Analysis of Flow Fluctuations Downstream of Ashton Dam

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Summary

- Fluctuations in flow downstream of Ashton Dam are of concern to anglers, fishery advocates, and irrigators, particularly during late summer and early fall. Stable flows no lower than 1000 cfs are desirable for irrigation operations and maintenance of fish habitat.
- River stage data were collected upstream and downstream of Ashton Reservoir and adjusted to remove rating shifts and place them on the same scales. Differences in adjusted stage were analyzed over the period 8 July to 12 November 2014.
- Daily cycles in river flow with amplitudes of roughly 2 inches in stage (discharge around 300 cfs) originate in the Harriman State Park reach of the river and are caused by daily cycles of macrophyte photosynthesis and respiration.
- High-frequency fluctuations have higher amplitude downstream of Ashton Dam than upstream; about 10% of these fluctuations exceeded one inch in magnitude (about 150 cfs in discharge).
- Stage downstream of Ashton Dam was systematically lower than that upstream by about 0.2 inches in the morning and higher by that same amount in the afternoon, although this daily cycle in stage differences accounted for only 3.6% of total variability in the differences and only 10% of the total amplitude of observed late-summer cycles.
- Variability in discharge at Ashton Dam, as measured by sums-of-squares, was explained by inflow (97.37%), daily periodic cycles (0.094%), lag-5 (1-hour, 15-minute) autocorrelation, i.e. persistence (1.78%), and 0.756% random, normally distributed noise.
- Observed daily cycles in flow would have negligible effect on river flow or ecology under unregulated flow conditions, but under regulated conditions, when 50% or more of the river's flow is diverted between Ashton and St. Anthony, these cycles result in flow dropping below 1000 cfs for several hours each day, even when mean flow remains well above 1000 cfs.
- During the 2014 analysis period, flow fell below 1000 cfs at St. Anthony for 178 hours, whereas the 24-hour moving average of flow fell below 1000 cfs for only 38 ¾ hours during the same time period.
- Smoothing outflow from Ashton Dam would provide benefits to the fishery and irrigators downstream but would require Ashton Dam operations to deviate from the instantaneous run-of-river requirements of the Federal Energy Regulatory Commission license.
- Preliminary calculations suggest that typical daily cycles observed during 2014 could be eliminated by daily storage and delivery of about 95 ac-ft in Ashton Reservoir, resulting in daily fluctuations in reservoir elevation of around 2.9 inches.

Introduction

For many years, outfitters and guides, anglers, and irrigation canal managers have inquired about the causes of daily fluctuations in streamflow in the Henrys Fork downstream of Ashton Dam (Figure 1). These fluctuations are large enough to be noticed by guides and anglers while they are out on the river and are large enough to cause canal diversion rates to vary throughout the day. Although fluctuations occur year-round, they are highest in amplitude and have the greatest effect on fishing, river ecology, and irrigation operations during the late summer and early fall, when streamflows are low. Fluctuations in October, during brown trout spawning, are of particular concern. Flow fluctuations have the largest effect between Chester Dam and the Independent Canal diversion, the reach of greatest diversion. Groundwater returns to the river increase flow downstream of the Independent Canal.

In general, U.S. Bureau of Reclamation and Fremont-Madison Irrigation District manage delivery of irrigation water from Island Park Dam so that flow at the St. Anthony gage remains relatively steady at no lower than 1000 cfs during irrigation season. Although we do not have detailed data relating habitat availability to streamflow in the Henry's Fork near St. Anthony, reports from guides and outfitters who spend a large number of days each year on the river there indicate that side-channel habitat becomes de-watered when flow drops below 1000 cfs at St. Anthony. Detailed cross-sectional surveys of the channel downstream of St. Anthony were made in the summer of 2005, when streamflow was around 1100 cfs at the St. Anthony gage. These surveys indicated adequate depth in side channels at this flow.

Key features of late-summer/early fall streamflow between Ashton Dam and St. Anthony, shown in Figure 1, are:

1. Discharge at St. Anthony reflects the combined effects of discharge in the Henrys Fork below Ashton Dam and inflow from Falls River.
2. Falls River responds to short-duration rainfall events, and these are reflected at St. Anthony.
3. Daily flow fluctuations are greatest at Ashton, somewhat lower at St. Anthony, and absent in Falls River.
4. When flow in Falls River is high, relative effect of fluctuations in Henrys Fork flow between is lower at St. Anthony than when Falls River flow is low.
5. Daily fluctuations are greatest during warm, sunny weather during late summer and early fall. In particular, in 2013, fluctuations were greatest during August, whereas in 2014, they were greatest during September.
6. Mean discharge at St. Anthony increases in late October/early November when irrigation diversion decreases.
7. Daily mean discharge at St. Anthony rarely drops below 1000 cfs, but daily values frequently fall below 1000 cfs during periods of high fluctuation.

Objectives

1. Quantify late-summer/early fall streamflow fluctuations in the Henrys Fork upstream and downstream of Ashton Reservoir.
2. Identify the river reach in which daily fluctuations originate.
3. Statistically describe differences in river stage between the USGS gage immediately downstream of Ashton Reservoir and a site upstream of Ashton Reservoir.
4. Quantify the potential to decrease frequency of low-flow events (flow less than 1000 cfs) at St. Anthony by smoothing daily fluctuations.

Methods

Detailed analysis used fifteen-minute river flow and raw river stage data observed over the time period 8 July 2014 to 12 November 2014. Data collected at USGS gage stations on the Henrys Fork at Island Park, Ashton, and St. Anthony were downloaded from the USGS surface water data base. In addition, two YSI EX02 recording water-quality sondes were installed in the Henrys Fork at Pinehaven, just downstream of the lower boundary of Harriman State Park, and at the old Marysville Bridge, about one mile upstream of the upper end of Ashton Reservoir. The sondes are part of a long-term water-quality monitoring program implemented by the Henry's Fork Foundation in the summer of 2014. This program was reviewed and endorsed by the Henry's Fork Watershed Council in April 2014.

The sondes record raw pressure (atmospheric pressure plus pressure of the water column above the pressure recorder) and were programmed to record at 15-minute intervals, to match the data resolution at the USGS sites. Atmospheric pressure was recorded at 15-minute intervals at an outdoor location in Ashton, using a recording instrument manufactured by In-Situ. Atmospheric pressure was subtracted from raw sonde pressure to obtain water-column pressure, and this was converted to depth of water, based on density of water at standard temperature and pressure.

