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MEMORANDUM

TO: Mr. Franz Ingelfinger, Restoration Ecologist
Massachusetts Department of Fish and Game, Division of Ecological Restoration

FROM: Neal Price, Senior Hydrogeologist

DATE: September 12 2014

RE: 2014 Hydrologic Data Update Report - Cold Brook, Harwich, Massachusetts

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Horsley Witten Group, Inc. (HW) is pleased to provide the Massachusetts Department of Fish and Game, Division of Ecological Restoration (DER) with this summary report of hydrologic data collection and assessment conducted in the spring and summer of 2014 at the Cold Brook restoration site in Harwich, Massachusetts (the Site). HW previously conducted a baseline evaluation of the Site in 2012. The goals of this 2014 study were to supplement data collected during the 2012 evaluation and advance understanding of Site hydrology through the collection of stream discharge information, installation of additional groundwater monitoring wells, and elevation survey of significant features. Ultimately, the study will aid in the restoration of natural processes to the Cold Brook system.

Field Activities

On May 22, 2014, HW staff installed two additional shallow monitoring wells and three stream gauging stations at the Site. DER Restoration Ecologist Franz Ingelfinger was on-Site and accompanied HW during the field activities. The locations of these new monitoring wells and stream gauging stations, as well as monitoring wells installed in 2012, are shown on Figure 1. Photographs of the new, 2014 monitoring wells and stream gauging stations are included in Appendix A. All new monitoring equipment, as well as other site features requested to be surveyed by DER, were surveyed using a combination of RTK GPS technology and traditional Total Station survey methodologies over several field days in May and June of 2014. Survey deliverables were previously provided to DER under separate cover.

Monitoring wells were constructed of two-inch inner diameter pvc with 0.10” slot screen, and were installed by advancing a soil auger inside of a four-inch pvc outer casing through the subsurface soil until the water table was encountered. The two inch well pvc well casing was then advanced into the water table with a safety hammer, the four-inch outer casing was removed, and the borehole was backfilled with the auger cuttings. Monitoring well HW-10 was installed in an exterior basement bulkhead at 35 Belle Brook Lane and monitoring well HW-11

was installed in a low-lying wooded area north of the bogs (Figure 1). DER water level loggers were subsequently installed in both monitoring wells. Relevant survey data for the 2014 monitoring wells are summarized in Table 1.

Stream gauging station SG-1, the most upstream gauging location, was established in the main stem channel of Cold Brook at the upstream side of a concrete weir box located approximately 200 feet east of Bank Street. Water level measurements at SG-1 are measured down from the center hole (painted orange) of an iron bar crossing the concrete weir box (see photograph in Appendix A). SG-1 receives flow crossing Bank Street from Grassy Pond, flow released from the Signet bogs to the southwest, and flow entering Cold Brook from Site bogs to the north through a 15-inch corrugated metal pipe (CMP) (Figure 1). A DER water level logger was installed in the main stem of Cold Brook in-between SG-1 and the 15-inch CMP inlet to the Brook. Relevant survey data for stream gauging stations are summarized in Table 1.

Stream gauging station SG-2 was established approximately 30 feet downstream (east) of a large metal culvert structure in the center of the bogs (Figure 1), and was marked on either side of the stream channel with oak stakes. Water level measurements at SG-2 are measured down from an orange paint mark at the river flow-right side of the culvert top, just upstream of SG-2 (see photograph in Appendix A).

Stream gauging station SG-3, the most downstream gauging location, was established at the upstream (north) end of a large metal culvert located at the northern end of a tailwater recovery pond (Figure 1). Water level measurements at SG-3 are measured down from an orange paint mark at the river flow-right corner of the weir structure, directly at the SG-3 location, upstream end of the culvert (see photograph in Appendix A). This location was chosen due to the large amount of organic material in the bottom of the downstream tailwater recovery pond and the slow flow in the tailwater recover pond, which would have made accurate streamflow measurements impossible.

Table 1. Survey Data for 2014-Installed Monitoring Stations

Station Name	Station Type	MP Elevation (ft NAVD 88)	Well Stickup Height (ft)	Well Depth (ft)	DTW(ft) (May 22, 2014)
HW-10	Well	5.70	0.13	5.23	2.09
HW-11	Well	6.79	0.29	5.20	2.20
SG-1	Streamflow	7.35	NA	NA	3.57
SG-2	Streamflow	6.90	NA	NA	5.25
SG-3	Streamflow	5.90	NA	NA	4.71

Notes:
MP – Measurement Point
DTW – Depth to Water

Streamflow measurements were collected at each gauging station with a Marsh McBirney Model 2000 digital flowmeter on eight occasions: May 22, June 4, and June 18, July 7, July 16, July 22, August 6, and August 19, 2014. To ensure representative flow measurements during stream gauging, each cross section is divided into uniform segments and velocity measurements are collected in the middle of each segment. Flow measurements from each cross section are then added together to determine the total discharge. Flow measurement data sheets are included in Appendix B. Flow was also estimated at the 15-inch inner diameter corrugated metal pipe (CMP) discharging into Cold Brook approximately 25 feet upstream of the HW SG-1 location by measuring the depth of water in the pipe and calculating flow using established pipe flow equations (Apprendix B). All flow measurements are summarized in Table 2, below, moving upstream to downstream from left to right across the table.

Table 2. Calculated Stream Discharge

Location	Culvert Above SG-1		Station SG-1		Station SG-2		Station SG-3	
Date	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD
5/22/2014	0.0497	0.0321	0.242	0.156	0.878	0.567	1.540	0.995
6/4/2014	0.0497	0.0321	0.150	0.097	0.606	0.392	1.550	1.002
6/18/2014	0.0497	0.0321	0.175	0.113	0.657	0.424	1.487	0.961
7/7/2014	0.0497	0.0321	0.130	0.084	0.600	0.387	1.650	1.066
7/16/2014	0.0497	0.0321	0.140	0.090	0.473	0.305	1.497	0.967
7/22/2014	0.0269	0.0174	0.095	0.062	0.462	0.299	1.173	0.758
8/6/2014	0.0025	0.0016	0.072	0.047	0.344	0.222	1.031	0.666
8/19/2014	0.0006	0.0004	0.118	0.076	0.379	0.245	1.133	0.732

Notes:
CFS – Cubic feet per second
MGD – Millions of gallons per day

Streamflow Data Evaluation

Rating curves were developed for each stream gauging site to develop a mathematical equation relating the stream discharge to the stream stage, based on the eight flow measurement dates collected over the summer of 2014. The stages presented in the rating curves are elevations (NGVD88 feet) calculated by subtracting measured depths to water from the surveyed elevations of the measuring points. The rating curves presented here can be refined as new data are collected and, ultimately, can be used to estimate flow based upon stage measurements alone. The rating curves, regression equations, and correlation coefficients for each station to date are presented in Appendix B. The regression equation for each station is a logarithmic equation, as is common for many streamflow sites. The regression equations for each station, along with their correlation coefficients, are summarized in Table 3.

Table 3. Streamflow Regression Equations and Correlation Coefficients

Station Name	Regression Equation	Correlation Coefficient
SG-1	y = 0.0773ln(x) + 3.9039	0.60
SG-2	y = 0.1526ln(x) + 1.7364	0.45
SG-3	y = 0.5541ln(x) + 0.9253	0.76

The correlation coefficients can be considered a measure of strength of fit; i.e., how well does one variable (in this case, stage) predict another variable (in this case, flow). A value of one indicates a perfect fit and a value of zero indicates no correlation. At Cold Brook, the correlation coefficients indicate mostly a moderate strength of correlation, with SG-3 having the best correlation and SG-2 having the worst.

