# Environmental Flow Implementation Below East Lynn Reservoir: The Potential to Improve In-stream Habitat and Water Quality

**US ARMY CORPS OF ENGINEERS**
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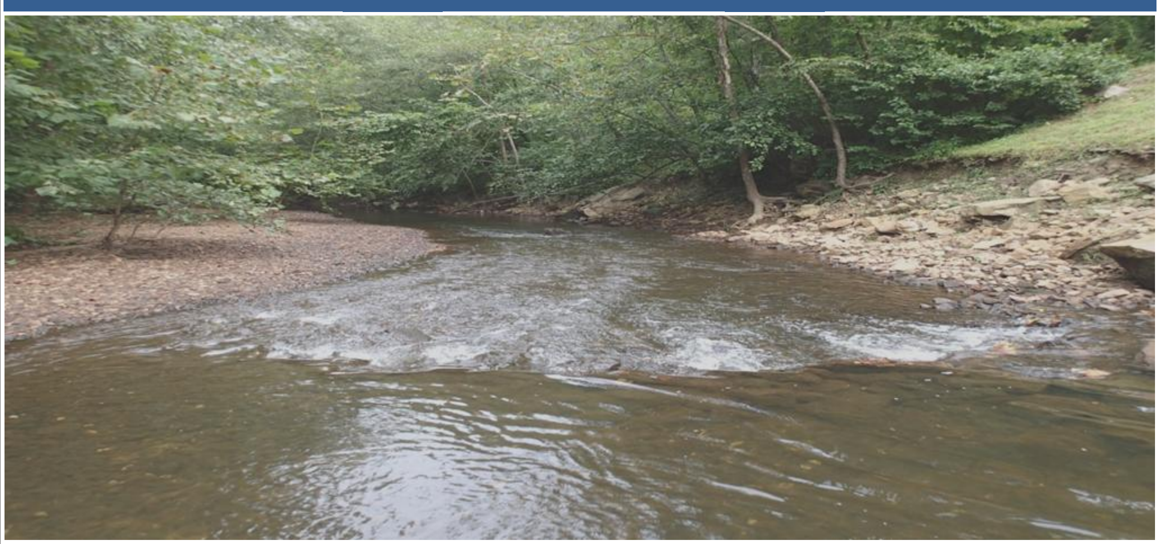

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**EXECUTIVE SUMMARY**

- The goal of this study was to determine a more natural operation of East Lynn Reservoir that balanced benefits achieved through environmental flows with existing authorized project purposes.
- Environmental flow is the process of managing water quantity, timing, and quality to sustain ecological integrity of riverine ecosystems.
- Hydrology is the driving force of a riverine ecosystem and is directly responsible for its biodiversity.
- Alterations to hydrology can severely impact aquatic ecosystems through changes in water quantity as well as water quality parameters such as temperature and sediment.
- Selective withdrawal capabilities at East Lynn Dam allow for limited control of the water temperature of releases in order to match the natural conditions in the unregulated stream.
- Temperatures in the tailwaters were significantly warmer from June to September than in the inflows and the West Fork of Twelvepole Creek.
- Both flood control releases and environmental flow pulses resulted in a sudden drop in temperature of between 4.2 C° to 8.5 C° in the tailwaters following increases in flow. These temperature decreases occurred over a period of less than one hour and were detected 4.4 km downstream of the dam.
- Sudden decreases in temperature when flows increase combined with the sudden temperature increase when flows return to normal are detrimental to aquatic organisms including fish, benthic macroinvertebrates and mussels.
- Pulses in flow greater than 1000 cfs significantly alter substrate characteristics at least 2.8 km downstream of the dam by reducing fine sediment and exposing fine gravel and boulders.
- Fish and benthic macroinvertebrate data collected during 2013 was collected to determine the extent of possible improvements in future years due to implementation of environmental flow recommendations.
- Recommendations based on results from this study:
    - Although the project is operated to balance the depth of the epilimnion and temperature of the discharge a decrease in temperature of 3 C° during the warmest months would bring the tailwater temperatures closer to those found in the West Fork of Twelvepole Creek and inflows.
    - Water Control Manuals should be re-evaluated to specifically address release of water during stratification periods.
    - Minimum flows during stratification months should be made by blending water from intake I-4 through the low flow gate with water from Sluice Gate 3 to maintain temperature guidelines. Temperature at intake I-13 is similar to I-4 during summer stratification.
    - Discharges greater than minimum flows (10 cfs) should be made by proportionally increasing flows through the low flow valve and Sluice Gate 3.
    - Releases greater than the maximum discharge of the low flow valve (154 cfs) should be made through the Sluice Gates 1 and 2 without changing the configuration of the low flow valve and Sluice Gate 3 when possible.
    - Once sluice gates reach an opening of 2.5 ft the low flow valve is closed to reduce the possibility of debris entering the intake. Closing this gate should be done in small increments to reduce sudden temperature changes.
    - All operational changes should be made with consideration to how those changes are going to influence temperature downstream.
    - All selective withdrawal projects should be evaluated to determine if similar temperature changes occur during summer stratification releases.

## Introduction

The US Army Corps of Engineers (USACE) is committed to environmental leadership, conservation, restoration, and stewardship. Water quality is an authorized purpose at many Huntington District reservoirs, however, even if not an authorized project purpose, water quality is an integral consideration during all phases of a project's life. The Huntington District manages 35 reservoir projects covering approximately 45,000 square miles of drainage area in nine river basins flowing into a 311 mile stretch of the Ohio River. Understanding the physical, chemical, and biological processes occurring in our waterways allows the USACE the opportunity to efficiently manage projects in ways that provide for sustainable human uses while conserving the environmental value of the resource.

Environmental flow is the process of managing water quantity, timing, and quality to sustain ecological integrity of riverine ecosystems. Currently it is difficult to measure how changes in flows will influence abiotic conditions such as temperature and sediment but even harder to determine how subtle changes in abiotic factors will change biotic communities (King et al., 2008). Ecologists understand the benefits of diversity in an ecosystem, yet most reservoirs operate with mandated engineered uniform flow guidelines through minimum and maximum flows. Healthy biotic communities thrive on variety in habitats, species richness, and environmental conditions. During dry years minimum flow regulations often lead to tailwaters of reservoirs being maintained at minimum flows for months with no variation in discharge creating a highly stable ecosystem. This highly stable ecosystem results in streams below reservoirs becoming dominated by equilibrium strategists and tends to select against opportunistic and periodic strategists (Mims and Olden, 2013).

