Water and Irrigation Year 2022 Review

Rob Van Kirk, Science and Technology Director
Henry's Fork Foundation (HFF)
January 3, 2023

Summary

1. **Climate**. Peak snow water equivalent (SWE) was 71% of average and 3rd lowest in the 1989-2022 record, but SWE peaked on April 24, 12 days later than average. Temperatures were well below expected values in the spring but set numerous record highs in July, September, and October. For the water year, mean temperature was 1 degree F above average. Water-year total precipitation was 91% of average—much higher than peak SWE—thanks to heavy precipitation in June and again in August. Short-term drought indicators improved modestly over the water year, while medium- and long-term indicators worsened. Most of the watershed ended the water year in "moderate drought," where it started.
2. **Natural flow**. Natural streamflow was 72% of average, ranking as the driest year in the 1978-2022 record. By subwatershed, natural flow was 73% of the 1978-2021 average in upper Henry's Fork, 73% in Fall River, and 70% in Teton River. In the long upper Henry's Fork record, natural flow was 77% of average, ranking 87th out of the last 93 years, just ahead of 2016. April-September natural flow was 69% of the 1978-2021 average, better than my April-1 prediction of 60% of average, due to spring rain. Center-of-mass, a measure of runoff timing, was 6 days later than average due to the cold spring. For the watershed as a whole, natural flow has been above the 1978-2022 average in 8 of the past 23 years, compared with 12 of the 22 years prior.
3. **Irrigation management**. Because of dry conditions across the entire upper Snake River Basin, Fremont-Madison Irrigation District accrued only 64% of its storage right. Due to poor administrative water availability, the cold spring, and low natural flow in mid- to late-summer, diversion during the 2022 irrigation season was 88% of the 2001-2021 average and the lowest since modern record-keeping began in 1978. Basin-wide water demand required release from Island Park Reservoir in excess of what was needed to meet needs within the Henry's Fork watershed. Between August 24 and September 19, about 16,140 ac-ft of water was sent from Henry's Lake and Island Park Reservoir to American Falls.
4. **Island Park Reservoir management**. Winter inflow to Island Park Reservoir was the second lowest in the 1934-2022 record, but the outflow of 220 cfs was higher than that in 14 other years since 1978. Island Park Reservoir filled physically in mid-May, and subsequent runoff events due to heavy rain required commensurate outflow increases to keep the reservoir full until needed to meet irrigation demand. Reservoir draft started on June 28 and ended on September 21—both around 5 days later than average. The reservoir reached its minimum for the year on September 20 at 45% full, compared with 45% full on average and 41% full last year. Over the past five years, a variety of water-management and conservation measures have resulted in an average annual increase in reservoir carryover of 25,000 ac-ft (48%) and in winter outflow from Island Park Dam of 116 cfs (38% improvement through the 2022 winter).

5. **Island Park stream gaging.** HFF made 14 flow measurements during the summer and fall of 2022. Mean absolute error of HFF measurements compared to USGS adjusted flow was 4.9%, the smallest since we started measuring streamflow there in 2019. Thus, our measurements provided accurate real-time estimates of streamflow to river and water users during time periods between USGS measurements.
6. **Accuracy of predictive models.**
   Natural streamflow for April-September was predicted to be 60% of average; actual outcome was 69% of average and well within the statistical prediction interval. Predictive models gave a slightly better than 50% chance that April-September streamflow would be the lowest in the 1978-2021 record; the actual outcome was 4th lowest. Runoff timing was predicted to be average; the actual outcome was 6 days later than average due to the cool spring. Mid-summer outflow from Island Park Reservoir was expected to be similar to that in 2021. That was the outcome for magnitude, but timing of peak outflow was delayed by three weeks in 2022 due to the cool spring. Predicted Island Park Reservoir carryover was 44% full; the actual outcome was 45% full.
7. **Water quality.** Due to cold, wet weather, water temperature was below average from early April through late June. Well above-average water temperatures in late summer and fall did not outweigh the earlier cold temperatures, delaying hatch timing and suppressing aquatic vegetation (macrophtye) growth for the whole summer. The latter resulted in much lower-than-average dissolved oxygen concentrations in river reaches dominated by macrophyte photosynthesis. However, dissolved oxygen was well within suitable ranges for trout in all river reaches all summer. Turbidity at Island Park Dam was above average for all of June and July, and this persisted throughout the Harriman Reach to Pinehaven, as macrophytes were not abundant enough early in the summer to trap suspended sediment. Over the year, net sediment export out of this reach was lower than in 2021 and much lower than in 2017 and 2018, when springtime flows were higher and irrigation-season flows were lower. Sediment data suggest that sediment from the 1992 event likely remains in the reach, but aquatic insects show substantial improvement since then.
8. **Fishing experience**. Our data corroborate angler experience of poor fishing on the Harriman Ranch reach in 2022: low fish population, delayed hatch timing, continuously cold weather in the spring, continuously hot weather in the late summer and fall, low macrophyte abundance, low insect abundance, high streamflow, and high turbidity combined to produce poor fishing. The two key factors affecting fishing experience there are water management and sediment export out of Island Park Reservoir. Collaborative improvements in water management and conservation have quantifiably reduced negative effects of the 2020-2022 drought on fishing experience. More detailed investigation of mechanisms that relate sediment mobilization in Island Park Reservoir to insect abundance will be needed to develop additional management actions to maintain the quality of hatches anglers desire.

Document Guide

Statistical summaries of water year 2022 (October 1, 2021 – September 30, 2022) and irrigation year 2022 (November 1, 2021 – October 31, 2022) are presented and interpreted in eight sections:

As always, data are subject to change upon review and final approval by government agencies and Henry's Fork Foundation (HFF). All primary and calculated statistics in this document are based on data available on and current through December 30, 2022. Most streamflow, climate, and water quality data will not change, but irrigation data will change slightly from what is reported here. Details on data sources, periods of record, and terminology are given in the daily water report glossary and station guide.

Unless otherwise indicated, periods of record for hydrologic comparisons are:

- Climate: water years 1989-2021, except there are no temperature data for 1996
- Streamflow and reservoir volume: water years 1978-2021 (lower Teton River forks 2004-2021)
- Irrigation diversion and related calculations: irrigation years 2001-2021 for averages; 1978-2022 for ranks
- Water quality: irrigation years 2014-2021 at Flatrock, Island Park Dam, Pinehaven, and Marysville; irrigation years 2015-2021 at Ashton Dam and St. Anthony

Statistics are compared with the period-of-record averages through 2021, so that the average is not influenced by the current year. Rank statistics include the current year in the record and are ordered from highest to lowest. For example, natural flow for water year 2022 is compared with the 1978-2021 average, and the rank is reported out of the full 1978-2022 record. Note that 75% *of* average is equivalent to 25% *below* average. A rank of 41/45 indicates the 5th *lowest* value in the 45-year record, whereas a rank if 5/45 indicates the 5th *highest* value.

Tables appear interspersed with text in the appropriate sections, although information in some tables is referenced in more than one section. All figures appear at the end of the document.

1. Climate

Water year 2022 was characterized by a cold wet spring, a hot summer and fall, and what is known as a "snow drought," which is a water year with very little snowpack but otherwise relatively good total precipitation.

Snowpack

After a promising start to the snow accumulation season, an extended dry period lasting from early January until early April led to well below average snowpack in 2022. Snow water equivalent (SWE) was 10% above average on January 7 but had dropped to 35% below average by April 10—second lowest only to 2001 at that point in the spring. However, a cold, wet weather pattern set up for the remainder of the spring, providing at least a little recovery. Peak SWE turned out to be 71% of average, third lowest in the 1989-2022 record behind 2001 and 2015 (Figure 1). More importantly, cold temperatures preserved the snowpack well into the spring. SWE reached its annual maximum on April 24, 12 days later than average (Table 1).

Table 1. Climate statistics. Ranks for SWE, precipitation and temperature are ordered from highest to lowest (1 = highest on record). Temperature statistics apply to all 12 stations in the watershed. Ranks for date of peak SWE are ordered chronologically (1 = earliest).

	Water year 2022		Water year 2021		1989-2021
	Value	1989-2022 rank	Value	1989-2022 rank	Average
Peak SWE (inches)	20.1	32/34	22.2	26/34	28.2
Date of peak SWE	April 24	28/34	March 26	4/34	April 12
Total precipitation (inches)	32.9	21/34	29.5	29/34	36.0
April-June temperature (°F)	42.2	26/33	47.3	6/33	44.5
July-Sept temperature (°F)	60.9	1/33	58.6	8/33	57.4

*Temperature records for 1996 are not available, so temperature ranks are relative to a 33-year record.

Temperature

Mean April-June temperature in the snow-accumulating areas of the watershed—roughly 6,000 feet in elevation and above—is a strong predictor of snowmelt timing. This important climatic characteristic has been increasing at a rate of a little over 1 degree F per decade for the last 40 years. This year's value was 40.5 degrees, far below the value of 44.5 degrees expected based on that trend, and one that was so far below the trend that it had less than a 5% chance of occurring—hence the late date of peak SWE (Figure 2). The last spring this cold was in 2011, which seems like a long time ago, especially because springtime temperatures in many recent years—notably 2015, 2016, 2017, 2018, and 2021—were 3-6 degrees warmer than what we experienced this year. However, in the big picture, this year's springtime temperature was only 0.5 degrees below the 1989-2022 average and ranked 13th coldest in that record. Nine of the 12 years with colder springtime temperatures occurred between 1989 and 1999, illustrating that even a seemingly cold spring by today's standards was warmer than the average year in the 1990s.

The cold weather pattern broke at the end of June, and temperatures quickly exceeded average for most of the rest of the summer (Figure 3). Mean July-September temperature was the warmest in the 1989-2022 record, and new record high daily mean and daily maximum temperatures were set on numerous different days in July, August, September and October. Figures for October are not reflected in water-year 2022 statistics but affected water quality, which we report on an irrigation-year basis. These records were set not only in the short 1989-2022 record I use for this report but in very long records all over eastern Idaho. Record highs were set on numerous days within a 10-day period in late August and early September. The month of September was over 4 degrees warmer than average and the warmest on record. For the water year as a whole, warm temperatures this summer—along with warm temperatures last fall—more than outweighed the cold spring; mean temperature for the water year was 1 degree above average.

Precipitation

Precipitation for the water year turned out to be much better than the SWE figures would indicate, thanks to heavy rain in the spring and summer (Figure 4). Precipitation in April and May was just a little above average, and that in June was well above average. Springtime precipitation greatly favored the northern part of the watershed, which had received less precipitation than other areas in 2020 and 2021. Areas along the Continental Divide received 3 inches or better in the mid-June storm that caused catastrophic flooding a little farther north and east in the Yellowstone River drainage.

After what turned out to be the driest July in the 1989-2022 record, the August monsoon season was relatively wet. Precipitation was above average in August and locally heavy. Most notably, the Ashton area received 2-3 inches in less than two hours on August 13, setting a new one-day precipitation record. Heavy showers fell in Ashton on several different days during August and September, making Ashton the only of the 12 stations in the watershed to receive above-average precipitation for the water year. Ashton's precipitation came in at 106% of average for the water year as a whole, while that only 25 miles away in Rexburg was 78% of average. Precipitation for the watershed as a whole ended the water year at 91% of average: 88% in the valley areas, 90% in the Teton headwaters, 92% in the upper Henry's Fork, and 94% in Fall River.

Drought status

The short-term drought indicator I use improved somewhat over the water year, primarily due to the cool, wet spring. The one-year cumulative moisture availability in the lower-elevation areas of the watershed (precipitation minus evapotranspiration) is a useful surrogate for long-term soil moisture conditions and also relevant as a measure of irrigation need (Figure 5). This index started water year 2022 at over 6 inches below average, following the very dry, warm summer of 2021. Cool, wet weather in the spring reduced that deficit to around 1.5 inches below average due to both lower evapotranspiration and higher precipitation. Following the hot, dry weather at the end of August and early September, the moisture availability index ended up at 2 inches below average—still indicative of drought but much better than it was a year ago.

The medium-term drought indicator I use is the 3-year rolling average of watershed-wide precipitation (Figure 6). I use three years because that is roughly the response time of the deep Yellowstone Plateau aquifers in the upper Henry's Fork headwater areas to precipitation and because it is the generation time of most trout populations in the watershed. That index has been in steep decline for the past three years, falling from 18% above average to 12% below average since October 1, 2019—a net drop of 11 inches. Heavy snow in December temporarily moved this index back up to average, but it quickly fell to about where it ended the water year by April. Because rain in June and August was fairly localized, neither of those wet periods had much of an effect on the 3-year average over the whole watershed.

These two specific measures of drought I use coincide well with continental-scale drought indices calculated by a partnership of federal agencies and updated weekly at https://droughtmonitor.unl.edu/. In October 2021, the central portion of the Henry's Fork watershed was classified in an area of "moderate drought" but surrounded by areas of "severe" to "extreme" drought to the west, north, and east that spilled over into the watershed. In October 2022, all but the eastern edge of the watershed was in moderate drought, but surrounding areas to our west and north have been downgraded from severe or extreme drought, indicating overall improvement. However, most of the northwest—including the entire upper Snake River was drought-free on October 1, 2019, consistent with the steady decline in 3-year average precipitation observed here.

2. Natural Flow

Long-term drought is best measured by natural streamflow, since it integrates effects of climate on the whole watershed over years to decades. Watershed-wide natural streamflow was 72% of the 1978-2021 average in water year 2022: 73% of average in upper Henry's Fork, 73% in Fall River, and 70% in Teton River (Table 2). The watershed total ranked as the driest in the 45-year 1978-2022 record, behind 2001 at 74% of average and 2016 at 75% of average (Table 3, Figure 7). In the longer 93-year record of natural watershed inflow between Henry's Lake and Ashton, water year 2022 came in at 77% of average, ranking 87th, ahead of 2016 by a fraction of one percent (Figure 8). The other five years with natural flow lower than this year occurred back in the 1930s.

Table 2. April 1 – September 30 natural flow statistics, including predictions made on April 1 and primary inputs to predictive model.

	Predictors (% of ave.)		Mean April 1 – September 30 natural flow					
			2022 prediction		2022 observed		2021 observed	
Subwatershed	Baseflow	Apr-1 SWE	cfs	% of ave.	cfs	% of ave.	cfs	% of ave.
Upper Henry's Fork	78%	66%	1,195	64%	1,290	69%	1,272	68%
Fall River	82%	62%	811	59%	483	70%	963	70%
Teton River	81%	67%	676	56%	400	67%	798	67%
WATERSHED TOTAL	**80%**	**66%**	**2,682**	**60%**	**3,051**	**69%**	**3,032**	**68%**

Table 3. Water-year natural flow statistics over the 1978-2022 period of record. The current year (2022) is not included in the averages but is included in ranks. The ranks are from largest to smallest (1 = wettest on record; 45 = driest on record).

	Water year 2022		Water year 2021		1978-2021
	Mean natural flow (cfs)	1978-2022 rank	Mean natural flow (cfs)	1978-2022 rank	Average annual natural flow (cfs)
Upper Henry's Fork	1,144	44/45	1,236	42/45	1,580
Fall River	704	42/45	733	39/45	968
Teton River	575	43/45	593	39/45	828
Watershed total	2,423	45/45	2,563	41/45	3,376

The water year started out poor as a result of very dry conditions during the summer and fall of 2022. Winter (October-March) natural flow was the lowest in the 1978-2022 record, at 79% of average (Figure 9). Because about half of the watershed's winter base flow comes from the groundwater-fed upper Henry's Fork, the low watershed-wide figure was driven primarily by the upper Henry's Fork, where winter flow was 79% of average and second lowest in the 1978-2021 record, ahead of 2016. Based on well below average snowpack in early April and on poor winter base flow, April-September natural flow was predicted to be only 60% of average and in a dead heat with 2001 for the lowest in the 1978-2022 record. However, above-average precipitation in May, June and August improved streamflow somewhat, and April-September natural flow came in at 69% of average, ranking 4th driest, ahead of 2001, 1992, and 2021.

The wet spring brought a modest improvement in drought conditions over the course of the water year, but it was not enough to keep water year 2022 from ranking as the driest overall in the last 45 years. In the context of long-term drought, natural flow has been above average in 8 of the past 23 years, compared with 12 in the previous 22 years. Looked at in terms of ranks, the median year (1980) divides the last 45 years into two 22-year periods—one with natural flow greater than that observed in 1980 and one with natural flow lower. Fourteen of the 22 years in the "dry" half have occurred since 2000, indicating persistence of dry conditions for the better part of the last two decades.

While the spring rains had only a modest effect on streamflow—mostly turning an extremely bad outlook for the summer into just a very bad one—cool temperatures had a much greater positive effect on summertime water supply. The center of mass of spring/summer natural streamflow—a measure of timing of streamflow--occurred 6 days later than the 1978-2021 average, 7 days later than it did last year, and 10 days later that in 2016 (Table 4). This delayed runoff made a meager snowpack last much longer into the summer than in other recent years with similar water supply. This had a substantial positive effect on need for reservoir storage to meet irrigation demand this year.

Table 4. Observed and predicted center-of-mass of April-September streamflow. Center-of-mass is a measure of the distribution of streamflow timing and is useful as an indicator of timing of snowmelt runoff.

Subwatershed	2022 prediction	2022 observation	2021 observation	1978-2021 mean
Upper Henry's Fork	June 24	June 22	June 23	June 21
Fall River	June 11	June 19	June 12	June 16
Teton River	June 12	June 21	June 14	June 17
WATERSHED TOTAL	June 18	June 24	June 17	June 18

3. Irrigation Management

While natural streamflow clearly reflected long-term hydrologic conditions and short-term precipitation and temperatures, patterns in irrigation demand and management in 2022 largely reflected poor water supply across the whole upper Snake River basin, with secondary dependence on water supply and weather within the Henry's Fork watershed.

Administrative water availability

The 1935- and 1936-priority storage rights in Island Park Reservoir and Grassy Lake, which belong solely to Fremont-Madison Irrigation District (FMID), did not accrue any water during irrigation year 2022, leaving FMID with 64% of its storage right. This was a consequence of low priority of FMID's storage rights within basin-wide administration, low upper Snake River reservoir carryover from 2021, and poor water supply across the basin. Irrigators within FMID knew ahead of irrigation season that storage would be limited, so they made crop choices and management decisions appropriate to the water supply. Those decisions put irrigation demand in the Henry's Fork watershed on a trajectory for low diversion from the beginning of the spring. In addition, the cold wet spring delayed need for irrigation; peak diversion in 2022 occurred on July 14, compared with July 9 on average and June 30 in 2021. The wet spring also maintained natural-flow priority near average until early July, much better than would have happened without the spring rains (Figure 10). Natural-flow rights in the Henry's Fork first dropped to 11/5/1895 priority on July 11, vs. July 15 on average and June 23 in 2021. This priority date is a good indicator of administrative water availability in the Henry's Fork watershed, as many large canals on the Henry's Fork and lower Fall River have priority dates on or slightly earlier than 11/5/1895. Natural-flow rights remained poor until late September, except for a few days in early August when widespread rain fell across the whole basin.

Irrigation diversion

The combination of low storage availability, cool wet weather in the spring, and poor natural-flow rights in the middle of the summer resulted in very low diversion during water year 2022. Based on preliminary numbers, total diversion was the lowest on record, at only 88% of the 2001-2021 average (Table 5). Daily diversion in 2022 was above-average for a day or two in mid-July and again during a period of record high temperatures and low precipitation in October (Figure 11). Even though physical water supply was low at that time, many canals elsewhere in the basin had already shut down operations for the season by then, allowing some more junior natural-flow users to divert water during the early fall.

Diversion during 2022 added yet one more data point in the long-term trend in diversion that has resulted from increased use of sprinkler irrigation vs. historic flood, furrow and border-ditch irrigation. Diversion decreased steadily during the 1980s and 1990s, the period of most rapid conversion in irrigation methods, dropped abruptly during the very dry year of 2001, and has stayed relatively constant since then (Figure 12). Although increased irrigation efficiency has reduced total annual diversion by about 240,000 ac-ft since the late 1970s, it has also reduced return flows to the river by about the same amount. These return flows are called "[river] reach gains" and travel primarily through shallow aquifers, which cool water temperature and act as a short-term storage mechanism. Given that diversion in 2022 was the lowest in the 1978-2022 record, it is not a surprise that reach gain was also among the lowest on record, ranking 39th out of 45 years (Figure 13). Total reach gain to the lower Teton River and Henry's Fork in 2022 was negative, meaning that over the irrigation year as a whole, the net movement of water between the river and the aquifer was away from the river and into the aquifer.

Teton River administration

Streamflow shortage in the Henry's Fork watershed during years of low snowpack is greatest in the Teton River, which necessitates greater need for augmentation of streamflow there to meet demand. Augmentation is supplied by two sources: 1) delivery of water diverted from the Henry's Fork to the Teton River through the Crosscut Canal and 2) water injected into the Teton River from so-called "exchange wells." These wells pump groundwater into the river and were drilled following the Teton Dam failure as a mechanism by which to offset pumping from the river by irrigators along the rim of Teton Canyon. These irrigators held storage rights in Teton Reservoir and would have pumped this water directly from the reservoir. In most years, the administrative aspect of this diversion can be met with FMID storage and other sources such as Palisades storage and rental water. The physical water is provided by Crosscut Canal injection as needed. In dry years such as 2021 and 2022, the exchange wells provide a mechanism for both administrative and physical delivery of water to the Teton River.

Table 5. Irrigation-year statistics. Coefficient of variation is defined as standard deviation divided by mean. Ranks are defined from highest to lowest (1 = highest in the record).

	Irrigation year 2022		Irrigation year 2021		2001-2021
	Value	Rank	Value	Rank	Average
Total diversion (ac-ft)	792,097	45/45	836,872	43/45	903,493
Crosscut Canal diversion to Teton (ac-ft)[1]	28,324	33/35	34,595	26/35	39,787
Teton exchange well injection (ac-ft)	26,296	10/45	27,314	8/45	14,291
Lower-watershed river reach gain (ac-ft)	-4,050	39/45	10,643	41/45	20,026
HF at St. Anthony summer flow (cfs)[2]	1,111	31/45	990	40/45	1,320
HF at St. A. flow coefficient of variation[2]	12%	38/45	12%	37/45	20%
HF at Parker summer flow (cfs)[2]	561	26/45	429	37/45	733
HF at Parker coefficient of variation[2]	42%	26/45	35%	34/45	41%
SF Teton River summer flow (cfs)[3]	114	12/19	114	13/19	195
SF Teton coefficient of variation[3]	100%	13/19	128%	6/19	113%

1. Water-rights accounting data for Crosscut to Teton diversion has 1988-2022 period of record.
2. 2022 values include water sent to American Falls above what was needed within the HF watershed.

South Fork Teton River gage has 2004-2022 period of record.

The total amount of injection into the Teton River was lower in 2022 than in 2021, reflecting overall lower diversion rates in 2022. Because exchange pumping is used only during dry years, it is not surprising that both 2021 and 2022 ranked among the highest years of exchange-well pumping. In both years, Crosscut Canal diversion was lower than average, in part because exchange pumping offset some of the need for Crosscut delivery and in part because overall diversion is lower during years of lower natural-flow availability.

Lower watershed streamflow

In most years the Henry's Fork irrigation system can be managed to meet physical demand only within the watershed, subject of course to the basin-wide administrative constraints mentioned above. In this case, the amount of water added to the lower-watershed irrigation system from the exchange wells and the watershed's three storage reservoirs (Grassy Lake, Henry's Lake, and Island Park Reservoir) must meet within-watershed diversion and leave enough in the river to provide adequate river stage ("depth") at the lowest points of diversion and maintain basic aquatic ecosystem function in the lower Henry's Fork. Surface water can leave the Henry's Fork irrigation system through three pathways: the South Fork Teton River, North Fork Teton River, and mainstem Henry's Fork. Higher streamflow in any one of these stream channels increases the amount available locally for aquatic ecosystem function but comes at the costs of higher exchange well pumping and higher draft of the reservoir system. The latter, in turn, has negative consequences for fisheries and aquatic ecosystem function upstream of, in, and immediately downstream of Island Park Reservoir. On the other hand, too little streamflow at the bottom of the irrigation system can lead to lower fish habitat and a shortage of water available for the downstream-most diversions, which are Rexburg Irrigation on the South Fork Teton, Teton Island Feeder on the North Fork Teton, and Consolidated Farmers on the Henry's Fork.

The general management strategy to balance these factors within administrative constraints is to:

- set flow in the North Fork Teton to 0 downstream of Teton Island Feeder when administrative storage is being used,
- maintain flow in the South Fork Teton just high enough to absorb daily fluctuation in diversion at Rexburg Irrigation (~50-150 cfs),
- fix a streamflow target flow in the lower Henry's Fork,
- minimize flow variability in the South Fork Teton and lower Henry's Fork.

The first of these components ensures that only the amount of water needed by the Teton Island Feeder water users is delivered to the North Fork Teton during the period when storage is being used. Any water in excess of this amount is charged to storage users, even if they can't or don't divert it all. There are several small diversions on the lower North Fork Teton, but they are entitled to only natural flow that emerges as groundwater inputs and return flows to the river downstream of Teton Island Feeder. Once the North Fork Teton constraint applies, a set of headgates at the North Fork-South Fork split (called the "splitter) is operated to send the appropriate amount of water down the North Fork, with the remainder flowing down the South Fork.

The total flow reaching the splitter is controlled by how much Henry's Fork water is diverted and delivered through the Crosscut Canal. On the Henry's Fork, water is delivered from the reservoir system to meet the Crosscut Canal need and meet diversion on the Henry's Fork downstream of the Crosscut plus the lower-Henry's Fork streamflow target. In previous years, that target was set at the St. Anthony streamflow gage and was usually around 1,000 cfs. However, that target does not consider variability in diversion downstream of St. Anthony and generally resulted in very low flows downstream of Consolidated Farmers Canal in July, higher releases than necessary from Island Park Reservoir later in the season, and generally higher variation in streamflow all summer. To remedy these shortcomings, the Henry's Fork Drought Management Planning Committee set the target at 350 cfs immediately downstream of the Consolidated Farmers diversion in 2020 and 2021. This flow is calculated by subtracting diversion from the four canals downstream of St. Anthony from flow at the St. Anthony gage and nominally represents the flow in the river at the Parker-Salem Highway (aka Red Road) bridge. In 2020, this new "Parker" target saved over 1,200 ac-ft in Island Park, while lowering variability.

Implementing this strategy is much easier said than done, given daily changes in diversion at over 100 pumps and canals in the watershed, stream and canal losses to and gains from groundwater, and streamflow travel times of around 20 hours from Island Park Reservoir to the Crosscut Canal diversion (Chester Dam), several more hours to reach the Teton River, and another hour or two to pass the splitter and reach the Rexburg Irrigation and Teton Island Feeder diversions. Fortunately, remote-controlled headgates at the Crosscut diversion and splitter installed in 2020 now allow FMID managers to make small adjustments at any time of day, saving water and reducing travel and time costs. New stream and canal gages and calculations provide real-time data to inform operation of the new remote-controlled headgates.

In some years physical water from the Henry's Fork watershed must be delivered to meet demand farther down on the Snake River (when physical water stored in Island Park belongs to American Falls Reservoir on paper), and 2022 turned out to be one of those years. Outflow from Island Park Reservoir was increased on August 24 above that needed to meet within-watershed needs as specified in the management strategy above and maintained at that level until September 19, two days prior to the end of reservoir draft. Streamflow at Parker during the complete period of Island Park Reservoir draft averaged 561 cfs, while streamflow during the period of reservoir draft but outside of the August 24-September 19 window averaged 466 cfs (Figure 14). The 2018-2021 average is 462 cfs, so within-watershed management in 2022 was consistent with that implemented over the past five years. Streamflow at Parker during the August 24-September 19 window averaged 780 cfs, and the difference between that and 466 cfs equates to about 16,140 ac-ft of water sent from the Henry's Lake and Island Park Reservoir to American Falls.

Even with that, streamflow at Parker and St. Anthony during the period of reservoir draft in 2022 was lower than the 2001-2022 average, saving water in Island Park Reservoir. Further, despite the additional variability in flow associated with this 26-day period of higher streamflow, coefficient of variation in streamflow at Parker in 2022 was only slightly higher than average. Streamflow in the South Fork Teton River at Rexburg was the same as it was in 2021 but with lower variability. These observations show that more precise management of the Henry's Fork irrigation system saves water in Island Park Reservoir and reduces day-to-day variability in lower-watershed streamflow even in years when additional water must be sent out of the watershed to meet basin-wide needs.

4. Island Park Reservoir Management

Keeping as much water in Island Park Reservoir has multiple benefits for irrigation, hydropower, water quality, and fisheries and so is the highest water-management priority in the watershed, subject to meeting irrigation demand.

Winter outflow from the reservoir is the single biggest variable determining survival of juvenile Rainbow Trout in the Box Canyon reach of the river. Statistically, survival of juvenile trout to age 2—when they join the fishable population—is determined by mean December-February flow through Box Canyon, which is the sum of outflow from Island Park Reservoir and natural flow in the Buffalo River (Figure 15). Since the latter is unregulated, outflow from the dam is the only component that can be managed. There is no scientific evidence that low streamflow during the fall has a negative effect on trout populations, as warmer temperatures and aquatic vegetation provide good fish habitat in the fall. In addition to benefits to the fishery, higher winter outflow benefits hydroelectric production, since power is worth more in the winter than earlier in the fall. Thus, both fisheries and power production benefit from setting outflows lower in the fall so they can be increased in the winter and still achieve reservoir fill prior to irrigation season.

Winter outflow

Inflow to the reservoir is a major component of management, and it was well below average in water year 2022, particularly during the winter. In fact, total October-March watershed inflow between Henry's Lake and Island Park—essentially the water available to fill Island Park Reservoir—was second lowest since the Island Park stream gage was first installed in 1934 (Figure 16). The only water year with lower fall/winter natural flow was 1935. As a result, total inflow to Island Park Reservoir was average during 2022 only for a few days during late October, when outflow from Henry's Lake was still contributing and rain added some water directly onto the reservoir surface (Figure 17).

Because of below-average winter precipitation, reservoir gain from direct precipitation on the reservoir surface was around 6,000 ac-ft, a little below the long-term average (Figure 18). However, heavy rain in the spring added over 2,000 ac-ft, and net gain from precipitation (less evaporation) over the water year ended up at 7,000 ac-ft, about 1,000 ac-ft greater than average. Although typical net gain from precipitation on the reservoir surface is only 5% of total reservoir capacity, direct precipitation allows slightly higher outflow during the winter than if reservoir fill were dependent on stream inflow alone. During the winter of water year 2022 (December 1, 2021-February 28, 2022), direct precipitation added an average of 26 cfs to reservoir inflow. The contribution of direct precipitation depends on reservoir surface area, which is greater when reservoir volume is greater, one reason to fill the reservoir as much as possible prior to the high-precipitation months of December-February.

Winter outflow from Island Park Dam averaged 220 cfs (Table 6), ranking 31st out of the 45 years in the "modern" management period (1978-present), compared to 370 cfs in the winter of 2021 (Figure 19). The lower value in 2022 was due both to lower physical reservoir carryover (minimum reservoir volume at the end of irrigation season) in 2021 and to near record-low reservoir inflow during the 2021-2022 winter. The 1978-2021 average winter outflow is 360 cfs.

Table 6. Island Park Reservoir statistics. Flow and volume statistics are ranked from highest to lowest (1 = highest flow or highest reservoir volume). Date statistics are ranked from earliest to latest.

	Water year 2022		Water year 2021		1978-2021
	Value	1978-2022 rank	Value	1978-2022 Rank	Average
Dec-Feb. IP outflow (cfs)*	220	31/45	370	21/45	360
Start of reservoir draft	June 28	25/45	June 10	11/45	June 23
End of reservoir draft	Sept. 21	36/45	Sept. 18	33/44	Sept. 15
Min. volume (ac-ft, % full)	60,791 (45%)	22/45	55,860 (41%)	25/45	60,184 (45%)
Sept. 30 vol. (ac-ft, % full)	60,948 (45%)	23/45	60,462 (45%)	24/45	62,936 (47%)

*This is "winter" flow out of Island Park Dam for the winter at the beginning of the water year and so primarily reflects conditions at the end of the previous irrigation season. For example, winter flow for water year 2022 is the mean for December 1, 2021 through February 28, 2022, reflecting summer 2021 conditions.

Fill and springtime management

Due to cool springtime temperatures, ice cover remained on the reservoir until early May. The peak of snowmelt upstream of the reservoir occurred a little earlier than ice-off, requiring a brief outflow increase to prevent ice interference with spillway infrastructure prior to ice-off. Outflow

was quickly reduced once ice melted and maintained at around 250 cfs until the reservoir filled in mid-May (Figure 20). The reservoir was then held constant until draft was needed to meet irrigation demand downstream. This required that outflow matched inflow between mid-May and mid-June.
In particular, two rapid increases in outflow—both from around 400 cfs to 1200 cfs—were required during the two biggest rain events to keep the reservoir constant. These increases were followed closely by rapid and large decreases. Although these large fluctuations in flow were not desirable from a fishing standpoint, they reflected natural precipitation-driven watershed runoff events. Regulated vs. natural flow at Island Park (Figure 21) shows that outflow peaks during the spring very closely matched the river's natural flow. In other words, even in absence of regulation at Island Park and Henry's Lake dams, the river's flow would have been essentially the same during this time period as we experienced. Because Island Park Dam is not authorized or used for flood control, and given the numerous reasons to keep it as full as possible year-round, the objectives of springtime reservoir management are to fill it as far ahead of potential irrigation need as possible and pass natural runoff events through the reservoir after that.

