Herrera Environmental Consultants, Inc.

Memorandum

To	Mindy Roberts, Washington State Department of Ecology
cc	John Lenth, Herrera Environmental Consultants
From	Dylan, Herrera Environmental Consultants
Date	March 14, 2011
Subject	Storm Event Delineation Method Description for the Toxics in Surface Runoff to Puget Sound: Phase 3 Data and Load Estimates

The Phase 3 study required delineation of hydrographs into storm and baseflow events for categorizing water quality sampling events. Various methods for estimating baseflow have been used by others (e.g., HYSEP by USGS). With any method, estimation of baseflow is a subjective process. HYSEP, for illustration, incorporates three alternative hydrograph separation methods but does not recommend the use of any particular method. The HYSEP program documentation cautions that "although HYSEP consistently applies various algorithms that are commonly used for hydrograph separation, hydrograph separation remains a subjective process."

The method described below was developed by Northwest Hydraulic Consultants and Herrera Environmental Consultants for hydrograph separation of local flow data that were collected at small stream and river monitoring locations in the Green/Duwamish Watershed (Herrera 2004). This method uses a permutation of the sliding-interval method described in the HYSEP documentation. Specifically, it assigns a preliminary baseflow equal to the minimum flow over a three-day window, and then adjusts the baseflow and identifies storm periods based on the following user input variables:

1. Starting baseflow rate (cubic feet per second [cfs]) if the initial flow value is missing from the hydrologic record
2. Maximum percent increase per day in baseflow
3. Maximum amount (cfs) of increase per day in baseflow
4. Minimum percent that the maximum daily discharge must exceed the daily average baseflow rate to be categorized as a storm event

In applying this method, user input variables were determined using daily maximum flow data for each of the 16 stream gauging stations. Daily data, rather than 15-minute data, are used to assign baseflow separation parameters because baseflows are stable and can appropriately be assessed on a daily time step. In addition, daily data allow for efficient visual evaluation of storm delineation results for the entire period of record.

Initially, the average daily baseflow rate was estimated as the minimum flow rate over a 3-day period, including 1 day prior and 1 day after the time step being evaluated. The algorithm requires an input variable for starting the baseflow rate if the first record is missing from the data set. The first record was not missing at any of the monitoring locations, so the default baseflow value of zero was used for all of the 16 monitoring locations.

The baseflow rate was then subject to a user-defined daily maximum percent increase. Various percent increases were applied depending upon the form of the hydrograph at each station, but the most common was a 20 percent increase (Table H-1). The one exception to this was station AG62, where a maximum baseflow increase of 1,500 percent was used. Though this value was high, it resulted in a realistic ratio of storm event volume to baseflow volume. A sensitivity analysis was conducted to determine the impact of using such a high value for the percent increase variable and it was determined that the effect on the separation was slight compared with the large increase in the variable. In other words, though the maximum percent increase was inflated, the actual percent increase for any given event was well below the maximum, and consequently the separation was not strongly affected. In addition to the maximum percent increase in baseflow rate, a maximum absolute amount (cfs) of increase in baseflow was specified because the percent increase alone is too restrictive for hydrographs with zero or near-zero baseflows. In all cases, a value of 4 cfs was used for this input variable.

Storm events were identified as the period during which flows exceed the estimated baseflow by a user-defined amount of 20 percent. The 20 percent amount was selected from an initial range of 10 to 20 percent and a subjective evaluation of the hydrograph plots. In the recession portion of a storm hydrograph, this variable causes the transition from storm event to baseflow condition to occur at the time step when the hydrograph recession rate falls to below 20 percent per day. During periods of relatively-stable flow, this variable causes very minor events (with baseflow accounting for at least 80 percent of total flow) to be included as baseflow periods.

The hydrographs in Attachment 1 were developed using this method and the four input variables described above. For each of the 16 gauging stations, daily maximum flow rates are plotted with calculated daily baseflow rates for the study period. An output summary is also presented on the hygrographs that includes the number of days with missing flow records, the number of storm events, and baseflow and storm event statistics (i.e., minimum, mean, and maximum values). Input and output data are also summarized in Table H-1.

Each hydrograph separation was evaluated visually to determine if input variables required adjustment. In addition, the percent storm event volume versus percent baseflow volume was assessed as a check prior to finalizing the analysis.

References

Herrera. 2004. Year 2003 Water Quality Data Report, Green-Duwamish Watershed Water Quality Assessment. Prepared for King County Department of Natural Resources and Parks, by Herrera Environmental Consultants, Inc., Seattle, Washington.

Table H-1. Input variables and hydrograph separation algorithm output for each of the 16 monitoring locations.

Monitoring Location ID	Starting Baseflow (cfs)	Maximum Baseflow Increase (%/day)	Maximum Baseflow Increase (cfs/day)	Storm if Baseflow is Exceeded by x (%)	Number of Missing Discharge Values (days)	Number of Storm Events	Baseflow (daily)			Storm Event (daily)	
							Minimum (cfs)	Mean (cfs)	Maximum (cfs)	Mean (cfs)	Maximum (cfs)
Snohomish River Watershed											
CB335	0	50	4	20	0	63	0.5	1.2	9	5	21.8
CBX	0	20	4	20	0	53	0	0.2	2.4	3.1	19.7
RB111	0	20	4	20	0	41	0	0.8	13	5.2	20.1
RB202	0	20	4	20	0	44	0	3.8	26.1	6.6	36.9
AG174	0	20	4	20	0	49	0	1.3	7.2	2.4	7.6
AGG	0	20	4	20	0	27	0	0.2	4.6	2.2	18.2
FB200	0	20	4	20	0	32	0	0.9	6.3	3.3	9
FB203	0	10	4	20	0	25	0.6	17.1	105.5	47.8	169.1
Puyallup River Watershed											
CBA	0	50	4	20	0	74	0	3.6	24.8	6.9	28
CBB	0	50	4	20	0	47	0	0.2	4.9	2.9	22.2
RB53	0	40	4	20	0	43	0	0.7	4	1.5	6.3
RB209	0	1	4	20	0	39	1.4	1.7	2.5	2.3	5.3
AG143	0	50	4	20	0	49	0	0.3	3.2	1.3	6.5
AG62	0	1500	4	30	0	59	0	1.4	10.8	4	16.5
FB130	0	10	4	20	0	45	0	0.8	3.4	1.4	5.5
FB372	0	10	4	20	0	40	0.1	1.1	6.1	4.9	24.1

cfs: cubic feet per second

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ATTACHMENT 1

Storm Event Delineation Input Variables and Output

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Snohomish

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INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)
2. VARY INPUT VARIABLES BELOW USING JUDGEMENT
3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
50.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