Because we have not yet developed stage-discharge relationships at the sonde locations, river stage was used as a surrogate for discharge. To account for differences in discharge and in channel configuration among sites, all comparisons were done on normalized scales. In particular, raw river stage at the USGS Ashton gage was first corrected for rating shifts that occur because of plant growth and senescence in the river during the summer and fall. Next, cross-correlation analysis was used to identify river travel time between Marysville and Ashton. Maximum correlation between stage at the two sites was 0.989223, at a lag of six 15-minute time steps. Thus, the Marysville record was advanced 1:30 to match that of the Ashton gage. Next, a linear adjustment was applied to stage heights recorded at the Marysville sonde to both translate stage to the same datum as used at the USGS Ashton gage and to scale changes in stage to match those at the Ashton gage. The combination of the time shift and the linear adjustment in stage resulted in records of stage above and below Ashton Reservoir that accurately reflected inflow to and outflow from Ashton Reservoir, on the same scales. The scale factor applied to Marysville stage was 1.098, so that stage there was increased by about 10% to match that at Ashton.

Analysis was then performed on the time series of difference between shift-adjusted stage at the USGS Ashton gage and adjusted stage at the Marysville sonde.

Results

Origination of daily cycles

Daily cycles in river stage are absent at the USGS gage immediately downstream of Island Park Dam but present at Pinehaven (Figure 2). These cycles persist all the way down the river to Rexburg (Figure 3). Travel times are roughly 7:30 hours from Pinehaven to Marysville, 1:30 from Marysville to Ashton, 3 hours from Ashton to St. Anthony, and 14 hours from St. Anthony to Rexburg. Daily cycles are attenuated somewhat between Pinehaven and Marysville, amplified between Marysville and Ashton, and attenuated again between Ashton and Rexburg. Note also the lack of a daily fluctuation on September 11, which was a cloudy day. Review of literature and other data collected by our sonde network and field research indicates that the daily fluctuations in flow are caused by physical storage and release of water in the Harriman State Park reach by macrophytes, as their volume expands and contracts with daily cycles of respiration. These cycles are greatest when macrophyte density and photosynthesis are greatest, which explains temporal variation in these cycles within and across years (Figure 1).

Differences in river stage between Ashton USGS gage and Marysville site

The raw stage records clearly depict the strong relationship between flow upstream of Ashton Reservoir and that downstream of the reservoir (Figure 4). These records also clearly show the effect of stage shift at Ashton due to macrophyte growth and senescence in the channel at the USGS gage site and the lack of such shifts in stage at Marysville, where macrophytes are absent. The adjusted stage records (Figure 5) illustrate that: 1) the vast majority of fluctuation in flow downstream of Ashton Reservoir is explained by fluctuations in inflow to the reservoir, and 2) high-frequency (periods less than 24 hours) fluctuations in flow have greater amplitude downstream of Ashton Reservoir.

Differences in adjusted stage show very little temporal pattern in either magnitude or direction (Figure 6). Slight patterns on the weekly time scale are most likely due to slight errors in shift adjustments to the Ashton USGS gage record, given that only four field measurements were made over the study period, and shift adjustments between measurements were estimated using linear interpolation. Except for a few large negative differences (stage below Ashton Dam much lower than that upstream), differences were symmetrically distributed around 0 (Figure 7). Statistical analysis of the differences showed that 5.3% of the stage differences exceeded 1 inch and 4.6% of the stage differences were less than -1 inch. Thus, nearly 10% of the differences exceeded 1 inch in magnitude. Detailed comparison of adjusted stage (surrogate for flow) clearly shows that flow downstream of Ashton Dam largely reflects inflow; however, when inflow changes rapidly over time scales of hours, outflow tends amplify these changes and in some cases shift them in time (e.g., on the last day of the record, when the river and reservoir were freezing). It is important to note that travel time and scale differences between the two sites have already been removed from the data, so that lags and amplitude differences depicted in Figure 8 are not due to differences in temporal and spatial scales between the sites.

Time series modeling, with Akaike's Information Criterion used to select models and draw inferences, showed that there was a statistically detectable 24-hour cycle in stage differences over the 8 July – 12 November modeling period (Figure 9). On average, adjusted stage at the USGS Ashton gage was lower than that at Marysville early in the morning (centered on 4 a.m.) and higher than that at Marysville 12 hours later. However, these daily cycles in difference accounted for only 3.6% of the variability in differences across the modeling period, and amplitude of the cycles was only 0.2 inches, compared with an amplitude of about 2 inches in the macrophyte-driven cycles (Figure 8). Cycles of other frequencies were not statistically detectable. Addition of 5-step (one hour, 15 minutes) autocorrelation to the 24-hour cycle produced the best statistical representation of the stage differences; this model accounted for 71.3% of the variability in differences across the modeling period, leaving 28.7% of sum-of-squares explained only by random, normally distributed variability. The physical meaning of the lag-5 autocorrelation is that differences between outflow and inflow persist on a time scale of about one hour and 15 minutes. That is, if outflow is lower (or higher) than predicted by the 24-

hour cycle, it is likely to remain lower (or higher) for the next hour and 15 minutes. One of the most important observations is that the magnitude of differences between outflow and inflow did not change across time—in particular; deviations from inflow were no higher or lower during the periods of largest macrophyte-driven cycles.

Although sums-of-squares are not additive in time series models fit with maximum likelihood, they are extremely close to additive when only AR components are included and the sample size is very large, which is the case here. Variability in discharge at Ashton Dam, as measured by sums-of-squares, was explained by inflow (97.37%), daily periodic cycles (0.094%), lag-5 (1-hour, 15-minute) autocorrelation, i.e. persistence (1.78%), and random, normally distributed noise (0.756%).

Potential improvements to river flow

In the range of river flows of greatest concern (1000-2000 cfs at Ashton), a one-inch change in stage is equivalent to a change in discharge of around 150 cfs (Figure 10). Therefore, the two-inch amplitude typical of the river's natural, macrophyte-driven cycles produces daily discharge changes on the order of ±300 cfs at Ashton (Figure 1). Furthermore, the 10% of stage differences that exceeded one inch in magnitude add discharge fluctuations on the order of 150 cfs to the river's natural daily cycles.

Under unregulated conditions, daily fluctuations in discharge on the order of ±300 cfs at Ashton (somewhat lower at St. Anthony, due to attenuation) would constitute around 10-15% of the river's flow at St. Anthony and never result in discharge falling below 1000 cfs (Figure 11). However, during late summer and early fall, when irrigation diversion removes half or more of the discharge between Chester Dam and St. Anthony, the same fluctuations constitute a much larger fraction of the river flow and result in flow dropping below 1000 cfs for many hours each day, even when mean flow remains well above 1000 cfs (Figure 10). During the analysis period of 8 July 2014 to 30 November 2014, actual discharge fell below 1000 cfs at St. Anthony for a total of 178 hours, whereas the 24-hour moving average of discharge fell below 1000 cfs for only 38 ¾ hours, a 78% reduction in duration of low-flow events. These statistics would be even more extreme during a dry, sunny year such as 2013 (Figure 1).