Although Island Park Reservoir would have physically filled by the end of May even without rain, the other two reservoirs in the watershed probably would not have filled. Based on April-1 conditions, Grassy Lake had nearly no chance of filling, and there was a pretty good probability that Henry's Lake would also not have filled. May and June rain, which was concentrated in the northern half of the watershed where those two reservoirs are located, filled both of them before reservoir draft was needed to meet irrigation demand (Figure 22). After spending the entire winter well below average, inflow to Henry's Lake during June was above average, in part because of rain and in part because of late snowmelt. As mentioned in the climate section, spring and summer rain in 2022 slightly improved drought in the short term, and the Henry's Lake basin and adjacent areas of the northern end of the watershed showed the greatest improvement during the water year (Figure 23).

Irrigation-season management

Because of the cool, wet spring, reservoir draft began on June 28, five days later than average and 18 days later than in 2021. Reservoir draft ended on September 21, six days later than average. Thus, the period of reservoir draft was average, but the entire period of draft was shifted 5-6 days later than average. Reservoir draft was again very well predicted by my "600-cfs rule," which is based on the observation that reservoir draft is generally needed to meet irrigation demand when natural-flow supply drops to within 600 cfs of total diversion (Figure 24). By that rule, reservoir draft would not have been needed for a day or two in August following widespread rain, but irrigation-system adjustments are not logistically feasible on such short time scales in the middle of the summer. Peak reservoir outflow occurred from July 7 to July 26; mean flow over that time period was 1351 cfs, compared with 1168 cfs on average.

As discussed in detail above, basin-wide needs required additional draft of Island Park Reservoir from August 24 to September 19 to send water to American Falls Reservoir. Of the 16,140 ac-ft sent out of the Henry's Fork watershed, roughly 6,000 was provided by additional draft of Henry's Lake (Figure 25), while the remainder came from Island Park Reservoir.

Despite the additional draft, minimum reservoir volume was 45% full, on September 20, compared with 41% full in 2021 and 45% full on average. Usually, a little reservoir fill is achieved in late September by lowering outflow. In 2021, late-September fill increased reservoir volume to 45% full by the end of the water year. Average September fill is around 2800 ac-ft, which results in a reservoir level of 47% full to begin the new water year. This year, hot dry weather persisted through most of the month of September and into October, allowing only a small amount of fill between the end date of reservoir draft and the end of the water year. The reservoir ended the water year at 45% full.

Physical reservoir carryover and winter flow statistics

To interpret the effectiveness of water conservation and management programs implemented by FMID, HFF and other partners over the past few years, physical reservoir carryover must be considered relative to the major variables that determine it. Statistically, the three most important predictors, in order of importance, are natural flow (positive effect), streamflow in the lower Henry's Fork (negative effect), and total diversion (negative effect). Together these three variables explain 85% of the year-to-year variability in carryover. Implementation of current water-management programs—including wide distribution and use of the information in my daily reports—first started in water year 2018. Additional research, monitoring, strategies, and irrigation infrastructure were added in subsequent years.

To objectively assess the effects of these programs, I fit a statistical model of physical reservoir carryover in Island Park to 1978-2017 data and then compared outcomes in 2018-2022 to those expected based on that statistical model. This approach essentially asks the question, "What would reservoir carryover and subsequent winter flow have looked like under 1978-2017 management, given the water years we have experienced since then?" Over the past five years, reservoir carryover has averaged nearly 25,000 ac-ft greater than expected, amounting to an average 48% increase in carryover (Table 7).

Table 7. End-of-season minimum volume in Island Park Reservoir ("carryover"), and outflow during the subsequent winter, relative to expected values based on water supply and other predictors. Expected values are calculated from statistical relationships observed prior to water year 2018, when precision water management was first implemented in the watershed. Winter outflow in 2022 was estimated based on December 1 reservoir content and inflow.

	Physical end-of-season carryover (ac-ft)			Subsequent winter outflow (cfs)		
Water year	Observed	Expected	Difference	Observed	Expected	Difference
2018	97,963	85,701	12,262	560	405	155
2019	98,323	73,223	25,100	532	361	171
2020	73,581	56,459	17,122	370	308	62
2021	55,860	29,106	26,754	220	144	76
2022	60,791	16,545	44,247	200	103	97
2018-2022 average	77,304	52,319	25,097	376	264	112
1978-2017 average	58,059			356		

Keep in mind that the expectation has already accounted for the effects of streamflow in the lower Henry's Fork. So, higher reservoir carryover is not simply a function of reducing lower-Henry's Fork streamflow. Because of the need to send water to American Falls this year, streamflow in the lower Henry's Fork during the period of reservoir draft was greater than it has been since 2014. Nonetheless, reservoir carryover this year beat expectations by 43,590 ac-ft, 2.5 times the expected value of 17,200 ac-ft. This indicates that improved carryover in Island Park is due to a variety of water-management and conservation practices across the whole watershed.

Increased reservoir carryover results in increased winter outflow, all other factors being equal. Winter flow from 2019 to 2022 (following water years 2018 through 2021) beat expectations every year and averaged 116 cfs (38%) higher than expected over the four years. That increase in winter flow is worth around 580 additional age-2 rainbow trout added in the Box Canyon population, roughly an 18% increase in the trout population.

Inflow to Island Park Reservoir is the single largest factor other than reservoir carryover that determines winter outflow. Thus, achieving near-average carryover in what turned out to be the driest water year in the 1978-2022 record will not be enough to guarantee average winter flow during the upcoming winter. Although conditions in the upper Henry's Fork subwatershed have improved a little over the past water year, inflow to Island Park Reservoir over the upcoming winter is forecast to be the 5th lowest in the 90-year record, behind 1935, 2022, 2016, and 2004 (Figure 26). As a result, expected winter flow based on 1978-2017 data is 99 cfs. Given very similar reservoir carryover as last year and slightly better watershed conditions, forecast winter flow this year is essentially the same as last year's, around 200 cfs. If that forecast holds up, the average improvement in winter flow over the past five years will stay around 115 cfs, but the percent improvement will increase to 42% as a result of beating the upcoming winter's expectation by over a factor of two.

5. Island Park Stream Gaging

For the fourth consecutive year, HFF measured streamflow in the Henry's Fork at Island Park weekly during the summer and fall, when the relationship between river depth and streamflow ("stage-discharge" or "gage rating") changes most rapidly ("shifts") due to growth and decay of aquatic vegetation (called "macrophytes"). As vegetation grows during early summer, it displaces water, leading to higher depth at a given flow. The opposite happens in late summer and fall. The U.S. Geological Survey (USGS) measures streamflow to update the rating curve every 2-10 weeks, depending on season of the year, but during periods of rapid shift, the actual streamflow indicated on the real-time USGS gage can be much higher or lower than the actual flow by the time several weeks have passed since the last adjustment. We use our weekly measurements to calculate an approximate rating shift in between the official USGS adjustments so that water managers and river users can have more accurate flow data on a day-to-day basis. In 2019, we were just learning how to use the Acoustic Doppler Current Profiler (ADCP) unit FMID has loaned us for this purpose. Not only were we learning how to use the unit and its software, but we were also learning how to row a drift boat across the river with the ADCP tethered off the front and adhere to standard measurement protocols. Those include two pairs of measurements in each direction across the river, three-minute duration of each pass across the river, and a total measurement error of around 4% or less. We were able to consistently meet those criteria in 2020, 2021, and 2022.

We made fewer measurements in 2022 than in previous years (Table 8) because USGS made more frequent measurements than in the past and because arrival of winter conditions in early November made access difficult after that. As has been the case over the past three years, our measurements were biased slightly high relative to USGS observations, but both our relative error and bias were smaller in 2022 than in previous years (Figure 27). Overall, our measurements and associated unofficial rating shifts again provided useful streamflow information to stakeholders in between USGS visits to the gage.

Table 8. HFF measurements of streamflow at Island Park Dam and error measures relative to shift-adjusted USGS streamflow data.

Year	No. HFF measurements	Mean absolute error	Mean relative error	Bias
2020	24	23.5 cfs	7.9%	+3.4%
2021	20	20.6 cfs	8.3%	+6.4%
2022	14	28.6 cfs	4.9%	+3.0%

6. Accuracy of Predictive Models

Based on hydrologic information available on April 1, models modestly underestimated April-September natural flow because of spring rain (Figure 28, Table 2). However, predicted natural streamflow at most locations over most of the spring and summer fell within the margin of statistical error (Figures 29-31). Cool springtime temperatures delayed both runoff and irrigation demand, so observed values of most relevant statistics deviated from predicted values primarily in June, when natural flow was higher and need for reservoir draft was lower than expected. However, model inputs and outputs correctly accounted for and captured expected dry-year aspects of water management in 2022, including the need to send water to American Falls and injection of water into the Teton River from the Crosscut Canal and the exchange wells. These aspects at the intersection of water administration and water management were new additions to the model to accommodate extremely low basin-wide water supply in 2022.

Prediction: *"Natural streamflow for April-September is predicted to be 60% of average, compared with 68% of average in 2021. There is a slightly better than 50% chance that April-September streamflow this year will be lower than it was in 2001, the lowest in the 1978-2021 record. However, there is less than a 5% chance that natural streamflow into Island Park Reservoir will be as low as it was in 1934, the driest year in the long-term upper Henry's Fork record."*
Outcome: April-September streamflow for the whole watershed turned out to be 69% of the 1978-2021 average but well within the 95% prediction interval and 4th lowest in the record (Figure 32). Similarly, for the long record in the upper Henry's Fork watershed, the observed value was slightly higher than predicted but well within the prediction interval (Figure 33). In that sense, the model performed well at predicting overall streamflow, despite above-average rain in May and June and record-low precipitation in July.

Prediction: *"Runoff timing in Fall River and Teton River is expected to be around 4-5 days earlier than average and 1-2 days earlier than in 2021."*
Outcome: I measure runoff timing by center of mass, which is the "balance point" of the April-September streamflow hydrograph. By that measure, runoff timing on Fall River was 8 days later

than predicted and 3 days later than average (Figure 30). Center-of-mass in Teton River streamflow was 9 days later than predicted and 4 days later than average (Figure 31). For the watershed as a whole, runoff timing was 6 days later than average and a week later than in 2021 (Figure 28, Table 4). These differences were outside of statistical error and therefore were very unlikely to occur, given conditions on April 1. As stated in the climate summary, SWE peaked 12 days later than average due to cool springtime temperatures, and this was reflected in streamflow.

Prediction: *"Mid-summer outflow from Island Park Reservoir is expected to be about like last year, but there is a small chance that it could be as high as 2,000 cfs for several weeks in July. Draft of Island Park Reservoir is expected to begin in mid-June, and outflow is likely to increase from around 600 cfs to 1,000 cfs by early July and stay around 1,500 cfs or possibly higher until mid-August."*
Outcome: In 2021, reservoir draft began on June 10. Outflow increased to 1,000 cfs on June 19, reached its maximum of 1,490 cfs on July 8, and exceeded 1,000 cfs until July 31. In 2022, the cool, wet spring delayed need for reservoir draft until June 28 (Figure 19). Outflow exceeded 1,000 cfs from July 7 to August 3, and the maximum of 1,402 cfs was reached on July 17. Thus, magnitude of peak flow was a little lower in 2022, and duration was a little shorter, but the biggest difference between the two years was timing. The typical three-week peak in outflow occurred around three weeks later in 2022 than in 2021, and this was reflected in observed vs. predicted outflow in 2022 (Figure 34).

Observed outflow from Island Park Reservoir fell within the statistical prediction interval throughout the summer, except during the period from August 24 to September 19 when water beyond that needed in the watershed was sent to American Falls. The model accommodated such a possibility by assigning a 50% probability to the need to send water to American Falls. However, I assumed that when this happened, delivery of around 9,000 ac-ft of water out of the watershed would be spread over a two-month period from August 1 – September 30. As it happened, around 12,000 ac-ft was sent over a 27-day period.

Similarly, the assumptions I used to model additional water sent from Henry's Lake to American Falls and pumping of Teton River exchange wells turned out to be pretty close to actual operations in total volume, although timing was a little different than I assumed. In particular, additional Henry's Lake draft started a later and ended a little earlier than modeled (Figure 35), and exchange pumping started earlier and ended earlier than coded in the model (Figure 36). Observed delivery of water to the Teton River through the Crosscut Canal was close to predicted value except for a later start to the delivery (Figure 37), again due to the cold, wet spring.

Prediction: *"Mid-summer, low-flow conditions are expected in the lower watershed to begin as early as early June and last possibly through most of September. Streamflow in lower Fall River is likely to drop to 50 cfs for an extended period lasting from mid-June through July and possibly later."*
Outcome: These predictions were not correct—at least on the front end. Cool temperatures and springtime precipitation delayed onset of low-flow conditions until July, around three weeks later than expected (Figures 31, 38-39). Rain in May and June filled Grassy Lake, which had not been expected to fill, allowing higher outflow from Grassy Lake to meet irrigation demand and

maintain streamflow in lower Fall River. Minimum regulated streamflow in lower Fall River was 129 cfs, on July 12. However, the prediction proved to be correct at the end of the summer, as low flows in the lower watershed continued well into the beginning of water year 2023.

Prediction: *"Reservoir draft is expected to begin on June 6 this year…Predicted end-of-September reservoir content is just a little below the long-term average of 60,000 ac-ft (44% full)...The middle 50% of all possible simulation outcomes predict September-30 reservoir content between 16% and 55% full."*
Outcome: Due to the cool, wet spring, reservoir draft started three weeks later than predicted. However, once draft started, draft rate was very close to the predicted value. Draft slowed during the two-week rainy period in August but increased again when water was sent to American Falls. This additional draft offset early-season retention, and the reservoir ended the water year at 45% full, essentially what the model predicted (Figure 40).

7. Water Quality

We started our current water quality monitoring program in late summer of 2013 and have steadily added sites, instrumentation, and parameters since then. The core of the program is a network of 11 multi-parameter sondes in the Henry's Fork and its tributaries that continuously record water temperature, conductivity, dissolved oxygen, turbidity and two measures of algae production. Sondes were installed on the main river at Flatrock, Island Park Dam, Pinehaven, and Marysville in 2014 and at Ashton Dam, St. Anthony, and Parker in 2015. We have since added other sites, including several on Island Park Reservoir that are measured weekly during the open-water season. We also collect water samples that are analyzed in the lab for suspended sediment concentration, turbidity, and nutrients.

At most sites, water-quality data collection occurs from late March through early November, roughly coincident with the April 1 – October 31 irrigation season and with the season of aquatic ecosystem production. So, we usually present and analyze our water-quality data on an irrigation-year basis. In 2022, failures of aging equipment and supply-chain issues resulted in loss of some data, as we borrowed equipment from lower-priority sites to keep real-time data flowing at the higher-priority sites such as Flatrock and Island Park Dam. At the same time, we implemented some new data quality assurance and quality control procedures in 2022 that have greatly improved accuracy of the sonde data, and we developed a new set of statistical models that calculate suspended sediment load from sonde and streamflow data at relatively high precision.

The second component of our water-quality monitoring program is consistent annual sampling of aquatic insects and other invertebrates living in and on the river bottom. We started that sampling in 2015, and sites at Flatrock, Last Chance, and Osborne Bridge have been sampled every March since then. Sites immediately above Ashton Reservoir and at St. Anthony have been sampled every year except 2020, due to covid restrictions that year. We sample invertebrates in mid-March, immediately prior to the first hatches of the season, so that all species are large enough to capture with the sampling equipment. Were we to sample later in the spring or during summer and fall, the sampling would miss species that had recently hatched, because they would be present only in egg or very early larval stages.

With nine seasons of data now in hand at the original sonde locations, eight years of invertebrate data, and detailed studies of aquatic ecosystem function conducted by Jack McLaren (now "Dr. Jack McLaren") as part of his Utah State Ph.D. dissertation, we are starting to uncover relationships among climate, streamflow, water quality, aquatic vegetation growth, and aquatic insects that determine the Henry's Fork fishing experience. As has been the case in recent years, water clarity—or rather lack of clarity—topped the list of angler concerns in 2022, followed by poor hatches. However, nearly everything related to water quality and aquatic ecology in 2022 started with the cold, wet spring described in earlier sections.

Temperature

Water temperature was well below average during April, May and most of June in all river reaches (Figures 41-43). By early July, water temperature had gotten back up to average, and temperatures generally exceeded average from mid-July until late October at all locations. However, the effect of the cold start to the growing season persisted into the fall.

One way to measure this persistence is by calculating the mean water temperature from April 1 through a given day of the growing season and plotting the trajectory of that cumulative mean through time (Figures 43-44). This cumulative mean was below average until mid-August at Flatrock, early October at Pinehaven, and early- to mid-September at all other locations. The seasonal mean ended up being average to a little above average by the end of October, as record high temperatures in September and October eventually outweighed cold temperatures in April, May and June to produce an "average" aquatic growing season, at least as measured by mean temperature.

Another, mathematically equivalent, way to measure the lingering effect of the cold spring is through the difference in time required for a given number of thermal units to be attained. Thermal unit accumulation is measured in degree-days. Because the freezing point of freshwater is 0 degrees Celsius, thermal unit accumulation is most naturally measured in Celsius and is the sum of daily water temperature (if positive) over a specified period of days. For example, if water temperature this year was 4, 5, 3, 2, and 3 degrees C on April 1-5, the thermal unit accumulation over that five-day period was 17 degree-days. If the average water temperature over April 1-5 is 3, 4, 5, 5, and 6 degrees, respectively, then on average, 17 degree-days are accumulated over the first four days of April, putting this year one day behind average by the fifth day of April. An organism that required 17 degree days to hatch would do so one day later this year than on average.

Aquatic organism growth and maturation rates are largely determined by thermal unit accumulation, especially early in the growing season. The dependence of aquatic insect emergence ("hatch") timing on thermal-unit accumulation has been well documented in the literature. Looked at in this way, hatches were delayed by 5-8 days watershed-wide by mid- to late-June, which is when the most popular insect hatches on the Henry's Fork occur (Figures 45-46). The biggest delay occurred at Pinehaven. Further, hatches were delayed by as much as two weeks relative to recent warm years such as 2016 and 2017.

However, the largest effect of the cold, wet spring on the aquatic ecosystem and the fishing experience was misalignment of thermal unit accumulation with solar radiation. Primary production in aquatic systems comes from photosynthetic organisms, including bacteria, algae, and rooted aquatic plants, the latter referred to as "macrophytes." These organisms provide food and physical habitat for insects and other invertebrates, which, in turn, provide food for trout and comprise the hatches that draw anglers to the Henry's Fork. The rate of primary production depends, among other factors, on water temperature and sunlight availability. In 2022, much of the potential growth that could have occurred during in May and June, when the sun angle is high and the days are long, was lost due to cold temperatures and cloud cover. Thermal unit accumulation didn't catch up to average until September, by which time sun angle and day length had decreased to where they were back at the beginning of April. Thus, record high temperatures in late summer and early fall did not result in as much primary production as those same temperatures would have facilitated in May and June.

The most consistent long-term measure of macrophyte growth we have is the amount of water depth displaced by macrophytes at the stream gage station at Island Park Dam. This displacement is the so-called "shift" in the curve that relates water depth and streamflow. As plants grow and displace water, water is deeper at a given streamflow than it would be in absence of the plants. Maximum displacement in 2022 was 0.62 feet, compared with 0.80 feet in 2021, 1.00 feet in 2020, and 0.86 feet in 2019, indicating far lower macrophyte growth this year than in recent years (Figure 47). Jack's research shows that macrophytes create most of the physical habitat fish use in low-gradient reaches of the Henry's Fork upstream of Riverside Campground, provide important growing-season habitat for many invertebrate species, and are associated with higher overall ecosystem productivity. Abundance, growth, and behavior of aquatic insects, fish, and other aquatic organisms were likely affected by lack of macrophyte growth in 2022.

Lastly with respect to temperature, mean daily water temperature stayed below 70 degrees F at all sites upstream of St. Anthony and exceeded 70 degrees for only a few days at St. Anthony (Figures 41-42). Given good dissolved oxygen levels and ability for fish to freely move to areas of cool groundwater or tributary inputs in each all river reaches, summertime water temperatures were unlikely to have had any long-term negative effects on fish abundance. In 2021, peak water temperatures occurred in mid-July, whereas in 2022, peak water temperatures at most locations occurred in mid-August, when sun angle is lower and day length is shorter. This reduced the relative effect of above-average air temperatures on water temperatures in 2022.

Dissolved oxygen

Dissolved oxygen (DO) stayed above the 6 mg/L standard set by the Idaho Department of Environmental Quality (IDEQ) for cold-water ecosystems at all stations for the whole year (Figures 48-49). At all locations except Island Park Dam, DO stayed above 7 mg/L; DO only briefly fell to 6 mg/L at the dam during early October. However, despite DO levels well above the standard throughout the summer, DO at Pinehaven, Ashton Dam, and St. Anthony was below average from mid-June through early September, far below 2021 values during that time period, and at record lows on many days. For example, mean daily DO at Pinehaven from June 15 to August 31 was 8.7 mg/L, vs. 9.1 mg/L on average and 10.6 mg/L in 2021. You guessed it—the reduction in DO at these three sites in 2022 was due to low macrophyte growth. These are the only three locations in our sonde network where DO is augmented by macrophyte photosynthesis, and these were the only locations with substantially lower DO during mid-summer. Not only was daily mean DO lower than average at these locations, but the amplitude of daily fluctuation in DO was also lower. The amplitude is a proxy measure of total aquatic ecosystem productivity, providing further quantitative evidence of the ecosystem-scale, season-long effects of the cold, wet spring.

Conductivity

Conductivity as reported in water-quality data is literally the electrical conductance of water. This is greater when ion concentration is higher in the water and hence is a measure of total dissolved solids. In general, conductivity in the Henry's Fork is much lower than in other regional streams because of the volcanic geology of most of the watershed. Because solubility of typical constituents in water increases with temperature, conductivity follows a predictable seasonal pattern that reflects water temperature. In 2022, the seasonal pattern was exaggerated because of the cold wet spring. Conductivity was generally below average during May and June and above average during mid- to late-summer (Figures 50-51).

In addition, conductivity at Flatrock was far higher than the 2014-2021 period-of-record maximum for most of the summer due to high outflow from Henry's Lake. Unlike the rest of the watershed, the geology of the Henry's Lake basin is dominated by sedimentary rocks, which have much higher concentrations of soluble minerals and salts than volcanic rocks. Hence, conductivity of water in Henry's Lake is much higher than in Big Springs. High outflow from Henry's Lake, combined with near record-low natural outflow from Big Springs, produced much higher conductivity in the river at Flatrock than we have observed since we first installed a sonde at Flatrock in 2014, illustrating the effect of water management on water quality.

Turbidity

Directly from our water quality website:

> *Turbidity is a measure of a liquid's visual clarity. Material inside of a liquid absorbs, reflects, and scatters light making it harder to see through. More material in the water results in higher turbidity, but variation in the size, shape, or color of that material impacts turbidity differently. We know that the type of suspended material in the Henry's Fork changes depending on the season or location. Thus turbidity is not a direct measure of concentration of suspended material in the river. The following categories summarize the three general types of material that impact turbidity and include examples from the Henry's Fork: 1) inorganic and suspended, this is mineral sediment like sand or silt that does not decay in the "short term"; 2) organic and suspended, such as bits of plants, cyanobacteria, or animal tissue that do decay in the short term; and 3) organic and dissolved, such as tannins from decaying vegetation.*
>
> *The Henry's Fork is a relatively clear river with usual levels of turbidity between 0.05 and 10 Formazin Nephelometric Units (FNU). For reference, well water typically ranges from 0.05 to 10 FNU, orange juice typically ranges from 300 to 900 FNU, and wastewater has a typical turbidity range of 70 to 2000 FNU.*

For further reference, the IDEQ standard for temporary water-quality permits issued for activities such as bridge construction is that turbidity is no higher than 50 turbidity units above background. Given typical background levels of 0.05-10 on the Henry's Fork, turbidity values of 50-60 would stay within the IDEQ standards. However, anglers generally express concern about turbidity on the Henry's Fork when it exceeds 5 FNU.

Water clarity at Flatrock, Marysville, and St. Anthony is affected primarily by natural watershed runoff processes. Thus, turbidity at these locations was highest in 2022 following heavy rain events in May and June (Figures 52-53). The mid-June rain, which caused flooding in Yellowstone, was the heaviest observed in the northern part of the watershed since 2011, likely mobilizing sediment that had been accumulating in stream channels and riparian areas for over a decade. As a result, turbidity stayed high in streams throughout the Yellowstone region—including our watershed—into July. Specific to the Henry's Fork, turbidity at Marysville was also very high following the 3-inch downpour that occurred in the Ashton area on August 13. Mobilization of sediment and organic material during that event persisted through Ashton Reservoir and all the rest of the way down the river for several days.

Although rain-driven turbidity produced some period-of-record highs at Flatrock, Marysville, and St. Anthony, consistently high turbidity at Island Park Dam and Pinehaven had much greater and longer-lasting negative effects on fishing experience. Turbidity at Island Park Dam was above average and generally above 5 FNU for most of June and July. Early in that time period, high turbidity from heavy rain was passed through a full reservoir, but high turbidity persisted long after the effects of rain had dissipated. High outflow from the reservoir to meet irrigation demand contributed to high turbidity in July, but even after accounting for that effect, turbidity was still higher than expected. Turbidity was also very high at Pinehaven from late May through Late July. Some of that was due to rain-driven runoff into the Buffalo River and smaller tributaries such as Thurmon Creek during May and June, but as at Island Park, turbidity was much higher than average well after the effects of rain passed through the watershed. Notably, turbidity was higher by 2-3 FNU at Pinehaven than at Island Park Dam for most of July, whereas turbidity is usually about the same at the two locations during that time period. The deviation from average was again due to low macrophyte growth in 2022, as discussed in more detail in the next subsection.

Data from our algae sensors clearly indicated that suspended sediment was the primary cause of high turbidity from the dam to Pinehaven through September. Once outflow from Island Park was reduced in late July, turbidity was close to or well below average for the remainder of the season at both locations. Late-season high turbidity events, which were observed at the dam but not at Pinehaven, were caused primarily by algae blooms associated with autumn turnover in the reservoir (Figure 54). Due to record heat well into October, these blooms lasted longer into November than usual.

Sediment transport and deposition

Although high turbidity has an immediate negative effect on fishing experience regardless of the cause or source of the turbidity, fine sediment can degrade stream substrate (material on the stream bottom), with potential long-term effects on fishing experience via decreased trout egg incubation success and lower quality of the aquatic invertebrate community. In the Henry's Fork, we have no indication that spawning success is a limitation to the trout population; decades of data and research show that juvenile trout survival during their first winter—determined largely by streamflow—is the limiting factor on trout recruitment (Figure 15). Thus, any negative effects of fine sediment deposition on the Henry's Fork fishery are realized through degradation of aquatic insect habitat, particularly between Island Park Dam and Pinehaven. As such, the remainder of this discussion is focused strictly on that river reach.

How we calculate the fine sediment budget

Calculating the sediment budget in a river reach, in this case Island Park Dam to Pinehaven, starts with an estimate of suspended sediment concentration. The only way to directly measure this is to analyze a water sample in the lab. The water is poured through a very fine filter of known weight, and then the filter and filtrate are dried and weighed again. The difference gives the mass of suspended sediment in the water sample, which, when divided by the volume of the sample, gives concentration in mg/L. We have been collecting field samples of suspended sediment on a weekly-to-monthly basis at Island Park Dam and Pinehaven since 2013, with lower sampling frequency at other locations. Median sediment concentrations we have observed over the years range from 0-2 mg/L in spring-dominated reaches (Big Springs, Flatrock, Buffalo River, Warm River), 3-4 mg/L at Ashton and Island Park dams and at Parker, and 5-6 mg/L at Pinehaven, Marysville and St. Anthony. The maximum we have ever observed is 62 mg/L at Parker on May 1, 2021 during peak snowmelt.

While highly accurate, field samples are expensive to collect and analyze and cannot provide the continuous, high-resolution data needed to calculate sediment loads. However, our sondes collect turbidity readings every 15 minutes, and although turbidity and suspended sediment are not equivalent, they are related. Using raw turbidity and suspended sediment data from the field samples and algae data from the sondes, we have developed statistical models that predict suspended sediment concentration from sonde turbidity data. Accounting for algae concentration and season of year results in much higher model precision at most locations than if we based the calculation on turbidity alone. At Island Park Dam, our model accounts for over 60% of the observed variability in suspended sediment concentration. At Pinehaven and most other sites, the model is even more precise, explaining around 90% of the observed variability in sediment concentration. Applying these statistical relationships to our sonde data produces a 15-minute record of suspended sediment concentration.

Using daily streamflow data from USGS and our own measurements, we calculate sediment load at a given location as concentration multiplied by streamflow rate. The most convenient unit of measure for load is tons of suspended sediment per day. Summing daily loads over a whole year gives the annual sediment load. For a given river reach, the sediment budget is defined as:

sediment export = sediment load out of reach – sediment load into reach

If that number is positive, more sediment moved out of the reach than flowed into the reach (net export of sediment from the reach), and if this number is negative, more sediment moved in than out (net deposition of sediment in the reach).

In the Island Park-to-Pinehaven reach, the sediment load into the reach is the sum of load out of Island Park Dam, load from the Buffalo River, and load from small, mostly spring-fed, tributaries between the Buffalo River and Pinehaven. In absence of sonde data from the small tributaries, we assume that their sediment concentration is the same as that in the Buffalo River, where we have deployed a sonde since 2016. Years ago, we gaged those small tributaries (Blue

Springs Creek, Thurmon Creek, etc.) and found that their combined flow was around 11% of that in the Buffalo River. Thus, with flow data from Island Park Dam and Buffalo River and sonde data from those locations, we can calculate load into the reach. Flow at Pinehaven is the sum of outflow from Island Park Dam and the combined flow of the Buffalo River and these small tributaries. Multiplying that by sediment concentration as estimated from the Pinehaven sonde data gives load at Pinehaven. The difference between that sediment inflow to the reach gives us the budget for the Henry's Fork between Island Park Dam and Pinehaven.

Sediment budget results

On average, sediment is deposited into this reach from mid-July through late-January, when macrophytes are abundant enough to trap most sediment that flows into the reach (Figure 55). The vast majority of sediment input to the reach during that time period comes from Island Park Reservoir. Sediment is removed from the reach from February through mid-July, when macrophyte abundance is low. Even though sediment input to the reach can be high during that time, macrophytes are not abundant enough to trap that sediment, which stays in suspension all the way through the reach. The greatest removal of sediment from the reach occurs during periods of high streamflow during March, April, and May (the so-called "springtime freshet").

During 2022, sediment export during the spring was very low due to extended periods of low outflow from Island Park Dam, as the reservoir was being filled. Only two very short-duration high flow events occurred during the spring, one immediately prior to ice-off in late April and another during the Memorial Day rain event. As a result, sediment export was well below-average during April and May. However, once the reservoir filled in late May and outflow was increased, sediment export was above average through late July because macrophyte abundance was lower than average. The period of net export lasted until July 25, ten days later than average, again due to lower macrophyte growth. While the effect of low macrophyte growth on sediment export was positive, the effect on fishing experience during June and July was negative, as sediment scoured from the stream bottom combined with above-average sediment outflow from the dam to produce higher turbidity throughout the reach. Worst, this higher-than-expected sediment export during June and July did not outweigh low export during the spring, and sediment export was much lower than it was in 2021 and less than half of what it was in 2017 and 2018 during years of much better water supply (Figure 56). This is likely to reduce the quality of insect hatches in 2023 and possibly beyond, depending on how water year 2023 shapes up.

Over the seven years for which we have calculated a complete sediment budget, mean annual export from the Island Park to Pinehaven reach was 680 tons/year. Total delivery of sediment from Island Park Reservoir during the 1992 sediment event was estimated at 50,000 to 100,000 tons. Not all of that was deposited in the Island Park to Pinehaven reach, but it is safe to assume that much of it was deposited there, because the event occurred during September, when macrophtye abundance was still high. If we use a conservative estimate that half of the exported sediment was deposited in the reach and assume that the net rate of removal is 680 tons/year, between 37 and 74 years (another 7-44 years from now) will be required to move all of that sediment out of the river reach between Island Park and Pinehaven.

Effects of sediment and streamflow on aquatic insects

With only eight years of invertebrate data collected under our current protocol and only seven years with a complete sediment budgets, we do not yet have enough data to statistically relate aquatic invertebrates to sediment export/deposition in the Island Park to Pinehaven reach. However, comparable invertebrate data were collected in the spring of 1993, following the 1992 sediment event, using similar methods as we use and at two of the same locations—Last Chance and Osborne Bridge.

To develop a streamflow-based proxy for sediment export out of the Island Park to Pinehaven reach, we used the observations made above about springtime scour and late-summer/fall deposition tied to the annual cycle of macrophyte growth and decay. This proxy also needs to account for the March-16 (plus or minus one day) timing of our annual invertebrate sampling. The invertebrates present in mid-March reflect the quality of the stream bottom over the previous year, which is determined by scour during the spring freshet and deposition during the late summer and fall of the previous year. Thus we defined the spring period as March 16 to May 31, immediately after the sampling of last year's invertebrates occurred. The overlapping period of greatest export of sediment from Island Park Reservoir and greatest macrophyte abundance is July 15 to January 15. Higher streamflow during the spring is expected to scour more sediment, while higher streamflow during the July 15-January 15 period is expected to deliver more sediment out of the reservoir. Thus, we defined a "freshet" index as the ratio of mean March 16-May 31 discharge out of Island Park Dam to mean July 15-January 15 discharge. A higher value of this ratio will scour more sediment and/or deposit less, leading to a higher net sediment export out of the reach.