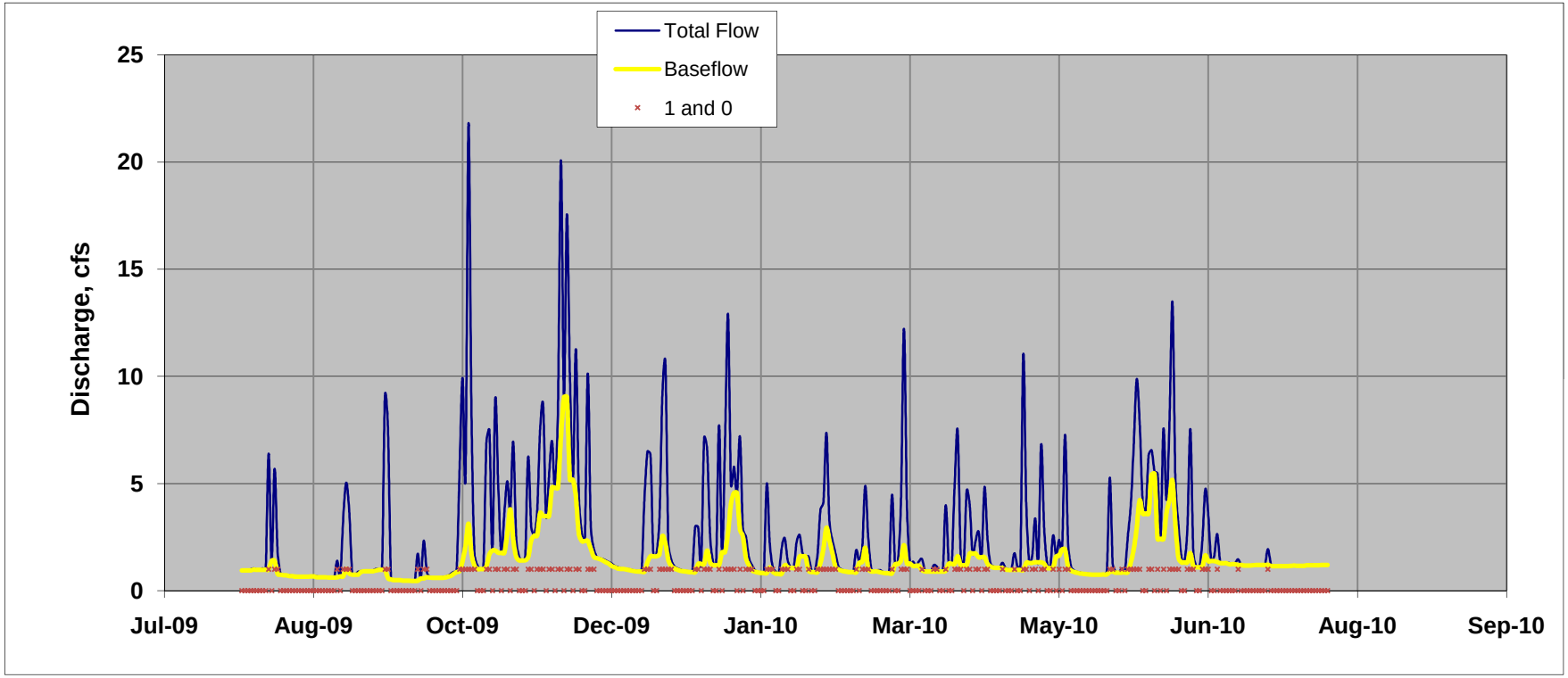
OUTPUT SUMMARY

Station ID 54C Max CB335

Number of Missing Data Values	**0**
Number of Storm Events	**63**

Stats	Baseflow	Stormflow
Min	0.5	n/a
Mean	1.2	5.0
Max	9.0	21.8

0 50.0% 4 20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)
2. VARY INPUT VARIABLES BELOW USING JUDGEMENT
3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

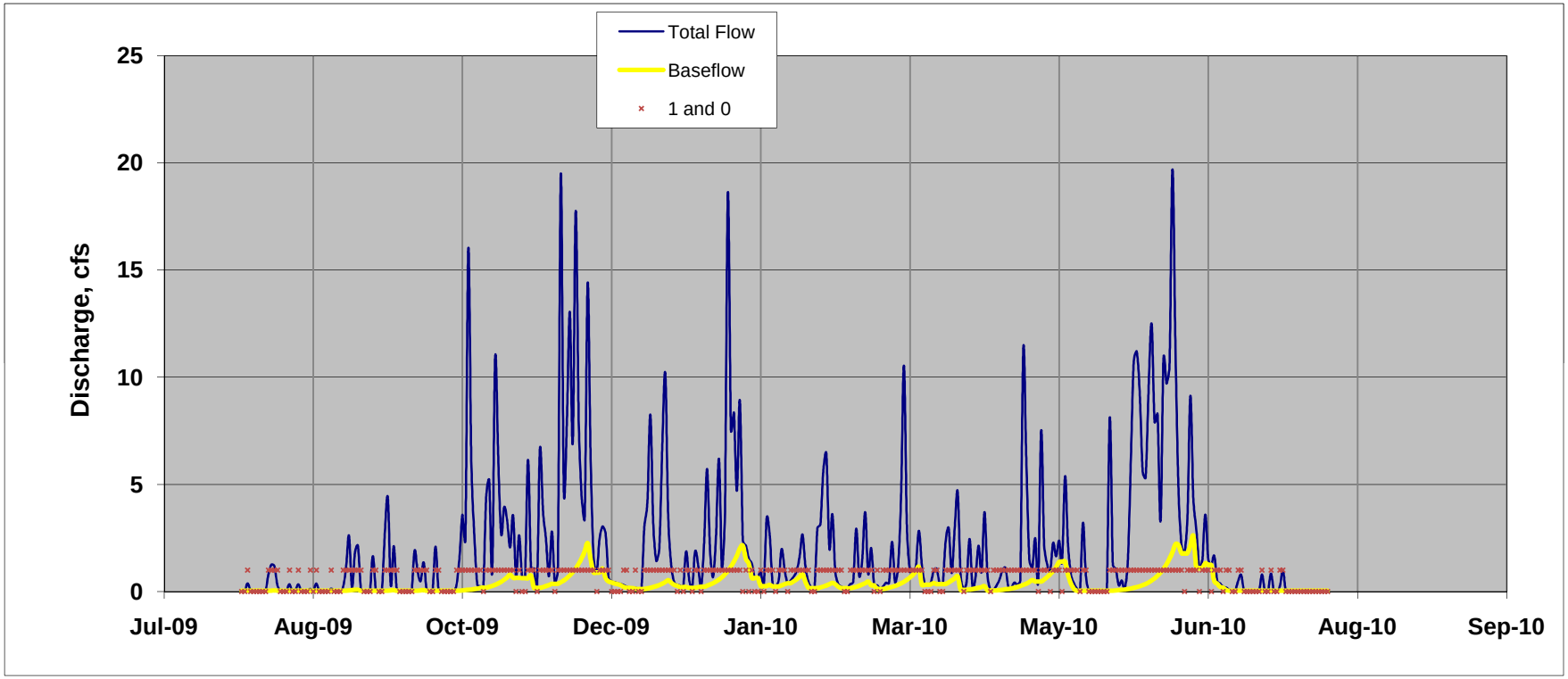
0	= Starting baseflow if 1st flow value is missing
20.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

OUTPUT SUMMARY

Station ID 54C Max CBX

Number of Missing Data Values	**0**
Number of Storm Events	**53**

Stats	Baseflow	Stormflow	
Min	0.0	n/a	
Mean	0.2	3.1	
Max	2.4	19.7	
0	20.0%	4	20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)
2. VARY INPUT VARIABLES BELOW USING JUDGEMENT
3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
20.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

