipitation values at both sites were averaged for the duration of the record. This data record was used to qualitatively correlate the discharge measurements calculated in this assessment. Monthly averages of rainfall were compared with monthly averages of discharge.

[2] The PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu/

3 ANALYSIS METHODOLOGY

The following sub-sections detail the methodology used by JEF. Data provided to JEF by RCM were initially reviewed to assess the quality and predictability of each dataset. As a result of this initial review and to span data gaps, barometric datasets were aggregated into a single dataset. This dataset was then used to determine hydrostatic pressure at un-vented PT locations. Rating curves were developed for each site to calculate discharge as a function of depth. The subsequent discharge record for each gauge was then used to estimate monthly streamflow statistics at each gauge.

3.1 INITIAL DATA REVIEW AND ANALYSIS

Each stream gauge and barometric pressure record was examined independently of other data records. Raw sensor values were plotted individually for each dataset to ensure that the data fell within an expected trend. Outlying data were quantitatively removed using a 99% confidence interval. This interval was generated by computing a moving average (n = 51), and standard deviations were computed using the same population for each time step. The data were assumed to be normally distributed, therefore the confidence interval can be defined as:

$$CI(99\%) = \mu \pm 3\sigma$$

Where μ is the moving average and σ is the standard deviation. Data that fell outside this confidence interval were removed from the analysis. This approach is useful to remove spurious, erroneous data which can be an issue associated with stream gauging. The normal distribution assumption assumes the overall trend of the data does not dramatically change over a short period of time. Rising limbs of some of the hydrographs did exceed the upper confidence interval, however they were not removed as an explainable, defendable trend can clearly be observed.

Figure 16 below depicts an example of this analysis applied toward the DC 5.5 pressure transducer.

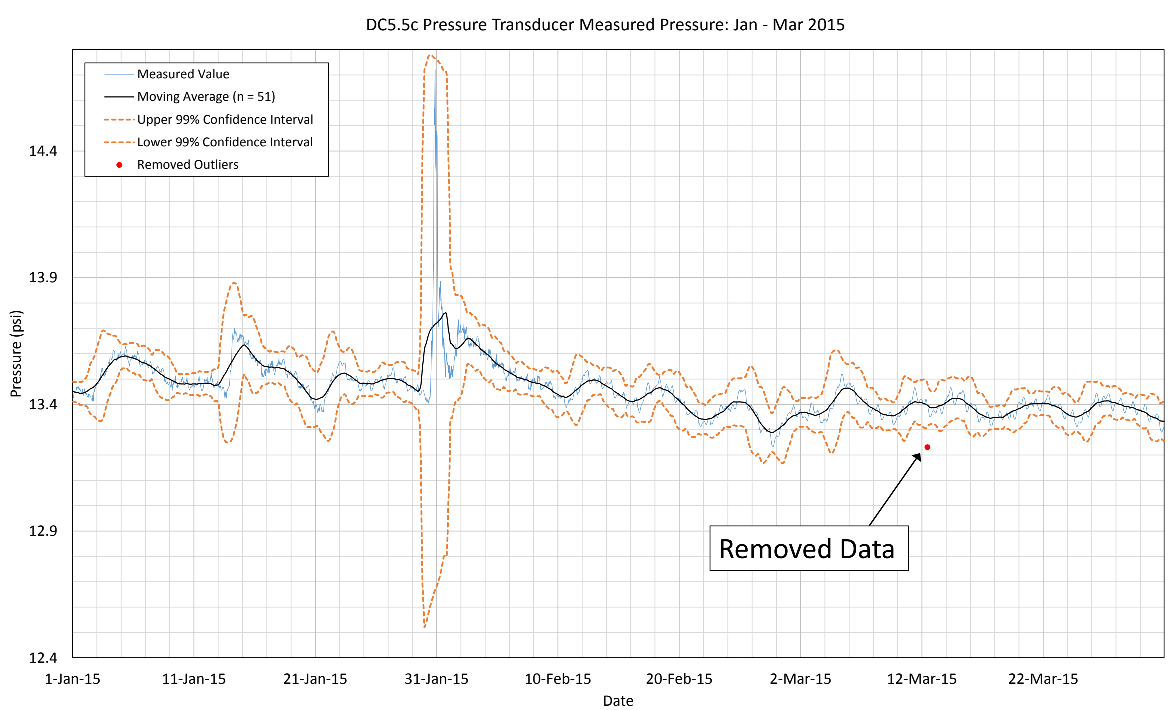

Figure 16. Initial Data Analysis Example.

3.2 GENERATION OF BAROMETRIC DATA RECORD

A total of twelve barometric data records were compiled for this analysis. Barometers have been installed adjacent to all RCM pressure transducers (DC 5.5, DC 13.5, Upper Mineral, Lower Mineral, Upper Carbonate, and Rancho Rio). Since these barometers do not cover the 2003 – 2010 time frame, barometric pressure data from gauges at the East and West Plane (KC1 and KC2, respectively) were included, as well as supplementary data collected from weather stations operated by the Flood Control District of Maricopa County. Given that no barometric data record covered the entire span of stream gauge data, and that barometers installed adjacent to un-vented pressure transducers do not span the entirety of each respective pressure transducer record, all available barometric data were aggregated together to form a single, continuous record of barometric pressure data.

Atmospheric pressure is largely a function of elevation, and given the close proximity of all gauges, other phenomenon that could affect pressure were disregarded. A commonly cited relationship between atmospheric pressure and elevation is 0.001639 psi / meter. Data from each barometric record were extracted for three randomly chosen time steps, and the measured pressure for each barometer was tabulated. Using the elevations reported in **Table 2** the measured pressure at each gauge was plotted with the corresponding elevation. This was repeated for all three time steps. As expected, a very strong, linear trend between elevation and air pressure was observed. The slope of each line was nearly identical and equal to 0.001584 psi / m. Given that this represents less than a 5% difference between the cited value, and that this relationship is repeatable, the calculated value was used for this analysis.

Each barometric dataset was then adjusted to reflect pressure at a common elevation, chosen to be the elevation of the lowest stream gauge site, Lower Mineral Creek. **Figure 17** below depicts the transformation of barometric pressure at varying elevations into a single barometric record referenced to a specific elevation. All barometric pressure datasets reporting were averaged for each hourly time step. This single, averaged barometric dataset was applied for all future calculations, while using known elevations of each stream gauge to correct the mean record for each site.

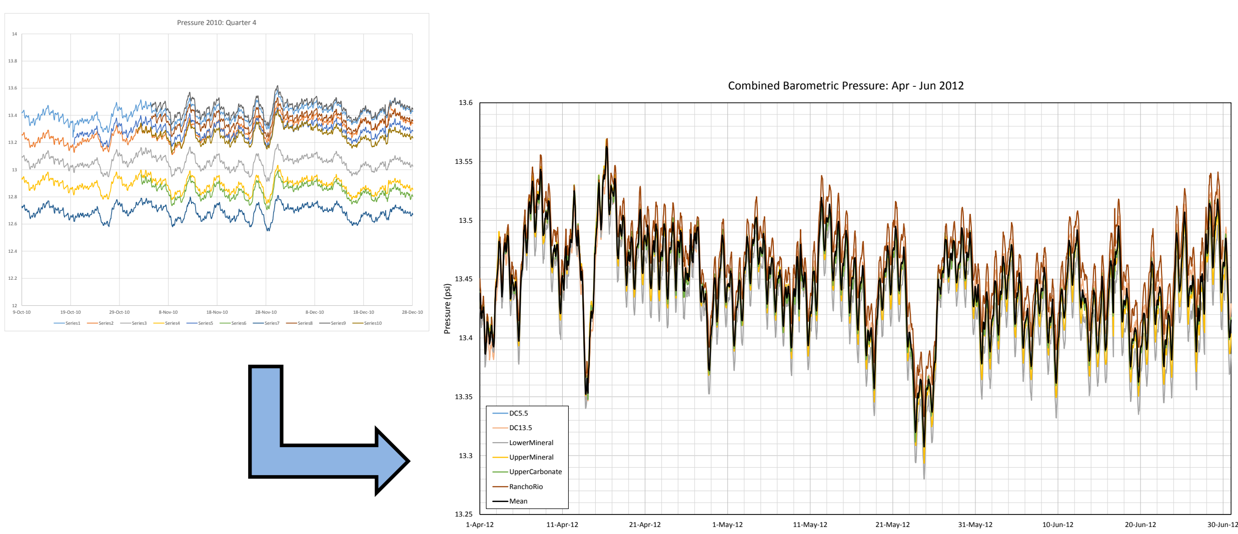

Figure 17. Example Depiction of Mean Barometric Pressure Record.

3.3 RATING CURVE DEVELOPMENT

A streamflow rating curve relates stream stage to discharge, and it is site-specific. A number of factors can influence this relationship including channel geometry, upstream and downstream hydraulic control features, channel slope, and channel roughness, among many other factors. Rating curves for DC SW1 and Magma Ave had already been developed as part of the gauge installation, and were used without modification in the present analysis. Rating curves for all other stream gauges were developed.

Cross-section surveys performed during the summer of 2015 by RCM were used to represent channel geometry for each gauge site. Hydraulic modeling was performed using HEC-RAS v 4.1.0 developed by the U.S. Army Corps of Engineers. This software package applies a step-backwater approach for determining the water surface elevation (among many other parameters) based on a supplied discharge rate. A series of discharge rates ranging from 0.1 cfs to 3,000 – 5,000 cfs were used to construct a rating curve. Friction losses were modeled using the Manning's roughness coefficient, *n*. Ineffective flow boundaries were used to account for pool storage below outflow points for those gauge locations with pressure transducers mounted in pool areas.

The HEC-RAS hydraulic modeling was used to construct the upper regions of rating curves for which field discharge measurements would be neither feasible nor safe; low-flow discharge measurements collected by RCM provided the depth/discharge information for the lower regions of the ratings. Taken together, the best possible stream stage/discharges relationship was developed for a wide range of flow conditions.

A "best-fit" function was applied to the combined rating curve data points and was calibrated initially using a least squares approach, and was further refined manually to reflect known calibration points (e.g., measured discharges and ponding depths). Greater emphasis on applying the best fit was placed on the base flow range of the rating curve as opposed to the higher discharge range. Rating curves were modeled using an exponential equation using the form below:

$$y = a + bx^c$$

Where y is the stream stage in feet above the orifice of the pressure transducer, x is the corresponding discharge in cubic feet per second (cfs) and a, b, and c are calibration coefficients. The term a in the equation above corresponds to the maximum depth above the pressure transducer that water can pool without any effective discharge. This term is useful to model rating curves in situations where the sensor is located in a pool that must fill up and spill over before effective surface water flow occurs. In this case this term should equal the vertical distance between the sensor's orifice and the brink of the pool area's outlet. This equation was used to represent all rating curves in this analysis. **Figure 18** below shows an example rating curve with modeled and measured discharges as well as the corresponding exponential fit to the data. Rating curves developed for each gauge location can be found in **Appendix B**.

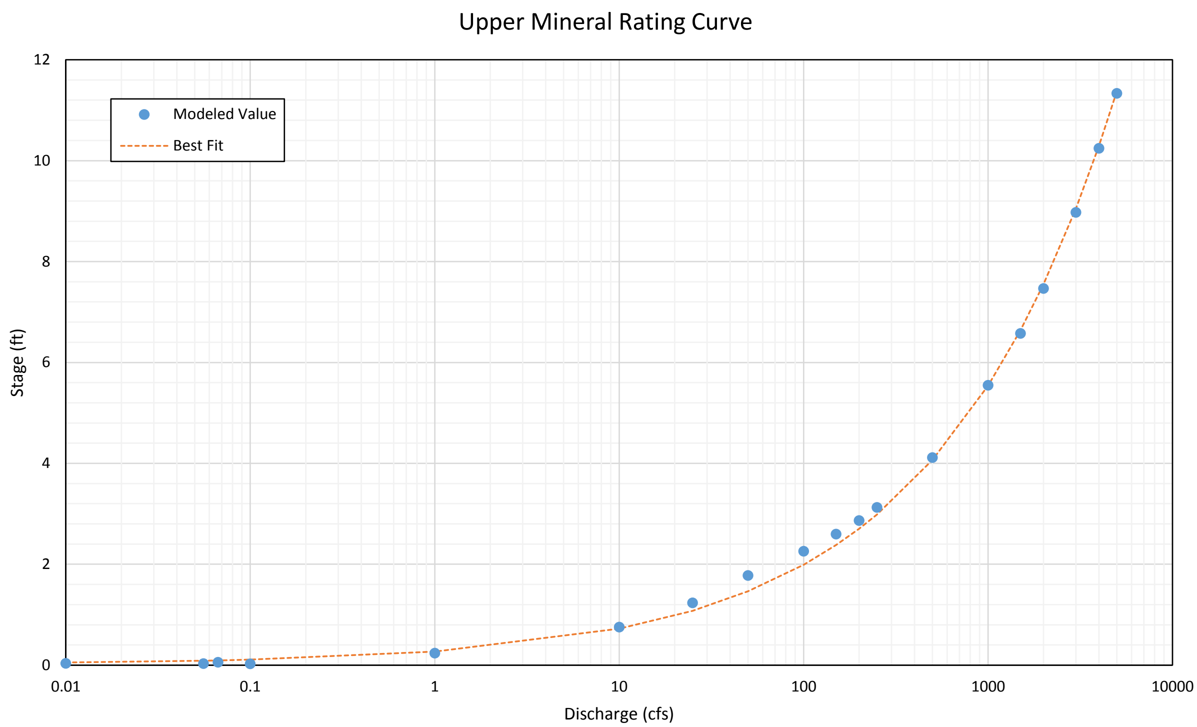

Figure 18. Typical Rating Curve.

3.4 DEPTH AND DISCHARGE CALCULATION

The process by which discharge records were developed is summarized below in **Figure 19**. Atmospheric pressure corrected for each gauge location was determined using the mean barometric record. This pressure was subtracted from the measured pressure for all un-vented pressure transducers to determine the hydrostatic pressure. Hydrostatic pressure was then easily converted into a water column depth above the sensor using the unit weight for water. The single vented PT measures hydrostatic pressure directly, and water depth was calculated at this location simply by converting the pressure into depth. The radar sensor location measures depth directly, so no conversion of the raw dataset was required.

Depth measurements were converted to the respective discharge using the site-specific exponential relationship. Surface water hydrographs were plotted on a log scale for clarity in the base flow range, therefore calculated discharges less than 0.001 cfs (0.4 gpm) were considered as zero in this analysis to satisfy requirements of base 10 logarithmic calculations.