East Lynn Lake is a reservoir located on the East Fork of Twelvepole Creek (EFTC) in Wayne County, West Virginia. The USACE impounded the EFTC in 1971 under the authority of the Flood Control Act of 1962 for the purposes of flood control, recreation, fish and wildlife conservation, low flow augmentation, and water quality. The dam is equipped with a selective withdrawal intake system that allows for water withdrawal from any combination of high-level intakes and bottom sluice gates (USACE, 2001). Therefore, it is possible, depending on flow conditions, to regulate both quality and quantity of water passing through the dam. East Lynn Lake covers approximately 1,005 acres (1.57 sq mi) at summer pool, which equates to about 12.7 stream miles of backwater and 17,200 gross acre-feet of storage (USACE, 2001). The major inputs to East Lynn Lake are East Fork of Twelvepole Creek, Kiah Creek, and Lick Creek with several small tributaries providing minimal direct surface water input. The EFTC joins with the West Fork of Twelvepole Creek (WFTC) near Wayne, WV to form Twelvepole Creek. Twelvepole Creek drains approximately 442 square miles (USGS, 2013) before eventually joining the Ohio River near Ceredo, WV. Other major inputs below the dam include Laurel Creek, Lynn Creek, Little Lynn Creek, and Camp Creek. Another reservoir in the watershed, Beech Fork Lake, impounds a small tributary of Twelvepole Creek near the town of Lavallette.

The East and West Forks of Twelvepole Creek, as well as Twelvepole Creek are listed on the West Virginia 2012 303(d) list as impaired for biological criteria. The EFTC is listed from river mile 4.4 to East Lynn dam and from river mile 41.3 to its headwaters. The WFTC is impaired throughout its entire reach. Twelvepole Creek is impaired from river mile 13.9 to its headwaters. Lynn Creek and Camp Creek are also listed as biologically impaired throughout their entire reaches (WVDEP, 2012a).

Hydrology is the driving force of a riverine ecosystem and is directly responsible for its biodiversity. Alterations to hydrology can severely impact aquatic ecosystems through changes in water quantity as well as water quality parameters such as temperature and sediment (Olden and Naiman, 2010; Hauer and Lorang, 2004; Bunn and Arthington, 2002). The presence of an impoundment alters the natural thermal regime of a once free-flowing stream. Due to a reservoir's mass, seasonal and daily temperature fluctuations tend to occur more slowly than in free-flowing streams. These changes can have an impact on how the downstream habitat is utilized such as trophic zones, thermal zone tolerances, and reproductive strategies. The extent of impact varies with the geography and environmental conditions of the reservoir, the influence of streams introduced below the dam, and how the dam is operated (Olden & Naiman, 2010). Selective withdrawal capabilities at East Lynn Dam allow for limited mitigation of temperature alterations. Any combination of intakes can be utilized to release high quality water that is similar to the natural conditions of an unregulated stream. The dam is currently operated to achieve release temperatures that fall between or reasonably close to temperature guide curves (Figure 1) using a single wet well. Discharge temperature guide curves were set by regulating agencies when the reservoir was designed and built. Reservoirs with single wet wells are not as effective at blending water at low flows due to water density differences between layers. Selective withdrawal outlet structures with dual wet wells enable reservoirs to blend water from warmer oxygen rich epilimnetic waters with cooler anoxic hypolimnetic waters to control for temperature and dissolved oxygen downstream during low flow stratification periods more effectively. Because temperatures vary from year to year efforts are focused on following the slope of the curves (i.e. rate of increase or decrease in temperatures) rather than matching them exactly. When available, operational changes are used to ensure that outflow temperatures do not inappropriately deviate from guide curves.

While selective withdrawal capabilities at East Lynn mitigate temperature changes to some extent, flows below the dam remain considerably altered from natural flows. Normal flows below East Lynn Dam range from 10 cfs to 2,380 cfs, with a maximum increase or decrease in discharge of 1 foot on the outflow gage per hour (USACE, 2001). When large rain events occur in spring and summer, releases are based on the amount of available storage in the lake. If the lake is below summer pool, the rain events are stored with minimum releases below the dam until summer pool is reached. Otherwise, rain events are released not to exceed 80% of inflow. Flood control becomes the top priority as the downstream channel approaches capacity. During flood conditions large pulses in flows are traded for sustained periods of higher than normal flows with little to no control over temperature. Although flood damage reduction projects are only operated for floods less than 10% of a year, operations during non-flood periods are often engineered to the same standards as flood operations. Maximum flow guidelines are set by downstream control points that are used to operate flood control reservoirs to minimize damages to human life and property. When a reservoir is designed and built minimum flow guidelines are established with inputs from regulating agencies in order to minimize impacts of low flows on biological communities, municipal water intakes and pollution inputs. Since minimum flows have been engineered to provide optimal flows, naturally diverse biological communities have been replaced with communities optimized for that flow. Communities of equilibrium strategists have become well established under these uniform flow regimes, thus making it difficult to alter that community without a perceived negative impact.

During summer and early fall, the lake typically experiences long-term periods of low flows interspersed with small rain events. Minimum releases are maintained through most of this period because many rain events that occur are usually stored to regain summer pool. These static minimum flows have an impact on habitat quality and availability immediately below the dam. Tailwater habitat under persistently low flows is characterized by diminished substrate diversity in the channel, low water levels, and lack of riparian vegetation (Long et al., 1997). Low flow impacts are worsened during fish reproductive seasons and during drought years. Additionally, sediment entering a lake from a watershed is typically deposited in the lake, remaining there while "sediment-starved" water is passed through the dam. Static low flows combined with sediment-starved water passing through the dam can result in armoring, homogeneous substrate, lack of depositional areas, and scour within the immediate tailwater area. These conditions may continue until bank erosion and downstream tributaries contribute enough sediment to reclaim natural levels (Donnelly, 1993; Curran & Tan, 2010). This phenomenon is normally exhibited in East Lynn Lake and EFTC. Substrate in the Twelvepole Creek basin is predominantly sands and fines, while substrate immediately below the dam is primarily small to large gravel that is void of sands and fines (USACE, 2001).

Long-term deposition of fine sediment is known to negatively impact biota in a stream, from primary producers to fish. Fine sediment deposition affects benthic macroinvertebrates and fish by altering habitat, depleting food supplies, and preventing successful spawning and reproduction. Deposition of fine sediment decreases species richness in macroinvertebrate communities by favoring those organisms that are tolerant to high sediment loads (Wood & Armitage, 1997). Conversely, it is known that a more heterogeneous substrate promotes species richness. Species richness in Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa is known to be negatively affected by increased fine sediment. Density and diversity of benthic macroinvertebrate communities tend to increase in pebble and cobble substrates (Kaller & Hartman 2004). Consequently, fish that prey on macroinvertebrates could be impacted by changes in species diversity and density instigated by sediment loading.

## Objectives

It is estimated that benefits to the EFTC from pulsed flows will be in the form of more natural temperature conditions and improved fish and benthic macroinvertebrate habitat below East Lynn Dam. This study will evaluate ecosystem changes in response to implementing environmental flow operations through East Lynn Lake. The desired result of this study is that the project will allow more natural temperature and flow regimes in the tailwaters without significant impacts to authorized project purposes or current quality resources. The specific objectives of this study include:

1. Determine temperature and sediment characteristics in EFTC below East Lynn Dam.
2. Assess how pulsed flows change the temperature and sediment heterogeneity downstream of dam.
3. Assess potential improvements to biological communities from changes in habitat availability and sedimentation due to pulsed flows.

