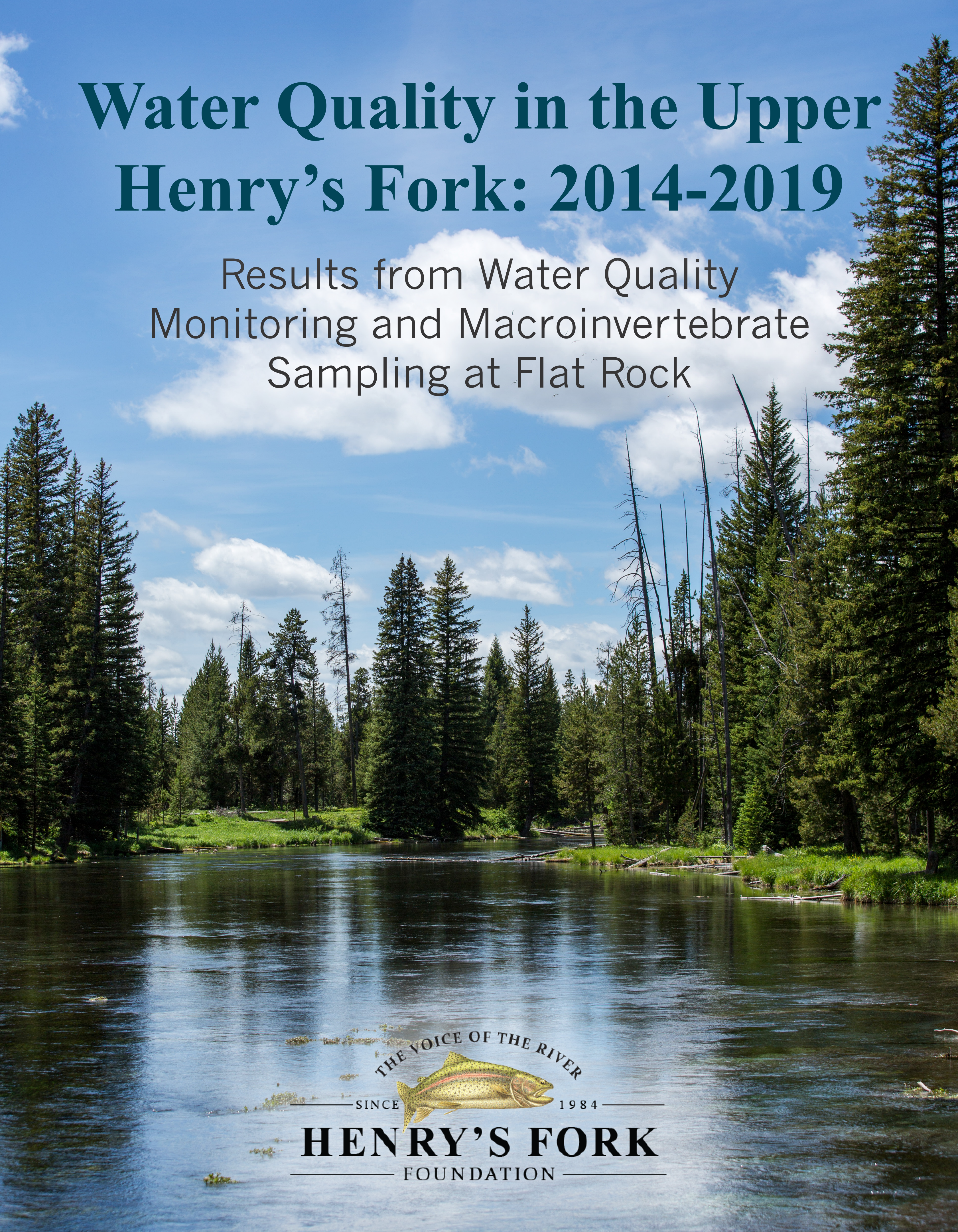
Water Quality in the Upper Henry's Fork: 2014-2019

Results from Water Quality Monitoring and Macroinvertebrate Sampling at Flat Rock



THE VOICE OF THE RIVER

SINCE 1984

HENRY'S FORK FOUNDATION

Background of HFF's Water-Quality Monitoring Program

The Henry's Fork Foundation initiated a continuous-time water-quality monitoring network in 2014 with plans to span the entire Henry's Fork of the Snake River watershed. The network monitors numerous water-quality parameters, which can be influenced by everything from our own habitat restoration projects to local water-management operations (reservoirs, irrigation diversions, hydro-electric power projects) to seasonal, annual, or long-term hydro-meteorological trends. Our water-quality monitoring network gathers detailed and comprehensive baseline information on existing trout habitat, giving us the tools to examine how the location and timing of chronic or acute fluctuations in physical and biochemical states impact wild trout.

