APPENDIX E.9.3

2018 HYDROMETRIC MONITORING REPORT

Environmental Applications Group

MEMORANDUM

To: William Bowden and Connor Devereaux
Environmental Superintendents, Baffinland Iron Mines Corporation

Date: March 13, 2019

From: Andrew Rees, Ph.D.
Senior Environmental Scientist

Re: 2018 AEMP Hydrometric Monitoring Program

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1 Introduction

The 2018 iteration of the Mary River Project (Project) Hydrometric Monitoring Program, a component study of the Project's Aquatic Effects Monitoring Plan (AEMP, Baffinland, 2015), was initiated in late June during the spring melt period, also known as freshet. Station visits were conducted by Story Environmental Inc. (SEI) to re-install pressure transducers and conduct flow measurements at seven (7) monitoring stations. Station identifiers, names, period of records, drainage areas, and locations for the seven (7) monitoring stations are summarized in Table 1.1.

Table 1.1 2018 Hydrometric Monitoring Program Stations

Station ID	Station Name	Period of Record	Drainage Area (km^2)	Coordinates (UTM)	
				Easting	Northing
H01	Phillips Creek Tributary	2006-2008, 2011-2018	250	532831	7946247
H02	Tom River near outlet to Mary Lake	2006-2008, 2010-2018	210	555712	7915514
H04	Camp Lake Tributary (CLT-2)	2006-2008, 2010-2018	8.3	557639	7915579
H05	Camp Lake Tributary (CLT-1)	2006-2008, 2010-2018	5.3	558906	7915079
H06	Mary River	2006-2008, 2010-2018	240	563922	7912984
H07	Mary River Tributary	2006-2008 2010, 2011, 2017-2018	14.7	564451	7913194
H11	Sheardown Lake Tributary (SDLT-1)	2011-2018	3.6	560503	7913545

During the June visit, benchmark and water level surveys were conducted and pressure transducers were installed. Where flows permitted safe access to a watercourse's channel, a wading current meter was used to measure discharge using the area-velocity technique. Where higher flows prevented the use of the wading current meter, dilution gauging was utilized to measure discharge. Following the June visit, additional station visits were made by Baffinland Iron Mines Corporation's (Baffinland) environmental staff during July and September to measure flows using the area-velocity technique, conduct benchmark surveys, and download data from the pressure transducers. The pressure transducers installed at the stations were removed by Baffinland's environmental staff in early September prior to winter freeze-up.

2 Stage-Discharge Measurements

The stage-discharge data obtained in 2018 were compared to the existing rating curves summarized in the 2017 Hydrometric Monitoring Program Summary (SEI, 2018). Rating curves for each station, inclusive of the data collected in 2018, are presented in Figures 1 to 7. A discussion and an interpretation of the fit of the 2018 data to the rating curves is provided in the following sections:

- **H01 (Phillip's Creek Tributary)** - A stage-discharge measurement was recorded at H01 during the June visit using dilution gauging. The measurement is generally consistent with the existing rating curve presented in Figure 1. The measurement of discharge is slightly greater than the discharge predicted by the rating curve but within the 15% uncertainty associated with dilution gauging. The discrepancy is not entirely unexpected as it can be challenging at H01 to get complete mixing of the rhodamine dye across the channel during lower flow conditions due to the large channel width and relatively shallow depth. As such, no update to the rating curve was required and it was used for the development of the 2018 streamflow record. In the future, it would be beneficial to have additional data to further verify the rating curve.
- **H02 (Tom River)** - A stage-discharge measurement was recorded at H02 during the June visit using dilution gauging and is consistent with the rating curve which was updated in 2012 (Figure 2). The flow measurements obtained since the 2012 update are a good fit with the rating curve. Additional high flow measurements would be useful to verify the upper portion of the 2012 rating curve. The 2012 rating curve was used for the development of the 2018 flow record.
- **H04 (Camp Lake Tributary CLT-2)** - A stage-discharge measurement was recorded at H04 during the June visit using a wading current meter and the area-velocity technique. The measurement is consistent with the rating curve that was updated in 2013 (Figure 3). The stage-discharge measurements conducted in July and September by Baffinland environmental staff are also consistent with the 2013 rating curve. There is less confidence in the accuracy of the updated rating curve for flows above 0.7 m^3/s due to the lack of validation measurements. Measurements during summer high flow conditions are recommended to further validate the 2013 rating curve update. The 2013 rating curve was used for the development of the 2018 flow record.
- **H05 (Camp Lake Tributary CLT-1)** – A stage-discharge measurement was recorded at H05 during the June visit using a wading current meter and the area-velocity technique. The measurement is consistent with the existing rating curve (Figure 4). Stage-discharge measurements using the area-velocity technique were also recorded by Baffinland environmental staff in July and September and are consistent with the existing rating curve. The existing rating curve was used for the development of the 2018 flow record.
- **H06 (Mary River)** – A stage-discharge measurement was recorded at H06 during the June visit using dilution gauging and is consistent with the existing rating curve (Figure 5). The existing rating curve was used for the development of the 2018 flow record.
- **H07 (Mary River Tributary)** – A stage-discharge measurement was recorded at H07 during the June visit using dilution gauging and is consistent with the existing rating curve (Figure 6). The June measurement was during mid-flow conditions and helped validate that portion of the rating curve. Additional flow measurements at H07 are recommended to further validate the low flow portion of the rating curve. The existing rating curve was used for the development of the 2018 flow record.
- **H11 (Sheardown Lake Tributary SDLT-1)** – A stage-discharge measurement was recorded at H11 during the June visit and is consistent with the rating curve updated in 2014 (Figure 7). Stage-discharge measurements were also record by Baffinland in July and September and are consistent with the 2014 rating curve. There remains some uncertainty around the higher stage-discharge conditions. As such, higher flow measurements should be obtained to validate the high flow rating curve. The 2014 rating curve was used for the development of the 2018 flow record.

3 Streamflow Hydrographs

Streamflow records were developed for each station by applying the water level records to the corresponding rating curves. The discharge hydrographs for H01, H02, H04, H05, H06, H07, and H11 are presented in Figures 8 to 14.

The discharge records from all stations were converted to equivalent unit runoff (discharge per unit area) and are presented on attached Figure 15 for comparison purposes. The records of unit runoff generally agree well with each other, exhibiting similar timing and magnitude of runoff events and similar patterns to previous years. It appears that the initial freshet period was not captured at any of the stations in 2018 due to an earlier melt than in most past years. The later period of the freshet was captured at the H02, H06, and H07 stations. A strong diurnal melt pattern is evident through the end of June and first half of July at these stations as they are higher elevation catchments. The snowmelt at lower elevations and the corresponding peak of freshet flows at the stations with smaller and lower elevation catchment occurred prior to the installation of the stations. The installation of the pressure transducers is difficult during early freshet due to safety concerns and the presence of ice in the channels. Ice in a channel can prevent access to the installation location and also alters the relationship between water level and discharge. Similar unit runoff is evident at all stations throughout August, which suggests that the precipitation was generally consistent throughout the region.

The pressure transducer at H07 malfunctioned and stopped recording data in early August. This station also had a similar malfunction in 2017. A preliminary model was developed to fill in the data gaps at H07. Concurrent daily average discharge data collected in 2017 and 2018 from H07 and H06 were correlated using a ranked linear regression technique. This technique is similar to ordinary linear regression, but the data are separated into distinct flow conditions and ranked from lowest to highest values prior to analysis. The H06 station has a larger catchment, but both stations are of similar elevation and typically exhibit similar runoff timing. In addition, the ranked regression equations account for differences in drainage area and other physical characteristics that affect runoff as it is assumed that these parameters are generally constant within seasons over a period of several years. When comparing sets of ranked daily flows for two or more gauging records, each flow value of equal rank has an equal probability of exceedance in the data set (since the data sets are of equal length). Therefore, a comparison of ranked daily flows amounts to a comparison of flow frequency distributions. The comparison of flow distributions rather than simultaneous daily flows overcomes differences in the timing of rainstorm or snowmelt events between watersheds, and ultimately provides a better model for synthetically generating flow data. When ranked regression is used, it is verified by comparing modelled data to observed data (i.e. determining the ability of the regression model to recreate measured data in terms of timing and magnitude). As such, it is a useful technique to examine the relationship between the flow at the two stations and to generate modelled data for comparison to measured data. However, it is important to note that the modelled data are not expected to reproduce actual flows, but to provide a general representation of the flow conditions during the period of missing data and a measure of the day-to-day variability of flows.

Ranked regression equations for the H06 and H07 data were developed for low flow, mid-flow, and high flow conditions and are shown on Figure 3.1.

The regression plot demonstrates a few consistent patterns. For low and mid-flows, the trend line has a slope that is similar and slightly less than the ratio of the drainage areas (equal unit runoff). This suggests that the watersheds had a relatively consistent difference in unit discharge through the range of measured flow. For higher flows there is a distinctive break and a marked decrease in slope, which suggests that H06 undergoes a relative increase in flow compared to H07. The relationships observed in Figure 3.1 are limited by the amount of data collected and the fact that no data were available in August and early September. The interpretation of the relationships would improve with the incorporation of additional data as a divergence in the runoff relationship would be expected in different seasons (i.e August and September). Additional data will allow for the segregation of the annual hydrograph into discrete periods (seasons or months) to account for runoff mechanisms which may vary seasonally and will improve the confidence in the modelled data.

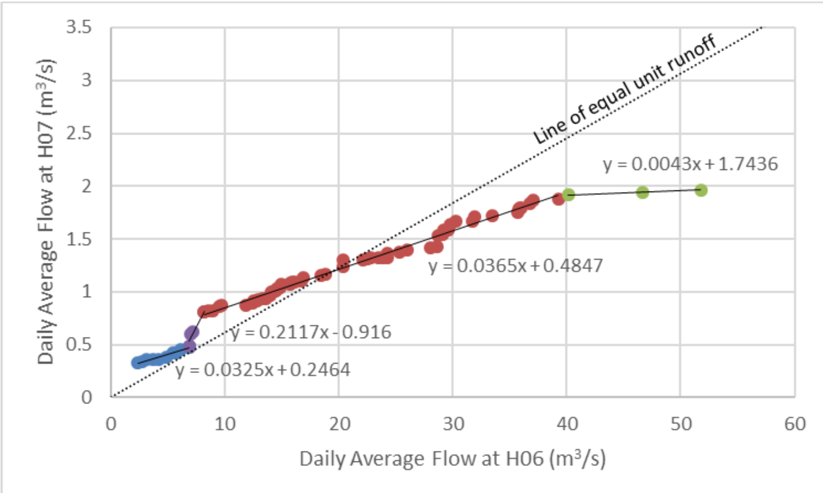

Figure 3.1 Ranked Regression of H06 and H07 Daily Flow

The effectiveness of the modelling procedure was assessed by comparing concurrent measured and synthesized flows for H07 in 2017 and 2018. The concurrent measured and synthetic flows from 2017 and 2018 are shown in Figures 3.2 and Figure 3.3, respectively.

