Development of conservation flow recommendations for Flint Brook at the Roxbury Fish Culture Station intake

Vermont Fish and Wildlife Department
Annual Report

State: Vermont **Project No.**: FW-19-T-43

Grant Title: Inland Waters Fisheries and Habitat Management

Study No. I **Study Title**: Technical Assistance for the Protection and Conservation of Fish and Wildlife Resources and Habitats

Period Covered: June 30, 2018 to July 1, 2019

INTRODUCTION

Owing to its ability to provide consistent, gravity-fed flows that are ideally suited for coldwater aquaculture (i.e., cold, well oxygenated), Flint Brook has long served as a primary water source for the Vermont Fish and Wildlife Department's (VFWD) Roxbury Fish Culture Station. The long-term, sustainable use of this water resource requires that an instream flow standard be established that ensures adequate protection for aquatic life living downstream of the diversion dam. Suitable conservation flows are also needed for the Vermont Department of Environmental Conservation (VDEC) to issue a 401 Water Quality Certificate permitting the facility's future use. Accordingly, VFWD staff initiated a field study of the brook's hydrology consistent with the 'Stream Hydrologic Analysis' method of the *Agency Procedure for Determining Acceptable Minimum Stream Flows* (VANR 1993; 'Flow Procedures', hereafter) during 2017. That study characterized relationships between flows recorded at Flint Brook and those measured at established long-term stream gages (McHugh 2018), however correlation coefficients fell short of the threshold required by the Flow Procedures for formal conservation flow development[1]. Thus, an additional year of data was needed in order to complete the assessment. This report serves as the second and final update for the study, presenting a complete analysis of the data and subsequent recommendations for conservation flows consistent with the requirements of the Flow Procedures.

The goal of this study is to characterize the hydrology of Flint Brook so that site- and period-specific flow statistics can be estimated to inform conservation flow recommendations. Our specific objectives were to: (1) establish gaging sites for quantifying unaltered, incoming flows immediately upstream of the diversion site, (2) develop stage-discharge relationships (rating curves) for estimating discharge from water level, (3) record instantaneous water levels for the summer monitoring period, which can then be translated into estimates of flow from the rating curves, (4) evaluate statistical relationships between

[1] Per the Flow Procedures, to develop conservation flow recommendations from a single year's data, the correlation coefficient (R) for the relationship between flows at the study site (Flint Brook) and the surrogate long-term site must be 0.90 or greater; if $0.80 < R < 0.90$, the assessment may proceed with two seasons of flow monitoring data.

stream flows observed in Flint Brook during the study period, and those recorded at long-term gaging stations, and (5) use the relationships developed under objective 4 to estimate a long-term flow record for Flint Brook from which flow statistics can be estimated. This report focuses primarily on the the summer flow management period (i.e., June 1-September 30).

METHODS

Site description

The Flint Brook diversion site is in Roxbury, approximately 1,000 ft above sea level, one quarter mile upstream from the brook's confluence with the Third Branch of the White River. The 4.4 mi^2 watershed upstream of the diversion dam is mountainous, reaching nearly 3,100 ft in elevation, and largely undeveloped (96% forest). The diversion structure sits at a significant geomorphic transition, where the brook exits a deeply incised, bedrock-controlled gorge and flows onto a fan-like feature into a larger alluvial valley. The *ca*. 0.25 mi length of stream between the diversion dam and the Third Branch of the White River is dominated by coarse bed material (boulder, cobble, and large gravel) with some bedrock exposure, and sections of both step-pool and pool-riffle channel types. It has been modified relative to its historic natural channel due to a combination of realignment and berming.

The fish community of lower Flint Brook is dominated by Brook Trout (*Salvelinus fontinalis*), with summer 2017[2] estimates of density computed at 1,770 individuals per mile (young-of-year [1,212] and age 1+ [558]) on average. Historically, Rainbow Trout (*Oncorhynchus mykiss*) were collected in Flint Brook as well as nearby stations. However, they have become rare in the upper Third Branch and its tributaries (including Flint Brook) since the 1990s, and were not collected during 2017 surveys.