Our monitoring network was implemented in three phases over three years to reduce the upfront cost of equipment and extend the fundraising period. The network currently consists of eleven YSI (Yellow Springs, OH) EXO2 multi-parameter sondes that are deployed semi-permanently at fixed locations in the river (Figure 1). Our sondes are configured to record every 15 minutes: temperature, conductivity, turbidity, dissolved oxygen, river depth (or stage), and an index of phytoplankton biomass, all of which are important drivers and indicators of trout life-history success, hydrologic processes, and aquatic-ecosystem production in the Henry's Fork.

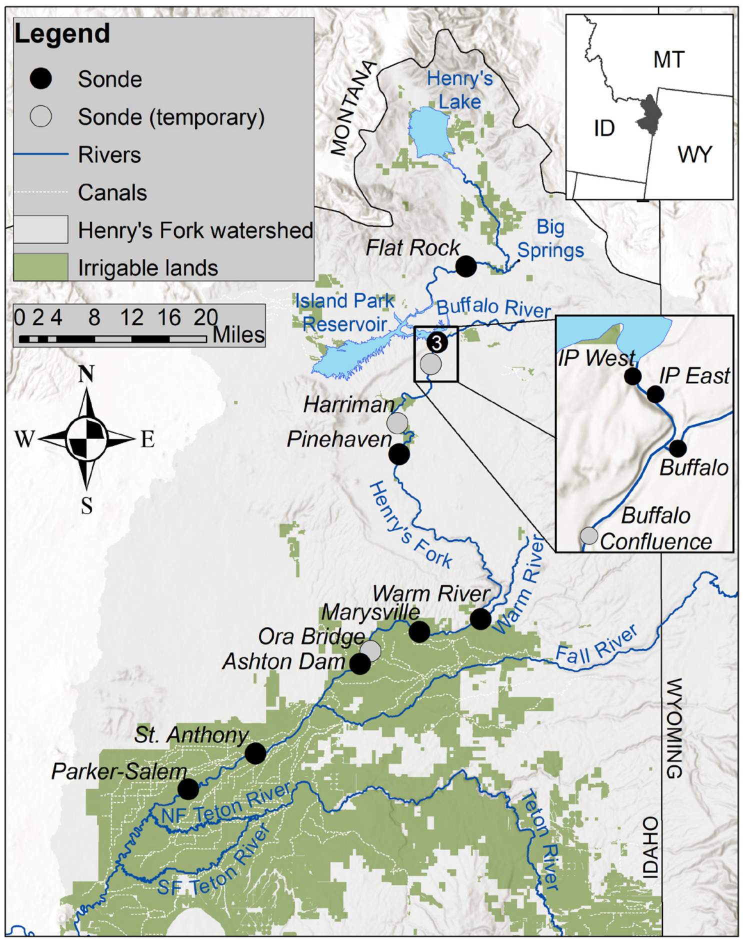
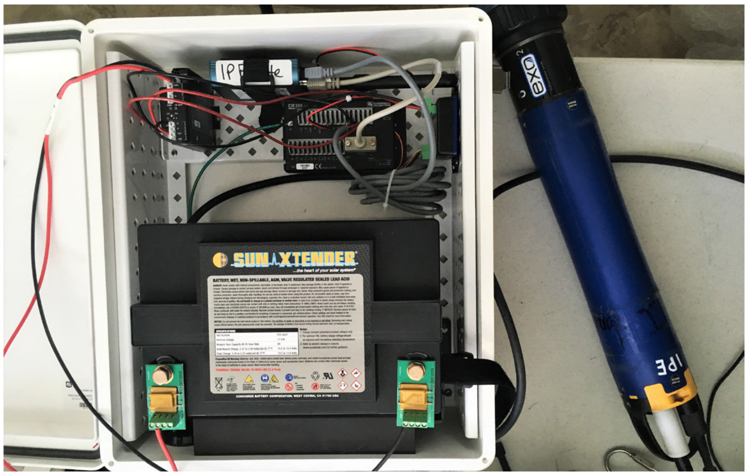


Figure 1 - Map of the sonde and sampling sites in the Henry's Fork Foundation water-quality monitoring network.

The Flat Rock Site's Value to the Water-Quality Monitoring Network



Sonde and equipment being assembled to remotely transmit water quality data back to the HFF office.