Although an argument could be made that the macrophyte-driven cycles are a natural part of the river's ecology and should be maintained in the reach between Ashton Dam and St. Anthony, all aspects of the river in that reach are already highly regulated, particularly diversion of a large fraction of the river's flow. Smoothing daily cycles in flow at Ashton Dam—whether "natural" or not—would benefit the fishery and irrigators downstream, and probably also operations at the Chester hydroelectric project. However, smoothing these cycles at Ashton Dam would require the Ashton hydroelectric power plant to deviate from the instantaneous run-of-river operational mode required by its Federal Energy Regulatory Commission license. In particular, dampening the daily macrophyte cycles will require a small amount of storage and delivery in Ashton Reservoir on a daily basis. When inflow exceeds the daily mean, water would be stored in the reservoir, and the reservoir elevation would increase. When inflow falls below this daily mean, the reservoir elevation would decrease. Outflow would remain roughly constant at its daily mean. Although this would deviate from run-of-river mode on an instantaneous basis, reservoir outflow would equal inflow over any given 24-hour period.

The amount of water that can be physically stored and released on a daily basis is constrained by the surface area of the reservoir and the daily change in reservoir elevation that is possible without damaging shoreline infrastructure and resources. Eliminating typical 24-hour cycles observed during 2014 would require storing and releasing about 95 ac-ft each day. Ashton Reservoir has a surface area of about 400 acres, so 95 ac-ft of storage and delivery would raise and lower the reservoir elevation by 2.85 inches each day. Implementing this daily storage and delivery will require adjusting the current control settings at the reservoir to decrease the frequency of flow adjustments and the increase the change in reservoir elevation required to initiate an outflow adjustment.

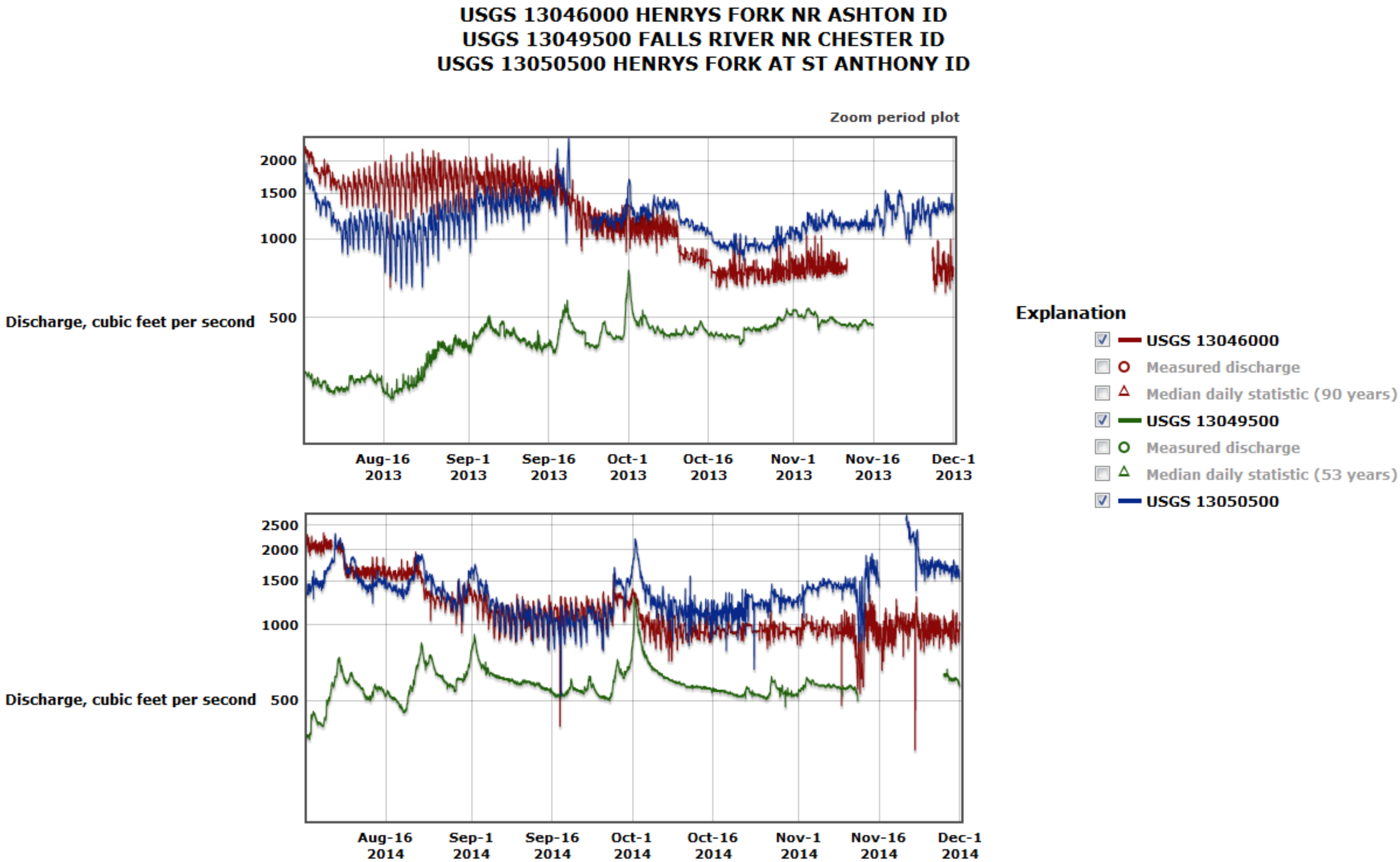

Figure 1. Fifteen-minute discharge record over the period 1Aug-30Nov 2013 (top) and 1Aug-30Nov 2014 (bottom), as recorded at Henrys Fork nr Ashton (red), Falls River nr Chester(green), and Henrys Fork at St. Anthony (blue).

