Final Report

Rating Relationships for the Flood Warning Gages on Upper Boulder and Fourmile Creek

Photo Taken by HDR Inc.

Submitted to:

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Boulder Creek Ratings Report
January 2004

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I.Background

The Urban Drainage and Flood Control District (District) along with Boulder County (County) operate continuous stage monitoring stations at critical locations in Upper Boulder Creek and Fourmile Creek. Data is telemetered in real-time to local base stations that assess the flooding potential during large runoff events. In addition to stage, discharge information is also required in the decision making process. Rating relationships (ratings) are used to convert the stage (water level in feet) monitored by a pressure transducer in the stream to values of flow (cubic feet per second). Flow data is required by forecasting systems such as David Ford Consulting Engineer's Catchment Forecast Modeling System which is currently being implemented for Boulder Creek.

Four stations in the Upper Boulder Creek and Fourmile Creek watersheds monitor stage on a continuous basis during the flood season which extends from April through October.

- Boulder Creek at Boulder Falls
- Boulder Creek at Orodell
- Fourmile Creek at Salina
- Boulder Creek at the Bridge

The general location of each gage is summarized in Table 1. Latitude and longitude were determined using a handheld GPS during field visits to each site.

Table 1. Stream Gage Locations

Station	Latitude (WGS84)	Longitude
Boulder Creek at Boulder Falls	N 40 deg 00.216 min	W 105 deg 24.056 min
Boulder Creek at Orodell	N 40 deg 00.390 min	W 105 deg 19.827 min
Fourmile Creek at Salina	N 40 deg 02.994 min	W 105 deg 22.153 min
Boulder Creek at the Bridge	N 40 deg 00.891 min	W 105 deg 19.261 min

The District and County have jointly funded the following work to develop a set of consistent ratings for each station that reflect the best available data from current literature including floodplain studies and hydraulic analyses.

This document develops ratings for each site extending to the 500-year flow event, a discussion of the quality of the ratings and recommendations for their continued improvement.

II.Literature Search and Review

A literature review within the District's library was conducted with Kevin Stewart's support for available floodplain studies, backwater analyses, watershed studies, and supplemental stream survey information (E19 reports). The following studies related to Boulder Creek were obtained and used to develop ratings.

- Floodplain Information Report, Upper Boulder Creek & Fourmile Creek, Prepared for Boulder County and Colorado Water Conservation Board, December, 1981, by Gingery Associates, Inc.
- E-19 Survey Reports, Prepared for Urban Drainage and Flood Control District, November, 2002, by HDR Engineering, Inc.
- State of Colorado, Division of Water Resources, Office of State Engineer, Rating Table for Boulder Creek at Orodell (BOCOROCO13).

1981 Floodplain Information Report (FIR)

The FIR summarizes an extensive hydrologic and hydraulic analysis of the Upper Boulder Creek and Fourmile Creek watersheds. The primary hydrologic evaluation was carried out by the U.S. Army Corps of Engineers (ACOE), Omaha District.

At the time of the study, the longest recording gage on Boulder Creek was Orodell. Because the Orodell gage is upstream of Boulder Creek's confluence with Fourmile Creek it was not used directly to estimate discharge probabilities. The record for Boulder Creek at Boulder, which is downstream of the confluence with Fourmile Creek, was too fragmented so discharge probabilities were estimated using the EPA's Stormwater Management Model. Peak discharges were developed for the 10-, 50-, 100-, and 500-year events using rainfall input derived from NOAA's precipitation atlas for Colorado. Precipitation totals for a 6-hour storm, summarized in the table below, were used to generate peak discharges.

Table 2. Six-hour Storm Totals (inches)

Watershed	10-year	50-year	100-year	500-year
Fourmile	1.9	2.8	3.2	4.3
Boulder Creek	1.7	2.5	2.8	3.8

Boulder Creek from Barker Reservoir and from Sunset on Fourmile Creek was modeled down to Arapahoe Road in Boulder which forms the downstream limit of the study area.

Once the hydrology was developed, water surface elevations were computed for each peak discharge using a step-backwater analysis in HEC-2. Stream channel cross sections were developed approximately every 500 feet along the stream with 2-foot contour resolution using aerial photogrammetric techniques. The cross sections were tied into established vertical control and referenced to mean sea level. Water surface elevations for each cross section were computed using the calibrated HEC-2 model.

Interpolation of FIR Results

Of the four stream gages, not one falls exactly on a modeled cross section. Peak discharges and water surface elevations for each gaging station were therefore estimated by interpolating between the HEC-2 modeled cross sections immediately above and below each gage. The peak discharges interpolated for each gage are summarized in the tables below.

Table 3. 10-Year, Peak Discharge and Water Surface Elevation

Gage	Stream Bed Elev. (ft-msl)	Water Surface Elev. (ft-msl)	Discharge (cfs)
Boulder Creek at Falls	6786.2	6790.8	1,310
Boulder Creek at Orodell	5831.4	5835.7	1,520
Fourmile Creek at Salina	6525.7	6531.5	1,190
Boulder Creek at Bridge	5693.0	5699.7	2,050

Table 4. 50-Year, Peak Discharge and Water Surface Elevation

Gage	Stream Bed Elev. (ft-msl)	Water Surface Elev. (ft-msl)	Discharge (cfs)
Boulder Creek at Falls	6786.2	6794.2	4,710
Boulder Creek at Orodell	5831.4	5838.9	5,270
Fourmile Creek at Salina	6525.7	6535.3	3,950
Boulder Creek at Bridge	5693.0	5706.2	7,960