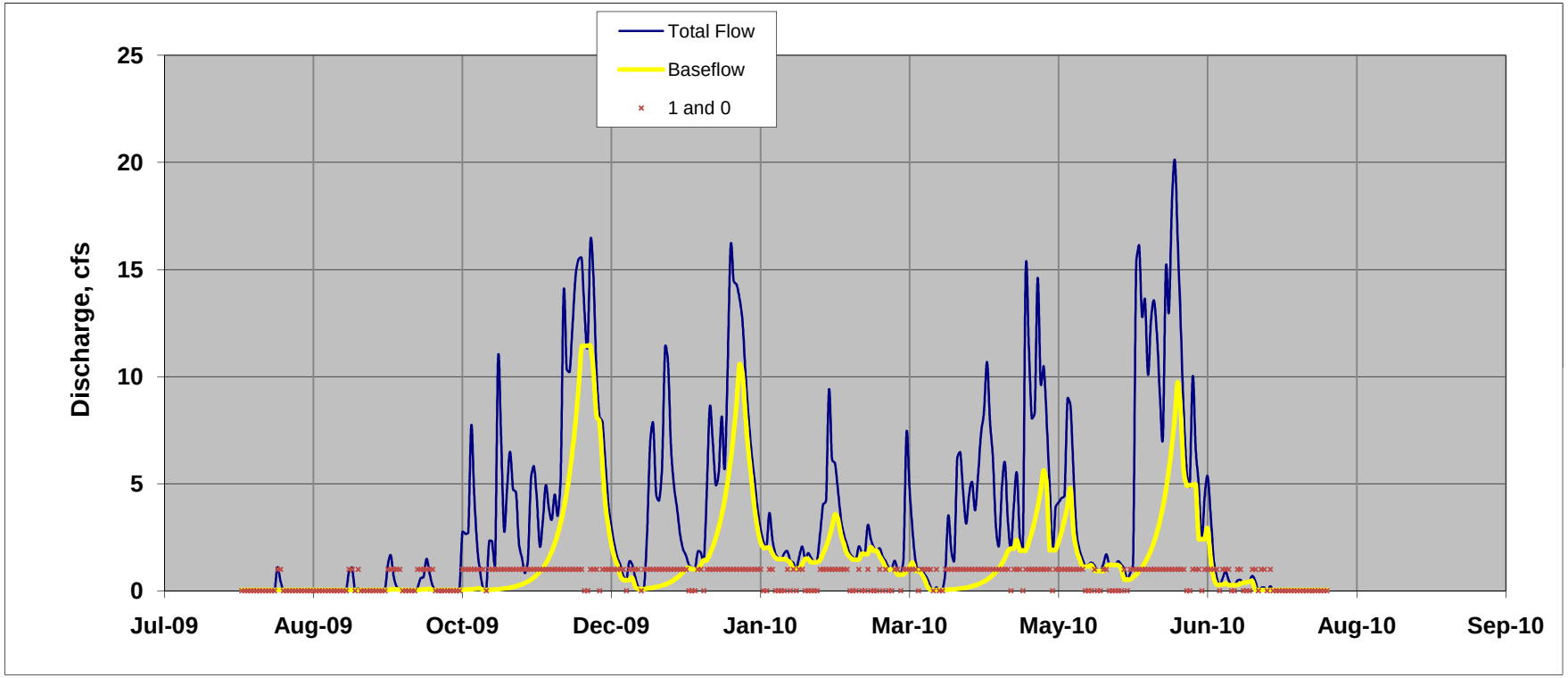
OUTPUT SUMMARY

Station ID 54C Max RB111

Number of Missing Data Values **0**

Number of Storm Events **41**

Stats	Baseflow	Stormflow	
Min	0.0	n/a	
Mean	0.8	5.2	
Max	13.0	20.1	
0	20.0%	4	20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)
2. VARY INPUT VARIABLES BELOW USING JUDGEMENT
3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

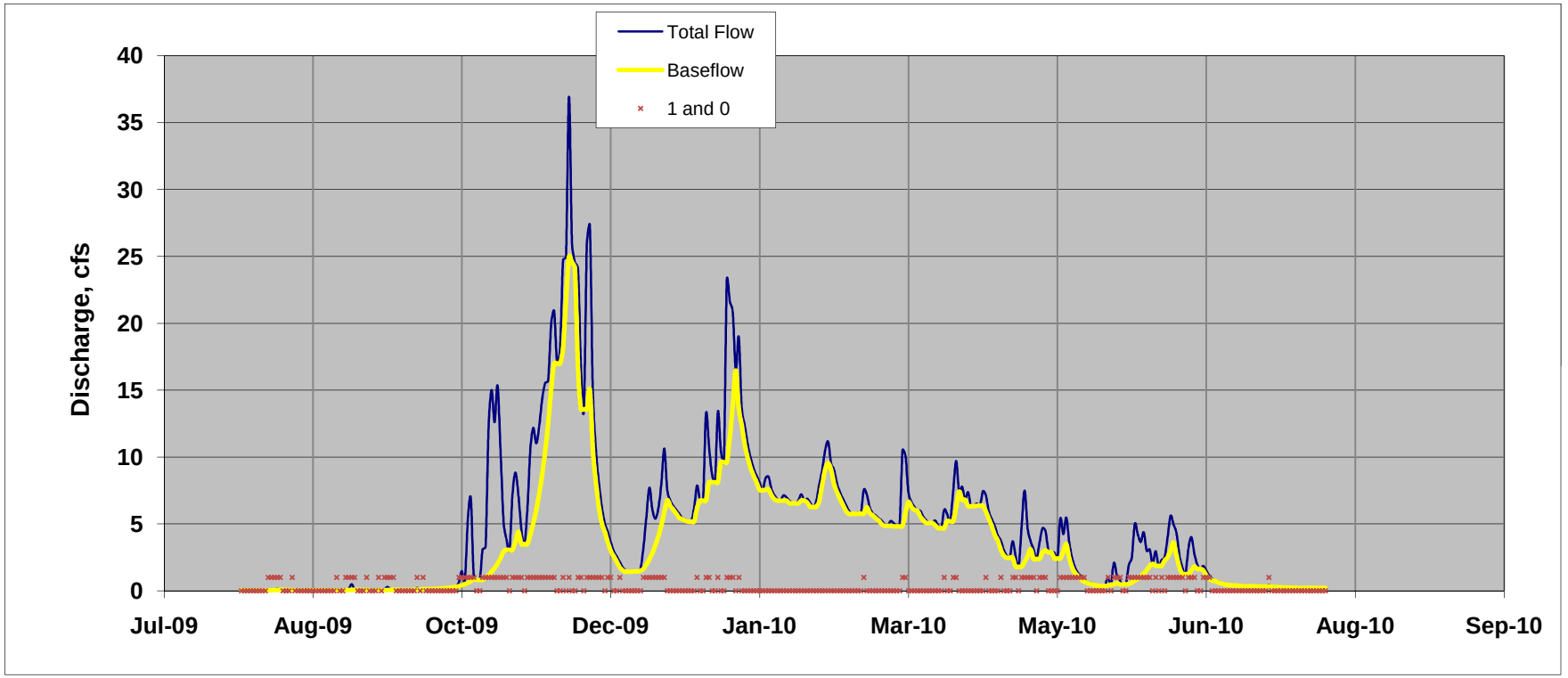
0	= Starting baseflow if 1st flow value is missing
20.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

OUTPUT SUMMARY

Station ID 54C Max RB202

Number of Missing Data Values	**0**
Number of Storm Events	**44**

Stats	Baseflow	Stormflow	
Min	0.0	n/a	
Mean	3.8	6.6	
Max	26.1	36.9	
0	20.0%	4	20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)
2. VARY INPUT VARIABLES BELOW USING JUDGEMENT
3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
20.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