To characterize natural, unmodified inflows approaching the Roxbury Hatchery diversion, we selected water-level and flow-monitoring stations upstream of the dam. For the 2017 season, the stage height logger was positioned near the head of a long run where it was expected to remain inundated at all flow levels, while also remaining relatively protected from extreme events. The cross section at which discharge was measured was located within the same habitat unit, in an area of low roughness that was amenable to reliable flow measurement. Due the potential for debris obstruction at the intake to artificially influence water depth at the logger's location (McHugh 2018), the water-level monitoring site was relocated to a pool *ca*. 100 ft upstream for the 2018 monitoring period; the flow-measurement station, however, remained the same. Thus, separate rating curves were developed for 2017 and 2018.

Rating curve development

Flows were measured using a SonTek Flow Tracker acoustic Doppler velocimeter following standard methods (Turnipseed and Sauer 2010). During each sampling occasion, individual depth and velocity measures were made at 20-30 points along the cross section, using 40-second flow period averaging, and flows were calculated using the midpoint method. Flow measurements were made so that a wide range of flows and water levels were included in the dataset and a stage-discharge relationship could be reliably estimated. Due to the small, steep nature of the Flint Brook watershed, it has a relatively flashy

[2] Two approx. 250 ft. sections of Flint Brook, below the diversion dam, were sampled using two-pass electrofishing depletion methods on August 16, 2017.

hydrology; thus, making high-flow observations required that sampling decisions be made opportunistically when runoff conditions were suitable. Additionally, because flows during the summer monitoring period (July-September) were relatively low during both years, rating curve development and flow monitoring necessarily encompassed a broader seasonal window (2017: July-Nov; 2018: May-Nov). Using the resulting stage (water level) and discharge (Q) data, the parameters of a rating curve of the form Q = a(stage)^b were estimated using simple linear regression (i.e., log(Q) vs. log(stage)) separately for each year.

<u>Water level monitoring</u>

Water level observations were recorded at 15-minute intervals using a pair of Onset U20L loggers, one fixed to rebar in the stream for recording water levels, the other fastened to a nearby tree to support barometric pressure data corrections. Instruments were deployed on July 5 in 2017 and May 2, 2018, at which time the elevation of the water level logger was also surveyed, along with that of the water surface and three stable benchmarks, using a laser level; subsequent surveys (mid study and when equipment was removed) were completed to assess the positional integrity of the logger. Following its initial deployment, the logger remained inundated for the entirety of the 2017 monitoring season. During the 2018 monitoring season, however, the logger was out of the water by early June, owing to the early deployment (i.e., May) when high-flow conditions were still present; it was thus repositioned (within the same pool) and resurveyed once prior to the July-September monitoring period. Instruments were removed in mid (2017) or late (2018) November, before anchor or surface ice altered the reliability of the summer rating curve or impacted logger function. Water level observations were translated into estimates of discharge using the rating curves derived according to the procedures described above.

<u>Assessing relationships with flow records for long-term gaging stations</u>

Developing conservation flows using the Stream Hydrologic Analysis of the Flow Procedures is predicated on (1) the estimation of a regression relating daily average flows in Flint Brook (response variable, y) with those estimated contemporaneously at another gaging site (predictor, x) for which at least ten years of historic data exist; and (2) the application of the resulting regression to predict a historic series for Flint Brook from which flow management period-specific medians can be estimated (VANR 1993). To be deemed acceptable for conservation flow estimation per the Flow Procedures, x-y pairs corresponding to the top 10% of Flint Brook observations must be excluded from the model fit and the correlation coefficient (R) must be 0.90 (or coefficient of determination, $R^2 > 0.81$) or greater[3]. Assuming acceptability, a historic Flint Brook dataset is then created and a summer conservation flow is estimated based on the median daily flow for August within the series (**Table 1**). As noted in the introduction, the 2017 data alone did not meet the regression strength requirements, thus the analysis presented in this report relies on a pooled 2017 (July 5[4]-Sept. 30) and 2018 (July 1-Sept. 30) dataset.

We evaluated four US Geological Survey (USGS) gaging sites for use in the Flint Brook Stream Hydrologic Analysis: (1) the Dog River, (2) the East Orange Branch, (3) Ayers Brook, and (4) the Mad River (**Figure 1**, **Table 2**). Although options for candidate sites are somewhat limited, these four are

[3] If the correlation coefficient is less than 0.90 but greater than 0.80 ($R^2 > 0.64$), the assessment is deemed acceptable with two seasons of flow monitoring; if greater than 0.90, only a single season of data is required.