The invertebrate metrics least sensitive to sample size and methodology are %EPT and HBI. The %EPT is the percent of total individual invertebrates belonging to the orders **E**phemeroptera (mayflies), **P**lecoptera (stoneflies), and **T**richoptera (caddisflies). The Hilsenhoff Biotic Index (HBI) is a measure of overall habitat and water quality, as reflected in the tolerance of invertebrates to pollution and habitat degradation. Each invertebrate species is assigned a tolerance level of 0-10, with 0 being intolerant to poor habitat and water quality and 10 being extremely tolerant. The HBI is the average tolerance of all invertebrates in the sample, weighted by the number of individuals in each tolerance level. For example, if a sample of 10 invertebrates contains 5 with a tolerance level of 1, 4 with a tolerance of 3, and 1 with a tolerance of 5, the HBI score is 2.2. If another sample of 10 contains 1 individual with a tolerance of 1, 4 with a tolerance of 4, and 5 with a tolerance of 7, the HBI score would be 5.2, indicating an invertebrate community with higher tolerance for degraded conditions. The higher score in the second sample indicates lower overall habitat and water quality. The HBI and %EPT metrics are correlated, since most EPT taxa tend to be less tolerant of pollution than other taxa, but the correlation is not perfect. Some EPT taxa are quite tolerant to habitat degradation, while some non-EPT taxa are intolerant. We used the average of Last Chance and Osborne Bridge invertebrate data in the analysis to represent conditions in the Island Park to Pinehaven reach as a whole.

As it turned out, both of these metrics were statistically significantly related to the freshet index (Figure 57). Higher springtime flows relative to subsequent summer/fall flows were associated with higher %EPT and lower HBI observed during the following invertebrate sampling year. Both indices indicated a far worse invertebrate community structure in 1993 when compared to any of the years in our 2015-2022 data set. The freshet index in 1993 was also far lower than any observed in the modern time period. The %EPT ranged from 24% in 1993 to 60% in 2022 and was at least 42% in each of 2015-2022. For comparison, in samples from the Bighorn River collected by the Bighorn River Alliance, %EPT ranged from around 7% to 37% at individual sites sampled during fall 2020 and spring 2021. The HBI ranged from 5.5 in 1993 (on the border between "fair" and "good") to 3.7 in 2019 (on the border between "very good" and "excellent"). In addition to the overall trend toward better invertebrate communities in the modern data set compared with that observed immediately after the 1992 sediment event, both metrics showed intermediate conditions in 2015 and 2017, following 2014 and 2016, both of which were dry years with low springtime flows and subsequently high irrigation-season flows. At least based on %EPT and HBI, the overall quality of the invertebrate community has been fairly consistent over the past five years (2018-2022). However, as discussed in section 8, these broad-scale indicators of invertebrate community quality do not always coincide with the quality of insect hatches from a fishing standpoint.

Suspended sediment export from Island Park Reservoir

Detailed study of Island Park Reservoir by Jack McLaren over the past few years has greatly improved our understanding of suspended export from the reservoir into the river and with that, our ability to predict and potentially manage it. Export of sediment from the reservoir requires three things:

1. Suspension of fine sediment into the reservoir water column.
2. Movement of that sediment to the dam.
3. Transport through the dam and into the river.

The primary cause of sediment export during the 1992 event was erosion of sediment deposited in the old river channel as the reservoir was drawn down to zero pool. Based on a variety of evidence, we believe that much of that sediment came from long-term effects of water and land management on Henry's Lake Flat and from erosion on the Yellowstone Plateau following the 1988 fire. Stream and riparian restoration, improved water management, and implementation of grazing best management practices on Henry's Lake Outlet starting in the mid-1990s appear to have reduced sediment input from the Outlet. Revegetation following the 1988 fire has probably also reduced sediment input from erosion on the Plateau. Part of the evidence that supports these claims is that the quality of the macroinvertebrate community, as measured by %EPT and HBI, improved significantly at Flatrock between the 1990s and our modern sampling period. These observations are completely independent of reservoir management. Further, Jack's data from 2021 and 2022 show that turbidity in the reservoir is consistently very low in the old river channel but is often very high on the west end of the reservoir. Jack's conclusion is that most sediment exported from the reservoir in recent years comes from the West End, not from Henry's Fork inflow. We know that sediment is mobilized there by northeast wind and sudden drops in surface temperature, particularly in late summer and fall when the large areas of sediment are exposed on the shoreline. However, turbidity is high on the West End much earlier in the summer, when these mechanisms do not exist and the reservoir is full. As part of his post-doctoral work at HFF, Jack will more carefully investigate mechanisms of sediment suspension on the West End, which could potentially include the effects of wake boats. Shoreline erosion from wake boats has been shown to be a source of sediment suspension in other reservoirs.

Once sediment is suspended in the water column, it must be transported to the dam for it to be exported into the river. During mid-summer, when the reservoir surface is warm and the Henry's Fork contributes the majority of reservoir inflow, cool clear water from the Henry's Fork moves along the reservoir bottom in the old river channel, preventing warmer sediment-laden water on the West End from moving toward the dam. During late summer and fall, the shallow West End cools more quickly than the Henry's Fork, and this cool water sinks to the bottom of the reservoir and transports sediment to the dam—staying underneath the now-warmer water entering the reservoir from the Henry's Fork. The September 2020 sediment event was an extreme example of this mechanism. Based on data from that event and from Jack's sampling, we successfully predicted a similar but much smaller event during September 2022 caused by northeast wind and sudden cooling. We correctly predicted timing, magnitude, and duration of that event several days in advance. However, this mechanism does not explain the consistently high sediment export we observed in June and July of 2022. It is possible that heavy rain in June—the highest in the northern part of the watershed in over a decade—kept inflow from West End tributaries such as Sheridan Creek higher longer into the summer than we have seen in recent years, maintaining high sediment transport from the West End to the dam into July.

Although we still have more to learn about sediment suspension and transport in the reservoir—particularly during the spring and early summer—we thoroughly understand the mechanisms that affect export out of the dam. For a given amount of sediment in suspension in the reservoir, export through the dam is higher when outflow is higher, reservoir draft rate is higher, and a greater proportion of outflow passes through the bottom-withdrawal gates than through the power plant. When total outflow exceeds the power-plant capacity of 960 cfs, some outflow is necessarily passed through the gates, which always results in increased sediment export, especially when the gates are first opened for the season and when outflow increases are made. During all but the wettest years, outflow exceeds 960 cfs during the peak of irrigation season, usually from late June through late July, which is when peak sediment export from the dam occurs. Once outflow drops back below 960 cfs later in the summer, as much outflow as possible is passed through the power plant. During late summer when water temperatures are warm and dissolved oxygen on the reservoir bottom is low, the power plant's aeration system is sometimes unable to introduce enough oxygen into the water to meet the plant's dissolved oxygen requirement. In that case, some flow is transferred from the plant back to the gates, where turbulent flow through the outlet tunnel mixes oxygen into the water and allows the DO requirement to be met. When this happens, sediment export from the reservoir increases again. Several years ago, HFF worked with partners to lower the plant's DO requirement from 7 mg/L to 6 mg/L during the summer. This reduces the need to transfer water to the gates, resulting in lower sediment export without negative consequences for fish in the river.

Given this knowledge, sediment transport out of the dam is lower, on average, when outflow is lower, reservoir draft rate is lower, and water on the reservoir bottom is colder. All three of these conditions are facilitated by precision water management and on-farm water conservation. As mentioned earlier, collaborative water management and conservation efforts have saved an average of 25,000 ac-ft of water in Island Park Reservoir each year, which is equivalent to a decrease of 125 cfs in outflow from the dam during the summer and also provides associated water-quality benefits in the reservoir. Without these measures, sediment export over the past five years would have been even higher than it was. However, it is clear that larger-scale management of sediment and other factors *in the reservoir* itself will be needed to further reduce sediment export. Developing such management strategies will be a large part of Jack's job over the next few years.

8. Fishing Experience

Fishing experience on the Henry's Fork is determined directly by fish abundance and size, aquatic insect abundance and species, weather and other environmental factors, and indirectly by the effect that environmental factors have on fish and insects. However, all of these effects are filtered through angler perception, expectations, and fishing preferences. Formal and informal surveys consistently indicate that the three characteristics of the Henry's Fork fishing experience most important to anglers are, in decreasing order of importance, the opportunity to fish to rising fish, aesthetics (including habitat quality), and number/size of fish caught. Streamflow directly affects these characteristics through aesthetics, which anglers perceive relative to their preferences for water depth and water clarity. Generally, anglers have a lower tolerance for higher flows when water clarity is poor and vice versa. Streamflow indirectly affects these characteristics via the positive relationship between winter outflow from Island Park Dam and trout recruitment into the population downstream. Winter flow is, in turn, primarily a function of overall water supply. These dependencies are well understood, can be predicted ahead of the fishing season, and can be influenced by water management and water conservation. The effects of water quality on fishing experience are less well understood, more difficult to predict, and harder to influence via management.

This section again focuses on the river reach between Island Park Dam and Pinehaven, draws heavily on information presented in other sections of this document, and includes predictions I made back in April.

Fish abundance and size

The abundance and size of trout in this river reach in a given year reflects winter flow conditions over the previous 2-4 years. Thus, I expected better trout abundance in 2022 than observed, given good winter flow in 2018, 2019, and 2020. Winter flow in 2021 was average but still much lower than it was in any of the three subsequent years. So, recruitment of age-2 fish and the trout population as a whole were lower in 2022 than they had been since 2018 (Figure 58), when effects of the 2013-2016 drought were realized in all fish age classes. The effects of drought in 2020-2022 will continue to affect the population for several years to come.

Prediction: *"The trout population in this reach of river this year will reflect four consecutive years of…average to above-average winter flow. Thus, trout of ages 2 through 5 (roughly 10-24 inches long) will be very abundant. The effect of this year's below-average winter flow will not be reflected in the two-year old cohort until 2023 and the three-year old cohort, the bulk of the 16"+ fish, until 2024."*
Outcome: The trout population in 2022 was only about one-half of what it was in 2021 (Figure 58), but extremely low water during sampling may have resulted in under-estimation of the population. Mean length of fish captured in 2022 was higher than in 2021, reflecting a higher proportion of older fish in the population as expected and/or under-sampling of smaller fish. The number of age-2 fish ("recruits") was lower than expected based on Box Canyon streamflow two

winters ago, again possibly due to the difficult sampling conditions. Expected recruitment in 2023 will be far below average, given low winter flow during the 2021-2022 winter (Figure 15).

Streamflow and water quality

In 2022, most angler dissatisfaction relative to streamflow occurred during rapid and large fluctuations in flow caused by heavy springtime rain and to high outflow from Island Park during July (Figure 19). These fluctuations could not have been avoided, since the reservoir was either at its ice constraint (in early May) or already full (late May and June), so large increases in inflow had to be passed through the reservoir. Although these events resulted in natural streamflow conditions downstream of the dam, natural flow is not necessarily any better than regulated flow for fishing experience. Given the importance of maintaining as much water as possible in the reservoir for all resources and stakeholders, the reservoir will always be held as full as possible during the spring, which will sometimes lead to unexpected outflow fluctuations due to natural snowmelt and rain events. In 2022, these just happened to be very large. Can you say "cold, wet spring" again?

High turbidity during June and July also contributed to poor fishing conditions (Figure 52). As mentioned above, turbidity was higher than average and somewhat higher than we expected during June and July, but we anticipated high turbidity early in the spring and predicted as much back in April.

Prediction: *"The expected high magnitude and long duration of high flows out of Island Park Reservoir this summer will result in higher-than-average turbidity."*
Outcome: Turbidity at Island Park Dam and Pinehaven was above average during June and July and either below- or near-average after that.

Otherwise with respect to water quality, our data indicate that water temperature, dissolved oxygen, and food availability do not limit the fish population in any way, even though short-term trout behavior may be affected in ways that reduce the quality of the desired angling experience.

Insect hatches

Timing of insect hatches was delayed in 2022 due to the cold wet spring, which we anticipated as early as mid-April.

Prediction: *"Cooler-than-average temperatures in late winter and early spring will push hatch timing later than the 2014-2021 average, at least through the spring."*
Outcome: Hatch timing and other measures of aquatic organism development lagged average until late summer and early fall not just between Island Park Dam and Pinehaven but throughout the whole watershed (Figures 45-46).

With respect to insect abundance, we are starting to uncover links between water management at Island Park Dam and quality of the aquatic invertebrate community. In this linkage, the aquatic invertebrate community lags streamflow, which in turn reflects overall water supply, by at least one year. Based on the relationship between the freshet index and measures of invertebrate community structure, I predicted lower %EPT and worse HBI in 2022, as a result of drought during water year 2021. Those specific predictions did not turn out to be true based on our spring invertebrate sampling, illustrating that many factors affect aquatic invertebrates. We probably measure most of these factors but do not yet have enough years of data to quantify their effects on insect hatches.

Prediction: *"It is likely that the numbers of sediment-intolerant [invertebrate] species will be lower this year even than last but not as low as they were following the 2013-2016 drought."*
Outcome: As measured by the Hilsenhoff Biotic Index (HBI), the abundance of sediment-intolerant species in 2022 was higher than in years during and immediately following the 2013-2016 drought and lower than in 2019, according to the prediction. It was about the same, if not slightly better than in 2018, 2020, and 2021, contrary to what I predicted.

On the other hand, our 2022 data showed that abundance of EPT taxa at Last Chance was the lowest in our 2015-2022 record (Figure 59). Abundance of caddisflies, Pale Morning Duns (PMDs), and Flavs were particularly low in 2022 and only a few percent of what they were in 2020, when most anglers reported the best hatches in years if not decades (Figure 60). Although our March stream-bottom ("benthic") sampling indicates abundance only of larval insects at that point in the year and therefore is not a measure of "hatch quality," our growing data set is showing substantial year-to-year variability that at least for some insects appears to match angler observations of hatches on the river (Figures 59-61). These correlations are strongest at Last Chance, where our data show particularly good abundances of important insects in 2017 and 2020 and very poor abundances in 2019, 2021, and 2022. Patterns at Osborne Bridge differ substantially from those at Last Chance—in some cases showing opposite trends—most likely due to inherently finer substrate and greater retention of macrophytes throughout the year at Osborne Bridge. Sampling variability at Osborne Bridge is also higher than it is at Last Chance because of lower habitat variability at Last Chance, which contributes to differences between the sites.

Conclusions

By most accounts, fishing experience on the Harriman Ranch reach was very poor in 2022. Our data corroborate angler experience on the Ranch in 2022: low fish population, delayed hatch timing, continuously cold weather in the spring, continuously hot weather in July and September, low macrophyte abundance, low insect abundance, high streamflow, and high turbidity combined to produce poor fishing. Of these, fish and insect abundance largely reflect conditions inherited from previous years. Given that water supply in 2022 was among the lowest in the last 90 years, the trout population will remain low at least for another two years. I expect EPT abundance to stay low for at least another year. The other factors—weather, turbidity, and streamflow during the fishing season—depend almost completely on weather and water supply in that year and so can improve dramatically in one year if weather and water supply cooperate.

In undertaking this detailed analysis of fishing conditions—made possible only by our intensive research and monitoring efforts—two factors affect fishing experience more than any others.

1. Water supply affects fishing experience both day-to-day and over the lifespan of insects and fish (1-4 years). The effects of recent drought on the aquatic ecosystem and fishing experience are lower than they would have been 5-10 years ago as a result of improved collaborative water management and conservation.

2. Sediment export from Island Park Reservoir affects water clarity on a given day of fishing and insect abundance a year or two hence. More detailed investigation of mechanisms that relate sediment mobilization in Island Park Reservoir to insect abundance will be needed to develop additional management actions to maintain the quality of hatches anglers desire.

Figures

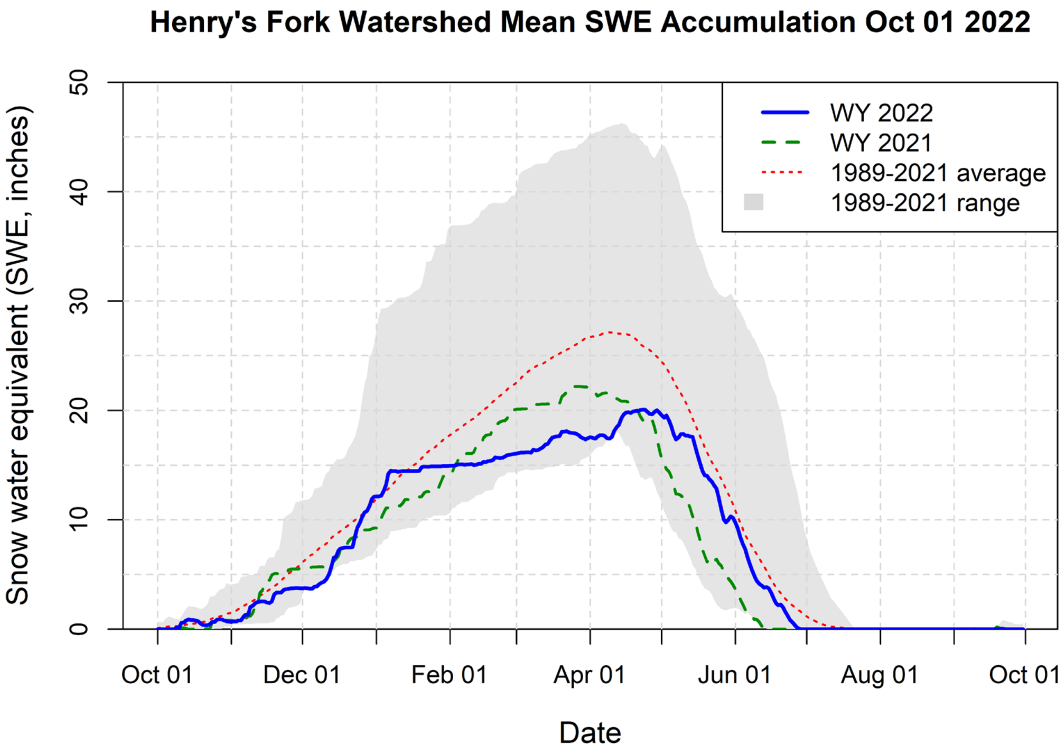

Figure 1. Watershed-averaged snow water equivalent (SWE).

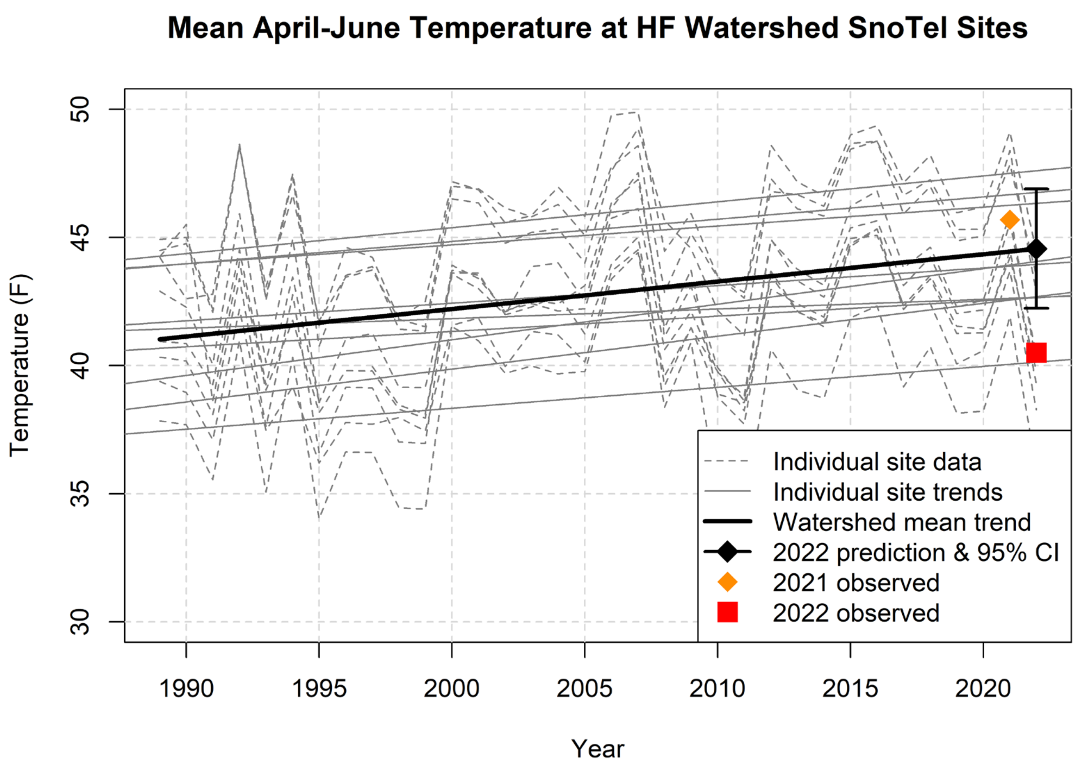

Figure 2. April-June temperature at SnoTel stations.

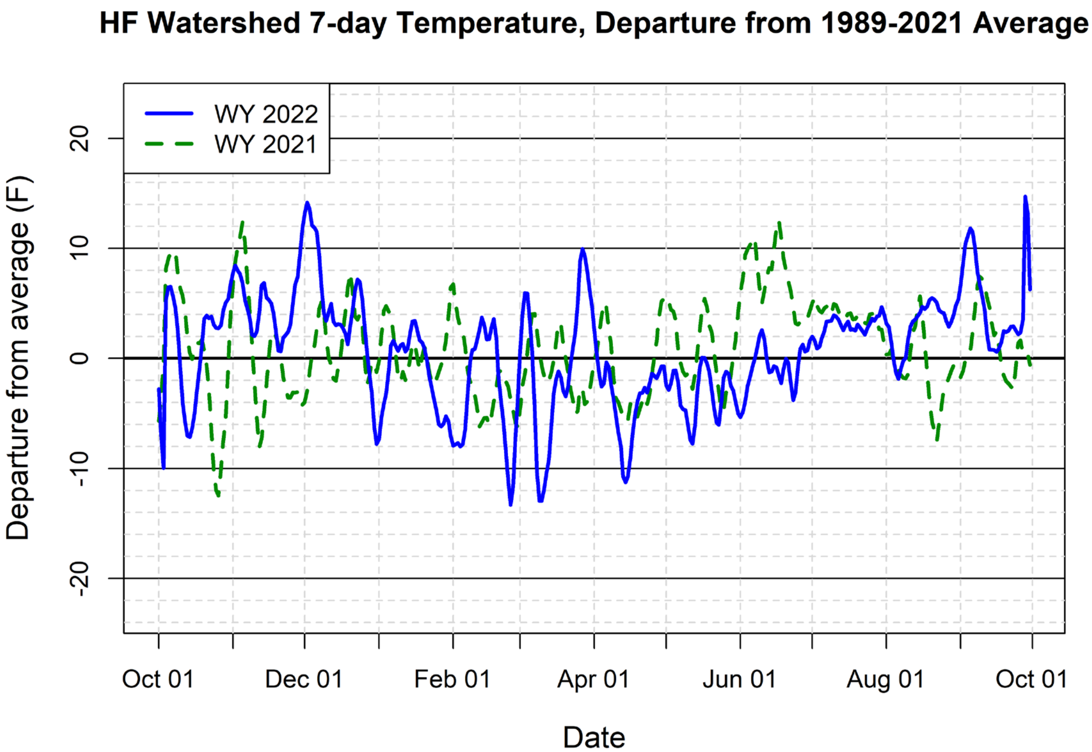

Figure 3. Watershed temperature departure from the 1989-2020 average.

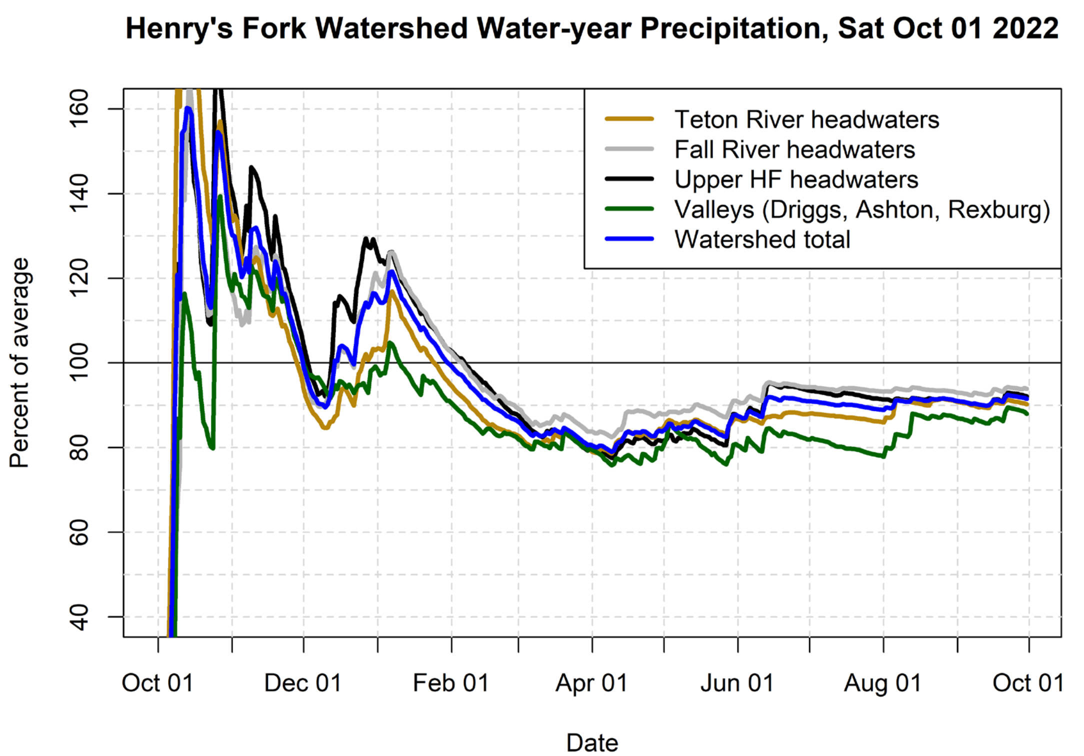

Figure 4. Water-year precipitation as a percent of the 1989-2020 average.

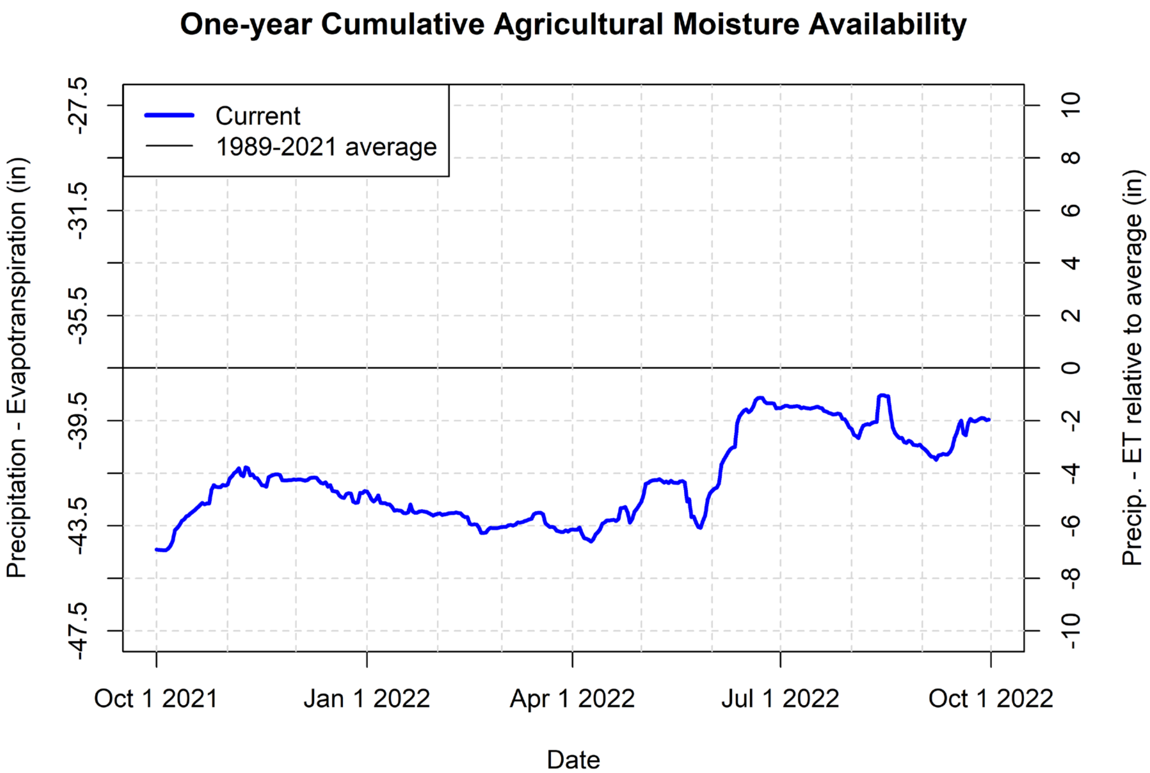

Figure 5. One-year accumulated agricultural moisture availability (precipitation minus evapotranspiration).

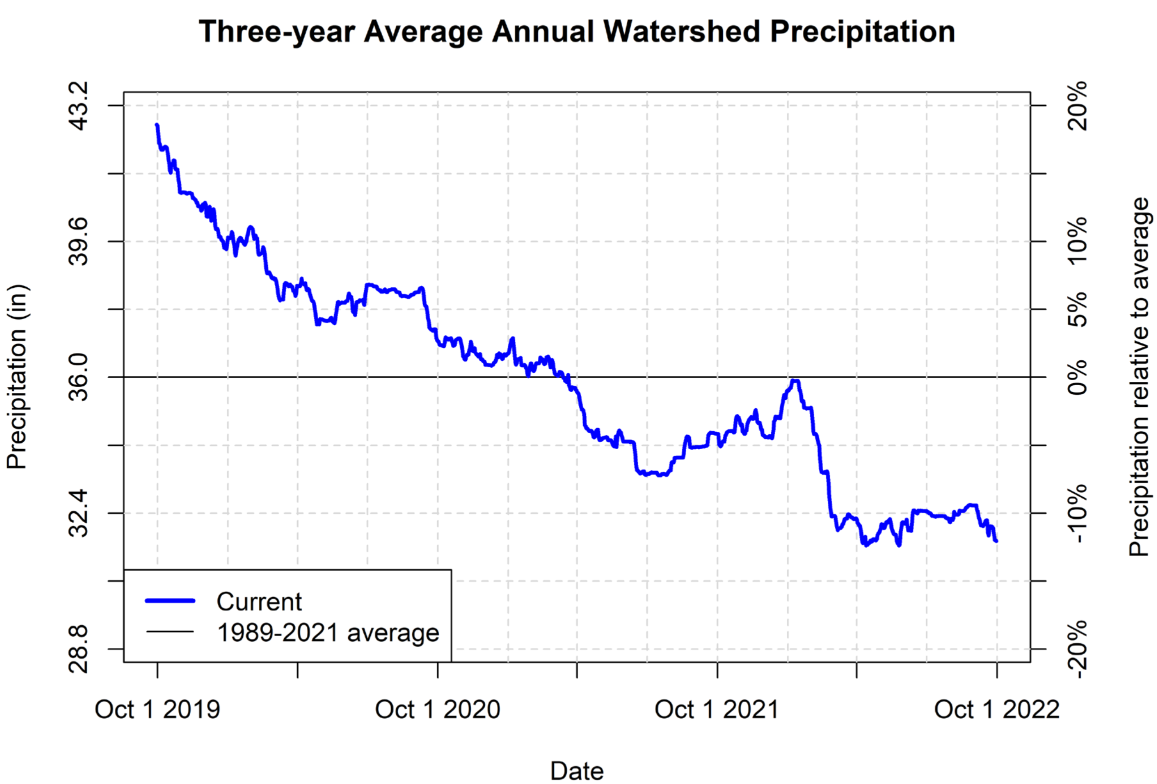

Figure 6. Three-year average watershed-total precipitation.

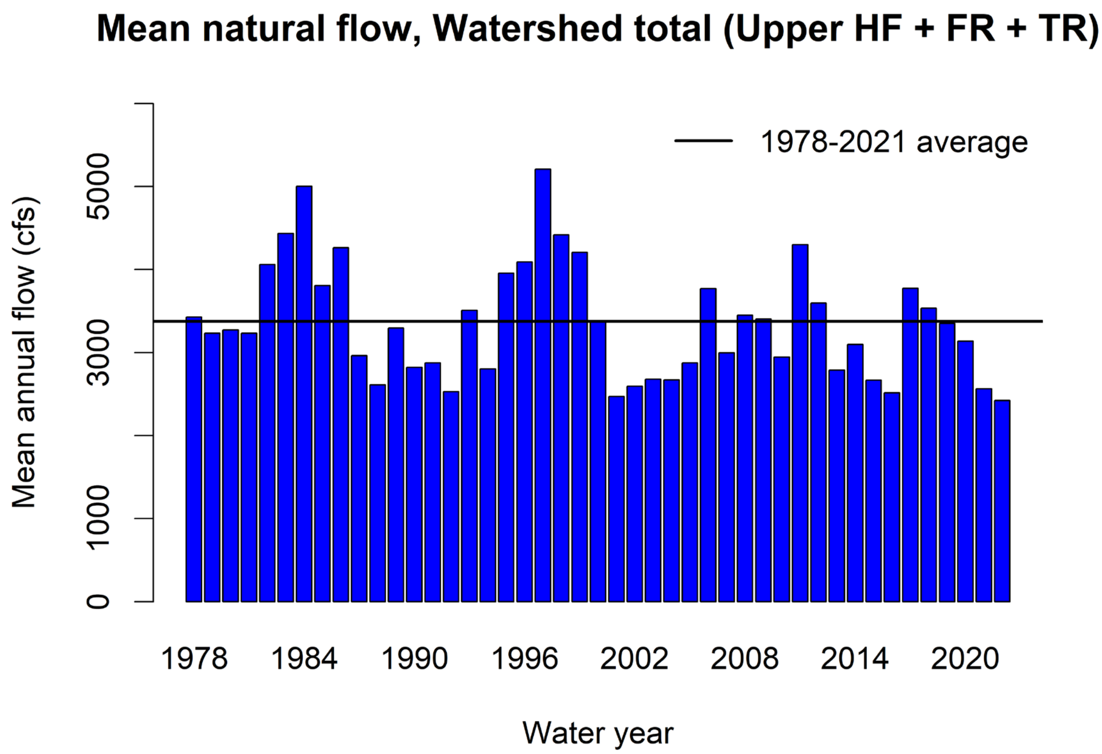

Figure 7. Time series of mean annual natural flow in the Henry's Fork watershed.