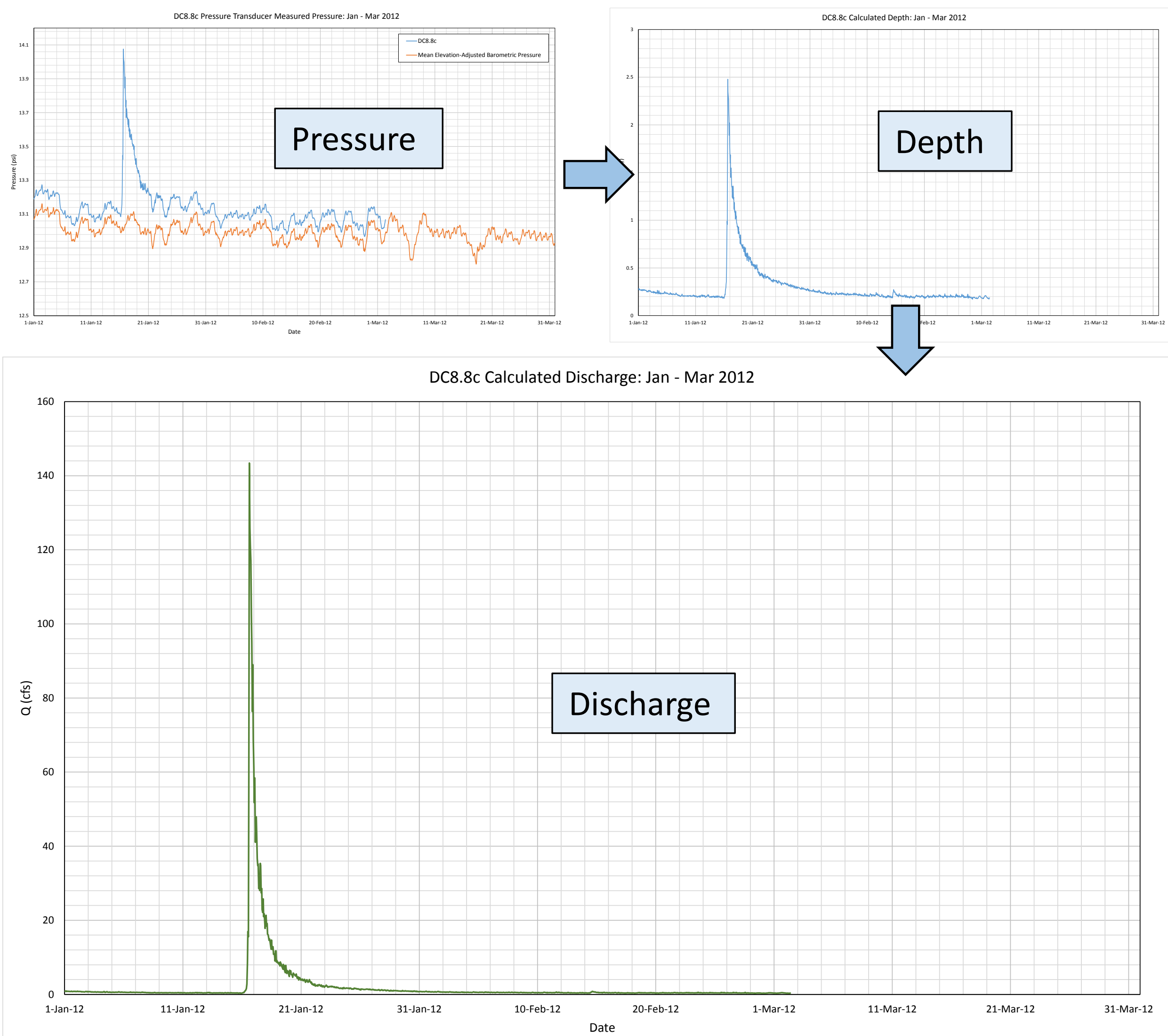

Figure 19. Data Processing Diagram.

3.5 STREAMFLOW STATISTICS

Discharge records for each dataset are provided as part of this deliverable. In addition, mean monthly discharges were calculated and reported by averaging the hourly data reported for each year by month. Months where less than 20% (146 records) of the hourly reported discharges were present were omitted as they were not considered to be representative samples of the streamflow for that month.

3.6 DATA OMISSIONS

Following the entirety of the data processing outlined above revealed instances where the resulting data were suspect. This largely occurred in the pressure record of the un-vented pressure transducers. Instances of clear, identifiable trends in the pressure transducer datasets that indicated sensor drift as well as sporadic periods of erroneous data were discovered. Sensor drift can occur when the compensating datum of a pressure transducer, such as reference voltage or temperature compensation shift as a result of the failure of any component in the sensor's integrated circuit. A common manifestation is the situation of a sensor's measured pressure which dips below the barometric pressure. Even if the stream bed were dry the pressure transducer should, at a minimum, be recording atmospheric pressure. Maintenance procedures include comparing the measured atmospheric pressure of each pressure transducer with a calibrated barometer to assess the accuracy of the pressure transducer datum.

Limited calibration data were available to test the entire reporting span of each gauge, but was applied when available. A series of measurements between 2009 and 2012 were taken where each pressure transducer was removed from the water during routine field visits so that an air pressure measurement could be recorded. JEF compared this dataset with the measured barometric pressure at the same date and time to assess the quality of the pressure transducer datum. All but one of the sensor reported pressures that closely matched barometric-pressure atmospheric pressure during this time period.

Each data record was closely examined, and instances of erroneous data were intermittently observed. In most cases, erroneous data could be attributed to sensor drift, however there were also instances where non-correlated pressure readings were recorded. Manual omission of this data was performed. It should also be reminded that calculated discharges less than 0.001 cfs (0.4 gpm) were recorded as 0.001 cfs in this analysis. This was done in order to provide a means to visualize zero discharge in the hydrograph plots. These plots were generated on a base 10 logarithmic scale, where a zero value cannot be displayed.

The stream flow gauge DC 7.1 reported values that were consistently higher than the barometric pressure. The difference between what the pressure transducer reported and the actual barometric pressure equated to an over prediction in depth of 0.50 and 0.80 feet at the low of the sensor's range or span. Calibration of this data record was not performed, given the period of record for this gauge (2004 – 2015) and the period of record for calibration data (2009 – 2012). Further, this type of calibration (a single-point calibration) only checks the "zero reference" of the sensor. It doesn't necessarily indicate the sensor's accuracy through its full range. Therefore, it is not advisable to simply apply a linear shift to the data set for such a sensor.

4 DISCHARGE RECORDS

Continuous discharge records were calculated for each of the twelve stream flow gauges using the methods outlined above. The results were examined individually as well as by reach (i.e., Devil's Canyon, Mineral Creek, and Queen Creek).

Mean monthly discharges were calculated and are discussed below. Hydrographs spanning the full range of available data for each stream gauge were constructed and are also presented below. Historical discharge measurements taken at each site were plotted with each discharge record (where applicable). The figures, plotted on 11" x 17" sheets can be found in **Appendix A**. Lastly, a brief discussion of the results by gauge is presented. Electronic copies of all data presented here, as well as intermediate calculations are submitted concurrently with this document.

In general, there was fairly close agreement between the historical discharge measurements and the calculated discharge records. Variability between measured and predicted values can largely be attributed to several causes: inaccuracies in the flow measurement, change in hydraulic characteristics over time, and seasonal variation. Accurate flow measurements can be difficult to obtain in certain conditions, as flow in a poorly confined channel can be difficult to direct into a flume without some losses. Secondly, infrequent, high-energy runoff events can move large amounts of sediment and debris, causing significant changes to low-flow channel geometry and attendant stage/discharge relationship, especially for magnitudes of flow associated with base flow conditions. Lastly, seasonal variations of riparian flora can have a significant impact of the low end of a stage/discharge rating due to the increased roughness of the channel. Seasonal growth of vegetation introduces added friction that requires a greater stage to achieve the same discharge.

4.1 MEAN MONTHLY DISCHARGE

Monthly discharge by reach are shown below in **Figure 20**, **Figure 21**, and **Figure 22**. Results for Devil's Canyon were plotted on a logarithmic scale for clarity, and results for the other two reaches were plotted on an arithmetic scale. Monthly discharge results followed a predictable trend of increasing discharge during the winter, and decreasing flow during the spring / summer. July marks the start of the monsoon season as indicated by both precipitation data and discharge data processed in this analysis. While the seasonal differences in mean discharge calculated here is largely driven by precipitation, evapotranspiration and evaporation also play a role in the increasing and decreasing base flow magnitude.

A clear reduction in mean discharge for the month of February as compared to average precipitation was observed for the following gauges: Ranch Rio, DC SW1, Lower Mineral, Upper Mineral, and Upper Carbonate. The rainfall that is presented below represents monthly mean rainfall spanning from 1900 to 2014. A closer look at the average rainfall between 2010 and 2014 (which encompasses the data record for each of the aforementioned gauges) indicates that the average rainfall for February between 2010 and 2014 was 0.97 inches as opposed to 2.57 inches for the full rainfall record (**Figure 23**). Discharge observed at Rancho Rio, DC SW1 and Upper Carbonate is primarily event-driven (as opposed to base flow), thus reductions in precipitation would have significant impacts on the mean discharges at those locations. Both Lower and Upper Mineral sites are fed by base flow, however, the reduction in rainfall (as compared to the average) is similar to the reduction in discharge (as compared to what is perceived as the average by assuming a linear change between January and February). The precipitation for February for 2010 to 1014 was 38% of the average February value, and discharges at Lower and Upper Mineral Creek were 56% and 27% respectively of the perceived average values.

Two prominent peaks in rainfall throughout the year were observed. The winter months, December through March, on average, comprise 48% of the annual rainfall, while the summer monsoon season (July through September) contributes 31% of the total annual rainfall. While the duration of the summer monsoon is shorter, the mean monthly rainfall for August is slightly higher than the wettest winter month (December). This similar order of magnitude for average monthly rainfall between these two periods does not translate into a similar magnitude of discharge for the same period. The average discharges observed for the winter months are consistently much higher than for the monsoon period. A difference greater than one order of magnitude between these periods can be seen in Devil's Canyon, while the winter months are approximately double that of the monsoon months for Mineral Creek.

A notable, longitudinal (downstream to upstream) trend in the Devil's Canyon mean monthly discharges was observed (**Figure 24**). A consistent trend of increasing flow in the upstream direction between DC 5.5 and DC 13.5 was noted when the monthly discharge for all sites increases. The opposite is also evident as the monthly discharge decreases throughout the year.

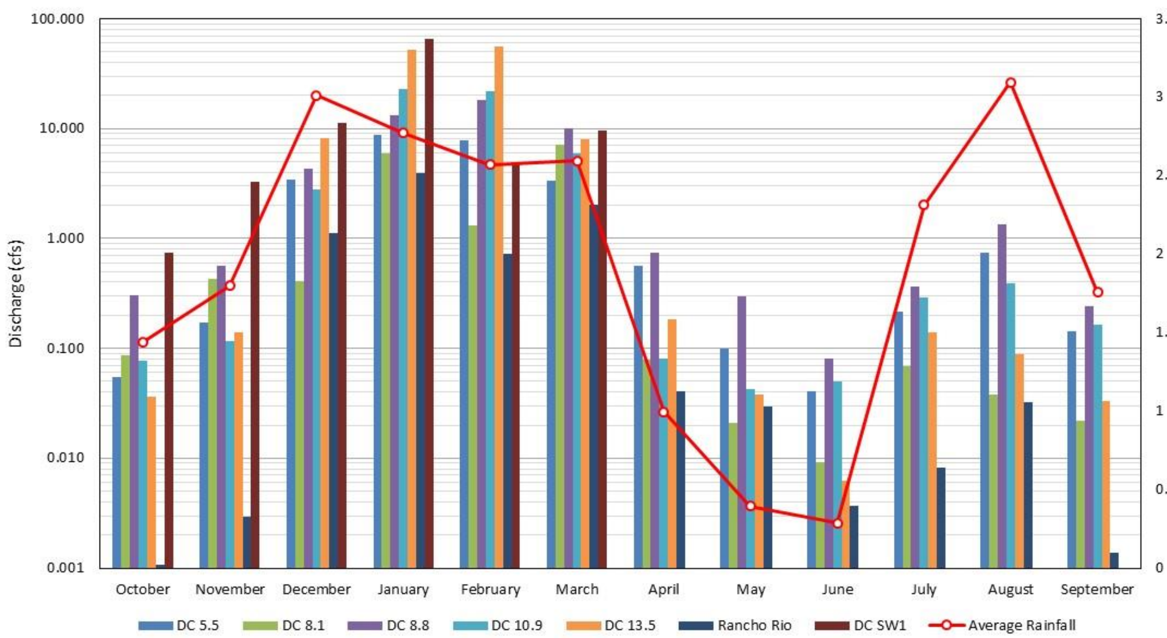

Figure 20. Devil's Canyon Mean Monthly Discharge.

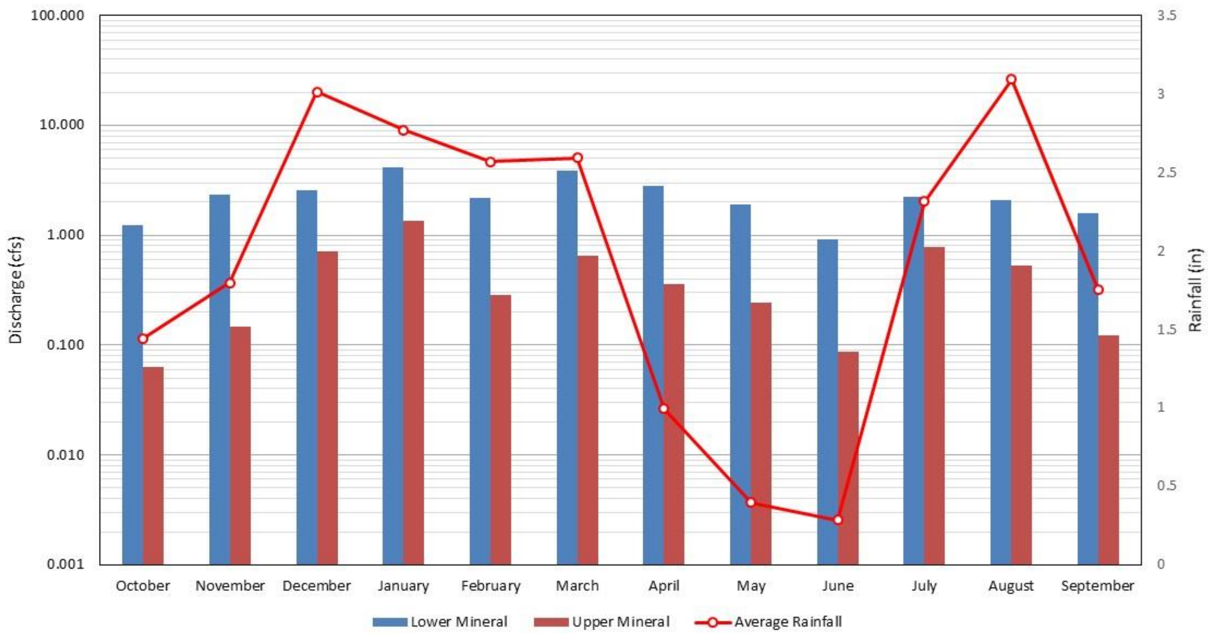

Figure 21. Mineral Creek Mean Monthly Discharge.