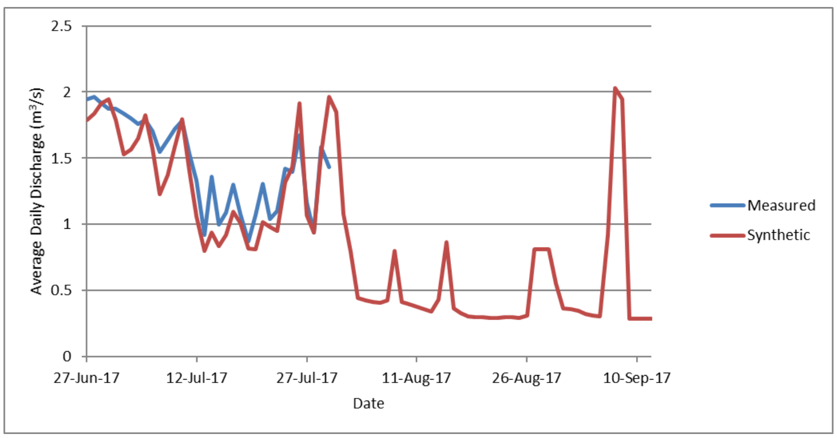

Figure 3.2 Comparison of Measured and Synthetic Flows at H07 in 2017

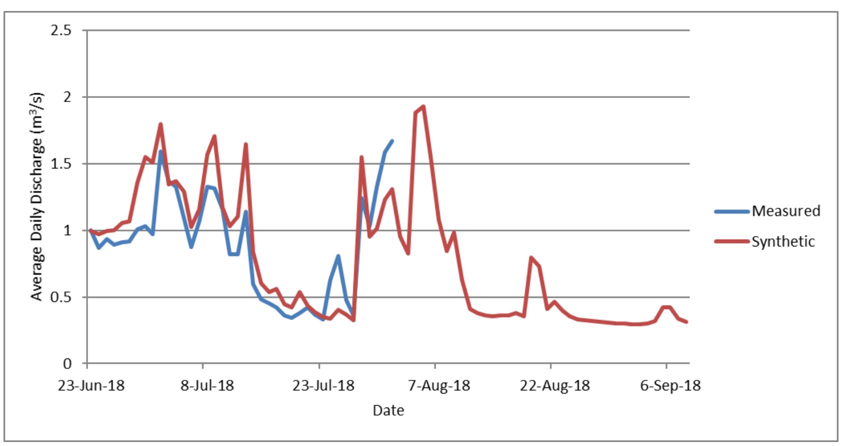

Figure 3.3 Comparison of Measured and Synthetic Flows at H07 in 2018

As shown in Figures 3.2 and 3.3, there is a generally good match between measured and synthetic flow hydrographs for 2017 and 2018. There are some notable differences, especially during peak flow events, but this is not unexpected given the differences in watershed size and the ranking process used for the synthetic flow development. In some cases the synthetic data (derived from the larger H06 watershed) does not capture the magnitude of short-term peak flows. In general, the modelling slightly underestimates measured flow in 2017 and slightly overestimates measured flow for most of the 2018 period of concurrent data. Due to the limited amount of concurrent data for comparison, the modelled data are considered preliminary in nature and the relationships can be re-examined after additional data are available, especially for the August and September periods. The modelled data were used to provide a general estimate of daily and monthly flow conditions at H07 in 2018.

To improve the model and collect additional data at H07, a new pressure transducer will be installed at H07 in 2019 and visited several times in 2019 to ensure stage-data is being recorded.

The estimated mean monthly discharge and unit runoff for each station in 2018 are summarized in Table 3.1.

Table 3.1 Summary of 2018 Mean Monthly Estimated Discharge and Unit Runoff

STATION	Drainage Area (km^2)	Estimated Mean Monthly Discharge (m^3/s)				Period of Record
		June	July	August	September	
H01	250	9.5	10.0	7.3	2.9	June 22 to September 7
H02	210	19.4	14.6	9.7	4.2	June 22 to September 7
H04	8.3	0.17	0.24	0.31	0.13	June 25 to September 6
H05	5.3	0.07	0.15	0.21	0.07	June 23 to September 6
H06	240	17.5	15.0	9.1	2.8	June 23 to September 8
H07	14.7	0.94	0.85	***0.67***	***0.34***	June 23 to August 1 (measured)
H11	3.6	0.038	0.114	0.146	0.043	June 20 to September 6

STATION	Drainage Area (km^2)	Estimated Mean Monthly Unit Runoff ($l/s/km^2$)				Period of Record
		June	July	August	September	
H01	250	38	40	29	12	June 22 to September 7
H02	210	93	70	46	20	June 22 to September 7
H04	8.3	20	30	37	16	June 25 to September 6
H05	5.3	14	29	40	13	June 23 to September 6
H06	240	73	63	38	12	June 23 to September 8
H07	14.7	64	58	***45***	***23***	June 23 to August 1 (measured)
H11	3.6	11	32	41	12	June 20 to September 6

Notes:
1. The mean monthly data for H07 during August and September (shown in bold font) were estimated using the synthetic data record

A summary of flows at H05 from 2006 to 2018 is shown on Figure 16 (attached). The total annual runoff recorded in 2018 at the H05 station was close to the average from 2006 to 2017 for concurrent periods of record. However, the flow measured in 2018 was lower than normal in June and early July, due to the initial part of freshet occurring prior to the re-installation of the stations, and higher than normal in summer months. The 2018 summer flow period (mid-July to mid-August) had the fourth highest measured flow volume and was 2.5 times greater than measured in 2017. The volume of flow measured in August 2018 was the second highest recorded at H05 since monitoring began in 2006.

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4 Summary

The 2018 iteration of the Project's Hydrometric Monitoring Program allowed for the continued monitoring of streamflow at hydrometric stations identified in the Project's AEMP (Baffinland, 2015). The data collected confirmed that the rating curves at all stations continue to be applicable. It is recommended that future hydrometric monitoring includes more opportunistic site visits during summer high flow events to confirm or improve rating curves.

5 References

Story Environmental Inc. (SEI), 2018. Memorandum to William Bowden, Baffinland Iron Mines Corporation. Re: *2017 AEMP Hydrometric Monitoring Program*. March 16. Haileybury, Ontario. Ref. No. 199-04-09.

Baffinland Iron Mines Corporation (Baffinland), 2015. Aquatic Effects Monitoring Plan – Rev. 1. October 30, 2015.

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Attachments:

Figure 1	H01 - Phillip's Creek Tributary Rating Curve
Figure 2	H02 - Tom River Rating Curve
Figure 3	H04 - Camp Lake Tributary (CLT-2) Rating Curve
Figure 4	H05 - Camp Lake Tributary (CLT-1) Rating Curve
Figure 5	H06 - Mary River Rating Curve
Figure 6	H07 - Mary River Tributary Rating Curve
Figure 7	H11 - Sheardown Lake Tributary (SLDT-1) Rating Curve
Figure 8	H01 – Phillip's Creek Tributary 2018 Streamflow Record
Figure 9	H02 - Tom River 2018 Streamflow Record
Figure 10	H04 - Camp Lake Tributary (CLT-2) 2018 Streamflow Record
Figure 11	H05 - Camp Lake Tributary (CLT-1) 2018 Streamflow Record
Figure 12	H06 - Mary River 2018 Streamflow Record
Figure 13	H07 – Mary River Tributary 2018 Streamflow Record
Figure 14	H11 - Sheardown Lake Tributary (SLDT-1) 2018 Streamflow Record
Figure 15	2018 Comparison of Unit Runoff
Figure 16	H05 – Camp Lake Tributary (CLT-1) Measured Streamflow Hydrographs 2006-2018