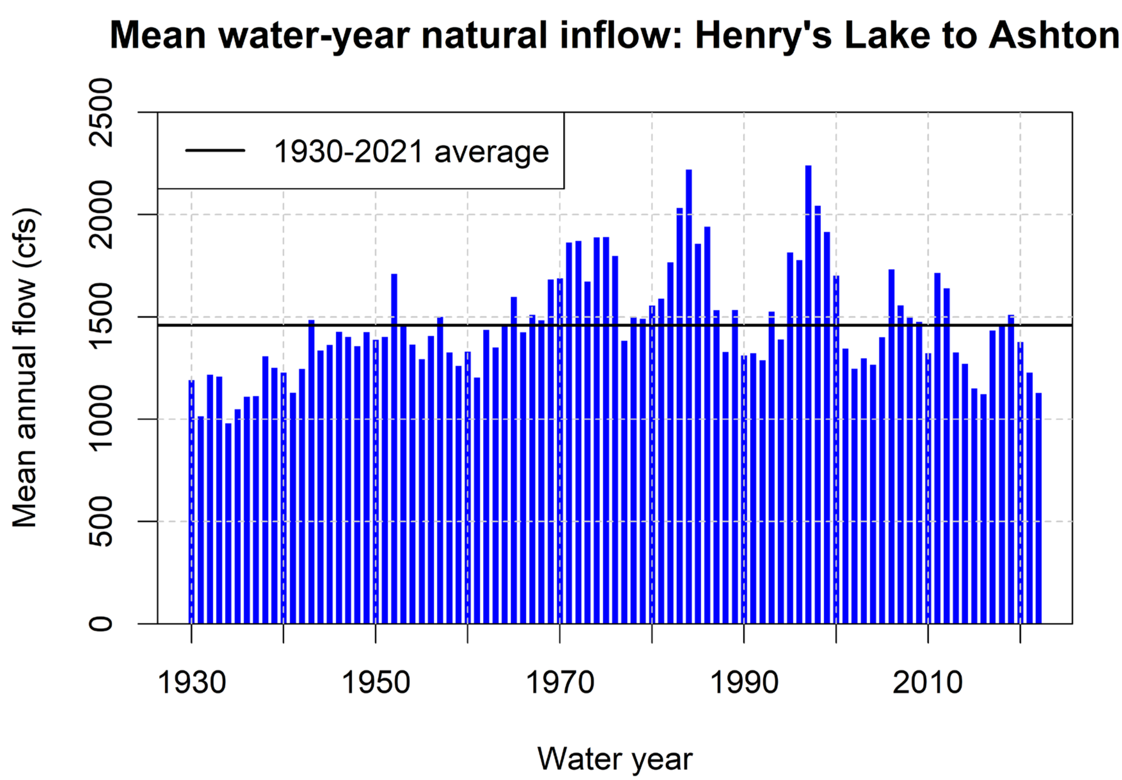

Figure 8. Time series of mean annual natural inflow to the Henry's Fork between Henry's Lake and Ashton.

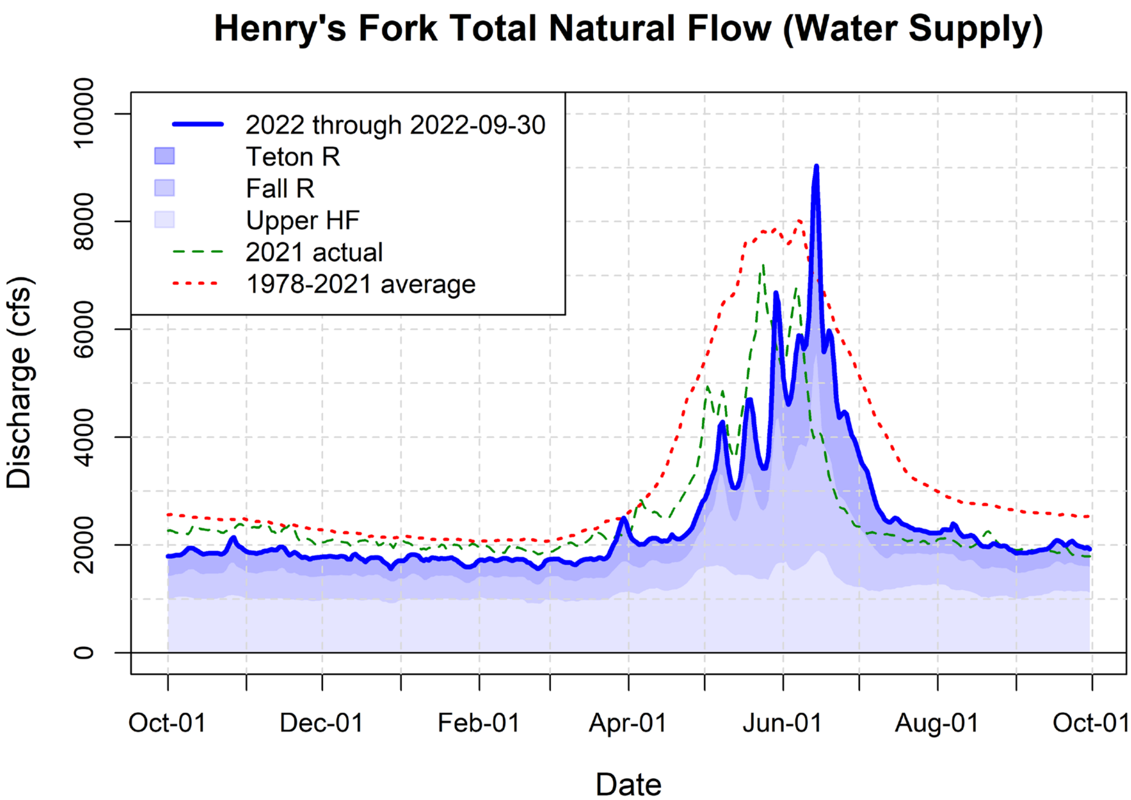

Figure 9. Watershed-total natural flow hydrograph.

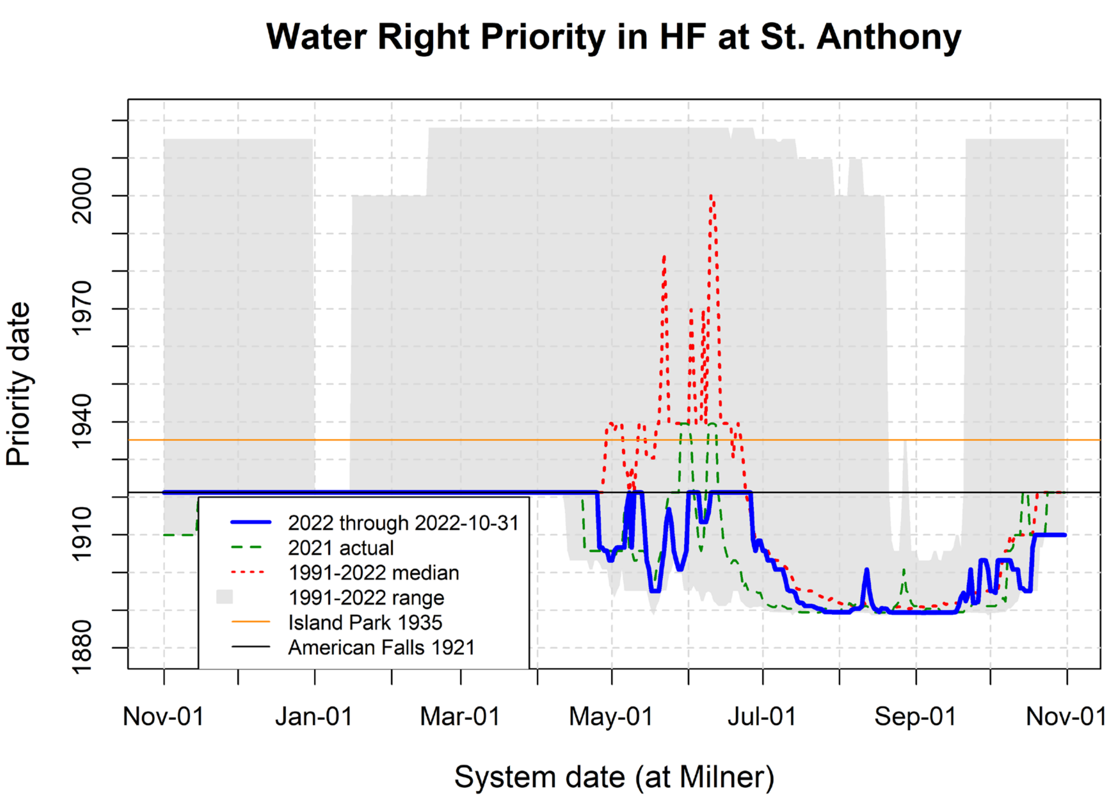

Figure 10. Irrigation-season natural-flow water-rights priority in the Henry's Fork at St. Anthony.

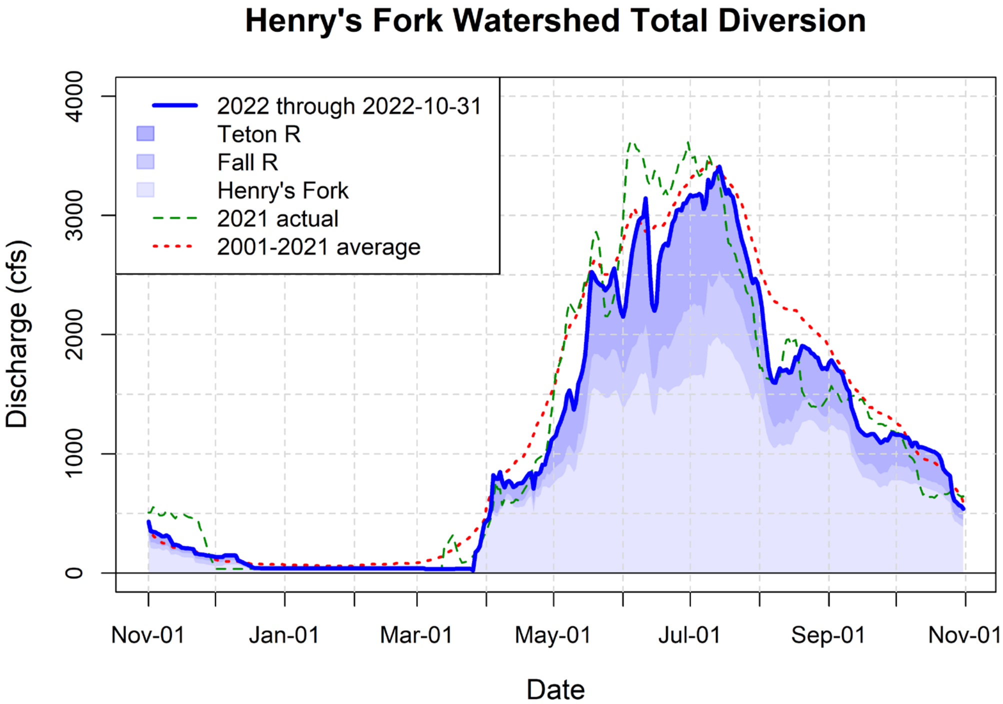

Figure 11. Henry's Fork watershed diversion hydrographs, by tributary. Data include diversion into the Crosscut Canal that is delivered to the Teton River.

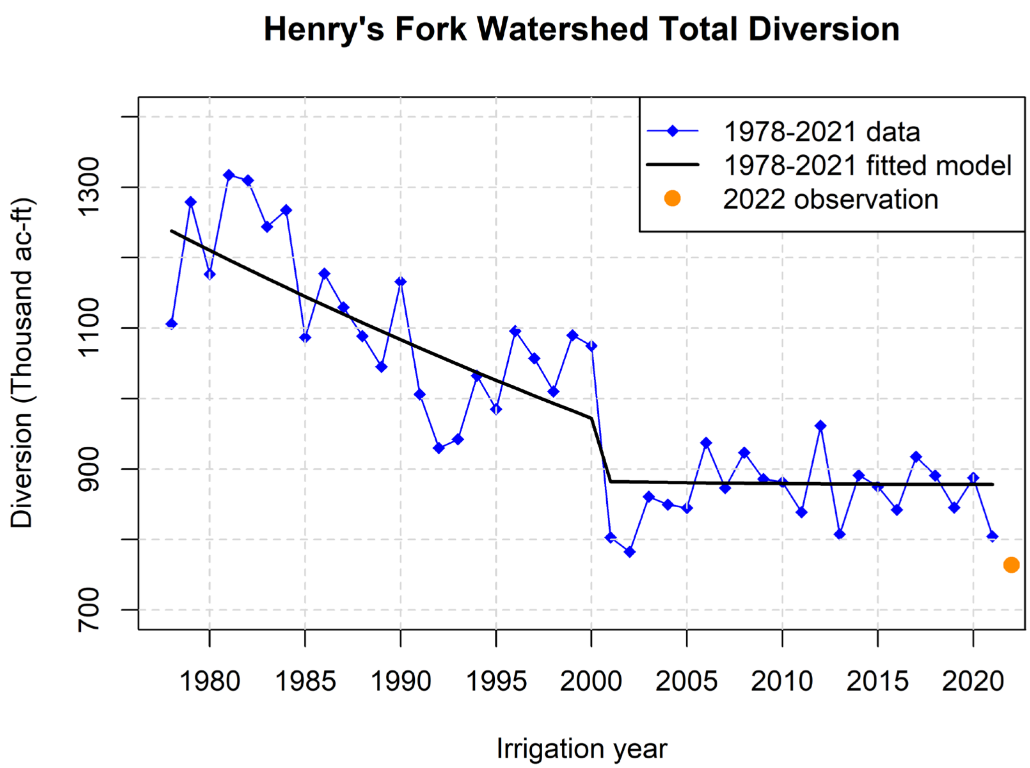

Figure 12. Time series of Henry's Fork watershed total diversion time. Figures do not include diversion into the Crosscut Canal that is delivered to and diverted again in the Teton River. That is, these figures are actual diversion from the watershed as a whole and do not double-count Crosscut Canal diversion.

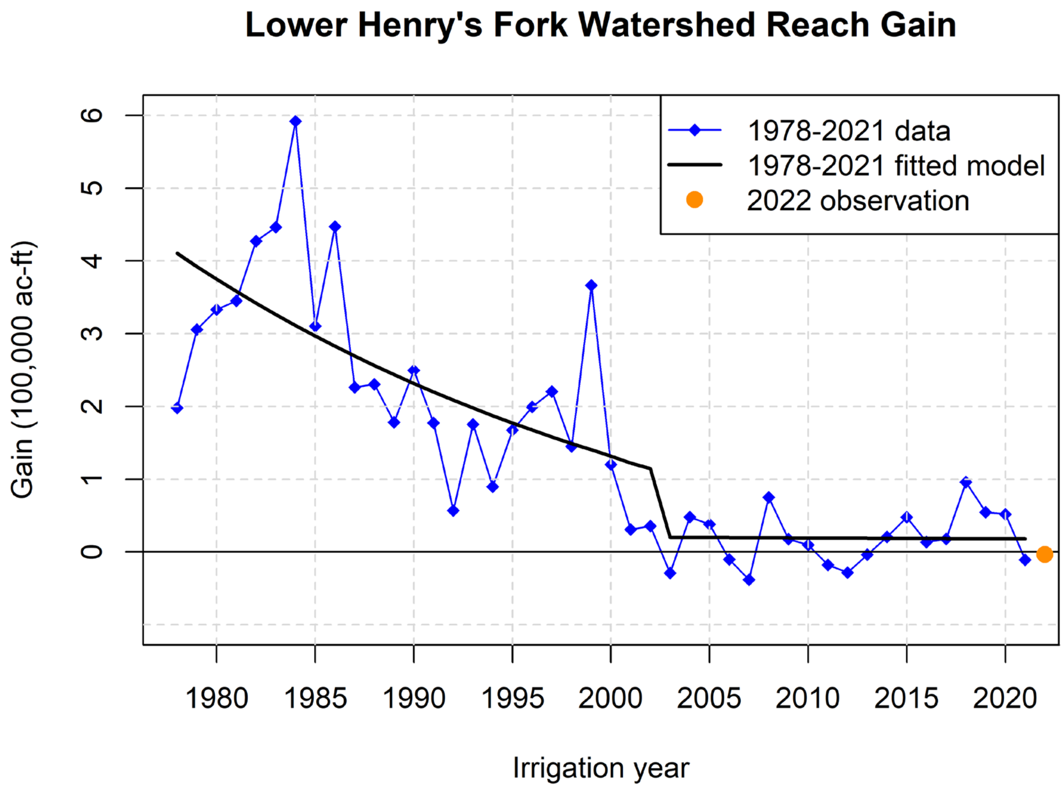

Figure 13. Lower Henry's Fork river reach gain as a function of total watershed diversion.

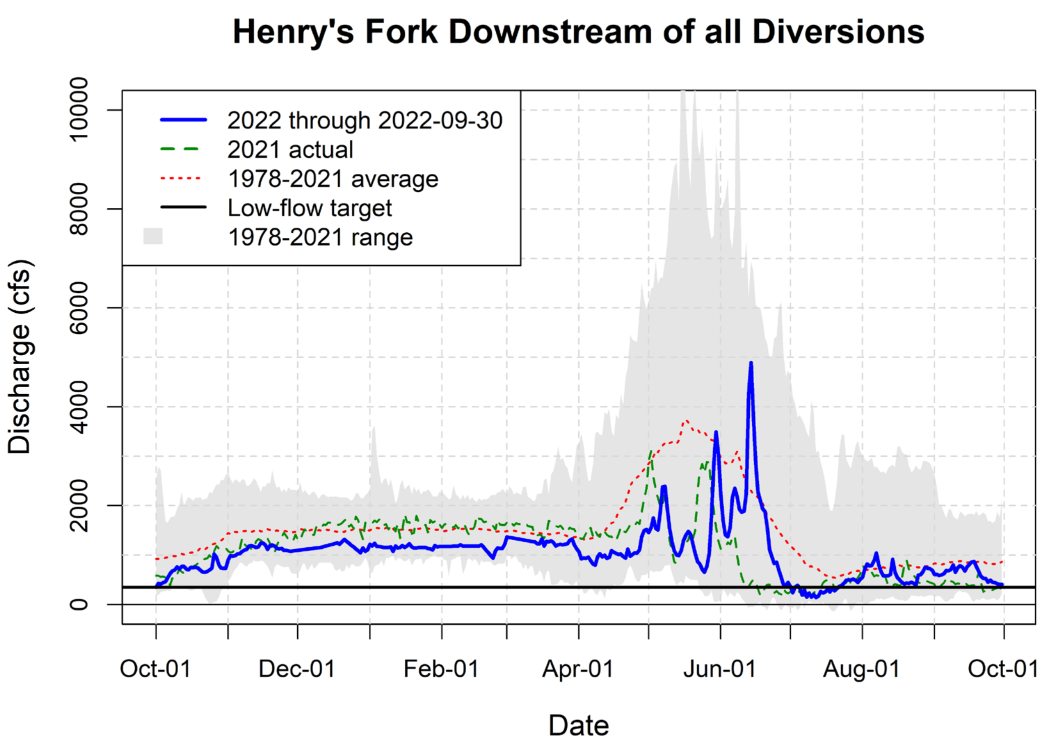

Figure 14. Streamflow in Henry's Fork at Parker (calculated flow downstream of all Henry's Fork mainstem diversions).

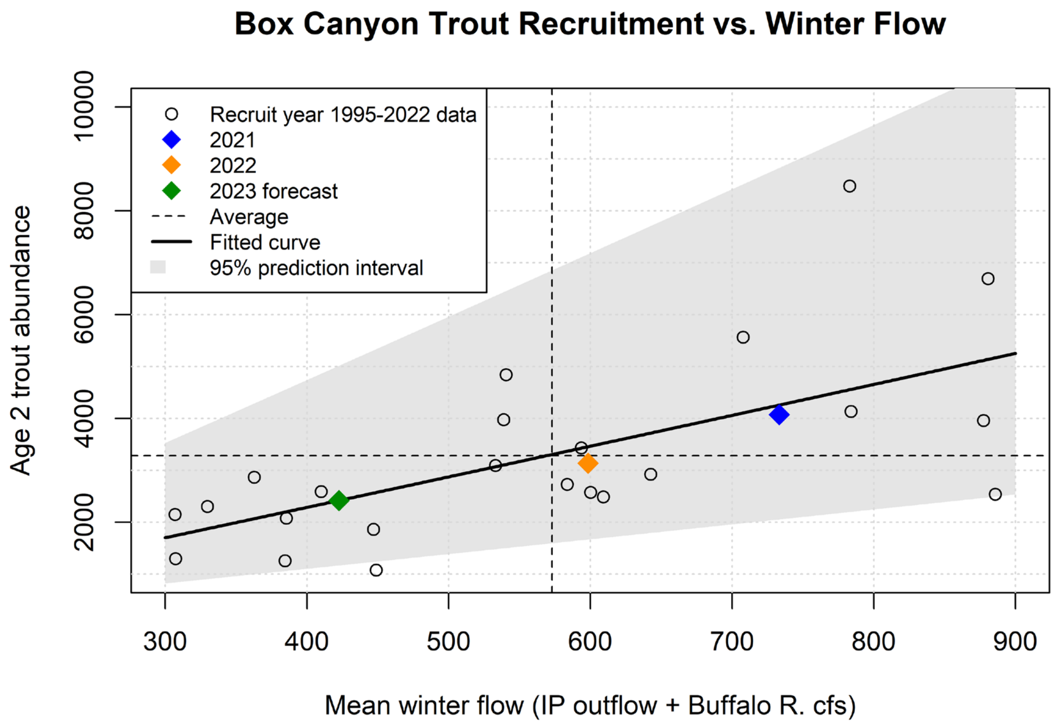

Figure 15. Dependence of trout recruitment in Box Canyon on winter flow.

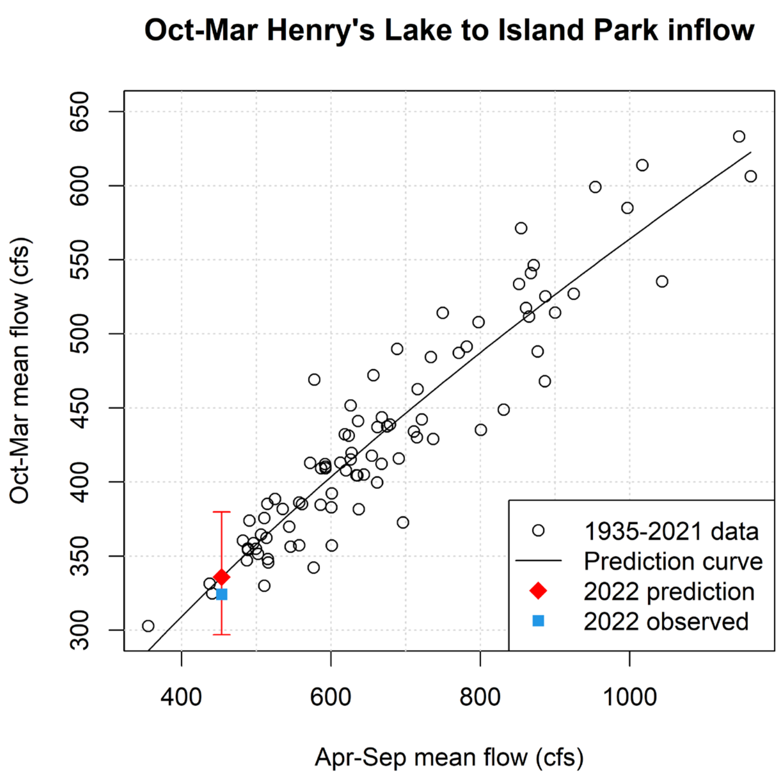

Figure 16. Predicted and observed winter inflow to Island Park Reservoir.

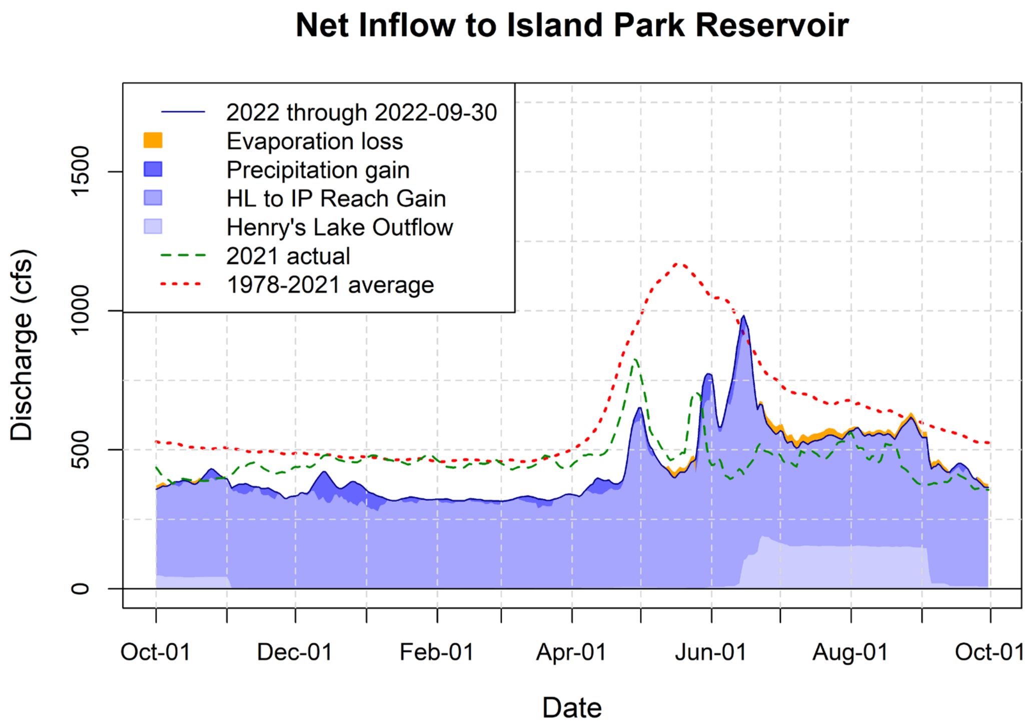

Figure 17. Net inflow to Island Park Reservoir.

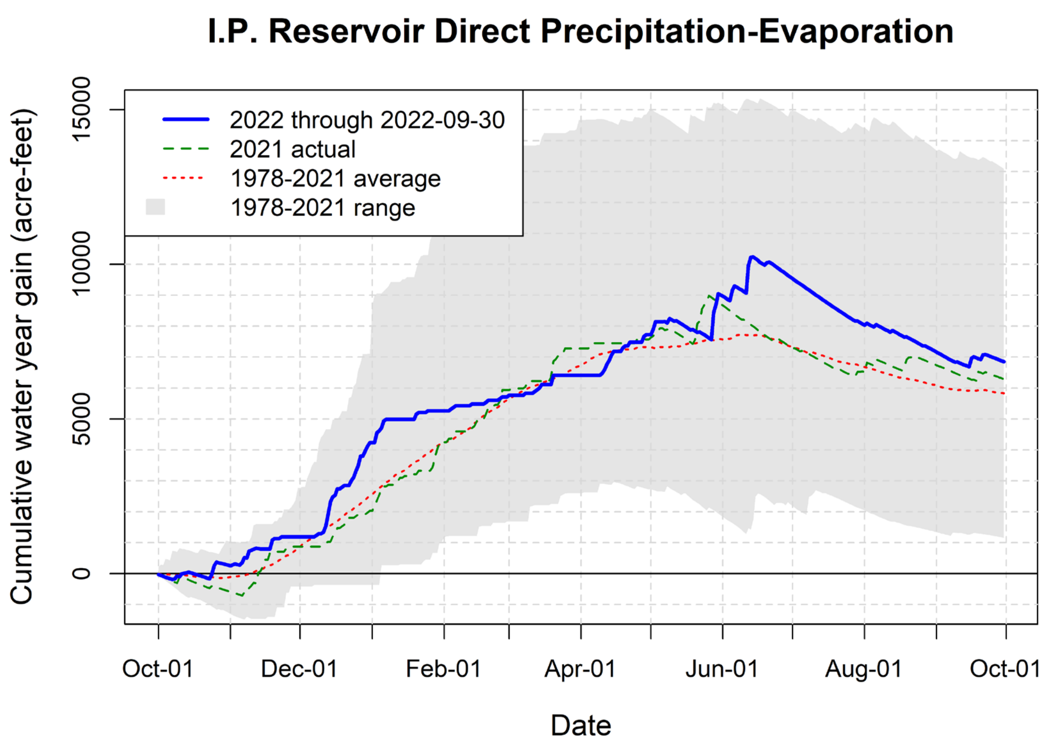

Figure 18. Cumulative gain in Island Park Reservoir from net precipitation (precipitation minus evaporation). Increasing trend indicates a net gain (precipitation is greater than evaporation), and decreasing trend indicates a net loss (evaporation greater than precipitation).

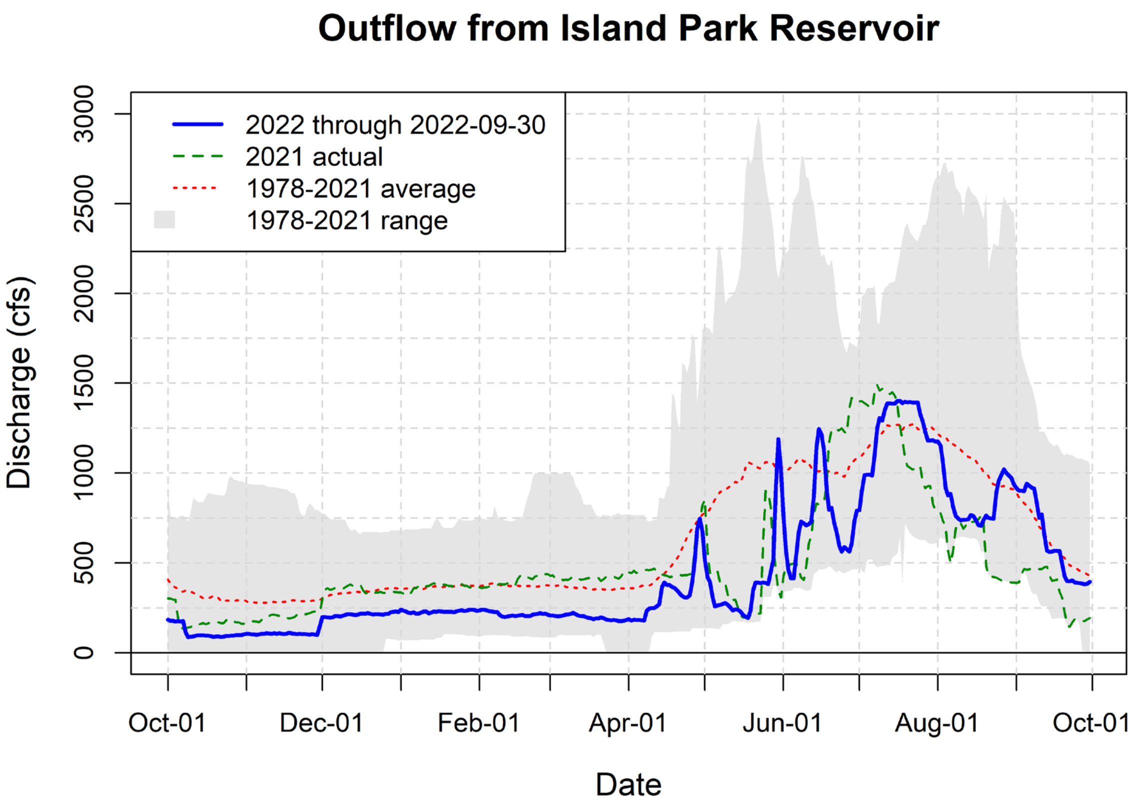

Figure 19. Outflow from Island Park Reservoir.