Figure 2 - *An image of the Flat Rock sonde housing, which is affixed under the upstream end of the Flat Rock Club's dock.*

An objective underlying our network's design is the ability to monitor each unique reach of the river. In the scientific literature, it is well known that reservoirs significantly impact downstream water quality. Thus, we installed sondes upstream and downstream of Island Park (IP) Reservoir to monitor its impact on downstream water quality. The Flat Rock Club's dock is home to the upstream sonde (Figure 2). Due to its location upstream of IP Reservoir, the Flat Rock sonde provides some information on what the water-quality of the Henry's Fork upstream of the Buffalo River confluence would be in absence of IP Reservoir. Therefore, we have been able to observe—and in some cases quantify—how the reservoir impacts downstream temperature, turbidity, and dissolved oxygen by comparing the downstream data to the Flat Rock sonde data. These analyses are ongoing and, as we collect additional years of data from our network, we continue to analyze trends in inter-annual impacts.

Maintaining the remote-transmission equipment at Pinehaven.

General Trends in Water-Quality at Flat Rock

The Henry's Fork at Flat Rock is very similar in water quality to the river at Big Springs. While there is a small contribution in flow from the Henry's Lake outlet, this comprises anywhere from 0–25% of the flow at Flat Rock, depending on the time of year. Thus Flat Rock provides excellent trout habitat, with water that rarely becomes too warm and almost never exhibits oxygen concentration that is too low. What's more, Flat Rock usually has cooler water temperature, lower turbidity, higher dissolved oxygen, lower nutrient concentration, and fewer macrophytes (rooted aquatic plants) than reaches downstream. There are certain times of year (and certain years) that these relationships do not hold, but generally this is the case. Therefore, out of the entire main-stem river, Flat Rock best represents the classic headwaters of a cold-water trout stream, with clear water and low productivity.

Many differences in water quality between Flat Rock and the rest of the Henry's Fork are due to the impacts of Island Park Reservoir downstream. We can observe and quantify differences in water quality due to the reservoir by comparing sonde data at Flat Rock to sonde data collected immediately below Island Park Dam (Figure 3). It is important to note that not all differences in water-quality between Flat Rock and the river immediately downstream of the reservoir are due to the reservoir or dam. Indeed, differences in water quality between Flat Rock and the downstream reaches would still exist if Island Park Dam had never been built. Obviously, reaches that are far downstream from Flat Rock will be characterized by the general patterns predicted by the river continuum concept. For example, we would expect to observe higher inputs of particulate material, lower water clarity, and higher numbers of organisms that feed on fine particulate organic matter in the lowest reaches of the Henry's Fork, when compared to the Flat Rock reach near the headwaters. In nearby reaches, there would also be differences in water quality due to inflow from springs and tributaries, differences in bedrock, bank vegetation, and other factors that influence stream morphology and hydrologic connectivity. For example, the tributaries to the now inundated Shotgun Valley still contribute flow and convey sediment into IP Reservoir, mostly during spring runoff though. In the Henry's Fork between Flat Rock and the confluence with the Buffalo River, the impact of these tributaries and the hydrologic and morphologic differences between reaches are subtler than the water quality changes caused by IP Reservoir, and their variation is thus overwhelmed by the downstream impacts of the reservoir at near proximity.

Collecting field samples of aquatic plants.