[4] Equipment could not be deployed prior to July 1st during the 2017 season due to persistent flooding (i.e., the June 29-July 4 floods of 2017) around central Vermont.

relatively close to Flint Brook (*ca*. 10-21 miles away) and within the same physiographic region, have extensive historic records, and have relatively small watershed areas (i.e., compared to larger mainstem rivers characterized by a lagged rainfall-runoff response). Data for these stations were downloaded for the period ranging July 5-September 30, 2017, and July 1-September 30, 2018. All downloaded data have received final approval from USGS at the time of this report's writing.

Relationships between daily average flows at Flint Brook and those for the four surrogate sites were evaluated on both an untransformed and log-log basis using simple linear regression. Models meeting the minimum correlation threshold of the Flow Procedures were used to construct a record of the most recent 30-year period for Flint Brook by applying the resulting regression equation to historic values for the surrogate site. The August median was then computed from this synthetic data series. While results for all models are presented here, the 'best' model was taken as that with the highest coefficient of determination (R^2) and predictive R^2 value.

RESULTS & DISCUSSION

During the 2017 and 2018 study periods, nine and six instantaneous measurements of flow and water level were made in support of rating curve development. They ranged two orders of magnitude in both years, from less than 1 cfs to greater than 100 cfs, but were largely confined to the low-to-mid end of the flow range given the prevalence of relatively low flows for much of the study. The stage-discharge relationships fitted for each each year described the data well (2017: $Q = 45.3[\text{stage}]^{3.22}$, $P < 0.001$ for all parameters, $R^2 = 0.97$; 2018: $Q = 0.4[\text{stage}]^{5.33}$, $P < 0.001$ for all parameters, $R^2 = 0.98$; **Figure 2**). These relationships were used to generate a time series of discharge (in cubic feet per second, cfs) from each respective year's instantaneous water-level dataset; and from these, records of daily mean flows were generated for each year's July-September summer assessment period.

Consistent with the different precipitation and temperature patterns for the two years, wherein 2017 was relatively wet and cool while 2018 was quite the opposite, flow patterns differed markedly between assessment periods. For example, the minimum, median, and maximum daily average flows for July[5]-September 2017 were 0.8, 2.0, and 9.8 cfs, respectively, whereas values for these same summary statistics were 0.2, 0.5, and 3.9 cfs for July-September 2018. These differences equated to a four-fold difference in the season-total yield of surface water for the Flint Brook watershed.

Daily average flows estimated for Flint Brook for the pooled 2017-2018 assessment periods were moderate-to-strongly correlated with those observed at the four candidate gaging stations, with R^2 and predictive R^2 values ranging 0.50-0.83 and 0.47-0.83 (**Table 2**, **Figure 4**). Relationships were stronger and above the minimum correlation threshold when both x and y flows were log transformed (i.e., log-log regressions), with the highest correlation occurring for the Mad River gage (R^2 and predictive $R^2 = 0.83$). The level of correlation with flows at the Ayers Brook gaging station was comparable, albeit slightly weaker, particularly for predictive R^2 (**Table 2**). The strength of relationship between Flint Brook and Dog River flows was lower, but still statistically adequate for the requirements of the Flow Procedures. The correlation between Flint Brook and surrogate site flows was the weakest for the East Orange Branch gage (0.70 for R^2 and predictive R^2; **Table 2**). Thus, despite gross differences in watershed characteristics

[5] Note, this excludes the high flows which delayed the initial deployment date to July 5, 2017.

between sites (**Table 2**), all four long-term gages are statistically adequate for record extension using log-log models but not linear models. Further and perhaps not surprisingly, flow records from watersheds with headwaters adjacent to those of Flint Brook appear to hold the greatest predictive power (**Figure 1**).

Using the log-log regression models summarized above, a 30-year historic record of August flows (1989-2018) for Flint Brook was estimated from historic data for each of the surrogate sites, and from each of these records the median value was obtained. The estimated August median was 1.63, 1.38, 1.30, and 1.20 cfs (all-site mean: 1.38 cfs) or 0.37, 0.31, 0.29, and 0.27 csm (all-site mean: 0.31 csm) using the data constructed from the Ayers Brook, Dog River, Mad River, and East Orange Branch models, respectively, values which are consistent with the approximation generated using 2017 data alone (McHugh 2017).

RECOMMENDATIONS

Based on the combined data collection and analysis for the FY2018 and FY2019 study periods, the following recommendations are offered:

- Adopt and implement a conservation flow consistent with the August median estimate from the single best regression model (i.e., Mad River, 1.30 cfs / 0.29 csm) for the summer flow management period (June 1-September 30).