## Funding

Funding support for equipment and labor was provided by the US Army Corps of Engineers Hydrologic Engineering Center (HEC) (Table 1). Additional funding was supplied by the Huntington District as part of the intensive sampling program for East Lynn Lake. Labor dollars include deploying and retrieving data from temperature loggers, completing habitat surveys, fish community and benthic macroinvertebrate samples, data analysis and report preparation. Labor funds for project personnel to make operational changes were minimal but the cost to the project is in lost time for other required scheduled activities that were not accomplished.

## OBJECTIVE 1 - Determine temperature and sediment characteristics in EFTC below East Lynn Dam.

### Methods

Temperature was collected prior to reservoir stratification in April, and then through September to capture the influences of stratified lake conditions. Temperature in the tailwaters of East Lynn Dam was collected at ten locations below the dam using data loggers to determine the extent of operational influence on EFTC (Table 2, Figure 1). Site selection was based on availability of access though 0.5 km spatial resolution was attempted. Data loggers were also placed on the inflows: Kiah Creek, Lick Creek and EFTC above the dam and on the WFTC above its confluence with the EFTC. Data loggers were deployed on April 8, 2013 before the lake stratified while downstream flows were reduced for summer fill. Data loggers were attached to 1/8” stainless steel cable that was anchored to duckbill earth anchors or to large exposed roots or tree trunks in a location that was completely submersed at minimum flows. Data loggers were programmed to record temperature hourly. Data was retrieved quarterly to ensure operation and replace damaged or missing loggers.

Temperature data did not have a normal distribution. It was organized by months and data were bootstrapped for number of data points collected per month with 10,000 replications. Box plots of the 0.025, 0.25, 0.5, 0.75, and 0.975 quantiles of the means were then generated for each month at each sample location. The 95th percent confidence interval (C.I.) of bootstrapped data were compared for temperature between all sites to allow for calculation of the distance of impact below the dam in relation to natural conditions, i.e. those in the reference sites. Statistical analysis of temperature was completed with R software (R Core Team 2012) using the R Commander package (Fox, 2005).

Substrate was analyzed using pebble counts (WVDEP, 2012b; Wolman, 1954) at five locations below East Lynn Dam, the three major inflows, and two sites on the WFTC during normal flows. Substrate category was collected at a total of 105 points within a 100 meter reach, specifically at five points along 21 transects. A random grab was performed at each point and the first substrate touched was categorized in one of eight size categories (Table 3). Substrate characterization was completed at the existing wetted channel at time of sampling and also at bank full elevation for each location. Substrate was characterized along the thalweg by collecting substrate size at one meter increments through the deepest part of the 100 meter reach. Thalweg, wetted width, bank full height, bank full width, and gradient was collected at each transect. Riffles, runs, pools, and large woody debris were tallied for each sample location. Mode was calculated to determine dominate and next dominate substrate for each site. Proportion of each substrate category was also calculated for each assessed location for substrate characterized in the wetted width and thalweg.

**Results**

April temperatures in the tailwaters were not significantly different than sites farther downstream of the dam and the site on the WFTC. The major inflows to the reservoir were slightly cooler than both the tailwaters and the WFTC (Figure 3). Mean temperatures in April and May were slightly cooler immediately below the dam and then warmed slightly and leveled out by 0.7 km downstream. In May there was a slight increase in temperature downstream of the dam that leveled out and was not significantly different than the WFTC (Figure 4). Starting in June there was an increase in temperature below the dam that was warmer than WFTC and the inflows (Figure 5). By July, warmer temperatures in the reservoir increased the mean temperature immediately below the dam 2.6 C° greater than temperatures in WFTC or the inflows. The mean temperature below the reservoir decreased over the next 2 km and then stabilized (Figure 6). In August and September the trend of warmer water from the reservoir continued and became more pronounced (Figures 7 and 8). For both August and September mean temperature immediately below the dam was 1.3 and 1.4 C° higher than where it stabilized at approximately 3.5 km downstream, 2.5 and 3.4 C° higher than the WFTC, and 3.3 and 4.5 C° warmer than the warmest inflow.

Substrate categories shifted significantly from immediately downstream of the dam to 0.9 km downstream of the dam (Figure 9). The substrate shifted from 40% coarse gravel at 0.3 km downstream, to 29% at 0.7 km to 11% by 0.9 km downstream. There was also a reduction in cobble from 0.3 km to 0.9 km downstream. Conversely, sand started at 16% at 0.3 km and shifted to 53% by 0.9 km. There was no silt or clay (fines) recorded at 0.3 km but it steadily increased to 22% of the sample by 2.8 km downstream. Substrate at 4.4 km downstream was absent of fines but was dominated by sand, coarse gravel and fine gravel with some cobble and boulders. The two major inflows to East Lynn Lake, EFTC and Kiah Creek were both dominated by sand while the Lick Creek inflow was a mixture dominated by Cobble with proportions of sand, fine and coarse gravel being relatively close. The lower WFTC site had several large riffles and was dominated by cobbles, sand and coarse gravel respectively while the upper WFTC site was 64% sand, 14% coarse gravel and 13 % fine gravel. The upper WFTC site had the highest proportion of sand of all locations sampled and the lowest proportion of cobble.

**Discussion**

Reservoir releases were reduced in April while the reservoir was filled to summer recreation elevation. The reservoir was not thermally stratified during spring fill, therefore withdrawals were made from bottom sluice gates since temperature is the same throughout all depths. It was expected that during this time temperatures in the reservoir were similar to nearby streams and inflows. As ambient stream temperatures increased during April and May tailwater temperatures remained slightly cooler than nearby streams due to the volume of cooler water in the reservoir. In June reservoir temperatures stabilized with input stream temperatures, and tailwater temperatures were uniform downstream; slightly warmer than the WFTC. As temperatures increase and the reservoir stratified, releases were shifted to low flow valves which enabled operators to pull water from different elevations based on temperature and dissolved oxygen concentrations. Discharge temperature targets were set by regulating agencies when the reservoir was designed and built (Figure 1). During summer as the reservoir stratified it was managed to balance cool water storage to maximize productive epilimnetic zones with maintaining tailwater temperatures and water quality. The increase in lake temperature and shift in operation caused July's mean water temperatures to increase immediately below the dam and level out by 2.2 km downstream. During the warmest months of August and September the increase in mean temperature below the dam was significantly higher than when it leveled out at near 3.9 km downstream. Even after the temperature leveled out it was still significantly warmer than the WFTC and the major inflow to the reservoir (Figure 10). The difference in temperature from the EFTC 3.9 km downstream and the WFTC may be attributed to land use differences and the difference in watershed size (Table 2). Olden and Naiman (2010) stated that reservoirs with epilimnetic releases may not be able to dissipate heat absorbed by the lake during summer months and downstream water temperatures may continue to increase due to normal stream processes.