Table 5. 100-Year, Peak Discharge and Water Surface Elevation

Gage	Stream Bed Elev. (ft-msl)	Water Surface Elev. (ft-msl)	Discharge (cfs)
Boulder Creek at Falls	6786.2	6795.3	6,040
Boulder Creek at Orodell	5831.4	5839.9	6,920
Fourmile Creek at Salina	6525.7	6536.5	5,570
Boulder Creek at Bridge	5693.0	5708.9	11,660

Table 6. 500-Year, Peak Discharge and Water Surface Elevation

Gage	Stream Bed Elev. (ft-msl)	Water Surface Elev. (ft-msl)	Discharge (cfs)
Boulder Creek at Falls	6786.2	6797.8	11,610
Boulder Creek at Orodell	5831.4	5842.3	12,360
Fourmile Creek at Salina	6525.7	6539.3	10,430
Boulder Creek at Bridge	5693.0	5714.5	21,180

III.Preliminary Data Analysis and Field Verification

Boulder Creek at Boulder Falls

This gage, located along Highway 119 between mile markers 33 and 34, approximately 8 miles upstream of the City of Boulder is the furthest upstream. It is located just downstream of North Boulder Creek's confluence with Middle Boulder Creek. Stage is monitored using a submersible pressure transducer housed inside a vertical 2-inch diameter stilling pipe installed in the left bank of the stream.

The stream reach in the vicinity of the pressure transducer is stable and contains no significant bends. Large boulders and dense underbrush line the stream along both banks.

The channel geometry at this location remains consistent with that modeled in the FIR.

Fourmile Creek at Salina

This gage is located along Fourmile Canyon Road approximately 6.6 miles upstream of the City of Boulder. Stage is monitored using a submersible pressure transducer housed inside a vertical 2-inch diameter stilling pipe installed in the left bank of the stream.

The stream reach in the vicinity of the pressure transducer is stable. Large boulders and dense underbrush line the stream along both banks.

The channel geometry at this locationremains consistent with that modeled in the FIR.

Boulder Creek at Orodell

This gage, located along Highway 119, upstream of Orodell and downstream of the hydroelectric plant near mile marker 38, is approximately 3 miles upstream of the City of Boulder. The site is co-located with an existing Colorado Division of Water Resources (DWR) gage located on the left bank inside a concrete gage house. The USGS operated a gage at this location from 1906 through 1995.

Stage is monitored inside an existing stilling well that also houses a shaft encoder operated by the DWR.

The stream reach in the vicinity of the pressure transducer is stable and contains no significant bends. Large boulders line the stream along both banks.

The channel geometry at this location remains consistent with that modeled in the FIR.

Boulder Creek at the Bridge

This gage is located along Highway 119 downstream from Orodell near mile marker 39, approximately 1.9 miles upstream of the City of Boulder. Stage is monitored using a submersible pressure transducer housed inside a vertical 2-inch diameter stilling pipe that is bolted to a vertical concrete rock wall that protrudes into the flow. The sensor is located on the left bank directly under the bridge.

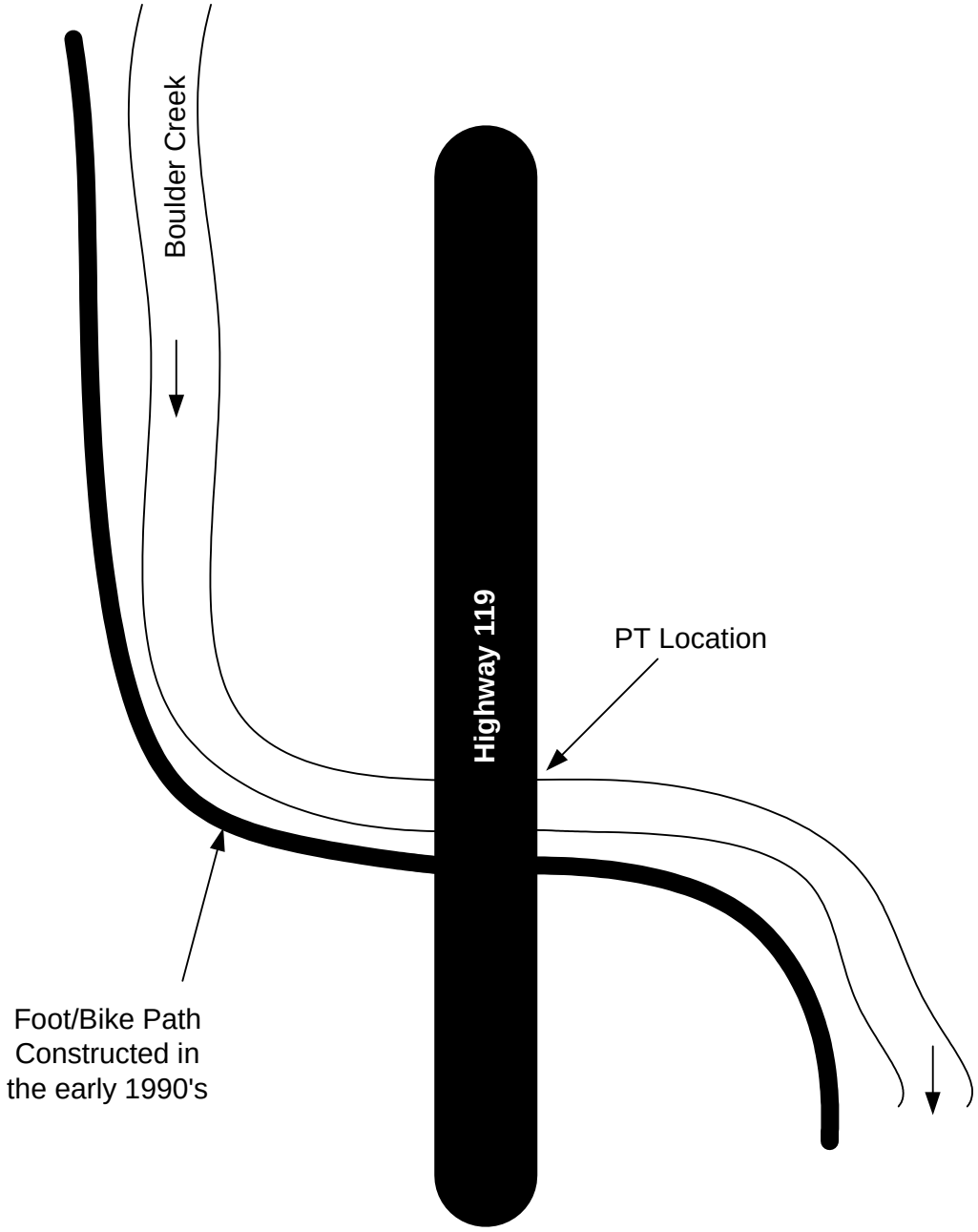
The stream reach in the vicinity of the pressure transducer is stable at low flows. A significant ninety-degree bend just upstream of the bridge, as shown in Figure 1, complicates the flow at higher stages. At high stages, the momentum of the water flowing parallel to Highway 119 will inundate the foot/bike path and "stack" along the right back. At significantly high stages the water will continue to run parallel to Highway 119 and jump out-of-bank before the bridge and continue down Highway 119.