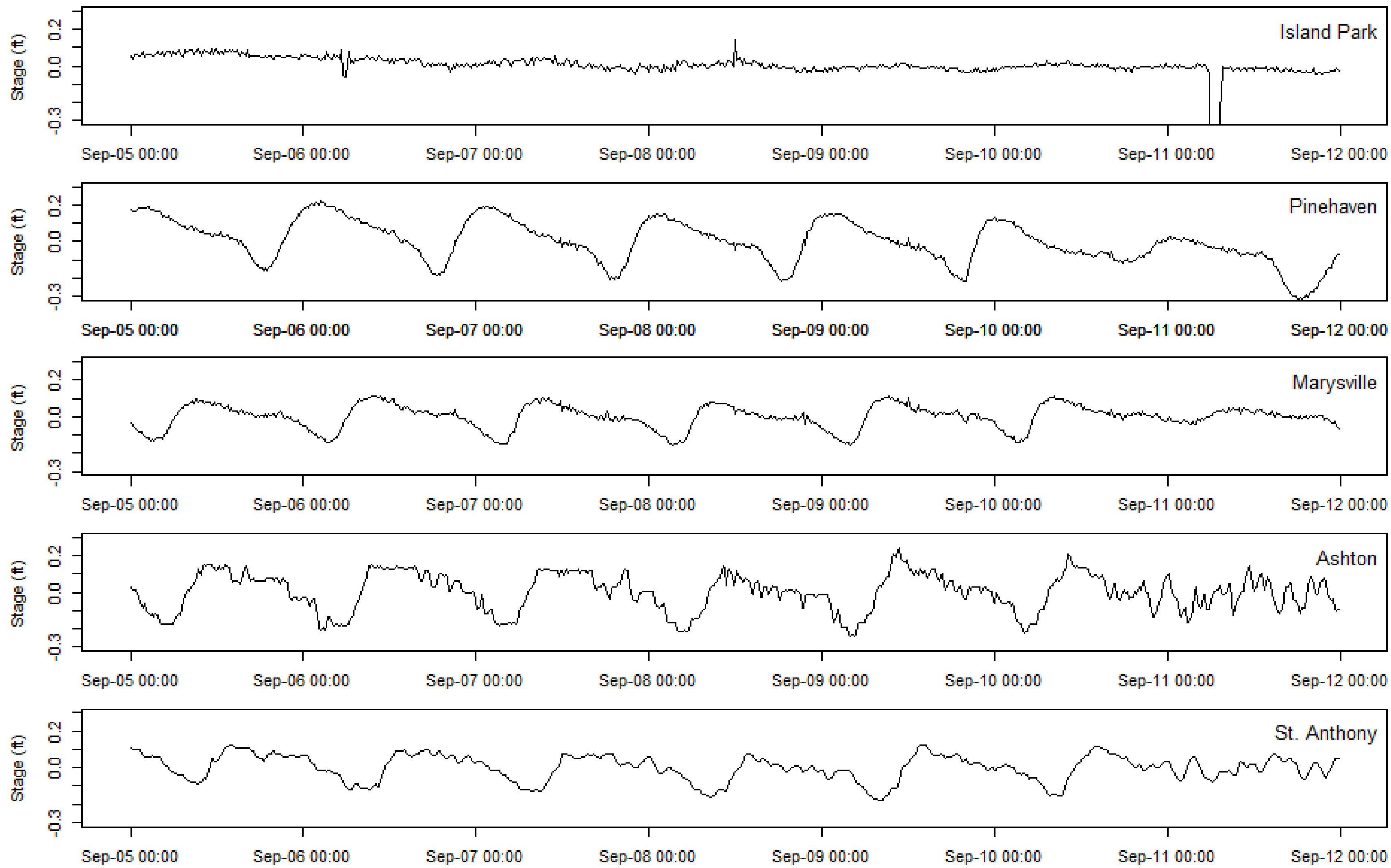

Figure 2. Fifteen-minute river-stage record over the period 5Sep-11Sep 2014, as recorded at six stations on the Henry's Fork between Island Park Dam and St. Anthony. Stage is given as deviation from the weekly mean at each site. All graphs are plotted on the same scale.

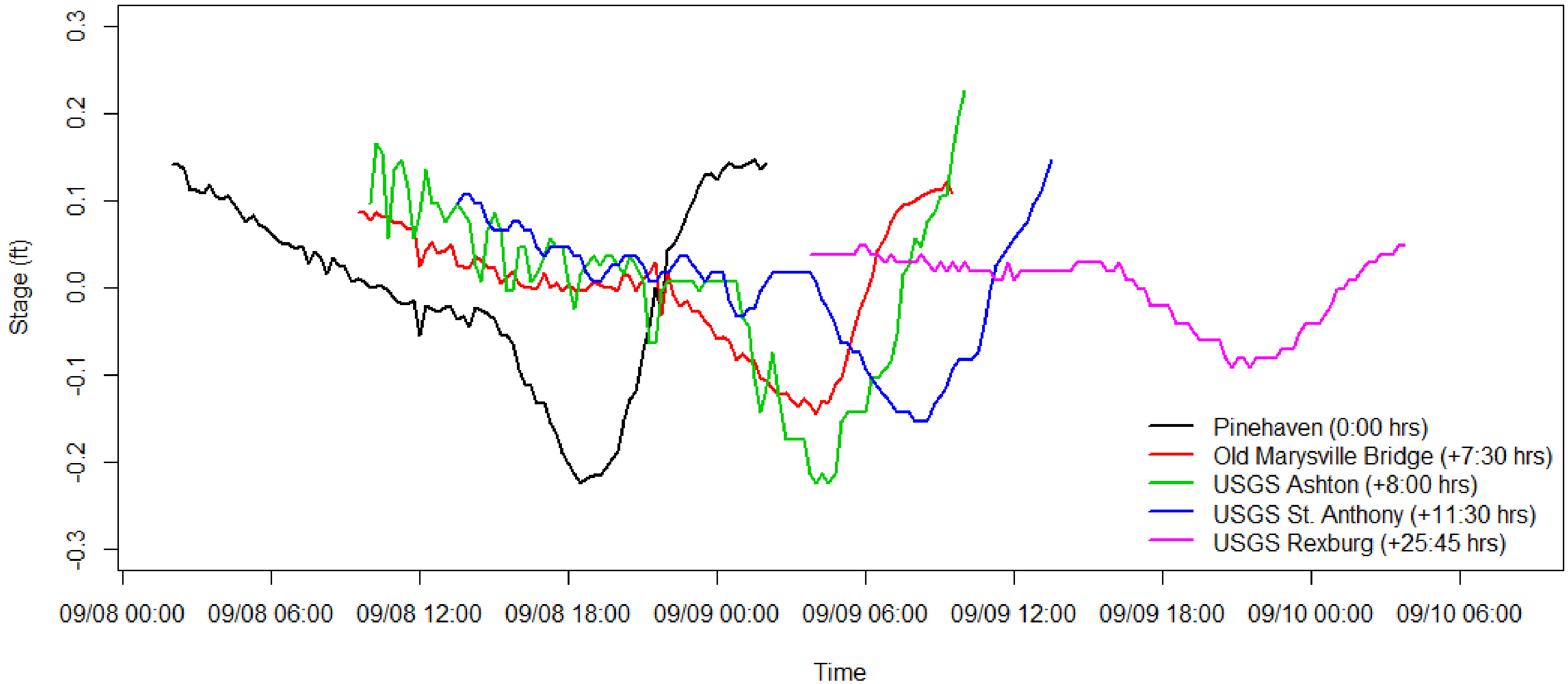

Figure 3. Downstream propagation of a single 24-hour cycle from Pinehaven to Rexburg. The initial peak of this cycle passed the Pinehaven sonde at 2:00 a.m. on September 8, 2015 and reached the USGS gage at Rexburg at 5:45 a.m. on September 9, 2015. Times at which the minimum point in the cycle passed each gage were 9/8/2015 6:30 p.m. at Pinehaven, 9/9/2015 4:00 a.m. at Marysville, 9/9/2015 4:30 a.m. at Ashton, 9/9/2015 8:00 a.m. at St. Anthony, and 9/9/2015 8:45 p.m. at Rexburg.

