

**Flow monitoring technology and methodology assessment
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Iowa Department of Natural Resources

Watershed Improvement Section

&

Watershed Monitoring and Assessment Section

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Executive Summary

Iowa Department of Natural Resources (IDNR) Total Maximum Daily Load (TMDL) watershed plans in Iowa focus on small (HUC 12) watersheds. These watersheds rarely contain U.S. Geological Survey (USGS) gaging stations, making flow one of the most difficult attributes to estimate for TMDL development. This lack of accurate flow data complicates the calibration of advanced models, such as SWAT, strains the ability to develop accurate and attainable TMDL targets, and limits the program's ability to show improvements in water quality through monitoring.

This study focused on assessing the accuracy and reliability of Area Velocity Flow Meters (AVFM) for use in TMDL development and subsequent water quality improvement monitoring in small (HUC 12) watersheds. The assessment of this flow collection technology and deployment methodology contributes to goal two of EPA's 2010 Strategic Plan – clean and safe water. Specifically, this project contributes to the first four strategic targets identified in this Strategic Plan. The first three targets relate to measurable goals of improving water quality adequately to eliminate impairments in water bodies and/or across watershed and the fourth target relates to preventing the deterioration of water quality in wadeable streams.

During this study, Isco 2150 AVFM units were co-located at existing USGS gage stations in three watersheds in eastern Iowa. The co-location with USGS gages allowed for an assessment of the accuracy of AVFM collected data. Two of the sites yielded positive results. Stage-discharge curves developed from Clear Creek and Rapid Creek had 95 and 98 percent (respectively) of discharge comparison points fell within an acceptable range of accuracy when compared to USGS generated data. Hoover Creek, the site with the smallest drainage area, did not perform well. Only 10 percent of all comparison points were acceptable when compared to USGS data. Site specific conditions were determined to be the primary cause of the errors found at this site.

On the whole this study determined that the Isco 2150 AVFM and other similar flow technologies can provide a useful tool for obtaining more accurate and affordable continuous flow data. The use of this technology with appropriate deployment methodologies has the potential to provide resource managers with site specific data critical to the development of restoration plans and could be a key component in continued monitoring for water quality improvements.

1. Introduction

Iowa Department of Natural Resources (IDNR) Total Maximum Daily Load (TMDL) watershed plans in Iowa have recently shifted focus from large basins, which typically contained one or more United States Geological Survey (USGS) gaging stations, to small (50 mi² or less) watersheds. These small watershed areas rarely include USGS gaging stations, making flow one of the most difficult attributes to estimate for TMDL development. This lack of accurate flow data complicates the calibration of advanced models, such as SWAT, and strains the program's ability to develop accurate and attainable TMDL targets with available resources.

Flow data collection for TMDL development in Iowa is currently conducted using manual flow measurements at established cross-sections where a continuous stage record is collected. These sites are routinely visited under low or base flow conditions and most attempts to collect flow during peak discharge conditions are unsuccessful. The problems associated with collecting peak discharge using this methodology stem from the relatively small size of TMDL project watersheds. Discharge events in these small watersheds are flashy in nature and have short duration high-flows that field crews rarely have an opportunity to measure. These high flow events are crucial in defining a proper rating curve, especially since they are also responsible for carrying the overwhelming majority of pollutant loads.

Collection of accurate flow data is necessary for the development of accurate and reliable TMDLs and equipping small watersheds with USGS gages is an expense that the current TMDL budget can not handle. Consequently, the developments of new methods for measuring flow in smaller watersheds is critical to the IDNR's ability to cost effectively develop accurate TMDL targets and maintain public credibility.

This study was designed to test the accuracy of stream rating curves created with a Teledyne ISCO 2150 Area Velocity Flow Meter (AVFM), and to develop deployment methodologies suitable for TMDL monitoring networks. The major objectives of this project were:

- 1) Determine how accurately and reliably AVFMs measure flow in small streams;
- 2) Determine how accurately and reliably pressure transducers measure stream stage in small streams using rapid deployment procedures; and
- 3) Test methodologies and determine costs (in terms of time) of using AVFMs and pressure transducers to create stream rating curves in small streams.

2. Materials and Methods

2.1. Study area and sampling design

The study area for this project centered on three watersheds in Cedar, Iowa, and Johnson counties in eastern Iowa (Figure 2-1). Each of these three watersheds contains USGS gages that have drainage areas near the IDNR TMDL target watershed size of roughly 50 mi² or less. Hoover Creek at Herbert Hoover National Historic Site, Rapid Creek near Iowa City, and Clear Creek near Oxford have drainage areas of 2.58 mi², 25.3 mi², and 58.4 mi² respectively.

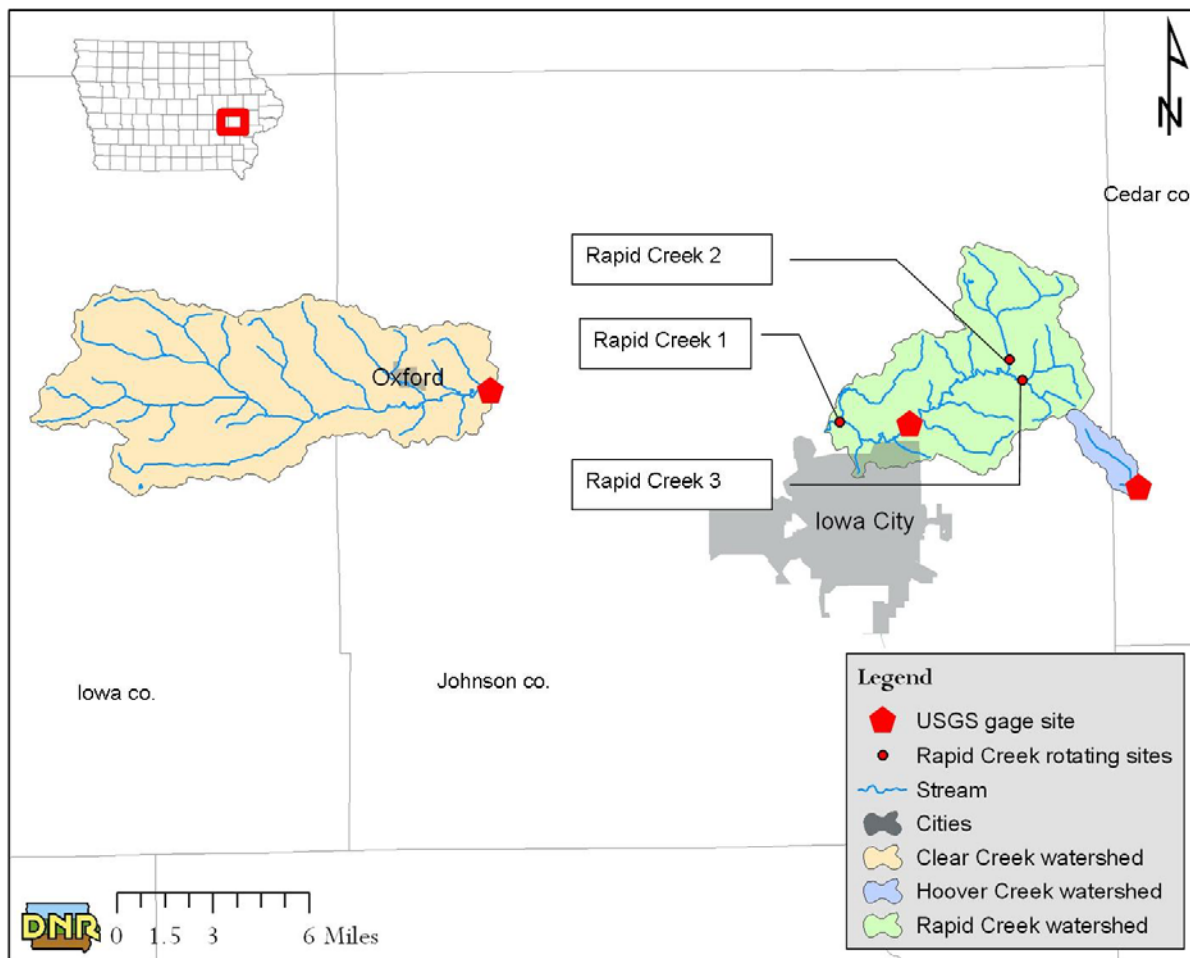


Figure 2-1 Map of study area

The areas around Cedar, Iowa, and Johnson counties receive an average of 35 inches of precipitation annually (Iowa Mesonet, 2010). The majority of this precipitation falls in spring and early summer. During this study in 2009, precipitation was near normal during April, May, and June and above normal in July and August (Figure 2-2). These precipitation events caused extensive flooding in streams later in the year than typically observed for those times of year.

The three USGS gages served as the fixed monitoring locations for this study. In April 2009, an Isco 2150 Area Velocity Flow Meter (AVFM) and an In-Situ Level Troll 100 pressure transducer were installed at each gage site. USGS gage data served as a benchmark to which the data collected with AVFMs and Level Trolls could be compared. In addition to the co-location with USGS gages, three flow cross-sections were established in the Rapid Creek watershed (Figure

2-1). These sites corresponded to locations that would have been established had Rapid Creek been subject to TMDL data collection. Rapid Creek 1 was established near the mouth of Rapid Creek and has a 29.4 mi² drainage area. Rapid Creek 2 and Rapid Creek 3 were established on two main tributaries to Rapid Creek in the upper portion of the watershed. Rapid Creek 2 has an 8.21 mi² drainage area; Rapid Creek 3 has a 2.04 mi² drainage area.

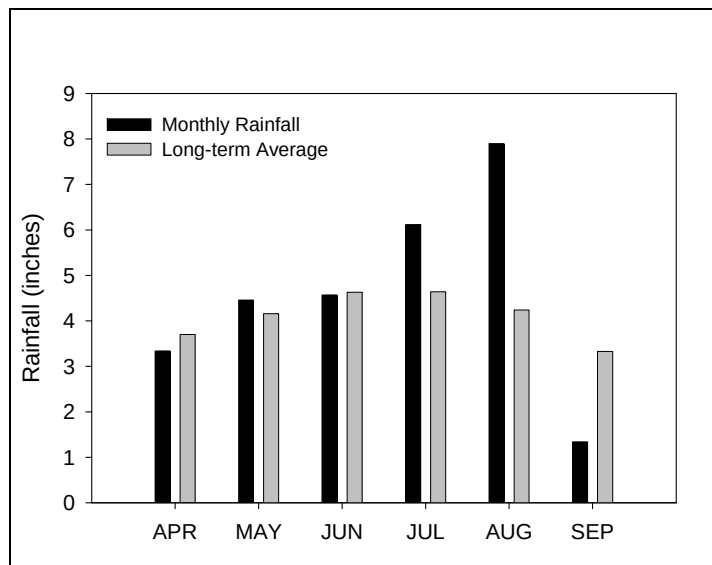


Figure 2-2 Monthly rainfall in study area across 2009 monitoring season

Each of the three additional sites along Rapid Creek had an In-Situ Level Troll 100 installed near the flow cross-section, which provided a continuous stage record throughout the monitoring season. During the monitoring season one AVFM was rotated among the three Rapid Creek rotating sites on a bi-weekly basis. Currently, IDNR TMDL sites are routinely sampled on a bi-weekly basis. Following this convention, all sites established during this study were visited on that schedule. During each bi-weekly monitoring trip a manual flow measurement was taken with a Marsh-McBirney Flo-Mate 2000 using procedures laid out in the project's QAPP (Appendix B), data were downloaded from all equipment, stage corrections, if necessary, were made, and one AVFM was moved from one rotating site to another. These rotating sites were established in order to test the flexibility this deployment methodology and determine how mobile the AVFM units are. Time spent moving units and re-establishing cross sections, durability of equipment, and reliability of data were all taken into consideration while testing the methodology.

2.2. Site selection and equipment installation

The initial installation of AVFMs and pressure transducers at USGS gage sites took place in early April 2009. The first step in this process was to select a suitable channel cross section for AVFM installation. The Isco 2150 Area Velocity (AV) sensor measures average velocity of the water column by using ultrasonic sound waves and the Doppler Effect. The unit uses sound waves reflected off particles and bubbles moving in the flow column to determine an average velocity. This velocity is used in conjunction with real-time stage data collected by a pressure transducer, which is built into the AV sensor. The combination of stage and velocity is used in conjunction with a user defined cross section to determine flow. The Isco 2150 allows for the selection of several cross section types. The user may choose from round (pipe), U-shaped, square, and trapezoidal channel types. While very few natural stream channels can be

considered perfect trapezoids, this channel type was the most suitable for deployments in this study.

Once a stable, trapezoid like cross section with minimal flow turbulence was identified the equipment was put in place. The AV sensor is connected to the control box and power supply by a long heavy gage cable and was anchored to the stream bottom using an auger style anchor that is screwed into the stream bottom (Figure 2-3-A). The length of anchor and width of auger necessary to hold the unit in place changes by substrate type. Armored clay or gravel bottoms required shorter anchors with smaller diameter augers while sandy bottom streams required long (36") shafts with 3" diameter augers.