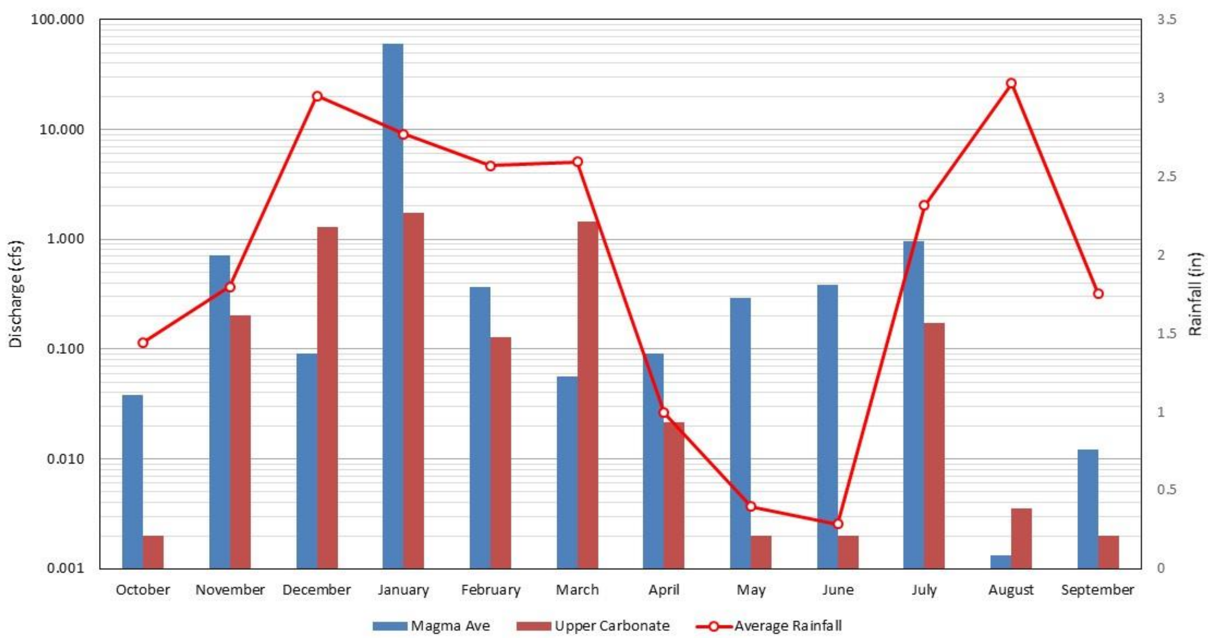

Figure 22. Queen Creek Mean Monthly Discharge.

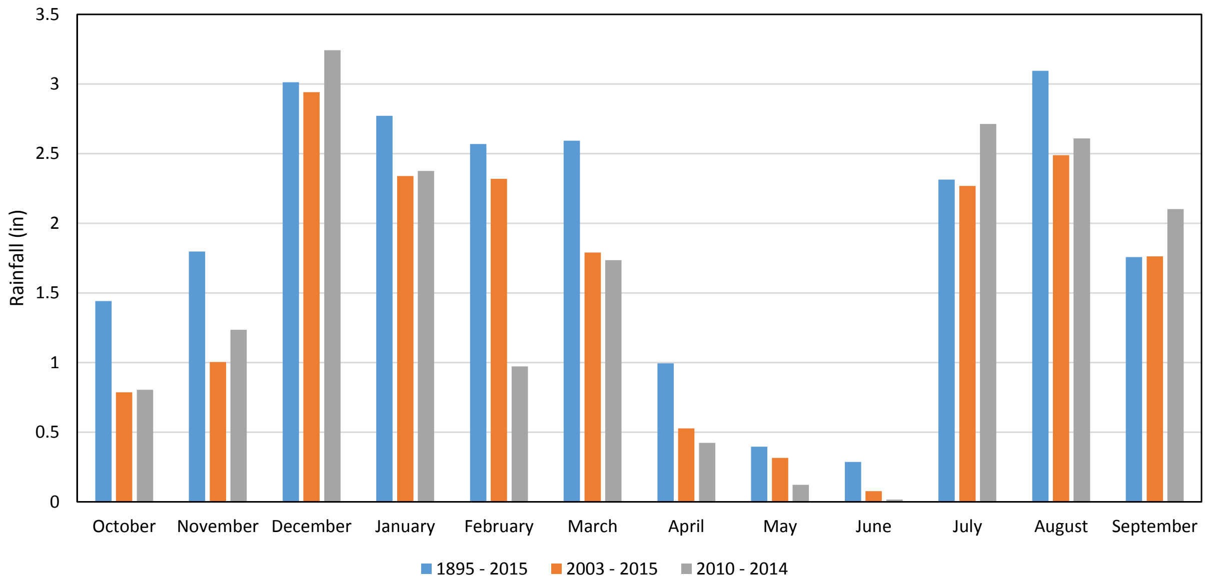

Figure 23. Mean Monthly Rainfall By Time Period.

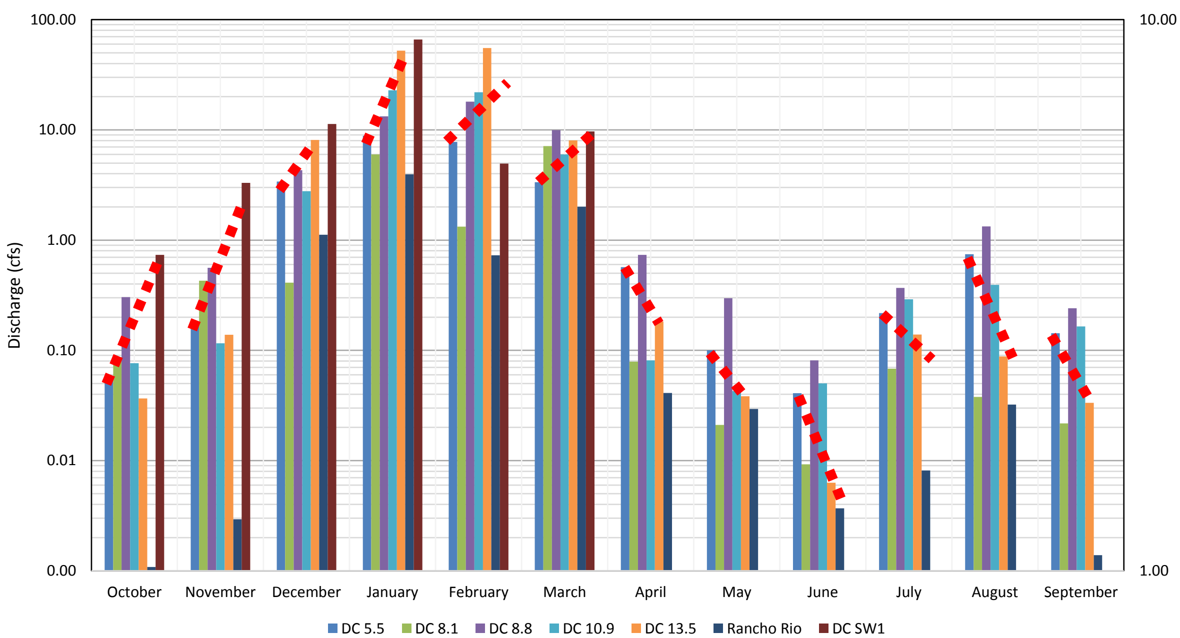

Figure 24. Devil's Canyon Downstream to Upstream Seasonal Trend.

4.2 DEVIL'S CANYON DISCHARGE RECORD

Results for individual gauges from downstream to upstream.

4.2.1 DC 5.5

See **Figure 25**. A reliable rating curve was established for this site. The winter months are fed by a combination of both event-driven flow and sustained base flow, and the summer months indicate low flows, and often times a discharge of less than 0.001 cfs. Several large gaps in the data are observed and they are attributed to gaps in the PT record. In addition, pressure transducer data spanning from August 2011 through December 2011 was omitted from the analysis. This data was not able to be correlated with atmospheric pressure.

4.2.2 DC 7.1

See **Figure 26**. The rating relationship for this site could not be established for data collected through June 2016, however a reliable rating curve was established for data collected after June 2016.

The data collected through June 2016 indicate that the datum of the pressure transducer has shifted over time. The variation in the sensor datum can solely be attributed to instrumentation error since the site is primarily bedrock and the hydraulic relationship between stage and discharge is not expected to change. Further, the datum shift has not been consistent over time, therefore, manual corrections to account for this shift cannot be made with confidence. The pressure transducer was replaced with a factory-calibrated sensor in June of 2016.

This site was studied extensively by JE Fuller during the 2016 field investigation, and it was confirmed that only a single outlet for flow from the pool exists. Even at extremely low flows (< 50 gpm), water discharging from this pool spills over a bedrock lip in freefall fashion, and this phenomenon can be modeled with precision. The geometry of the overtopping lip was measured, and a broad-crested weir equation was applied in order to relate depth on the upstream side of the lip to the discharge over the lip. The measured flow depth over the lip during the JE Fuller field investigation was applied to the model and a predicted discharge of 672 gpm was obtained. This result was compared to the discharge measurement taken just upstream of the data location (646 gpm), and the close agreement between the two results supports the validity of the simple model. That said, a detailed rating curve was developed for this location that can be used moving forward (**Figure 38**).

4.2.3 DC 8.1

See **Figure 27**. A reliable rating curve was established for this site. Seasonal characteristics of flow reflect sustained base flow in the winter and low and no flow in the summer, aside from event-driven runoff. Pressure transducer drift was detected in the data spanning between August and September of 2015, and this data were removed from the analysis.

4.2.4 DC 8.8

See **Figure 28**. A reliable rating curve was established for this site. Sustained flow in both winter and summer periods was observed. A number of data omissions were made on the grounds of perceived erroneous pressure transducer data. Abrupt pressure transducer datum shifts were observed for the periods of July 2003 – February 2004 and July 2014 – September 2014. Data were omitted from the analysis for these periods. Gradual pressure transducer drift was observed in October and November of 2011, and the data here were omitted as well. Sporadic pressure measurements were also detected in August 2013, November 2013, and February 2014, and data here were omitted as well. Analysis of the data also revealed that the temperature compensator is likely malfunctioning, as wide variations in reported pressures during drier seasons were found during the summer months of 2012, 2013, 2014, and 2015. While the data here were certainly suspect, they were not removed from the analysis, as it could not be confirmed with complete certainty that this was the issue.

4.2.5 DC 10.9

See **Figure 29**. A reliable rating curve was established for this site. Sustained flow in both winter and summer periods was observed. Very little gaps in the data were noted, and no omissions were made that were attributed to erroneous data.

4.2.6 DC 13.5

See **Figure 30**. A reliable rating curve was established for this site. The results at this location suggest that runoff in this reach is primarily event-driven, and that little base flow is sustained through the winter. There were noticeable instances of oscillations in measured pressure from the data sensor during the summer months. This likely occurred when the sensor was dry (typically in summer and autumn months), and that the temperature compensator inside of the data sensor was faulty.

4.2.7 DC SW1

See **Figure 31**. The rating curve for this site was developed as part of the gauge installation and was used without modification here. The results indicate that all runoff associated with this station is event-driven.

4.2.8 RANCHO RIO

See **Figure 32**. A reliable rating curve was established for this site. While most of the runoff at this site appears to be event-driven, there does appear be to be some sustained base flow in the spring months. A large shift in pressure transducer readings occurred in October 2013, and data spanning through March 2014 were omitted. In addition, large variations in pressure readings from September 2014 through January 2016 were observed, and all data during this period were omitted from the analysis.

Data collected through 2016 have been subject to intermittent faults in the pressure transducer that can be solely attributed to excess heat generated by direct sunlight combined with the ephemeral nature of this location. Improvements are currently being developed in order to minimize future sensor failures.

4.3 MINERAL CREEK DISCHARGE RECORD

Results for individual gauges from downstream to upstream.

4.3.1 LOWER MINERAL

See **Figure 33**. A reliable rating curve was established for this site. A clear trend of increasing flow in the winter and decreasing flow in the summer can be seen. This oscillation in flow is primarily base flow driven. Data from this site did not indicate daily flows less than 0.001 cfs for the entire duration, indicating that this reach had not been dry during the period of record. There were noticeable instances of drift in the pressure transducer measurements from January 2015 through May 2015 as well as August 2015 through November 2015.

4.3.2 UPPER MINERAL

See **Figure 34**. A reliable rating curve was established for this site. Sustained base flow during the winter appears to be prevalent, with mean daily flows trending toward less than 0.001 cfs during the summer months. Pressure transducer drift was observed spanning from July 2014 through January 2015. Excessive drift was also observed from July 2015 through January 2016, and this data was omitted from the analysis.

4.4 QUEEN CREEK DISCHARGE RECORD

Results for individual gauges from downstream to upstream.

4.4.1 MAGMA AVENUE

See **Figure 35**. The rating curve for this site was developed as part of the gauge installation and was used without modification here. This rating curve was developed for purposes of flood warning and estimation of high discharges. This rating curve does, however, provide the transition between pooled water with no discharge and effective discharge. The results indicate that all runoff measured at this site is event-driven.

4.4.2 UPPER CARBONATE

See **Figure 36**. A reliable rating curve was established for this site. The results indicate that summer months are generally dry and discharge was reported for winter months. Minor pressure transducer drift was observed in the data spanning from June 2014 through August 2014.

APPENDIX A DISCHARGE RECORD PLOTS

The plots depict the discharge record for each gauge.

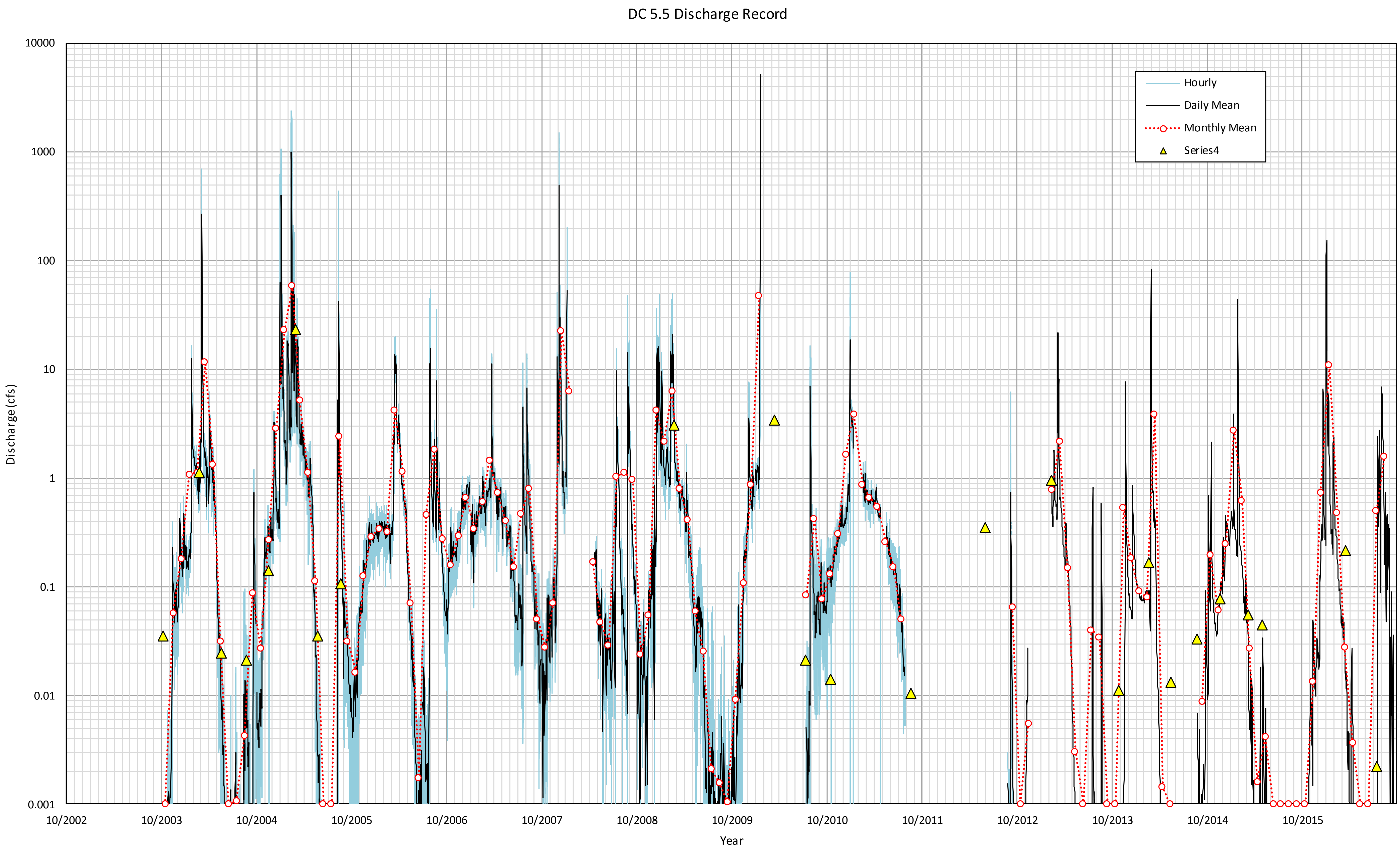

Figure 25. DC 5.5 Discharge Record.