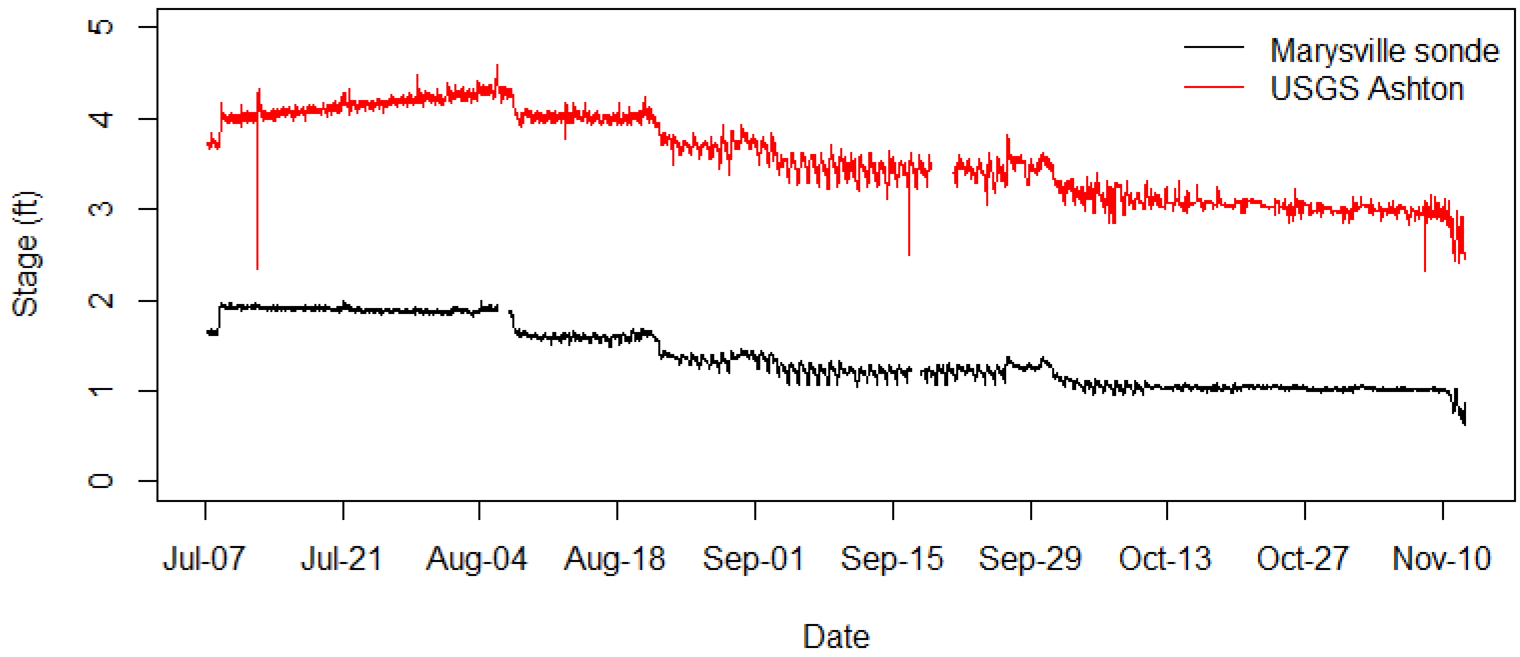

Figure 4. Raw river stage records from USGS Ashton gage and the Marysville sonde.