- Develop a flow management plan that allows available water to be easily accessed while simultaneously ensuring that conservation flows are maintained.

ACKNOWLEDGMENTS

This project was made possible by fishing license sales and matching Dingell-Johnson/Wallop-Breaux funds available through the Federal Sportfish Restoration Act. Thanks to Adam Miller and Jeremy Whalen for sharing information about the diversion site, the hatchery's water use history, and on-the-ground observations of stream conditions during the completion of this study.

Prepared by: Pete McHugh
Date: 4/19/2019 (with 8/6/2019 revision drawing on final, approved USGS data)

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Table 1. Periods of assessment and application for the Stream Hydrologic Analysis method of the Flow Procedures.

Flow Management Period	Date Range	Stream Hydrologic Analysis Assessment Period	Conservation Flow Statistic
Summer	Jun 1-Sept 30	Jul 1-Sept 30	August median
Fall/Winter	Oct 1-Mar 31	Dec 15-Mar 15	February median
Spring	Apr 1-May 31	Mar 15-May 31	April-May median

Table 2. Watershed characteristics of the Flint Brook and long-term USGS gaging stations used in the Flint Brook Stream Hydrologic Analysis. Also presented are the coefficients of determination from regressions relating surrogate gaging station flows with those estimated for Flint Brook.

Gage Name	USGS Station Number	DBA (mi^2)	Elev. (ft)	% Forest Cover	Correlation with Flint (R^2)
Flint Brook	N/A	4.4	1,012	96	N/A
Ayers Brook at Randolph, VT	01142500	30.5	630	30	*linear* = 0.54 *log-log* = 0.81
Dog River at Northfield Falls, VT	04287000	76.1	603	66	*linear* = 0.50 *log-log* = 0.78
East Orange Branch at East Orange, VT	01139800	8.95	1,180	71	*linear* = 0.52 *log-log* = 0.70
Mad River at Moretown, VT	04288000	139	544	76	*linear* = 0.61 *log-log* = 0.83