Substrate characteristics varied considerably within and between the WFTC and EFTC basins. The Twelvepole Creek basin is dominated by sands and this was evident at most sites that were assessed. This held true at all sites except those immediately below the dam, the Lick Creek inflow and the lower WFTC Site. As with most locations immediately below a dam the tailwaters of East Lynn Lake were starved for fine sediments and sands since the reservoir itself acted as a sediment sink. At 0.3 km downstream of the dam the substrate was dominated by 40% coarse gravel. Downstream from this site the substrate shifted to increased proportions of sands and fines as bank erosion and tributary input overcame the dam's influence. By 0.9 km downstream of the dam the inputs of sands and fines increased enough that sand became the dominate substrate and coarse gravel and cobbles became embedded virtually everywhere but riffle locations. The site located 4.4 km downstream was dominated by sand. However several large riffles created by bridge abutments caused high proportions of fine and coarse gravels with cobble and boulder levels higher than 10% and virtually no fine sediment.

The Lick Creek inflow is a small watershed that had relatively little headwater disturbances. This contributed to lower temperatures and a more heterogeneous substrate composition. An increased number of riffles and lower embeddedness contributed to the substrate dominated by cobble and coarse gravel. The EFTC and Kiah Creek both had substantial amounts of headwater disturbances and were both dominated by sand substrates. Kiah Creek had more riffle habitat than the WFTC which led to increased amounts of cobbles and less fines. The lower WFTC site was located at a bridge crossing and was dominated by riffle habitat, thus explaining the dominance of cobble while proportions of sand and coarse gravel were almost equal. The upper WFTC site had a lower gradient and was located in a long pool with few small riffles and runs, resulting in a predominately sand substrate and a lack of larger particles.

**OBJECTIVE 2 - Assess how pulsed flows change the temperature and sediment heterogeneity downstream of dam.**

**Methods**

Following 20 days at near minimum flows in July and August 2013, flow was pulsed from 12 cfs to 1042 cfs and back to 12 cfs over a 13 hour period. Additionally, four large releases (greater than 800 cfs) occurred in the tailwater between May and July due to an inclemently wet summer. The three locations sampled below the dam were sampled during normal flows prior to and immediately following the planned flow pulse on August 20, 2013. Temperature changes downstream were collected by temperature data loggers already deployed.

Temperature data were analyzed for five pulses greater than 600 cfs and for one pulse of 228 cfs to assess how water temperatures changed below the dam and how far downstream temperatures were affected. The first four pulses in May through July were due to natural rain events so temperature changes in the outflow were compared to temperature changes in the inflows caused by storm water inputs. Distance to temperature stabilization was compared during pulsed flows to determine the distance of temperature influence of the dam.

Substrate samples were collected using the same procedures described in Objective 1. Analysis of substrate results was completed by comparing the conditions prior to the August 20$^{th}$ pulse to the substrate conditions following the pulse. A different starting point was established for each sampling reach to allow for independent datasets. Modes for dominant and next dominate substrates were compared prior to and after the pulse. A Chi-square test of independence was used to determine if changes in categories at each site were significant. Difference in proportions of each category were then plotted with plus and minus 2 standard errors to determine which changes in proportion were significant. Difference in proportions was calculated for each size category (fines, sand, small gravel…) and compared to no change (0 difference in proportion) to determined if the change was significant for the given sample size. Changes in proportion that were +/- 2 SE above or below 0 represent a significant change in proportion for that size category.

**Results**

At each pulse there was a noticeable drop in temperature immediately below the project (Figure 11). The water temperature immediately below the dam following discharge of a rain event on June 10$^{th}$, 2013 decreased 7.9 C° over a two hour period. The lower temperatures remained for about 24 hours and then transitioned back to baseline in a two hour period (Figure 12). A similar discharge on July 18$^{th}$, 2013 of 229 cfs resulted in a temperature decrease of 8.5 C° over a one hour period (Figure 13). The same pulse translated to a 3.3 C° decrease in temperature over a nine hour period 4.4 km downstream of the dam (Figure 14). The planned pulse that occurred on August 20$^{th}$, 2013 resulted in a 4.2 C° decrease over one hour, a 3.7 C° increase over five hours, another 3 C° decrease over five hours and a final 3.7 C° increase over 3 hours (Figure 15). Figure 16 shows that a temperature decrease at a discharge of 1040 cfs was just as abrupt at 4.4 km downstream as it was at 0.3 km downstream of the dam but the temperature rise following the pulse was slower further downstream.

Changes in the proportion of substrate categories were similar between the wetted channel and the thalweg datasets except at 0.9 km downstream where there was a significant change seen in the thalweg but not the wetted channel (Table 4). This was due to a large increase in sand and decrease in fine gravel in the thalweg that was not seen in the wetted width. There was no significant change in overall substrate composition 0.3 km downstream of the dam in either the substrates measured in the wetted width or in the thalweg as determined by the chi-square test of independence. There was a slight increase in silt and clay 0.3 km downstream of the dam with a decrease in the proportions of silt and clay at 2.8 km downstream (Figure 17). Proportions of sand did not change immediately below the dam but increase further downstream (Figure 18). Fine gravel did not change below the dam but it was significantly lower at 0.7 km downstream and significantly higher by 2.8 km downstream of the dam (Figure 19). The proportions of coarse gravel and cobble did not change at 0.3 or 0.7 km downstream but was significantly lower by 2.8 km downstream of the dam (Figures 20 and 21). There was a significant increase in boulder proportions at 2.8 km downstream of the dam but not at 0.3 and 0.7 km downstream (Figure 22).

**Discussion**

Changes in temperature affect the oxygen affinity of hemoglobin in fish as well as the partial pressure of dissolved oxygen (Moyle and Cech, 2004). Temperature cues are important to benthic macroinvertebrates through regulation of metabolisms, reproduction, emergence and distribution. Variance in temperature further impacts benthic macroinvertebrates by eliminating key developmental cues, influencing growth rates, and disrupting season patterns of life cycles (Vannote and Sweeney, 1980). Sudden decreases in temperature combined with sudden increases shortly after could be detrimental to aquatic organisms including fish, benthic macroinvertebrates and mussels. If sudden temperature changes occur during specific times of the year, reproduction of aquatic species could also be disrupted.

The sudden temperature decrease following each increase in discharge was not an expected result of this study because of the project's selective withdrawal capability. The outlet structure for the reservoir was designed to pull oxygen rich warm water from the epilimnion and mix it with cool anoxic water from the hypolimnion before being discharged through a low flow valve to meet temperature and oxygen requirements downstream. This system is designed with a capacity for 154 cfs through the low flow valve. Based on temperature data it is apparent that once flows exceeded 154 cfs the discharge was transferred to the sluice gates located entirely in the hypolimnion. The switch from the low flow valve to the sluice gates caused the sudden temperature decline during increased flows. Temperature declines were observed in the inflows and the WFTC during large rain events but the changes in temperature took place over days, not hours. Temperature changes were most significant and pronounced immediately below the dam. Temperature changes during lower flows were less pronounced in both temperature extremes and duration with increasing distance from the dam. However, the effects of the pulse could be seen as far downstream from the dam as 4.4 km for a pulse of 229 cfs. With larger pulses the temperature change was pushed further downstream and impacted a larger area of stream.