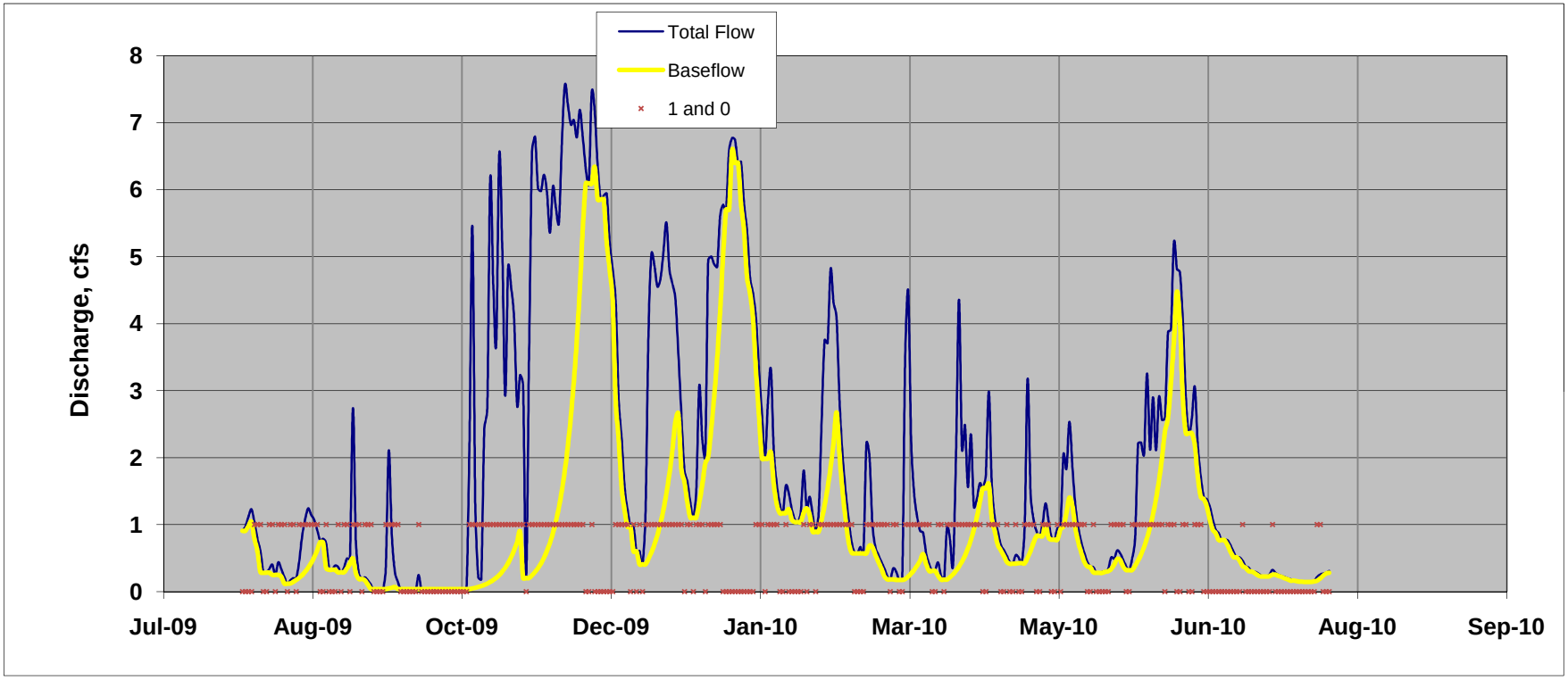
OUTPUT SUMMARY

Station ID 54C Max AG174

Number of Missing Data Values	**0**
Number of Storm Events	**49**

Stats	Baseflow	Stormflow
Min	0.0	n/a
Mean	1.3	2.4
Max	7.2	7.6

0 20.0% 4 20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)

2. VARY INPUT VARIABLES BELOW USING JUDGEMENT

3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
20.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

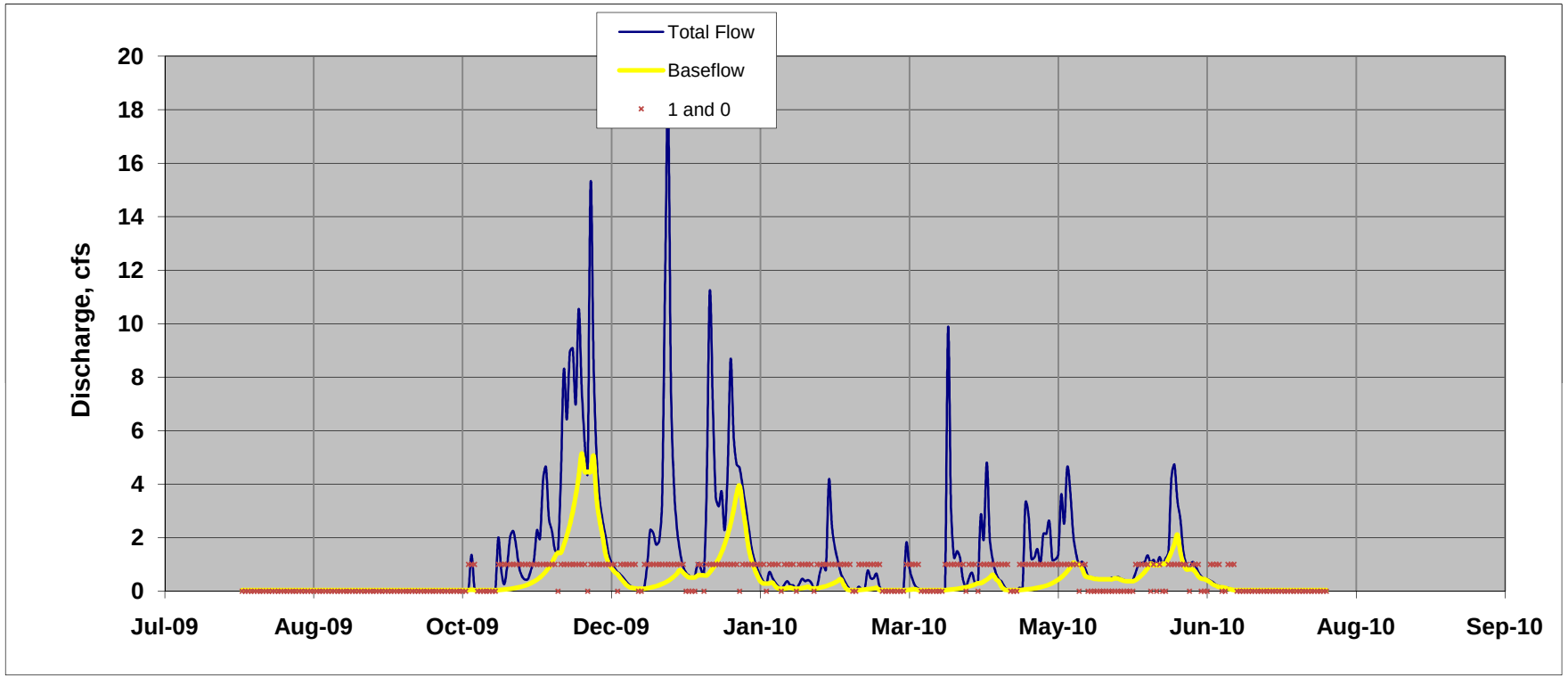
OUTPUT SUMMARY

Station ID 54C Max AGG

Number of Missing Data Values **0**

Number of Storm Events **27**

Stats	Baseflow	Stormflow	
Min	0.0	n/a	
Mean	0.2	2.2	
Max	4.6	18.2	
0	20.0%	4	20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)

2. VARY INPUT VARIABLES BELOW USING JUDGEMENT

3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
20.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

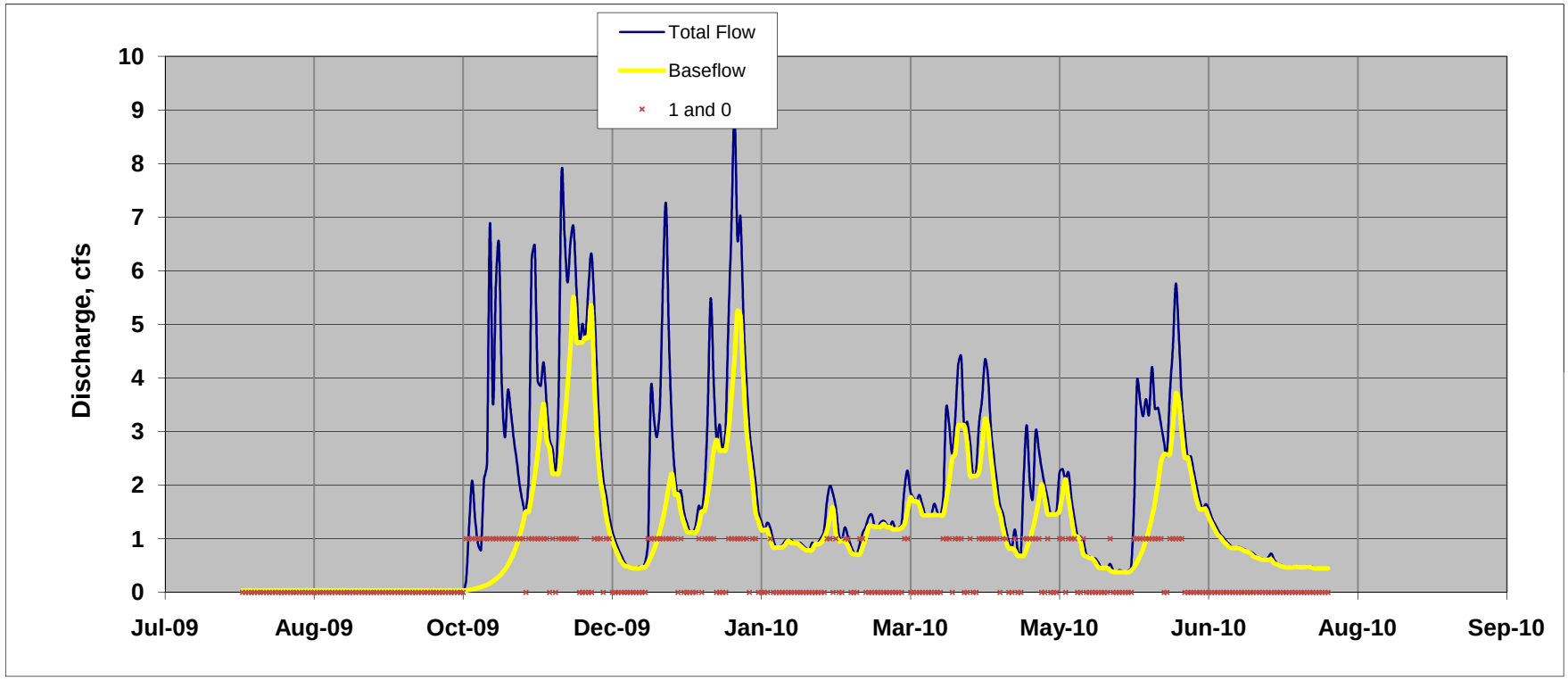
OUTPUT SUMMARY

Station ID 54C Max FB200

Number of Missing Data Values **0**

Number of Storm Events **32**

Stats	Baseflow	Stormflow	
Min	0.0	n/a	
Mean	0.9	3.3	
Max	6.3	9.0	
0	20.0%	4	20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)