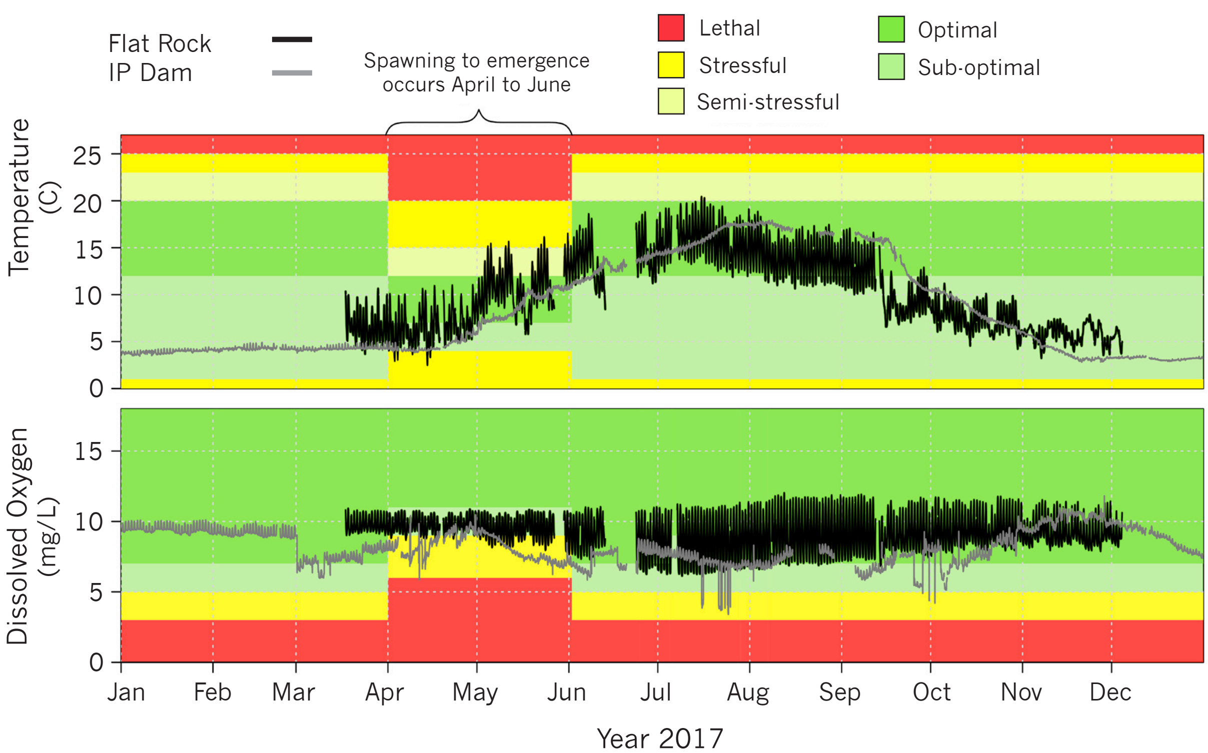


***Figure 3** - Temperature and dissolved oxygen data from the Flat Rock (black line) and Island Park East (grey line) sondes from 2017. Data shown are at 15-minute resolution. Sonde locations can be referenced in Figure 1. Rainbow Trout preferences for temperature and dissolved oxygen are shown as background colors in each panel and interpretation of each color range is provided in the top-right margin. The Flat Rock installation collects high quality data that are representative of that river reach, but other factors prevent the sonde from overwintering in its housing, thus all data collected in 2017 are from mid-March through early December.*

The Henry's Fork at Flat Rock and immediately below IP Dam exhibit daily and seasonal variation in temperature and dissolved oxygen but with several important differences. First, daily variation is drastically lower below IP Dam than at Flat Rock: daily water temperature at IP Dam fluctuates a mere 1˚C (1.8°F) on average compared to an average daily fluctuation of 5˚C (9°F) at Flat Rock. Regular daily variation in water quality is directly and indirectly caused by the daily fluctuation in sunlight and air temperature. For example, solar heating directly impacts water temperature in the river, and sunlight drives photosynthesis of macrophytes, which in turn impacts that reach's dissolved oxygen concentration. In contrast, all but the upper few feet of water in the reservoir is insulated from sunlight or ambient air temperature. Second, while these two reaches exhibit similar seasonal variation in temperature (cool in winter, warm in summer, etc.) the pattern observed at Flat Rock occurs 1–2 weeks later below the dam. Interestingly, the reasons for this lag differ between seasons. IP Reservoir is a large mass of slow moving water, so it takes longer to heat up and cool down than the shallower river reaches. It is also thermally stratified for much of the year: under ice cover the warmest layer is on the bottom (water is most dense at 4˚C, or 39˚F) and the coldest layer is usually on the bottom during ice-free months. Thus, water below the dam is cooler than Flat Rock in spring and early summer, but warmer in late summer and early fall. However, if the river at Flat Rock warms and cools with the air temperature, why isn't Flat Rock at freezing (and thus colder than IP Dam) during the winter? The groundwater springs at the headwaters keep Flat Rock much warmer than it otherwise would be and also warmer than the reservoir outflow.

Collecting water samples at Flat Rock.