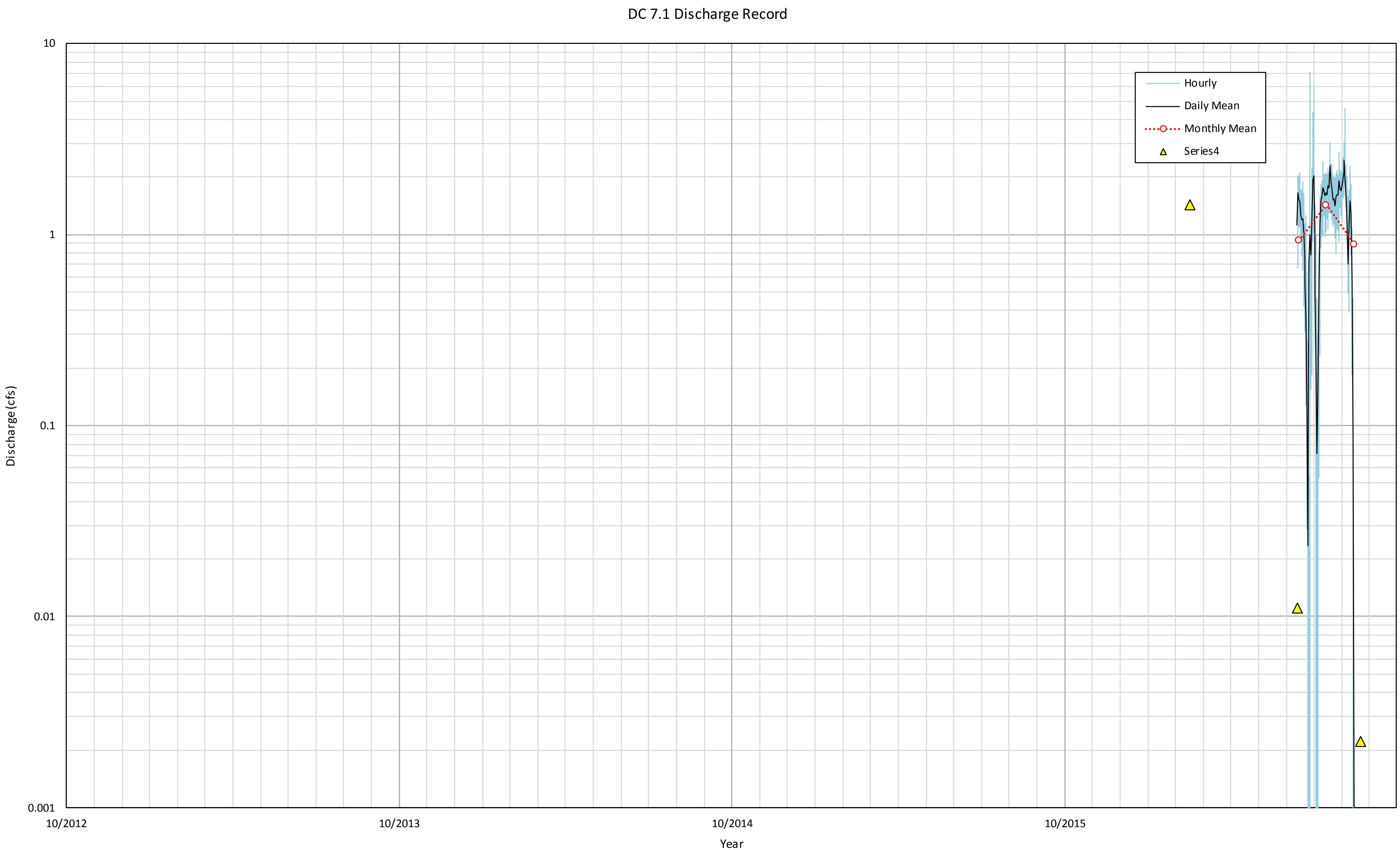

Figure 26. DC 7.1 Discharge Record.

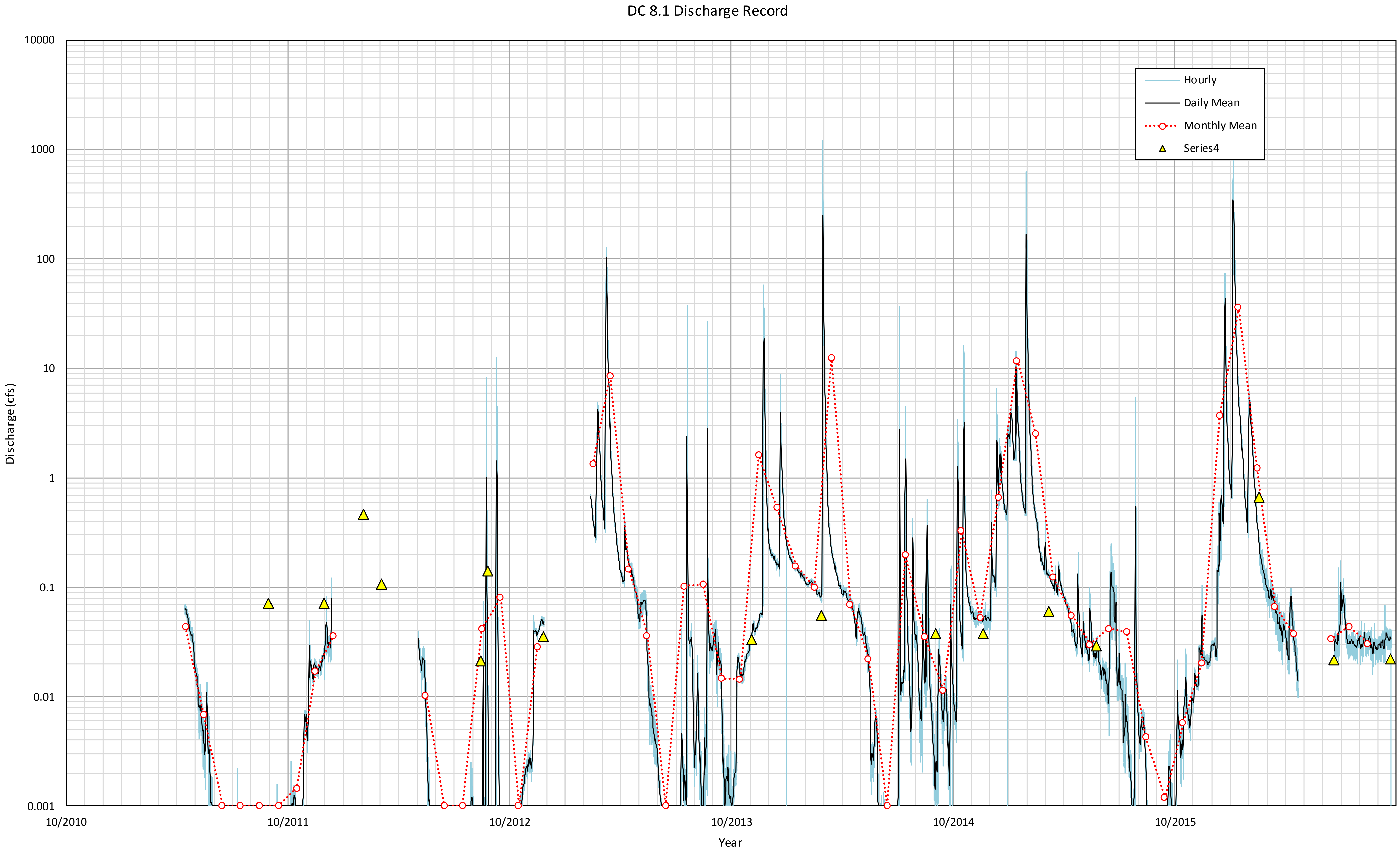

Figure 27. DC 8.1 Discharge Record.

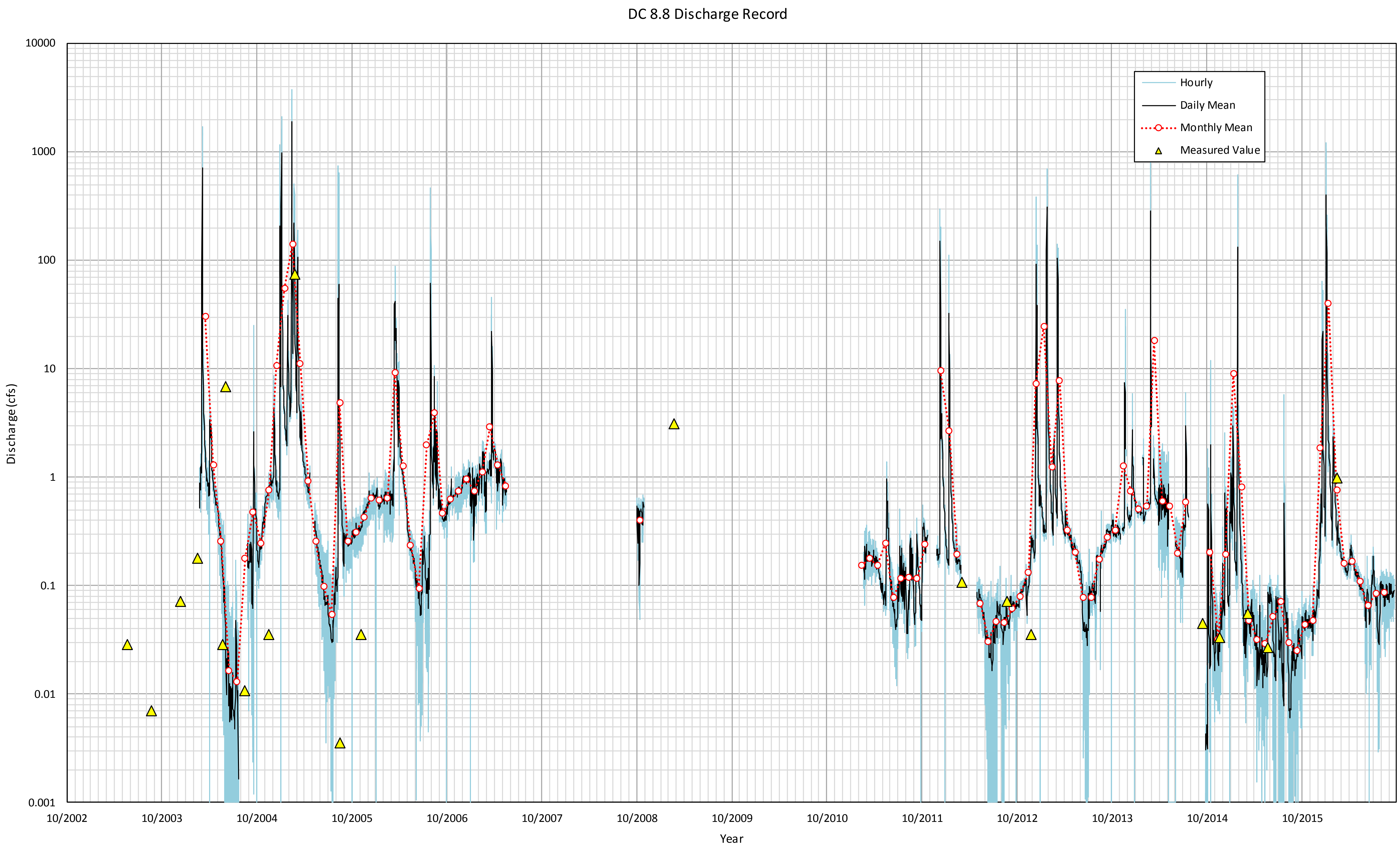

Figure 28. DC 8.8 Discharge Record.

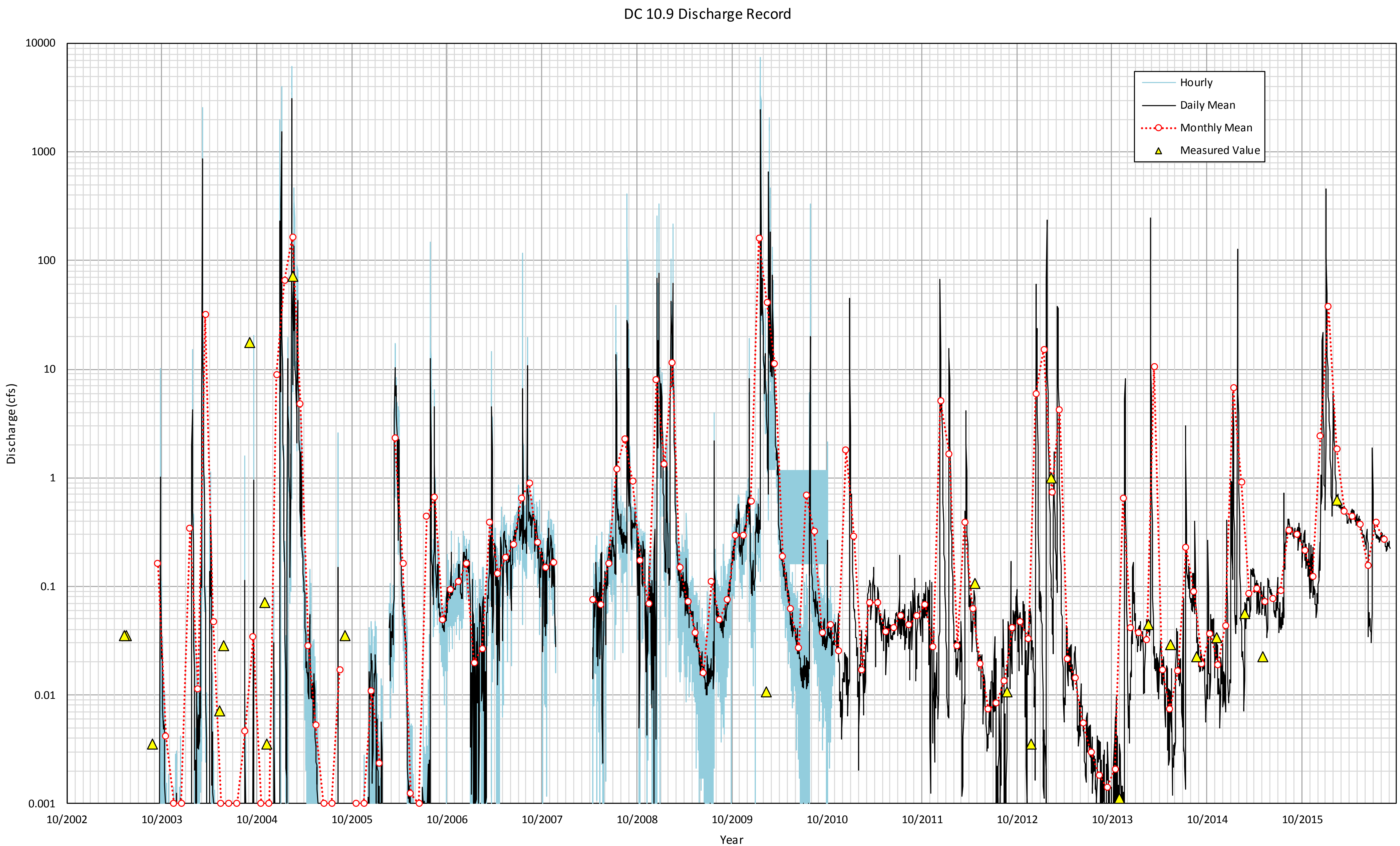

Figure 29. DC 10.9 Discharge Record.