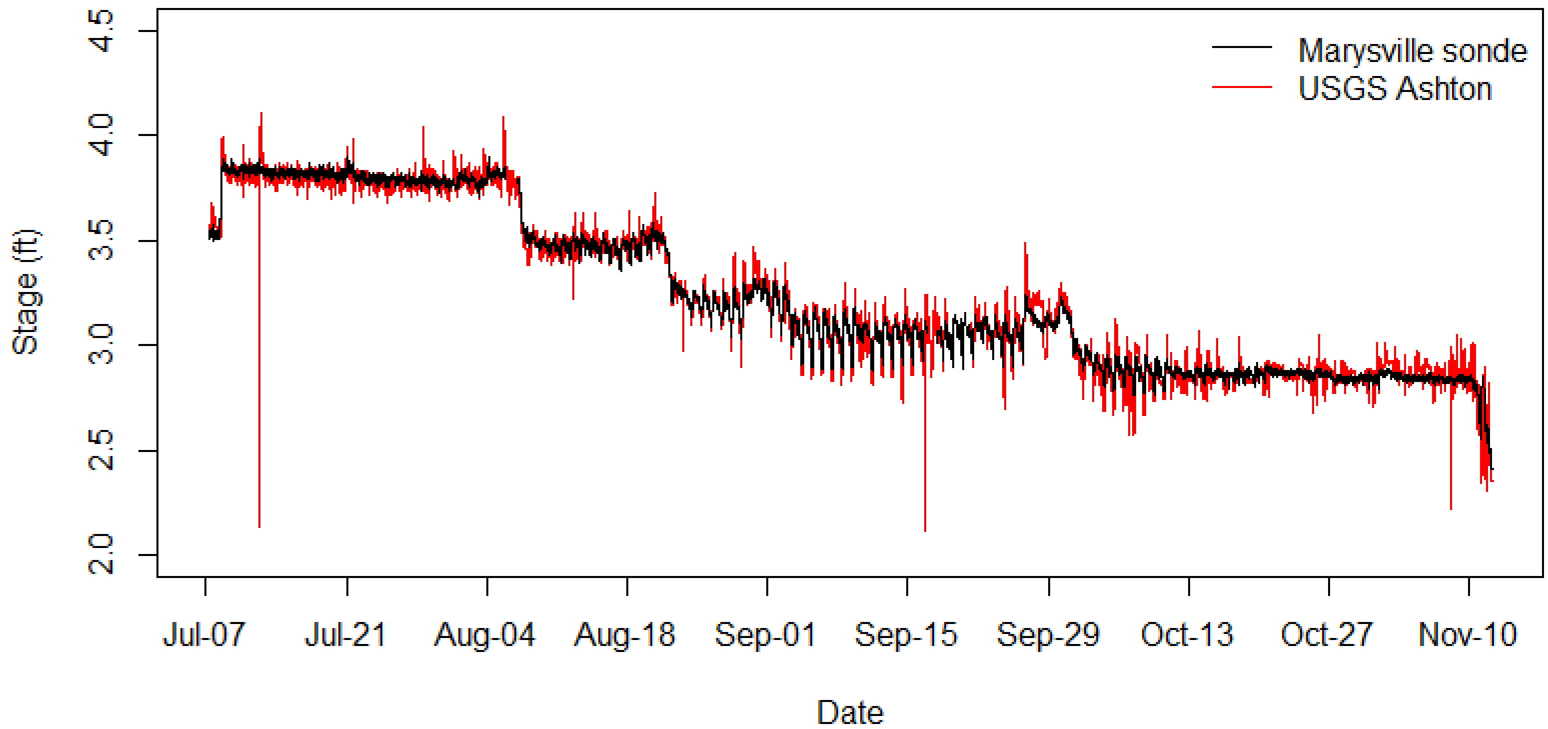

Figure 5. Fifteen-minute record of shift-adjusted stage at the USGS Ashton gage and adjusted stage at the Marysville sonde.

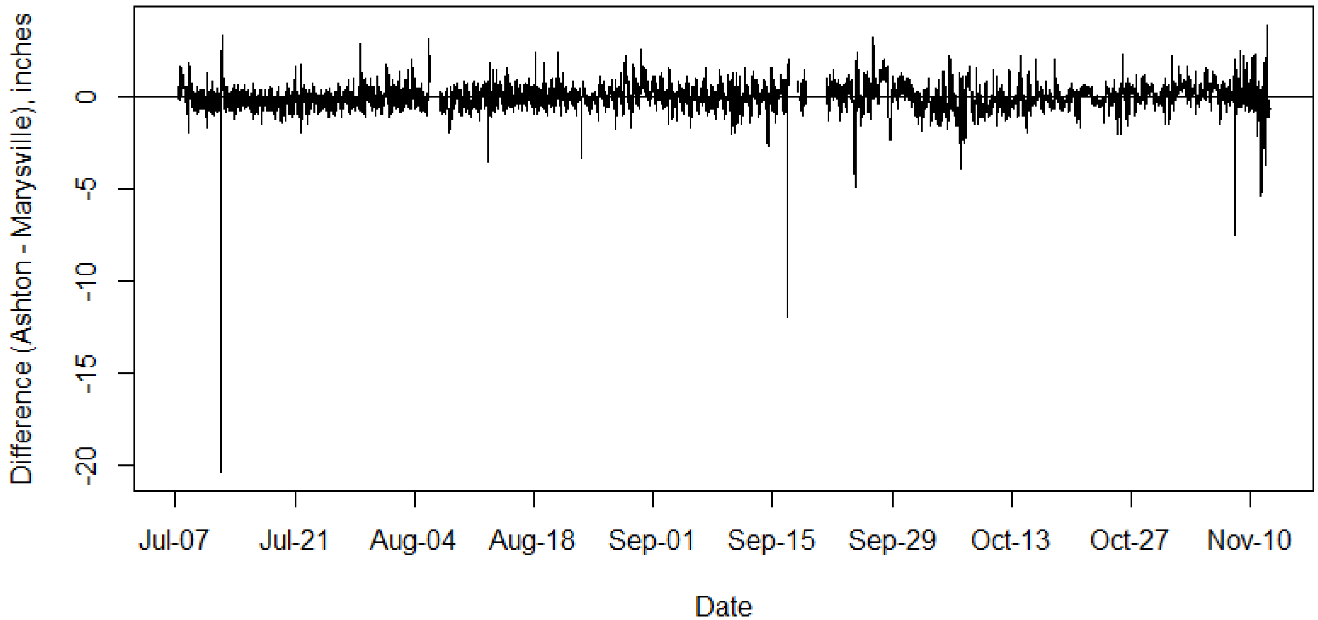

Figure 6. Time series of difference between adjusted stage at USGS Ashton and adjusted stage at Marysville.

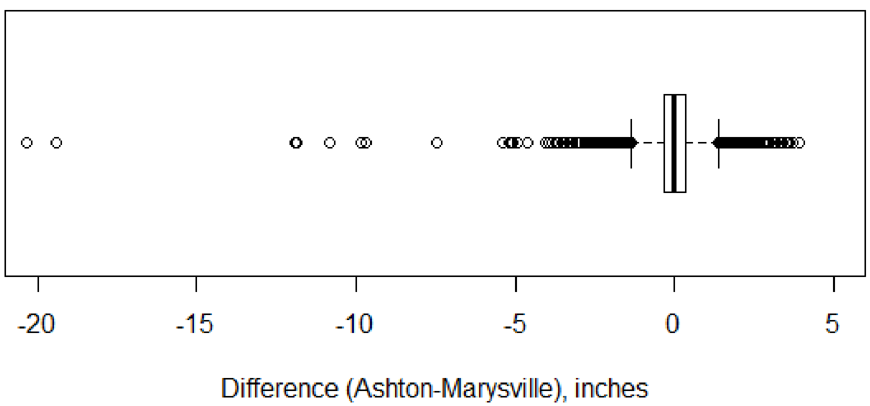

Figure 7. Box-and-whisker plot of differences between adjusted stage at USGS Ashton and adjusted stage at Marysville.