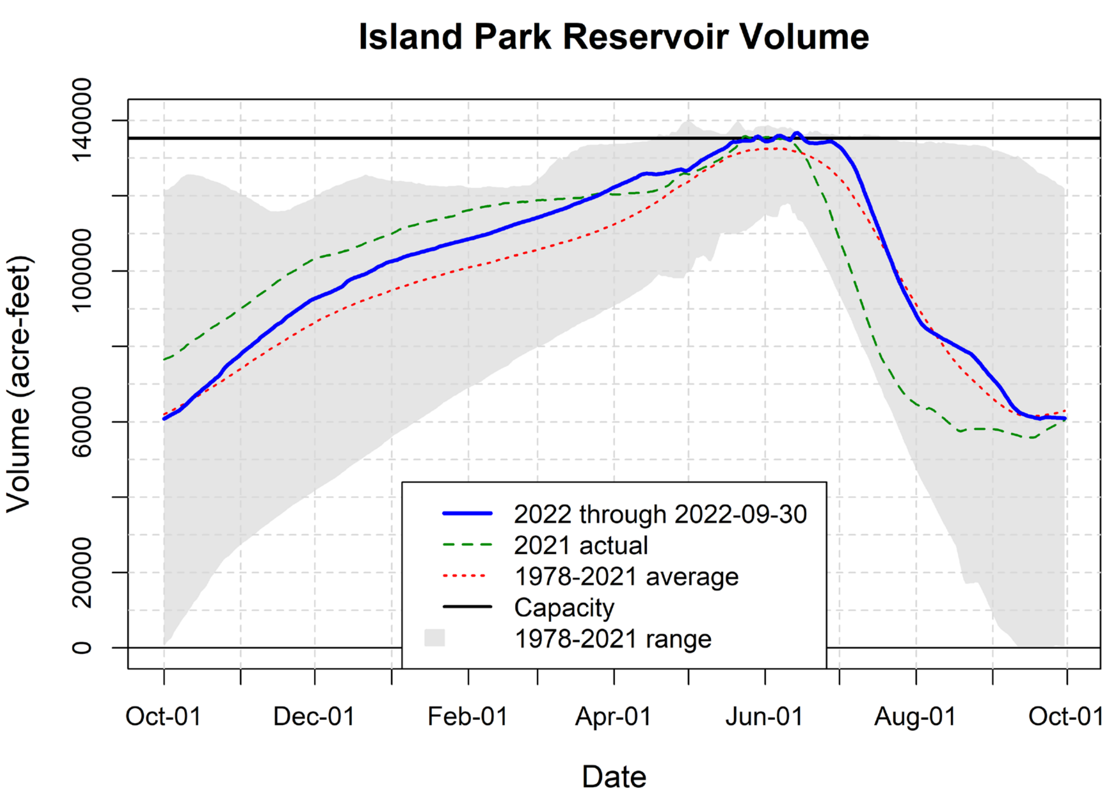

Figure 20. Island Park Reservoir volume.

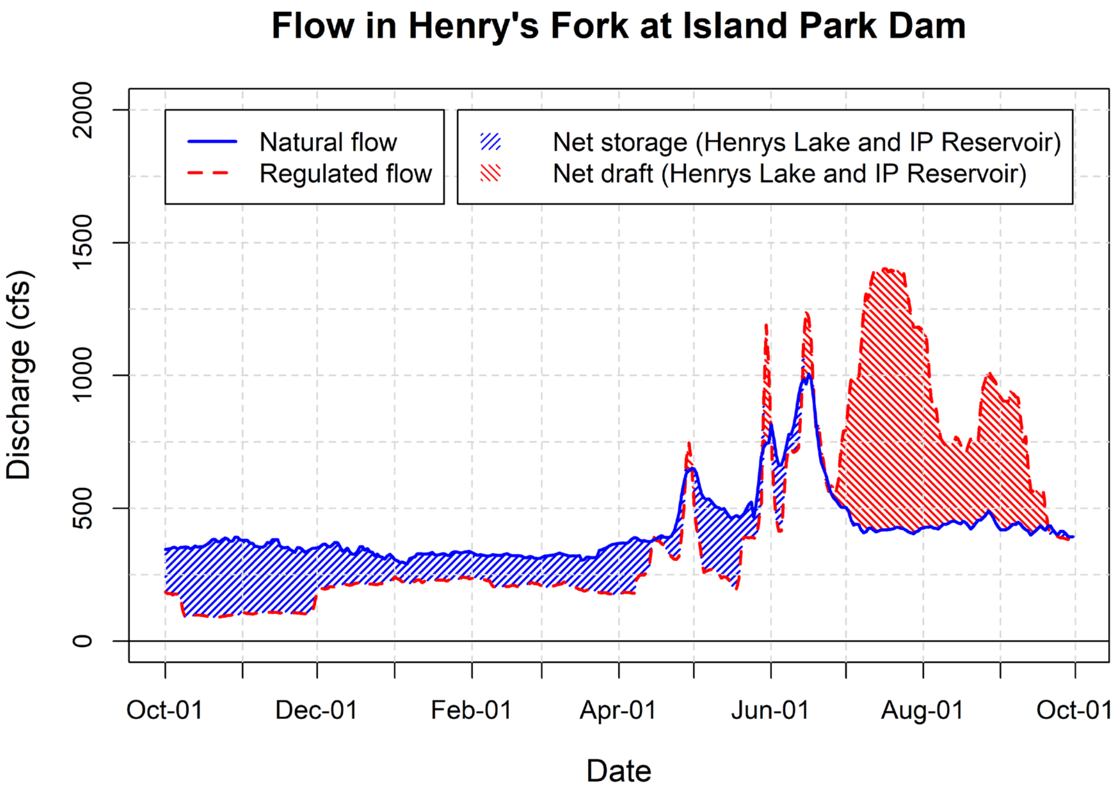

Figure 21. Natural and regulated flow in the Henry's Fork at Island Park Dam, showing net storage and draft of Island Park Reservoir and Henrys Lake.

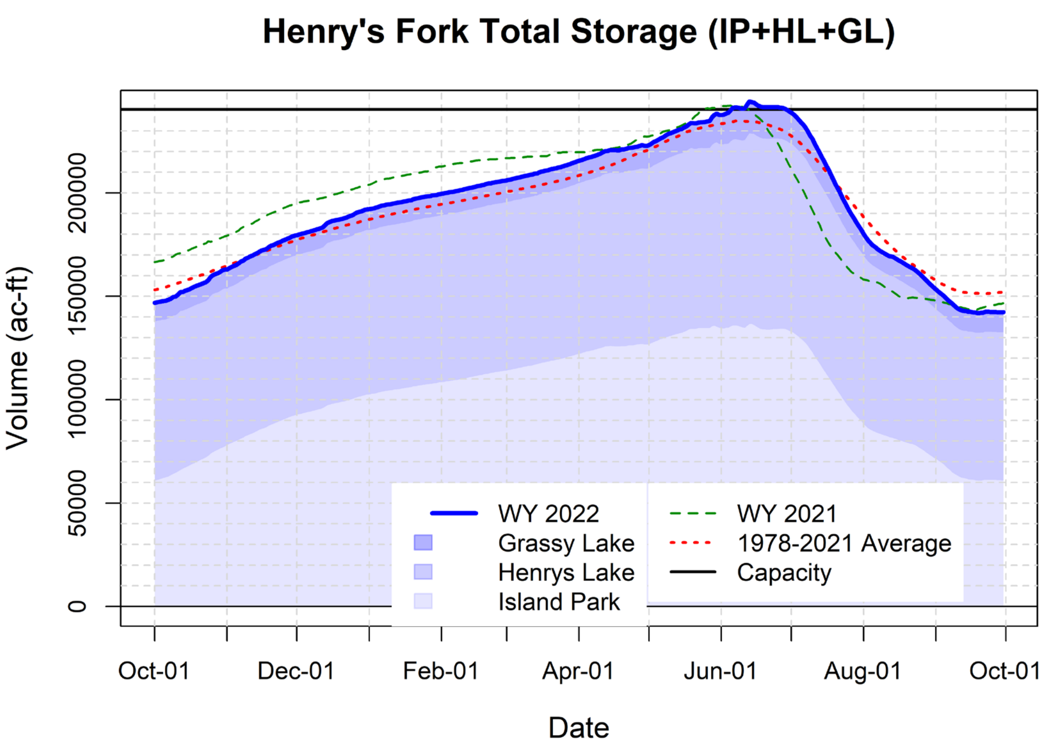

Figure 22. Combined volume of Henry's Lake, Island Park Reservoir and Grassy Lake.

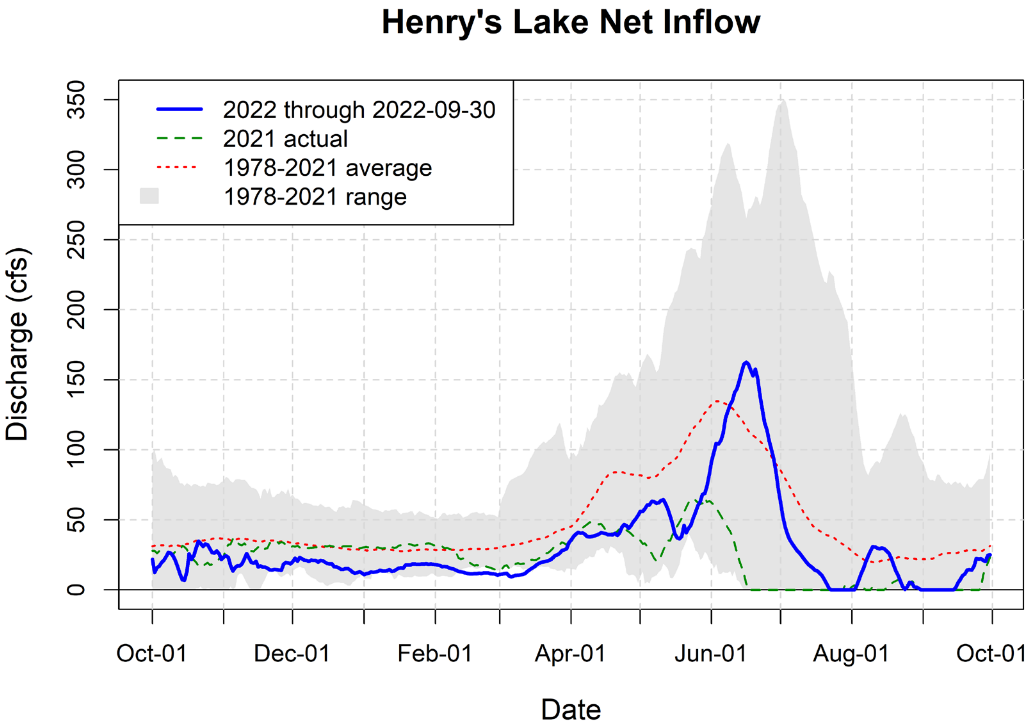

Figure 23. Inflow to Henry's Lake. Zero values indicate that evaporation from the lake surface exceeds inflow from streams and springs.

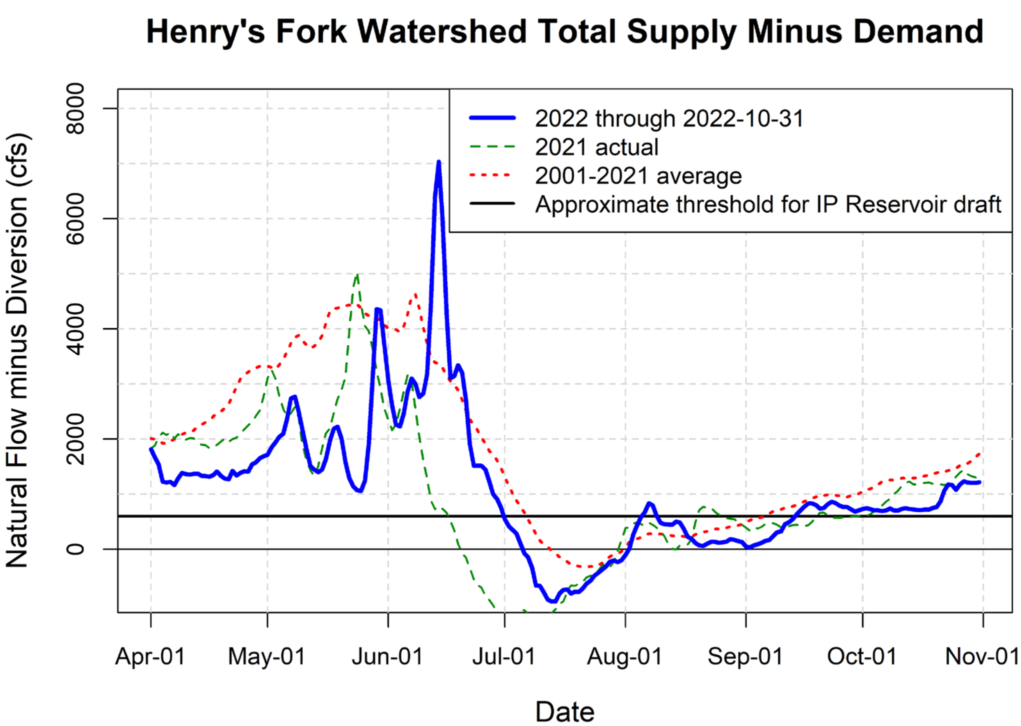

Figure 24. Henry's Fork watershed supply and demand (natural flow minus total diversion). The horizontal black line indicates the approximate threshold for Island Park Reservoir draft ("600-cfs rule").

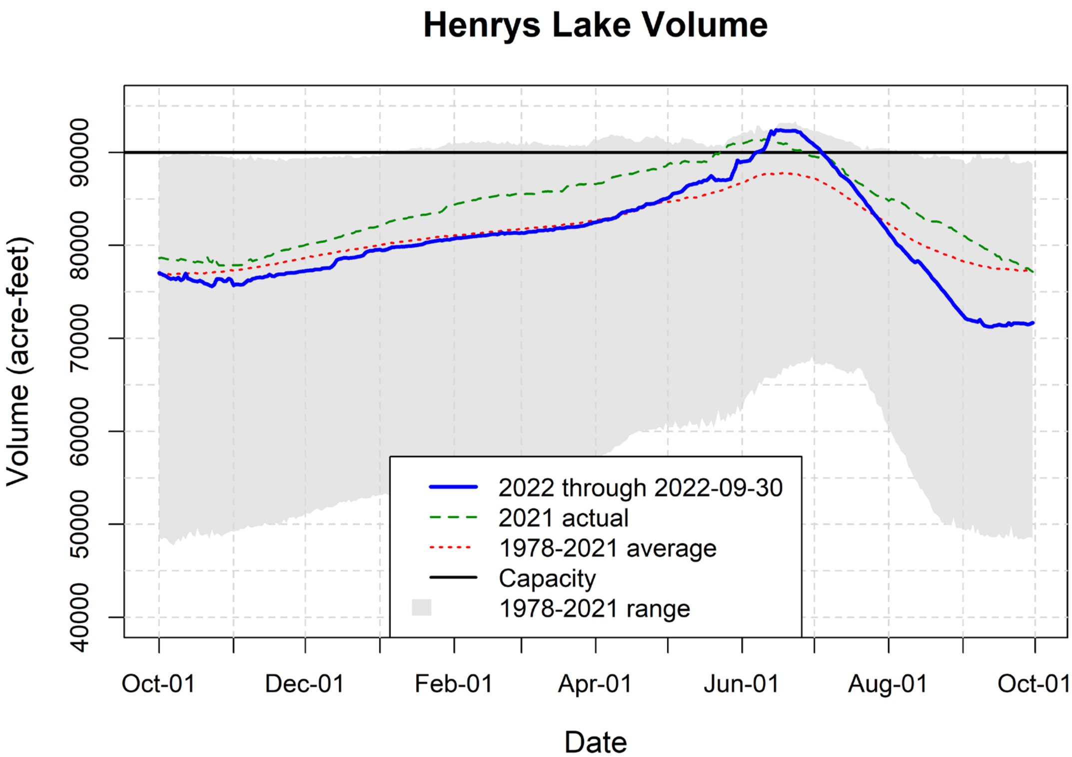

Figure 25. Henry's Lake volume.

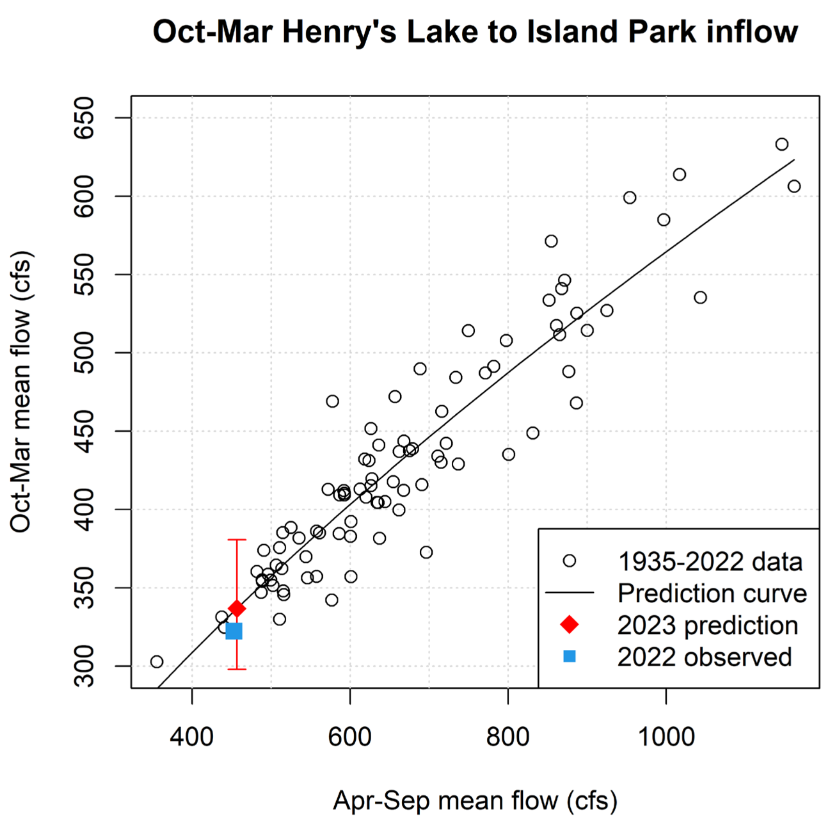

Figure 26. Predicted inflow to Island Park Reservoir for winter 2023, showing observed value for winter 2022 for comparison.

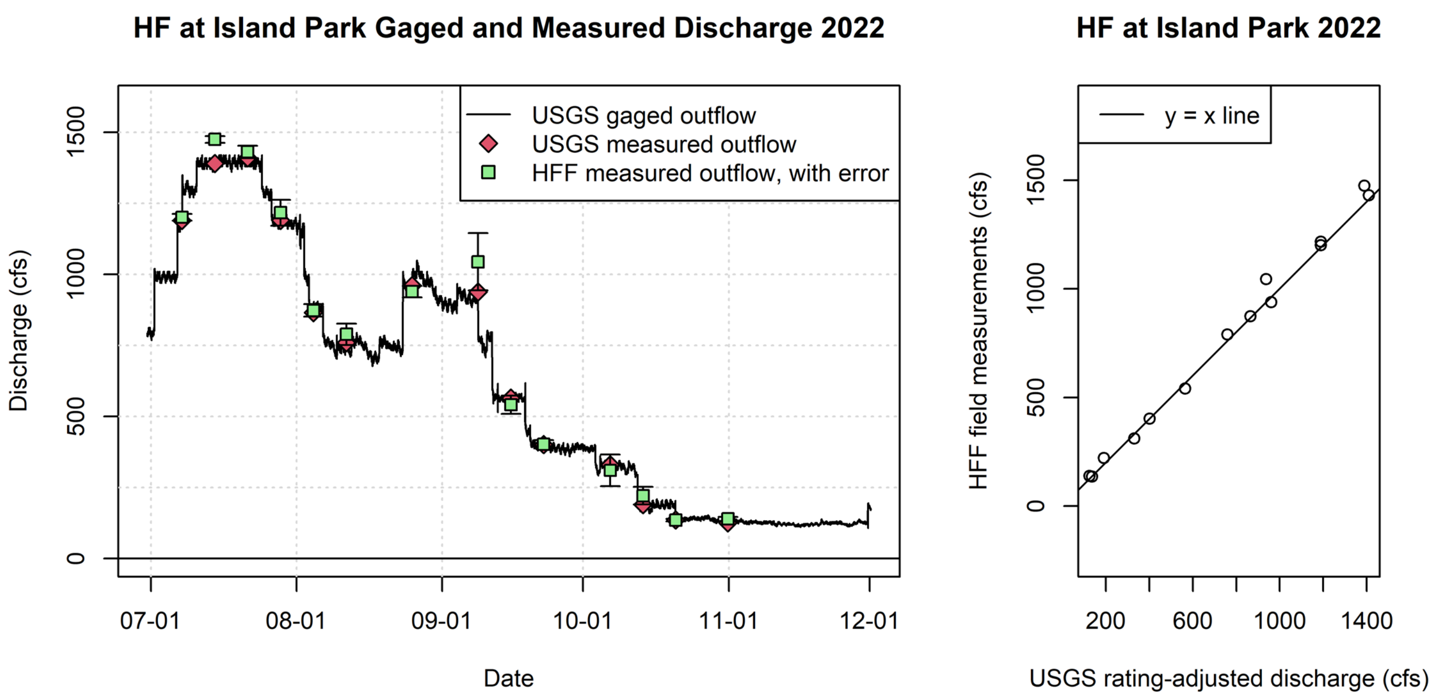

Figure 27. Island Park Reservoir outflow, showing all USGS and HFF streamflow measurements during summer/fall 2022 (left) and comparison of HFF measurements and USGS gaged discharge (right).

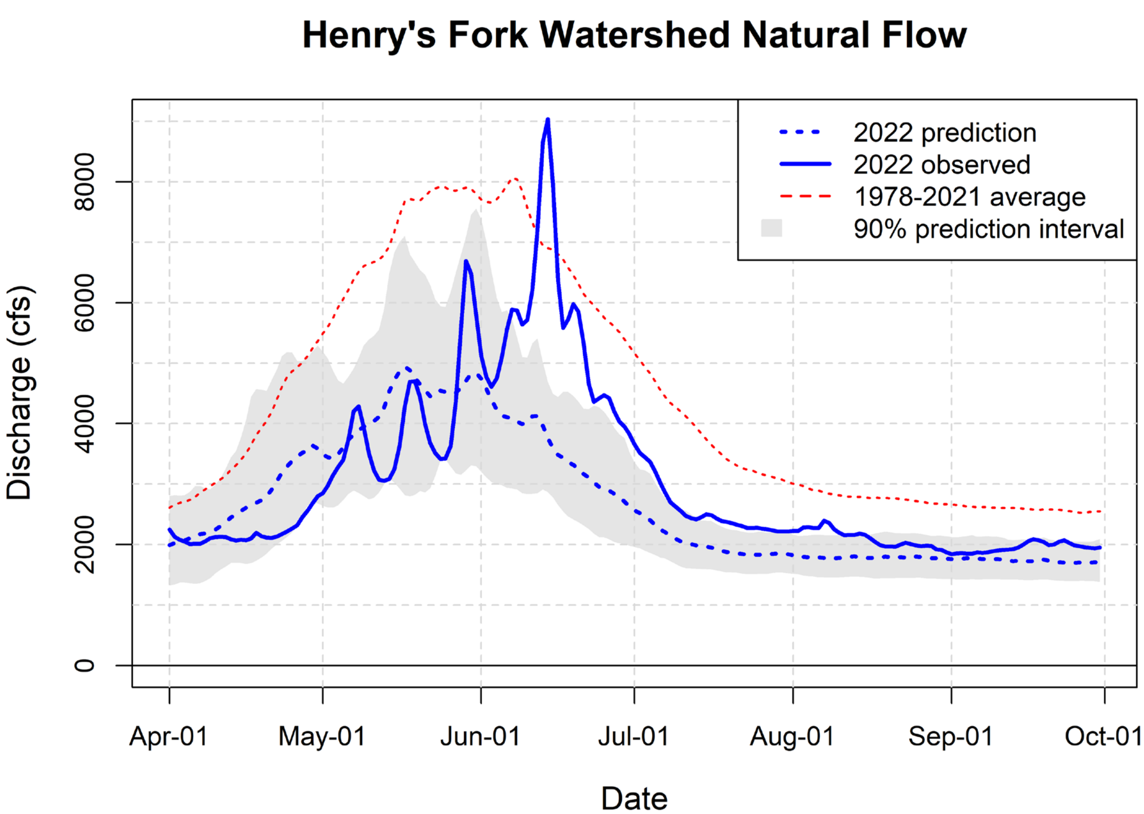

Figure 28. Predicted and observed watershed-total natural flow.

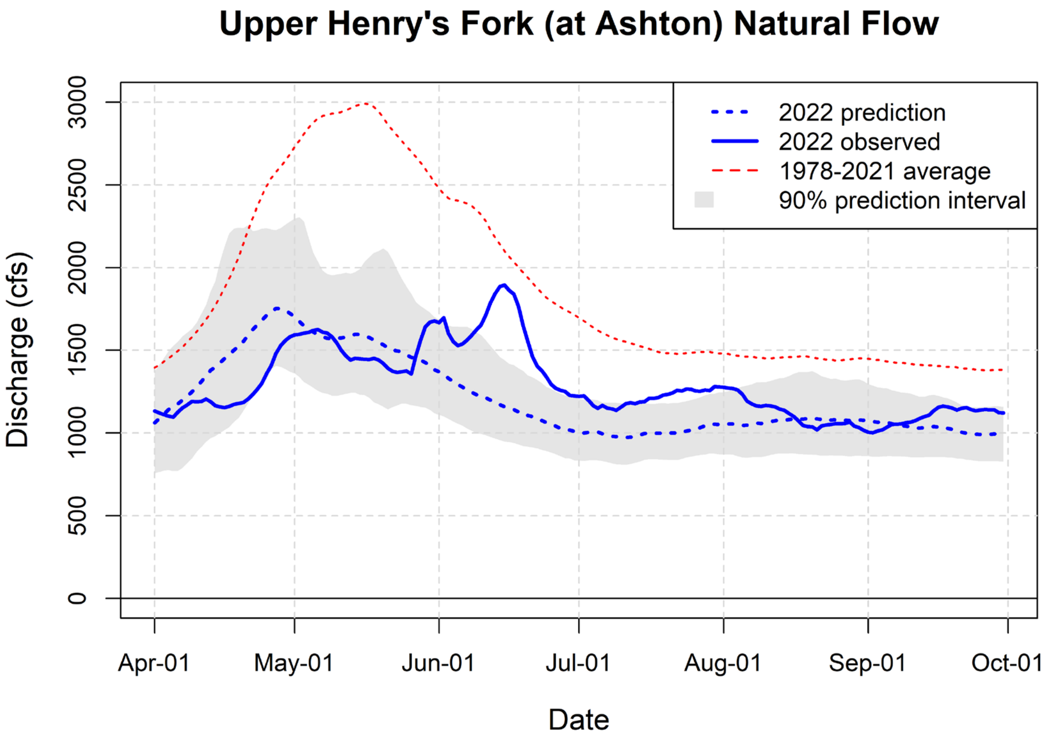

Figure 29. Predicted and observed natural flow in at Ashton (upper Henry's Fork subwatershed).

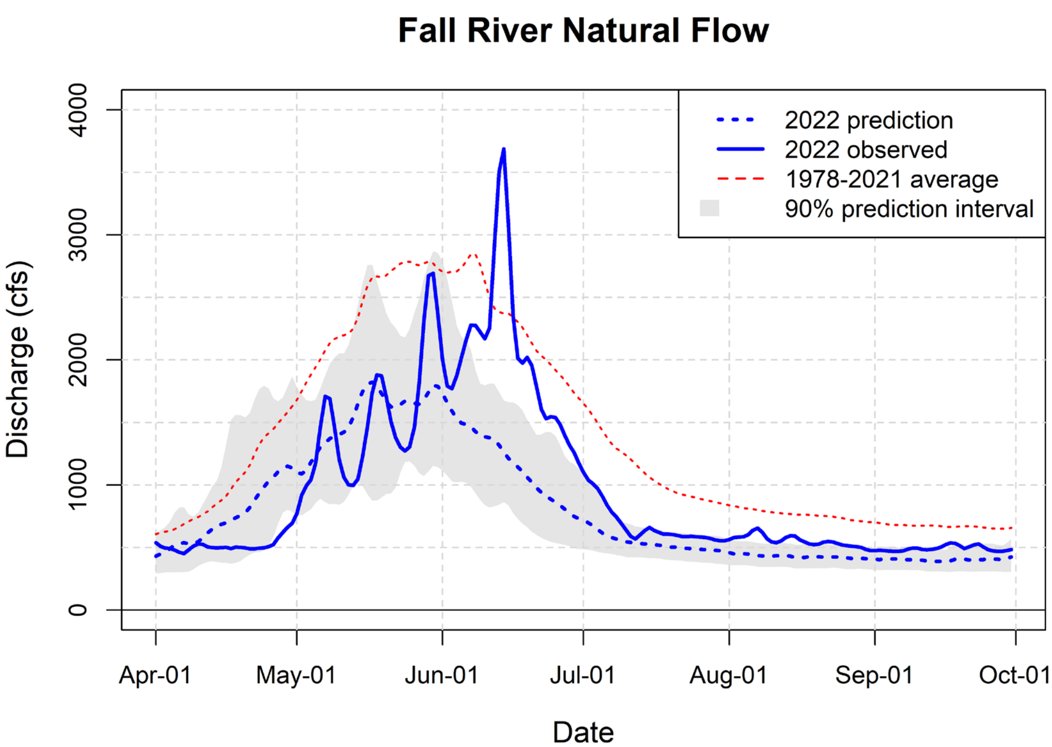

Figure 30. Predicted and observed natural flow in Fall River.

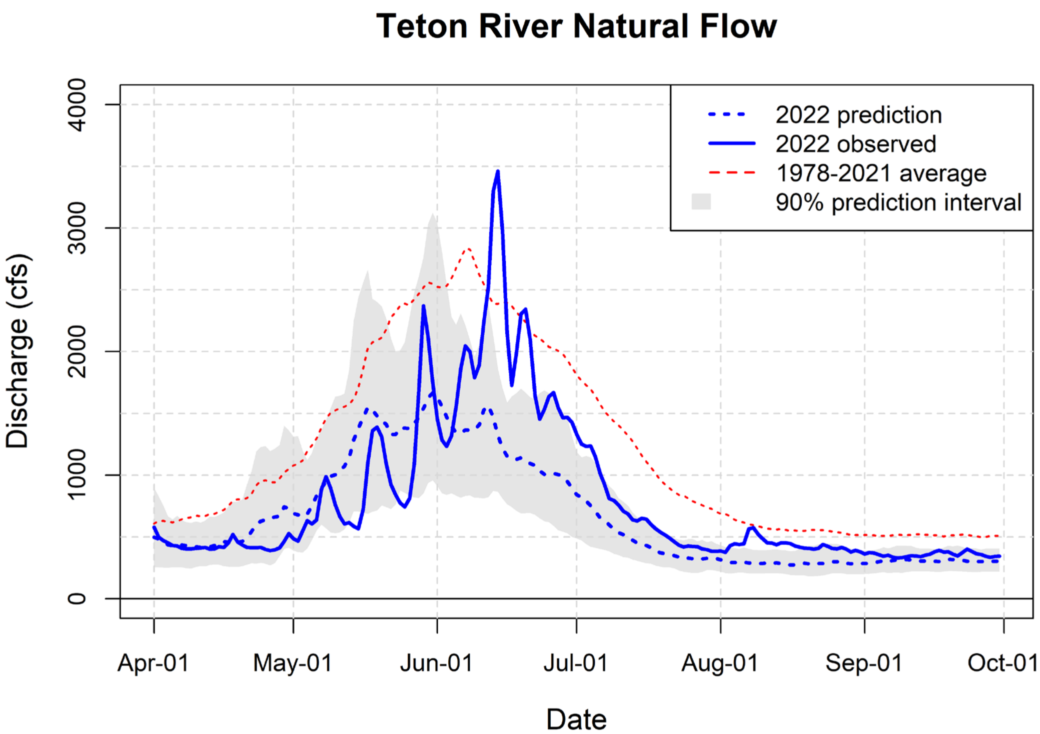

Figure 31. Predicted and observed natural flow in Teton River.

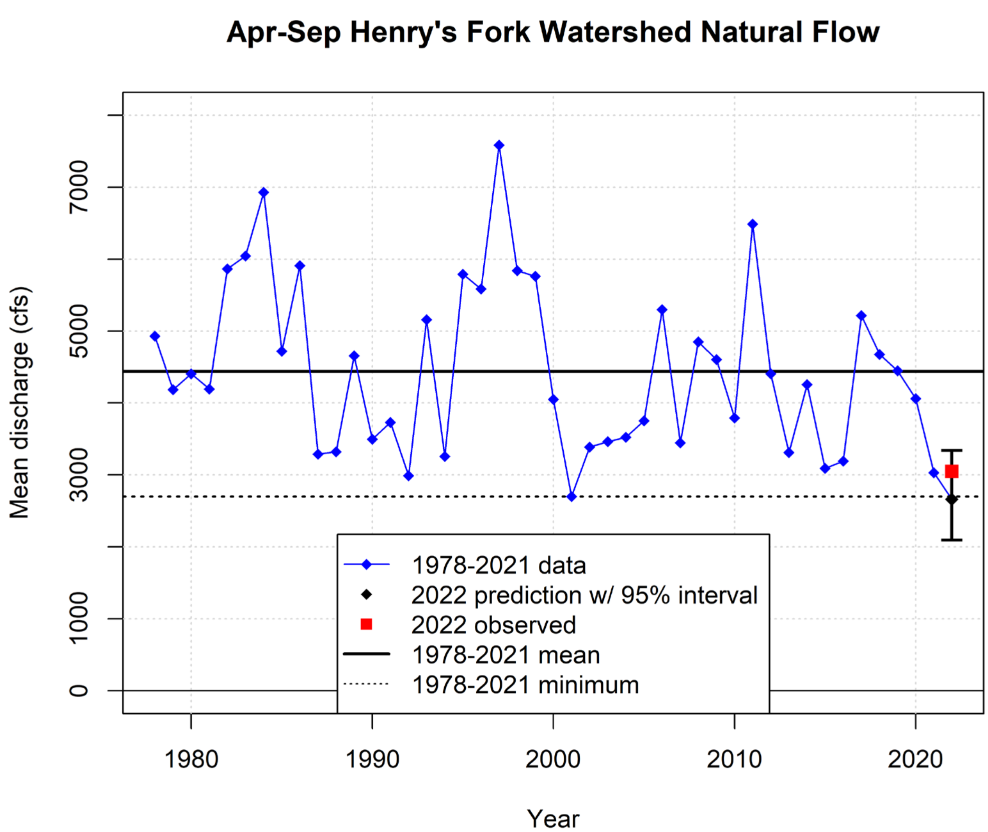

Figure 32. Predicted and observed April-September natural flow for the Henry's Fork watershed.