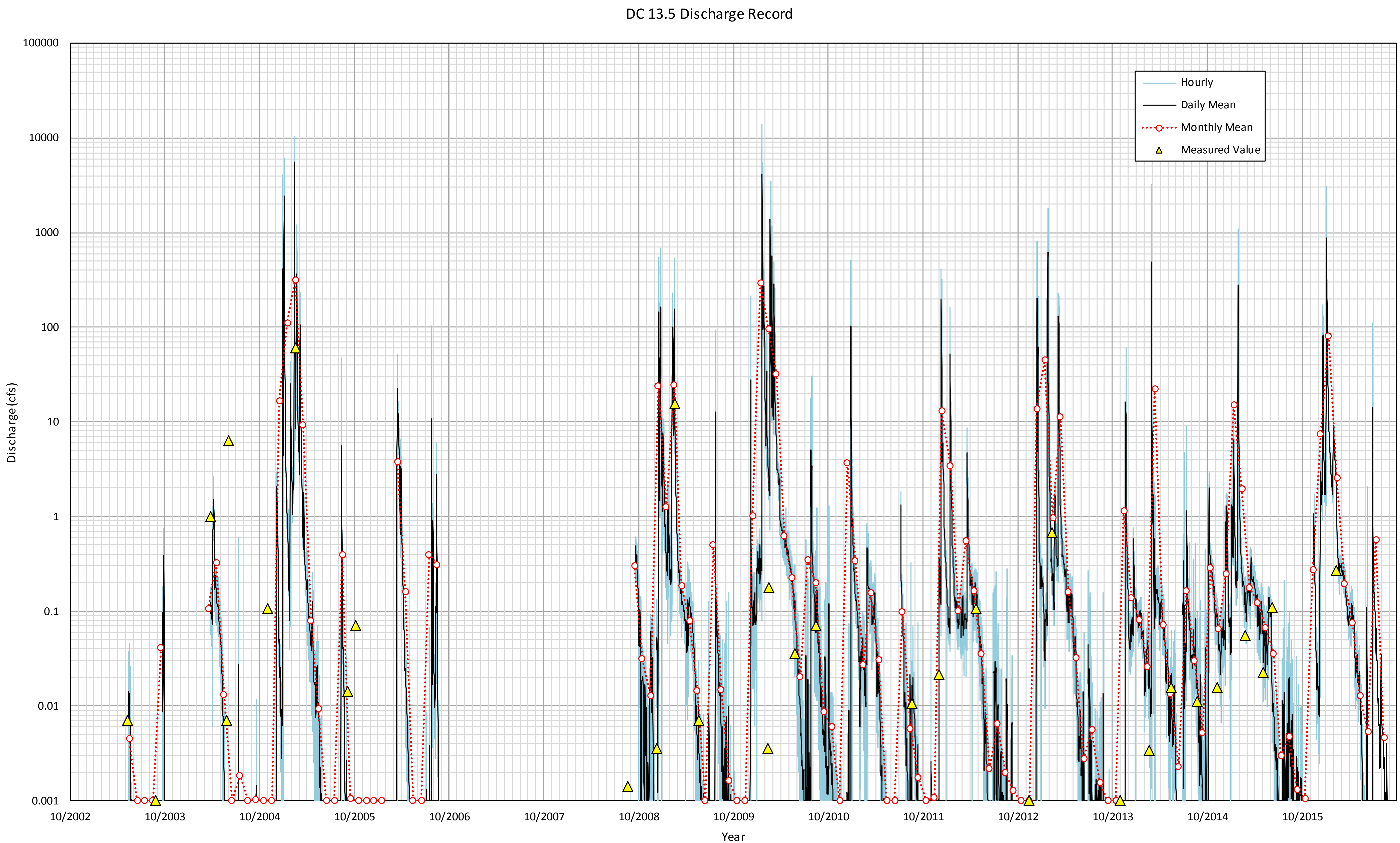

Figure 30. DC 13.5 Discharge Record.

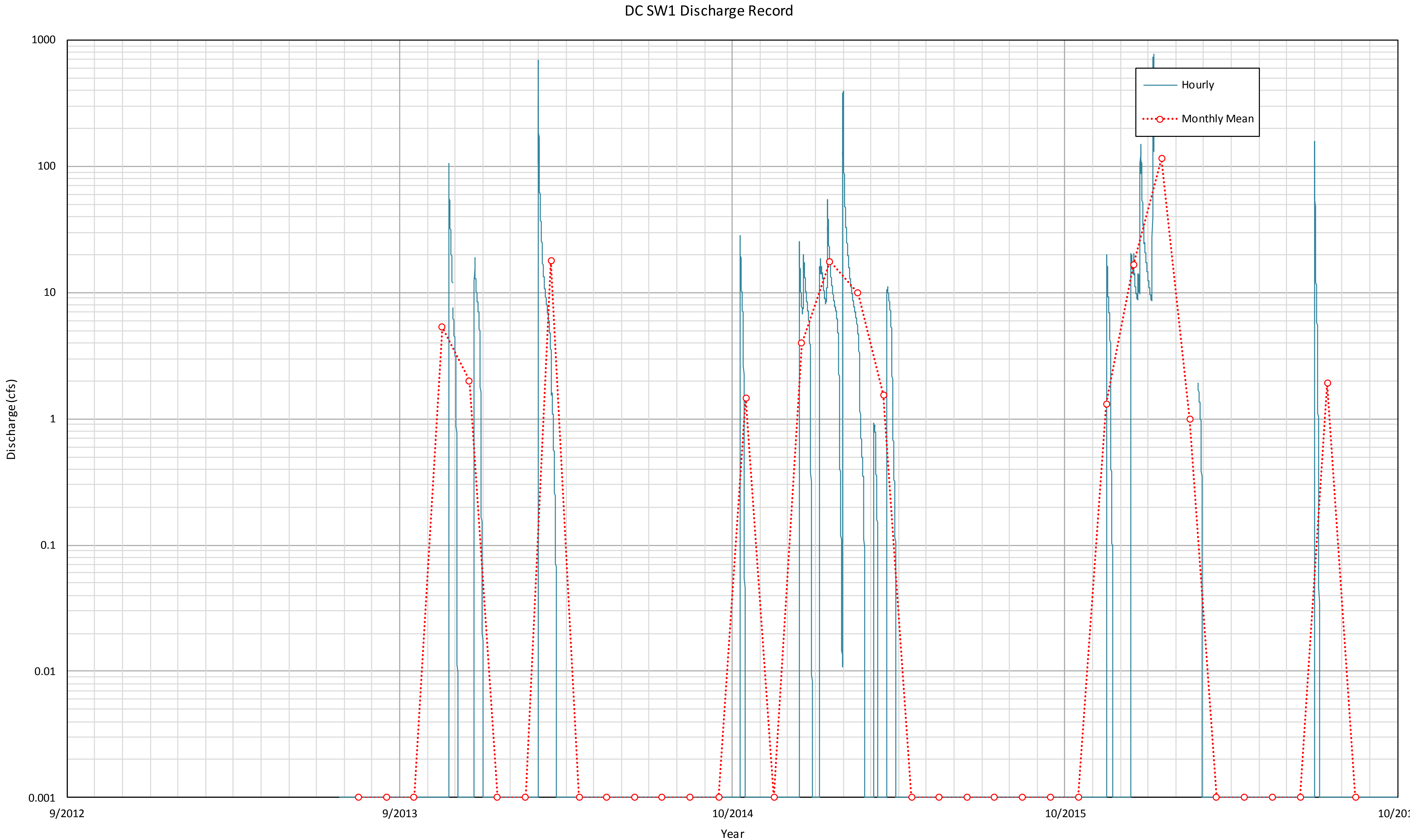

Figure 31. DC SW1 Discharge Record.

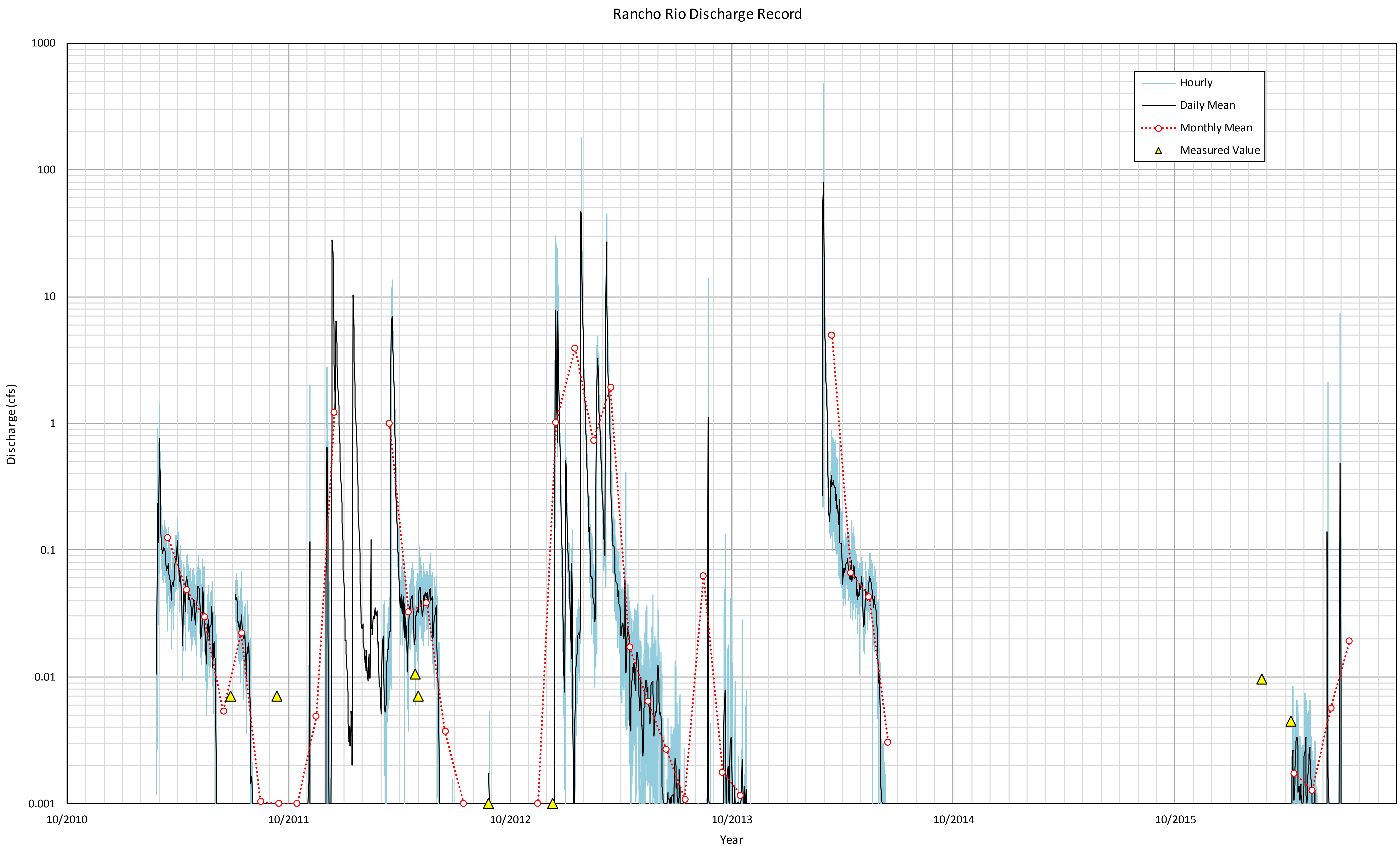

Figure 32. Rancho Rio Discharge Record.

Figure 33. Lower Mineral Discharge Record.