Substrate characteristics below the dam were unique in the Twelvepole Creek basin due to conditions created by the reservoir. A high proportion of coarse gravels with a near even mixture of sand, fine gravel, cobble and boulder were created due to the retention of fine sediments in the lake. As the distance from the dam increased fines and sands were introduced to the system from tributaries and bank erosion. The slight changes in proportions below the dam due to the pulse were not significant enough to conclude they were not by chance. Changes in proportion do not determine if a significant or large amount of sediment was moved; it determined if a shift in proportion from before the pulse to after the pulse levels at a given sample size would occur by chance. At 0.7 km downstream of the dam there was a slight increase in sand and coarse gravel and significant decrease in fine gravel in the samples taken from the wetted channel. There was a significant increase in sand and decrease in fine gravel in the thalweg samples collected at that site. There was one tributary upstream and one tributary within the sample location that input sediment into the sample location. There was also a minor increase in coarse gravel and cobble in both the wetted channel and thalweg samples, though the amount was not considered significant. The pulse moved sand into the sample location, probably from below tributaries and bank erosion, and covered fine gravel substrates while causing some clearing of coarse gravel and cobble substrates.

The largest changes in substrate proportions of the three locations sampled occurred 2.8 km downstream of the dam. This sample location is immediately below Big Lynn Creek which is a major input of sand into the EFTC and is characterized by steep constricting banks. A significant decrease in fines was noticed in both the wetted channel and thalweg samples with a significant increase in fine gravel and boulders. As flows increased, fine gravel and boulders substrates covered with fines were exposed while coarse gravel areas may have been covered with sand resulting in the slight increase in sand and decrease in coarse gravel.

## OBJECTIVE 3 - Assess potential improvements to biological communities from changes in habitat availability and sedimentation due to pulsed flows.

### Methods

Baseline fish community data were collected in September in coordination with the West Virginia Department of Natural Resources (WVDNR). Four WVDNR personnel and four Huntington District Personnel cooperated to sample eight locations, three below the dam, three inflows, and two locations on the WFTC. Fish were collected from a 160 m reach using an electric seine. Small fish were preserved in 10% buffered formalin to be identified by WVDNR personnel.

Baseline quantitative benthic macroinvertebrate community data was collected at eight locations by compositing four riffle kicks (1.0 $m^2$) using a 500 micron mesh and a 0.5 m dip net. Samples were stored in 70% ETOH and shipped to a contract lab for identification. A sample of 300 (+/- 20%) benthic macroinvertebrate organisms will be identified to the genus level when possible, with life stage noted from each sample. Analysis will include standard metrics with percent abundance of each taxonomic level observed, percent dominant taxa, percent of each trophic level, HBI, Shannon-Weiner Index and West Virginia Stream Condition Index (WVSCI).

Fish and benthic macroinvertebrate data collected in 2013 will be compared to historical data and will be used to determine how future operations influence these biotic communities. Data collected during 2013 were not collected to determine the impacts from this year's operations but to determine possible improvements in future years. Although final samples have yet to be completely identified some field observations at the time of collections and results from previous surveys will be discussed.

### Results

Fish community data from below the dam in 2006 show an impaired condition and differed drastically from inflow streams. Only 11 species and 34 individuals were collected below the dam while 19 species and 99 individuals were collected from Kiah Creek above the reservoir (Tables 6 and 7). The dominate species collected in the tailwaters was the striped shiner (*Luxilus chrysocephalus*) and only one darter, a greenside darter (*Etheostoma blennioides*) was collected. A high proportion of lithophilic spawners were collected and 42% of individuals were considered tolerant in the tailwaters. The dominant species in Kiah Creek was the rainbow darter (*E. caeruleum*) and five other darter species were collected. There were also a high proportion of lithophilic spawners in Kiah Creek with 33% of individuals being considered tolerant. During collections in 2013 no variegate darters (*E. variatum*) were collected from below the dam to 4.4 km downstream of the dam though they were collected at both locations on the WFTC and below the old mill dam 21 km downstream of East Lynn Dam. Eastern sand darters (*Ammocrypta pellucida*) were collected in the EFTC above the lake in 2013 and on Twelvepole creek 45 km downstream of the dam (unpublished data) but were not collected directly below the dam or on the WFTC.

Benthic macroinvertebrate data has been collected from the tailwaters of East Lynn Reservoir by USACE since 1973. West Virginia Stream Condition Score (WVSCI) was determined for all samples collected below the dam and in Kiah Creek (Figures 23 and 24). Tailwater benthic macroinvertebrate communities ranged from very poor to poor for the first 10 years after impoundment and have ranged from very poor to good between 1982 and 2007. Kiah Creek ranged from fair to excellent from 1977 to 1995 and ranged between poor and good from 2002 to 2007.

**Discussion**

Changes in fish community structure below dams have been well documented (Lessard and Hayes 2003; Edwards, 1978). Yet the specific drivers causing these changes are not fully understood. Carlisle et al., (2010) states that diminished flow magnitudes are a primary predictor of biological integrity of fish and benthic macroinvertebrate communities. In addition to flows, temperature is a major driver of life history traits and directly impacts metabolic rates and physiological processes in aquatic organisms (Mims and Olden, 2013). Fish and benthic macroinvertebrate communities below the dam have been altered since impoundment of the reservoir in 1971 in both density and community structure. Changes to biotic communities are likely a result of altered flow and temperature regimes.

Two species of fish are found above or near the tailwaters of the dam but not within the influence of the dam. The variegate darter was collected at both sample locations on the WFTC and downstream of the dams influence but it was not collected in the tailwaters. Variegate darters prefer moderate to fast water habitats (Wehnes, 1973) over large gravel and cobble substrates. Variegate darters were collected in the upper location of the WFTC in the only riffle over large gravel predominantly surrounded by sand. The upper WFTC location had very little habitat suitable for use by the variegate darter though it was collected there. Habitat located below the dam is considered more ideal for use by the variegate darter yet it has not been collected at this site. This may be evidence that the variegate darter is more sensitive to flow and temperature than habitat since it was collected on the WFTC and not below the dam. Sand darters prefer habitats composed of fine gravel and sand with predominately >90 % sand with gentle currents and little fine sediment deposition (Ontario Ministry of Natural Resources, 2013). Sand darters were collected in the EFTC above the lake and have been historically collected 45 km downstream of the dam on Twelvepole Creek. However, they were not collected in sandy substrates below the dam during this study though habitat conditions were optimal at several locations.