2. VARY INPUT VARIABLES BELOW USING JUDGEMENT

3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
10.0%	= Max allowable baseflow increase per day in %:
20	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

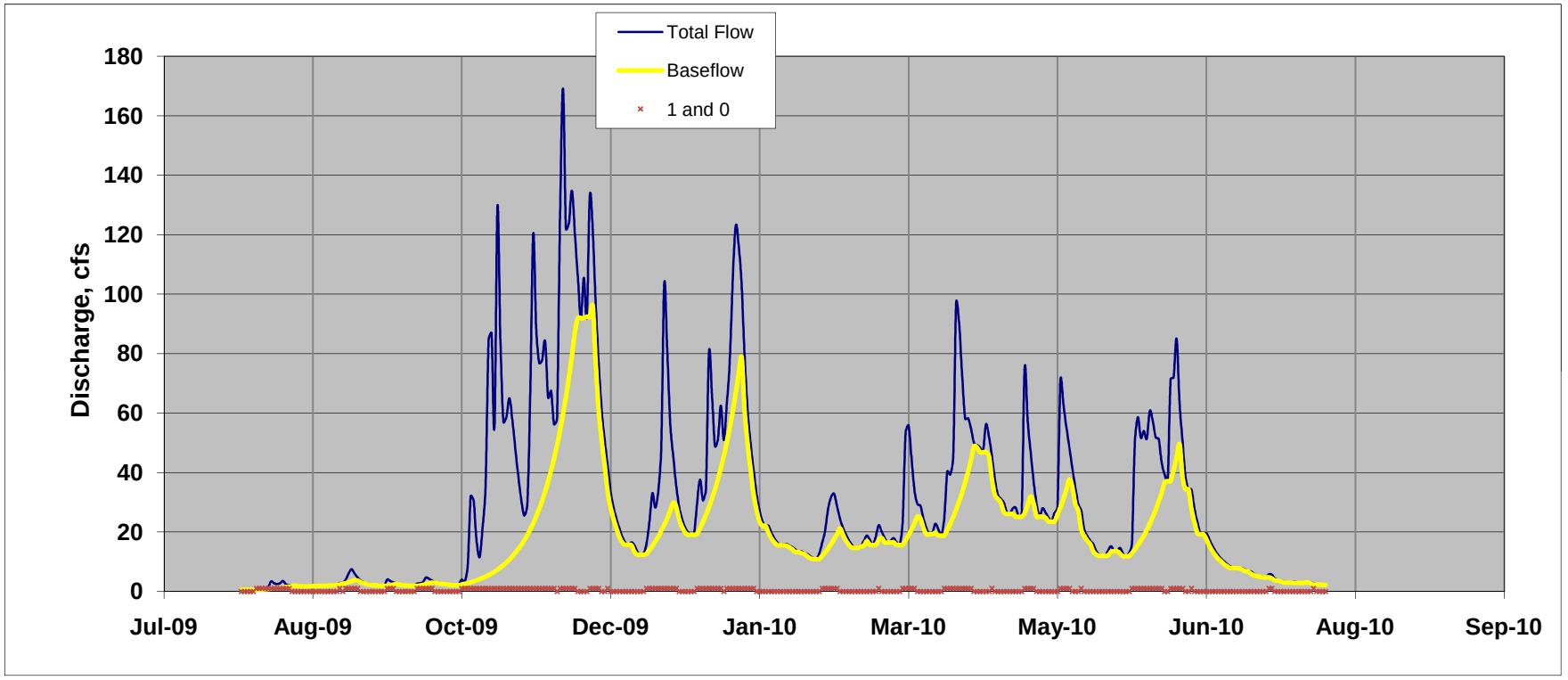
OUTPUT SUMMARY

Station ID 54C Max FB203

Number of Missing Data Values **0**

Number of Storm Events **25**

Stats	Baseflow	Stormflow	
Min	0.6	n/a	
Mean	17.1	47.8	
Max	105.5	169.1	
0	10.0%	20	20.0%



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INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)
2. VARY INPUT VARIABLES BELOW USING JUDGEMENT
3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

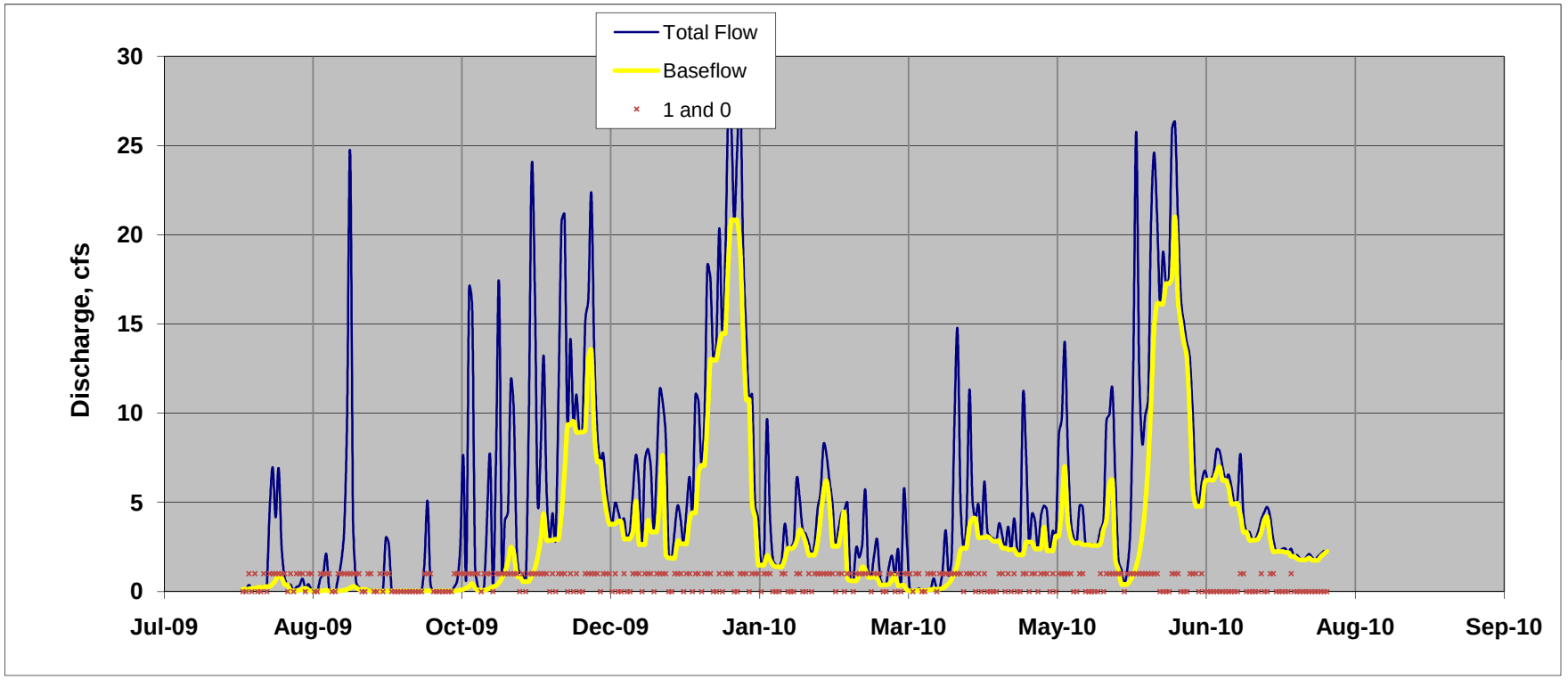
0	= Starting baseflow if 1st flow value is missing
50.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