The strength of correlation at all sites likely suffers from the fact that all flow measurements were collected over a relatively short window in the summer of 2014 characterized by relatively consistent "summer-season" hydrology. Without much natural variation in flow or stage, relatively small measurement or equipment errors end up playing a larger role than they would for a data record comprised of greater natural variability.

Correlation coefficients also generally tend to increase in a downstream direction along with total discharge. This is because low flow velocities are nearer to the accuracy limits of the velocity flow meter and, therefore, a larger portion of the observed variation tends to be caused by instrument accuracy limitations. This is particularly true for Station SG-1 where both the stage values and velocity readings were very low over the measurement period. This expected upstream to downstream improvement of correlation based upon increasing flow does not hold true for Station SG-2 which has the lowest correlation of the three stations. This could be because Station SG-2 is the only station of the three not located in a hard, controlled structure. Shifting sandbars and vegetation may decrease the correlation at this site.

Table 4 details the observed pattern of increasing flow across the site from upstream to downstream. The stream channel distance between SG2 and SG3 (1,260 feet) is only approximately 25% longer than the stream channel distance between SG1 and SG2 (930 feet) yet the observed average flow increase between SG2 and SG3 (.833 cfs) is more than double the observed flow increase between SG1 and SG2 (.410 cfs). The average flow change normalized per length of stream channel between SG2 and SG3 (3.49 cfs per mile of stream length) is approximately 66% greater than the same normalized change between SG1 and SG2. One possible explanation for the proportionally greater increase in streamflow moving downstream across the site is the limiting role on the watershed played by Bank Street, shortly upstream of SG1. Most of the watershed upstream of SG1 contributes to Grassy Pond, upstream of Bank Street and SG1. Flow out of Grassy Pond across Bank Street is controlled by a

weir structure on private property to which we did not have access. Since that weir likely artificially holds back water upstream of Bank Street, the effective watershed to SG-1 is therefore, relatively small. Moving further downstream across the site, the effective natural watershed areas to SG2 and then SG3 become proportionally larger than that of SG1.

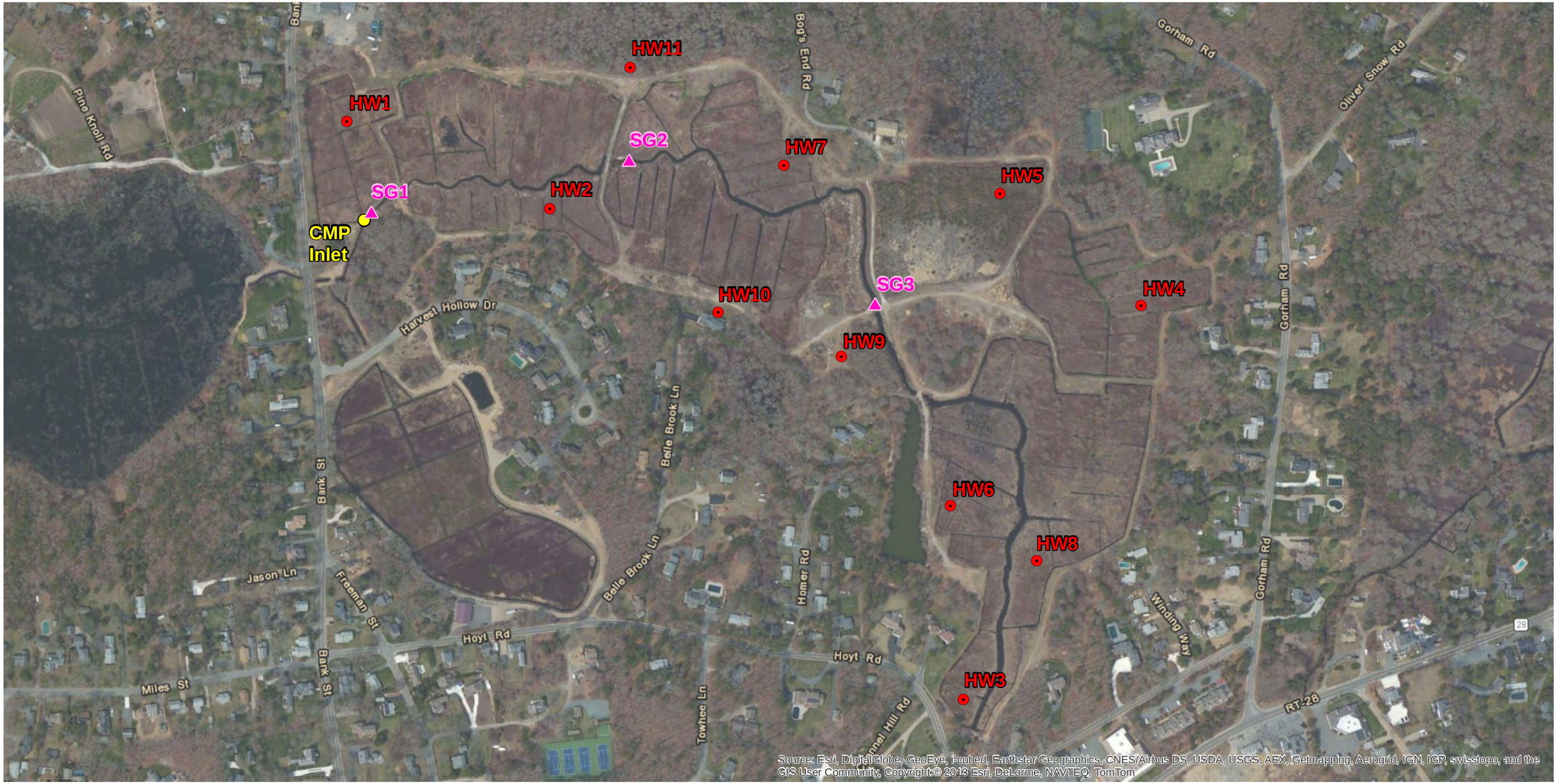
Table 4. Streamflow Change Across Site

Date	SG1 (CFS)	SG2 (CFS)	SG3 (CFS)	Flow Change SG1-SG2 (CFS)	Flow Change SG1-SG2 (CFS/mile)	Flow Change SG2-SG3 (CFS)	Flow Change SG2-SG3 (CFS/mile)
5/22/2014	0.242	0.878	1.540	0.636	3.61	0.662	2.77
6/4/2014	0.150	0.606	1.550	0.456	2.59	0.944	3.96
6/18/2014	0.175	0.657	1.487	0.482	2.74	0.83	3.48
7/7/2014	0.130	0.600	1.650	0.47	2.67	1.05	4.40
7/16/2014	0.140	0.473	1.497	0.333	1.89	1.024	4.29
7/22/2014	0.095	0.462	1.173	0.367	2.08	0.711	2.98
8/6/2014	0.072	0.344	1.031	0.272	1.54	0.687	2.88
8/19/2014	0.118	0.379	1.133	0.261	1.48	0.754	3.16
AVERAGE	**0.140**	**0.550**	**1.383**	**0.410**	**2.33**	**0.833**	**3.49**

Notes:
Stream Distance from SG-1 to SG2 is 930 feet, and from SG2 to SG3 is 1,260 feet
CFS = cubic feet per second

That upstream to downstream change of effective watershed size is further supported by the streamflow and precipitation data shown in Figure 2. Figure 2 shows SG2 and, particularly, SG3 responding to the most significant precipitation events (as recorded at the Chatham Airport), while SG1 does not respond at all. The flow record for SG1 is nearly constant with only a slight downward trend as the summer progresses. One potential explanation for this pattern is also the limiting watershed factor created by the Bank Street weir structure. If little of the approximately 1.6-inch rain event on July fourth topped over the Bank Street weir, the watershed contributing to SG1 would be very small and no significant flow increase two days following the storm would be expected. SG-3, with its proportionally larger natural watershed area, would likely continue to exhibit increased flow rates for a longer time after the rain event ended.