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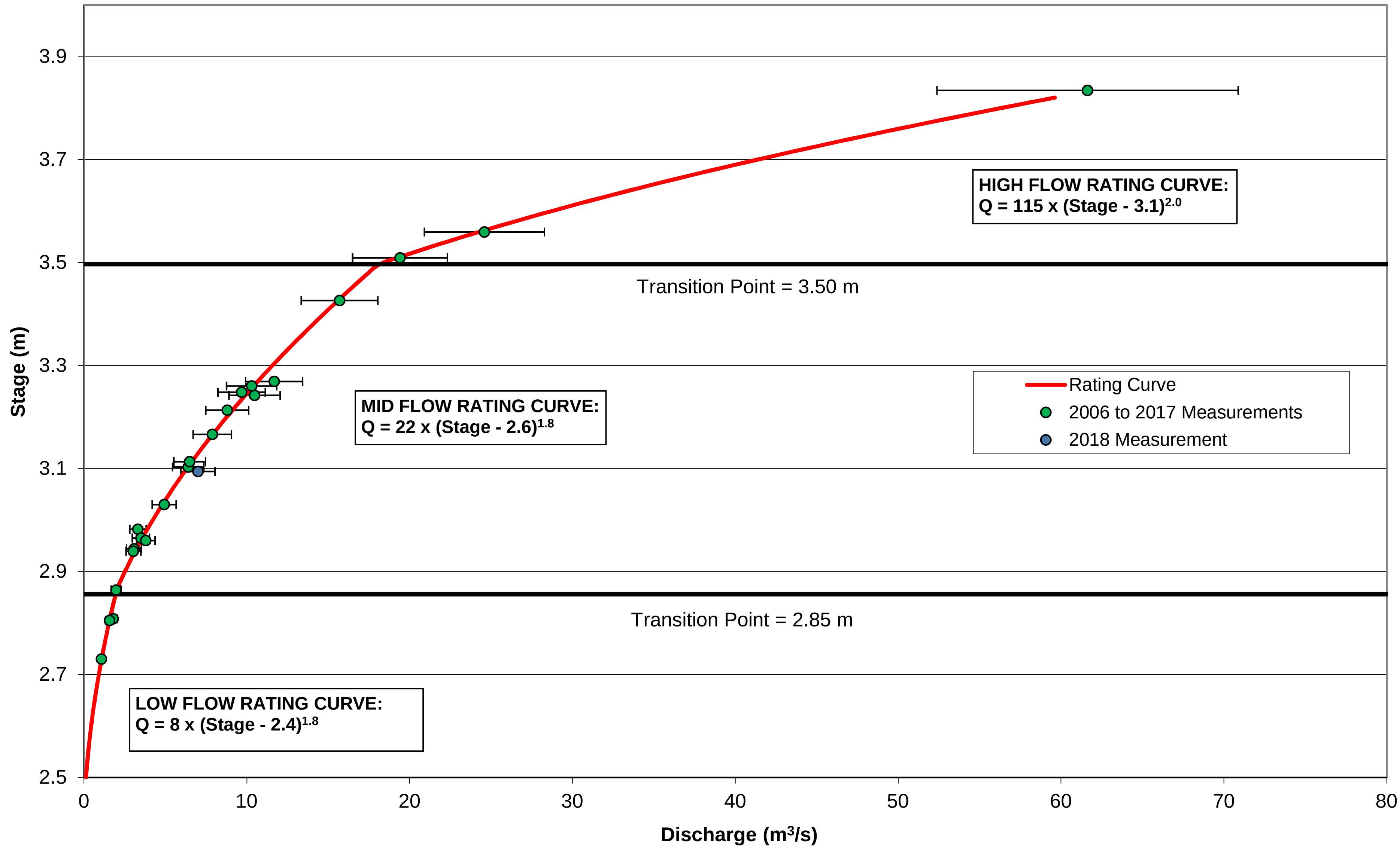
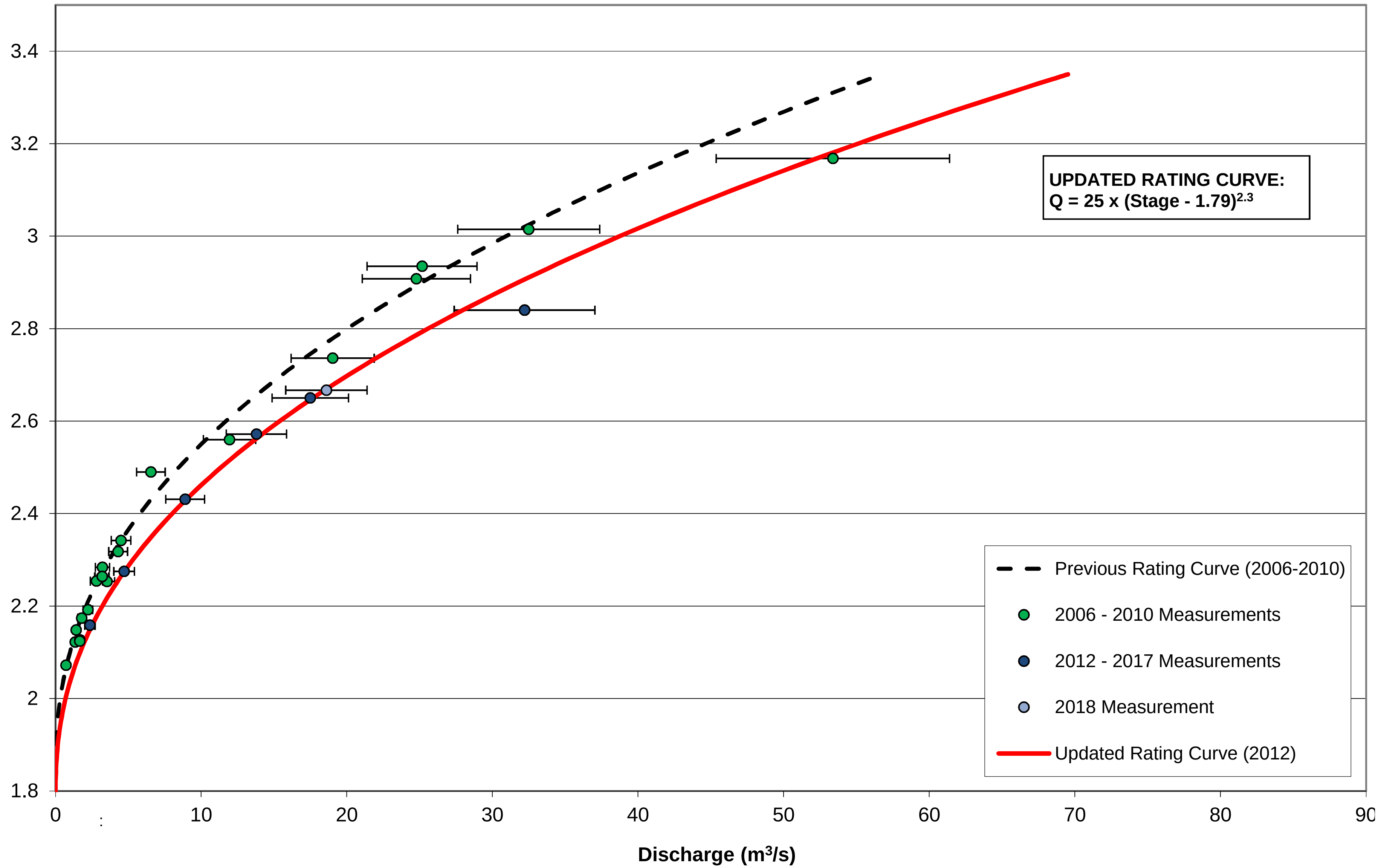
Attachments