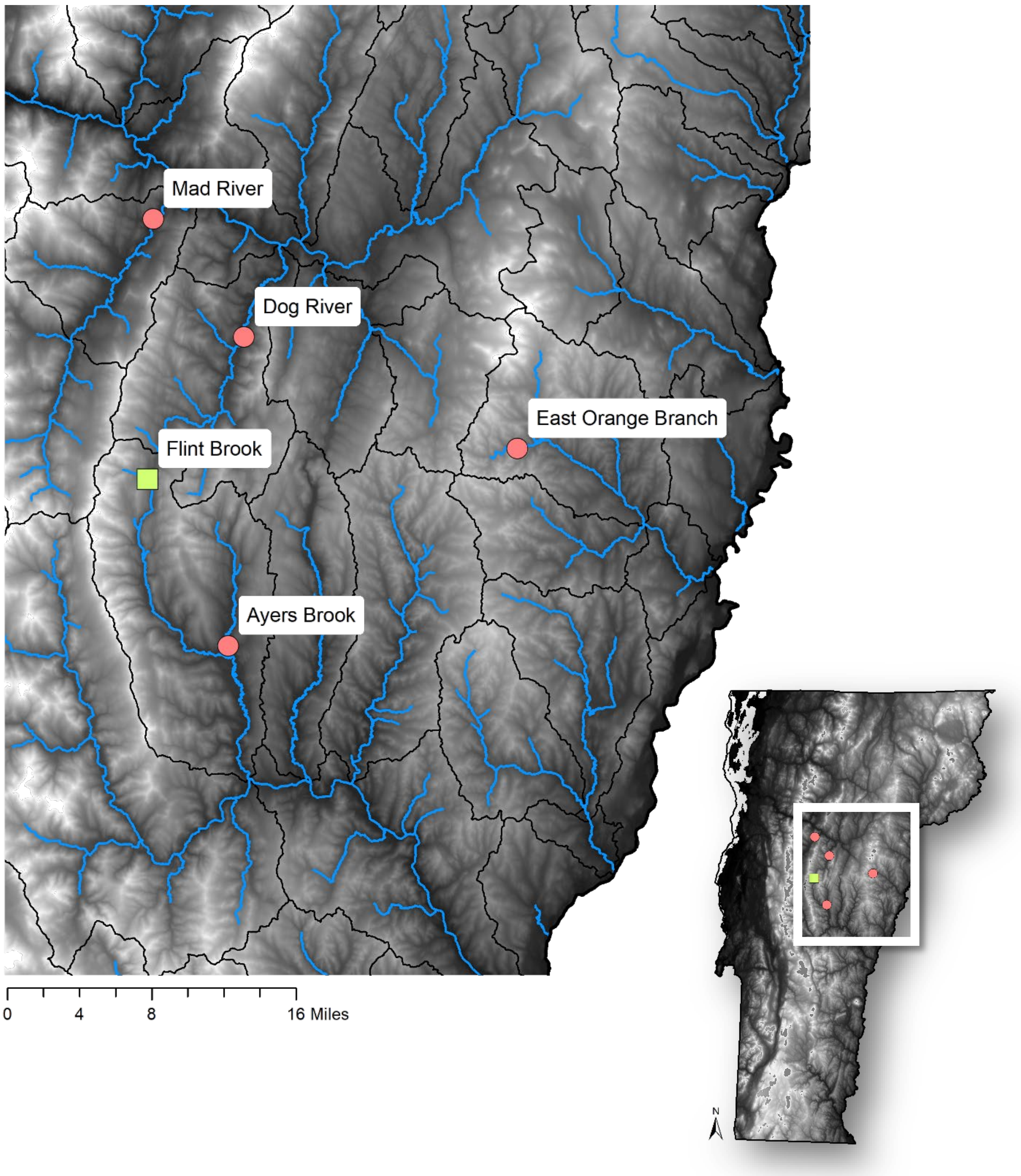

Figure 1. Map of the Flint Brook study site and the USGS gaging stations evaluated for use in record extension.