The AV sensor was placed near the center of the channel where the thalweg was located and was positioned with the sensor facing directly into the main flow of the channel (Figure 2-3-B). The cable leading from the AV sensor to the control box was tethered to metal t-posts and was installed along the stream bottom behind the AV flow cross section (Figure 2-3-C). The control box and power supply were housed in a tool box and anchored to a structure above typical flood stage. Control and programming of the 2150 AVFM were achieved using a simple USB connection port to connect any Windows based operating system computer to the device (Figure 2-3-D).



A: Installing sensor to stream bottom



B: AV sensor on stream bottom



C: Securing cable to T-post



D: Programming AVFM unit

Figure 2-3 Initial 2150 AVFM installation photos

Once the equipment was in place the unit was powered on according to procedures outlined in the documentation provided by Isco, and programmed using Isco's Flowlink for Windows software. The initial programming for each site requires the measurement of channel attributes in order to collect flow data. Selection of the trapezoid channel type requires a top of channel width, bottom of channel width, maximum flow depth, and current channel stage (Figure 2-4).

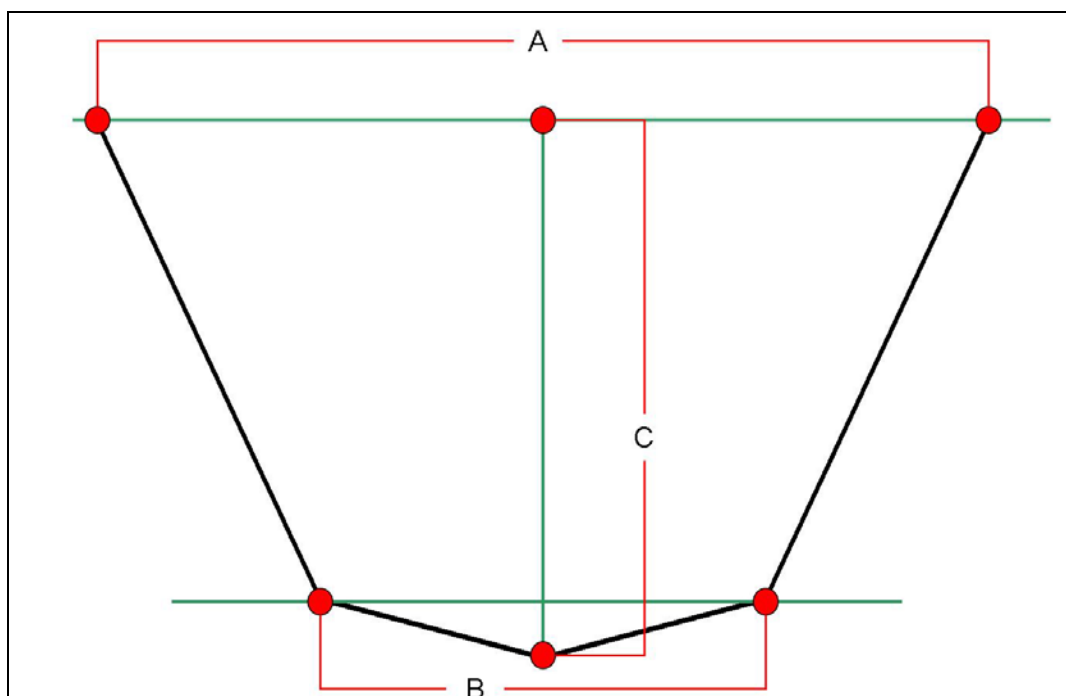


Figure 2-4 Channel cross section diagram, (A) top of channel width, (B) bottom of channel width, (C) maximum flow depth.

Each of the AVFM units was initially programmed to collect data every 15 minutes, which matches the frequency of data collected at most USGS gages. The AVFM units have the ability to collect data more frequently once certain stream stage thresholds were exceeded. To better define flow during flood events, the units at the three USGS gage sites were later programmed to collect data more frequently when the stream stage exceeded a specified level. The sample frequency during high flow events was set at 5 minutes, 1 minute, and 2 minutes at Clear Creek, Rapid Creek, and Hoover Creek, respectively.

This AVFM installation procedure was repeated for each of the fixed USGS sites and was performed at each of the three rotating sites on Rapid Creek. As long as the unit was placed in the same location and the channel cross-section had not been altered, the initial installation measurements for each rotating site needed to be collected only once since the site information was stored in the AVFM unit.

All sites in this study were equipped with In-Situ Level TROLL 100 pressure transducers to monitor stream stage. The Level TROLL 100s were not directly vented to the atmosphere; therefore the measurements were affected by barometric pressure changes. In-Situ Baro TROLL 100 units, which measure barometric pressure, were located at the three USGS gages and were used to correct for the effects of barometric pressure changes on the stream stage measurements within each watershed. Each transducer collected data at 15-minute intervals,

matching the frequency of data collection at most USGS gages. Data were transferred from the pressure transducer to a laptop computer, using In-Situ Win-Situ software, during each bi-weekly site visit. In-Situ's Baro Merge software was used to apply barometric correction to all water level measurements.

The pressure transducers were mounted in a slotted well casing to prevent damage during high flow events. The well casing was attached to a fence post that was anchored in the streambed and was (if possible) placed in an area out of the main flow of the channel, further protecting the transducer from high flow events.

The pressure transducers located at USGS gage sites were programmed to match USGS stage measurements. Each of the three USGS gage sites had onsite equipment that allowed accurate stream stage measurements to be made at each bi-weekly visit. These stage measurements were used to program and track the accuracy of the pressure transducers at the USGS gage sites. At the remaining three rotating sites, a staff plate was erected on a bridge abutment in order to collect accurate stream stage measurements during each bi-weekly visit. Measurements from these staff plates were used as a reference for programming the pressure transducers at the non-gage sites.

3. Analysis results

Data collected during this study in 2009 was impacted by a manufacturer's recall, which occurred after the end of the 2009 field season. All of the Isco 2150 units, In-Situ Baro Troll-100 units, and In-Situ Level Troll-100 units were recalled by their respective company. The In-Situ troll units were recalled due to faulty batteries and problems with the connection interface. These problems did not occur during the 2009 field evaluation. Therefore, the authors believe that the recall issues had no impact on the quality of data collected in the 2009 field season. However, problems with the Isco 2150 AVFM units did have an impact on our study.

In November 2009, Isco informed the principal investigator on this project that an issue related to a faulty velocity capacitor had resulted in the recall and replacement of all 2150 AVFM units used during this investigation. The problem associated with this recall resulted in a drop out of velocity readings over large intervals of the deployment time period. Analysis of diagnostic files from project equipment performed by Isco technical support determined that at least three of the AVFM units displayed a high likelihood that they were experiencing the problems associated with the recall.

The overall impact of the faulty equipment is hard to assess and is addressed to some degree in the conclusions section of this report. Isco assured investigators that accurate velocity measurements were collected when the AVFM was registering a velocity. Isco informed investigators that data quality filters in the software were intact and any faulty readings due to the equipment failure would show up as zero values or "drop outs." An example of these drop outs is displayed in a graph of the Rapid Creek USGS gage site (Figure 3-1)

Analysis of equipment accuracy and reliability were conducted under the veil of this recall. All analysis and interpretation were performed with the assumption that all non-zero (non drop out) data collected during this investigation represents the full potential and technical capabilities of the both the Isco 2150 Area Velocity Flow Meter and the deployment methodology utilized during this project.

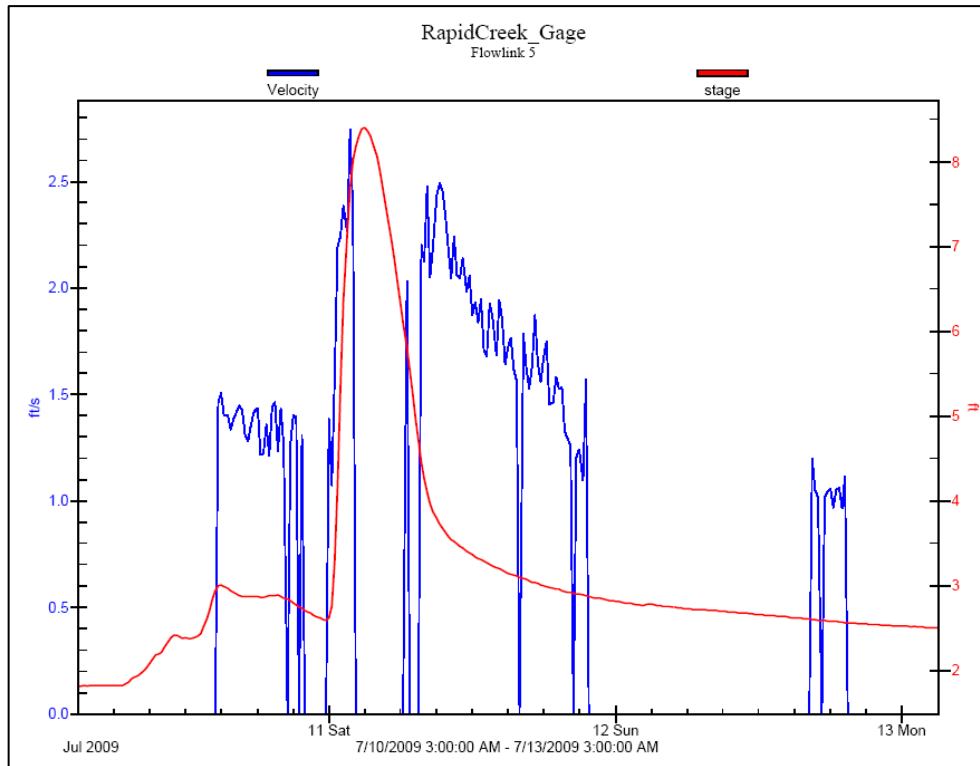


Figure 3-1 Stage and velocity graph which shows velocity drop outs along hydrograph related to Isco 2150 factory recall

3.1. Area Velocity Flow Meter deployments

Two different analysis methods were used to compare AVFM collected data to corresponding USGS gage data. The first method of comparison involved a side by side comparison of discharge values from both the USGS gage and the AVFM at each discrete measurement point. The other data analysis involved developing stage-discharge curves from AVFM units and comparing the accuracy of those curves to existing USGS stage discharge curves. Additionally, stage-discharge curves developed from manual flow measurements made during bi-weekly return trips were compared to USGS and AVFM data.

Analysis of the accuracy of both incremental flow values and stage discharge curves was conducted using a USGS method. The USGS measures the degree of accuracy using a four level ranking approach (USGS, 2008) where a ranking of “excellent” indicates that about 95 percent of the measurements are within 5 percent of the true value; “good” within 10 percent; and “fair” within 15 percent. “Poor” indicates that daily discharges have less than “fair” accuracy. The percent relative error of AVFM readings from the actual USGS value was used in conjunction with the above USGS method to assess the accuracy of the AVFM technology and deployment methodology.

Real-time flow data

Real-time discharge data collected with Isco units at the three USGS gage sites were filtered for zero velocity readings, which were removed from the data set. The zero velocity readings were either the result of flows too low to keep particles suspended or a result of the velocity drop out problems discussed earlier. Graphs of filtered AVFM data and USGS discharge for each site

can be found in Appendix A, Figures A through C. Once the data set was filtered, the discharge readings from the AVFM were compared to USGS gage discharge readings at each time interval. Example: Isco reading at 08:00 on 6/7/2009 was compared to USGS reading from exact same time. This was done for every interval which had a valid reading from both the USGS gage and the AVFM.

Data from this analysis showed that the mean of percent errors for real-time AVFM flow measurements were 30.3 percent at Clear Creek, 55.9 percent at Hoover Creek, and 18.4 percent at Rapid Creek. The majority of individual AVFM flow measurements at each gage site exceeded $\pm 15\%$ of the USGS flow measurement (Table 3-1). Flow measurements collected by the AVFMs at these sites during this project were ranked as “poor” based on the USGS ranking method discussed earlier.