March 13, 2019



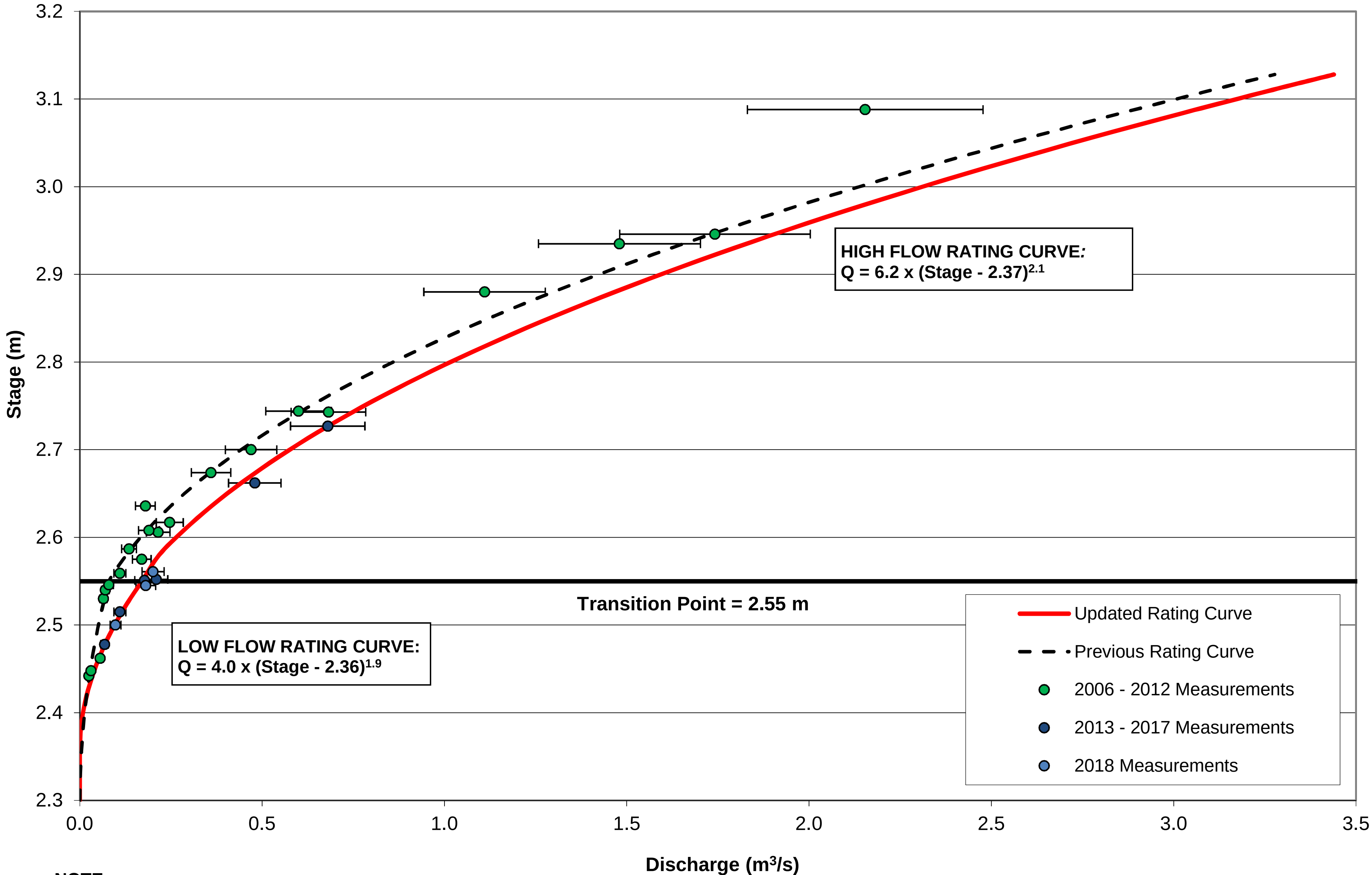
NOTE:
1. RATING CURVE SHOWN TO MAXIMUM RECORDED STAGE IN 2018

Figure 1 **H01 - Philips Creek Tributary Rating Curve**



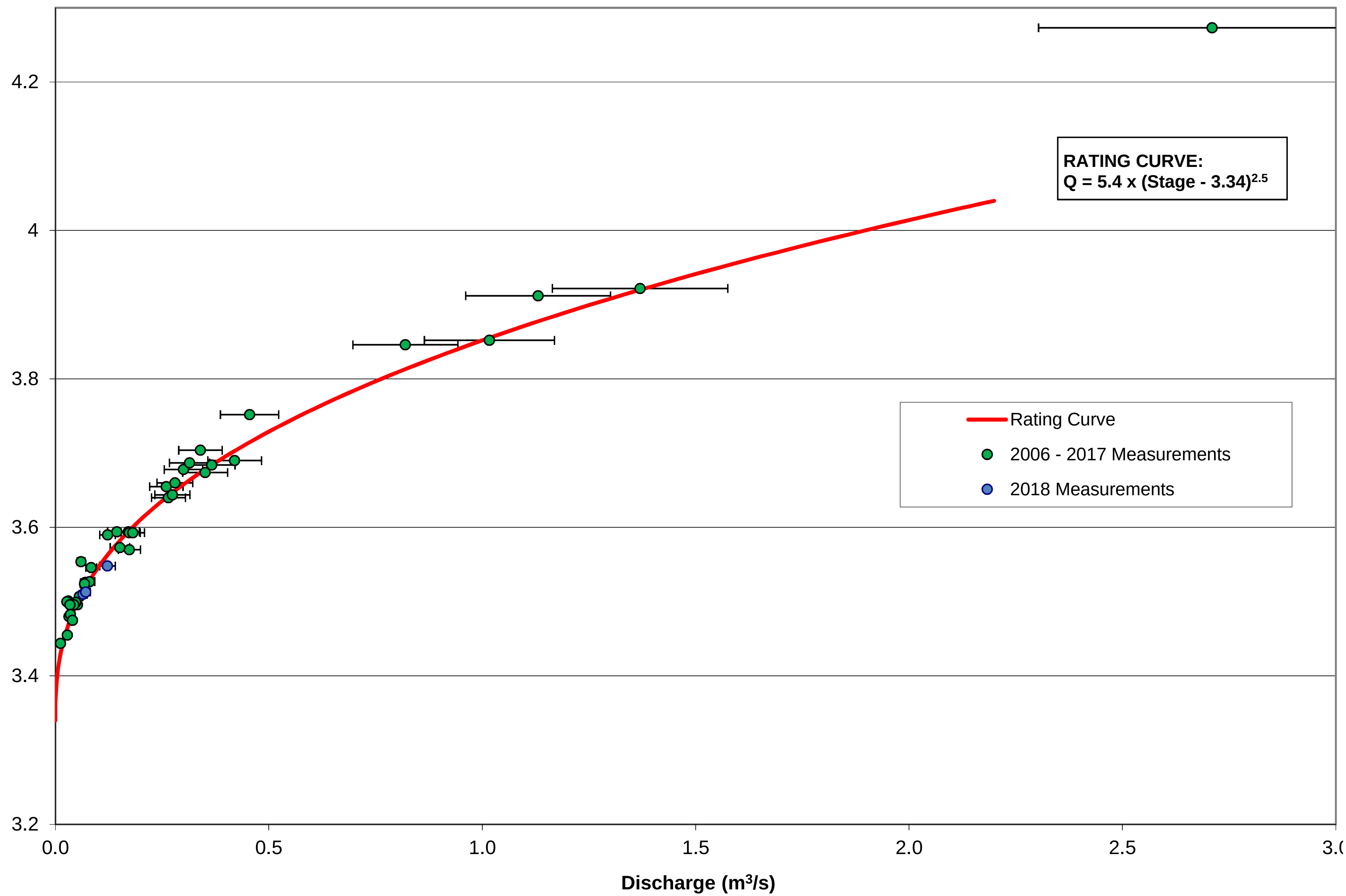
NOTE:
1. RATING CURVE SHOWN TO MAXIMUM RECORDED STAGE IN 2018

Figure 2 **H02 - Tom River Rating Curve**



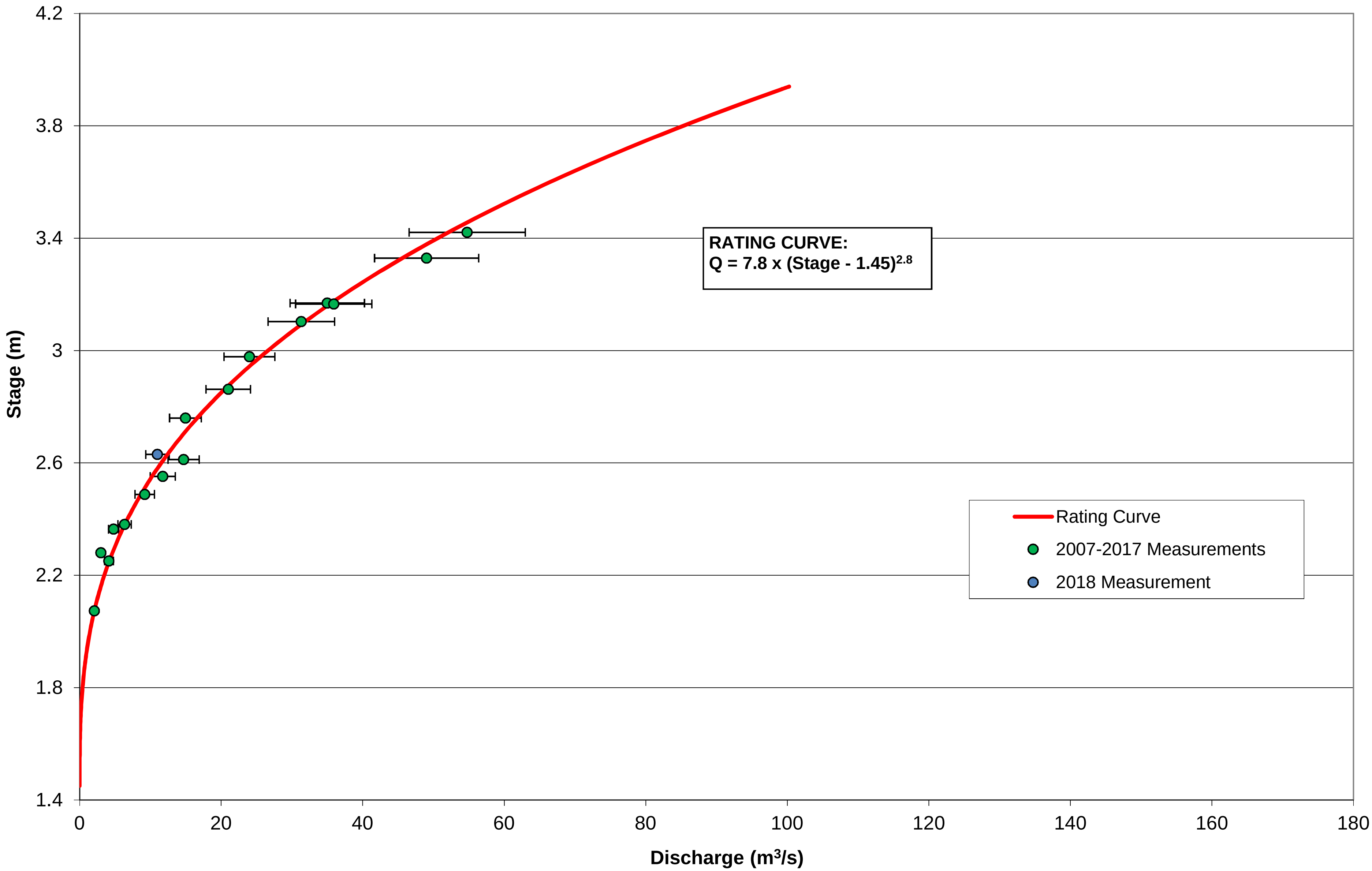
NOTE:
1. RATING CURVE SHOWN TO MAXIMUM RECORDED STAGE IN 2018