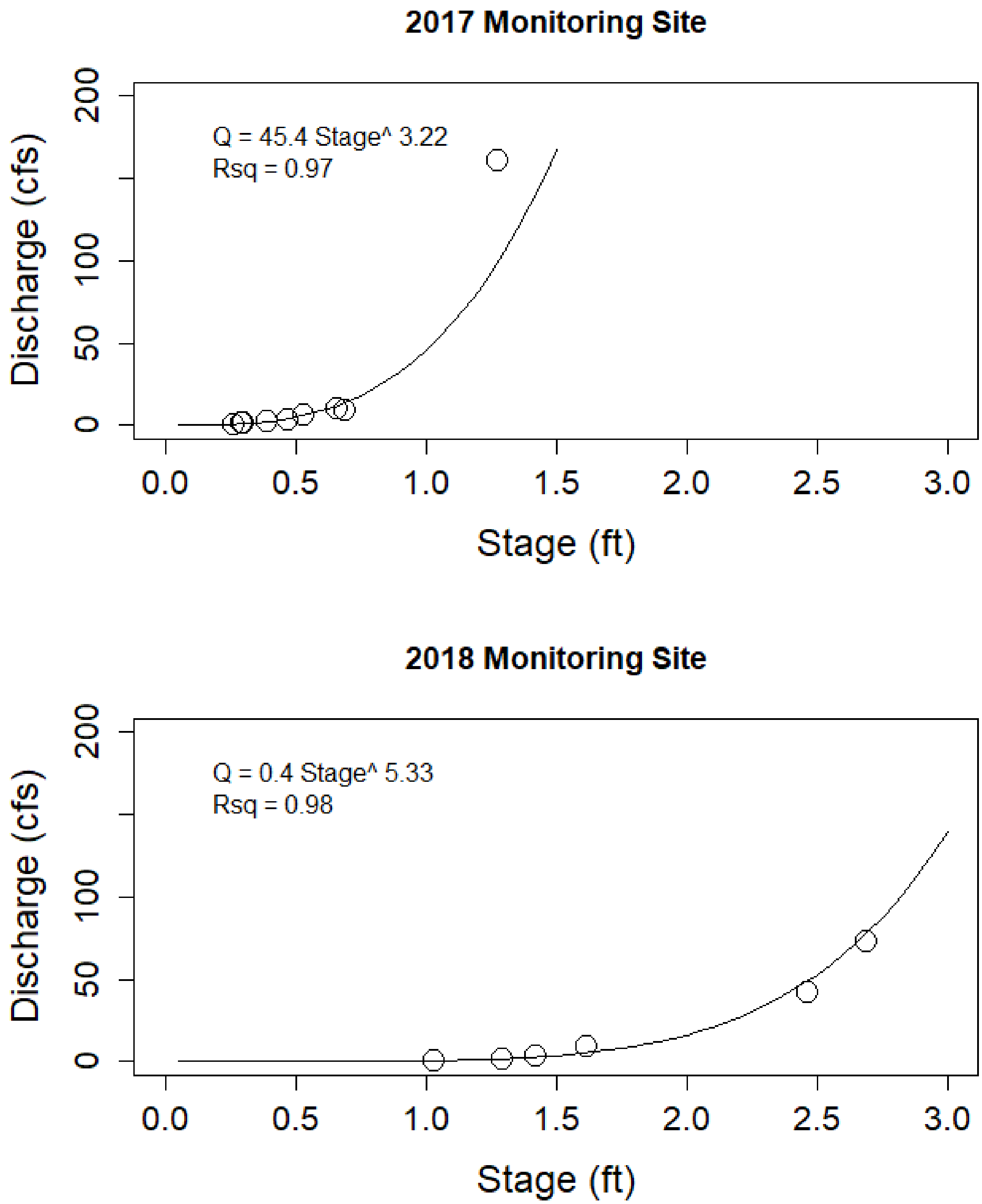

Figure 2. Stage-discharge relationship for the 2017 and 2018 flow monitoring sites at Flint Brook.

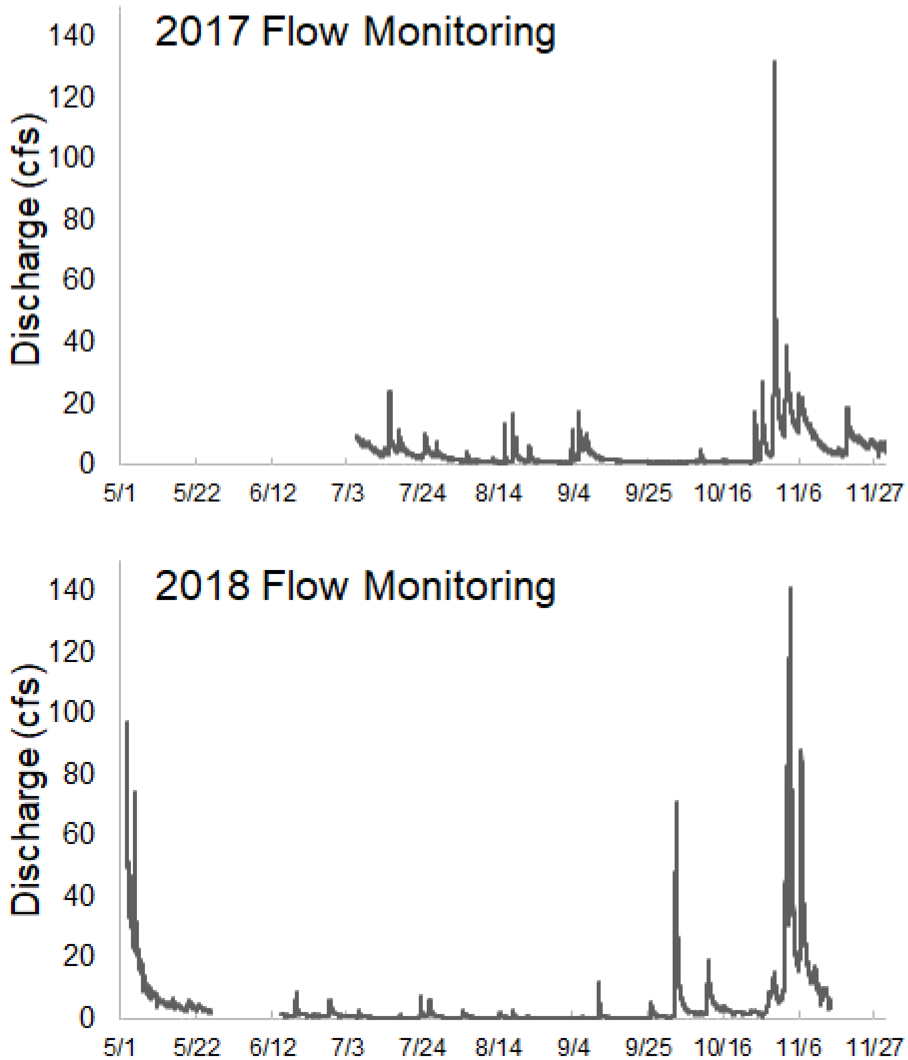

Figure 3. Hydrograph for Flint Brook for the 2017 and 2018 monitoring periods. Although the full period of monitoring is displayed, the record-extension analysis was confined to the July-September monitoring period only.