Table 3-1 Summary statistics for real-time flow data from AVFM deployments at USGS gage sites

	Clear Creek	Rapid Creek	Hoover Creek 2009	Hoover Creek 2010
Mean % error	30.3	18.4	55.9	40.9
Median % error	28.1	9.1	46.7	37
Std. Deviation	18.8	26.6	34.9	30.1
% < 15% error	23.9	64.9	3.3	17
% > 15% error	76	35.1	96.7	83

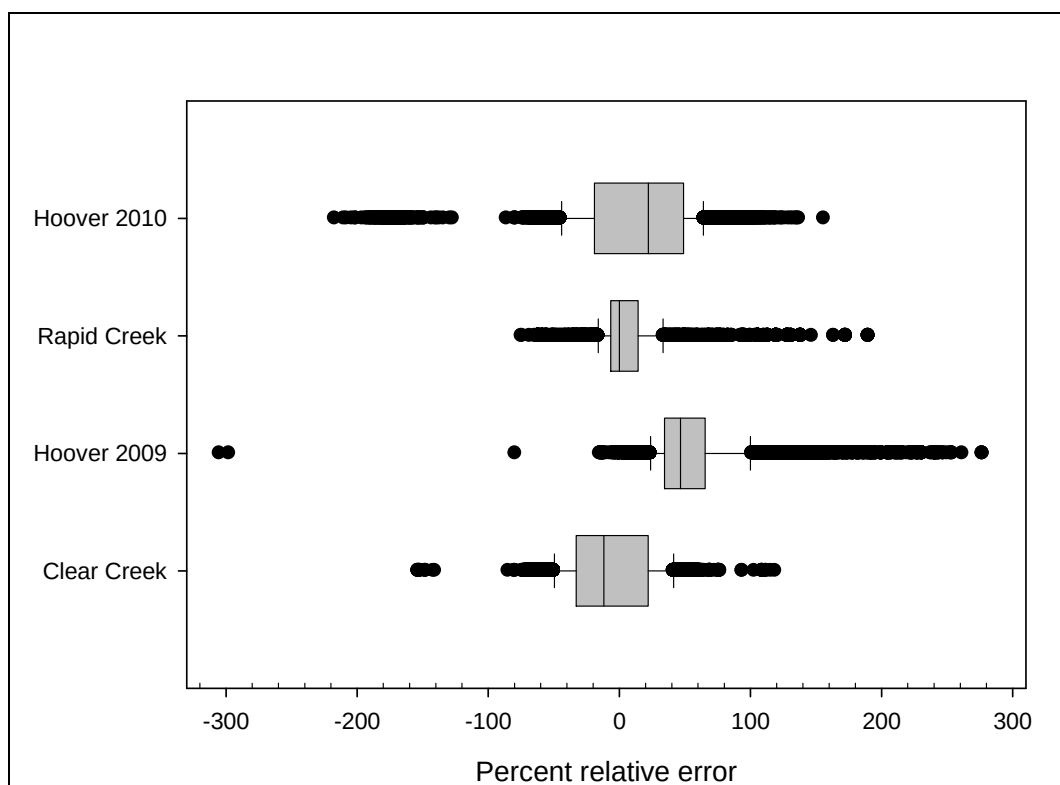


Figure 3-2 Box plots of AVFM real-time flow data error at USGS gage sites

Accuracy of individual measurements taken at each gage site during the entire deployment timeframe fluctuated greatly. Percent errors from individual readings were as high as 300 percent and the standard deviation ranged from 18-36 percent (Table 3-1). A box plot of real-time data from each site shows the spread of data collected during this investigation (Figure 3-2).

The AVFM at Hoover Creek, the smallest gaged site, consistently overestimated flow in the stream and also had the largest percent relative errors (Appendix A Figure D). Channel geometry, particularly in small streams, was hypothesized to have a large impact on flow values calculated for a site. The AVFM at Hoover Creek gage was initially programmed in 2009 to calculate flows based on a trapezoidal shaped channel with an area of 123.9 ft². A more detailed cross section of the site was collected in 2010 and a best fit trapezoid with an area of just 103.6 ft² was developed. An AVFM redeployed to this site in 2010, programmed with channel dimensions based on the new survey, continued to calculate flows higher than the USGS gage. The average percent error of the measurements however dropped from 55.9 percent to 40.9 percent, though the majority of the data were still off by greater than $\pm 15\%$.

Stage-discharge curve data

Real-time discharge data collected with AVFM units at the three USGS gage sites were filtered for zero velocity readings as previously discussed. The datasets stage readings were corrected to the corresponding USGS gage. This served as the master dataset for each gage from which all curves and comparisons were drawn.

Analysis of the real-time data indicated a wide spread of accuracy for individual readings (Figure 3-2), indicating that there is a potential for outlier data points to impact curve development. Any outliers in the data set were ultimately incorporated into the curve development but were somewhat marginalized by averaging the flow data by stage intervals. AVFM data from each gage site were categorized into 0.1 ft stage intervals and flow data were averaged for each of those intervals. These values were the final numbers used to develop stage-discharge curves from AVFM units.

This method of data analysis/management was utilized for several reasons. This study was conducted to assess the accuracy of the AVFM deployments. If the variation found in the discharge data is inherent to this equipment then any analysis should be conducted in a manner which incorporates this all data, including outliers. One goal of this study was to assess the feasibility of utilizing this deployment methodology at ungaged stream sites in order to develop discharge curves for TMDL project development. All analyses needed to be conducted using a data set developed as though no benchmarks were available for comparison. If no data, other than AVFM data, were available from a site, then one would have to assume that any and all readings could be accurately representing stream flow in the channel. For instance, the AVFM unit could consistently under represent the flow on site and a few high measurements, which on the surface would appear to be outliers in the data set, could be most representative of flow conditions in that system. Due to these factors, averaging the dataset by stage was determined to be the most straightforward and repeatable approach for developing curves from AVFM data.

All stage-discharge curves developed and compared in this analysis were created using a second order quadratic fit. Curves were compared to the USGS rating curve for the corresponding gage. Comparisons were only made for stage intervals which were contained within the channel. Any flows which rose out of the channel and spilled onto the floodplain were not used in the following analysis as the AVFM deployment was not designed to capture out-of-bank flow events and could not accurately measure such flows. Analysis of accuracy was conducted using the USGS four-level approach discussed earlier (USGS, 2008).

The initial stage-discharge curves for each gage site were developed using data from the entire deployment timeframe. Data analysis determined that certain sections of the deployment were

more accurate than others. This was mostly due to physical impacts to the stream cross-section or the AVFM sensor that affected the accuracy of data collected; these issues are discussed in the deployment assessment section. Discharge curves were developed for each gage that corresponded to deployment timeframes which were not impacted by physical factors. Additionally, a stage-discharge curve was developed from manual measurements collected during bi-weekly return trips at each site.

Two stage-discharge curves were created from the AVFM data collected at the Rapid Creek USGS gage site. One curve was developed using data from the entire deployment timeframe and the other was developed using data that excluded a large out-of-bank flow in August. During the August high flow event the batteries in the AVFM died, resulting in questions regarding the quality of data collected during the event. A third stage-discharge curve was developed using data from the manual flow measurements collected at the bi-weekly maintenance trip.

The curve developed from the entire data set compared favorably with the USGS discharge for all but the lowest stage of flow, where percent relative errors rose above 15 percent. As a whole 96.7 percent of the 500 discrete curve comparison points (0.1 ft intervals) fell within 15 percent relative error of the USGS curve. Additionally, 60 percent were within 10 percent and 26.7 percent were within five percent of the USGS curve (Table 3-2). The 3.3 percent of the comparison points that fell outside of the 15 percent relative error threshold occurred at the lowest stages of the curve. These points occurred at stages between 4 and 4.17 feet where the AVFM was underestimating flow by between 16 to 47 percent (2 to 6 cfs).

Table 3-2 Percent error information for discharge curves from Rapid Creek USGS gage site

Curve ID	Avg % error	<5% Excellent	<10% Good	<15% Fair
Curve A	9	27%	60%	97%
Curve B	6	40%	96%	98%
Curve C	26	12%	36%	45%

Curve A = AVFM data no Aug event, Curve B = AVFM, all data, Curve C = Manual flow measurements

As evident in Table 3-2, eliminating the August event timeframe from the data set utilized to develop the discharge curve resulted in very little change in percentage of data classified as fair or acceptable (< 15 percent relative error). The only major changes were observed in the percentage of data classified as good, which rose from 60 percent to 96 percent. Only the data from stages between 4 and 4.07 ft ranked below fair and the maximum percent error observed in those 8 measurements was 28 percent (Figure 3-3). The curve developed from this data set does a good job of capturing accurate flow data from all but the lowest in-channel flows (Figure 3-4)

The stage-discharge curve developed using manual flow measurements taken at bi-weekly return trips had the highest percentage error of the three curves. Less than half (45 percent) of all stage discharge comparison points ranked below 15 percent relative error (Table 3-2). The curve from this data set ranked as “good” at stages from 4.3 to 5.9 ft, but then quickly deteriorates as stage rises from this point (Figure 3-4). This result was not surprising as all manual stage collection for this site occurred between stages of 4.06 to 5.07 ft.

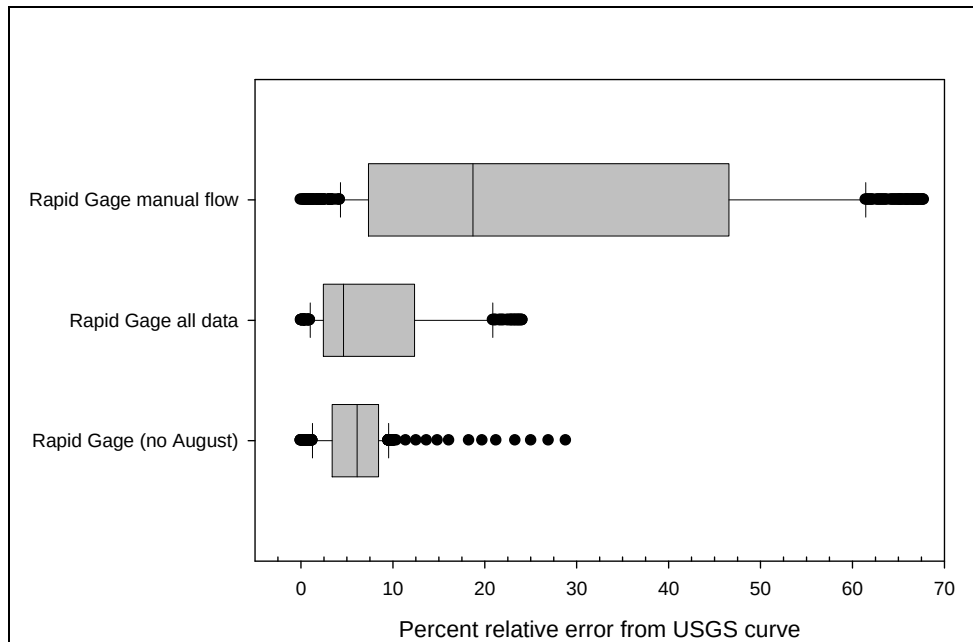


Figure 3-3 Box plots for stage discharge curves from Rapid Creek USGS gage site

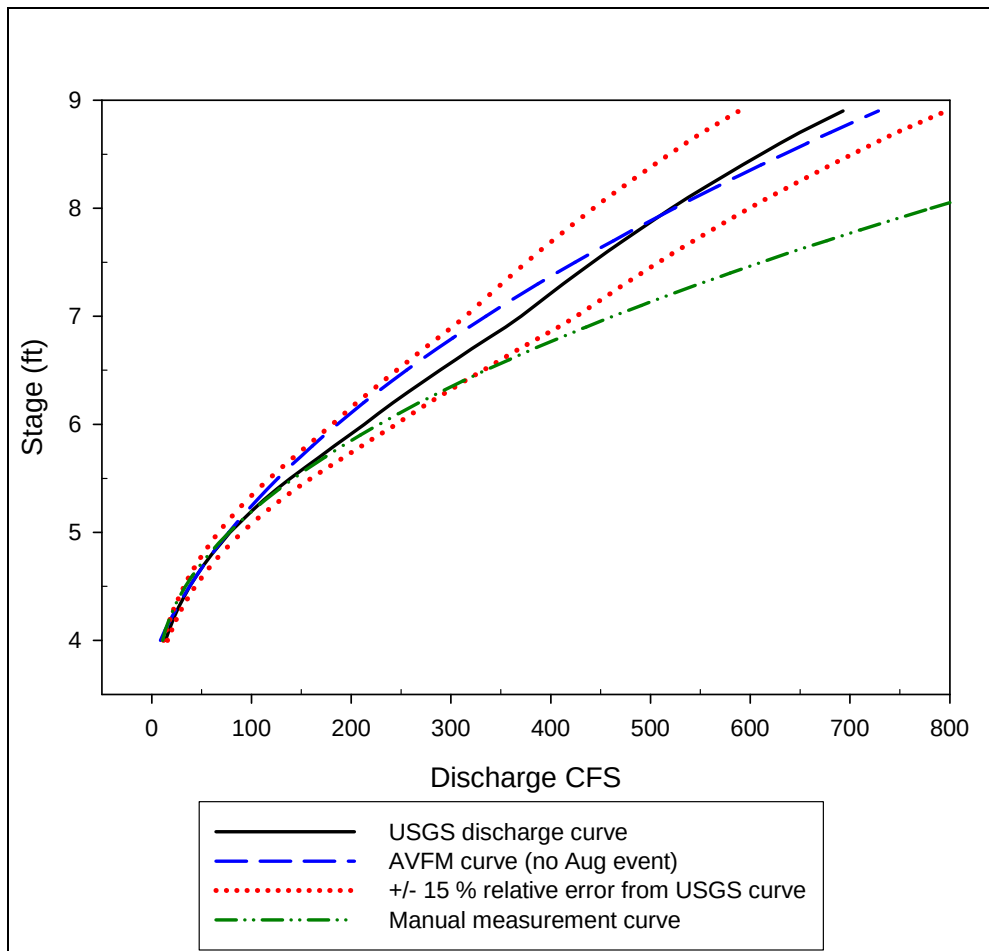


Figure 3-4 Stage discharge curves from Rapid Creek USGS gage site

AVFM data collected at the Clear Creek gage site had to be culled slightly more than the Rapid Creek data to develop an accurate curve. A stage-discharge curve was not developed from the entire data set for the season at Clear Creek as multiple high flow events impacted both the cross-section and the AVFM sensor's placement in the channel. These disturbances are discussed in the deployment assessment section.