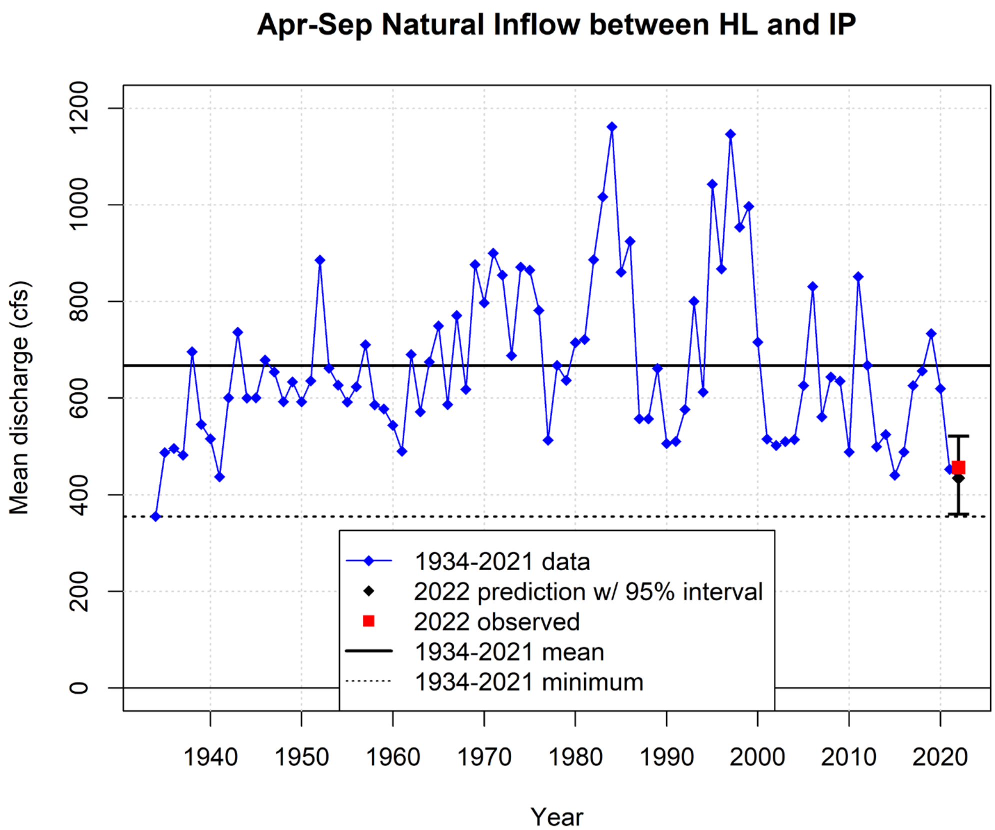

Figure 33. Predicted and observed April-September natural flow between Henry's Lake and Island Park.

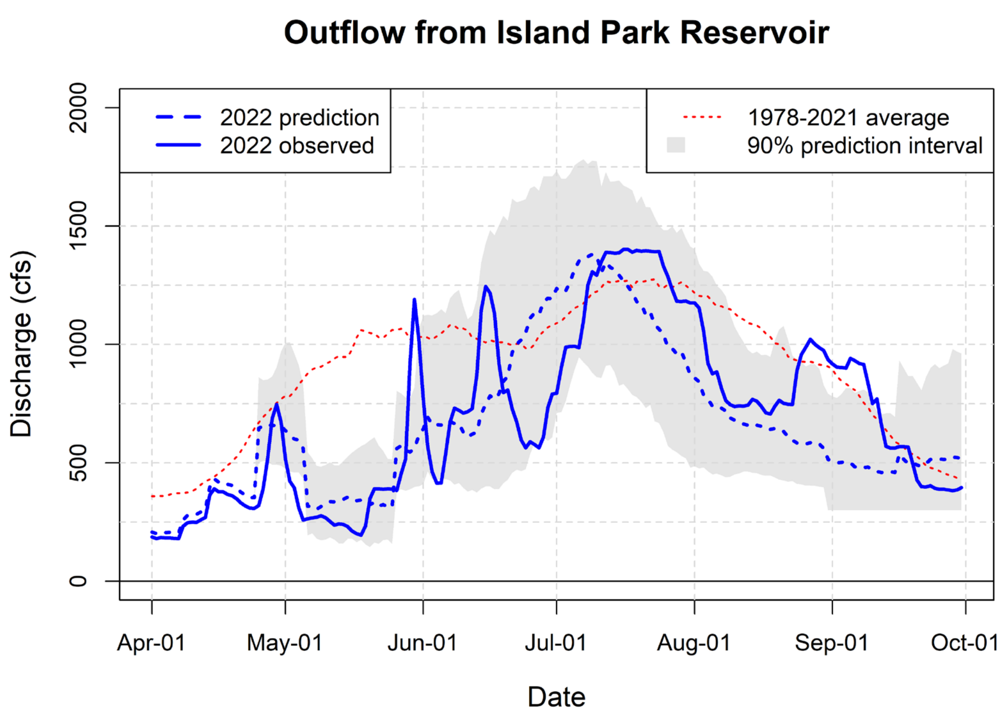

Figure 34. Predicted and observed outflow from Island Park Reservoir.

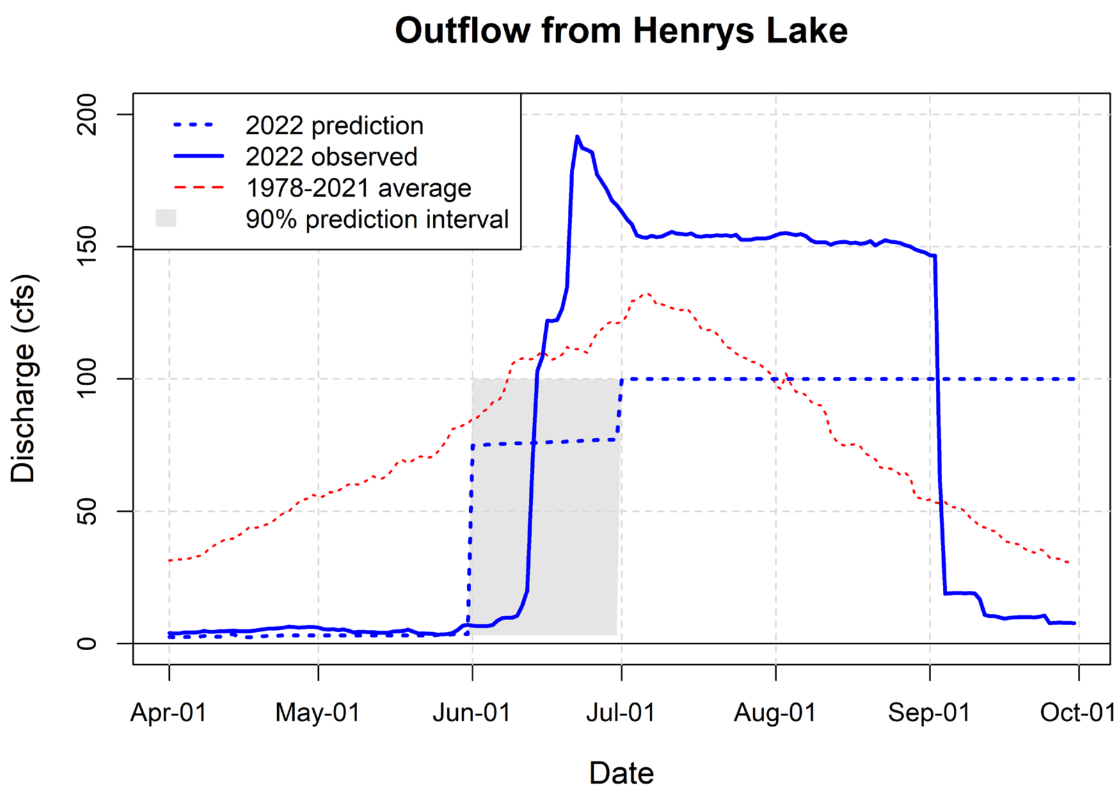

Figure 35. Predicted and observed outflow from Henry's Lake.

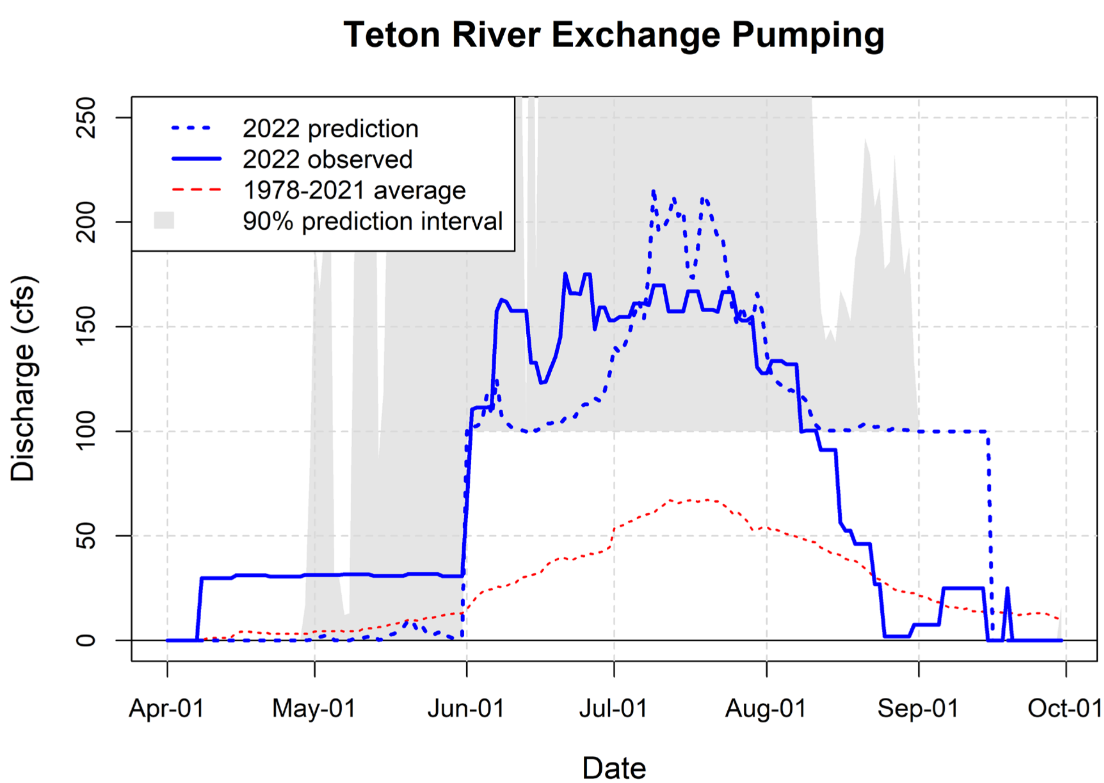

Figure 36. Predicted and observed exchange well pumping into the Teton River.

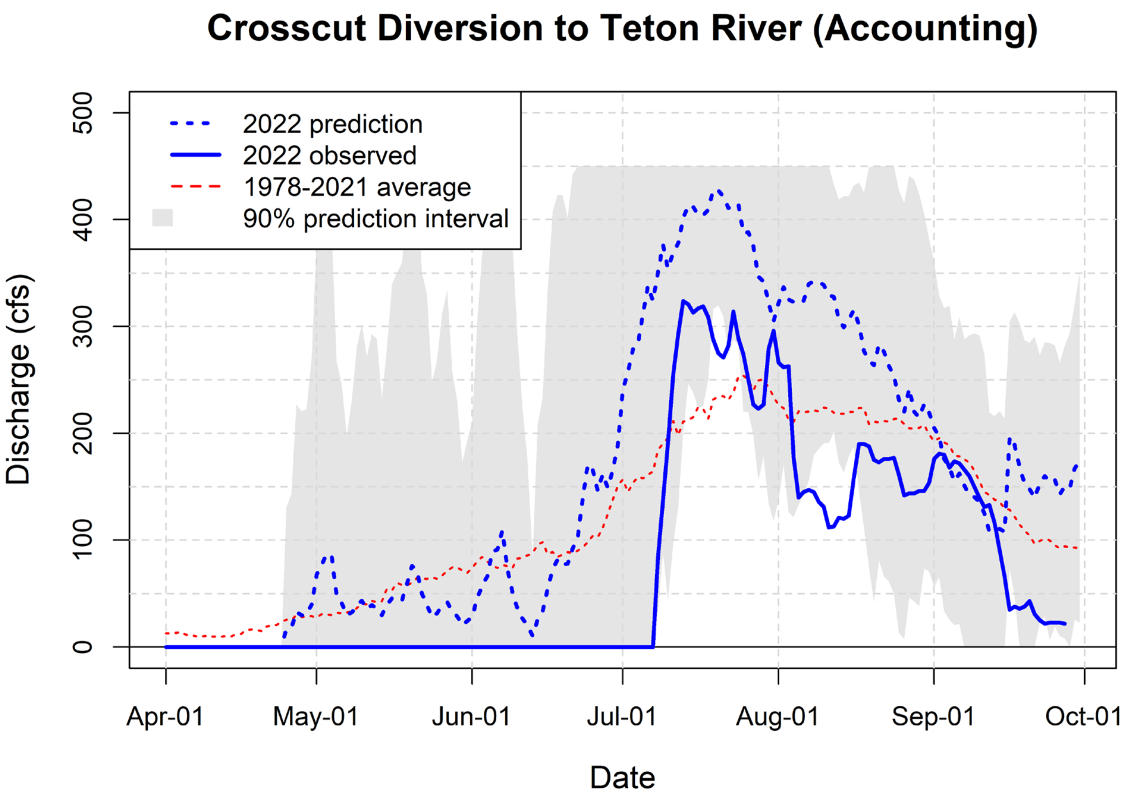

Figure 37. Predicted and observed diversion into the Crosscut Canal for delivery to the Teton River.

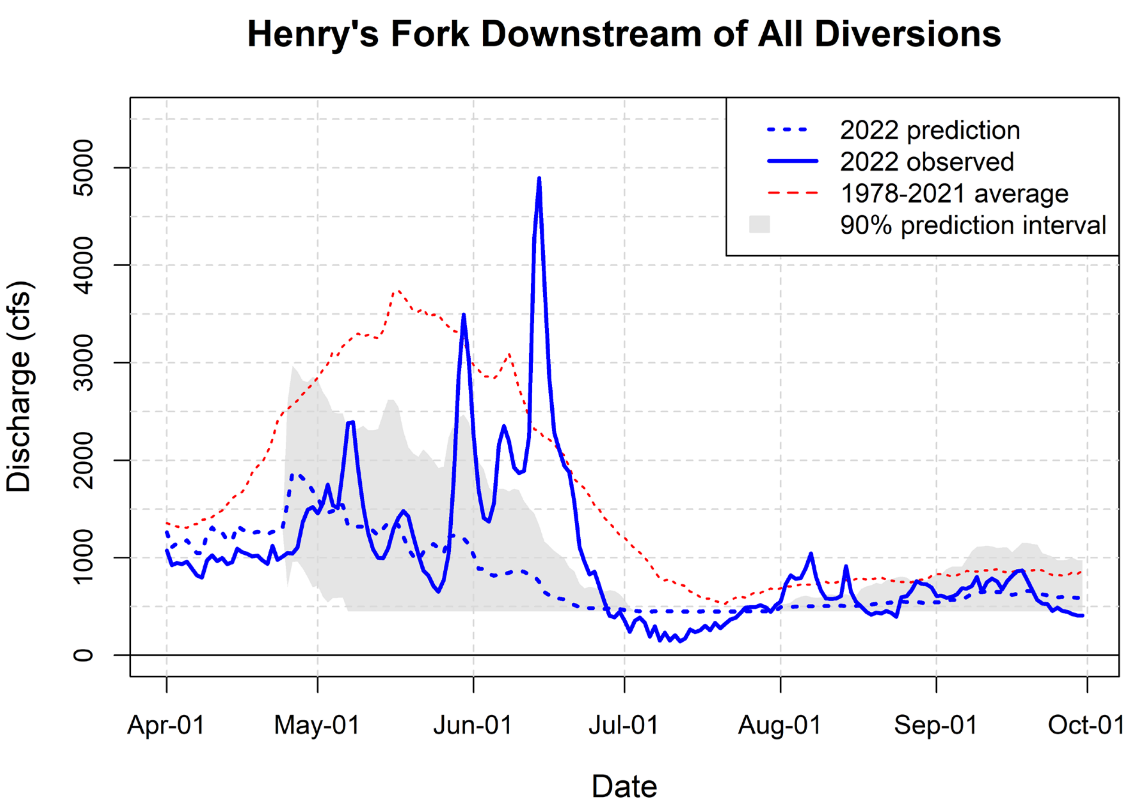

Figure 38. Predicted and observed streamflow in Henry's Fork downstream of all diversions.

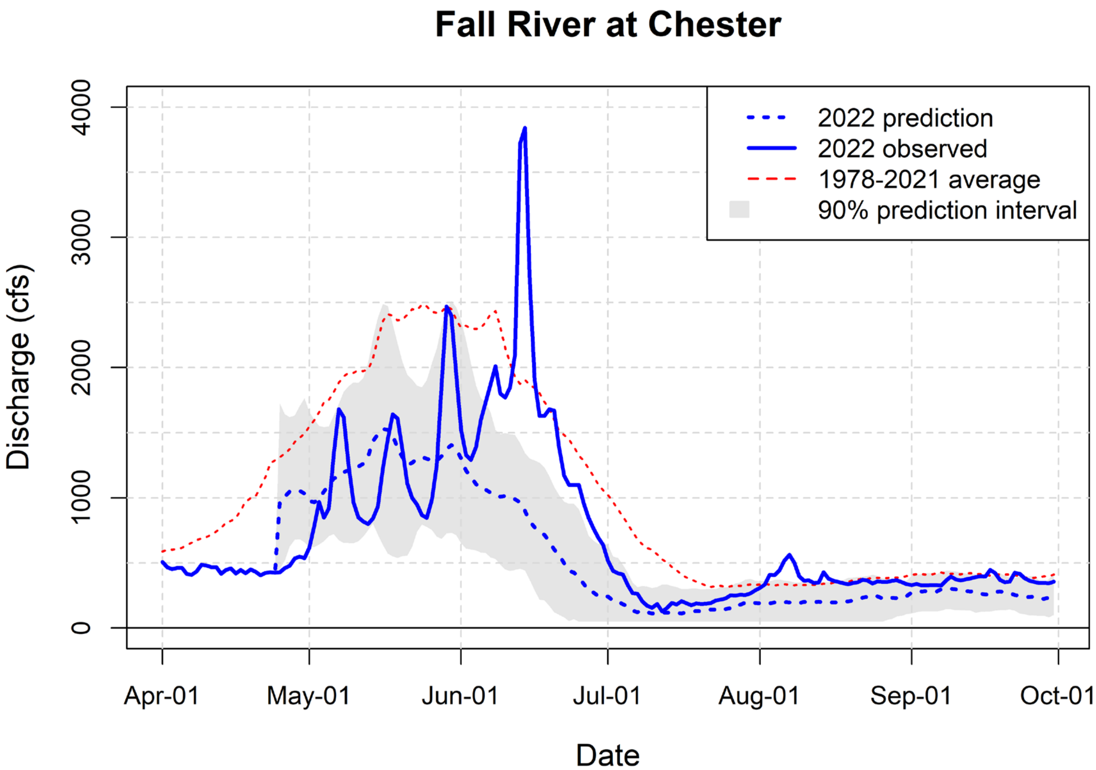

Figure 39. Predicted and observed regulated streamflow in Fall River at Chester.

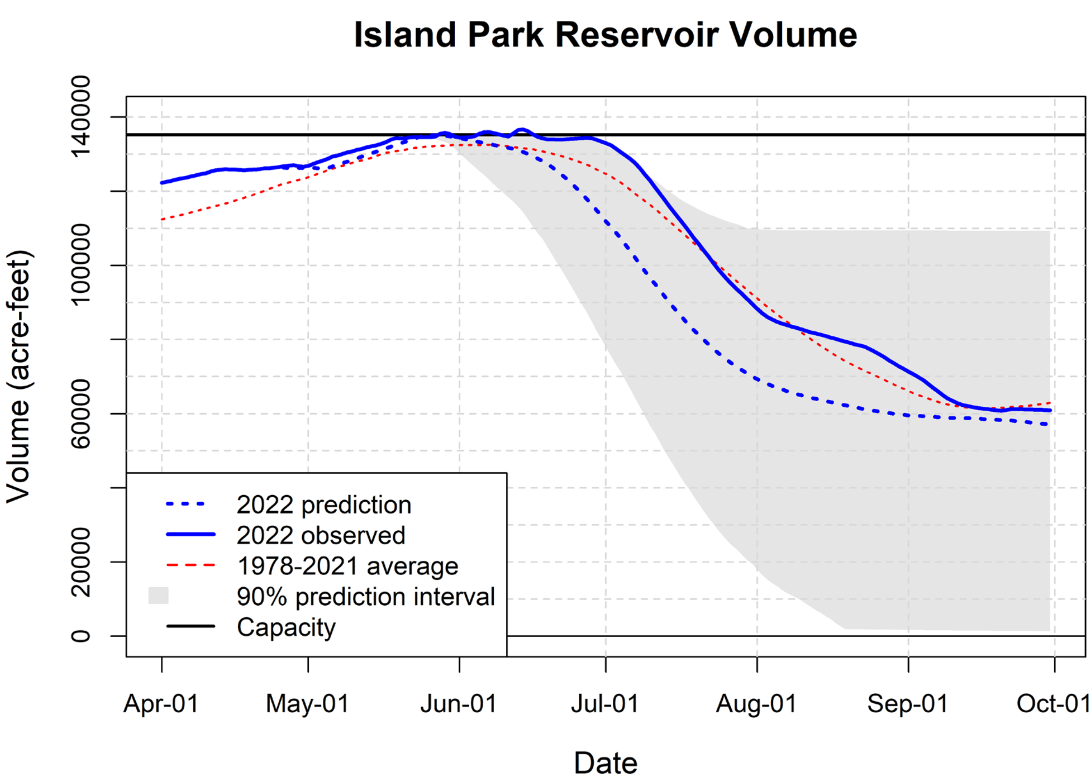

Figure 40. Predicted and observed volume in Island Park Reservoir.

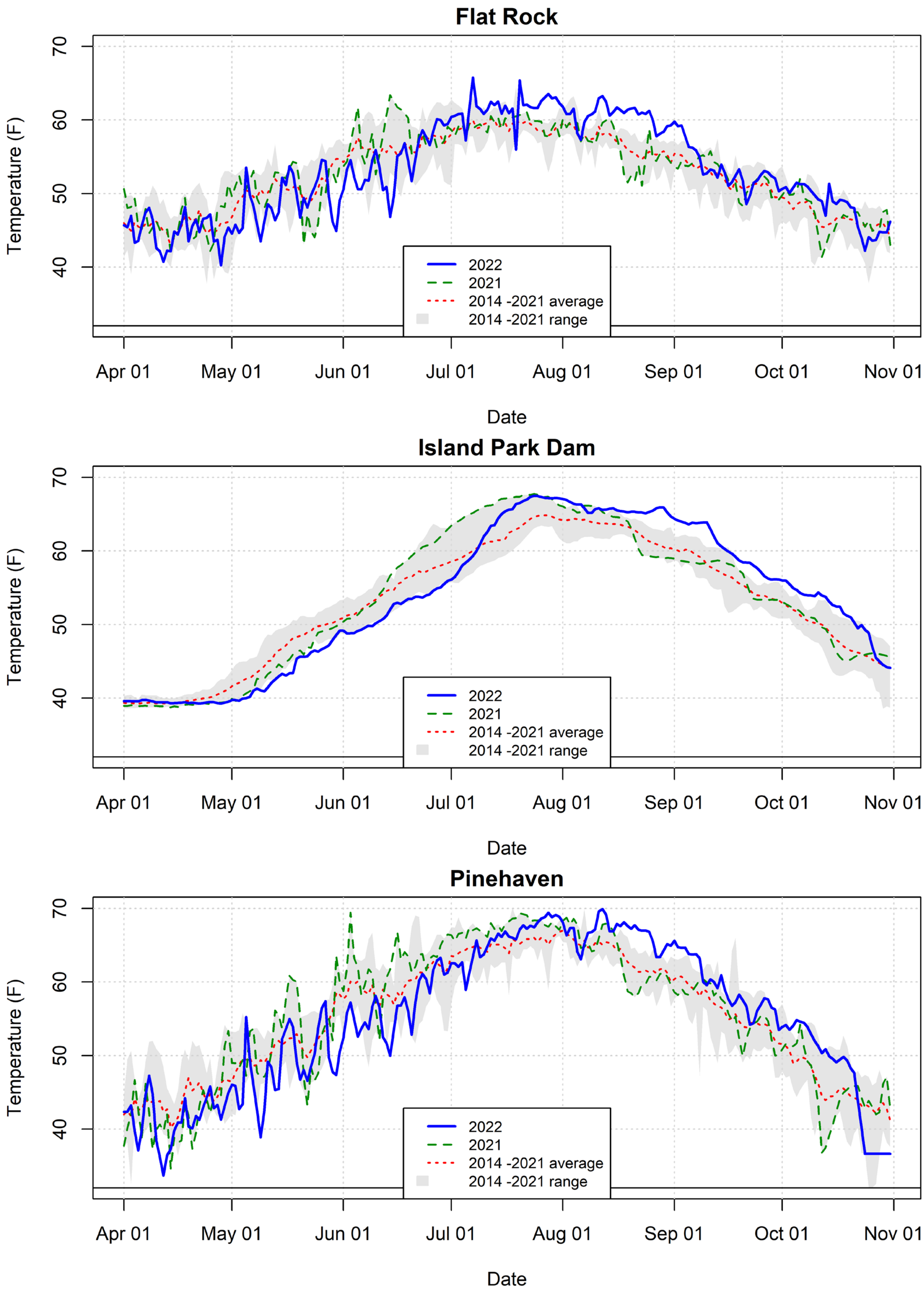

Figure 41. Water temperature at the three upper watershed water quality stations.

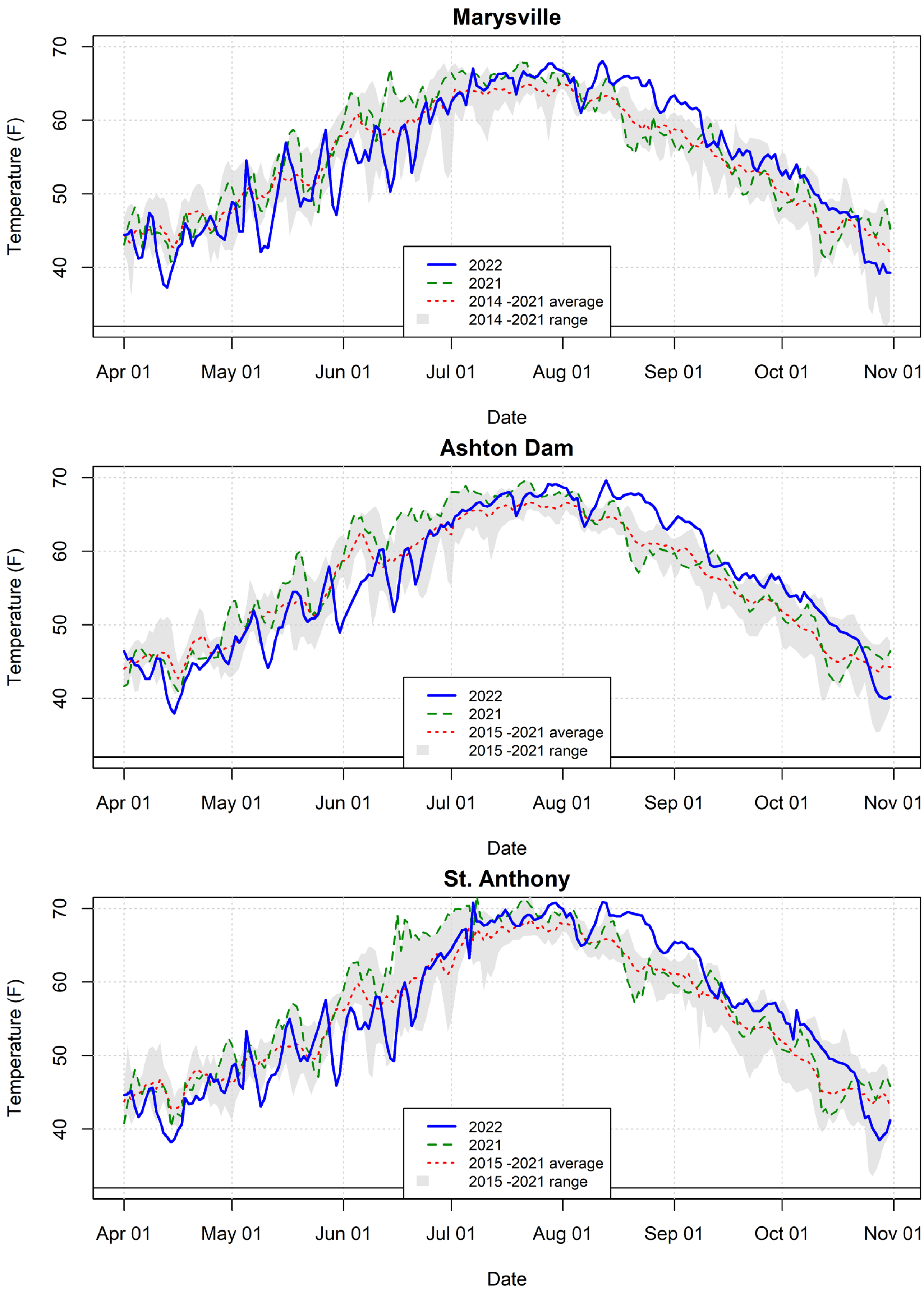

Figure 42. Water temperature at the three lower watershed water quality stations.

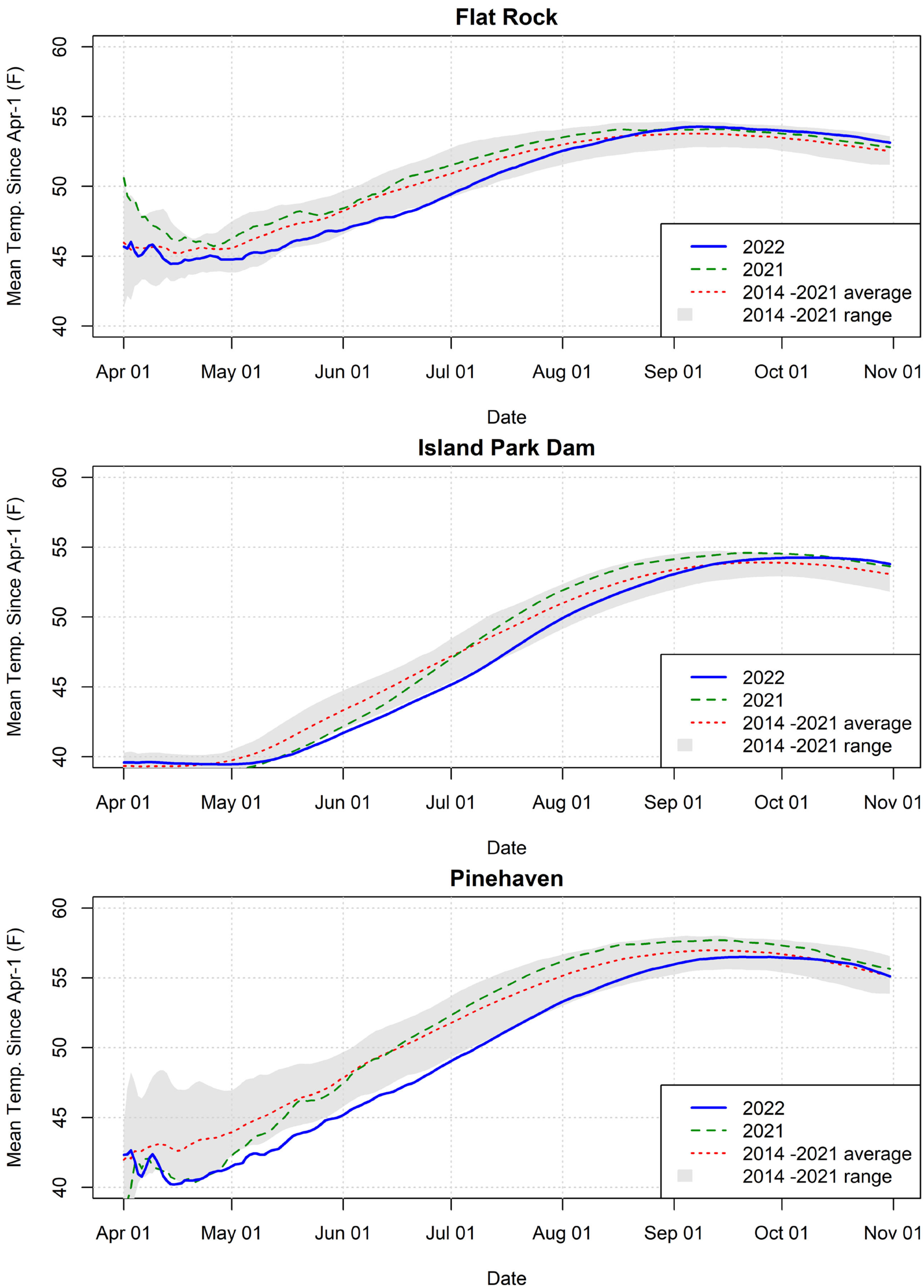

Figure 43. Cumulative water temperature from April 1 at the three upper watershed water quality stations.