Benthic macroinvertebrate communities are also altered below dams due to changes caused by the reservoir. Communities shift from a diverse EPT dominated community to one dominated by filter feeding Trichoptera, Chironomidae, and Simuliidae. Benthic macroinvertebrates below East Lynn Dam have seen this shift in community structure evident by the low WVSCI scores following impoundment. As communities have stabilized scores leveled out and slightly improved over time (Figure 23). More interpretation and comparisons will be possible once 2013 data are received and analyzed.

## SUMMARY

Many improvements have been made in the operation of East Lynn Reservoir although several opportunities still exist. Selective withdrawal capabilities have allowed operators to follow temperature trends by mixing warm epilimnetic water with cool hypolimnetic water. Moving the start of winter drawdown after reservoir mixing allowed operators to reduce releases of anoxic water downstream. Temperature is often cited as an important component of E-flow (Dyson et. al., 2003) but tailwater temperature changes due to increased flows during lake stratification have not been discussed. By using the temperature data collected this year, recommendations can be made on operation of the project that can significantly improve tailwater habitats.

Although the project is operated to balance the depth of the epilimnion and temperature of the discharge, a decrease in temperature of 3 C° during the warmest months would bring the tailwater temperatures closer to those found in the WFTC and inflows. This would require existing models to be rerun to determine how using larger amounts of cooler water from the hypolimnion to reduce tailwater temperature may impact depth of epilimnion. The most significant change in operations needs to address how the project is managed during release of excess water during summer stratification months. Sudden drops in temperature over short periods of time due to hypolimnetic releases are detrimental to biotic communities. It is critical that impacts to water temperature from increased flows be taken into account when determining operation of reservoirs (Olden and Naiman 2010). Water Control Manuals should be re-evaluated to specifically address release of water during stratification periods.

While this study did not address metals concentrations in the hypolimnion, high levels of dissolved metals are the reason that sluice gate releases are avoided during stratification. High iron levels can bond substrate downstream and increase armoring. Metal concentrations need to be evaluated in the hypolimnion and the tailwaters during proposed operations to determine possible impacts. Minimum flows during stratification months should be made by blending water from intake I-4 through the low flow gate with water from Sluice Gate 3 to maintain temperature guidelines. This will allow for more precise blending of layers since flows will not be influenced by water density differences. Intake I-13 should remain closed to maximize the amount of oxygen rich water that can be blended. Discharges greater than minimum flows (10 cfs) should be made by proportionally increasing flows through the low flow valve and Sluice Gate 3 to maintain temperatures as close as possible. Releases greater than the maximum discharge of the low flow valve (154 cfs) should be made through Sluice Gates 1 and 2 without changing the configuration of the low flow valve and Sluice Gate 3 when possible. Once a sluice gate reaches an opening of 2.5 ft the low flow valve is closed to reduce the possibility of debris entering the intake. Closing this gate should be done in small increments to reduce sudden temperature changes. All operational changes should be made with consideration to how those changes are going to influence temperature downstream. If desired results are not obtained then attempts should be made to lengthen the duration of increased flows to maximize use of the low flow valve if recreation and flood control are not impacted.

It has been well documented that dams alter temperature regimes in tailwater streams (Lessard and Hayes 2003; Ligon et al., 1995; Dyson et al., 2003). Reservoirs alter thermal cycles downstream by acting as buffers for diurnal and annual fluctuations due to the mass of water. Stream temperatures are a critical factor in biological, chemical and physical process (Mims and Olden, 2013). Water chemistry conditions below East Lynn Reservoir are better than either of the two major inflows and a large percentage of other streams in watershed due to the buffering capacity of the reservoir and use of the selective withdrawal structure (unpublished data). Water chemistry and fine sediment are not limiting factors to success of biotic communities in the tailwaters so returning temperature and flow regimes to more natural conditions should benefit those communities. By eliminating sudden temperature changes and returning flows to more natural conditions, reducing minimums and returning pulses, biotic communities should return to a more natural condition.

This study showed:

- Pulses in flow greater than 1000 cfs significantly alter substrate characteristics at least 2.9 km downstream of the dam by reducing fine sediment and exposing fine gravel and boulders.
- One foot of water from the lake was needed to create a 1000 cfs pulse. An inflow pulse of 2000 cfs is needed to raise the lake one foot. Thus the release was only half of what would have occurred in normal conditions.
- Flows greater than 154 cfs can be detrimental to biotic communities by causing large changes in

temperature over a short period of time.

- Further studies need to be accomplished to determine if the positive effects of pulses can be accomplished at lower discharges.

**Future Work**

- Implement new management strategies during summer stratification months
  - Pass majority of flows through the low flow valve and Sluice Gate 3
    - Monitor metal concentrations in the hypolimnion to determine how increased flows pulled from the hypolimnion could potentially impact downstream water quality conditions
    - Water in the lower zones of the lake which are subject to reducing conditions during stratification contain iron
    - When hypolimnetic water is released and aerated in the stilling basin, the iron precipitates as iron hydroxide and potentially coats the streambed resulting in armoring of the substrate
  - When discharges exceed capacity of low flow valve release additional required flow through the sluice gates without closing low flow gates/valve
  - Examine possibility of balancing rise in reservoir during non-flood events with recreation to allow for extended length of release at lower flows if simple flow changes are not effective
- Determine how blending more water from the hypolimnion to meet temperature goals impacts the dissolved oxygen and water chemistry (hydrogen sulfide and metals) downstream
- Evaluate substrate at multiple locations below the dam following pulses of varying magnitude
- Balance positive effects of pulsed flows with minimizing stream erosion and permitting natural formations of islands and bars
- Deploy temperature data loggers beyond 4.4 km downstream of the dam and on inflows just above lake influence
- Set temperature data loggers to record at 15 minute intervals to further determine distance of impacts and better evaluate benefits of new operations
- Collect additional fish and benthic macroinvertebrate community samples on the WFTC, EFTC further downstream of dam, and on Twelvepole Creek below their confluence to determine potential effects to biological communities
- Evaluate the influence of hyporheic flows on temperatures below East Lynn Dam
- Compare gradients and land use types between sample locations
- Evaluate timing of discharges to coincide with natural high water events to determine impacts of sediment from tributaries deposited in the main channel
- Reduce minimum flows or establish a mean flow from mid-July through October during low water years with additional storage gained in the lake pulsed during natural rain events
  - Same volume of water should be discharged over a given time period
  - This would not be a tool for maintaining recreational pool
- Re-evaluate current minimum flow guidelines and establish criteria for seasonal biotic flow requirements
- Extended minimal flows may decrease the beneficial effect that pulsed flows have on moving substrates and increase armoring

- Static low flows combined with sediment-starved water passing through the dam can result in armoring, homogeneous substrate, lack of depositional areas, and scour within the immediate tailwater area
- Armoring of substrate immediately below the dam was not observed in 2013 due to higher than normal flow and lack of extended periods of minimum flows but should continue to be assessed in 2014
- Long periods of minimal flows should be eliminated to mimic a more natural dynamic flow regime during summer and fall months.