Three separate curves were developed from the AVFM data at the Clear Creek gage site. One curve was developed with data from the beginning of the deployment (early April) through the end of May. The data was cut off here for the rest of the year due to multiple flood events which repeatedly impacted the equipment. Another curve was developed from data which includes all data through the first storm event (early May). The final curve developed from AVFM data utilized the April – May data combined with manual flow measurements to refine the curve. As before, a stage-discharge curve was also developed using only manual flow measurements taken at bi-weekly return trips.

The curve developed from AVFM data from April through May was not acceptable under the protocol set by the USGS four-level raking approach. Only 76 percent of the 1120 discrete comparison points fell within 15 percent relative error of the USGS stage discharge curve (Table 3-3). This curve failed to match USGS curve values in the upper foot of confined channel and over the lowest two and a half feet of stage. The maximum error observed across this curve had roughly a 43 percent relative error (Figure 3-5).

Table 3-3 Percent error information for discharge curves developed at Clear Creek USGS gage site

Curve ID	Avg % error	< 5% Excellent	< 10% Good	< 15% Fair
Curve A	13 %	0 %	47 %	76 %
Curve B	6 %	50 %	78 %	95 %
Curve C	45 %	9 %	13 %	17 %
Curve D	10 %	7 %	56 %	90 %

Curve A = AVFM data from April and May, Curve B = AVFM data through first storm event, Curve C = Manual discharge measurements, Curve D = April & May AVFM data manual measurement data hybrid

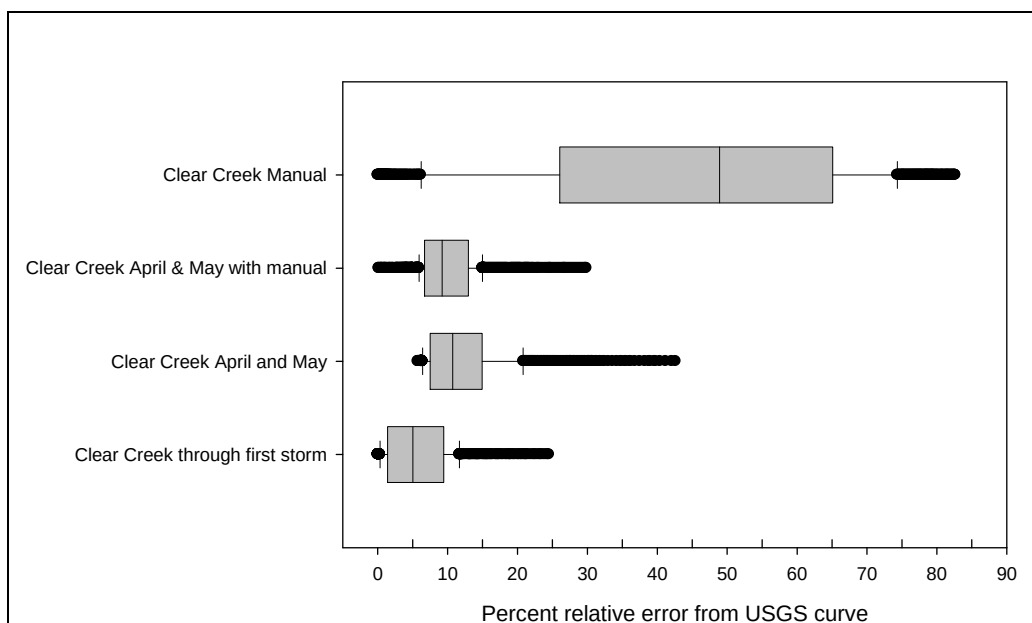


Figure 3-5 Box plots from stage discharge curves at Clear Creek USGS gage site

The second stage-discharge curve was developed using AVFM data from the start of the season through the first high flow event in early May. This time period was chosen for analysis due to changes in stream characteristics that occurred during this event; this may have impacted the data collected after this event. The site on Clear Creek had a sandy bottom which was mobilized during discharge events. It was noted on the return trip after this event that the AVFM sensor was covered in roughly an inch of sand and that the low-flow thalweg had shifted location slightly, altering the area of flow captured by the AVFM sensor. The sand was cleared from the sensor but no adjustments to the set up were made.

Analysis of this curve uncovered a data set which more closely matched the USGS curve for this site. Roughly 95 percent of all discrete comparison points fell within 15 percent relative error from the USGS curve (Table 3-3). The five percent which fell outside of the 15 percent error window occurred in the upper one-half foot of confined channel stage and in the first 0.10 foot of stage at the lowest end of the curve. The maximum observed error on this curve was roughly 25 percent (Figure 3-5).

The storm event return interval which was captured using the AVFM curve from April was determined using USGS gage records for the site. The Clear Creek channel confines up to just over a two-year return flow event and the curve developed accurately characterized flows up to the two-year return interval threshold (Figure 3-6).

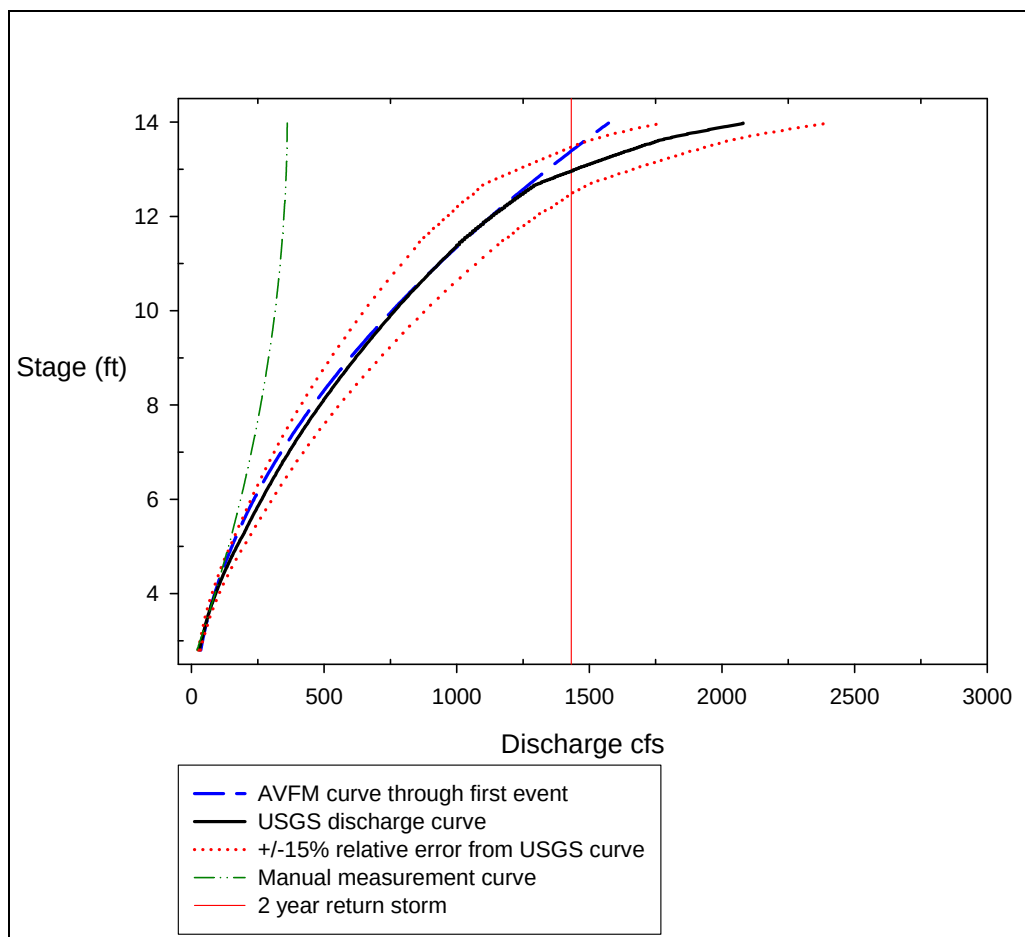


Figure 3-6 Stage discharge curves from Clear Creek USGS gage site

Manual discharge measurements made during bi-weekly maintenance trips were used to develop an additional rating curve for the site. The resulting curve was almost completely inaccurate when compared against USGS curve data (Table 3-3 & Figure 3-6). The 17 percent of discrete comparison points which fell below 15 percent relative error occurred between 3 to 4.8 feet of stage and the maximum error observed along this curve was roughly 83 percent (Figure 3-5). For consistency the curve used in this analysis and depicted in Figure 3-6 is a second-order polynomial which may not have been suitable for the data set at hand. A linear curve developed from this data set also under represented flow by up to 70 percent. As was the case in Rapid Creek, this result was expected. All manual discharge measurements conducted on site occurred at stages between 2.9 and 4.9 feet.

The final discharge curve developed for this site was a hybrid between the manual discharge measurements and AVFM data through the end of May. The changes that occurred in the set up after the first storm event were subtle at best and resulted in inaccurate data collection mainly in the lower stage levels which impacted this curves ability to accurately predict discharge in the lower two and a half feet of stage. In an attempt to correct this problem, stage discharge data from manual measurements were combined with stage discharge data from the AVFM unit. The resulting curve was an improvement on the April – May data set. However, the curve did not attain the accuracy seen in the AVFM data set through the first storm event (Table 3-3). The percentage of readings below 15 percent relative error increased from 76 to 90 percent and the maximum percent error observed dropped from 43 to 30 percent (Figure 3-5).

The Hoover Creek gage site had the smallest drainage area and the largest percent relative errors. Three stage-discharge curves were developed using AVFM data from this site. One curve was developed using data from the entire 2009 season deployment. A second curve was developed using data from a follow up deployment in 2010. The third curve was a hybrid between the 2010 data and manual discharge measurements. As with the other sites, a stage-discharge curve was developed from the manual discharge measurements collected at bi-weekly maintenance trips.

The discharge curve developed from 2009 AVFM data had high relative errors. Not a single discrete comparison point fell below 15 percent relative error of the USGS rating curve (Table 3-4). The curve from this unit consistently overestimated flow. Data depicted in Figure 3-7 show a wide range of accuracy across the curve and a maximum percent error of roughly 254 percent. A majority of the highest percent errors occurred near the bottom of the stage-discharge curve where relatively small differences in discharge equate to very high percent errors. For instance, the maximum percent error of 254 percent occurred at a stage of 1.5 feet where the curve predicted a discharge of 4.6 cfs and the USGS curve shows a discharge of 1.3 cfs.

Table 3-4 Information on discharge curves developed at Hoover Creek USGS gage site

Curve ID	Avg % error	< 5% Excellent	< 10% Good	< 15% Fair
Curve A	81 %	0 %	0 %	0 %
Curve B	29 %	1 %	2 %	10 %
Curve C	51 %	7 %	12 %	16 %
Curve D	29 %	1 %	2 %	10 %

Curve A = AVFM data from 2009, Curve B = AVFM data from 2010, Curve C = Manual discharge measurements, Curve D = 2010 AVFM data and manual measurement data hybrid

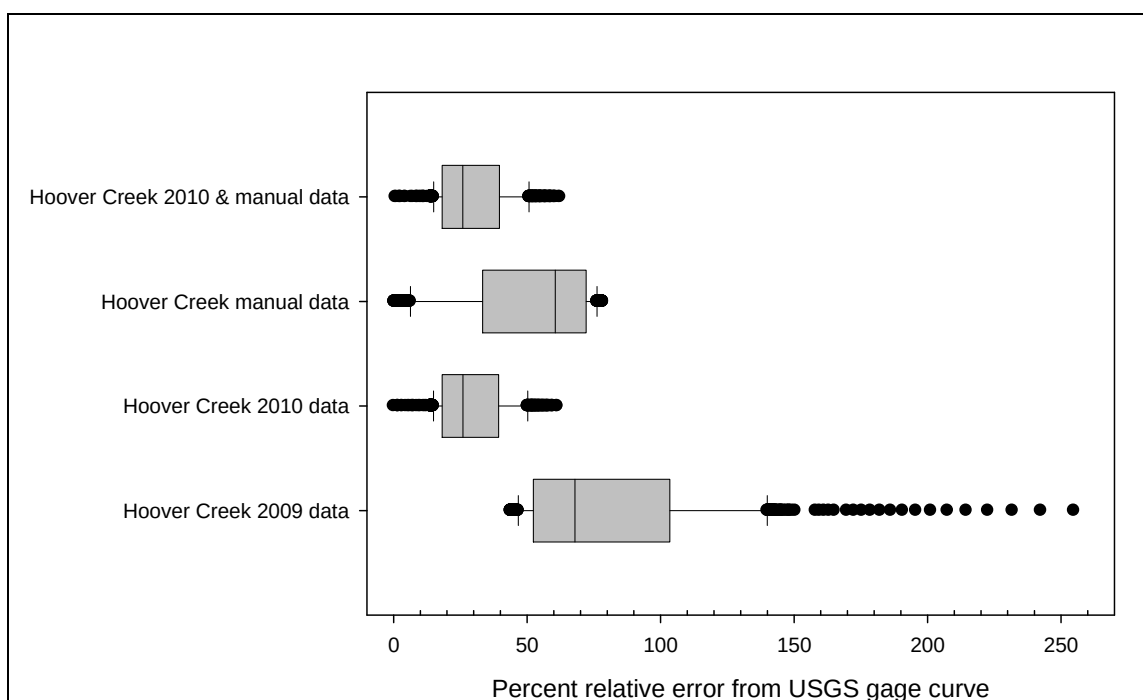


Figure 3-7 Box plots from discharge curves at Hoover Creek USGS gage site

As discussed in the real-time flow data section, small errors in the actual cross-sectional area of a channel across flow stages may lead to an over estimation of flow. In response to this, an AVFM was redeployed at the Hoover Creek site in 2010 with an adjusted cross-sectional area. Analysis of this curve showed marginal improvement over data collected in 2009 (Table 3-4 and Figure 3-7). However, the curve still consistently overestimated flow. The average percent error for the curve dropped from 81 percent down to 29 percent and the maximum observed error fell from 254 to 61 percent (Figure 3-7). As in 2009, the highest percent error occurred at the lowest stages of flow where relatively small changes in cfs resulted in high relative errors. The discharge curve created using a hybrid between 2010 AVFM data and manual flow measurements provided no improvements (Table 3-4).