Figure 3 H04 - Camp Lake Tributary (CLT-2) Rating Curve



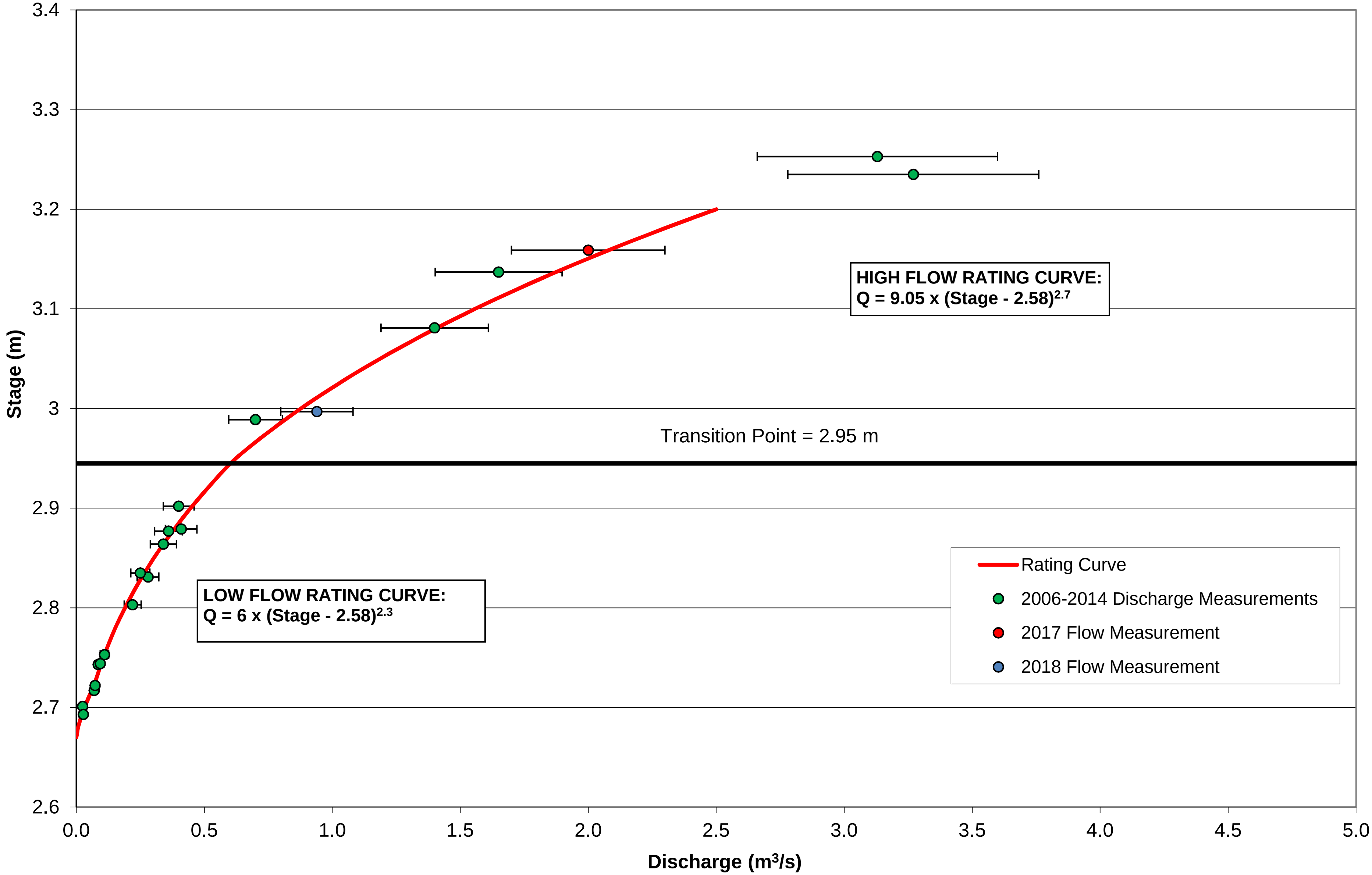
NOTE:
1. RATING CURVE SHOWN TO MAXIMUM RECORDED STAGE IN 2018

Figure 4 **H05 - Camp Lake Tributary (CLT-1) Rating Curve**



NOTES:
1. RATING CURVE SHOWN TO MAXIMUM RECORDED STAGE IN 2018

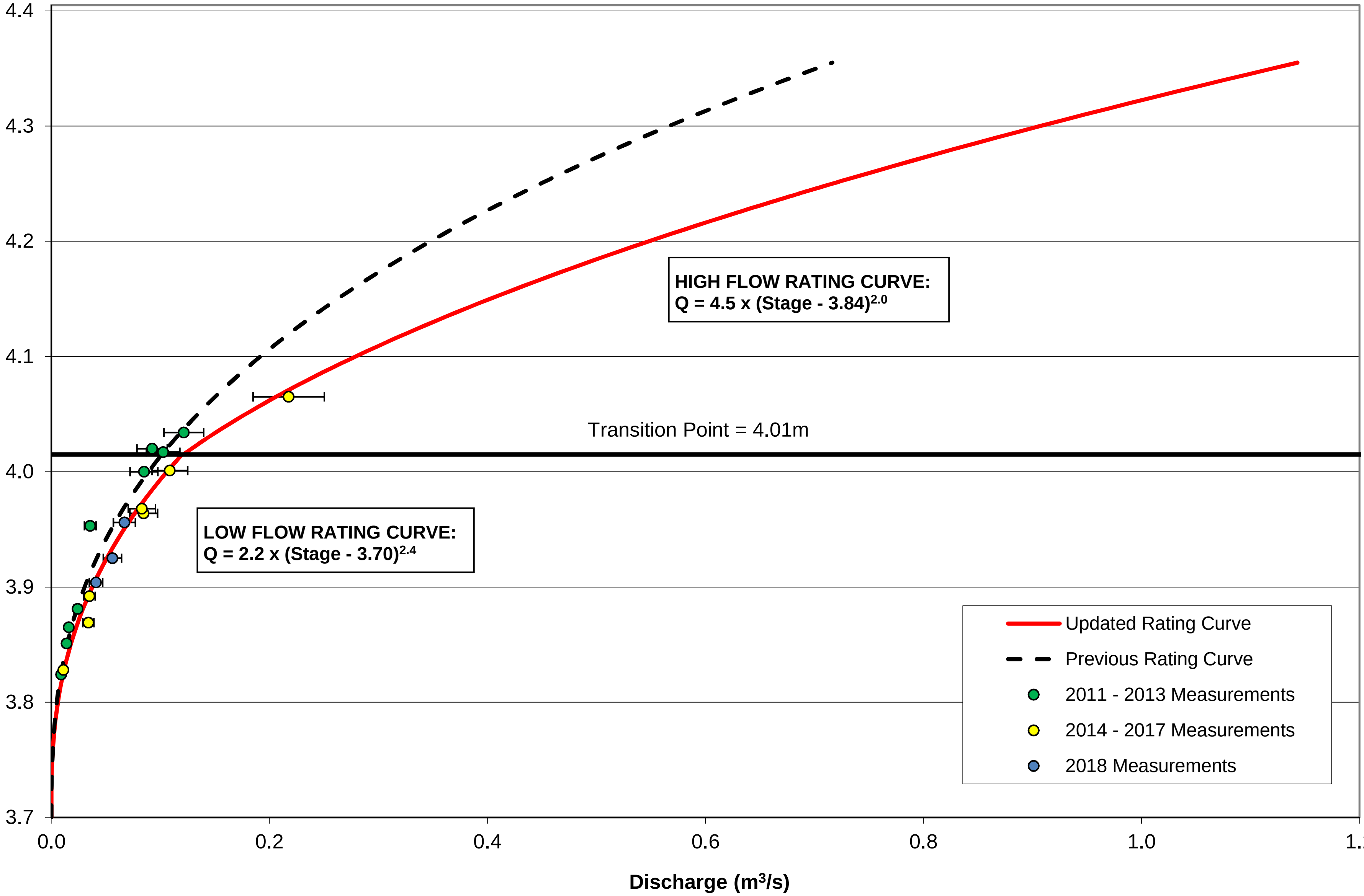
Figure 5 H06 - Mary River Rating Curve



NOTES:

1. RATING CURVE SHOWN TO MAXIMUM RECORDED STAGE IN 2018

Figure 6 **H07 - Mary River Tributary Rating Curve**



NOTE:
1. UPDATED RATING CURVE SHOWN TO MAXIMUM RECORDED STAGE IN 2018

Figure 7 H11 - Sheardown Lake Tributary (SDLT-1) Rating Curve

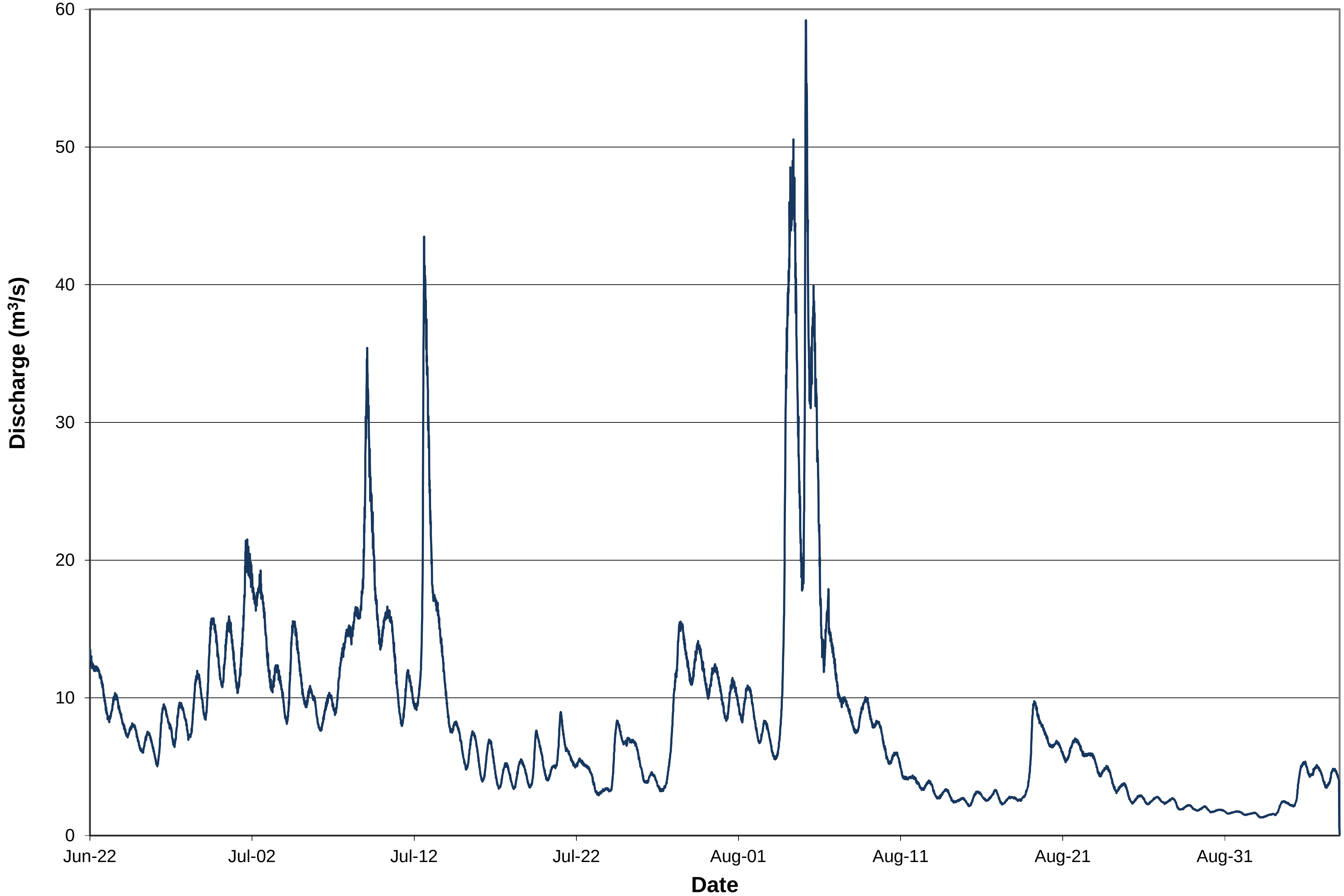


Figure 8 **H01 - Philips Creek Tributary 2018 Streamflow Record**

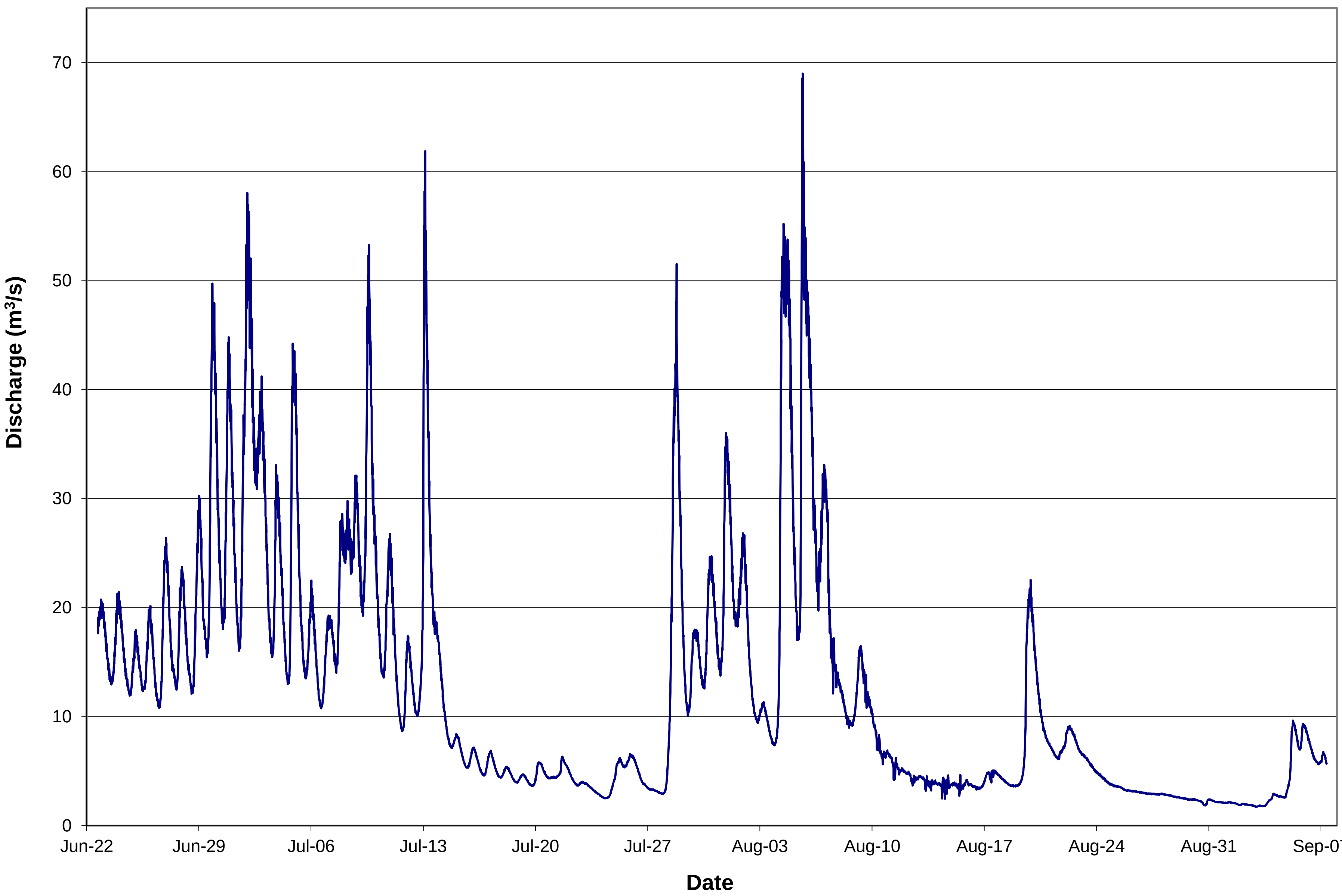


Figure 9 **H02 - Tom River 2018 Streamflow Record**