This location is less than ideal for a stream gage due to the complex channel hydraulics caused by the ninety-degree bend.

The channel geometry at this location is no longer consistent with that modeled in the FIR. Significant changes to the right stream bank resulted when the foot/bike path was constructed in the early 1990's.

An attempt was made to obtain a current floodplain/hydraulic analysis for Boulder Creek that includes the channel modifications associated with the construction of the foot/bike path. Both Boulder County and the City of Boulder were contacted to obtain the relevant studies but neither entity could produce an updated floodplain report. Boulder County could not find a floodplain permit associated with the construction effort and the City of Boulder concluded that a floodplain/hydraulic study probably does not exist.

Figure 1
Boulder Creek at the Bridge



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Boulder Creek at the Bridge	
Markus Ritsch, P.E.	BldrCrk.vsd
January 6, 2004	Sheet 1 of 1

IV.Rating Analysis

The step-backwater results (Tables 3, 4, 5, and 6) from the FIR were used to generate ratings for each station using procedures developed by the U. S. Geologic Survey as documented in Geologic Survey Water-Supply Paper 2175, "Measurement and Computation of Streamflow: Volume 2, Computation of Discharge". A summary of the procedure is as follows:

1. A smooth curve is fit to the log-log plot of the water surface elevation/discharge pairs derived from the FIR. The results from this analysis produce the rating for water surface elevations ranging from the 10-year to the 500-year event.
2. A low-flow extrapolation is performed for water surface elevations below the 10-year event. A smooth curve is fit to the rectangular-coordinate plot of the water surface elevation/discharge pairs to produce the rating for water surface elevations below the 10-year event.
3. The two curves are merged to produce a single rating that extends from the stream bed up to the 500-year water surface elevation.
4. A low-flow extrapolation was not performed for Boulder Creek at Orodell. The Colorado Division of Water Resources maintains a rating curve for Orodell which was used directly for stage values up to the 10-year event. The rating curve reported in this document (Attachment A) is not adjusted for a rating shift. The State reports a rating shift, which changes over time, that should be applied to the rating reported here before its application in an operational setting.
5. Ratings for each station are generated up to the 500-year event. None of the ratings are extrapolated beyond the 500-year event.

The log-log plots developed in step 1 for each station are provided in Attachment B.

For stations other than Orodell, there is no assurance that the low-flow extrapolation is realistic until it can be validated against observed low-flow discharge measurements. In general, all the ratings generated from the above analysis should be revised using manual discharge measurements taken at low and medium flows throughout the coming year.

V.Conclusions and Recommendations

Ratings for four stations reflecting the best available data from current literature including floodplain studies, hydraulic analyses, and hydrographic work were developed.

The stations, located in the Upper Boulder Creek and Fourmile Creek watersheds, include:

- Boulder Creek at Boulder Falls
- Boulder Creek at Orodell
- Fourmile Creek at Salina
- Boulder Creek at the Bridge

The primary source of hydraulic information used to develop the ratings was from a Floodplain Information Report for Upper Boulder Creek & Fourmile Creek, prepared for Boulder County and the Colorado Water Conservation Board in December of 1981. Most of the hydraulic work completed in the 1981 report is still applicable today because little or no modifications to the channel geometry have occurred. The one exception is in the lower part of the Upper Boulder Creek drainage where a new foot/bike path was constructed in the early 1990's. The foot/bike path starts in the City of Boulder and ends about 200 feet past the turn off to Fourmile Canyon. An attempt was made to obtain a current floodplain/hydraulic analysis for Upper Boulder Creek that includes the channel modifications associated with the construction of the foot/bike path. Such a study was not found so ratings were developed for all four gages using data from the 1981 FIR.

Boulder Creek at Bridge

The rating developed for Boulder Creek at the Bridge (shown in Attachment A) is poor and should not be used in an operational setting. The rating does not reflect the current channel geometry. It is recommended that the channel in the vicinity of the gage be re-surveyed and a new hydraulic analysis be completed in order to develop an accurate rating.