The manual measurement discharge curve for this site had a larger percent of discrete measurement points below 15 and 10 percent relative error than any other curve (Table 3-4). The manual discharge curve had highest accuracy in stages between 1.6 and 2.7 feet. All manual measurements were taken at stages between 1.5 and 1.75 feet. The curve was most inaccurate at higher flows. For instance, the peak percent error for this curve was around 78 percent; at this point the manual flow curve predicted a flow of 81 cfs. At the same stage USGS discharge value was 376 cfs, a difference of 295 cfs. Figure 3-8 shows all stage-discharge curves developed for Hoover Creek; the manual flow discharge curve does not even follow the basic trend of the USGS discharge curve for this site.

The AVFM data allowed for the creation of at least one stage-discharge curve at Rapid Creek and Clear Creek that accurately reflected the USGS stage-discharge curve. The AVFM data failed to create an accurate stage-discharge curve at Hoover Creek. However, the AVGM derived stage-discharge curves were found to be more accurate than stage-discharge curves generated using manual flow measurements at all three USGS gage sites.

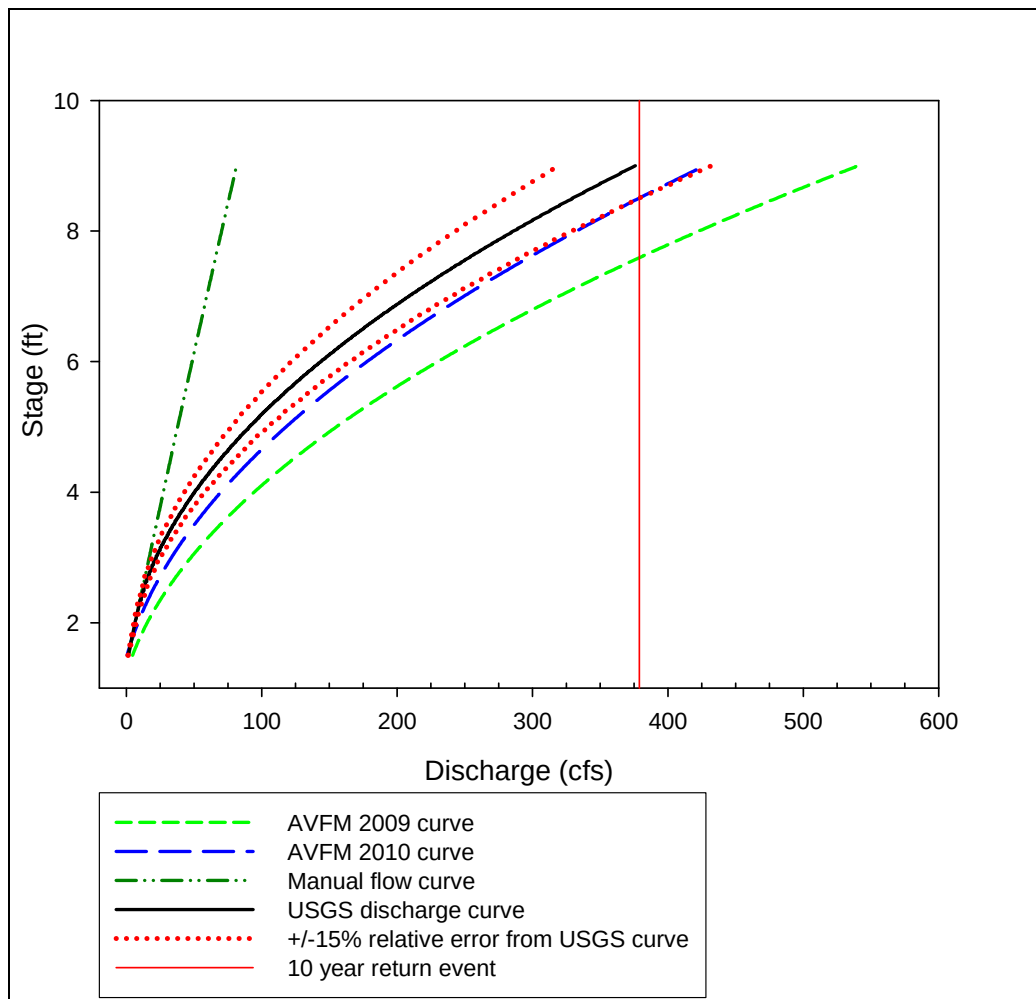


Figure 3-8 Discharge curves from Hoover Creek USGS gage site

3.2. Transducer deployments

The pressure transducers and deployment methodology used in this study performed well under varying stream conditions. Transducer collected stage measurements closely matched USGS stage measurements at the three USGS gage sites (Appendix A Figure D). With erroneous data removed, causes of which are discussed later, the average percent error for transducer stage measurements was 0.87% at Clear Creek, 1.91% at Hoover Creek, and 0.6% at Rapid Creek. The majority of the transducer stage measurements at all three gage sites were within 5% of the USGS stage measurement. This number is nearly 100% when data that are known to be erroneous are removed (Figure 3-9).

The USGS four-level ranking approach (USGS, 2008) was used to assess the accuracy of the transducer data sets. The transducer stage measurements collected at the gage sites during this project have a ranking of “excellent”; about 95 percent of the measurements are within 5 percent of the true value.

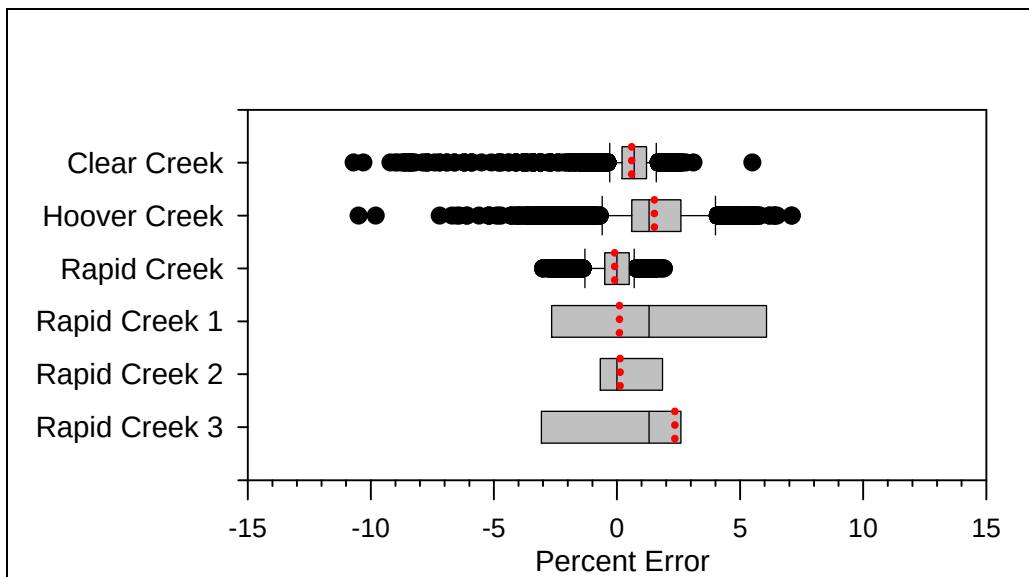


Figure 3-9 Distribution of percent errors for transducers with erroneous data removed. Average percent error is shown as red dotted line

The transducers at non-USGS gage sites also performed well for a majority of the season. Figure 3-10 compares the stage measurements collected at the non-USGS gaged sites versus the transducer stage data. The majority (75%) of the transducer measurements were within 0.03 feet of the actual stage measurement. Based on the USGS ranking method, the transducer stage measurements would be ranked as “excellent” at Rapid Creek 2, and “poor” at Rapid Creek 1 and Rapid Creek 3. However, these rankings are based on 8 observations per site, which means each observation is 12.5% of the total. Only a single measurement at Rapid Creek 1 and Rapid Creek 3 differed by $\pm 15\%$ and this sole measurement was responsible for the “poor” ranking.

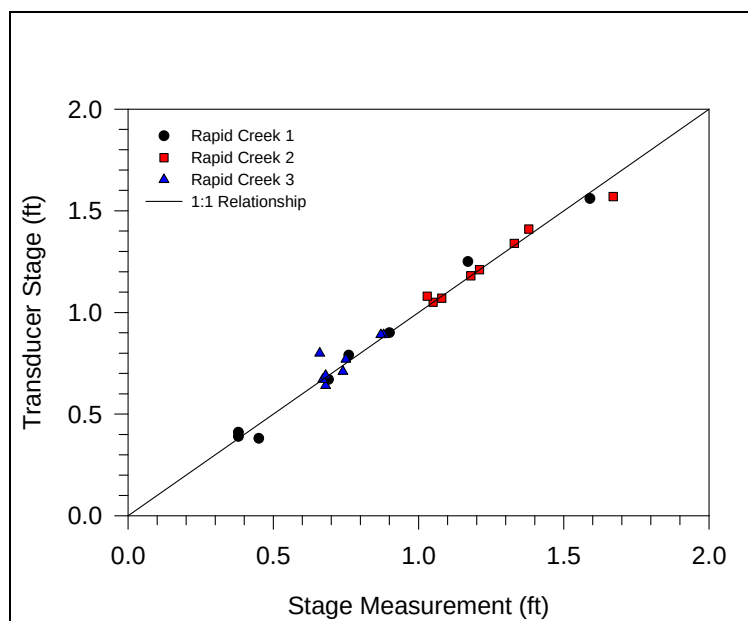


Figure 3-10 Comparison of stage measurements at non-gaged sites vs. transducer readings

3.3. Deployment assessment

AVFMs

Analysis conducted on curve data from the AVFM units provides evidence that this equipment is capable of collecting useful information about stream flow in lower order stream channels. However, there were some deployment issues/equipment limitations that occurred during the monitoring season.

The AVFM underestimates stream flow when high flow events cause the stream to flood onto the floodplains. The AVFMs are programmed with only the dimensions of the stream channel; the dimensions of the floodplain are not used. During high flow events that spill onto the floodplain, the AVFM would underestimate the total cross-sectional area of the stream. Consequently, the AVFM would underestimate the flow during these events. Rapid Creek, for example, overflows onto its floodplain at approximately 700 cfs. The Rapid Creek gage AVFM unit consistently underestimated flows above 700 cfs. Due to this limitation, field staff must know the stage where the stream spills onto the floodplain at each site. If there is an error in this stage, the upper end of the curve developed from the data set will likely under represent the actual flow in the channel.

Problems anchoring the AVFMs flow sensor to the bottom of the channel could be an issue. The combination of a shifting sand bottom and high stream power at the Clear Creek gage site tested the limitations of the deployment methodology. The initial anchor system (three foot long) was adequate to hold the equipment in place during high flow events. However, during an event on June 20, 2009, the anchor system was likely struck by debris causing the anchor to bend (Figure 3-11). Instead of the sensor being aligned parallel with the flow, the sensor was reading the flow at an acute angle to the flow direction. This caused the AVFM to calculate lower than actual flows. The replacement anchor was only a foot in length and was easily dislodged by subsequent high flow events.



Figure 3-11 Photo of stream anchor damage at Clear Creek, June 2009

For extremely small streams, the ability of the AVFM deployment to accurately calculate flow is a problem. As previously discussed, the AVFM calculated flows consistently overestimated flow in the Hoover Creek channel. The actual flows in Hoover Creek were relatively low, with more than 75% of the data collected below 4 cfs. Small discrepancies in actual cfs can result in a large percent error being calculated at such low flows. For example, a measurement of 5 cfs compared to a true value of 4 cfs would result in a percent error of 25%.