FIGURES



Path: H:\Projects\2012\12061 COM DER Cold Brook Restoration\GIS\Maps\Staff_Gauges.mxd

Legend

- Monitoring Well
- Stream Gauging Station
- CMP Inlet (15" diameter)

N

0 300

1" = 300 feet

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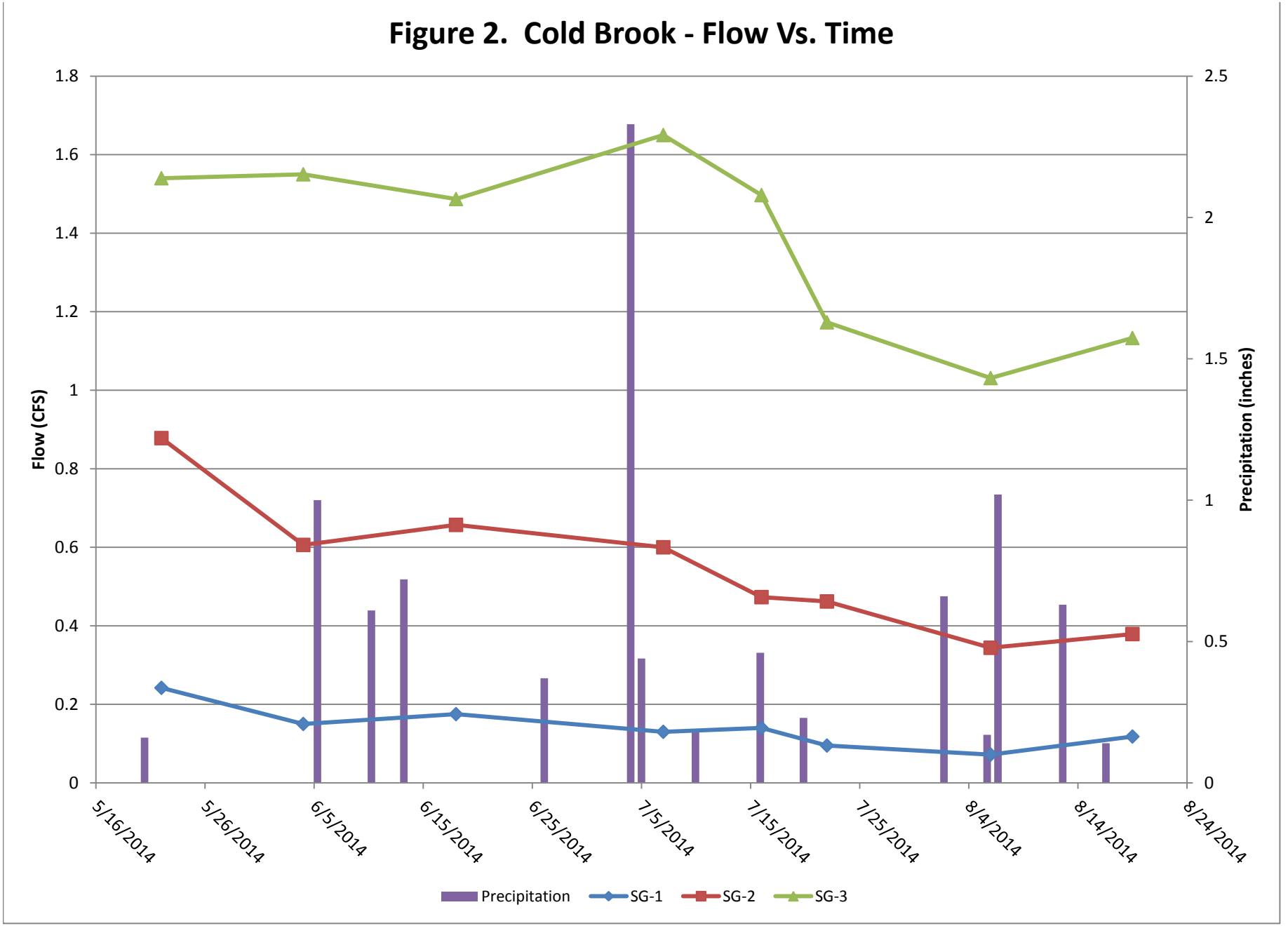
Monitoring Well &
Stream Gauging Locations
Cold Brook
Harwich, MA

Date: 8/29/2014 Figure 1

Figure 2. Cold Brook - Flow Vs. Time



APPENDIX A- SITE PHOTOS

Culvert above SG1

Streamflow Station SG1

SG2 Stage Measurement Point

Streamflow Station SG2

Streamflow Station SG3

Monitoring Well HW10

Monitoring Well HW11

APPENDIX B – FLOW DATA AND RATING CURVES

Station Number HW SG-1 **Date** 5/22/2014
Location Concrete Weir Box - approx. 200 east of Bank Street **Operator** GWTH
Time 12:45

SG: 3.57' (distance to water surface measured from middle of metal bar across weir structure)
0.1' depth of water in 16" culvert

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.625	0.20	0.00	0.13	0.000
2.0	0.5	0.20	0.38	0.10	0.038
3.0	0.5	0.20	0.00	0.10	0.000
4.0	0.5	0.20	0.49	0.10	0.049
5.0	0.5	0.20	0.48	0.10	0.048
6.0	0.5	0.20	0.47	0.10	0.047
7.0	0.5	0.20	0.47	0.10	0.047
8.0	0.625	0.20	0.10	0.13	0.013

0.242 cfs
0.156 mgd

Station Number HW SG-1 **Date** 6/4/2014
Location Concrete Weir Box - approx. 200 east of Bank Street **Operator** ACS
Time 1:15

SG: 3.57' (distance to water surface measured from middle of metal bar across weir structure)
0.1' depth of water in 16" culvert

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.625	0.125	0.25	0.08	0.020
2.0	0.5	0.125	0.39	0.06	0.024
3.0	0.5	0.125	0.39	0.06	0.024
4.0	0.5	0.125	0.44	0.06	0.028
5.0	0.5	0.125	0.40	0.06	0.025
6.0	0.5	0.125	0.38	0.06	0.024
7.0	0.5	0.125	0.09	0.06	0.006
8.0	0.625	0.125	0.00	0.08	0.000

0.150 cfs
0.097 mgd

Station Number HW SG-1 **Date** 6/18/2014
Location Concrete Weir Box - approx. 200 east of Bank Street **Operator** ACS
Time 11:30