This location is less than ideal for a stream gage due to the complex channel hydraulics caused by the ninety-degree bend immediately upstream of the bridge. If possible, this gage should be relocated to a channel section that is straight and stable.

Fourmile Creek at Salina and Upper Boulder Creek at Boulder Falls

The ratings developed for Salina and Boulder Falls (shown in Attachment A) are good and can be used in an operational setting. There is no assurance that the low-flow rating extrapolation for these sites is realistic. It is recommended that the ratings for both sites be validated against observed low-flow discharge measurements.

Boulder Creek at Orodell

The rating developed for Orodell (shown in Attachment A) is reasonable and can be used in an operational setting. The low-flow portion of the rating is taken directly from the State of Colorado Division of Water Resources.

The log-log plot found in Attachment B for Orodell shows both the low-flow values from the State as well as the high-flow values from the FIR. The plot shows two distinct linear portions with a change in slope at a stage value of approximately 4.5 feet. This change in slope coincides with the top of bank as reported in the E-19 survey as 4.56 feet. The channel exhibits a distinct change in cross sectional geometry for elevations greater than 4.56 feet which would cause the change in slope seen in the log-log plot.

The final rating shown in Attachment A does not incorporate a rating shift. The operational use of this rating should incorporate the current rating shift as published by the State. The shift will change through time so care should be taken to keep it current to what the State has published at the time.

The rating for this site should be updated periodically to match the rating published by the State which adjusts their rating to manual discharge measurements taken throughout the year.

VI.Attachment A - Rating Tables

The final ratings for each station are provided as stage/discharge pairs where stage is computed as the water surface elevation minus the stream bed elevation. The corresponding water surface elevation can be derived by adding the stream bed elevation for each site as provided in Table 3 to the stage.

Tables 7, 8, 9, and 10 summarize the peak discharge and corresponding stage values as determined from the FIR.

Final ratings up to the 500-year event are provided in Table 11.

Table 7. Boulder Falls Stage/Peak Discharge Values from 1981 FIR

Gage	Stage above Stream Bed (ft)	Discharge (cfs)
10-Year	4.6	1,310
50-Year	8.0	4,710
100-Year	9.1	6,040
500-Year	11.6	11,610

Table 8. Orodell Stage/Peak Discharge Values from 1981 FIR

Gage	Stage above Stream Bed (ft)	Discharge (cfs)
10-Year	4.3	1,520
50-Year	7.5	5,270
100-Year	8.5	6,920
500-Year	10.9	12,360

Table 9. Salina Stage/Peak Discharge Values from 1981 FIR

Gage	Stage above Stream Bed (ft)	Discharge (cfs)
10-Year	5.8	1,190
50-Year	9.6	3,950
100-Year	10.8	5,570
500-Year	13.6	10,430

Table 10. Bridge Stage/Peak Discharge Values from 1981 FIR

Gage	Stage above Stream Bed (ft)	Discharge (cfs)
10-Year	6.7	2,050
50-Year	13.2	7,960
100-Year	15.9	11,660
500-Year	21.5	21,180

Table 11. Final Ratings

The rating for the Bridge is poor and should not be used in an operational setting.

Stage (ft)	Boulder Falls Q (cfs)	Salina Q (cfs)	Orodell Q (cfs)	Bridge Q (cfs)
0.00	0.00	0.00	0.00	0.00
0.10	0.17	0.08	0.00	0.41
0.20	0.86	0.39	0.00	1.66
0.30	2.22	1.03	0.00	3.77
0.40	4.33	2.04	0.00	6.74
0.50	7.30	3.48	0.00	10.59
0.60	11.16	5.37	0.00	15.32
0.70	16.00	7.75	0.00	20.93
0.80	21.84	10.64	0.00	27.43
0.90	28.75	14.09	0.00	34.81
1.00	36.76	18.11	0.00	43.09
1.10	45.92	22.72	0.40	52.26
1.20	56.25	27.95	0.70	62.32
1.30	67.81	33.82	1.50	73.28
1.40	80.60	40.35	3.00	85.14
1.50	94.68	47.55	5.50	97.91
1.60	110.07	55.45	8.50	111.57
1.70	126.79	64.06	12.50	126.13
1.80	144.88	73.39	17.00	141.60
1.90	164.36	83.48	22.50	157.98
2.00	185.25	94.32	30.00	175.26
2.10	207.59	105.94	40.00	193.46
2.20	231.39	118.35	52.00	212.56
2.30	256.67	131.56	67.00	232.57
2.40	283.47	145.59	85.00	253.49
2.50	311.80	160.45	106.00	275.33
2.60	341.67	176.16	131.00	298.07
2.70	373.12	192.72	160.00	321.73
2.80	406.17	210.15	193.00	346.31
2.90	440.82	228.46	231.00	371.80
3.00	477.10	247.67	275.00	398.21
3.10	515.04	267.78	325.00	425.54
3.20	554.63	288.81	380.00	453.78
3.30	595.92	310.76	440.00	482.94
3.40	638.91	333.65	510.00	513.03
3.50	683.61	357.49	590.00	544.03
3.60	730.05	382.29	680.00	575.95
3.70	778.25	408.06	780.00	608.79
3.80	828.21	434.81	880.00	642.56
3.90	879.95	462.55	1000.00	677.24
4.00	933.50	491.29	1120.00	712.85