Multiple sources of potential error could result in these small discrepancies. The AVFM velocity sensor has an accuracy of ± 0.1 ft/sec (Isco, 2008). Minor differences in the velocity measurement could result in small differences in flow, which in turn cause the large percent errors. Additionally, the cross-section which was programmed into the Isco 2150 was a trapezoid. The actual cross-section of the stream will rarely match a trapezoid shape exactly, which was the case on Hoover Creek (Figure 3-12).

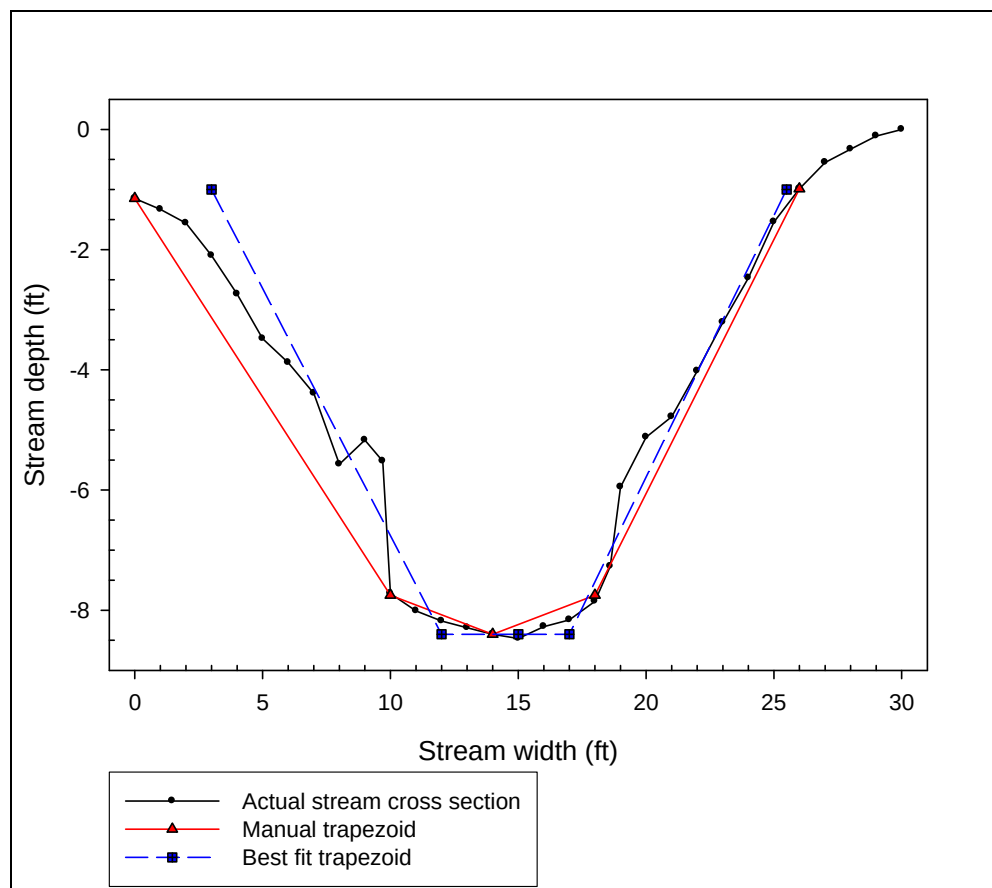


Figure 3-12 Comparison of cross sections at the Hoover Creek USGS gage site

Errors in the cross section and velocity measurements could have impacted data collection during an event at the Hoover Creek USGS gage site. In the situation depicted in Table 3-5, simply accounting for the ± 0.1 ft/sec could have resulted in a 4 percent swing in relative error. Introducing one-half foot of error in the cross-sectional area combined with the potential velocity error places the AVFM collected flow within 13 percent relative error of the USGS flow. As shown in Figure 3-12, errors in excess of one-half foot are easily introduced in a stream's cross-section when limited to a trapezoidal shape.

Table 3-5 Potential sources of error in cross section and velocity measurements at the Hoover Creek gage site

Scenario	AVFM Velocity (fps)	Area (sq ft)	AVFM (cfs)	USGS gage (cfs)	% Error
Actual measurements	2.7	23.61	63.7	53.0	20
Velocity off 0.1	2.6	23.61	61.4	53.0	16
X-section off 0.5 ft	2.7	23.11	62.4	53.0	18
X-section off 0.5 ft and Velocity off 0.1	2.6	23.11	60.1	53.0	13
X-section off 1 ft	2.7	22.61	61.0	53.0	15
X-section off 1 ft and Velocity off 0.1	2.6	22.61	58.8	53.0	11
X-section off 1.5 ft	2.7	22.11	59.7	53.0	13
X-section off 1.5 ft and Velocity off 0.1	2.6	22.11	57.5	53.0	8

These cross-sectional area issues are of greater importance to overall discharge calculations in smaller streams. The relative impact of a foot or two cross-sectional error becomes much less important to the overall accuracy of discharge measurement as the total cross-sectional area increases. Because of this limitation, it is recommended that users avoid streams with narrow cross-sections or irregular shapes. This does pose a problem with site selection in “natural” unmodified streams. It is recommended that field staff target areas near bridge crossings that are typically stable and as close to a trapezoid as one can expect to find in a “natural” stream setting.

In addition to the above issues, the possibility that sediment or debris will collect on and bury the sensor placed in the bottom of the stream channel exists. Placing the equipment as low in the flow profile as possible is the only real way to avoid debris collection. Careful site selection and knowledge of how streams function during high flow will help minimize the potential for sediment collection. However, some sedimentation is a possibility no matter what precautions are taken.

AVFMs rotating site procedure

The AVFMs were extremely mobile, requiring a team of two people less than 1 hour to move between sites. Removing an AVFM from a site generally took 10-15 minutes. Installing an AVFM at a new site generally took less than 30 minutes, but the time varied based on stream size. The AVFM took longer to install on larger streams because anchoring the AVFM's cable to the streambed required more work, the larger channel dimensions required more time to accurately measure, and the stream flow measurement required more time because the streams were wider. Programming an AVFM with the new site data generally took less than 10 minutes. The AVFMs used in this study stored much of the data necessary to program the unit internally. Consequently, when an AVFM was redeployed to a site, many of the variables needed to program the unit, such as collection rate, could be pulled from its memory.

The results of this study may underestimate the time needed to accurately program the AVFMs. As discussed earlier, a technical problem with the AVFMs caused errors in collecting instantaneous velocity readings on the AVFMs. This problem prevented the AVFM from calculating and displaying an accurate flow reading. In some setups associated with this study, several hours passed before a good velocity reading was collected and flow was calculated. The field crew generally had to leave a site before an accurate flow measurement was displayed, which caused some uncertainty in how accurately the AVFMs were measuring flow.

Since this issue was identified, fully functioning AVFMs have been deployed to several sites. Programming the AVFMs at these sites has taken slightly longer because the AVFM placement and cross section can be adjusted to more accurately match stream flow measurements.

This study found the most efficient method to install and program the AVFMs was to set up and anchor the AVFM at the site, measure the channel dimensions, measure the stream flow, and then program the AVFM. Installing the AVFM first allows time for the unit to adjust to stream conditions while field personnel collect other measurements. Measuring stream flow prior to programming the AVFM gives the most accurate values to compare against the AVFM readings and adjust the AVFM variables if needed.

Pressure transducers

The In-Situ model Level TROLL 100 pressure transducers used in this study were simple and straightforward to install and operate. Since the pressure transducers used were non-vented, there was no cable to protect along the streambank. The deployment techniques tested in this study were by and large successful, though some limitations were noted during the study.

Programming errors and well casing problems were the largest source of errors in the transducer stage measurements. Figures E through G in Appendix A, shows the daily stage measurements and the percent error for each USGS gage site. Initially, the reference stage was incorrectly programmed into the transducers, which caused them to read a stage higher than true conditions. This problem was identified within a few days and the reference stage was correctly programmed into the transducers.

High flow events caused problems with equipment at sites where adequate protection was not provided to the pressure transducers. To minimize disturbance within Hoover National Park, only a small fence post was used to anchor the well casing to the streambed. Two high flow events that occurred in 2009 knocked over the well casing and caused erroneous stage readings. No location existed at the Clear Creek site to protect the well casing from the direct flow of the channel. Debris hitting the well casing during high flow events tipped the well casing and caused erroneous stage readings.

At certain times water levels in the stream would go over the top of the well casing, which prevented access to the transducer. In these instances data on the transducer could not be accessed until water levels receded enough to allow access to the well casing.

Another potential issue was that programming the transducers required stable water levels in the stream. The transducers were programmed to set the initial stream stage at the time of the transducer's first measurement. If the stream's water level changed from the time that the transducer was programmed to the time of the first measurement, the transducer would be set to an incorrect stage and all the water level readings collected would be in error. The best way to avoid this potential problem was to program the units at low flow and set the unit to start logging data as soon as possible.

At times it was observed that sand would build up in the bottom of the well casing if there was not adequate space between the bottom of the casing and the bottom of the stream to allow material to flush out. Other than these small problems/issues, the pressure transducer deployments worked well and collected accurate and reliable data.

4. Conclusions and recommendations

The Isco 2150 AVFM (if deployed in the proper setting using the installation procedure previously described) provides researchers and resource managers a tool that improves the accuracy of stream discharge curves critical to project/research success while simultaneously reducing the demands placed on field staff. The AVFM equipment does however place some additional demands on field staff as regular maintenance visits are necessary to keep the equipment operating accurately and efficiently. However, due to the ease of use, these trips can be incorporated into the normal sampling/monitoring interval currently planned for sites.

Under proper conditions the AVFMs were capable of providing USGS quality stage-discharge curves for in-channel flows. However, the units also displayed the capability of drastically over/under estimating stream discharge. A user of this equipment must take precautions to ensure that the set up occurs in a stable section of stream with uniform flow and minimal turbulence at low and high flow.

Field staff must pay particular attention to the condition of the cross-section and equipment placement at each return trip. Very small changes to the equipment can result in a loss of data accuracy. The authors of this paper recommend that when using this equipment only data from deployment intervals where no observable change to the equipment or cross-section occurred be accepted as valid data. Any data from deployments where the site was impacted should not be considered reliable.

Based on the assessment and analysis conducted during this study it is recommended that this equipment only be used in locations with 10 to 60 mile drainage areas until further assessment of the equipment and deployment methodology is conducted. Streams below the 10 mile drainage area may have cross-sections and/or flow conditions that are difficult to capture with this tool. As previously noted small errors in average velocity combined with small errors in actual cross-sectional area can result in large relative errors in these smaller systems.

Streams with drainage areas larger than Clear Creek may be too large for the deployment methodology. The equipment may be technically capable of accurately measuring discharge in these large channels. However, physical factors may overwhelm the installation. As the stream increases in size, the ability for high flows to mobilize large material and scour the channel becomes greater. The anchoring systems used in this assessment will not stand up to repeated high flows in these large channels, and the potential for equipment loss becomes very high. Additionally larger streams tend to stay at peak discharge for a longer period of time making manual flow collections easier to time, provided crews are available and have proper equipment.

Given the physical limitations of the equipment and the regularity of necessary maintenance trips, the Isco 2150 is best utilized as a short term component of project specific monitoring plans. This equipment is not suitable for long-term placement in stream gaging style applications. If long-term data sets are necessary, this equipment should be used on site to periodically collect data for the development and maintenance of stage discharge curves. The long-term stream gaging data set should be collected using pressure transducers, stilling wells or some other stream stage gaging technology to collect stage data which relates to the curve developed using the AVFM technology.