SG: 3.51' (distance to water surface measured from middle of metal bar across weir structure)
0.1' depth of water in 16" culvert

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.625	0.15	0.27	0.09	0.025
2.0	0.5	0.15	0.40	0.08	0.030
3.0	0.5	0.15	0.38	0.08	0.029
4.0	0.5	0.15	0.35	0.08	0.026
5.0	0.5	0.15	0.38	0.08	0.029
6.0	0.5	0.15	0.28	0.08	0.021
7.0	0.5	0.15	0.20	0.08	0.015
8.0	0.625	0.15	0.00	0.09	0.000

0.175 cfs
0.113 mgd

Station Number HW SG-1 **Date** 7/7/2014
Location Concrete Weir Box - approx. 200 east of Bank Street **Operator** ACS
Time 14:00

SG: 3.58 (distance to water surface measured from middle of metal bar across weir structure)
0.10 depth of water in 16" culvert

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.625	0.10	0.16	0.06	0.010
2.0	0.5	0.10	0.29	0.05	0.015
3.0	0.5	0.10	0.37	0.05	0.019
4.0	0.5	0.10	0.40	0.05	0.020
5.0	0.5	0.10	0.47	0.05	0.024
6.0	0.5	0.10	0.45	0.05	0.023
7.0	0.5	0.10	0.42	0.05	0.021
8.0	0.625	0.10	0.00	0.06	0.000

0.130 cfs
0.084 mgd

Station Number	HW SG-1	**Date**	7/16/2014
Location	Concrete Weir Box - approx. 200 east of Bank Street	**Operator**	ACS
		Time	10:15

SG: 3.60 (distance to water surface measured from middle of metal bar across weir structure)
0.10 depth of water in 16" culvert

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.625	0.10	0.38	0.06	0.024
2.0	0.5	0.10	0.17	0.05	0.009
3.0	0.5	0.10	0.36	0.05	0.018
4.0	0.5	0.10	0.37	0.05	0.019
5.0	0.5	0.10	0.45	0.05	0.023
6.0	0.5	0.10	0.21	0.05	0.011
7.0	0.5	0.10	0.36	0.05	0.018
8.0	0.625	0.10	0.32	0.06	0.020
					0.140 cfs
					0.090 mgd

Station Number	HW SG-1	**Date**	7/22/2014
Location	Concrete Weir Box - approx. 200 east of Bank Street	**Operator**	ACS
		Time	13:00

SG: 3'7.4" (distance to water surface measured from middle of metal bar across weir structure)
0.08 depth of water in 16" culvert

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.625	0.10	0.32	0.06	0.020
2.0	0.5	0.10	0.32	0.05	0.016
3.0	0.5	0.10	0.24	0.05	0.012
4.0	0.5	0.10	0.27	0.05	0.014
5.0	0.5	0.10	0.22	0.05	0.011
6.0	0.5	0.10	0.16	0.05	0.008
7.0	0.5	0.10	0.11	0.05	0.006
8.0	0.625	0.10	0.15	0.06	0.009
					0.095 cfs
					0.062 mgd

Station Number	HW SG-1	**Date**	8/6/2014
Location	Concrete Weir Box - approx. 200 east of Bank Street	**Operator**	ACS
		Time	13:15

SG: 3'7.8" (distance to water surface measured from middle of metal bar across weir structure)
0.03 depth of water in 16" culvert

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.625	0.10	0.31	0.06	0.019
2.0	0.5	0.05	0.38	0.03	0.010
3.0	0.5	0.05	0.44	0.03	0.011
4.0	0.5	0.05	0.37	0.03	0.009
5.0	0.5	0.05	0.41	0.03	0.010
6.0	0.5	0.05	0.27	0.03	0.007
7.0	0.5	0.05	0.17	0.03	0.004
8.0	0.625	0.05	0.06	0.03	0.002
					0.072 cfs
					0.047 mgd

Station Number	HW SG-1	**Date**	8/19/2014
Location	Concrete Weir Box - approx. 200 east of Bank Street	**Operator**	ACS
		Time	13:55

SG: 3'8" (distance to water surface measured from middle of metal bar across weir structure)
0.01 depth of water in 16" culvert

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.625	0.10	0.25	0.06	0.016
2.0	0.5	0.10	0.35	0.05	0.018
3.0	0.5	0.10	0.30	0.05	0.015
4.0	0.5	0.10	0.27	0.05	0.014
5.0	0.5	0.10	0.28	0.05	0.014
6.0	0.5	0.10	0.33	0.05	0.017
7.0	0.5	0.10	0.16	0.05	0.008
8.0	0.625	0.10	0.29	0.06	0.018
					0.118 cfs
					0.076 mgd

Station Number	HW SG-2	**Date**	5/22/2014
Location	Downstream of culvert	**Operator**	GWTH
		Time	1:30

SG: 5.25 (distance to water surface from measuring point)
0.2' depth of water in culvert
4.26 velocity in culvert (feet per second)

Tape Distance	Width	Depth	Velocity	Area	Discharge
ft	ft	ft	ft/second	ft^2	cfs
0.75	0.5	0.00	0.00	0.00	0.000
1.25	0.5	0.00	0.00	0.00	0.000
1.75	0.5	0.10	0.00	0.05	0.000
2.25	0.5	0.25	0.23	0.13	0.029
2.75	0.5	0.40	0.40	0.20	0.080
3.25	0.5	0.40	0.35	0.20	0.070
3.75	0.5	0.45	0.37	0.23	0.083
4.25	0.5	0.45	0.38	0.23	0.086
4.75	0.5	0.50	0.40	0.25	0.100
5.25	0.5	0.50	0.33	0.25	0.083
5.75	0.5	0.50	0.23	0.25	0.058
6.25	0.5	0.50	0.45	0.25	0.113
6.75	0.5	0.40	0.35	0.20	0.070
7.25	0.5	0.40	0.24	0.20	0.048
7.75	0.5	0.30	0.25	0.15	0.038
8.25	0.5	0.30	0.15	0.15	0.023
8.75	0.5	0.25	0.00	0.13	0.000
9.25	0.5	0.00	0.00	0.00	0.000
9.75	0.5	0.00	0.00	0.00	0.000
					0.878 **cfs**
					0.567 **mgd**

Station Number	HW SG-2	**Date**	6/4/2014
Location	Downstream of culvert	**Operator**	ACS
		Time	14:00

SG: 5.17' (distance to water surface from measuring point)
0.25' depth of water in culvert
3.63 velocity in culvert (feet per second)

Tape Distance	Width	Depth	Velocity	Area	Discharge
ft	ft	ft	ft/second	ft^2	cfs
0.75	0.5	0.10	0.00	0.05	0.000
1.25	0.5	0.20	0.00	0.10	0.000
1.75	0.5	0.30	0.02	0.15	0.003
2.25	0.5	0.50	0.18	0.25	0.045
2.75	0.5	0.50	0.17	0.25	0.043
3.25	0.5	0.50	0.19	0.25	0.048
3.75	0.5	0.60	0.17	0.30	0.051
4.25	0.5	0.60	0.21	0.30	0.063
4.75	0.5	0.65	0.18	0.33	0.059
5.25	0.5	0.60	0.22	0.30	0.066
5.75	0.5	0.60	0.26	0.30	0.078
6.25	0.5	0.60	0.27	0.30	0.081
6.75	0.5	0.50	0.12	0.25	0.030
7.25	0.5	0.50	0.10	0.25	0.025
7.75	0.5	0.45	0.07	0.23	0.016
8.25	0.5	0.40	0.00	0.20	0.000
8.75	0.5	0.35	0.00	0.18	0.000
9.25	0.5	0.00	0.00	0.00	0.000
9.75	0.5	0.00	0.00	0.00	0.000
					0.606 **cfs**
					0.392 **mgd**