4.10	988.86	521.04	1250.00	749.39
4.20	1046.05	551.81	1453.38	786.85
4.30	1105.08	583.61	1513.83	825.23
4.40	1165.97	616.44	1594.08	864.54
4.50	1228.74	650.33	1676.64	904.77
4.60	1293.39	685.26	1761.52	945.93
4.70	1359.95	721.27	1848.73	988.01
4.80	1428.42	758.34	1938.29	1031.03
4.90	1498.81	796.50	2030.20	1074.97
5.00	1571.15	835.75	2124.48	1119.84
5.10	1645.45	876.10	2221.14	1165.63
5.20	1721.71	917.56	2320.20	1212.36
5.30	1799.95	960.13	2421.66	1260.02
5.40	1880.19	1003.82	2525.53	1308.60
5.50	1962.43	1048.65	2631.83	1358.12
5.60	2046.69	1094.62	2740.57	1408.56
5.70	2132.98	1141.73	2851.76	1459.94
5.80	2221.31	1190.00	2965.40	1512.25
5.90	2311.70	1214.05	3081.52	1565.49
6.00	2404.15	1266.81	3200.11	1619.66
6.10	2498.67	1320.94	3321.20	1674.77
6.20	2595.29	1376.44	3444.79	1730.80
6.30	2694.01	1433.33	3570.89	1787.78
6.40	2794.83	1491.62	3699.50	1845.68
6.50	2897.79	1551.32	3830.65	1904.52
6.60	3002.87	1612.45	3964.34	1964.29
6.70	3110.10	1675.00	4100.58	2050.36
6.80	3219.48	1739.01	4239.38	2112.17
6.90	3331.03	1804.47	4380.75	2174.90
7.00	3444.75	1871.40	4524.69	2238.55
7.10	3560.66	1939.81	4671.22	2303.12
7.20	3678.77	2009.72	4820.35	2368.61
7.30	3799.09	2081.12	4972.08	2435.03
7.40	3921.62	2154.04	5126.43	2502.36
7.50	4046.38	2228.48	5283.40	2570.61
7.60	4173.38	2304.46	5443.00	2639.78
7.70	4302.62	2381.99	5605.24	2709.88
7.80	4434.13	2461.07	5770.13	2780.89
7.90	4567.90	2541.72	5937.68	2852.83
8.00	4703.94	2623.95	6107.89	2925.68
8.10	4842.28	2707.76	6280.78	2999.46
8.20	4982.90	2793.18	6456.35	3074.16
8.30	5125.84	2880.21	6634.61	3149.77
8.40	5271.08	2968.85	6815.56	3226.31
8.50	5418.66	3059.13	6999.23	3303.77