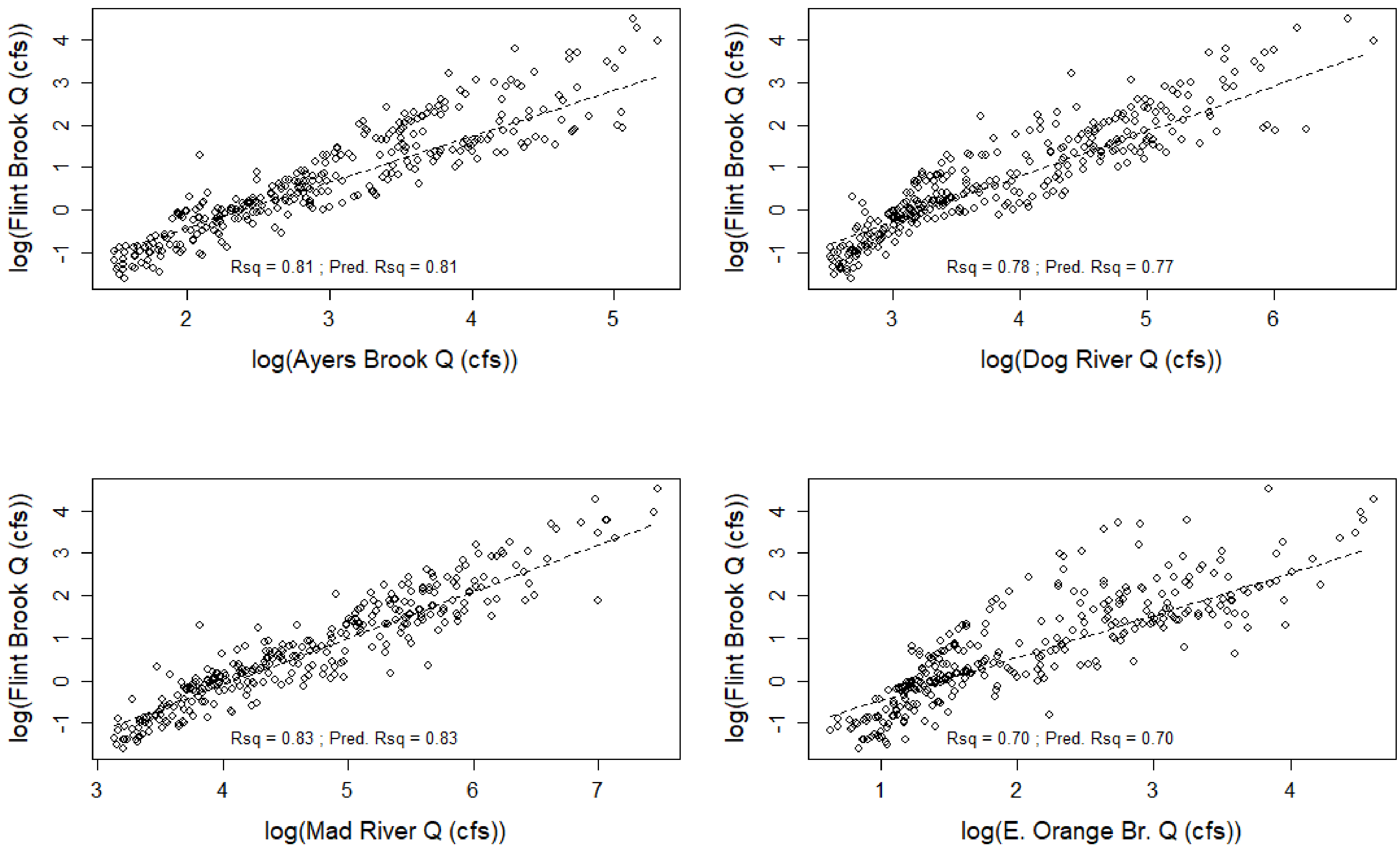

Figure 4. Relationships between flows at Flint Brook and those recorded at long-term USGS gaging stations. The strength of correlation for each relationship is indicated by the coefficients of determination, R^2 ('Rsq' in figures) and predictive R^2 ('Pred. Rsq') in the bottom of each figure.