Station Number	HW SG-2	**Date**	6/18/2014
Location	Downstream of culvert	**Operator**	ACS
		Time	12:30

SG: 5.19' (distance to water surface from measuring point)
0.2' depth of water in culvert
not collected velocity in culvert (feet per second)

Tape Distance	Width	Depth	Velocity	Area	Discharge
ft	ft	ft	ft/second	ft^2	cfs
0.75	0.5	0.10	0.00	0.05	0.000
1.25	0.5	0.15	0.00	0.08	0.000
1.75	0.5	0.25	0.08	0.13	0.010
2.25	0.5	0.55	0.30	0.28	0.083
2.75	0.5	0.55	0.21	0.28	0.058
3.25	0.5	0.55	0.20	0.28	0.055
3.75	0.5	0.55	0.21	0.28	0.058
4.25	0.5	0.50	0.19	0.25	0.048
4.75	0.5	0.50	0.21	0.25	0.053
5.25	0.5	0.55	0.26	0.28	0.072
5.75	0.5	0.60	0.20	0.30	0.060
6.25	0.5	0.50	0.23	0.25	0.058
6.75	0.5	0.50	0.28	0.25	0.070
7.25	0.5	0.40	0.02	0.20	0.004
7.75	0.5	0.40	0.13	0.20	0.026
8.25	0.5	0.30	0.03	0.15	0.005
8.75	0.5	0.30	0.00	0.15	0.000
9.25	0.5	0.05	0.00	0.03	0.000
9.75	0.5	0.00	0.00	0.00	0.000
					0.657 **cfs**
					0.424 **mgd**

Station Number	HW SG-2	**Date**	7/7/2014
Location	Downstream of culvert	**Operator**	ACS
		Time	14:30

SG: 5.19' (distance to water surface from measuring point)
0.2' depth of water in culvert
not collected velocity in culvert (feet per second)

Tape Distance	Width	Depth	Velocity	Area	Discharge
ft	ft	ft	ft/second	ft^2	cfs
0.75	0.5	0.10	0.00	0.05	0.000
1.25	0.5	0.20	0.00	0.10	0.000
1.75	0.5	0.30	0.14	0.15	0.021
2.25	0.5	0.65	0.24	0.33	0.078
2.75	0.5	0.60	0.17	0.30	0.051
3.25	0.5	0.60	0.15	0.30	0.045
3.75	0.5	0.60	0.10	0.30	0.030
4.25	0.5	0.60	0.21	0.30	0.063
4.75	0.5	0.60	0.23	0.30	0.069
5.25	0.5	0.60	0.20	0.30	0.060
5.75	0.5	0.65	0.15	0.33	0.049
6.25	0.5	0.60	0.18	0.30	0.054
6.75	0.5	0.55	0.20	0.28	0.055
7.25	0.5	0.50	0.00	0.25	0.000
7.75	0.5	0.45	0.11	0.23	0.025
8.25	0.5	0.40	0.00	0.20	0.000
8.75	0.5	0.30	0.00	0.15	0.000
9.25	0.5	0.10	0.00	0.05	0.000
9.75	0.5	0.00	0.00	0.00	0.000
					0.600 **cfs**
					0.387 **mgd**

Station Number	HW SG-2			**Date**	7/16/2014
Location	Downstream of culvert			**Operator**	ACS
				Time	11:00

SG: 5.31 (distance to water surface from measuring point)
0.30 depth of water in culvert
not collected velocity in culvert (feet per second)

Tape Distance	Width	Depth	Velocity	Area	Discharge
ft	ft	ft	ft/second	ft^2	cfs
0.75	0.5	0.00	0.00	0.00	0.000
1.25	0.5	0.10	0.00	0.05	0.000
1.75	0.5	0.20	0.05	0.10	0.005
2.25	0.5	0.50	0.21	0.25	0.053
2.75	0.5	0.50	0.26	0.25	0.065
3.25	0.5	0.50	0.09	0.25	0.023
3.75	0.5	0.50	0.13	0.25	0.033
4.25	0.5	0.50	0.27	0.25	0.068
4.75	0.5	0.50	0.16	0.25	0.040
5.25	0.5	0.50	0.22	0.25	0.055
5.75	0.5	0.50	0.17	0.25	0.043
6.25	0.5	0.50	0.19	0.25	0.048
6.75	0.5	0.50	0.13	0.25	0.033
7.25	0.5	0.40	0.02	0.20	0.004
7.75	0.5	0.40	0.03	0.20	0.006
8.25	0.5	0.30	0.00	0.15	0.000
8.75	0.5	0.20	0.00	0.10	0.000
9.25	0.5	0.00	0.00	0.00	0.000
9.75	0.5	0.00	0.00	0.00	0.000
					0.473 **cfs**
					0.305 **mgd**

Station Number	HW SG-2			**Date**	7/22/2014
Location	Downstream of culvert			**Operator**	ACS
				Time	13:30

SG: 5.35 (distance to water surface from measuring point)
? depth of water in culvert
not collected velocity in culvert (feet per second)

Tape Distance	Width	Depth	Velocity	Area	Discharge
ft	ft	ft	ft/second	ft^2	cfs
0.75	0.5	0.00	0.00	0.00	0.000
1.25	0.5	0.00	0.00	0.00	0.000
1.75	0.5	0.10	0.00	0.05	0.000
2.25	0.5	0.50	0.17	0.25	0.043
2.75	0.5	0.40	0.33	0.20	0.066
3.25	0.5	0.40	0.12	0.20	0.024
3.75	0.5	0.40	0.09	0.20	0.018
4.25	0.5	0.40	0.27	0.20	0.054
4.75	0.5	0.45	0.22	0.23	0.050
5.25	0.5	0.50	0.28	0.25	0.070
5.75	0.5	0.50	0.21	0.25	0.053
6.25	0.5	0.40	0.21	0.20	0.042
6.75	0.5	0.40	0.09	0.20	0.018
7.25	0.5	0.30	0.09	0.15	0.014
7.75	0.5	0.30	0.08	0.15	0.012
8.25	0.5	0.20	0.00	0.10	0.000
8.75	0.5	0.20	0.00	0.10	0.000
9.25	0.5	0.00	0.00	0.00	0.000
9.75	0.5	0.00	0.00	0.00	0.000
					0.462 **cfs**
					0.299 **mgd**

Station Number	HW SG-2			**Date**	8/6/2014
Location	Downstream of culvert			**Operator**	ACS
				Time	13:45

SG: 5.32 (distance to water surface from measuring point)
0.25 depth of water in culvert
not collected velocity in culvert (feet per second)