8.60	5568.56	3151.05	7185.60	3382.16
8.70	5720.80	3244.62	7374.70	3461.46
8.80	5875.40	3339.85	7566.53	3541.68

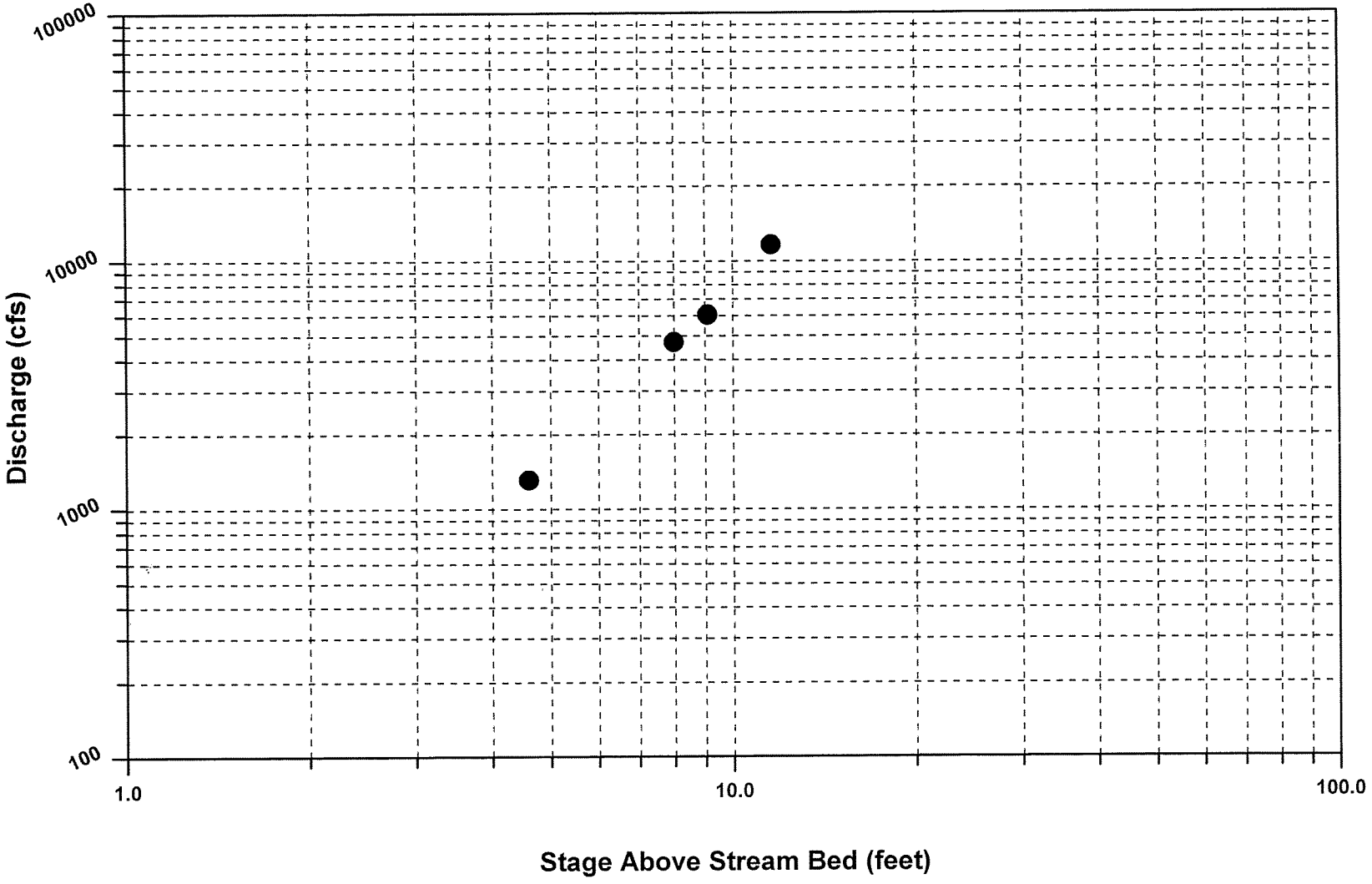
8.90	6032.36	3436.75	7761.10	3622.83
9.00	6191.68	3535.34	7958.41	3704.89
9.10	6353.39	3635.61	8158.48	3787.88
9.20	6517.48	3737.59	8361.30	3871.79
9.30	6683.96	3841.28	8566.89	3956.62
9.40	6852.85	3946.69	8775.26	4042.37
9.50	7024.15	4053.83	8986.41	4129.04
9.60	7197.87	4162.71	9200.35	4216.64
9.70	7374.02	4273.35	9417.09	4305.16
9.80	7552.61	4385.74	9636.63	4394.59
9.90	7733.65	4499.90	9858.98	4484.95
10.00	7917.13	4615.85	10084.15	4576.24
10.10	8103.09	4733.58	10312.14	4668.44
10.20	8291.51	4853.11	10542.97	4761.56
10.30	8482.41	4974.44	10776.64	4855.61
10.40	8675.80	5097.60	11013.15	4950.58
10.50	8871.68	5222.58	11252.51	5046.47
10.60	9070.07	5349.40	11494.74	5143.28
10.70	9270.96	5478.06	11739.83	5241.02
10.80	9474.38	5608.58	11987.79	5339.68
10.90	9680.32	5740.96	12238.64	5439.26
11.00	9888.80	5875.21		5539.76
11.10	10099.82	6011.35		5641.18
11.20	10313.38	6149.37		5743.53
11.30	10529.51	6289.30		5846.80
11.40	10748.20	6431.13		5950.99
11.50	10969.46	6574.89		6056.10
11.60	11193.31	6720.57		6162.13
11.70		6868.18		6269.09
11.80		7017.74		6376.97
11.90		7169.26		6485.77
12.00		7322.73		6595.50
12.10		7478.18		6706.15
12.20		7635.60		6817.72
12.30		7795.02		6930.21
12.40		7956.43		7043.63
12.50		8119.84		7157.97
12.60		8285.27		7273.23
12.70		8452.73		7389.41
12.80		8622.21		7506.52
12.90		8793.74		7624.55
13.00		8967.31		7743.50
13.10		9142.94		7863.38
13.20		9320.63		7984.18
13.30		9500.40		8105.90
13.40		9682.24		8228.54
13.50		9866.18		8352.11
13.60		10052.22		8476.60