Abrupt changes in the daily cycles of temperature and dissolved oxygen occur for different reasons at Flat Rock than below the dam. At Flat Rock, where the river is wide and shallow, changes in weather such as cloudy conditions or rain cause striking irregularities in the daily cycles. Conversely, IP Reservoir's large mass resists the impacts of these short-term weather changes on water quality so that most of the abrupt changes observed below the dam are caused by seasonal weather changes or management decisions (gray lines in Figure 3). The impact on water quality at Flat Rock of several large rain events in May, June, and July of 2017 can be detected where temperature and its daily variation suddenly plummet (black line in Figure 3, top panel). There are corresponding changes in the dissolved oxygen cycle at Flat Rock (the amplitude of the daily cycles shrink) as biological processes are also impacted by short-term weather changes, e.g. photosynthesis slows down under cloud cover (black line in Figure 3, bottom panel). Natural processes that can abruptly influence water quality in IP Reservoir include chemical and thermal stratification, ice-on, ice-off, algae and cyanobacteria bloom and decay, and occasionally turnover. Management decisions that impact water quality below the dam include the timing and quantity of water released for irrigation with minor to major considerations made for production of power from Fall River Rural Electric Cooperative's hydroelectric power plant. On paper, it is convenient to separate natural processes from management decisions, but in the real world, these factors interact and have novel impacts on the ecosystem; one such interaction is explained in the next paragraph.

During the ice-free months, the interaction between reservoir volume, discharge, and stratification drives many observable changes in water quality immediately below the dam. Stratification inside IP Reservoir is primarily characterized by warmer, highly oxygenated water near the top and cooler, oxygen-depleted water near the bottom.

The hutch that houses the remote transmission equipment at the Flat Rock Club.

Note that cooler water can hold more dissolved oxygen, so this relationship may seem counter-intuitive. Stratification sets up as cooler (denser) water sinks below the lighter, warmer water. This stratification is exaggerated as the summer sun warms the top layers while the bottom layers are insulated from this solar energy. Eventually the lower layer gets depleted of oxygen by decomposition of organic matter at the bottom without a process to replenish oxygen—wave action occurring at the surface doesn't impact the lower depths of IP Reservoir when it is full. However, if summertime discharge is high enough to either mix these layers or diminish reservoir volume such that the cool "pool" at the bottom is spent, that stratification breaks down and dissolved oxygen of outflow increases, but so