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| Table 1. Funding for project. | | |
|---|---|---|
| **Labor** | HOURS | FUNDS |
| Funded by HEC | 344.5 | $ 26,000.00 |
| Funded by LRH | 376 | $ 29,800.00 |
| Project labor to pulse flow | | $ 250.00 |
| | | |
| **Travel** | | $ 1,000.00 |
| | | |
| **Equipment purchased with HEC funds** | QTY | COST |
| Earth Anchor 68 1100 lb hold | 40 | $ 118.00 |
| Earth Anchor 40 250 lb hold | 40 | $ 62.00 |
| Drive Rod for earth anchors | 2 | $ 8.50 |
| HOBO Water Temperature Pro v2 Data Logger | 14 | $ 1,582.00 |
| HOBO Conductivity Data Logger | 2 | $ 1,298.00 |
| | | $ 3,068.50 |
| | | |
| **Equipment and products purchased with LRH funds** | QTY | COST |
| HOBO Water Temperature Pro v2 Data Logger | 24 | $ 2,712.00 |
| HOBO Conductivity Data Logger | 15 | $ 9,735.00 |
| HOBOware Pro Win Software | 1 | $ 99.00 |
| HOBO® Waterproof Shuttle | 1 | $ 237.00 |
| Benthic macroinvertebrate analysis | 8 | $ 3200.00 |
| | | $ 15,983.00 |
| | | |
| TOTAL HEC FUNDS | | $ 30,068.50 |
| TOTAL LRH FUNDS | | $ 45,783.00 |
| **TOTAL PROJECT FUNDS** | | $ 76,101.50 |

Table 2. Sampling locations and parameters collected. EFTC = East Fork Twelvepole Creek

| Stream | Site Description | Lat/Long | Watershed Size ($mi^2$) | Distance Downstream (DS) | Parameters |
|---|---|---|---|---|---|
| **EFTC** | Immediately below dam in mid-channel | 38 8 43, -82 22 56 | 132 | 0.1 km DS | Temp |
| **EFTC** | Next to parking lot in tailwater recreation area | 38 8 49.5, -82 22 52 | 133 | 0.3 km DS | Fish, habitat |
| **EFTC** | Downstream of playground in tailwater recreation area | 38 8 53, -82 23 5 | 136 | 0.7 km DS | Temp, habitat |
| **EFTC** | Upstream of Route 37 bridge | 38 8 60, -82 23 12 | 137 | 0.9 km DS | Temp |
| **EFTC** | Behind old garage on Route 37 | 38 9 17, -82 23 3 | 138 | 1.7 km DS | Temp |
| **EFTC** | Behind abandoned store on Route 37 | 38 9 35, -82 23 8 | 138 | 2.2 km DS | Temp |
| **EFTC** | Immediately below low-water bridge near Post Office | 38 9 46, -82 23 25 | 138 | 2.8 km DS | Temp, fish, habitat |
| **EFTC** | Behind East Lynn Elementary off Route 37 | 38 9 42, -82 23 1 | 138 | 3.5 km DS | Temp |
| **EFTC** | Immediately downstream of East Lynn Fire Dept off Route 37 | 38 9 53, -82 22 51 | 138 | 3.9 km DS | Temp |
| **EFTC** | Immediately above Camp Creek | 38 10 1, -82 22 42 | 138 | 4.2 km DS | Temp |
| **EFTC** | Downstream of Camp Creek and Route 37 bridge | 38 10 5, -82 22 45 | 144 | 4.4 km DS | Temp, fish, habitat |
| **EFTC** | Off Route 37 approx. 2 miles south of Wayne | 38 11 56, -82 26 14 | 169 | 15 km DS | Temp |
| **Lick Creek** | Above the lake off Lick Creek Road | 38 6 49, -82 19 17 | 8 | Lake inflow | Temp, fish, habitat |
| **EFTC** | Above the lake off County Route 35 | 38 3 8, -82 18 29 | 53 | Lake inflow | Temp, fish habitat |
| **Kiah Creek** | Above the lake off County Route 33 | 38 3 37, -82 15 55 | 28 | Lake inflow | Temp, fish, habitat |
| **West Fork Twelvepole Creek** | At Old Twelvepole Rd bridge off Route 37 | 38 10 52, -82 28 33 | 108 | --- | Temp, fish, habitat |
| **West Fork Twelvepole Creek** | Off Route 152 approx. 1.6 miles south of Genoa | 38 6 27, -82 27 57 | 85 | --- | Fish, habitat |

Table 3. Substrate size categories.

| **Category** | **Size (mm)** | **Score** |
|---|---|---|
| silt/clay | <0.06 | 1 |
| sand | >0.06 - 2.0 | 2 |
| fine gravel | >2.0 - 16.0 | 3 |
| coarse gravel | >16.0 - 64.0 | 4 |
| cobbles | >64.0 - 250 | 5 |
| boulders | >250 - 4000 | 6 |
| hardpan | >4000 | 7 |
| bedrock | >4000 | 8 |

Table 4. Chi-square test of independence on substrate size class counts before and after planned pulse below East Lynn Lake.

| | Substrate Size Class | silt/clay | sand | fine gravel | coarse gravel | cobbles | boulders |
|---|---|---|---|---|---|---|---|
| Wetted Width | 0.3 km Downstream before pulse | 0 | 16 | 19 | 41 | 14 | 13 |
| | 0.3 km Downstream after pulse | 2 | 16 | 13 | 43 | 17 | 12 |
| | Chi-square p-value= | 0.623 | | | | | |
| Thalweg | 0.3 km Downstream before pulse | 0 | 10 | 10 | 56 | 18 | 3 |
| | 0.3 km Downstream after pulse | 0 | 6 | 8 | 58 | 28 | 13 |
| | Chi-square p-value= | 0.073 | | | | | |
| Wetted Width | 0.9 km Downstream before pulse | 10 | 26 | 21 | 30 | 12 | 5 |
| | 0.9 km Downstream after pulse | 7 | 31 | 11 | 33 | 15 | 7 |
| | Chi-square p-value= | 0.428 | | | | | |
| Thalweg | 0.9 km Downstream before pulse | 0 | 19 | 35 | 33 | 12 | 1 |
| | 0.9 km Downstream after pulse | 0 | 32 | 13 | 38 | 14 | 2 |
| | Chi-square p-value= | 0.007 | | | | | |
| Wetted Width | 2.8 km Downstream before pulse | 22 | 34 | 13 | 15 | 7 | 7 |
| | 2.8 km Downstream after pulse | 13 | 42 | 24 | 4 | 5 | 13 |
| | Chi-square p-value= | 0.011 | | | | | |
| Thalweg | 2.8 km Downstream before pulse | 9 | 19 | 12 | 33 | 17 | 6 |
| | 2.8 km Downstream after pulse | 2 | 25 | 23 | 27 | 14 | 14 |
| | Chi-square p-value= | 0.029 | | | | | |