13.70				8602.01
13.80				8728.35
13.90				8855.61
14.00				8983.80
14.10				9112.90
14.20				9242.93
14.30				9373.89
14.40				9505.76
14.50				9638.56
14.60				9772.29
14.70				9906.94
14.80				10042.51
14.90				10179.00
15.00				10316.42
15.10				10454.76
15.20				10594.02
15.30				10734.21
15.40				10875.32
15.50				11017.36
15.60				11160.32
15.70				11304.20
15.80				11449.01
15.90				11594.74
16.00				11741.40
16.10				11888.98
16.20				12037.48
16.30				12186.90
16.40				12337.25
16.50				12488.53
16.60				12640.73
16.70				12793.85
16.80				12947.90
16.90				13102.87
17.00				13258.76
17.10				13415.58
17.20				13573.32
17.30				13731.99
17.40				13891.58
17.50				14052.10
17.60				14213.54
17.70				14375.90
17.80				14539.19
17.90				14703.40
18.00				14868.54
18.10				15034.60
18.20				15201.58
18.30				15369.49
18.40				15538.33

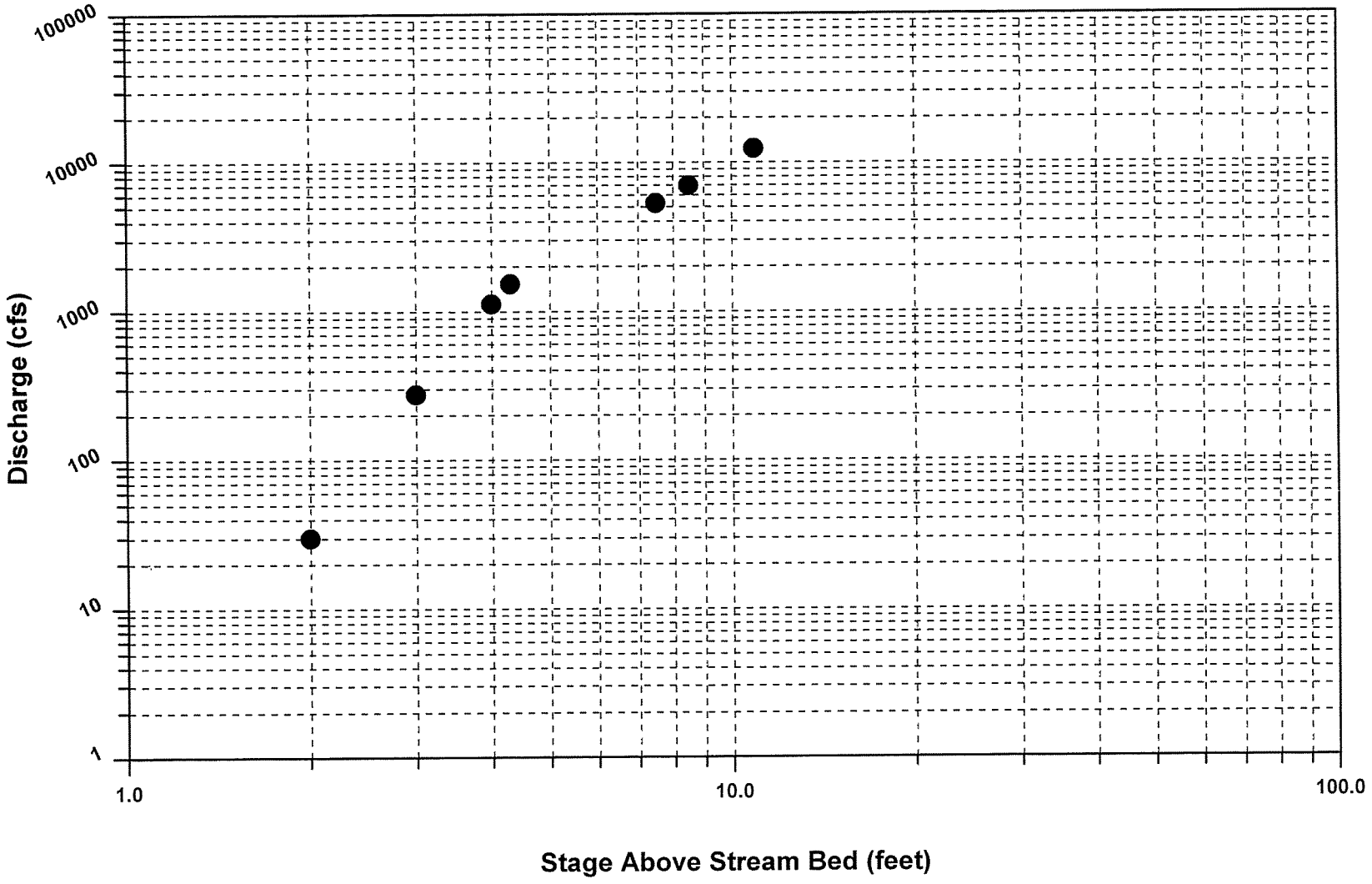
18.50				15708.09
18.60				15878.77
18.70				16050.38
18.80				16222.91
18.90				16396.37
19.00				16570.75
19.10				16746.06
19.20				16922.29
19.30				17099.44
19.40				17277.52
19.50				17456.53
19.60				17636.46
19.70				17817.31
19.80				17999.09
19.90				18181.80
20.00				18365.42
20.10				18549.98
20.20				18735.46
20.30				18921.86
20.40				19109.19
20.50				19297.44
20.60				19486.62
20.70				19676.72
20.80				19867.75
20.90				20059.70
21.00				20252.58
21.10				20446.39
21.20				20641.11
21.30				20836.77
21.40				21033.35
21.50				21230.85