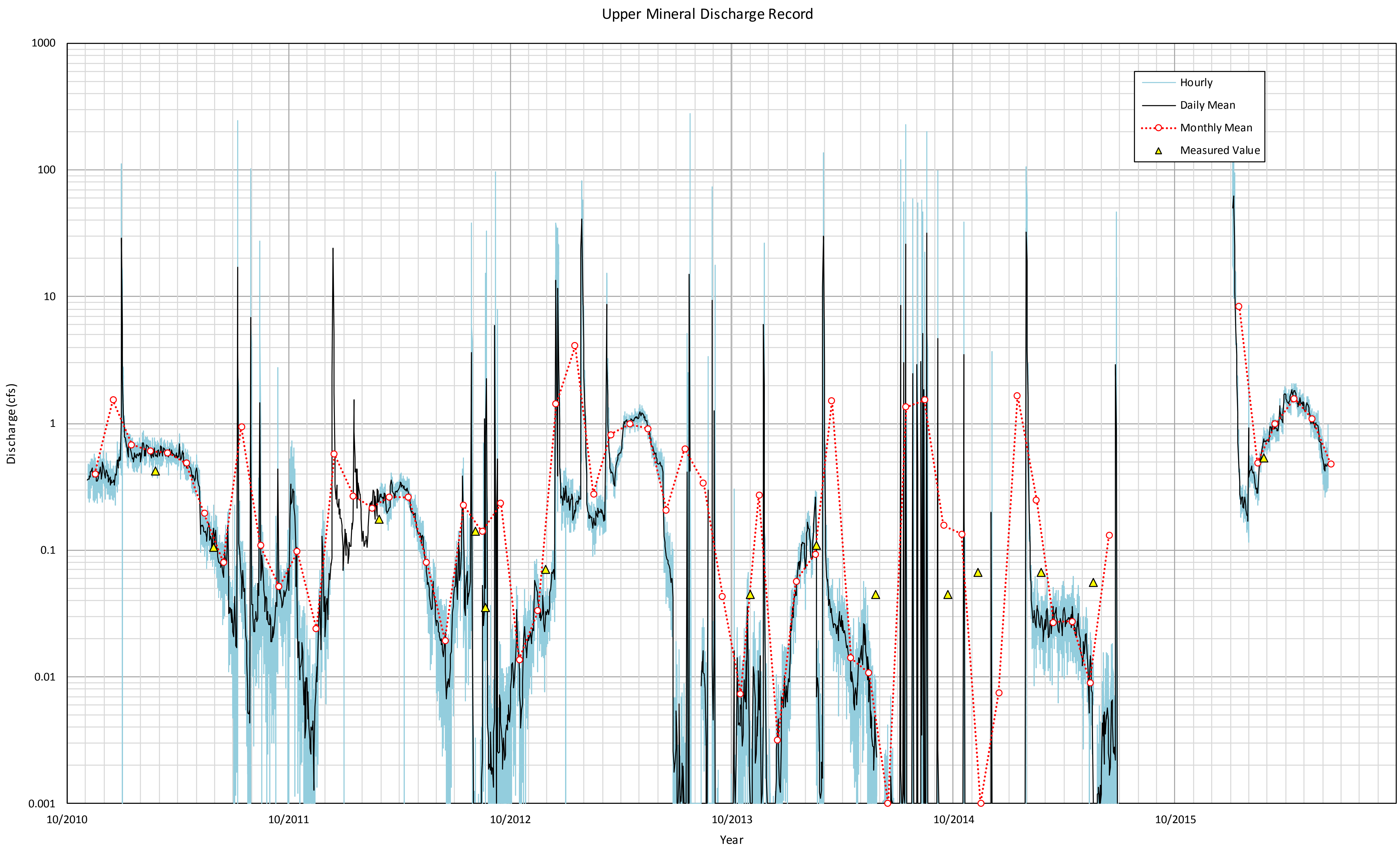

Figure 34. Upper Mineral Discharge Record.

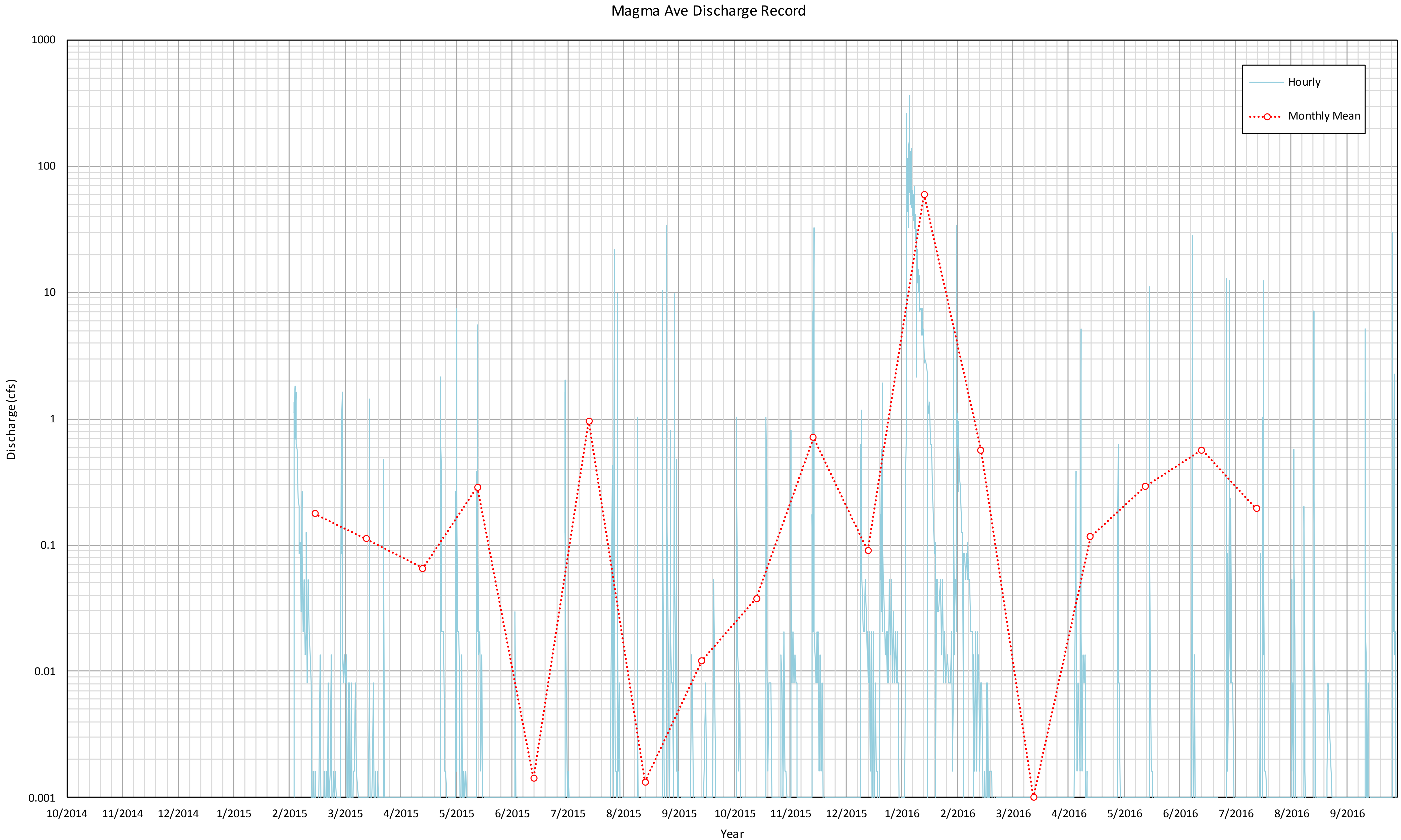

Figure 35. Magma Avenue Discharge Record.

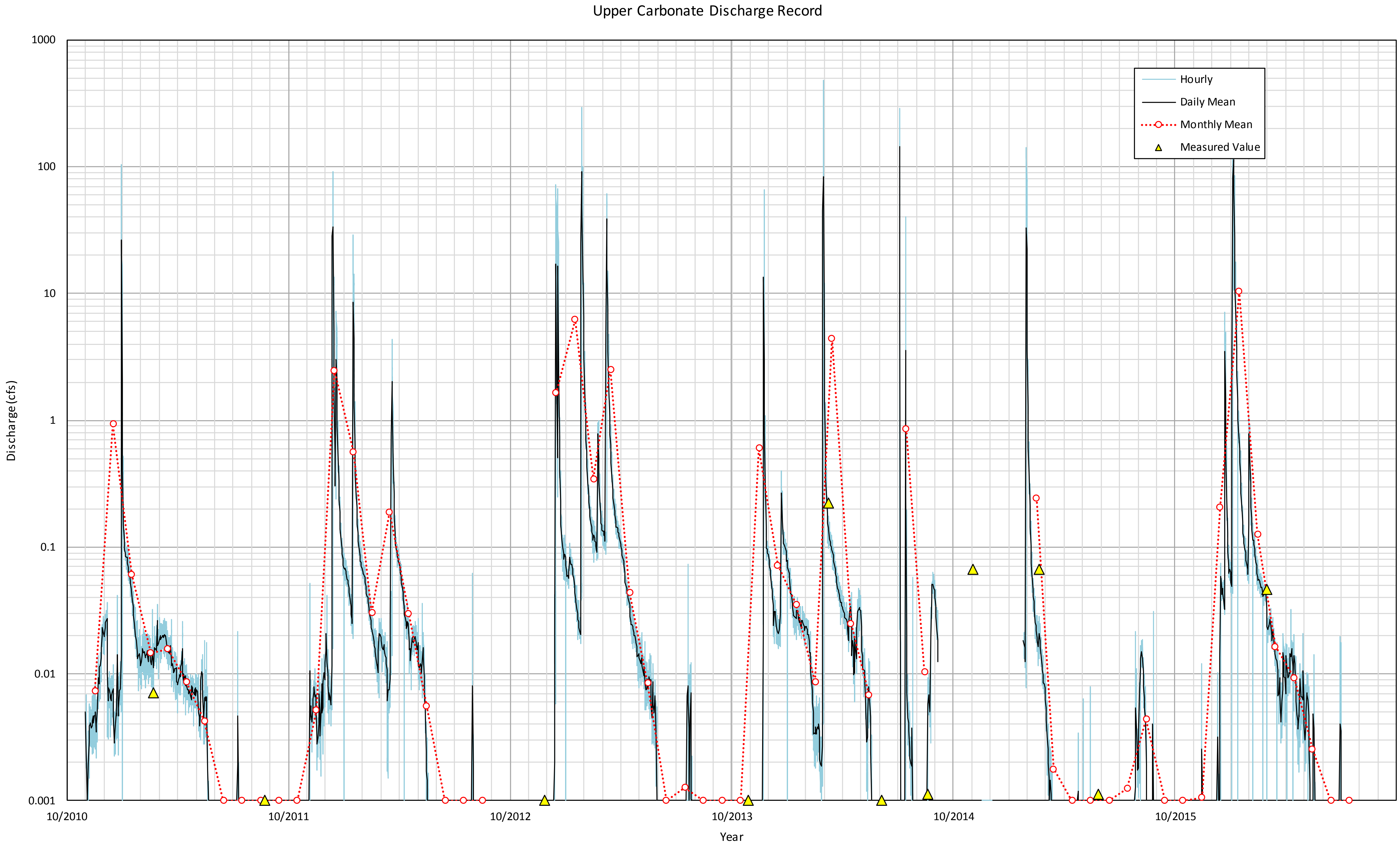

Figure 36. Upper Carbonate Discharge Record.

APPENDIX B SITE-SPECIFIC RATING CURVES

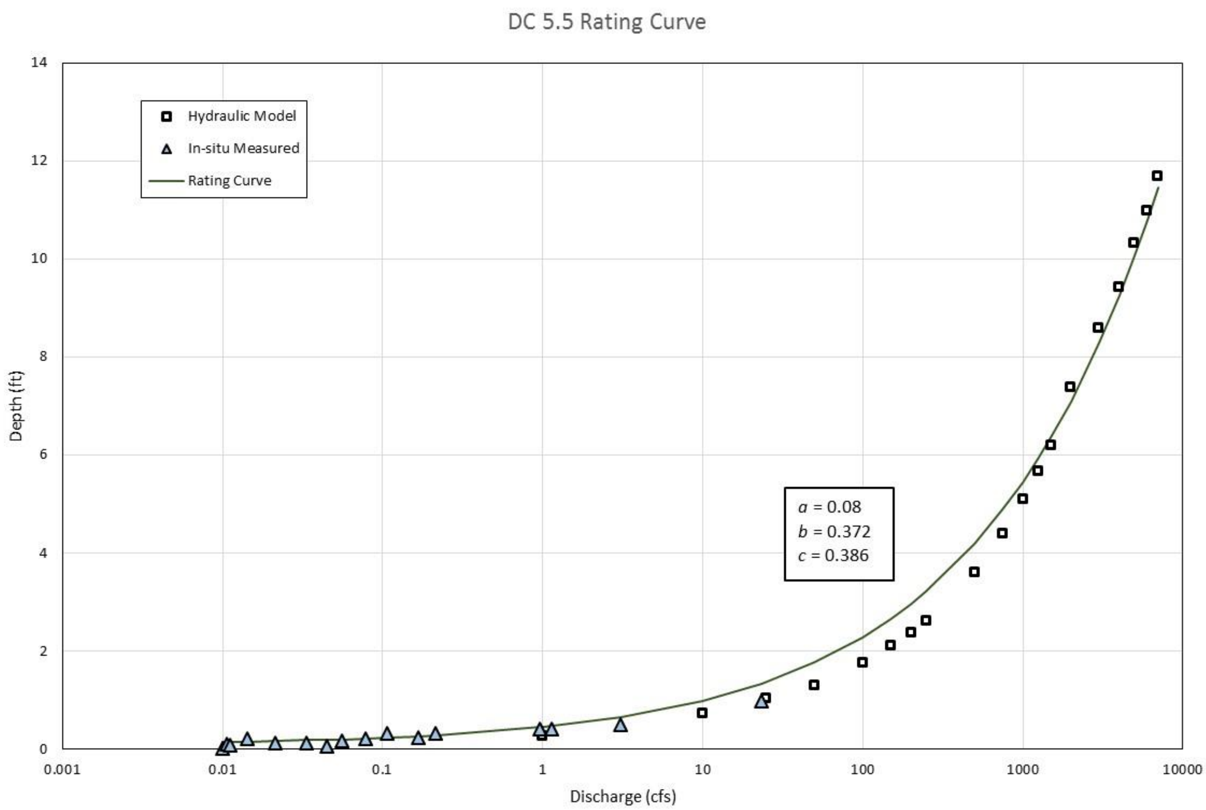

Figure 37. DC 5.5 Rating Curve.

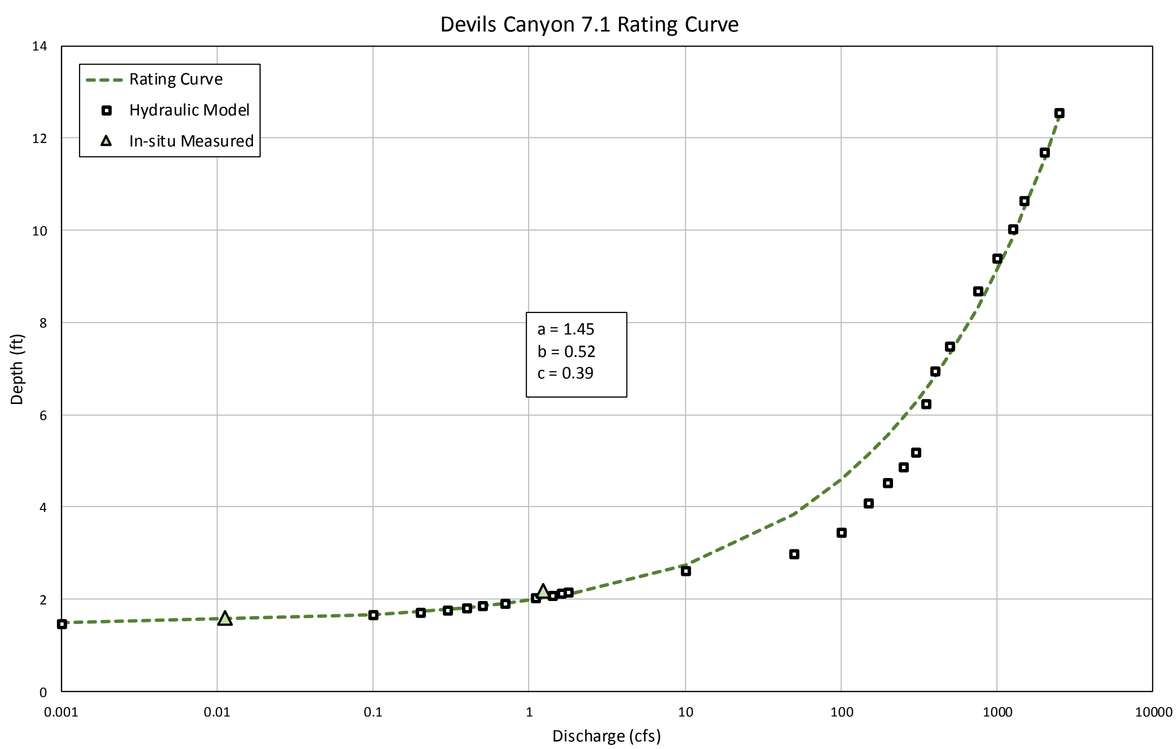

Figure 38. DC 7.1 Rating Curve.