OUTPUT SUMMARY

Station ID 54C Max CBA

Number of Missing Data Values	**0**
Number of Storm Events	**74**

Stats	Baseflow	Stormflow	
Min	0.0	n/a	
Mean	3.6	6.9	
Max	24.8	28.0	
0	50.0%	4	20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)
2. VARY INPUT VARIABLES BELOW USING JUDGEMENT
3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
50.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

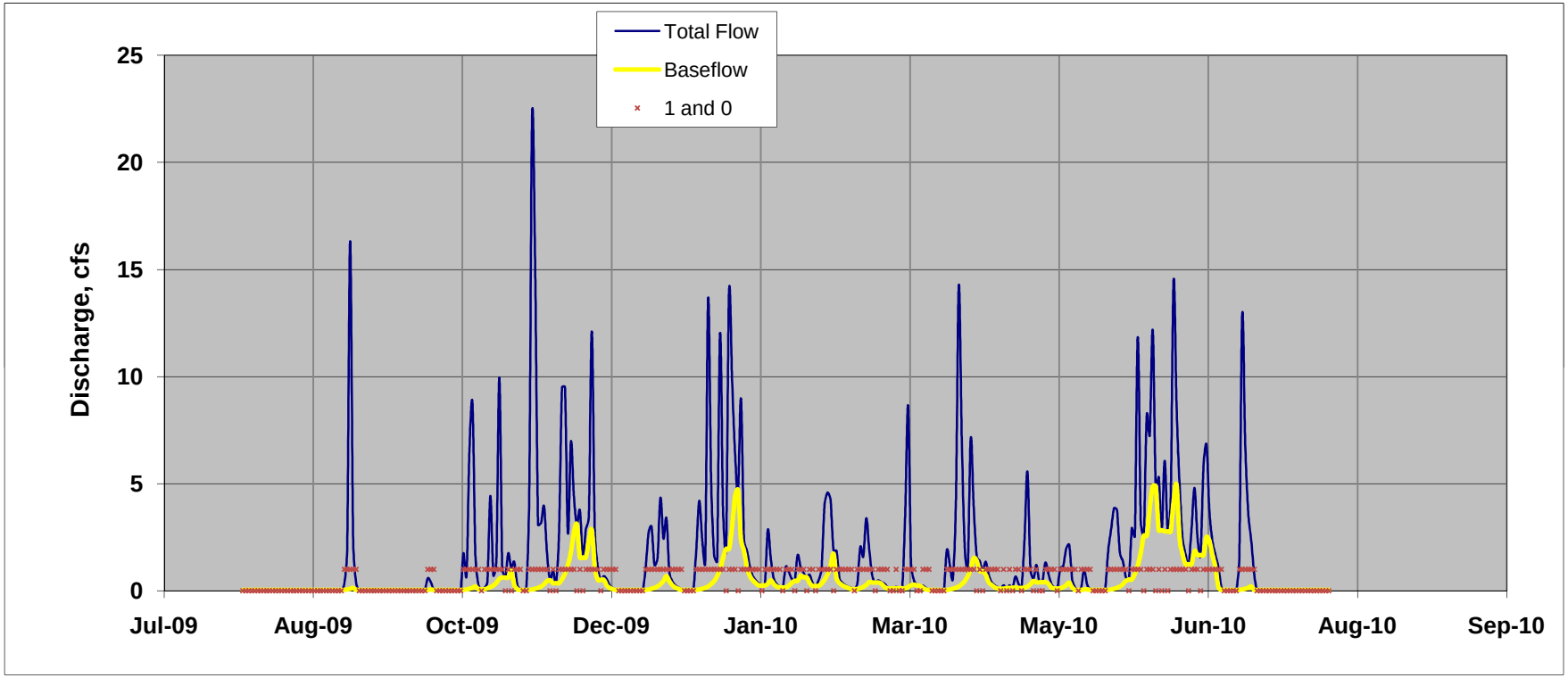
OUTPUT SUMMARY

Station ID 54C Max CBB

Number of Missing Data Values	**0**
Number of Storm Events	**47**

Stats	Baseflow	Stormflow
Min	0.0	n/a
Mean	0.2	2.9
Max	4.9	22.2

0 50.0% 4 20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)

2. VARY INPUT VARIABLES BELOW USING JUDGEMENT

3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
40.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

OUTPUT SUMMARY

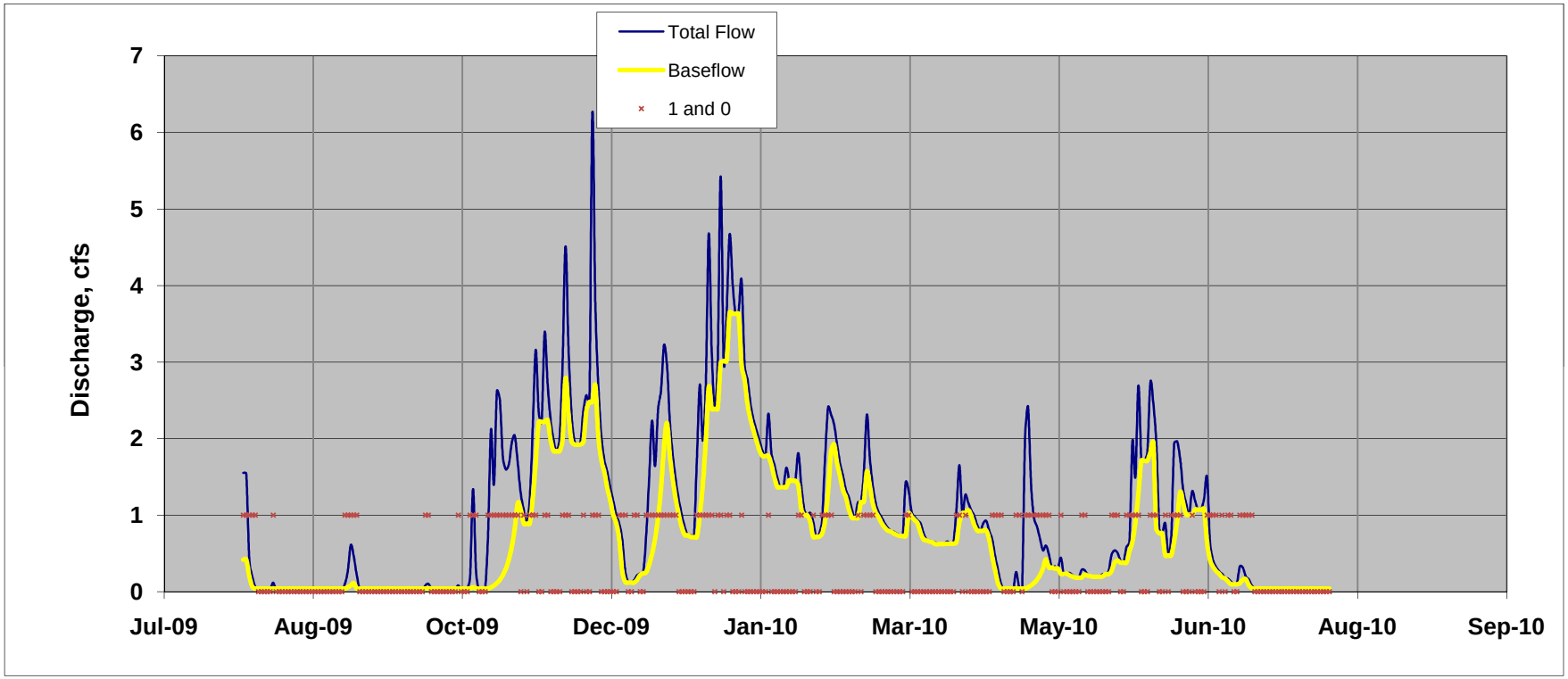
Station ID 54C Max RB53

Number of Missing Data Values **0**

Number of Storm Events **43**

Stats	Baseflow	Stormflow
Min	0.0	n/a
Mean	0.7	1.5
Max	4.0	6.3

0 40.0% 4 20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)