5. References

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Appendix A

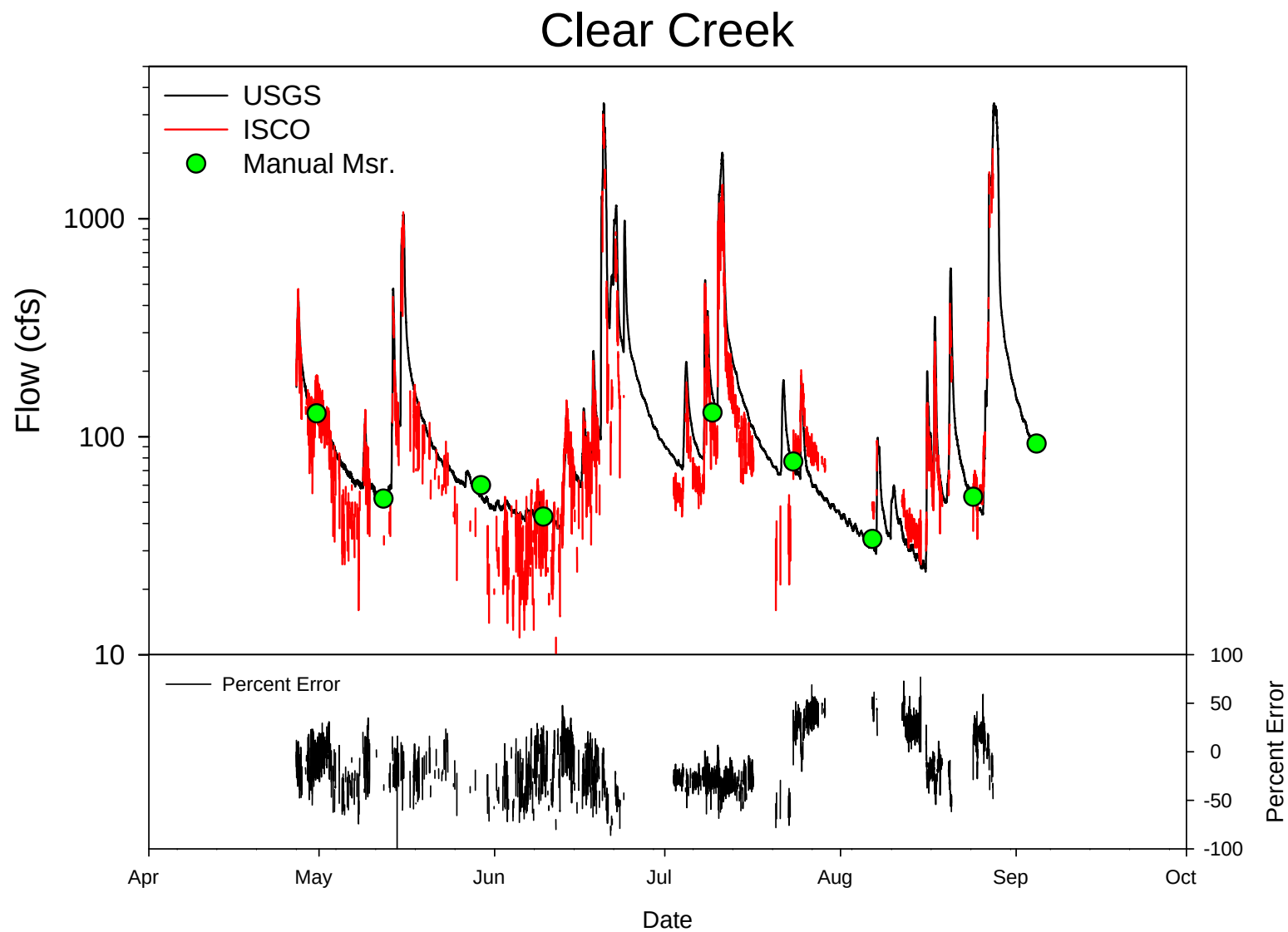


Figure A Clear Creek gage site USGS flow, ISCO flow and percent error 2009 season

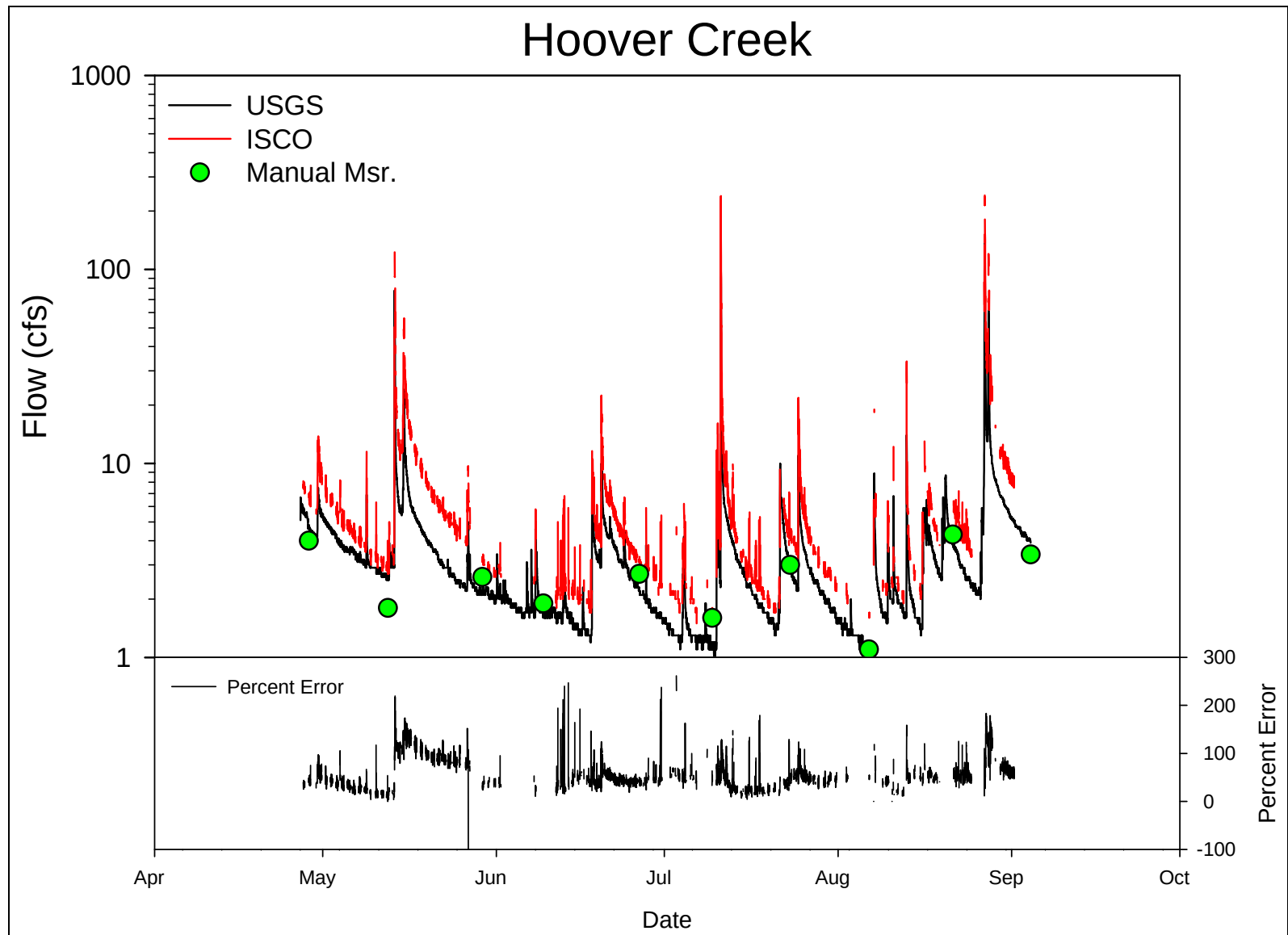


Figure B Hoover Creek gage site USGS flow, ISCO flow and percent error 2009 season

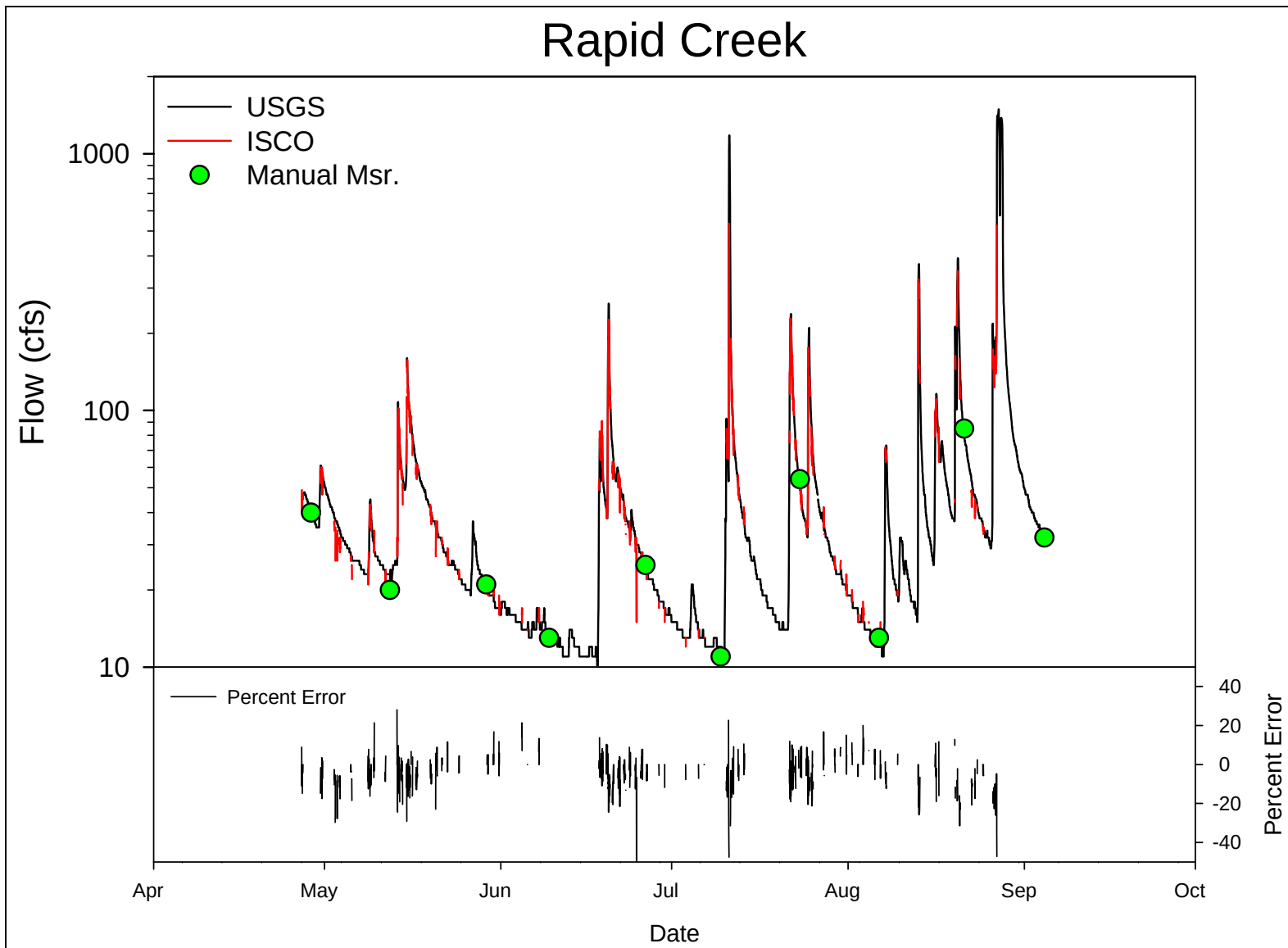


Figure C Rapid Creek gage site USGS flow, ISCO flow and percent error 2009 season

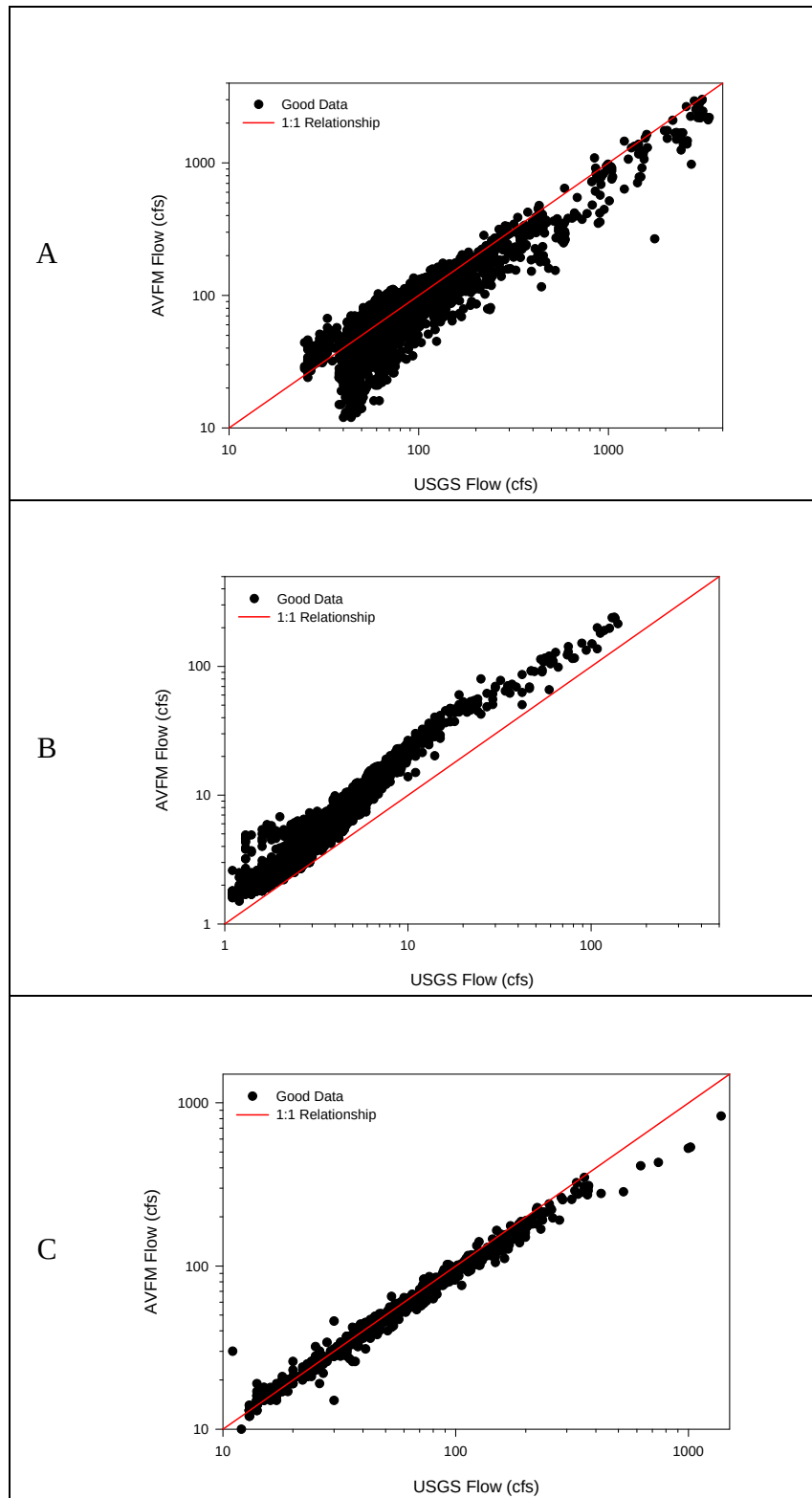


Figure D Comparison of USGS flow data to ISCO collected flow data. A = Clear Creek, B = Hoover Creek, C = Rapid Creek