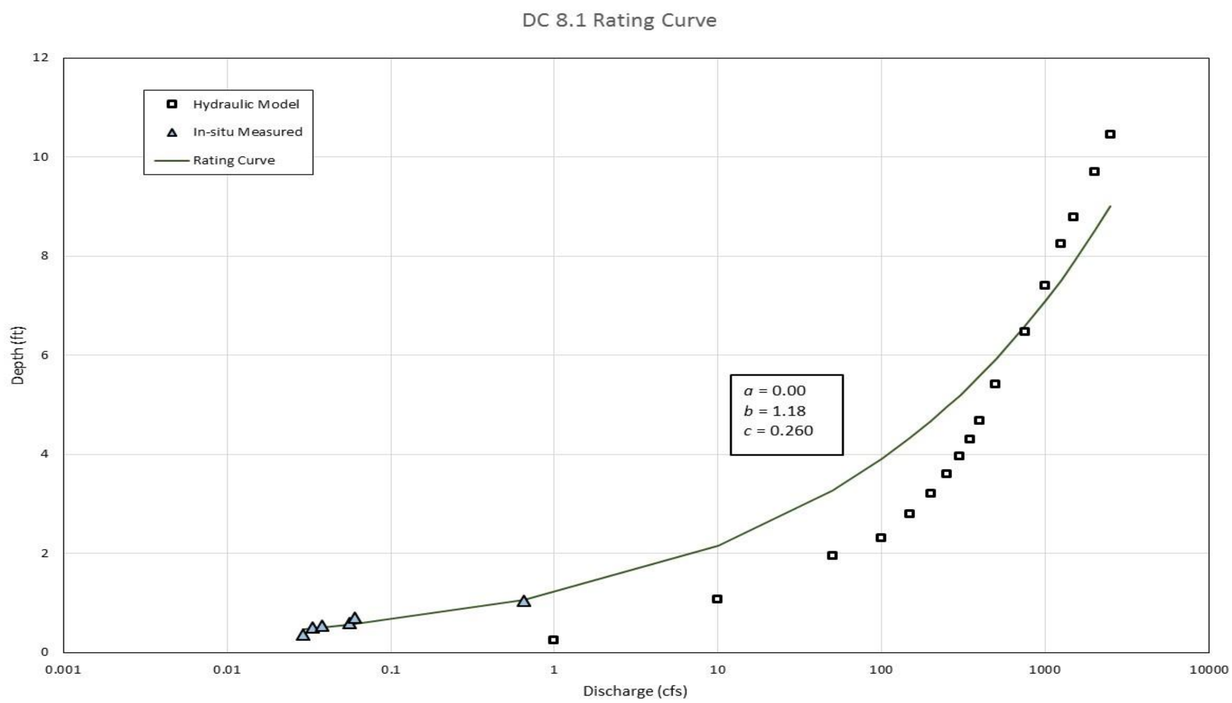

Figure 39. DC 8.1 Rating Curve

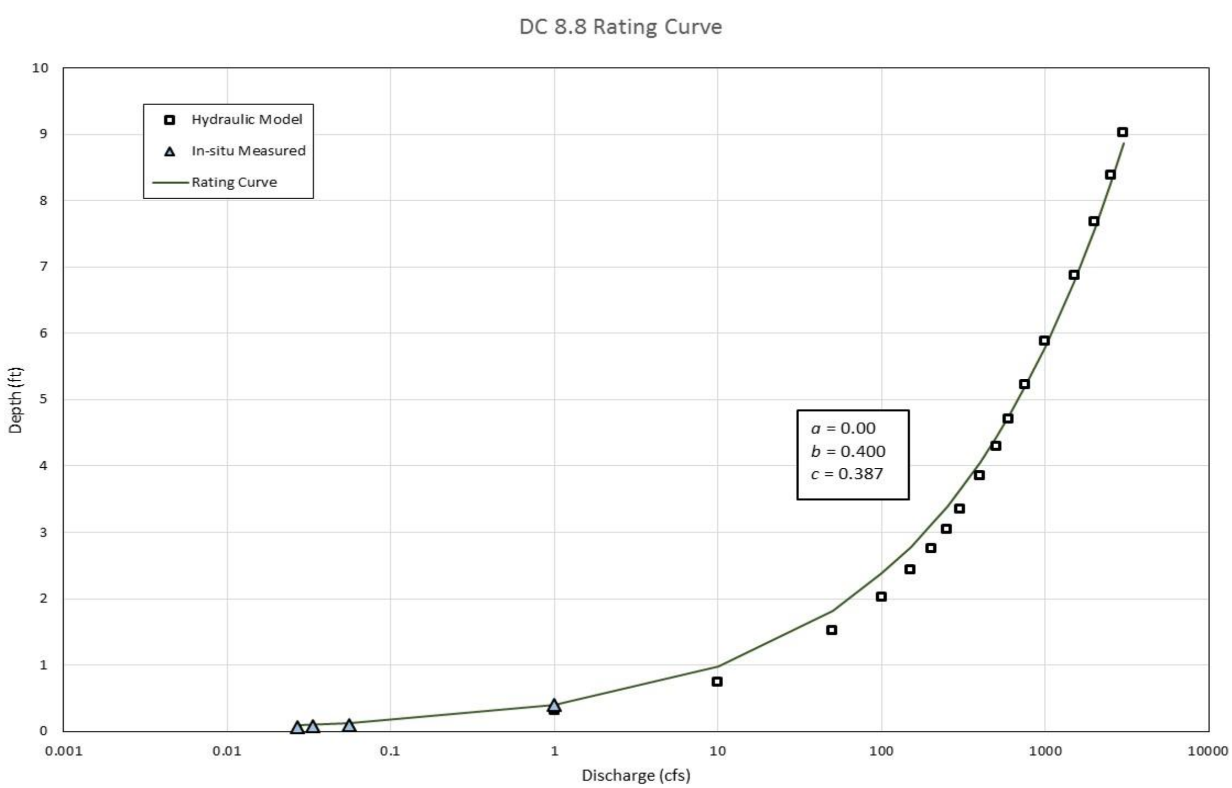

Figure 40. DC 8.8 Rating Curve

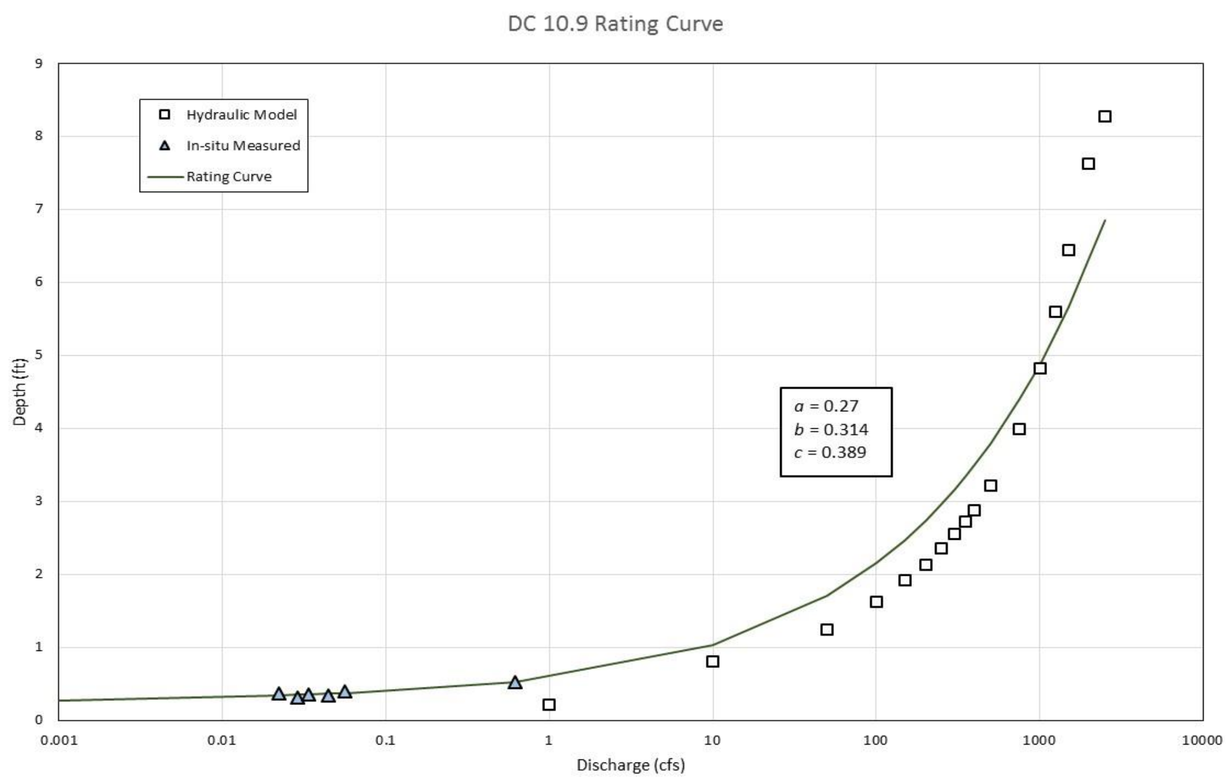

Figure 41. DC 10.9 Rating Curve.

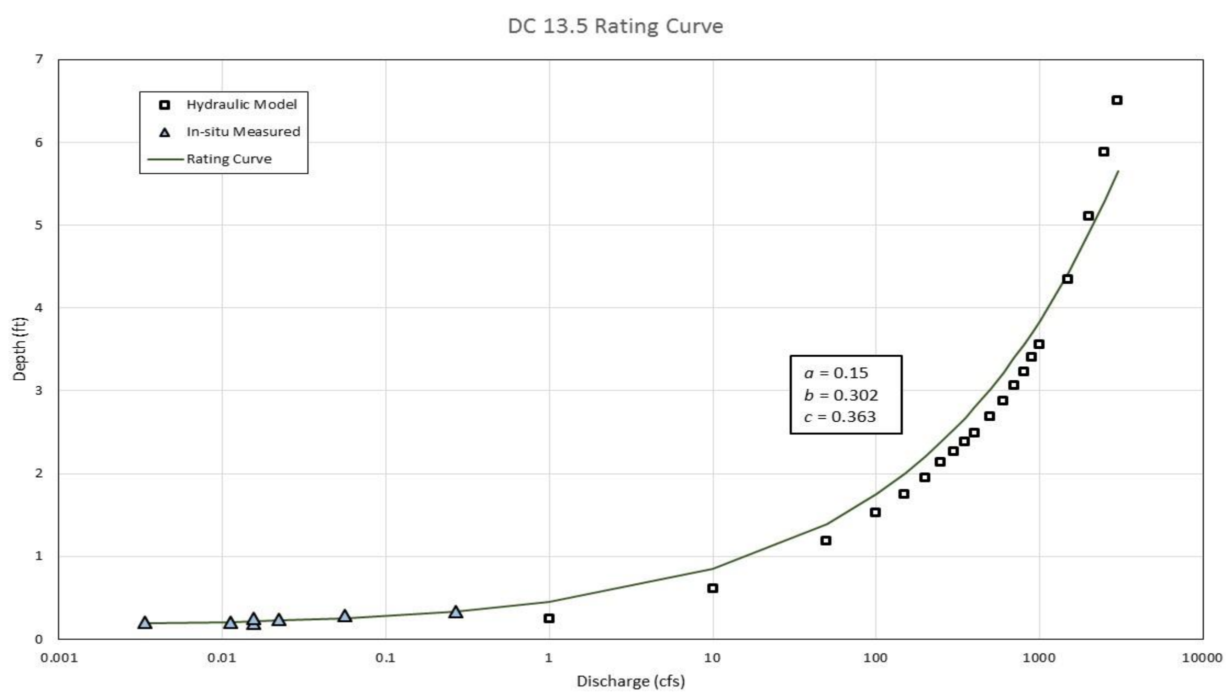

Figure 42. DC 13.5 Rating Curve.

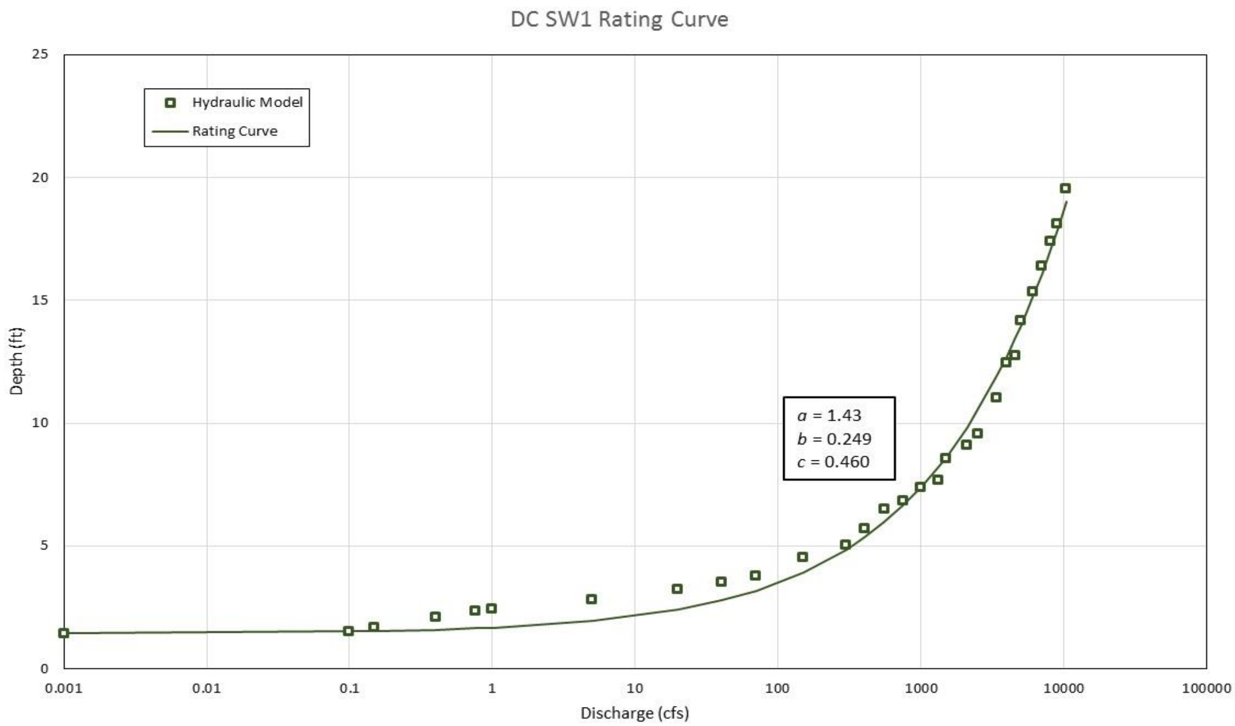

Figure 43. DC SW1 Rating Curve.