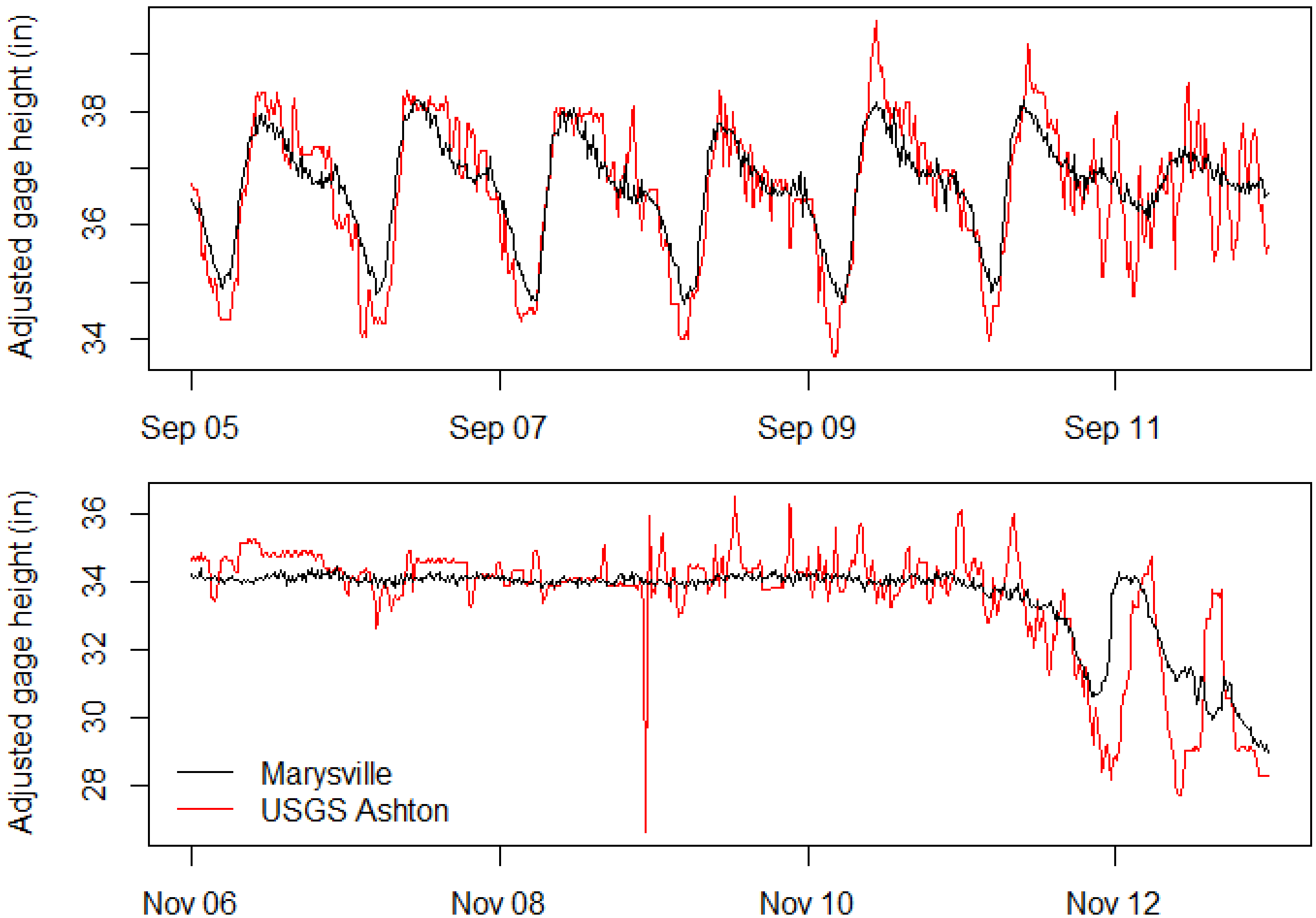

Figure 8. Comparison of adjusted stage at USGS Ashton gage and Marysville sonde over two one-week time periods in 2014, one during period of maximum daily fluctuations and the second during the week leading up to the first river and reservoir freeze-up event of the winter.

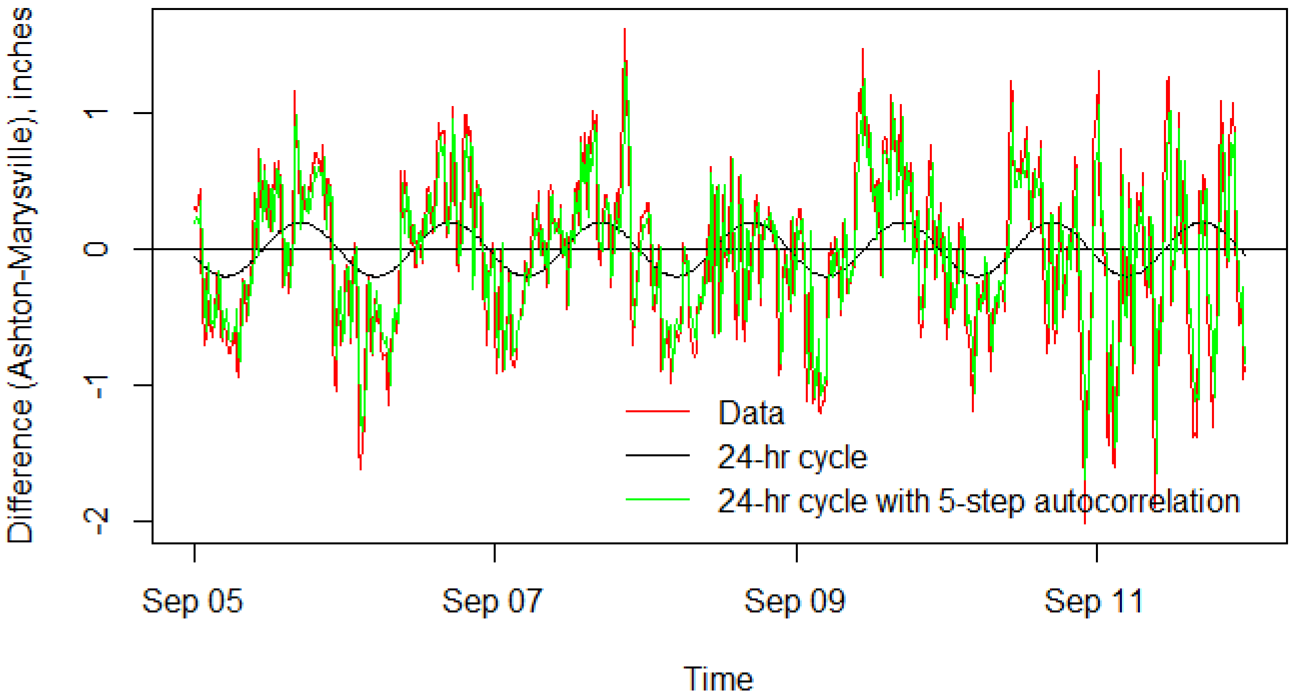

Figure 9. Difference between adjusted stage at USGS Ashton gage and Marysville sonde over the week 5 September – 11 September, 2014, showing raw data, statistically modeled 24-hour cycle, and statistically modeled 24-cycle with 5-step (one-hour, 15-minute) temporal autocorrelation. The 24-hour cycle explained 3.6% of sum-of-squares in differences across the entire 8 July – 12 November period, whereas the model that included both the 24-hour cycle and 5-step autocorrelation explained 71.3% of the sum-of-squares.