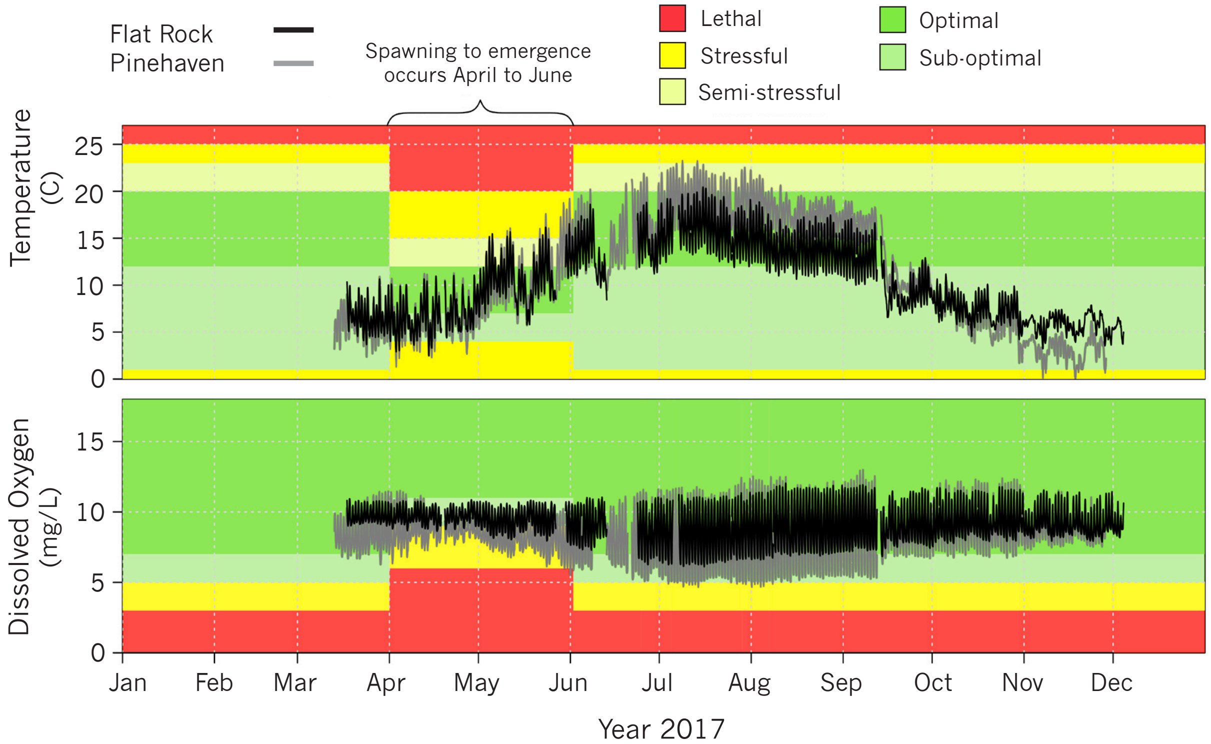


Figure 4 *- Temperature and dissolved oxygen data from the Flat Rock (black line) and Pinehaven (gray line) sondes. Sonde locations can be referenced in Figure 1. Rainbow Trout preferences for temperature and dissolved oxygen are shown as background colors in each panel and interpretation of each color range is provided in the top-right margin. Sonde installations at both of these locations collect high quality data that are representative of that river reach, but are such that the sondes cannot overwinter in their housings, thus all data collected in 2017 was from mid-March through early December.*

does temperature. More information about the interaction between volume, draft, and water temperature of Island Park Reservoir can be found in our work published in the *Journal of the American Water Resources Association*[1].

Overall, there are more similarities between the Flat Rock and Pinehaven reaches than between Flat Rock and the reach immediately downstream of the dam, and this is because the reservoir's influence on temperature and dissolved oxygen is generally reset by the time that water passes through Pinehaven (Figure 4). The timing and magnitude of daily cycles in temperature and dissolved oxygen are very similar at Flat Rock and Pinehaven, and the same short-term changes are apparent. Most importantly, the timing of seasonal changes in temperature is the same at Flat Rock and Pinehaven; the 1–2 week lag introduced by the reservoir has disappeared. This is because changes in solar heat and ambient air temperature are again the primary processes impacting water quality at Pinehaven. The impact of macrophytes on water quality (broad daily cycles in dissolved oxygen) again returns to the river after only a few miles of distance below the dam, and this is apparent in the similar trends found at Flat Rock and Pinehaven. However, summertime temperatures and the magnitude of dissolved oxygen daily cycles are higher and stronger at Pinehaven than at Flat Rock. There is a substantially higher density of macrophytes in the Henry's Fork from Harriman to Pinehaven. These aquatic plants predictably impact dissolved oxygen as the daily cycle of photosynthesis and respiration further elevate and diminish oxygen concentration beyond the impact of changing water temperature. It should be noted that summertime air temperatures, and hence water temperatures, in 2017 were some of the highest observed in recent years (not shown). Over the life of our monitoring program, our data show that these higher summertime water temperatures observed at Pinehaven are still cool enough to provide good Rainbow trout habitat.

[1] McLaren J.S., R.W. Van Kirk, T.V. Royer, and M.L. Muradian. 2019. Management and Limnology Interact to Drive Water Temperature Patterns in a Middle Rockies River-Reservoir System. *Journal of the American Water Resources Association* 55:1323-1344.

General Trends in Upriver Nutrients

We collect weekly or bi-weekly water samples from each sonde location as an additional component of our water-quality monitoring program. These water samples are tested for two nutrient concentrations: Total Nitrogen and Total Phosphorus. Using this weekly nutrient data, we have confirmed that the Flat Rock reach generally has lower nutrients than the reaches downstream of Island Park Reservoir. This is because the nutrients present in the river upstream of IP Reservoir are at background or baseline levels commensurate with watershed geology and hydrology, whereas river reaches downstream of IP Reservoir gain additional nutrients from storage and production inside of the reservoir.

Nutrient concentration is higher immediately below IP Dam and at Pinehaven than at Flat Rock. From the scientific literature we know that reservoirs store and produce nutrients, and our data show this is occurring in IP Reservoir (Table 1). A brief explanation of how reservoirs store and produce nutrients follows: as sediments (both organic and inorganic) accrue at the bottom of reservoirs, so do the nutrients contained in that material. Organic sediments (algae, plant, and animal tissue) readily decompose at the bottom of the reservoir, releasing their nutrients. During periods of no or very low oxygen at the bottom of the reservoir, anaerobic bacteria convert nutrients locked inside of inorganic sediment (gravel, sand, and silt) into a more biologically available form that dissolves into the water column.

Table 1 - Median concentration (mg/L) of Total Nitrogen and Total Phosphorus by site of data collected 2016–2018.

	Total Phosphorus	Total Nitrogen
Flat Rock	0.03 mg/L	0.05 mg/L
Island Park Dam	0.05 mg/L	0.85 mg/L
Pinehaven	0.04 mg/L	0.60 mg/L
Marysville	0.04 mg/L	0.55 mg/L

Taking measurements of macrophyte abundance.