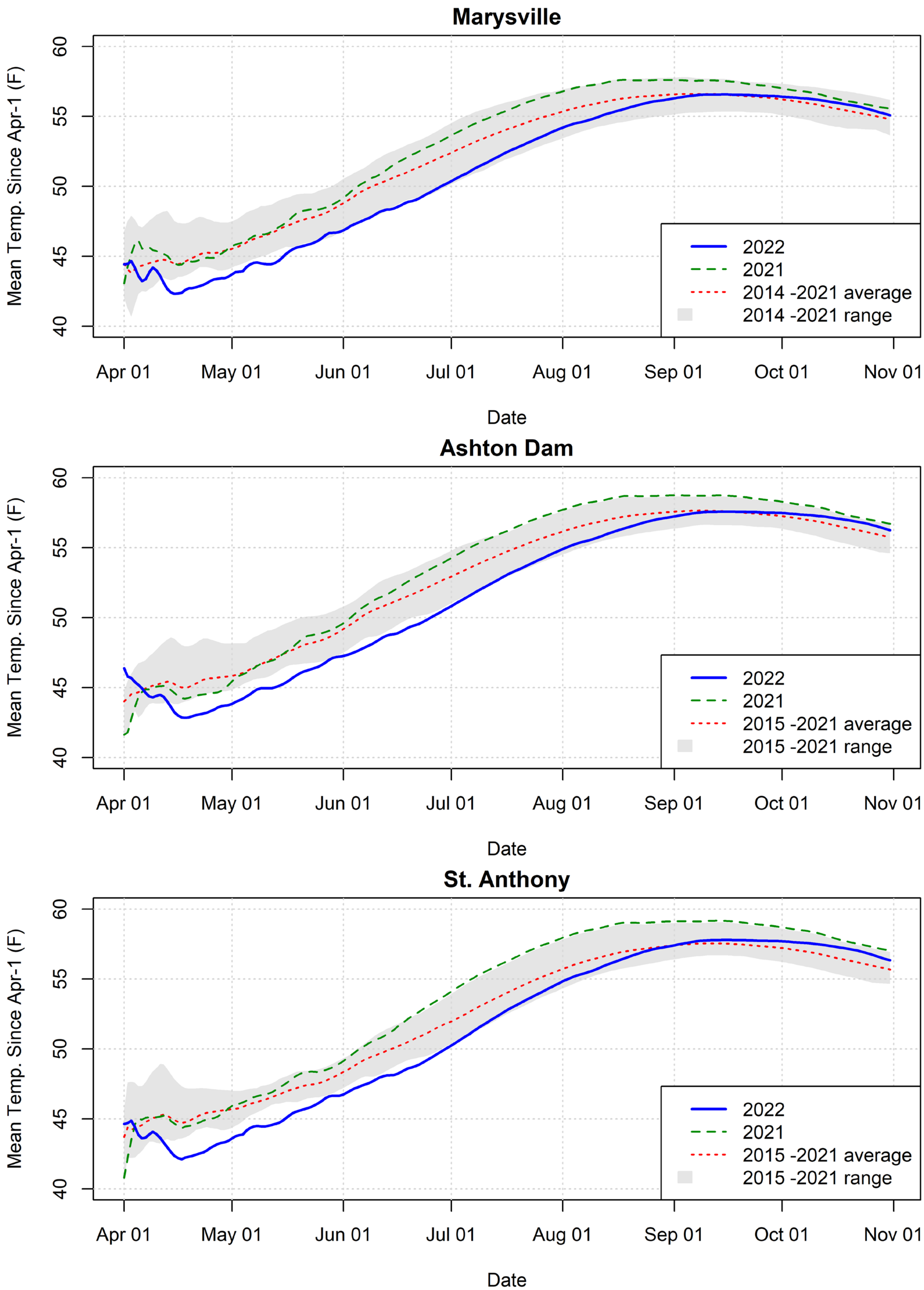

Figure 44. Cumulative water temperature from April 1 at the three lower watershed water quality stations.

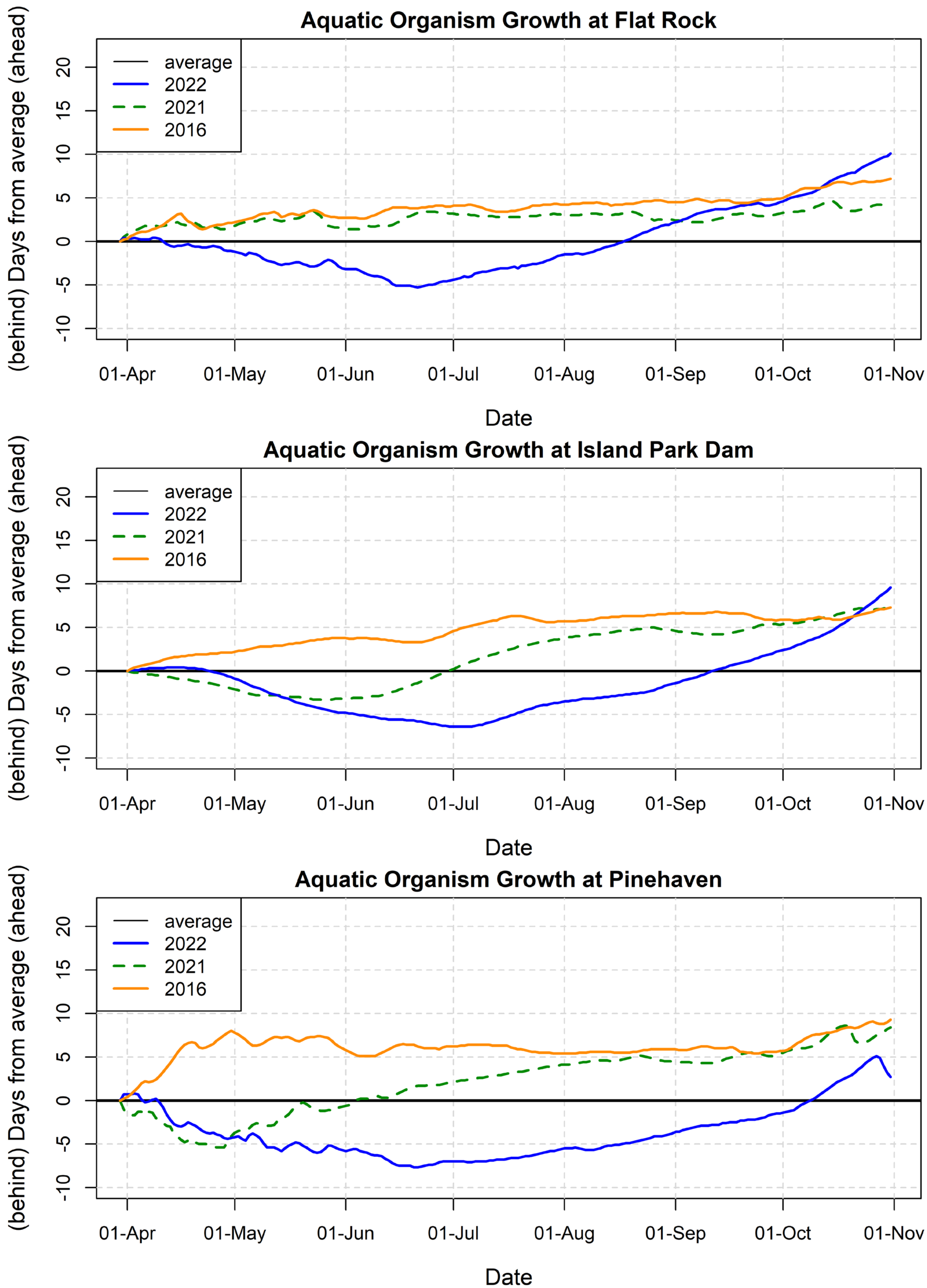

Figure 45. Aquatic organism temperature-dependent growth at the upper watershed water quality stations.

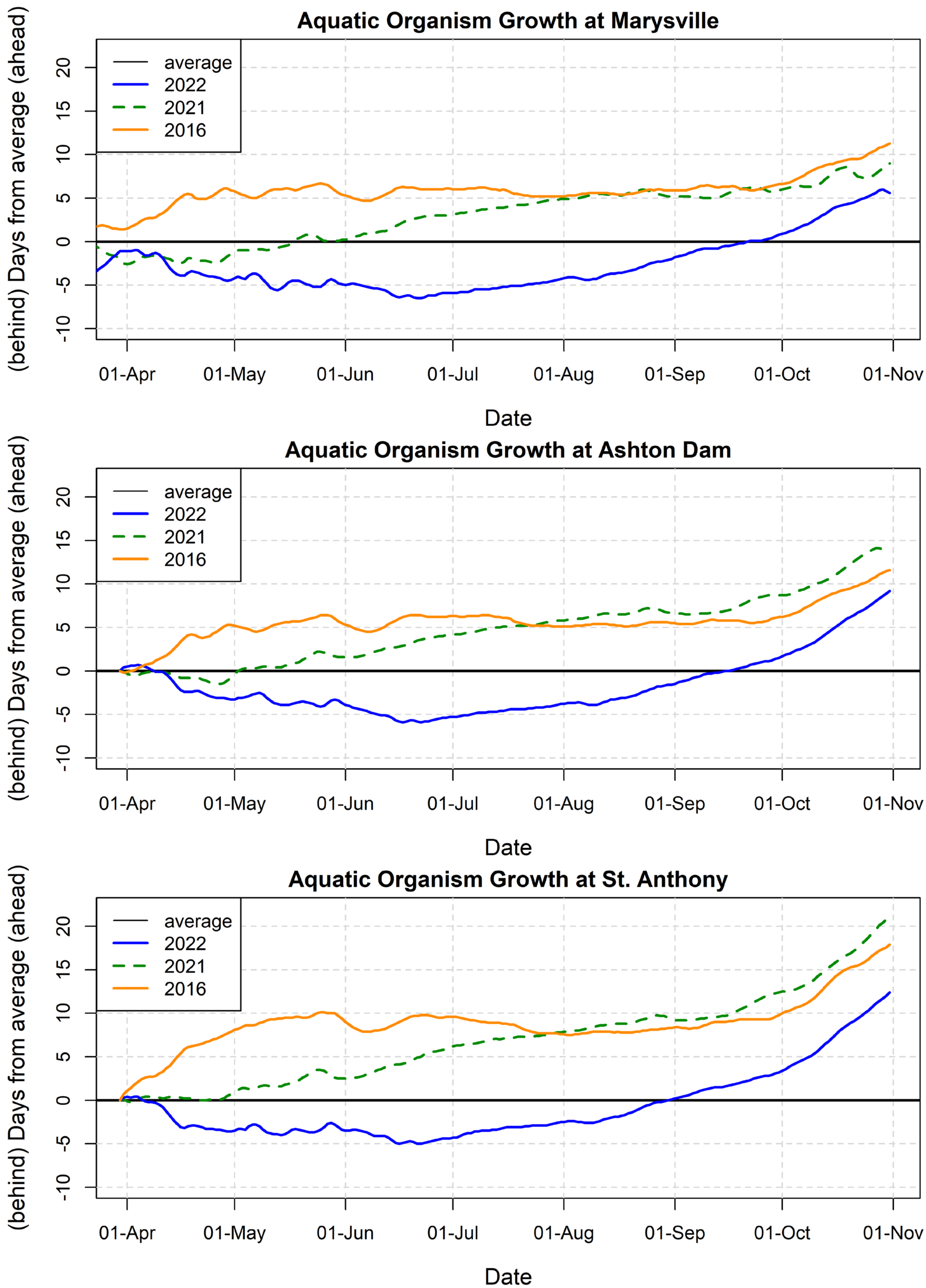

Figure 46. Aquatic organism temperature-dependent growth at the lower watershed water quality stations.

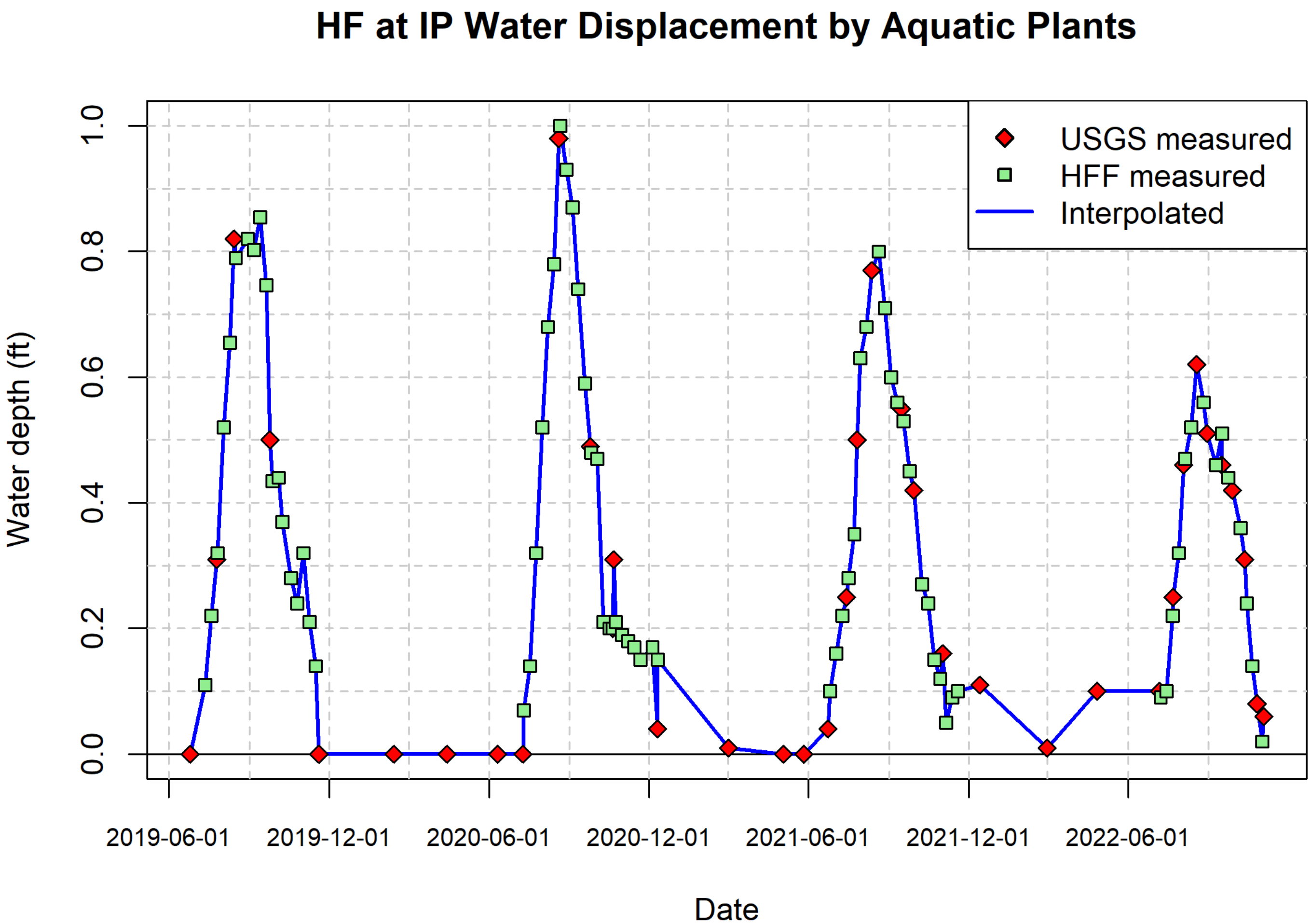

Figure 47. Depth of water displaced by aquatic plants ("macrophytes") at Island Dam, 2019-2022.

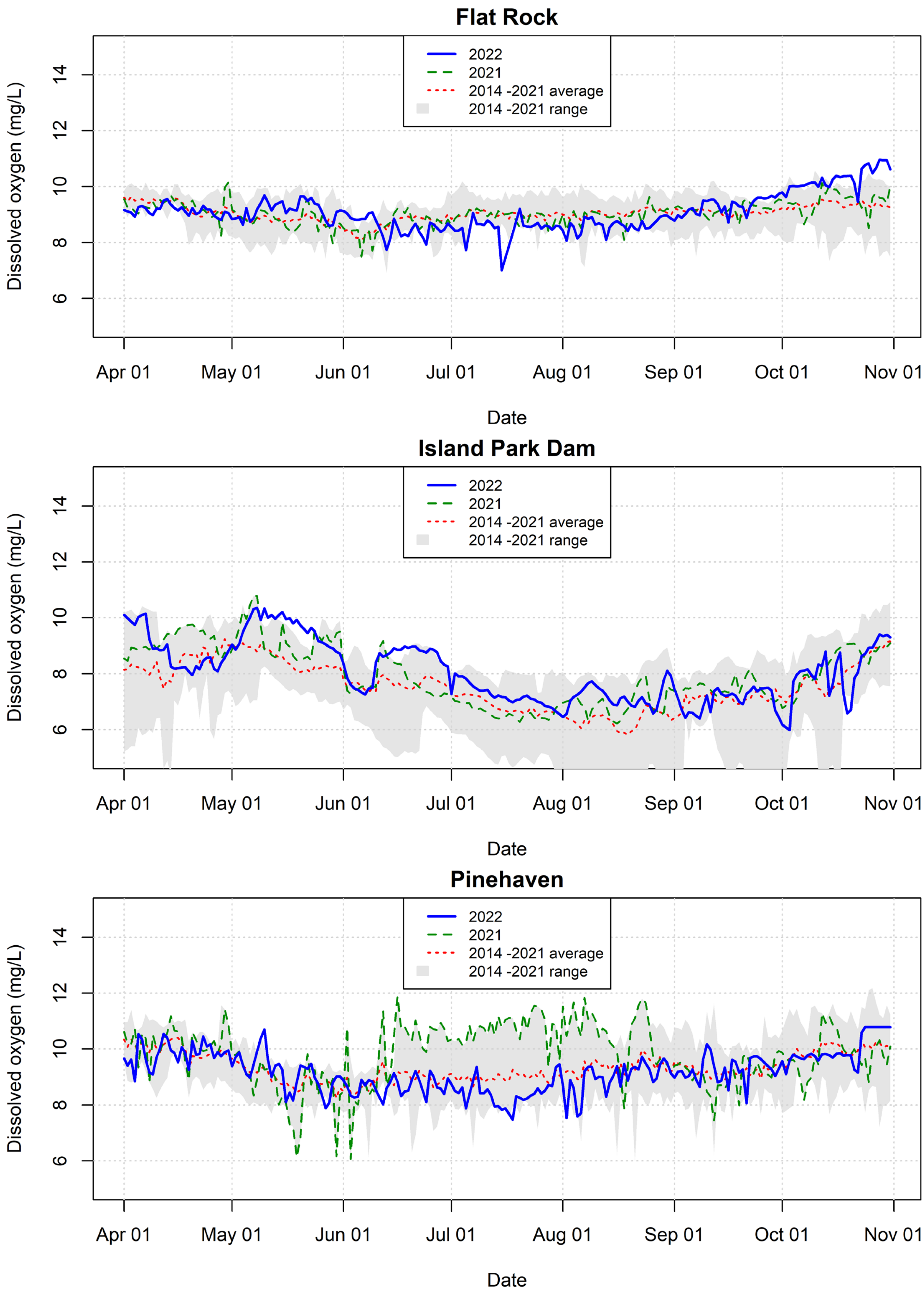

Figure 48. Dissolved oxygen at the three upper watershed water quality stations.

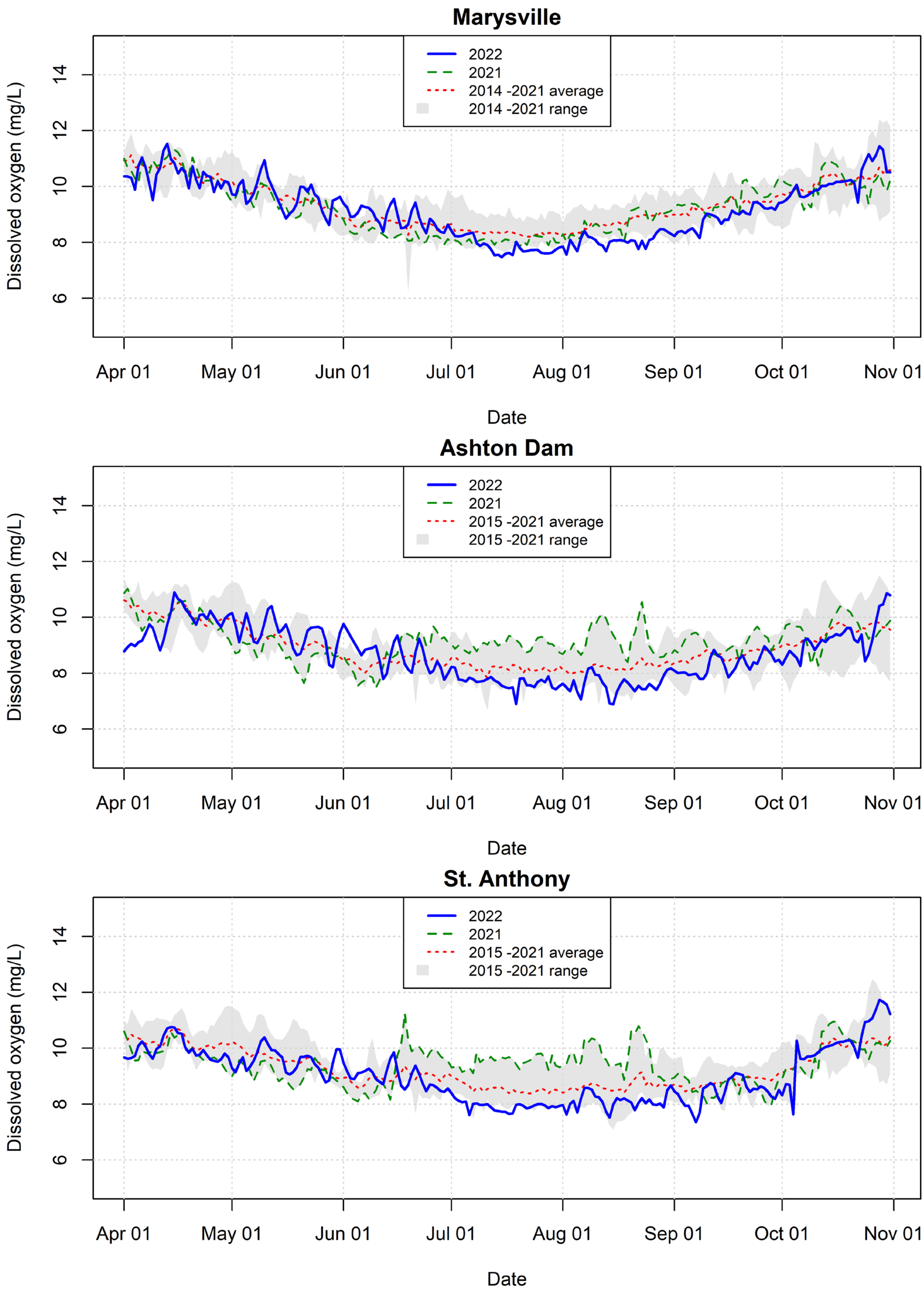

Figure 49. Dissolved oxygen at the three lower watershed water quality stations.

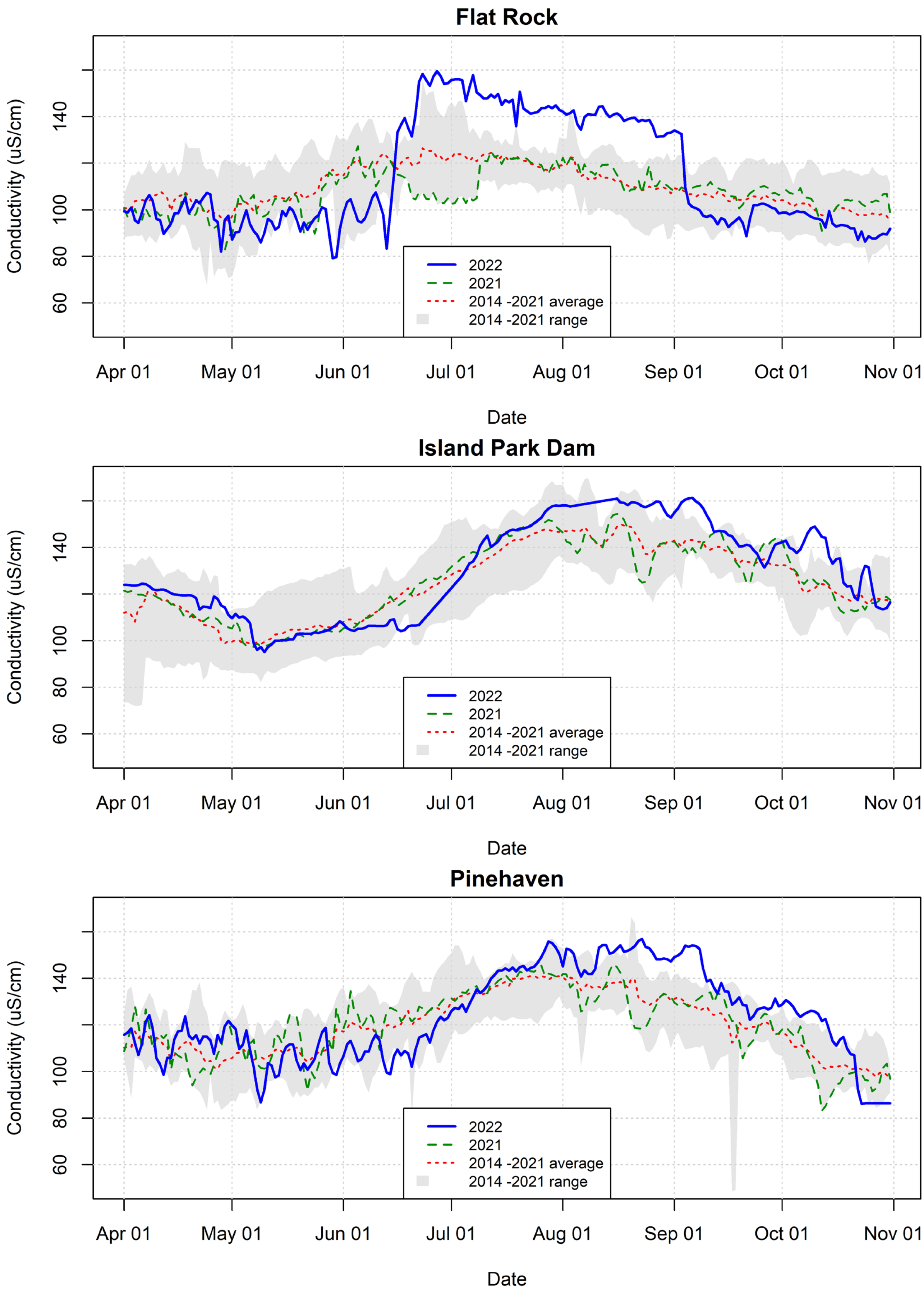

Figure 50. Conductivity at the three upper watershed water quality stations.

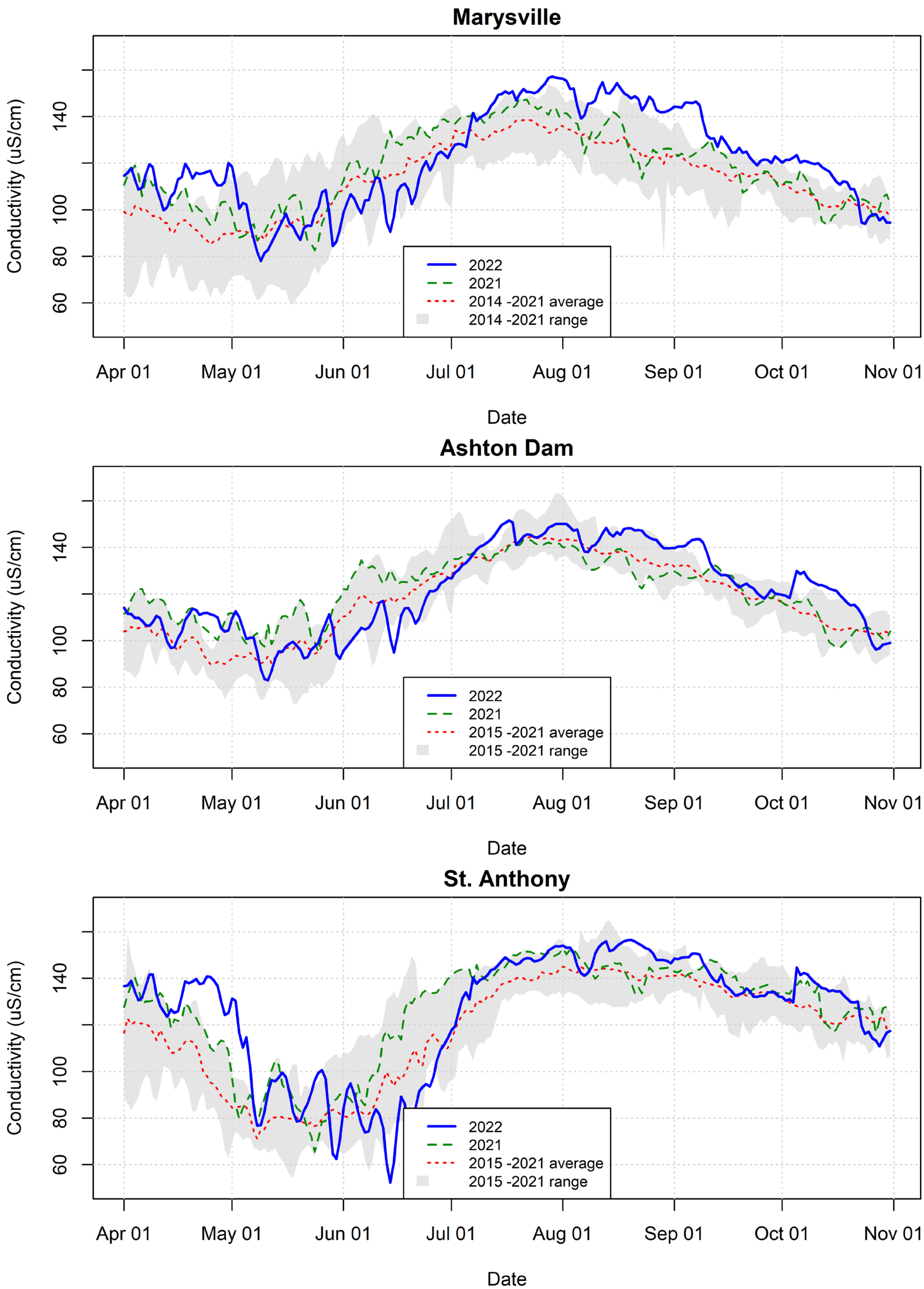

Figure 51. Conductivity at the three lower watershed water quality stations.

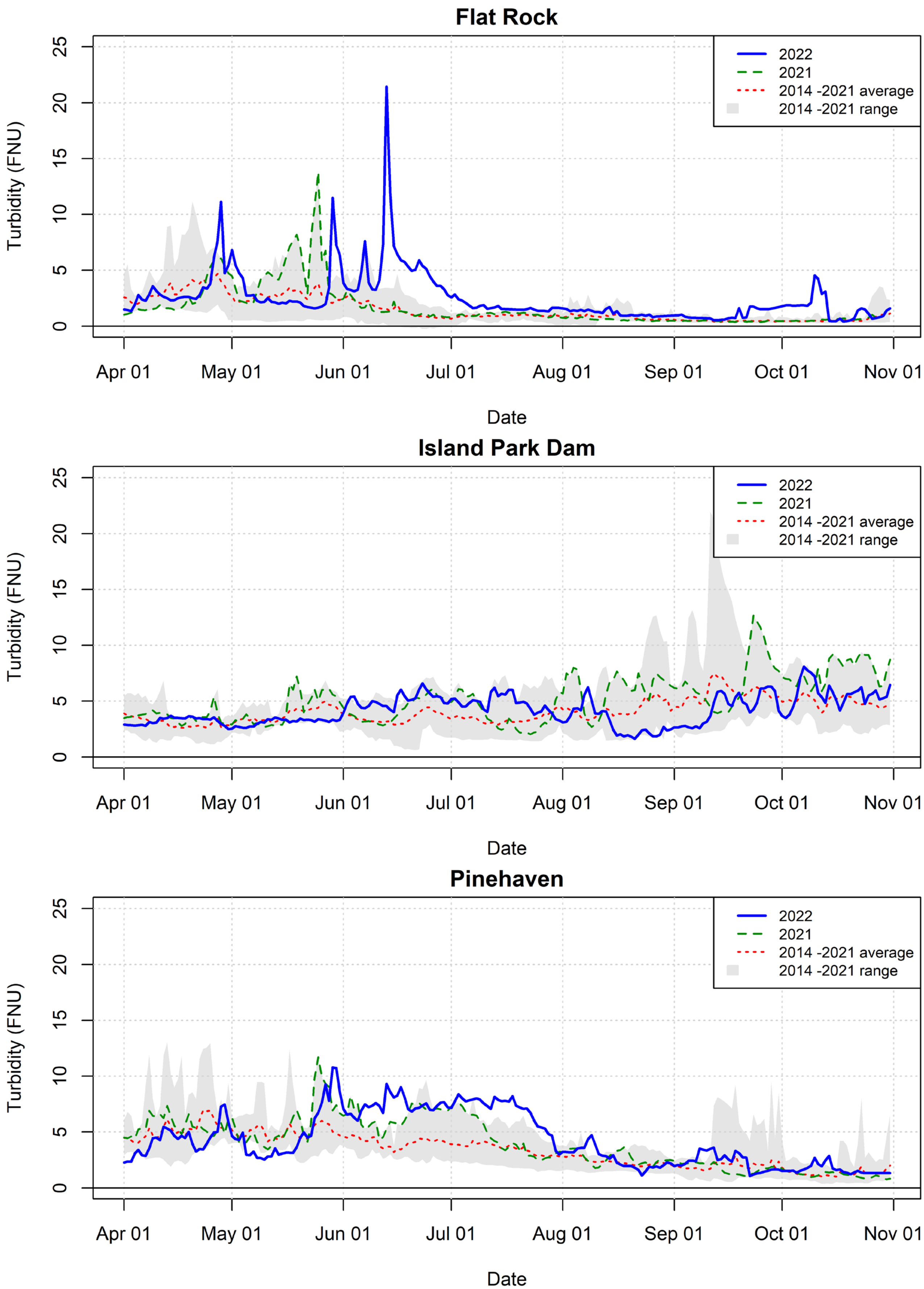

Figure 52. Turbidity at the three upper watershed water quality stations.