Tape Distance	Width	Depth	Velocity	Area	Discharge
ft	ft	ft	ft/second	ft^2	cfs
0.75	0.5	0.00	0.00	0.00	0.000
1.25	0.5	0.25	0.00	0.13	0.000
1.75	0.5	0.10	0.00	0.05	0.000
2.25	0.5	0.50	0.12	0.25	0.030
2.75	0.5	0.50	0.20	0.25	0.050
3.25	0.5	0.50	0.14	0.25	0.035
3.75	0.5	0.40	0.17	0.20	0.034
4.25	0.5	0.40	0.22	0.20	0.044
4.75	0.5	0.50	0.19	0.25	0.048
5.25	0.5	0.50	0.17	0.25	0.043
5.75	0.5	0.40	0.15	0.20	0.030
6.25	0.5	0.40	0.06	0.20	0.012
6.75	0.5	0.30	0.03	0.15	0.005
7.25	0.5	0.30	0.03	0.15	0.005
7.75	0.5	0.30	0.06	0.15	0.009
8.25	0.5	0.25	0.01	0.13	0.001
8.75	0.5	0.20	0.00	0.10	0.000
9.25	0.5	0.00	0.00	0.00	0.000
9.75	0.5	0.00	0.00	0.00	0.000
					0.344 **cfs**
					0.222 **mgd**

Station Number	HW SG-2			**Date**	8/19/2014
Location	Downstream of culvert			**Operator**	ACS
				Time	14:15

SG: 5.31 (distance to water surface from measuring point)
0.20 depth of water in culvert
not collected velocity in culvert (feet per second)

Tape Distance	Width	Depth	Velocity	Area	Discharge
ft	ft	ft	ft/second	ft^2	cfs
0.75	0.5	0.00	0.00	0.00	0.000
1.25	0.5	0.10	0.00	0.05	0.000
1.75	0.5	0.20	0.03	0.10	0.003
2.25	0.5	0.60	0.30	0.30	0.090
2.75	0.5	0.50	0.24	0.25	0.060
3.25	0.5	0.50	0.06	0.25	0.015
3.75	0.5	0.50	0.19	0.25	0.048
4.25	0.5	0.45	0.21	0.23	0.047
4.75	0.5	0.50	0.24	0.25	0.060
5.25	0.5	0.50	0.05	0.25	0.013
5.75	0.5	0.50	0.04	0.25	0.010
6.25	0.5	0.50	0.08	0.25	0.020
6.75	0.5	0.50	0.04	0.25	0.010
7.25	0.5	0.40	0.02	0.20	0.004
7.75	0.5	0.40	0.00	0.20	0.000
8.25	0.5	0.30	0.00	0.15	0.000
8.75	0.5	0.20	0.00	0.10	0.000
9.25	0.5	0.00	0.00	0.00	0.000
9.75	0.5	0.00	0.00	0.00	0.000
					0.379 **cfs**
					0.245 **mgd**

Station Number HW SG-3 **Date** 5/22/2014
Location Metal Weir Box - upstream side at tailwater recovery pond **Operator** GWTH
Time 14:15

SG: 4.65' (distance to water surface from measuring point)

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.5	0.20	0.66	0.10	0.066
2.0	0.5	0.50	0.95	0.25	0.238
3.0	0.5	0.70	0.90	0.35	0.315
4.0	0.5	0.75	0.53	0.38	0.199
5.0	0.5	0.70	1.10	0.35	0.385
6.0	0.5	0.50	0.90	0.25	0.225
7.0	0.5	0.30	0.75	0.15	0.113

1.540 cfs
0.995 mgd

Station Number HW SG-3 **Date** 6/4/2014
Location Metal Weir Box - upstream side at tailwater recovery pond **Operator** ACS
Time 14:50

SG: 4.71' (distance to water surface from measuring point)

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.5	0.10	0.60	0.05	0.030
2.0	0.5	0.45	1.02	0.23	0.230
3.0	0.5	0.70	1.03	0.35	0.361
4.0	0.5	0.80	0.66	0.40	0.264
5.0	0.5	0.70	1.10	0.35	0.385
6.0	0.5	0.45	0.85	0.23	0.191
7.0	0.5	0.20	0.90	0.10	0.090

1.550 cfs
1.002 mgd

Station Number HW SG-3 **Date** 6/18/2014
Location Metal Weir Box - upstream side at tailwater recovery pond **Operator** ACS
Time 13:30

SG: 4.72' (distance to water surface from measuring point)

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.5	0.10	0.90	0.05	0.045
2.0	0.5	0.40	1.29	0.20	0.258
3.0	0.5	0.70	1.04	0.35	0.364
4.0	0.5	0.80	0.27	0.40	0.108
5.0	0.5	0.70	1.26	0.35	0.441
6.0	0.5	0.40	1.17	0.20	0.234
7.0	0.5	0.10	0.74	0.05	0.037

1.487 cfs
0.961 mgd

Station Number HW SG-3 **Date** 7/7/2014
Location Metal Weir Box - upstream side at tailwater recovery pond **Operator** ACS
Time 15:00

SG: 4.76 (distance to water surface from measuring point)

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.5	0.15	0.78	0.08	0.059
2.0	0.5	0.40	1.00	0.20	0.200
3.0	0.5	0.70	1.16	0.35	0.406
4.0	0.5	0.80	0.65	0.40	0.260
5.0	0.5	0.70	1.24	0.35	0.434
6.0	0.5	0.45	1.02	0.23	0.230
7.0	0.5	0.15	0.82	0.08	0.062

1.650 cfs
1.066 mgd

Station Number HW SG-3 **Date** 7/16/2014
Location Metal Weir Box - upstream side at tailwater recovery pond **Operator** ACS
Time 12:00

SG: 4.80 (distance to water surface from measuring point)

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.5	0.20	0.86	0.10	0.086
2.0	0.5	0.45	0.93	0.23	0.209
3.0	0.5	0.60	1.06	0.30	0.318
4.0	0.5	0.75	0.52	0.38	0.195
5.0	0.5	0.60	1.17	0.30	0.351
6.0	0.5	0.50	0.91	0.25	0.228
7.0	0.5	0.20	1.10	0.10	0.110

1.497 cfs
0.967 mgd

Station Number HW SG-3 **Date** 7/22/2014
Location Metal Weir Box - upstream side at tailwater recovery pond **Operator** ACS
Time 14:30

SG: 4.91 (distance to water surface from measuring point)

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.5	0.00	0.00	0.00	0.000
2.0	0.5	0.10	0.96	0.05	0.048
3.0	0.5	0.50	1.17	0.25	0.293
4.0	0.5	0.60	0.80	0.30	0.240
5.0	0.5	0.60	1.24	0.30	0.372
6.0	0.5	0.40	0.99	0.20	0.198
7.0	0.5	0.10	0.44	0.05	0.022

1.173 cfs
0.758 mgd

Station Number HW SG-3 **Date** 8/6/2014
Location Metal Weir Box - upstream side at tailwater recovery pond **Operator** ACS
Time 14:30

SG: 4.91 (distance to water surface from measuring point)

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.5	0.00	0.00	0.00	0.000
2.0	0.5	0.20	0.57	0.10	0.057
3.0	0.5	0.50	1.16	0.25	0.290
4.0	0.5	0.60	0.87	0.30	0.261
5.0	0.5	0.50	0.99	0.25	0.248
6.0	0.5	0.30	1.02	0.15	0.153
7.0	0.5	0.10	0.44	0.05	0.022

1.031 cfs
0.666 mgd

Station Number HW SG-3 **Date** 8/19/2014
Location Metal Weir Box - upstream side at tailwater recovery pond **Operator** ACS
Time 15:00