2. VARY INPUT VARIABLES BELOW USING JUDGEMENT

3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
1.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
2.0%	= Must exceed baseflow by this much to flag as storm

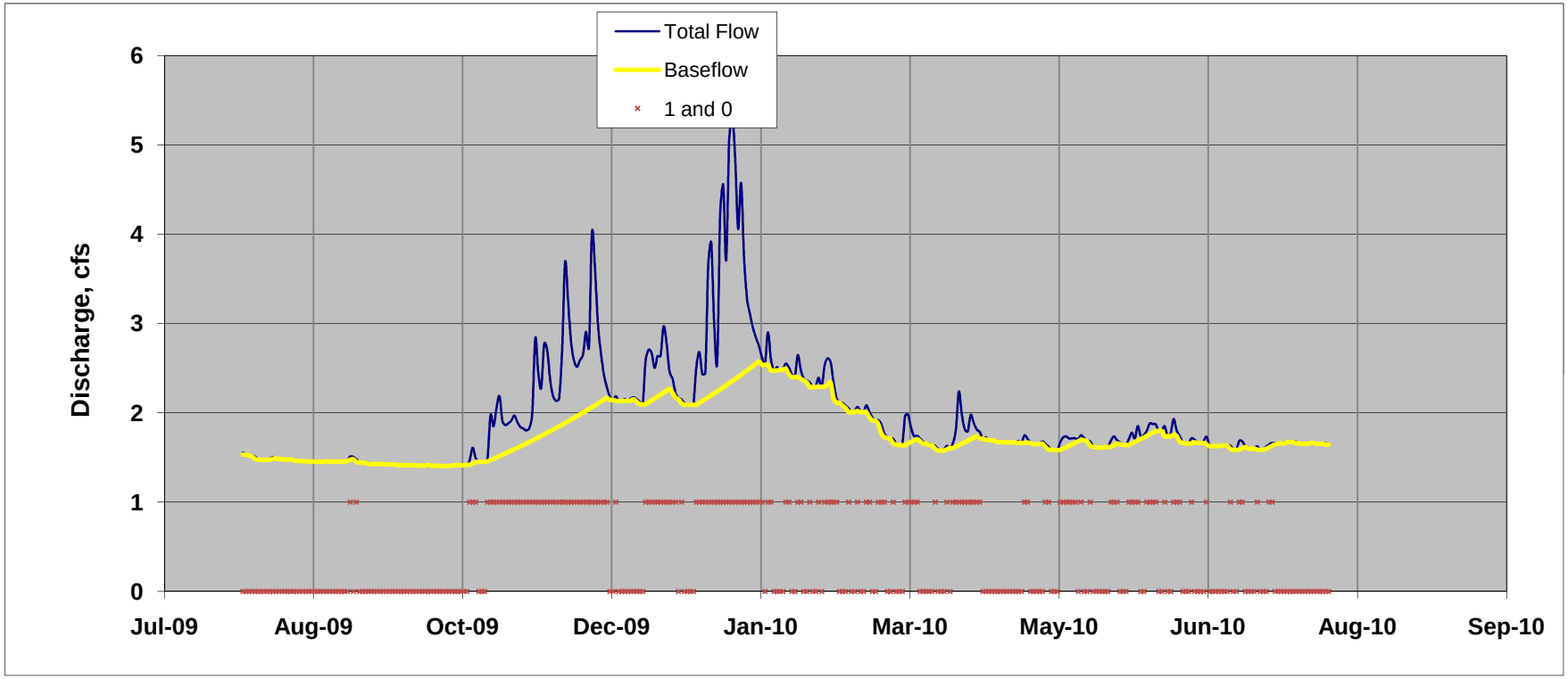
OUTPUT SUMMARY

Station ID 54C Max RB209

Number of Missing Data Values	**0**
Number of Storm Events	**39**

Stats	Baseflow	Stormflow
Min	1.4	n/a
Mean	1.7	2.3
Max	2.5	5.3

0 1.0% 4 2.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)
2. VARY INPUT VARIABLES BELOW USING JUDGEMENT
3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
50.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

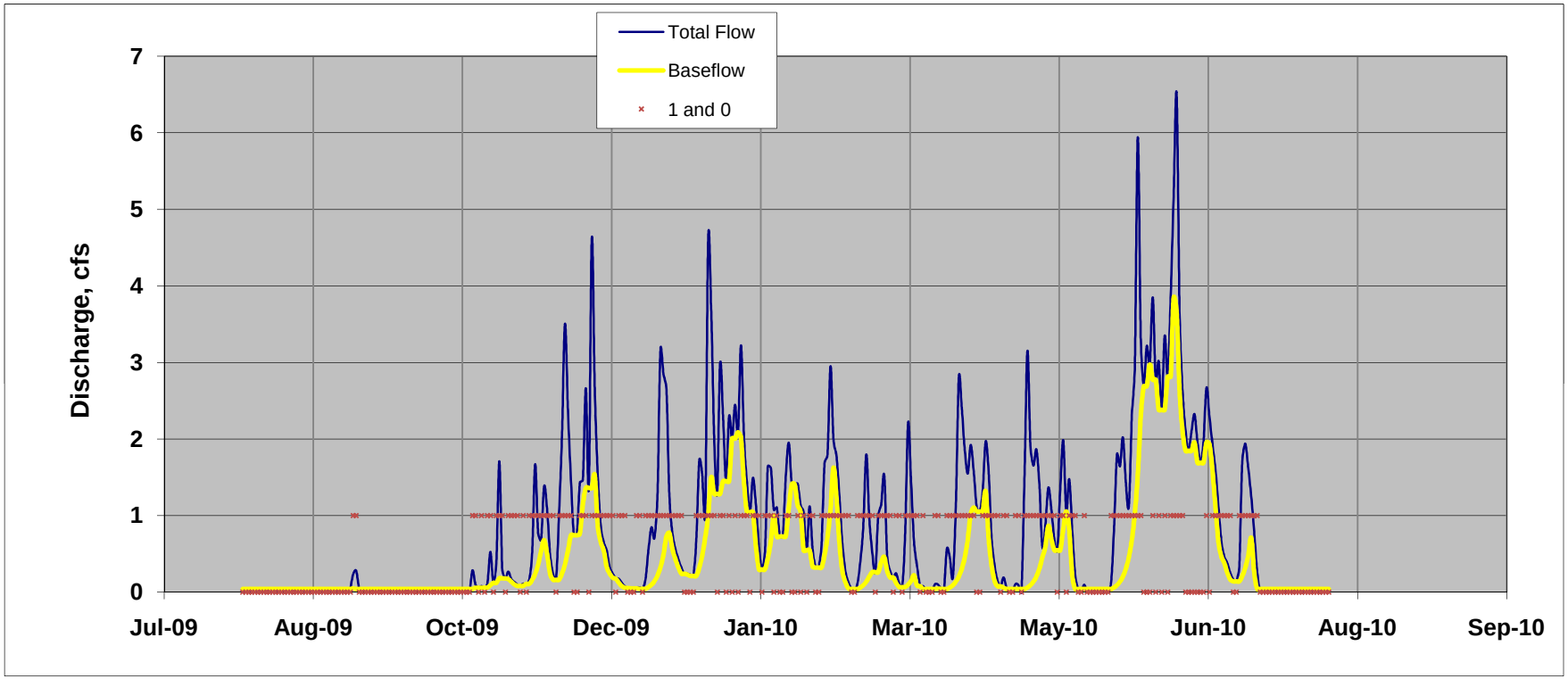
OUTPUT SUMMARY

Station ID 54C Max AG143

Number of Missing Data Values **0**

Number of Storm Events **49**

Stats	Baseflow	Stormflow	
Min	0.0	n/a	
Mean	0.3	1.3	
Max	3.2	6.5	
0	50.0%	4	20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)

2. VARY INPUT VARIABLES BELOW USING JUDGEMENT

3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
1500.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
30.0%	= Must exceed baseflow by this much to flag as storm