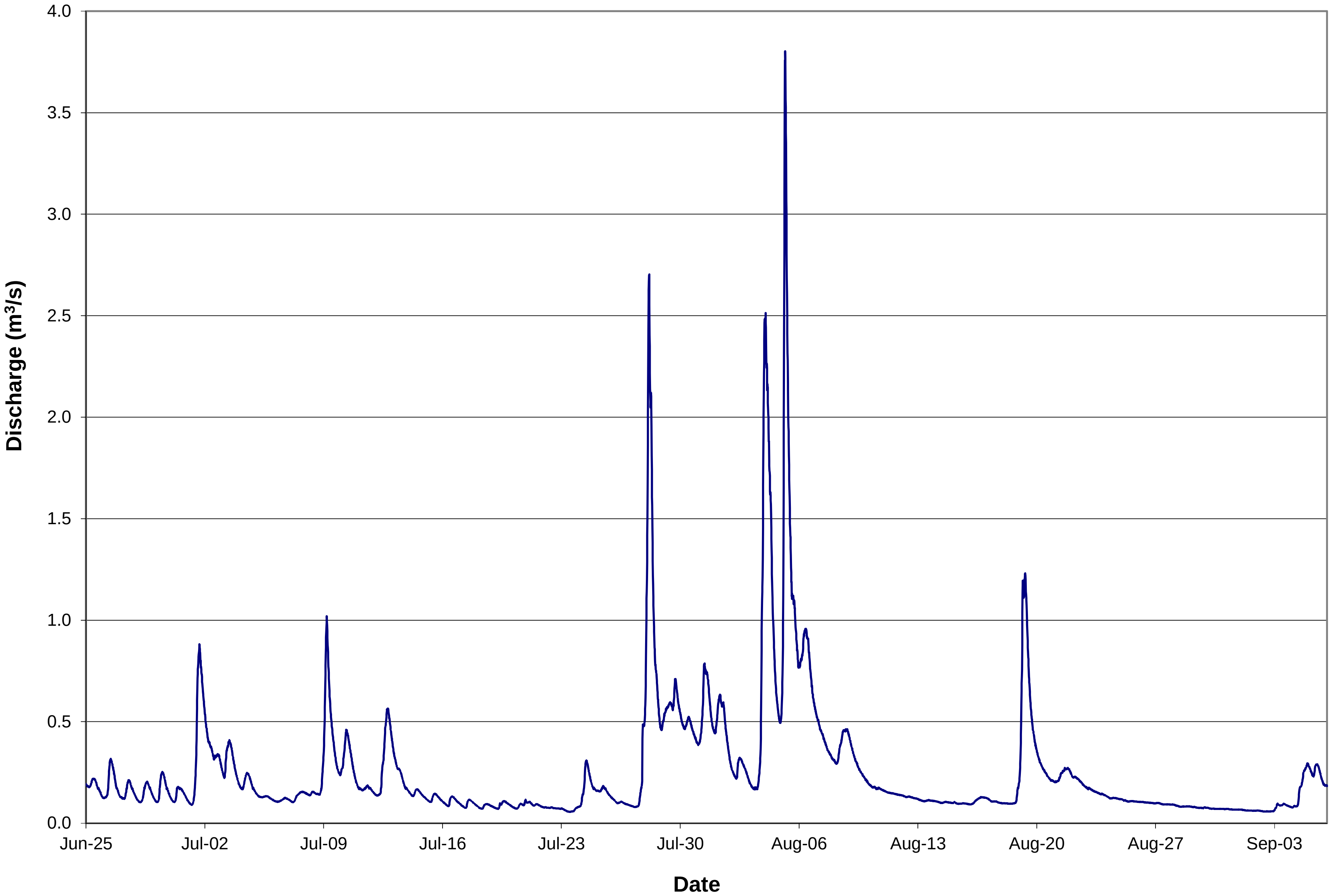


Figure 10 **H04 - Camp Lake Tributary (CLT-2) 2018 Flow Record**

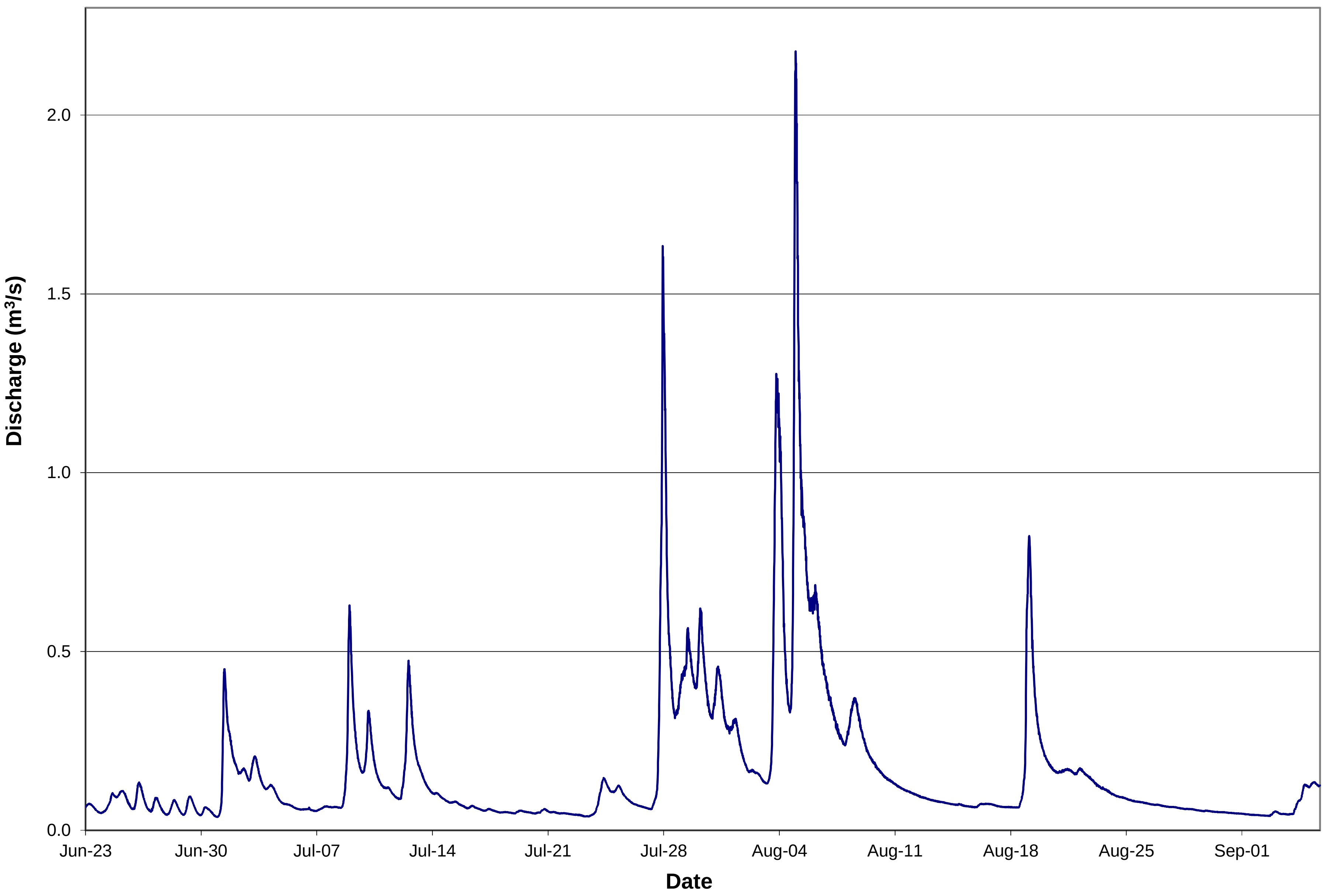


Figure 11 **H05 - Camp Lake Tributary (CLT-1) 2018 Flow Record**

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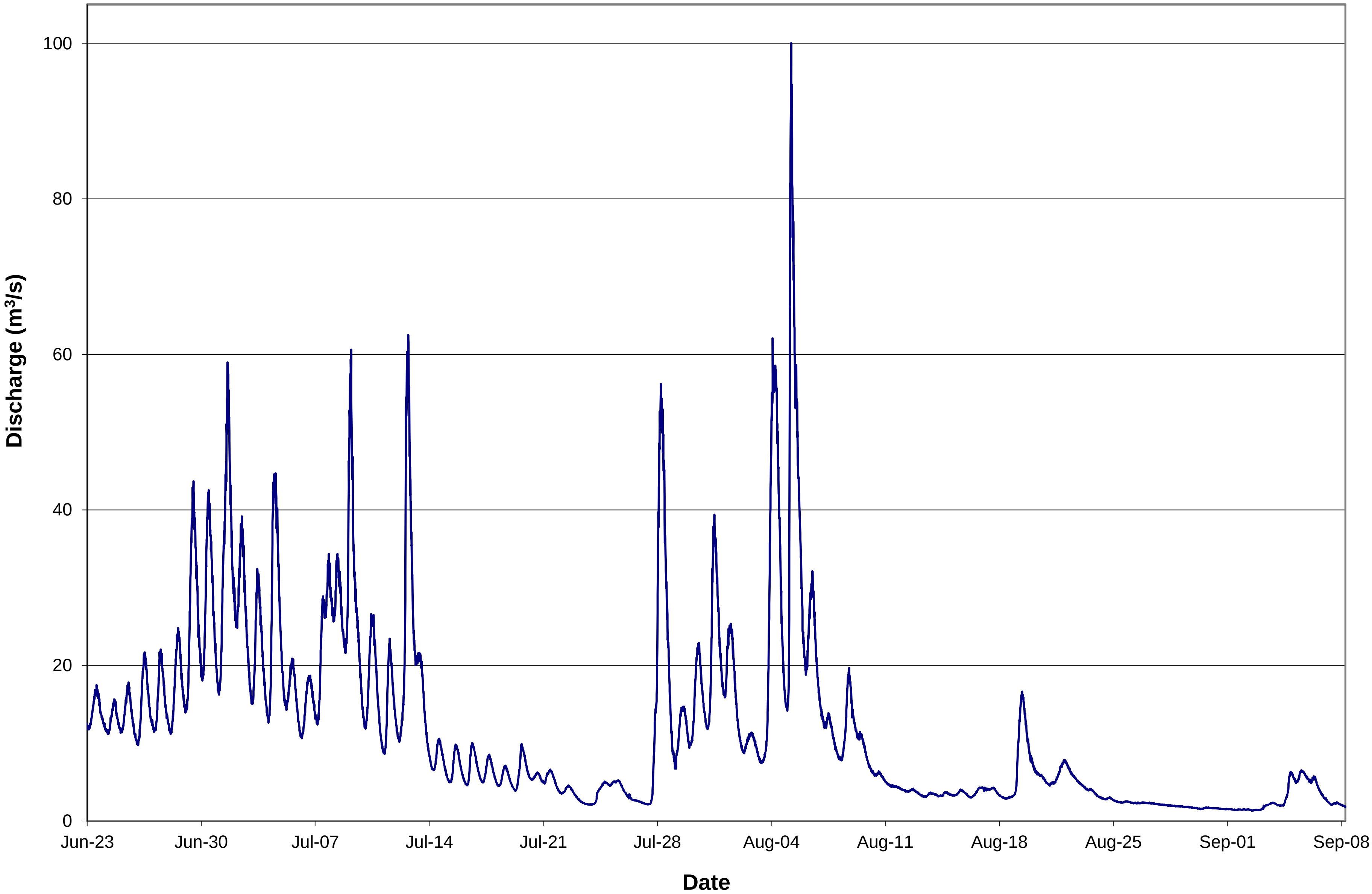

Figure 12 H06 - Mary River 2018 Flow Record

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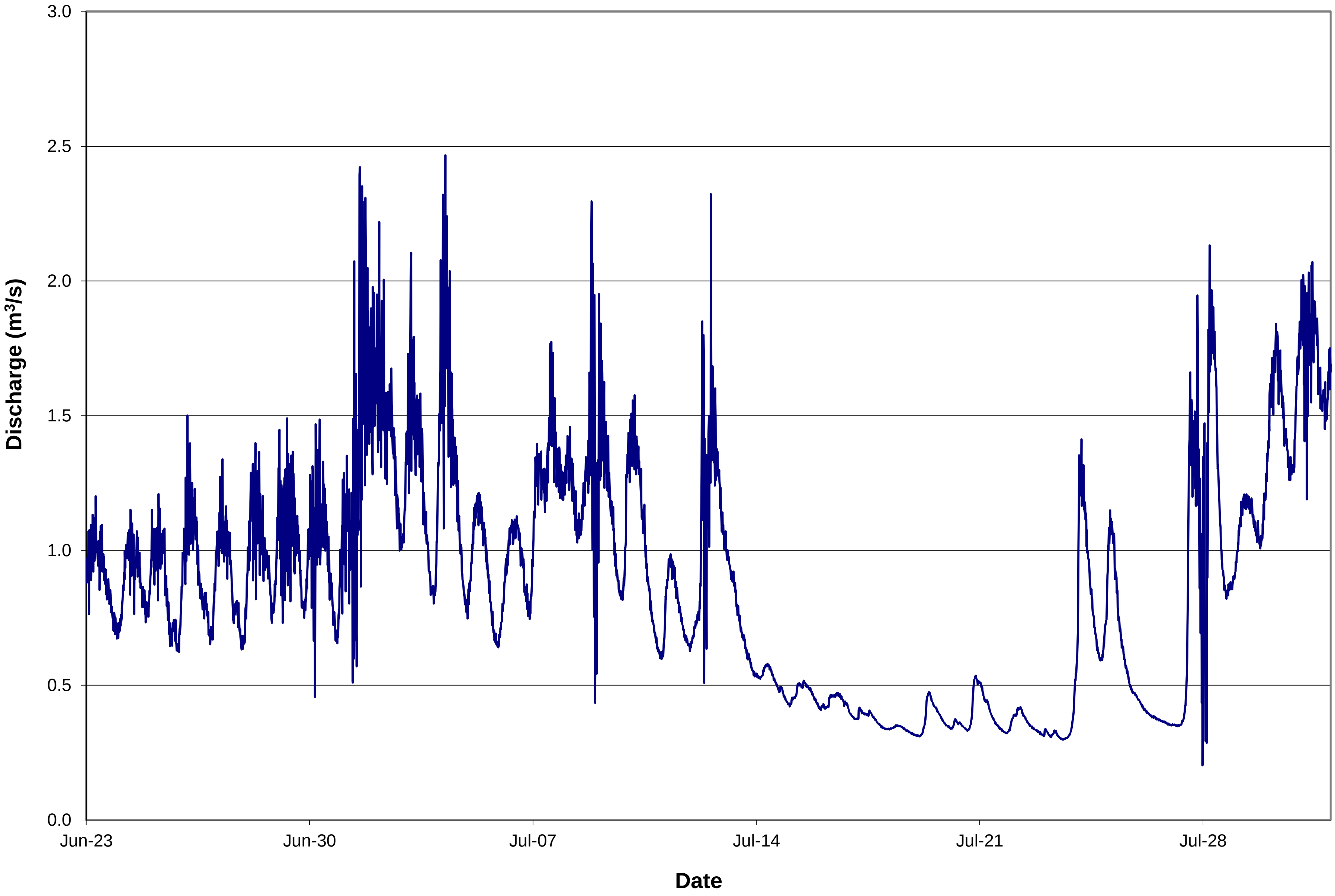