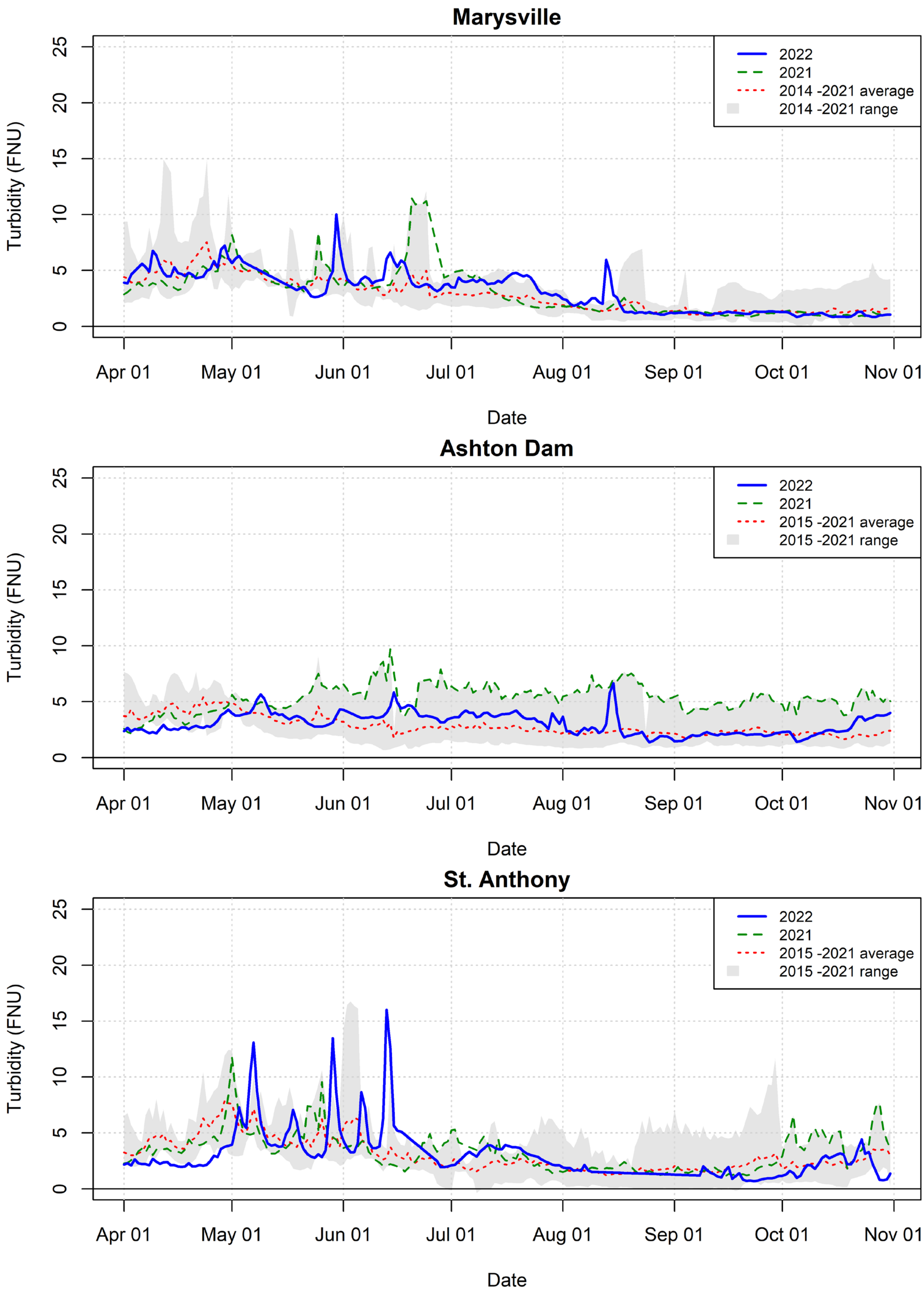

Figure 53. Conductivity at the three lower watershed water quality stations.

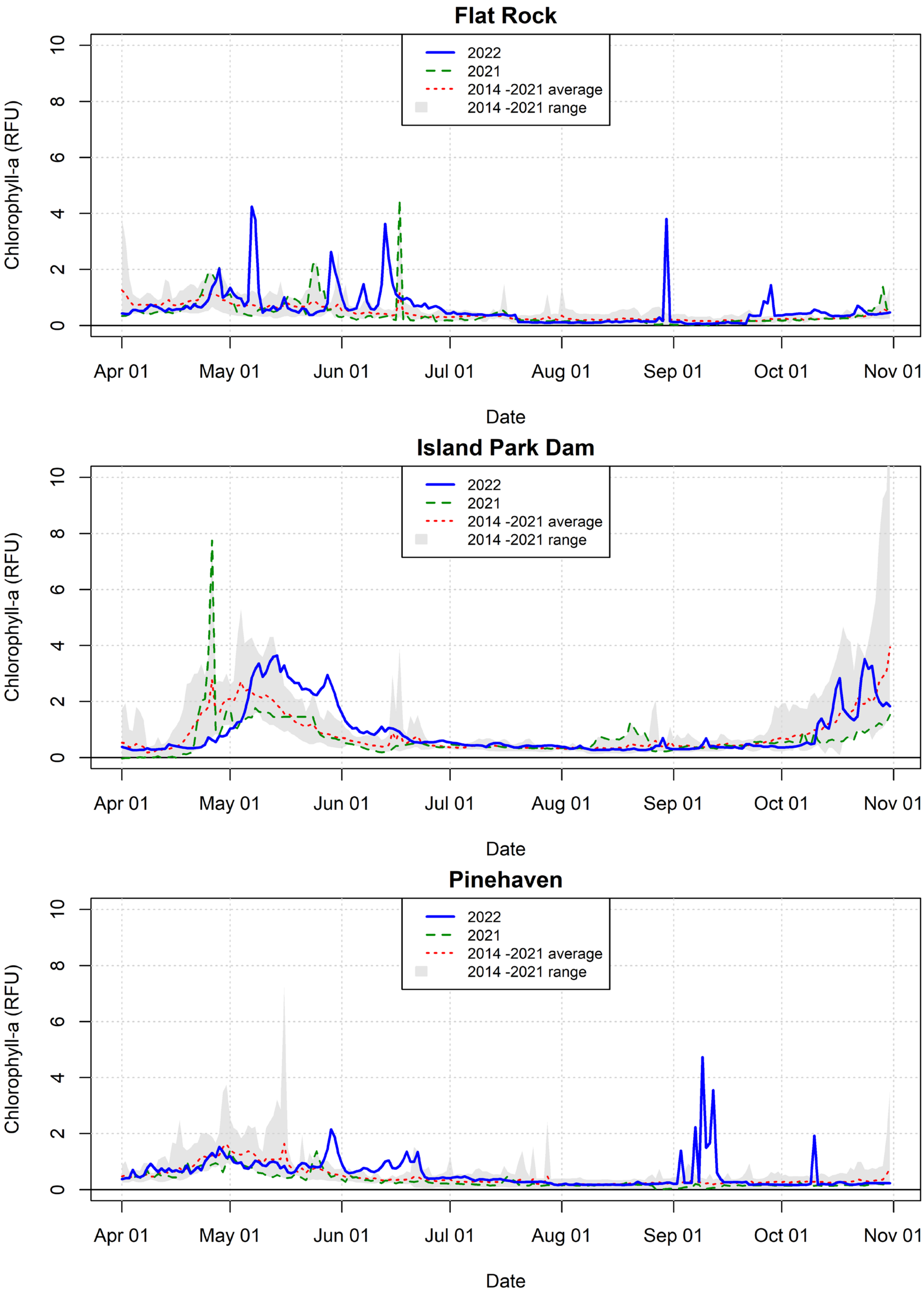

Figure 54. Chlorophyll index at the three upper-watershed water quality stations.

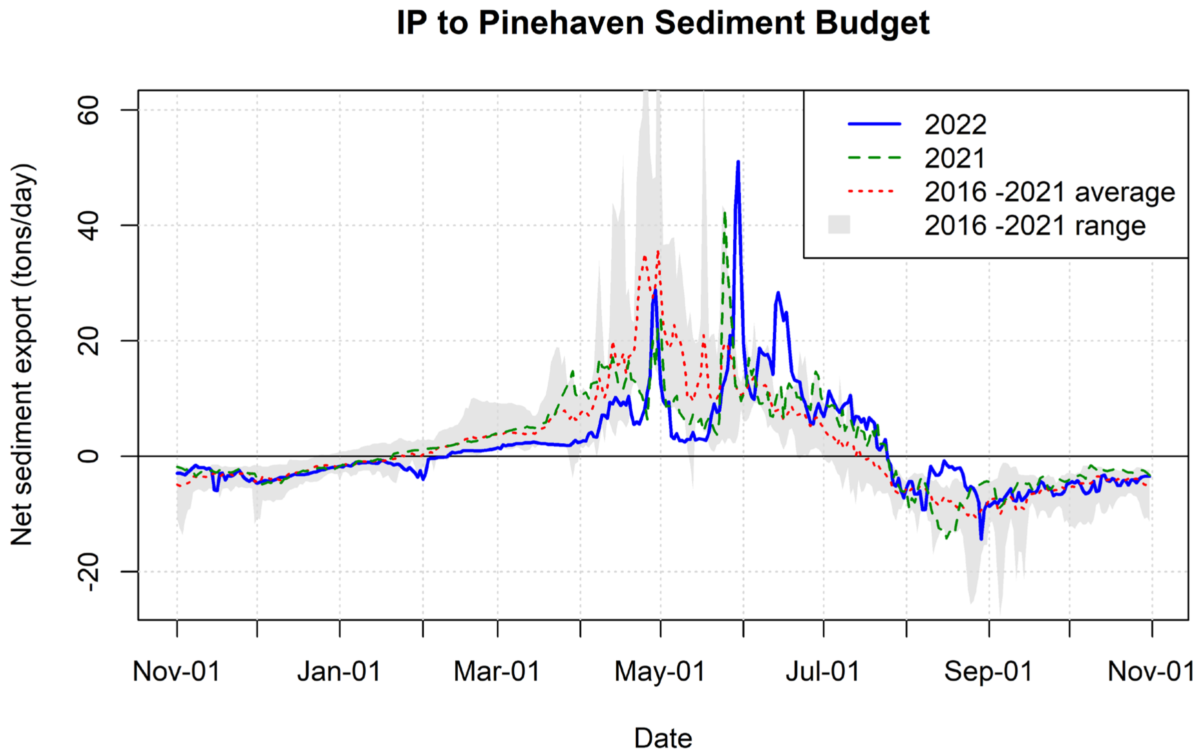

Figure 55. Sediment budget for Island Park Dam to Pinehaven reach of the Henry's Fork. Positive values indicate net export of sediment out of the reach. Negative numbers indicate net deposition in the reach.

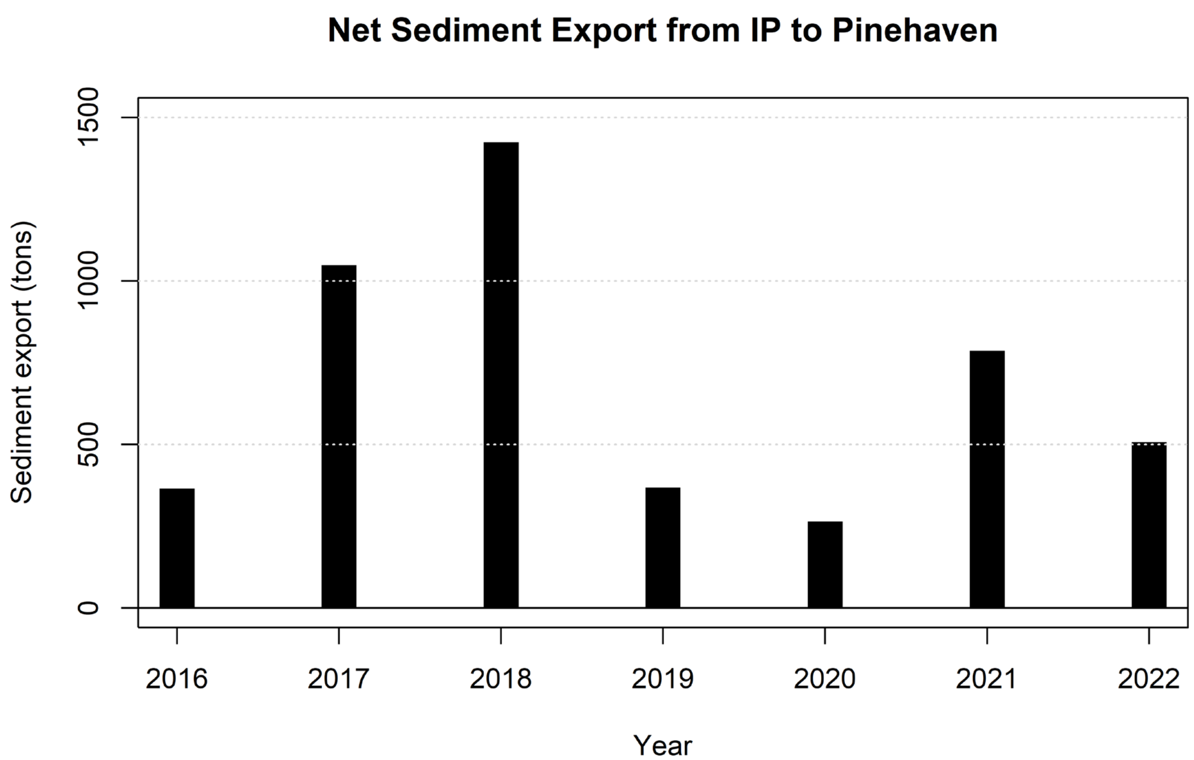

Figure 56. Net sediment export from the Island Park Dam to Pinehaven reach of the Henry's Fork.

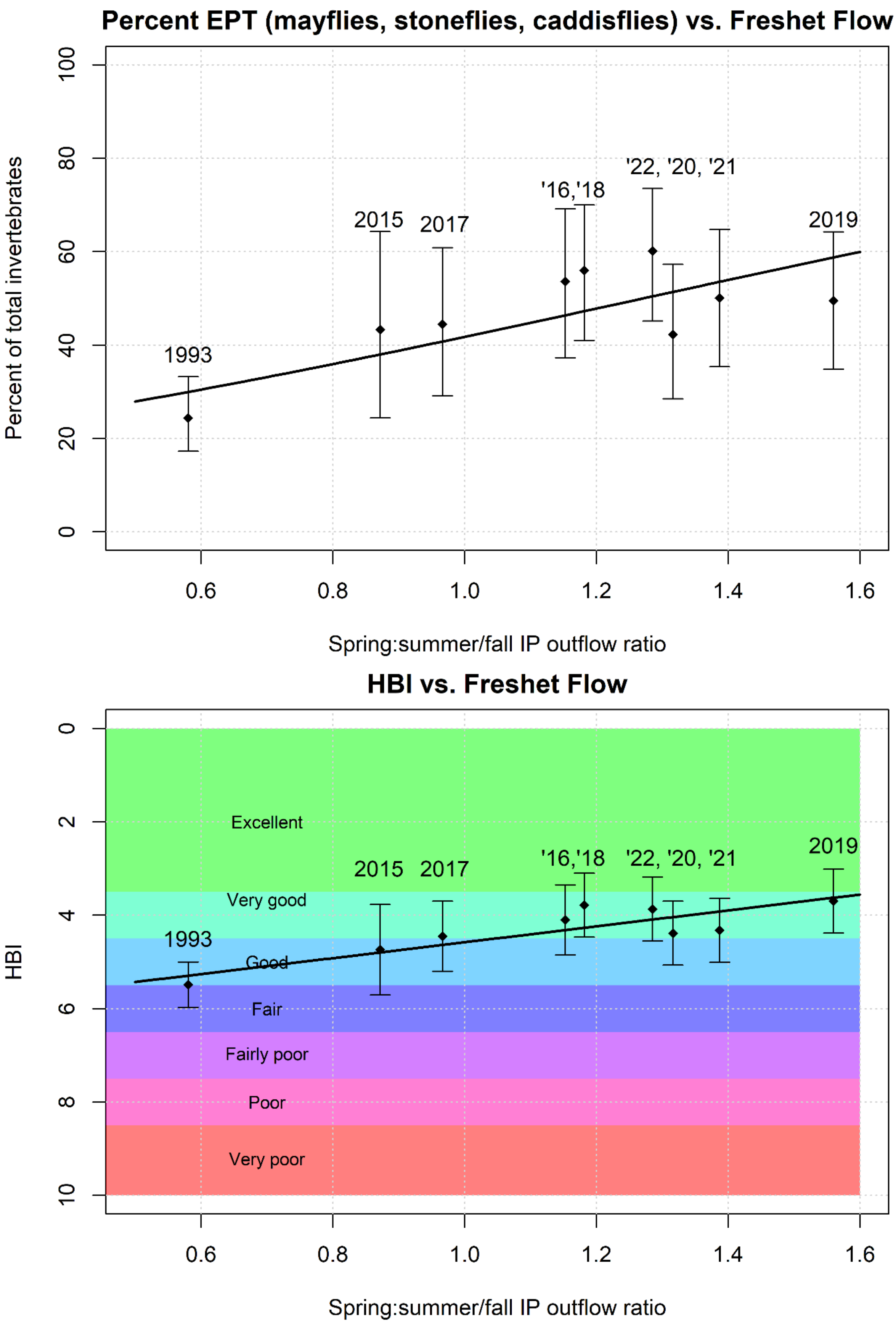

Figure 57. Response of percent EPT (top) and Hilsenhoff Biotic Index (bottom) to freshet flow index (ratio of springtime to summer/fall outflow from Island Park Dam).

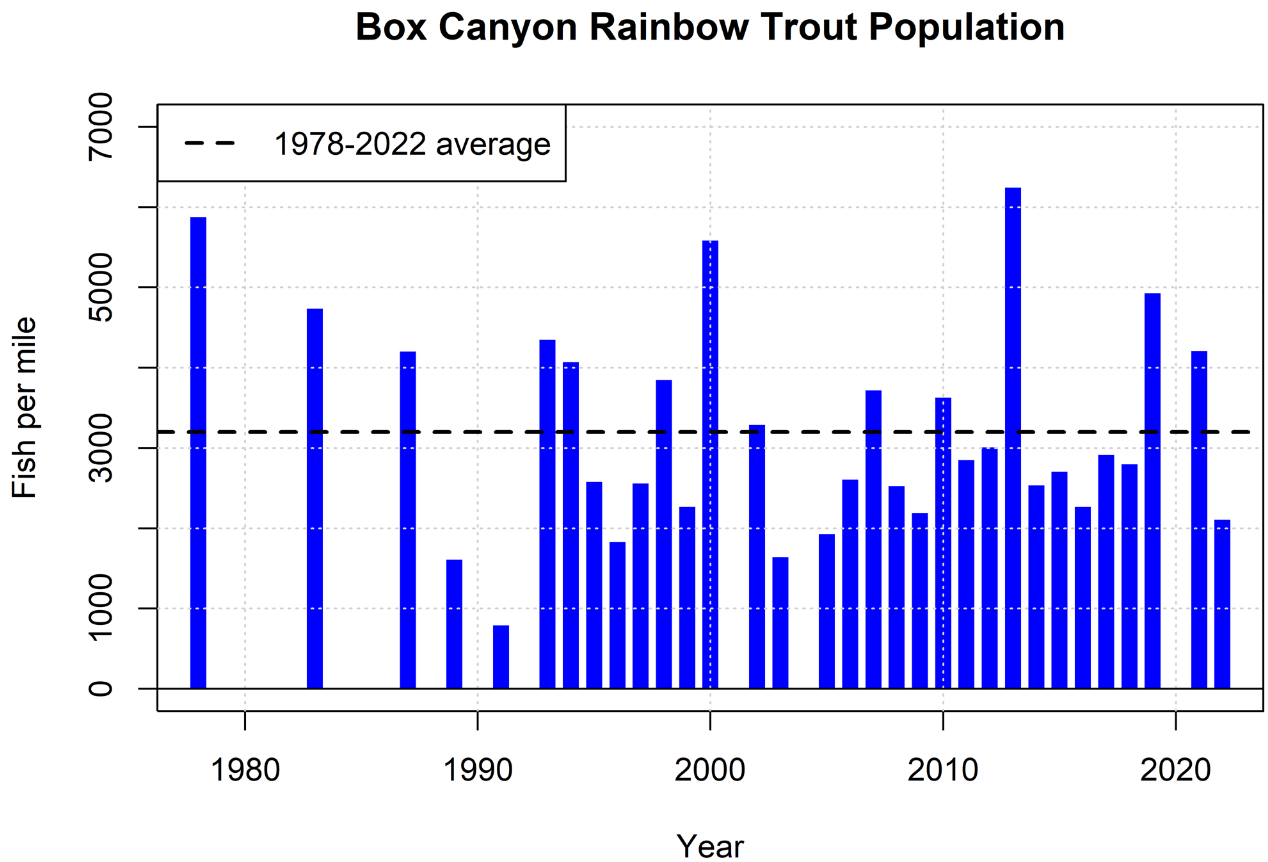

Figure 58. Box Canyon rainbow trout population.

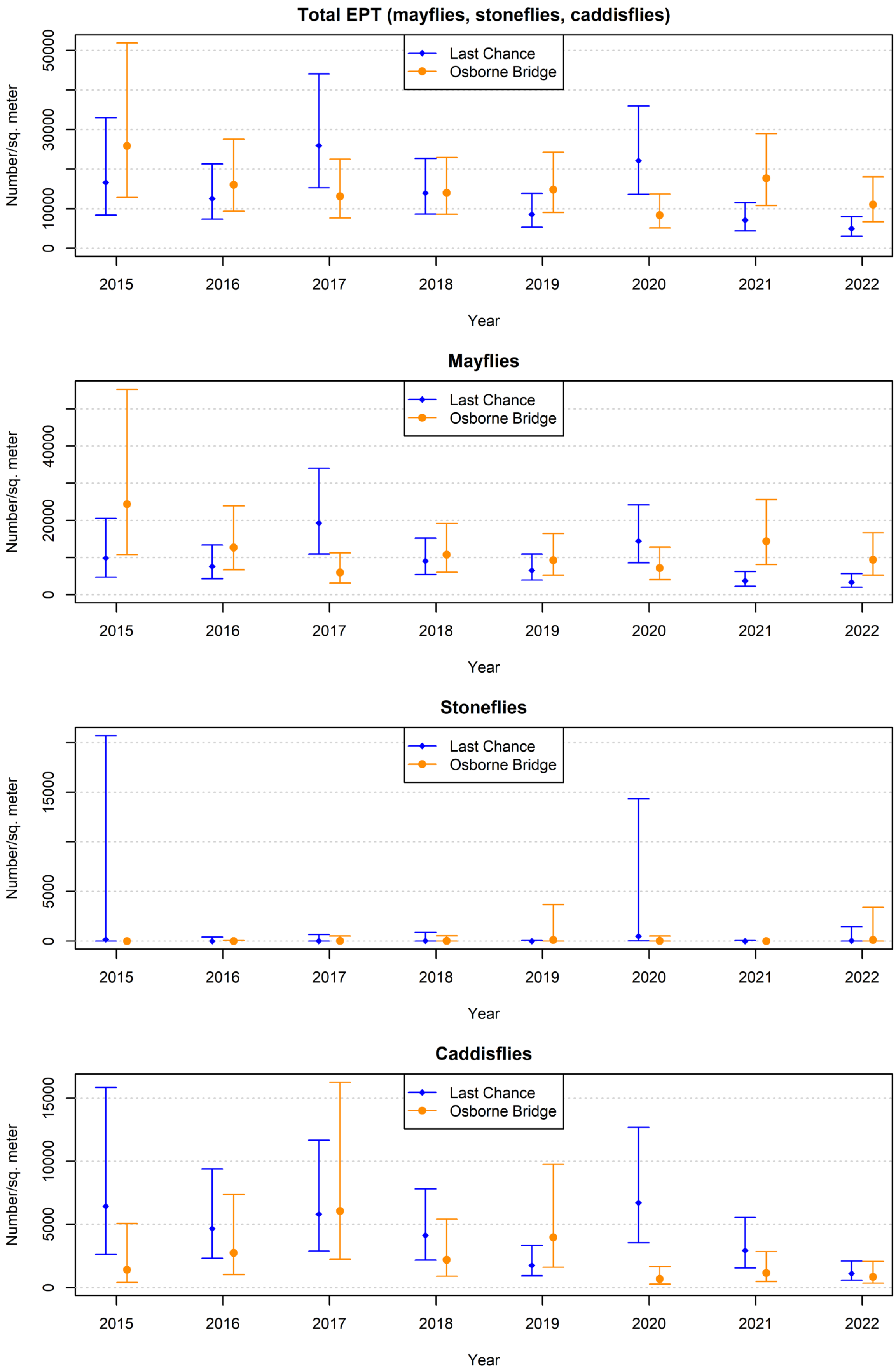

Figure 59. Abundance of mayflies, stoneflies, and caddisflies at Last Chance and Osborne Bridge.

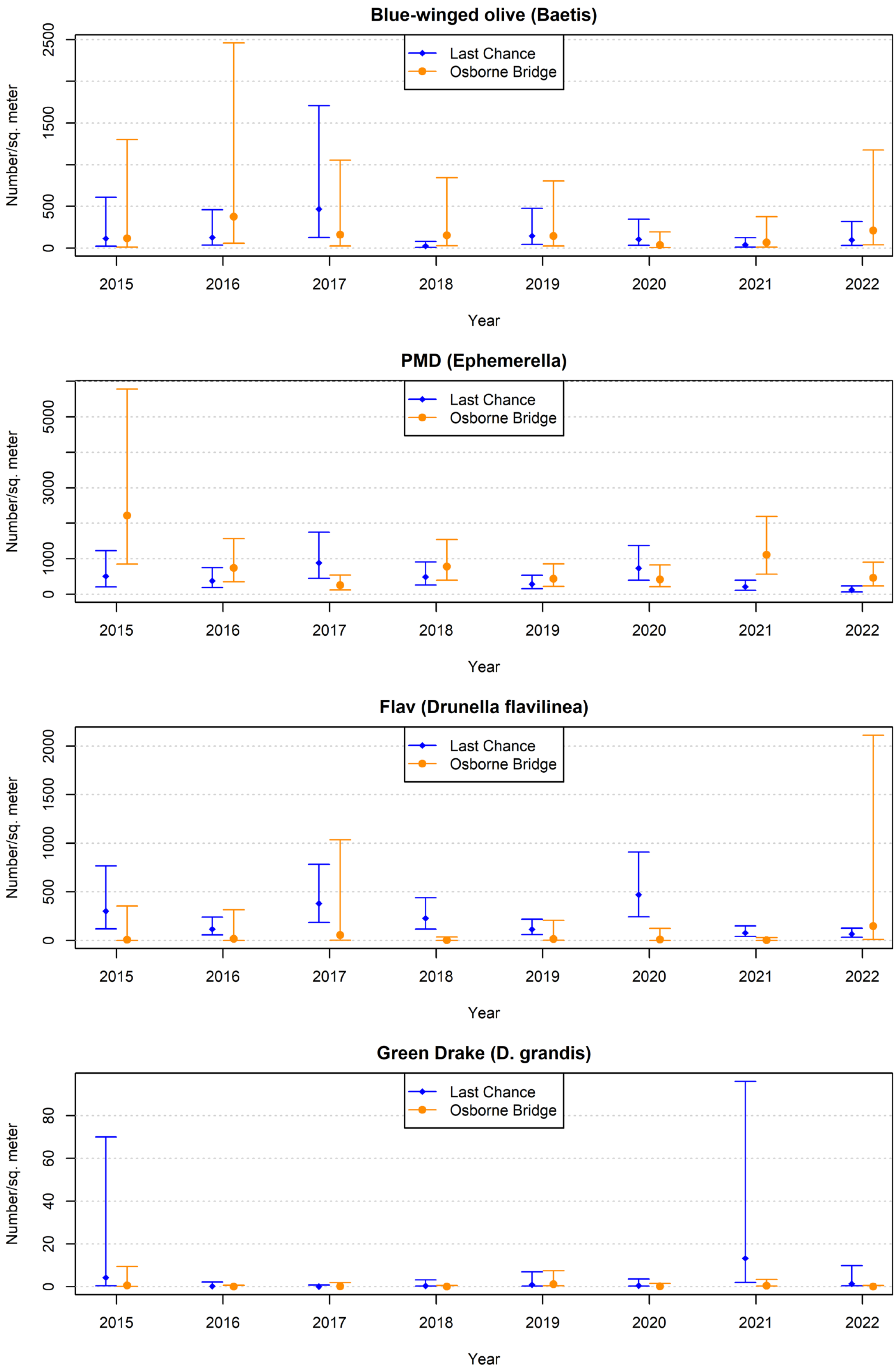

Figure 60. Abundance of selected mayfly species at Last Chance and Osborne Bridge.

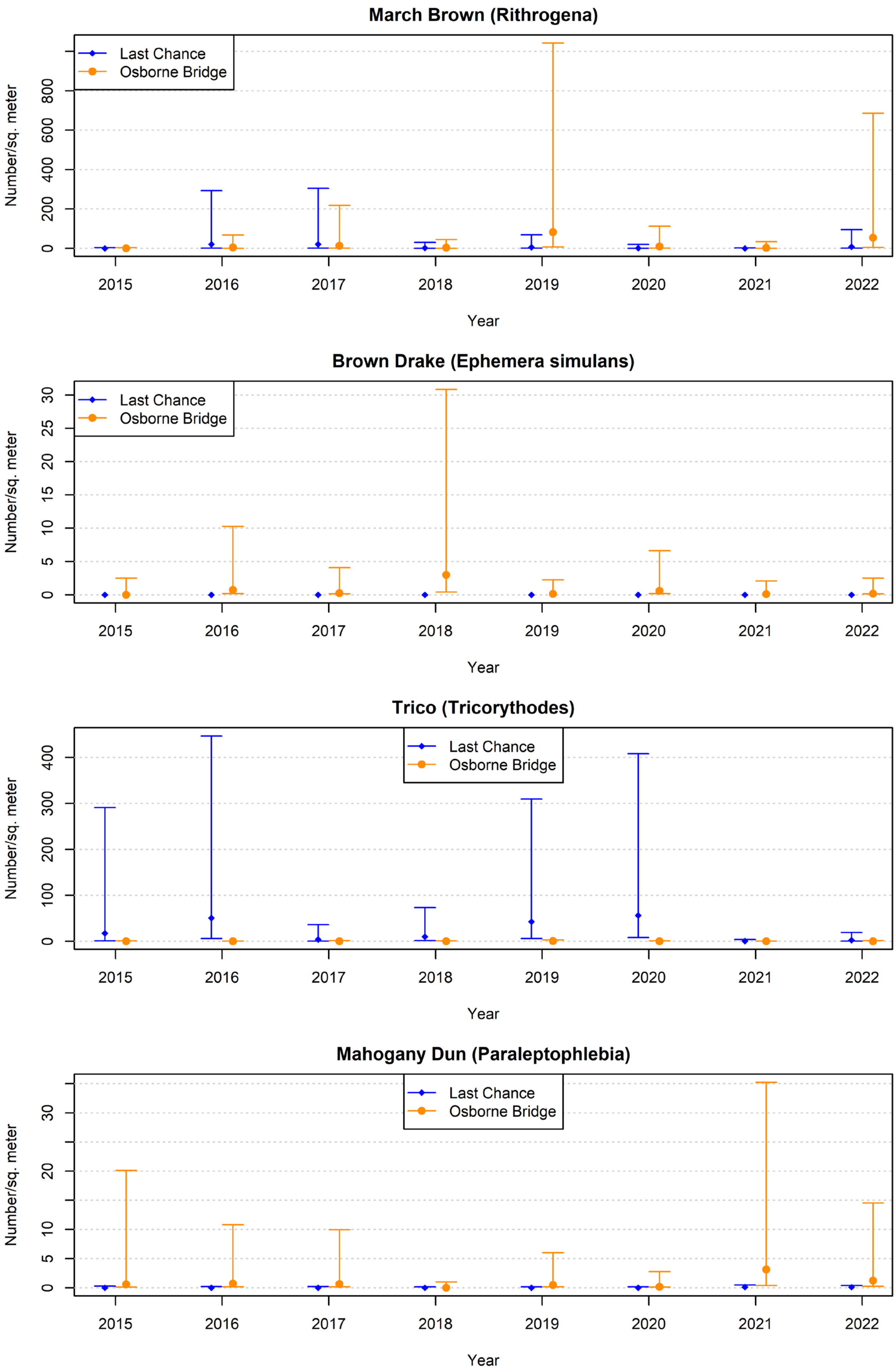

Figure 61. Abundance of selected mayfly species at Last Chance and Osborne Bridge.