Nutrient concentration at Pinehaven (15 river miles downstream of IP Dam) is more similar to the concentration at Flat Rock than immediately below IP Dam (Table 1). At this point in our analysis we hypothesize that either the lower nutrient water from the Buffalo River is diluting the concentration out of the reservoir, or the nutrients are being used to grow aquatic plants between IP Dam and Pinehaven. Most likely, both are occurring. Keep in mind these are preliminary results since we are only using a couple of years' worth of data in this analysis. As we collect more data, we will gain a better understanding of nutrient transport and uptake in the Henry's Fork. Similar to the pattern observed in temperature and dissolved oxygen, it is clear that much of the reservoir's influence on nutrient concentration is lost by the time that water passes through Pinehaven.

General Trends in Macroinvertebrate Data

In the spring of 2015 we added macroinvertebrate sampling to the water-quality monitoring program. HFF had done sporadic sampling of macroinvertebrates in previous years, but in 2015 we improved the sampling protocol and plan to repeat it every year going forward. From our macroinvertebrate data, we have learned that the Flat Rock reach is one of the very best sections of the Henry's Fork in terms of consistently good water quality, high diversity of aquatic invertebrates, and a high percentage of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies).

We summarize our macroinvertebrate data using three metrics: Hilsenhoff Biotic Index (HBI), Shannon's diversity index, and % EPT. First, the HBI creates a relationship between macroinvertebrate data and water quality. HBI uses the fact that different types (order, genus, or species) of macroinvertebrates have lower tolerance for pollution and fine sediment than others. A lower HBI score indicates presence of invertebrates that are very sensitive to pollution and hence better water quality. Second, we measure diversity using a metric where a higher score indicates more types of macroinvertebrates and/or a more uniform distribution of those types. Third, % EPT is the percentage of the total individuals made up of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies). A higher % EPT indicates

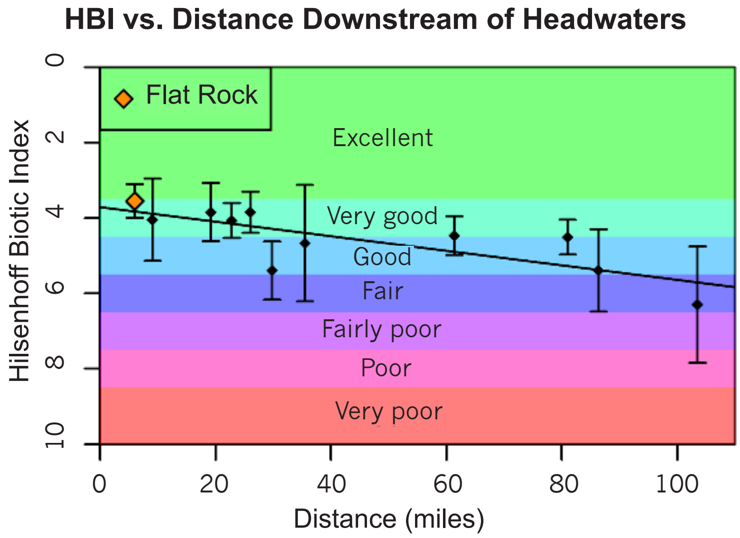


Figure 5 *- Flat Rock is the left-most point and a site near Rexburg is the right-most point. Points in between were sampled from the Henry's Fork moving downstream from Flat Rock until the confluence with the South Fork. Flat Rock has the best HBI score (closest to zero) in the Henry's Fork, which indicates the best water quality is found at Flat Rock and degrades with distance from the headwaters. Notice a lower HBI score indicates better water-quality, so points near the top of the graph indicate better habitat.*

better water quality due to the low tolerance of these macroinvertebrates to pollution and fine sediment.

All three metrics we calculated for Flat Rock have remained stable over the timespan of our data, which includes consistent sampling since 2015 and various types of sampling conducted over years scattered between 1993

Collecting macroinvertebrate samples.

and 2007. Thus, a main point we've learned from our macroinvertebrate data is there have not been any large changes in water-quality, diversity, or % EPT at Flat Rock since the early 1990s. What's more, Flat Rock has very good water quality: it has the best HBI score and one of the highest % EPT in the Henry's Fork (Figures 5 and 6). We conducted an analysis to predict HBI and % EPT using proximity to the headwaters and we found that Flat Rock's location relatively close to the headwater springs is the primary explanation for why it has better water quality than reaches downstream (regression lines in Figures 5 and 6). Proximity to headwaters summarizes the various effects on water quality of elevation, stream gradient, and substrate—all of which also change predictably with distance from headwaters.