Figure 13 **H07 - Mary River Tributary 2018 Flow Record**

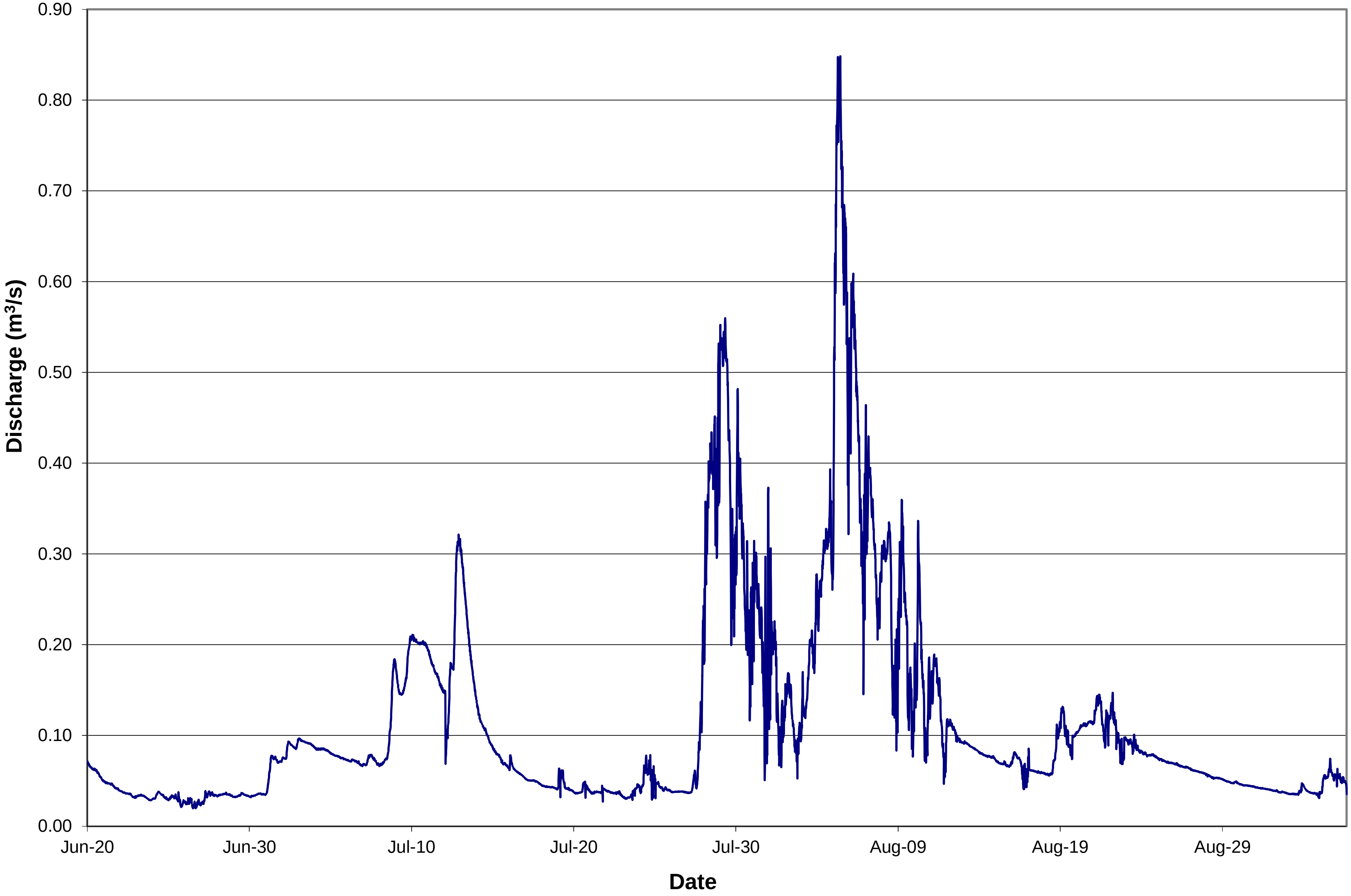

Figure 14 **H11 - Sheardown Lake Tributary (SDLT-1) 2018 Streamflow Record**

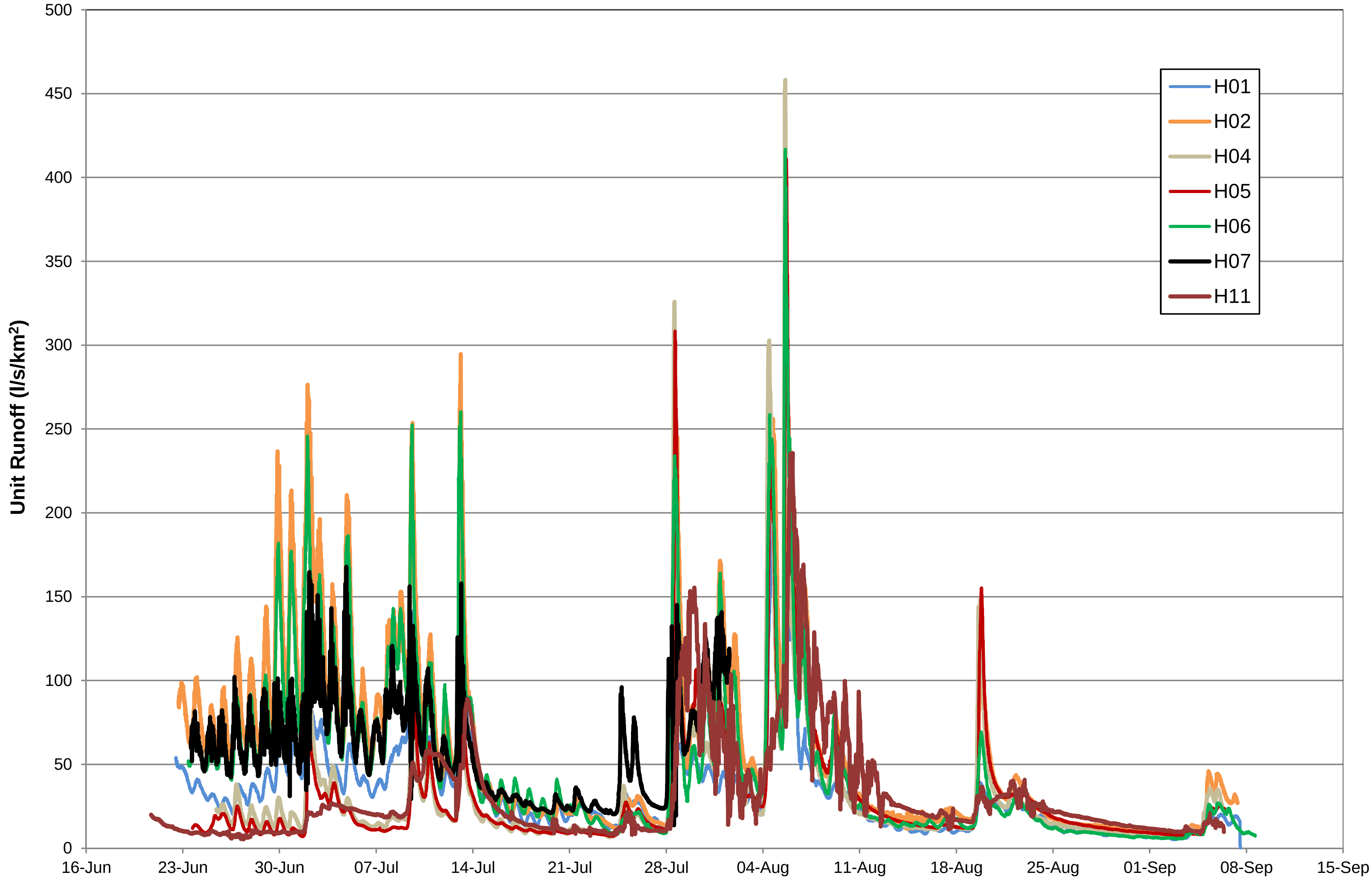

Figure 15 2018 Comparison of Unit Runoff

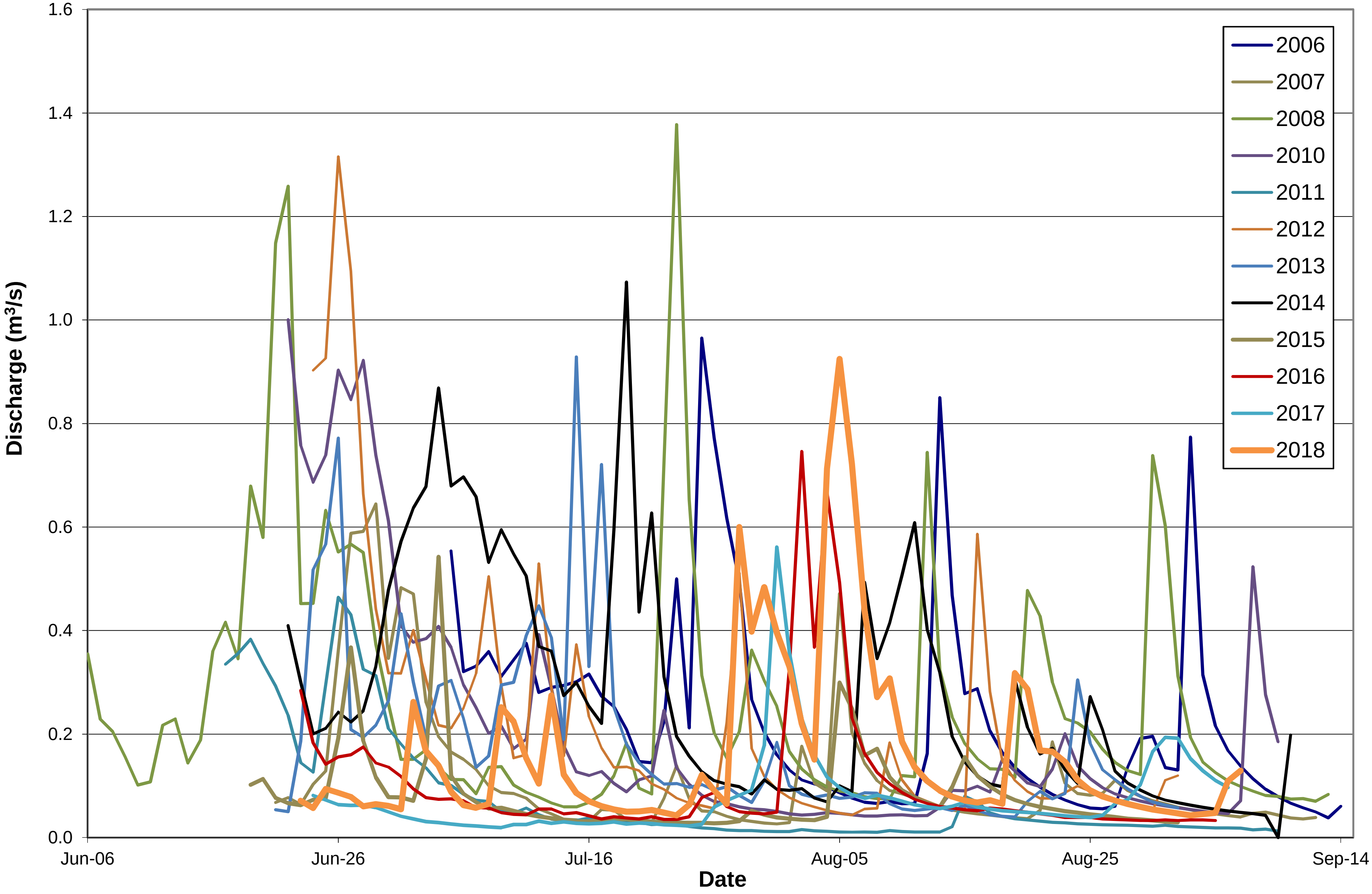

Figure 16 **H05 - Camp Lake Tributary (CLT-1) Measured Streamflow Hydrographs 2006 - 2018**