SG: 4.96 (distance to water surface from measuring point)

Section	Width	Depth	Velocity	Area	Discharge
	ft	ft	ft/second	ft^2	cfs
1.0	0.5	0.00	0.00	0.00	0.000
2.0	0.5	0.20	0.66	0.10	0.066
3.0	0.5	0.50	1.33	0.25	0.333
4.0	0.5	0.60	0.80	0.30	0.240
5.0	0.5	0.50	1.14	0.25	0.285
6.0	0.5	0.35	0.98	0.18	0.172
7.0	0.5	0.10	0.76	0.05	0.038

1.133 cfs
0.732 mgd

SG-1 UPSTREAM CULVERT

Date	Water Height	d/D	R/D	R	V (ft/sec)	Area/D^2	Area (ft^2)	Q (cfs)
5/22/2014	0.100	0.080	0.0513	0.0641	1.0821	0.0294	0.0459	0.049711
6/4/2014	0.100	0.080	0.0513	0.0641	1.0821	0.0294	0.0459	0.049711
6/18/2014	0.100	0.080	0.0513	0.0641	1.0821	0.0294	0.0459	0.049711
7/7/2014	0.100	0.080	0.0513	0.0641	1.0821	0.0294	0.0459	0.049711
7/16/2014	0.100	0.080	0.0513	0.0641	1.0821	0.0294	0.0459	0.049711
7/22/2014	0.075	0.060	0.0389	0.0486	0.8998	0.0192	0.0300	0.026995
8/6/2014	0.025	0.020	0.0132	0.0165	0.4378	0.0037	0.0058	0.002531
8/19/2014	0.010	0.008	0.0066	0.0083	0.2758	0.0013	0.0020	0.00056

$v = k_n / n R^{2/3} S^{1/2}$

v = cross-sectional average velocity (ft/s, m/s)

k_n *= 1.486 for English units and* k_n *= 1.0 for SI units*

A = cross sectional area of flow (ft^2, m^2)

n = Manning coefficient of roughness

R = hydraulic radius (ft, m)

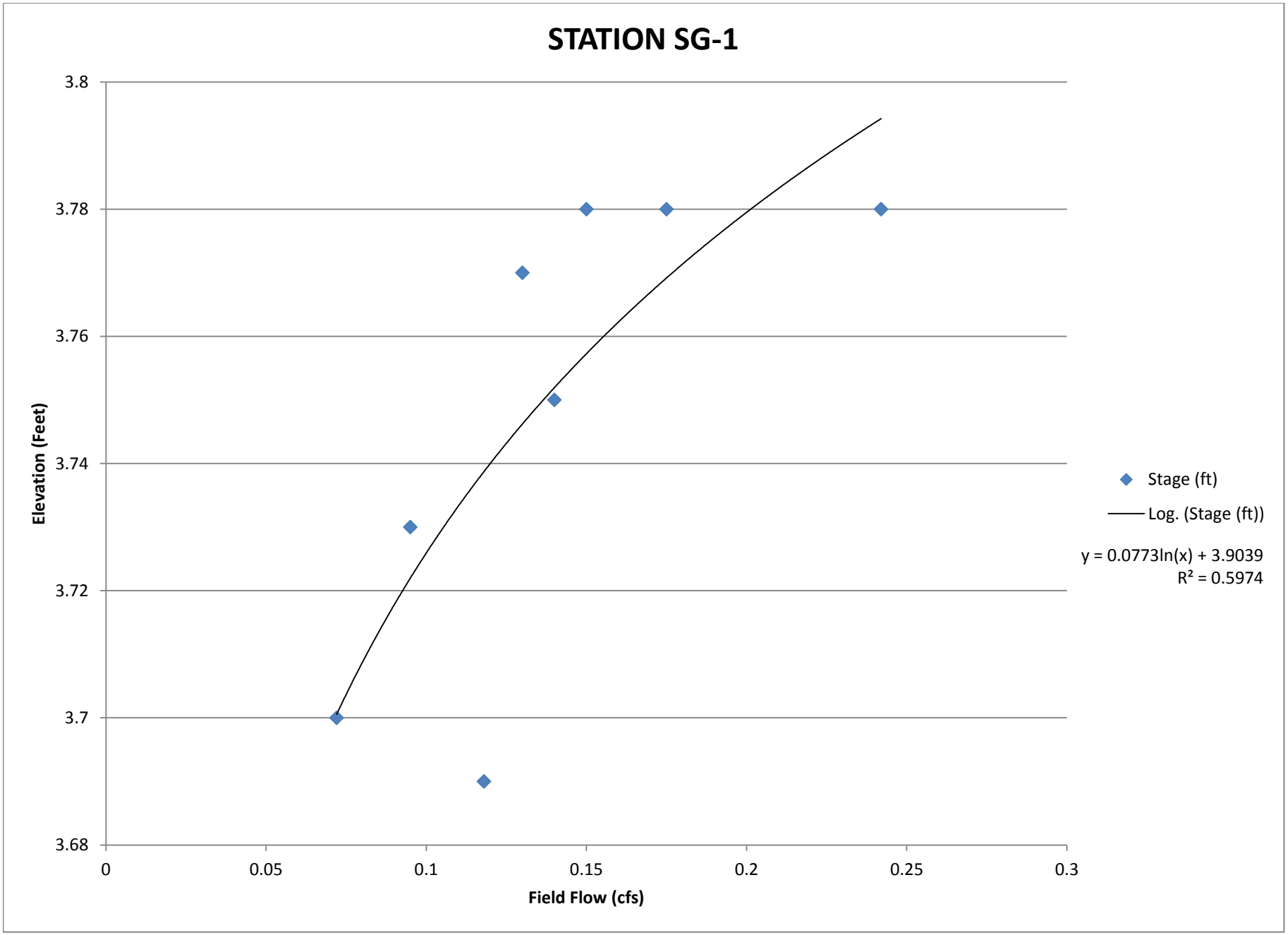
S = slope of pipe (ft/ft, m/m)