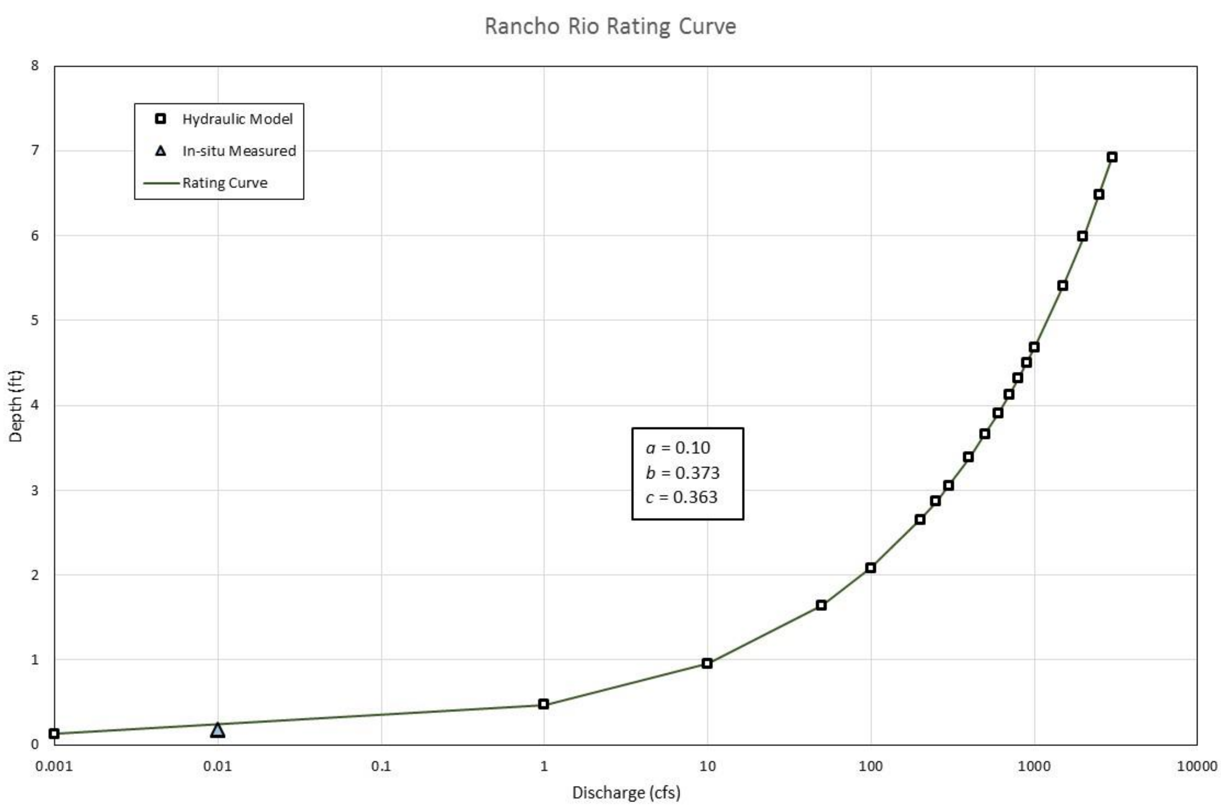

Figure 44. Rancho Rio Rating Curve.

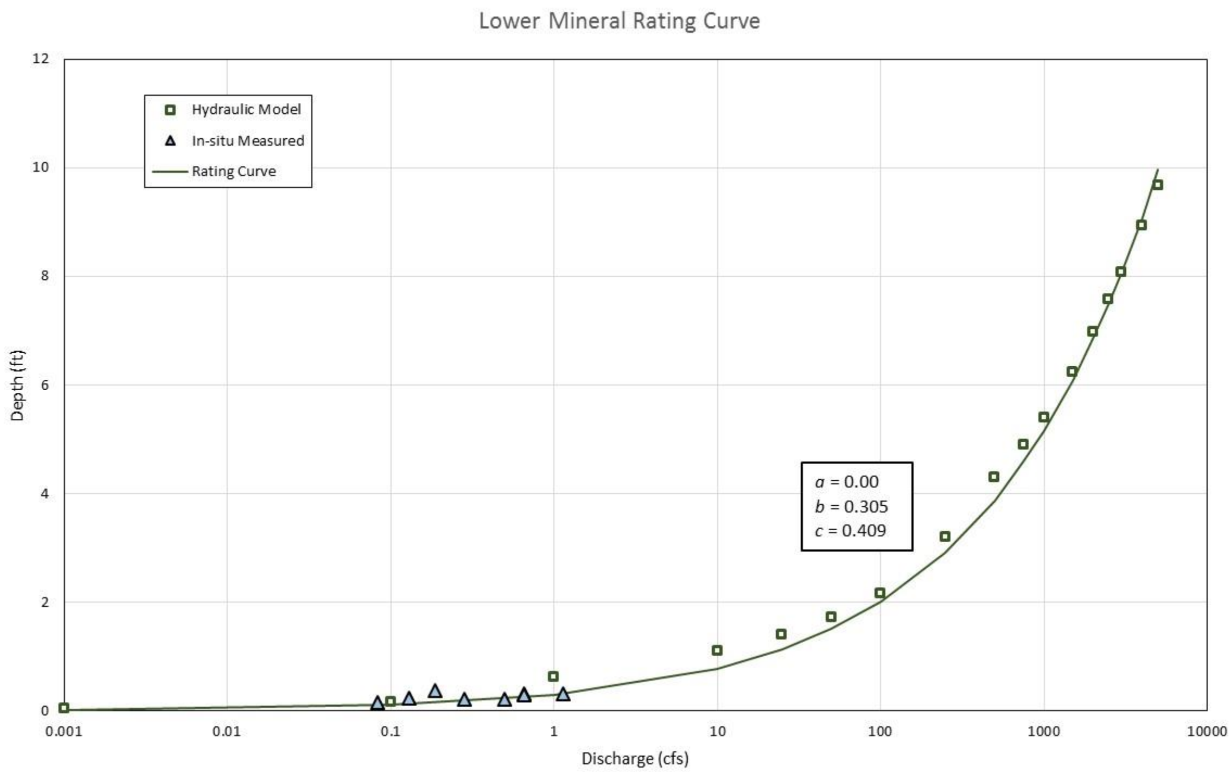

Figure 45. Lower Mineral Rating Curve.

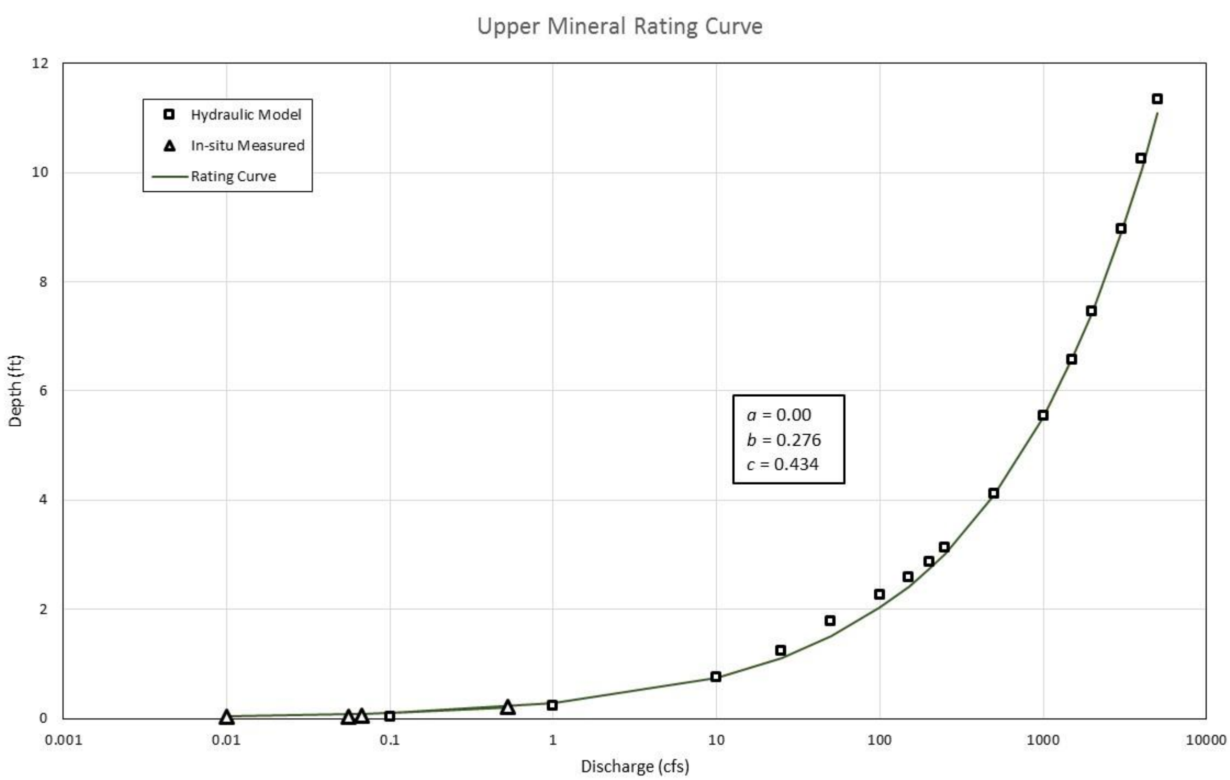

Figure 46. Upper Mineral Rating Curve.

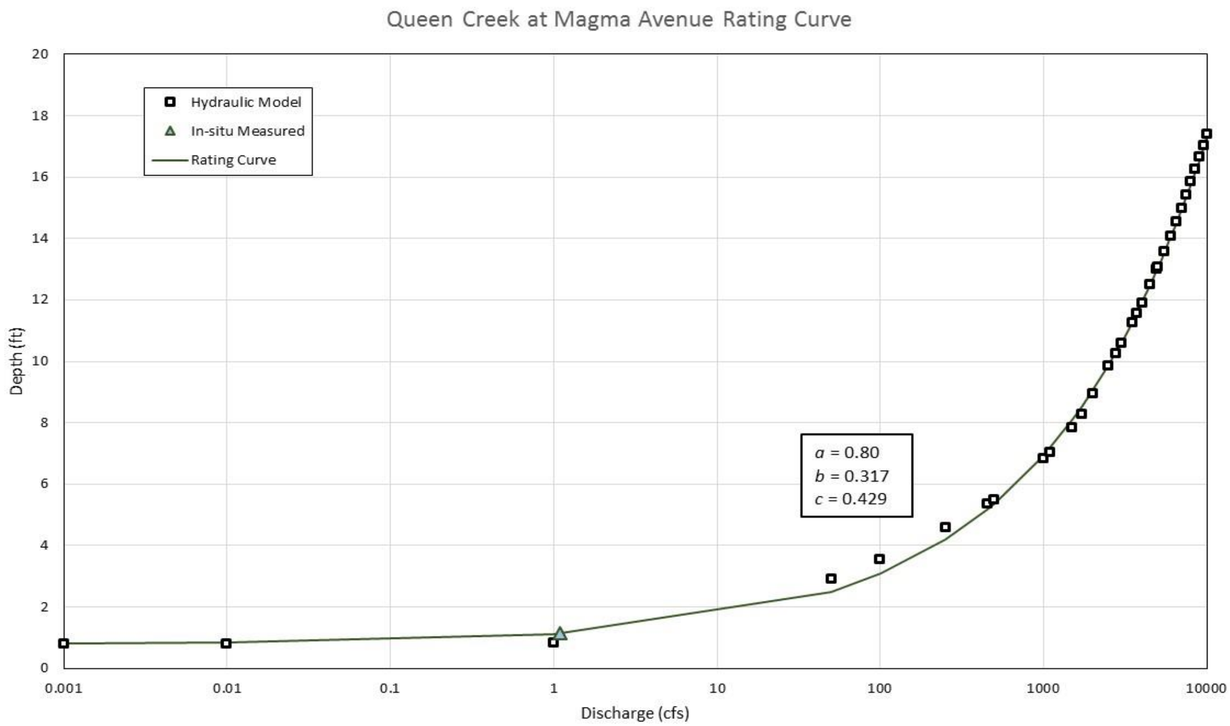

Figure 47. Queen Creek at Magma Avenue Rating Curve.

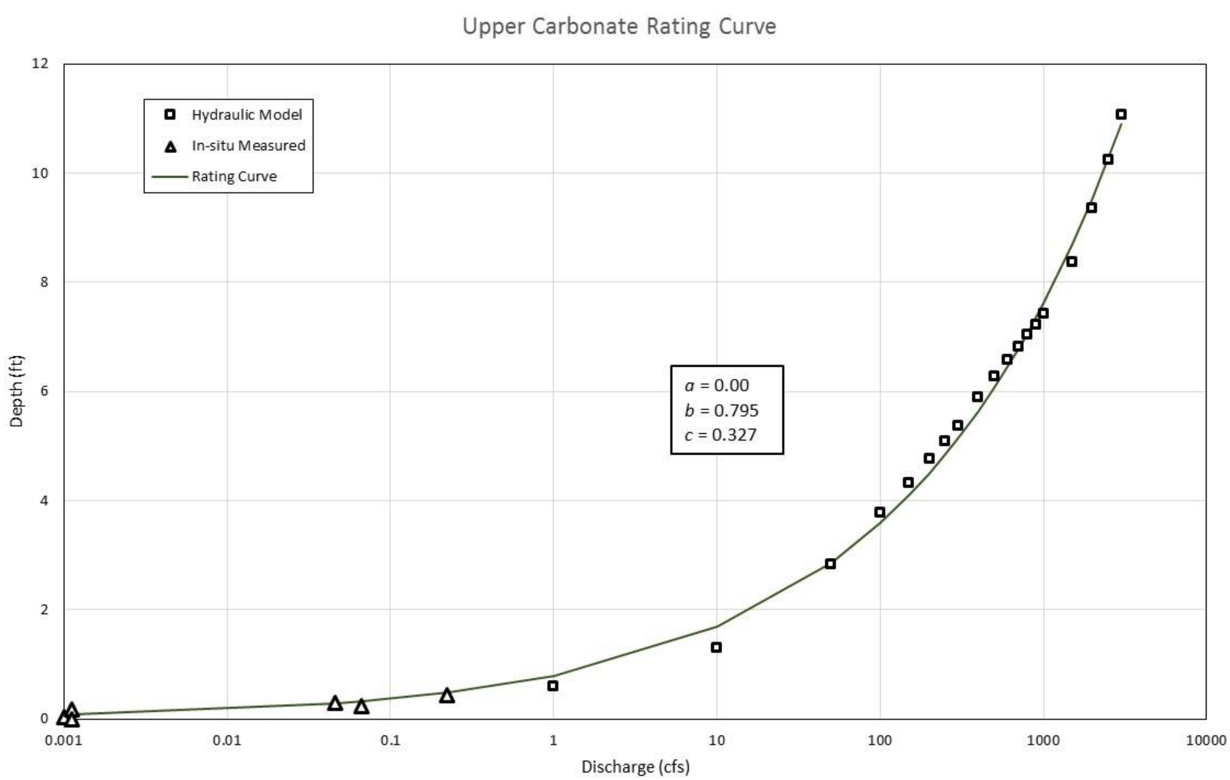

Figure 48. Upper Carbonate Rating Curve.