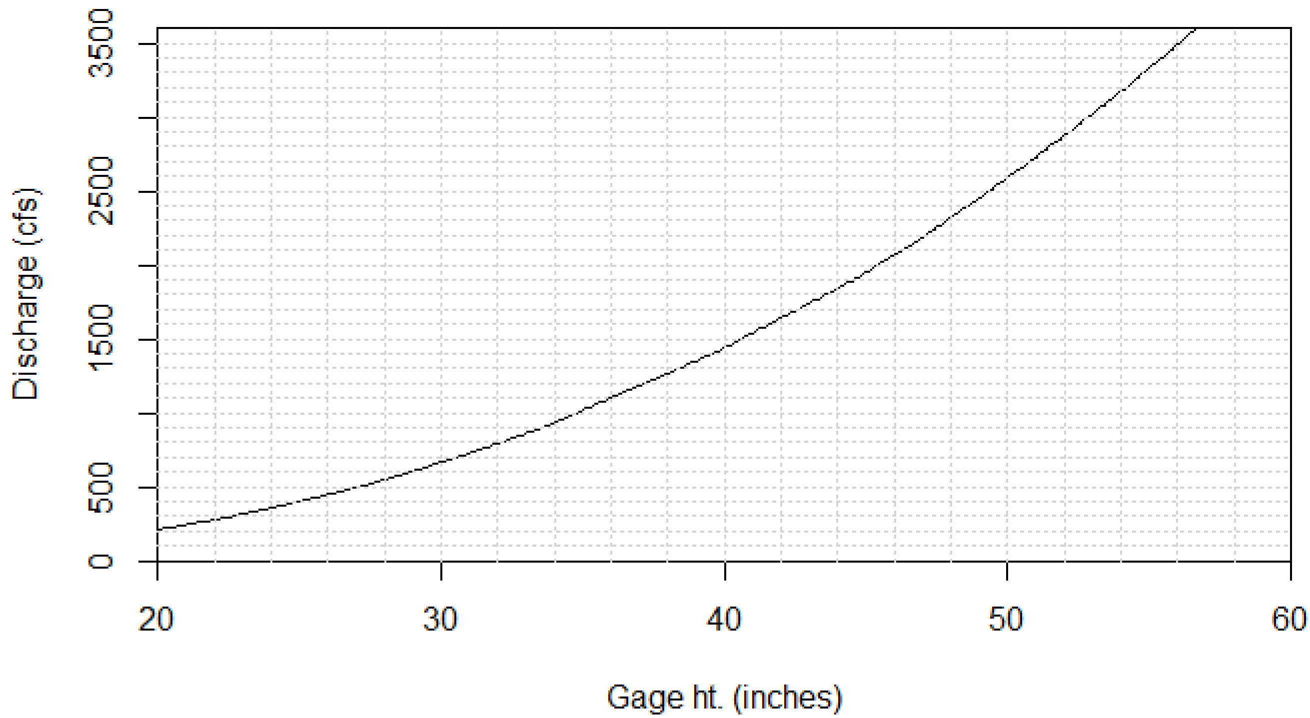

Figure 10. Zero-shift stage-discharge relationship at USGS Ashton gage.

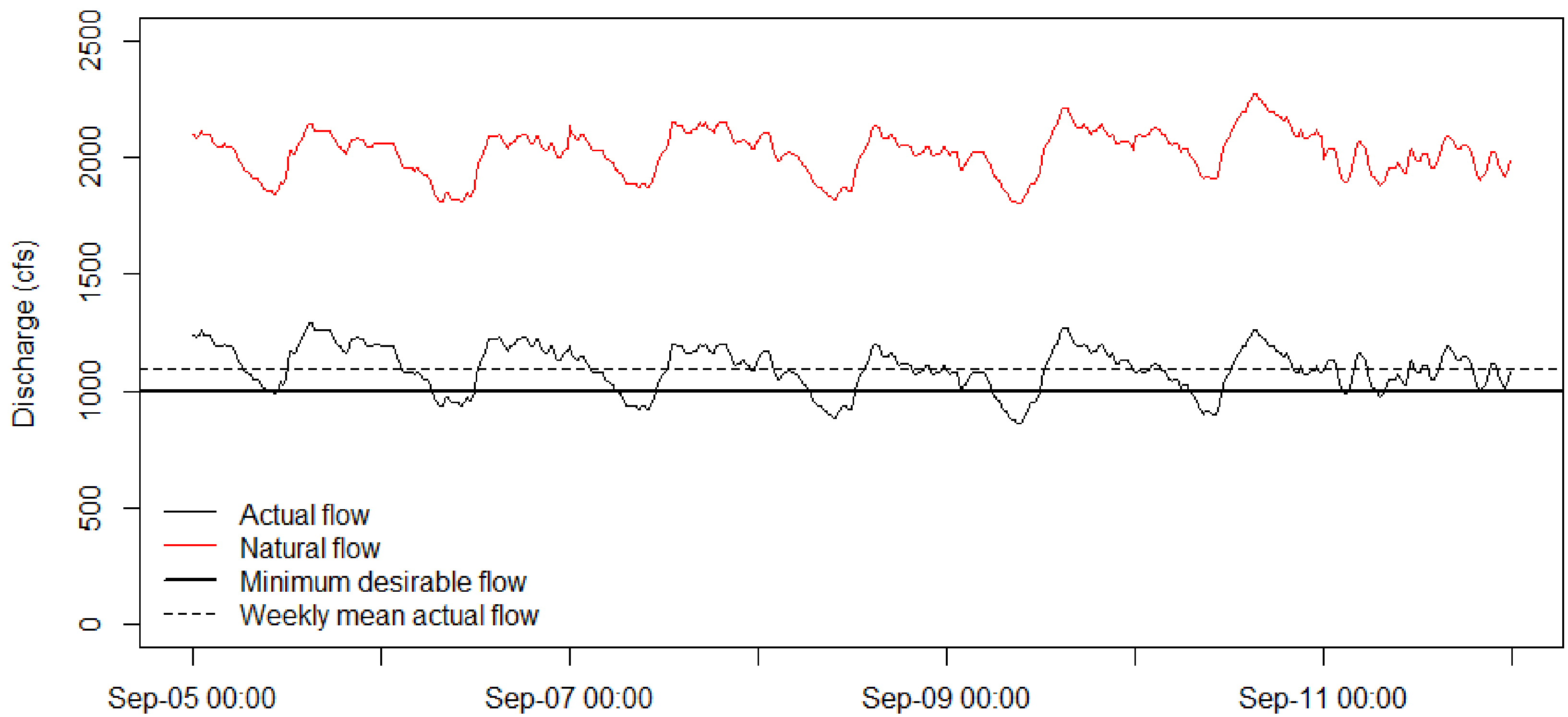

Figure 11. Fifteen-minute discharge record over the period 5Sep-11Sep 2014 at the St. Anthony gage. Natural flow was estimated by adding daily upstream change in storage and upstream diversions to actual flow, under the assumption that the observed daily cycles are "natural." Diversion and storage data were obtained from Idaho Department of Water Resources, Water District 1 water-rights accounting model.