OUTPUT SUMMARY

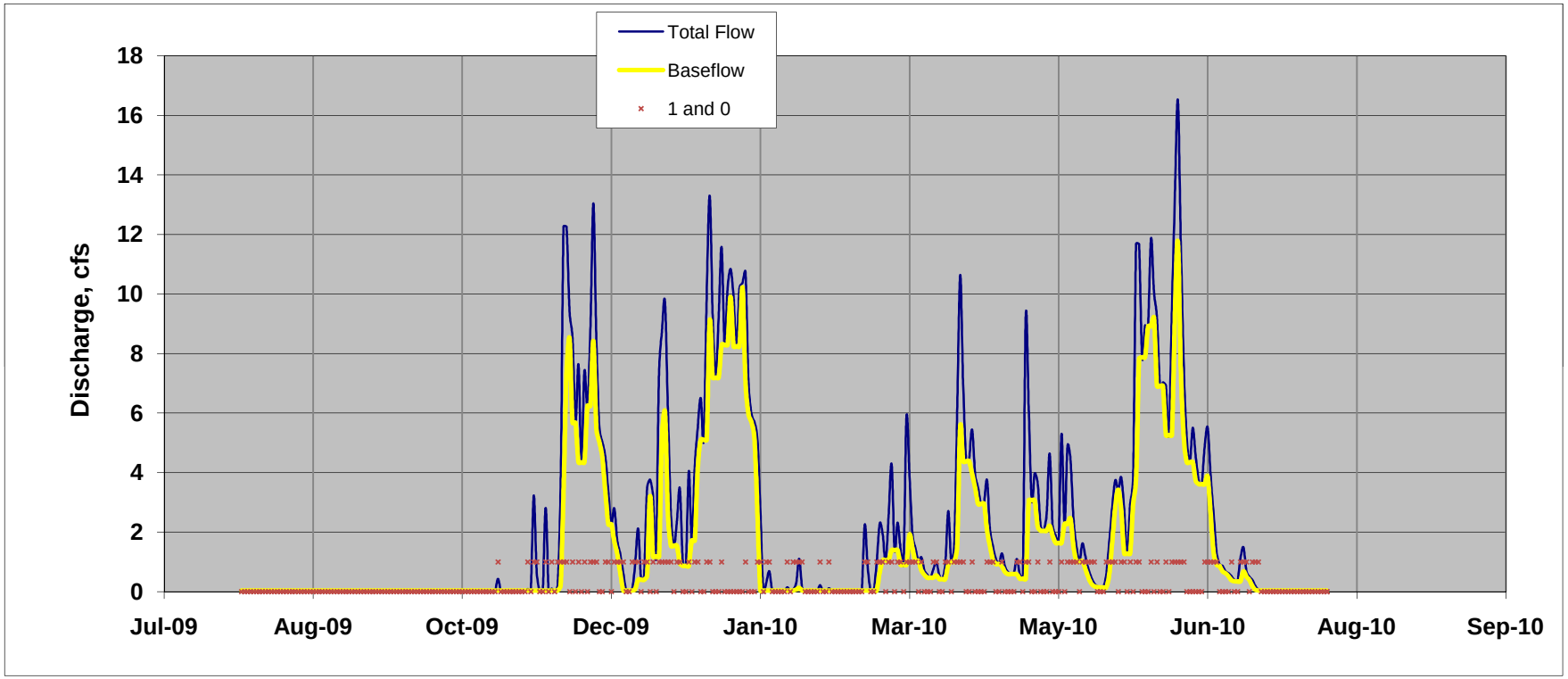
Station ID 54C Max AG62

Number of Missing Data Values **0**

Number of Storm Events **59**

Stats	Baseflow	Stormflow
Min	0.0	n/a
Mean	1.4	4.0
Max	10.8	16.5

0 1500.0% 4 30.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

1. COPY DAILY DATA SET INTO COLUMN A
(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)

2. VARY INPUT VARIABLES BELOW USING JUDGEMENT

3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
10.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

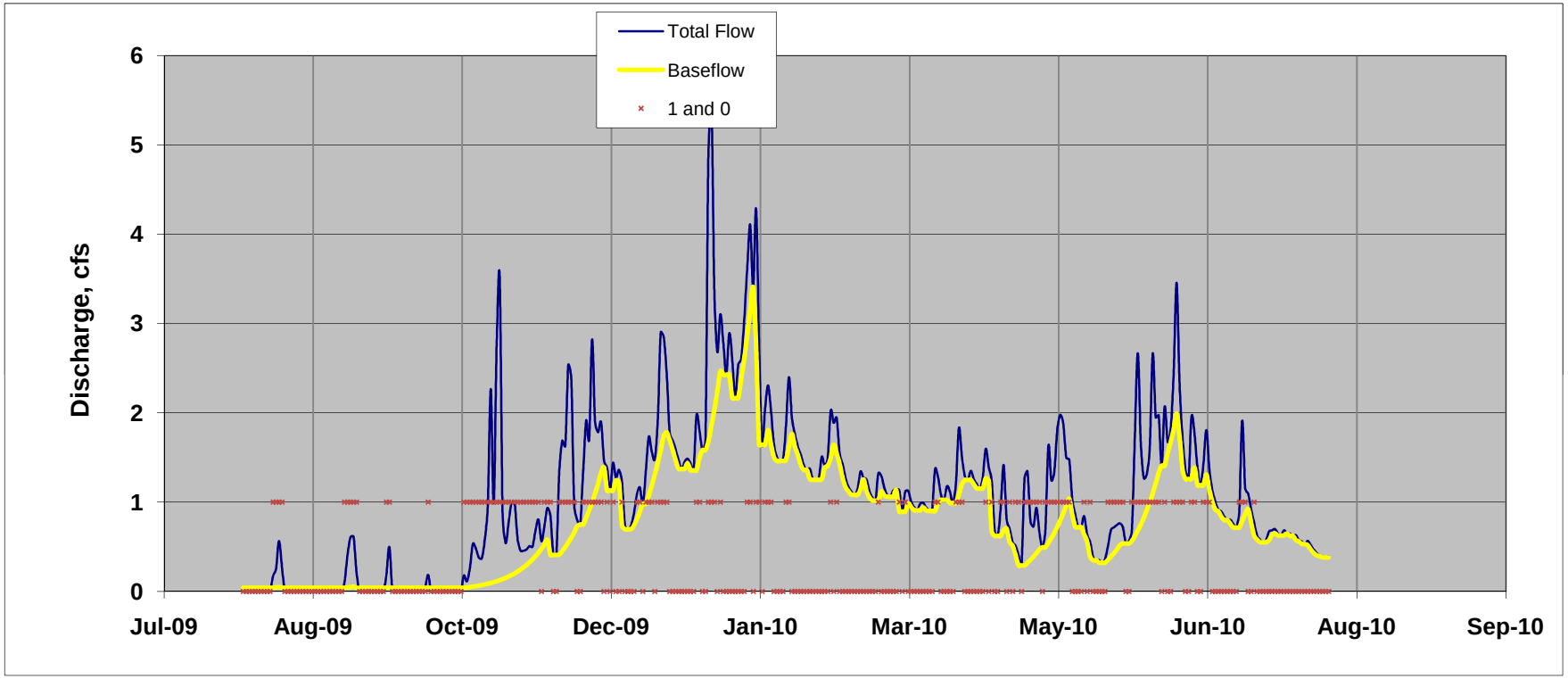
OUTPUT SUMMARY

Station ID 54C Max FB130

Number of Missing Data Values **0**

Number of Storm Events **45**

Stats	Baseflow	Stormflow	
Min	0.0	n/a	
Mean	0.8	1.4	
Max	3.4	5.5	
0	10.0%	4	20.0%



INSTRUCTIONS FOR DAILY FLOW STORM SEPARATION:

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(COPY ENTIRE COLUMN FROM RAW DATA SETS SHEET)
2. VARY INPUT VARIABLES BELOW USING JUDGEMENT
3. SAVE RESULTS ELSEWHERE.

USER INPUT VARIABLES

0	= Starting baseflow if 1st flow value is missing
10.0%	= Max allowable baseflow increase per day in %:
4	= Max allowable baseflow increase per day in cfs
20.0%	= Must exceed baseflow by this much to flag as storm

OUTPUT SUMMARY

Station ID 54C Max FB372

Number of Missing Data Values	**0**
Number of Storm Events	**40**

Stats	Baseflow	Stormflow	
Min	0.1	n/a	
Mean	1.1	4.9	
Max	6.1	24.1	
0	10.0%	4	20.0%