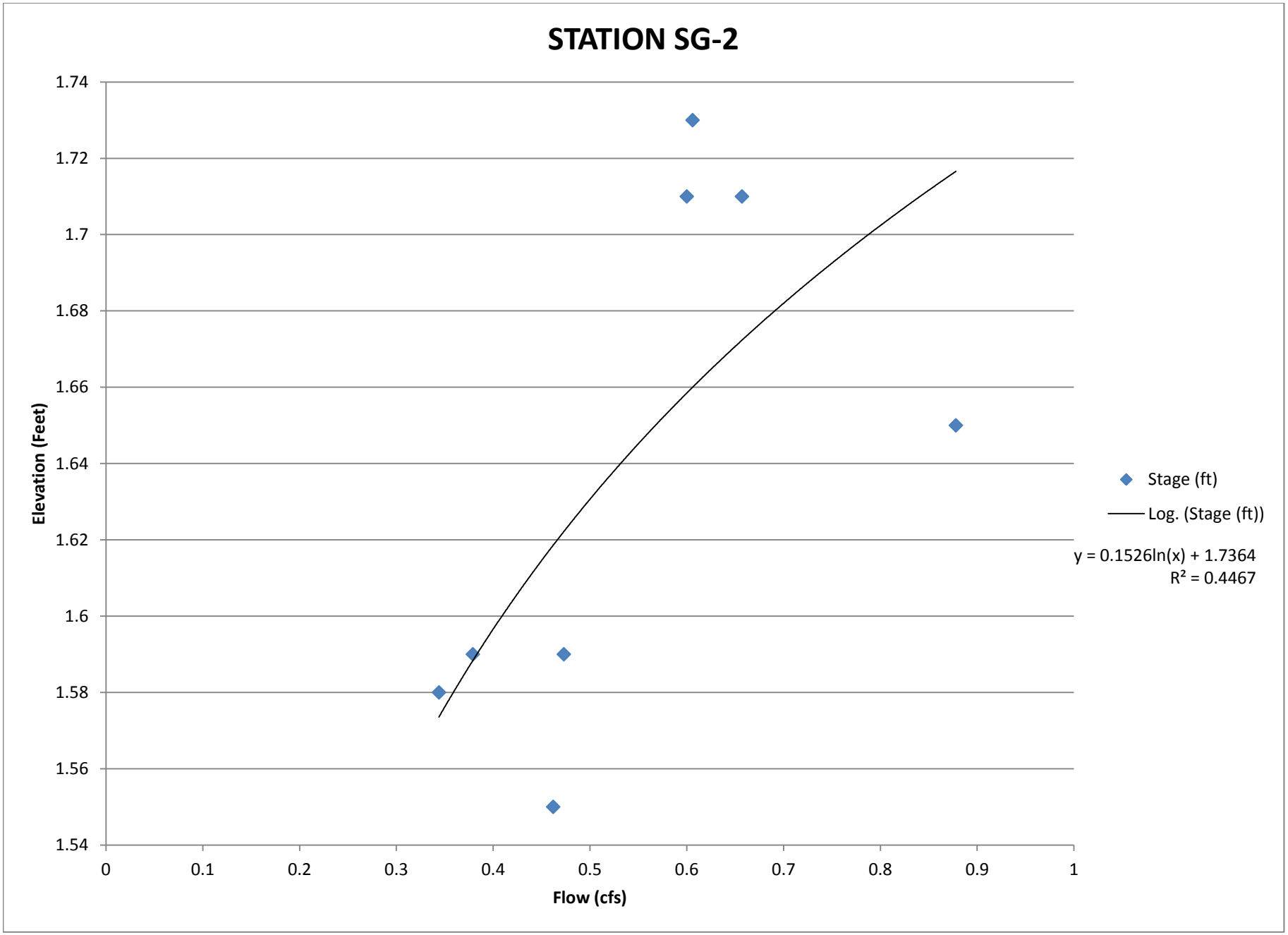
D= 1.25

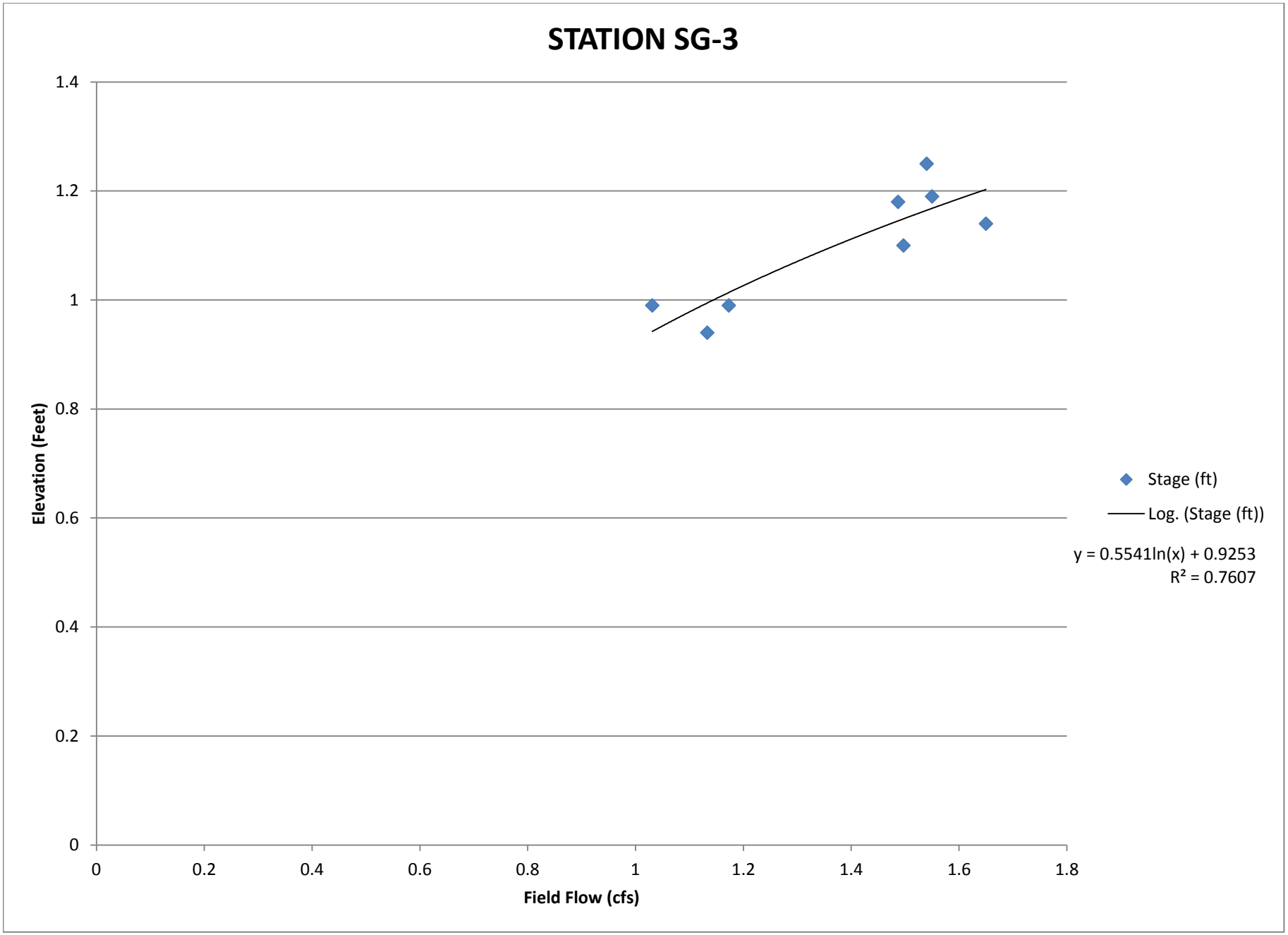
k= 1.486

n= 0.022

S= 0.01


STATION SG-1
3.8
3.78
3.76
3.74
3.72
3.7
3.68
Elevation (Feet)
0
0.05
0.1
0.15
0.2
0.25
0.3
Field Flow (cfs)
Stage (ft)
Log. (Stage (ft))
y = 0.0773ln(x) + 3.9039
R² = 0.5974


STATION SG-2
Elevation (Feet)
1.74
1.72
1.7
1.68
1.66
1.64
1.62
1.6
1.58
1.56
1.54
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow (cfs)
Stage (ft)
Log. (Stage (ft))
y = 0.1526ln(x) + 1.7364
R² = 0.4467


STATION SG-3
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Elevation (Feet)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Field Flow (cfs)
Stage (ft)
Log. (Stage (ft))
y = 0.5541ln(x) + 0.9253
R² = 0.7607