VII. Attachment B – Log-Log Analysis Plots

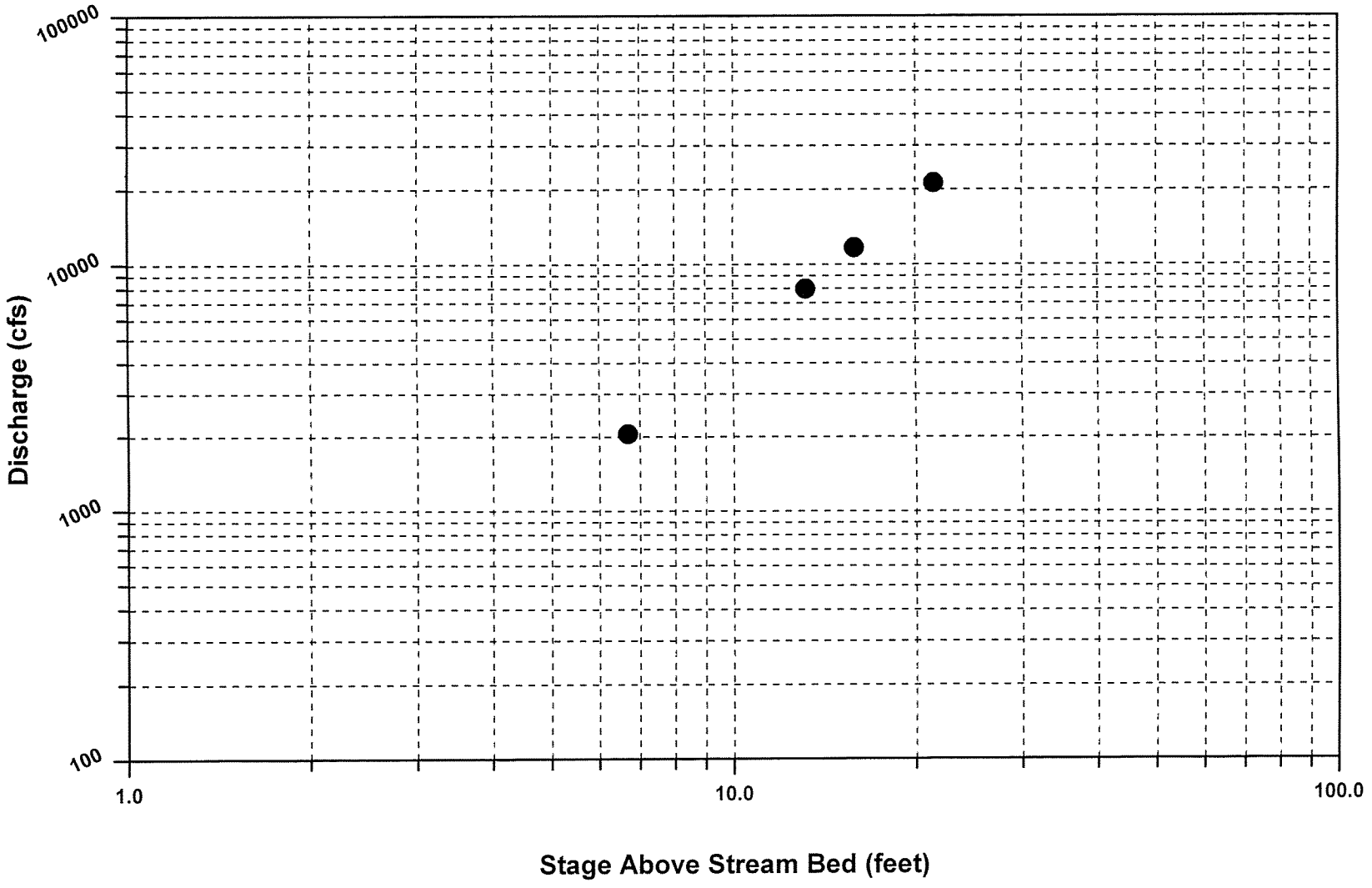
Boulder Creek at Boulder Falls



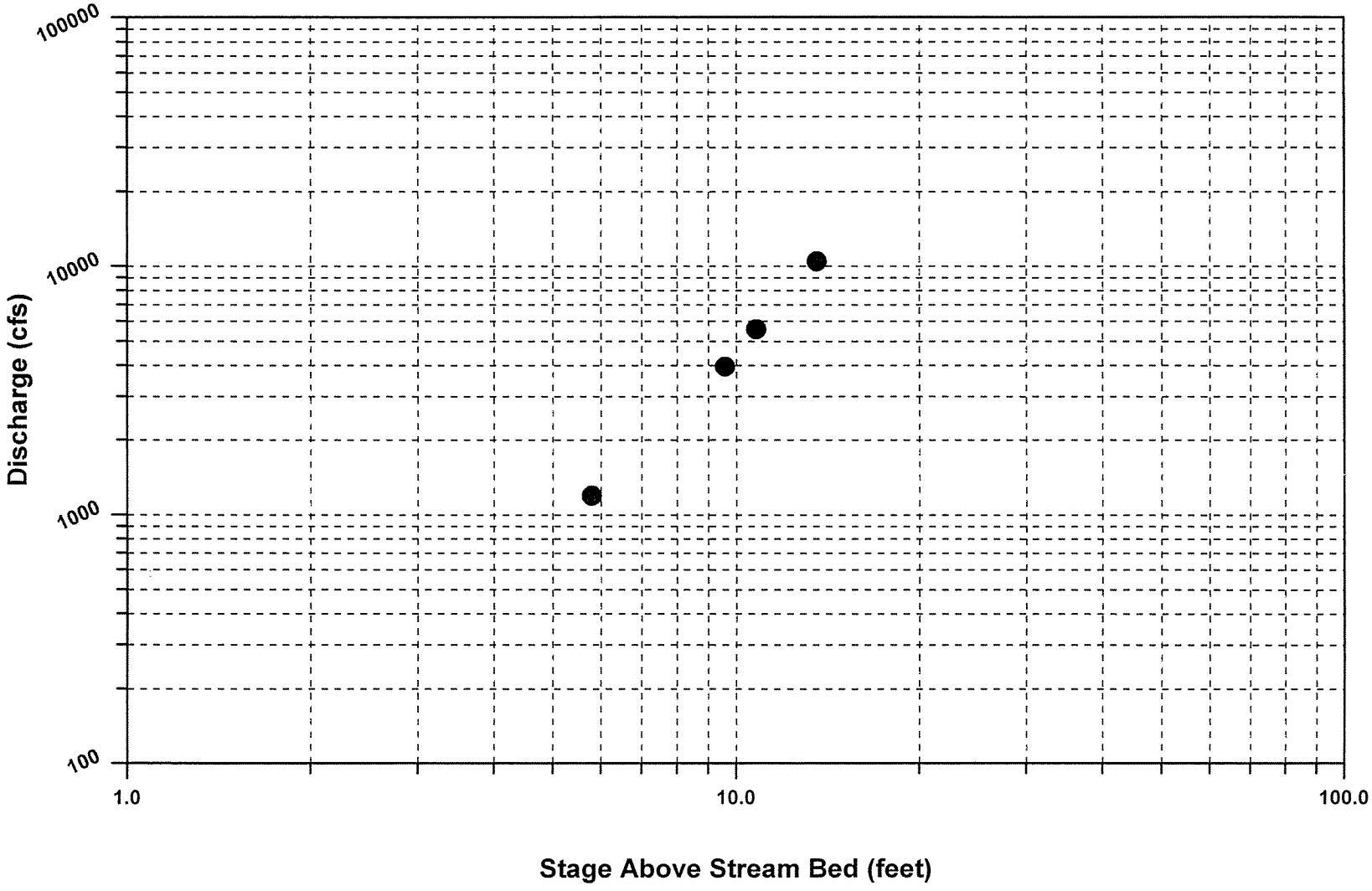
Boulder Creek at Orodell



Boulder Creek at the Bridge



Fourmile Creek at Salina



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