A few details on diversity for the bug nerds follow. In 2019, 62 different types of aquatic invertebrates were observed across the six samples taken at Flat Rock. By far, the most abundant invertebrate was the Pale Morning Dun mayfly (*Ephemerella* sp.), at 37% of the total number of individuals observed. The next most common invertebrate was a freshwater clam (*Spheariidae*), at 10%, followed by Flav mayflies (*Drunella flavilinea*) at 7%. All other types were each less than 6% of the total. The top 10 included three types of mayflies, two types of midges, two caddis species, and one type each of worms, clams, and scuds (freshwater shrimp). After the Pale Morning Dun and Flav, the most common mayflies were the Brown Dun (*Ameletus* sp.), Green Drake (*Drunella grandis*), and Mahogany Dun (*Paraleptophlebia* sp.).

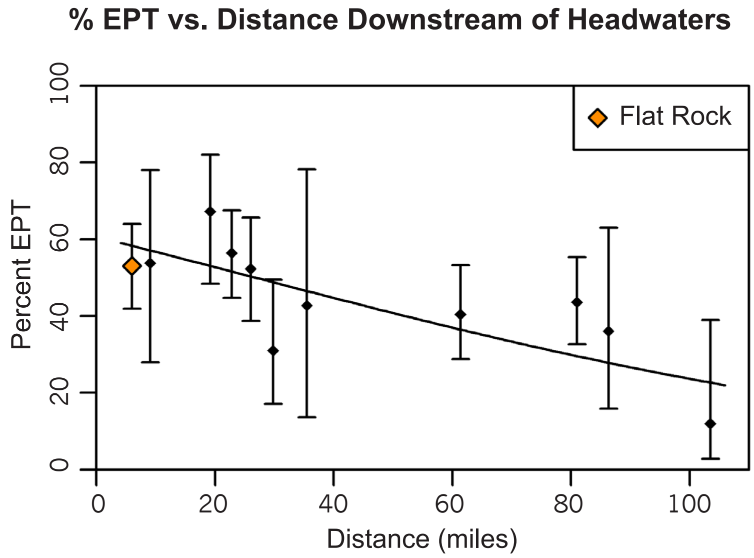
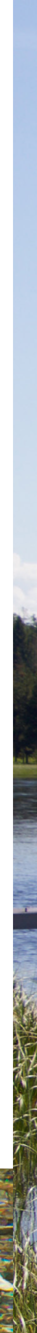


Figure 6 *- Flat Rock is the left-most point and a site near Rexburg is the right-most point. Points in between were sampled from the Henry's Fork moving downstream from Flat Rock until the confluence with the South Fork. Flat Rock has one of the highest % EPT in the Henry's Fork. Due to the low tolerance of these macroinvertebrates to pollution and fine substrate, a higher % EPT indicates better water quality.*



Next Steps

Looking forward, there is potential for the impacts of IP Reservoir to spread upstream toward Flat Rock, instead of only affecting the downstream ecosystem. HFF has started a brand new project that consists of projecting impacts on the river upstream of IP Reservoir of proposed changes to the Mack's Inn wastewater treatment plant. There will be forthcoming communication about this issue in greater detail, especially as we draw conclusions. However, the current summary of this work entails evaluating the impact of discharging treated wastewater into Henrys Lake Outlet, which will increase nutrients above IP Reservoir. Higher nutrient content will produce more macrophytes, which provide high quality trout habitat through increasing summertime cover and foraging opportunity. These benefits of macrophytes to trout habitat were established through collaboration between HFF's science program and Grand Valley State University and published in the journal *Ecology of Freshwater Fish*[2]. We know that increasing trout habitat in the Henry's Fork will directly increase trout population numbers. Furthermore, we hypothesize the currently struggling population of reservoir Kokanee will be primary beneficiaries of this high quality habitat. In short, we wouldn't be able to do this research if we didn't have several recent years of baseline data about the reaches upstream of IP Reservoir provided by the Flat Rock sonde.

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[2] Kuzniar, Z.J., R.W. Van Kirk, and E.B. Snyder. 2017. Seasonal effects of macrophyte growth on rainbow trout habitat availability and selection in a low-gradient, groundwater-dominated river. Ecology of Freshwater Fish 26:653-665.

Thank you to the many individuals and organizations that contributed to this project!

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