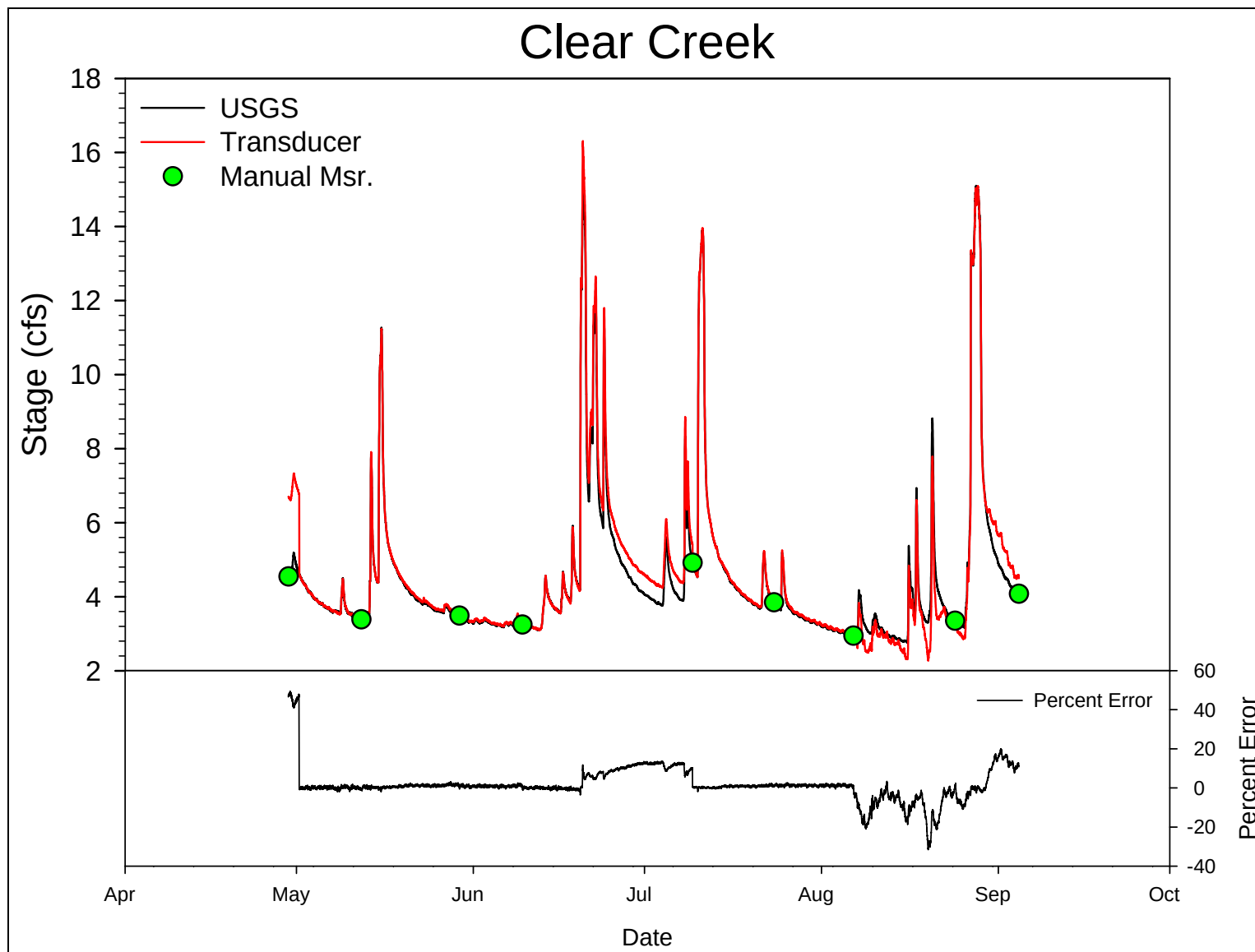


Figure E Transducer readings and error from USGS stage at Clear Creek

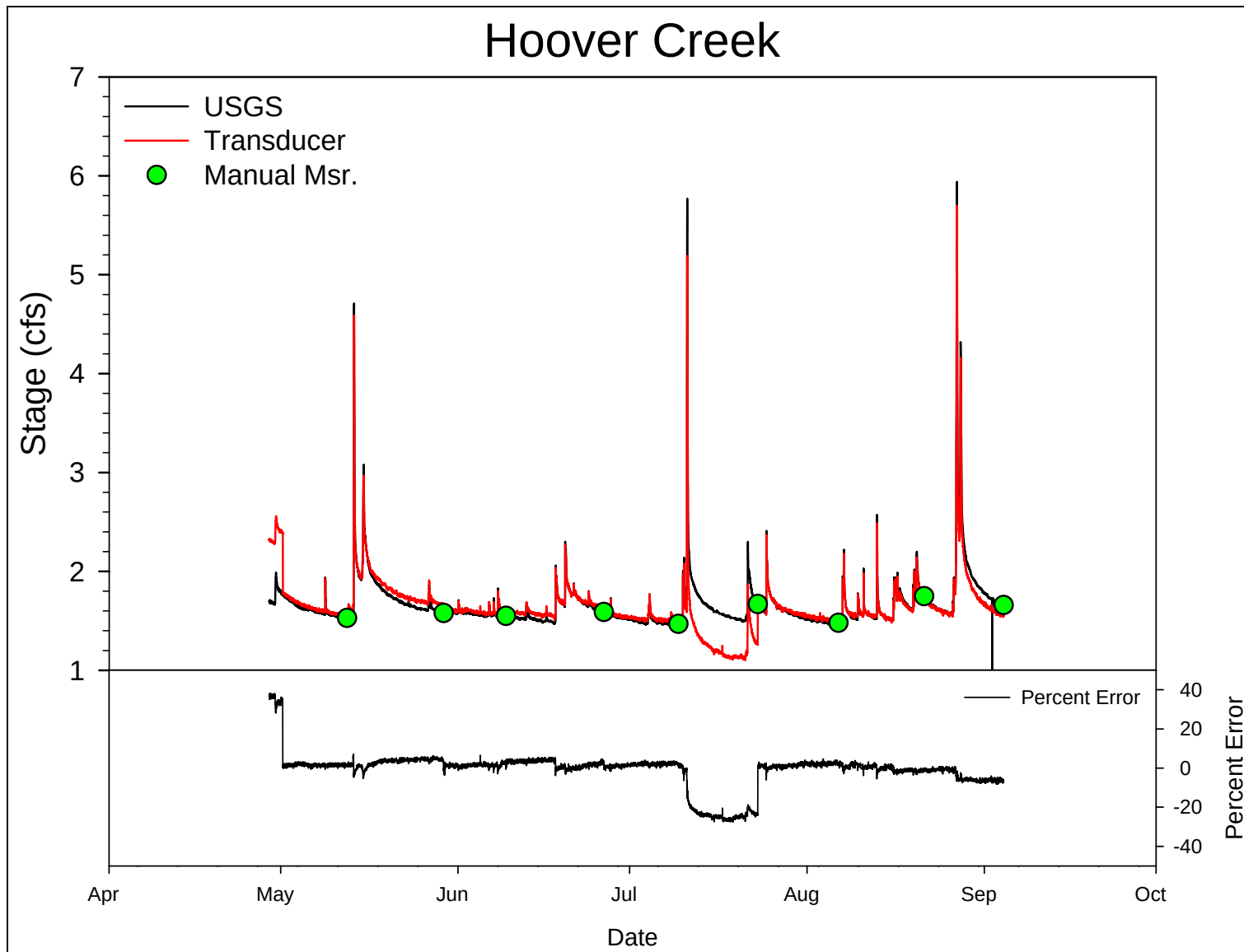


Figure F Transducer readings and error from USGS stage at Hoover Creek

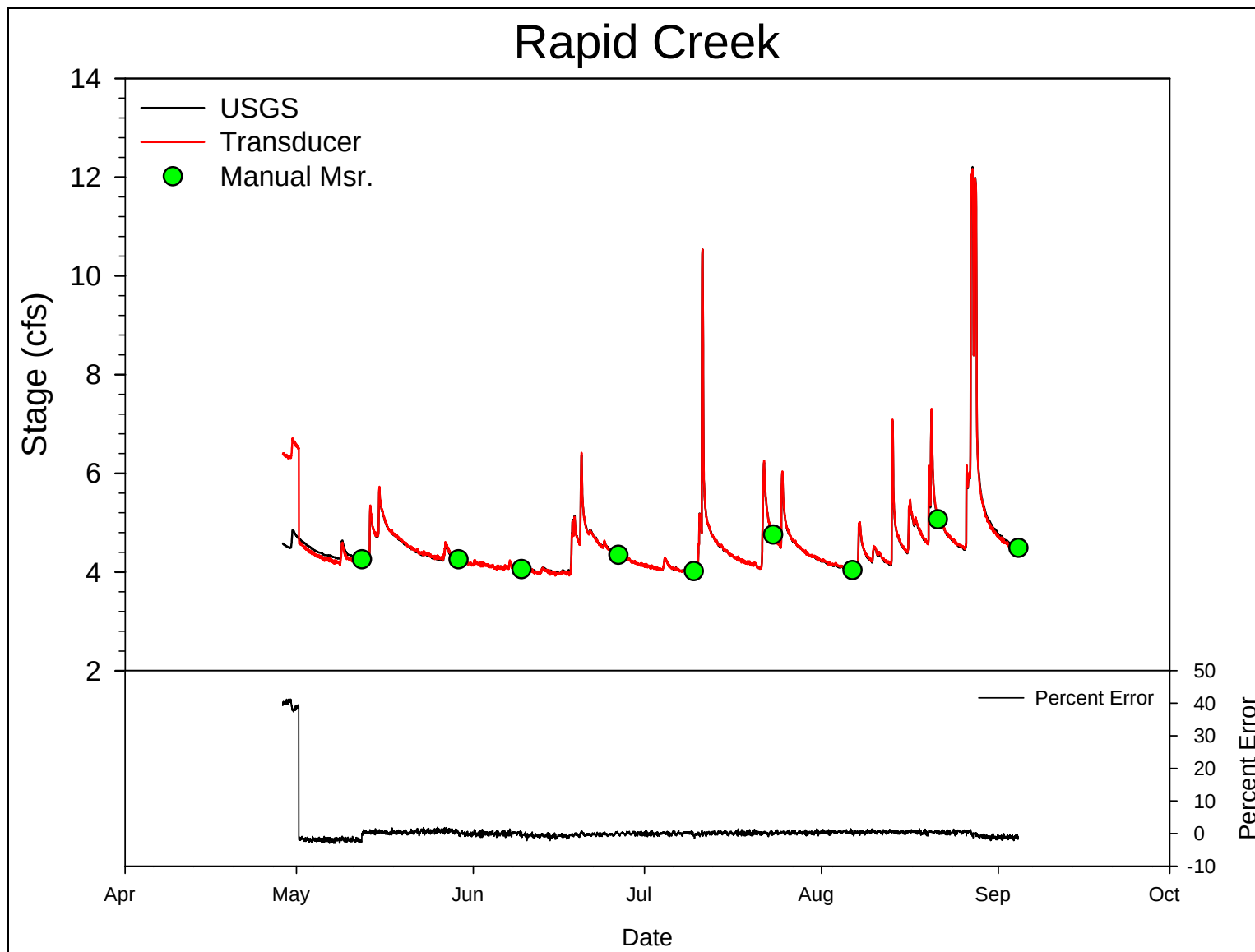


Figure G Transducer readings and error from USGS stage at Rapid Creek

Appendix B Quality Assurance Project Plan