Significant with p<=0.05 (there is less than a 5% probability that the difference in substrate before and after pulse occurred by chance)

Table 5. Fish species collected below East Lynn Reservoir on August 31, 2006

| Genus | Species | Common Name | Group | Total collected |
|---|---|---|---|---|
| *Campostoma* | *anomalum* | central stoneroller | Minnow | 10 |
| *Etheostoma* | *blennioides* | greenside darter | Darter | 1 |
| *Hypentelium* | *nigricans* | northern hog sucker | Sucker | 1 |
| *Lepomis* | *macrochirus* | bluegill | Sunfish | 2 |
| *Lepomis* | *megalotis* | longear sunfish | Sunfish | 2 |
| *Lepomis* | *XXXX* | sunfish hybrid | Sunfish | 1 |
| *Luxilus* | *chrysocephalus* | striped shiner | Minnow | 11 |
| *Micropterus* | *punctulatus* | spotted bass | Top Carnivore | 1 |
| *Minytrema* | *melanops* | spotted sucker | Sucker | 1 |
| *Nocomis* | *micropogon* | river chub | Minnow | 2 |
| *Notropis* | *rubellus* | rosyface shiner | Minnow | 2 |

Table 6. Fish species collected from Kiah Creek on October 31, 2007

| Genus | Species | Common Name | Group | Total Collected |
|---|---|---|---|---|
| *Ambloplites* | *rupestris* | rock bass | Sunfish | 6 |
| *Ameiurus* | *natalis* | yellow bullhead | Other | 1 |
| *Campostoma* | *anomalum* | central stoneroller | Minnow | 9 |
| *Catostomus* | *commersonii* | white sucker | Sucker | 2 |
| *Etheostoma* | *blennioides* | greenside darter | Darter | 4 |
| *Etheostoma* | *caeruleum* | rainbow darter | Darter | 21 |
| *Etheostoma* | *nigrum* | johnny darter | Darter | 5 |
| *Etheostoma* | *zonale* | banded darter | Darter | 2 |
| *Hybopsis* | *amblops* | bigeye chub | Minnow | 1 |
| *Hypentelium* | *nigricans* | northern hog sucker | Sucker | 7 |
| *Lepomis* | *cyanellus* | green sunfish | Sunfish | 1 |
| *Lepomis* | *macrochirus* | bluegill | Sunfish | 8 |
| *Lepomis* | *megalotis* | longear sunfish | Sunfish | 3 |
| *Lepomis* | *XXXX* | sunfish hybrid | Sunfish | 2 |
| *Luxilus* | *chrysocephalus* | striped shiner | Minnow | 8 |
| *Notropis* | *stramineus* | sand shiner | Minnow | 4 |
| *Noturus* | *miurus* | brindled madtom | Madtom | 1 |
| *Percina* | *caprodes* | logperch | Darter | 3 |
| *Pimephales* | *notatus* | bluntnose minnow | Minnow | 11 |

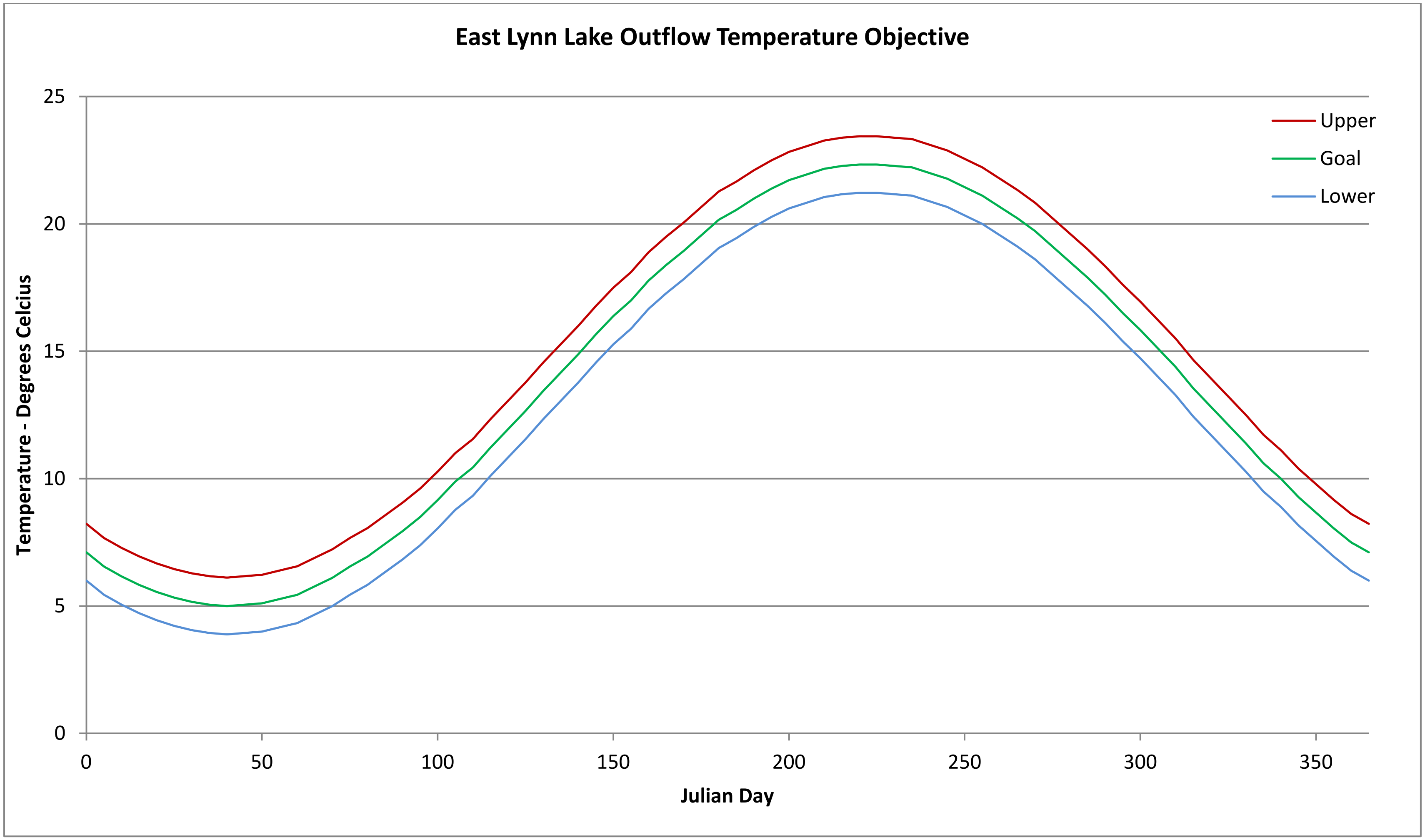


Figure 1. Temperature guide rule curve for tailwaters of East Lynn Lake.

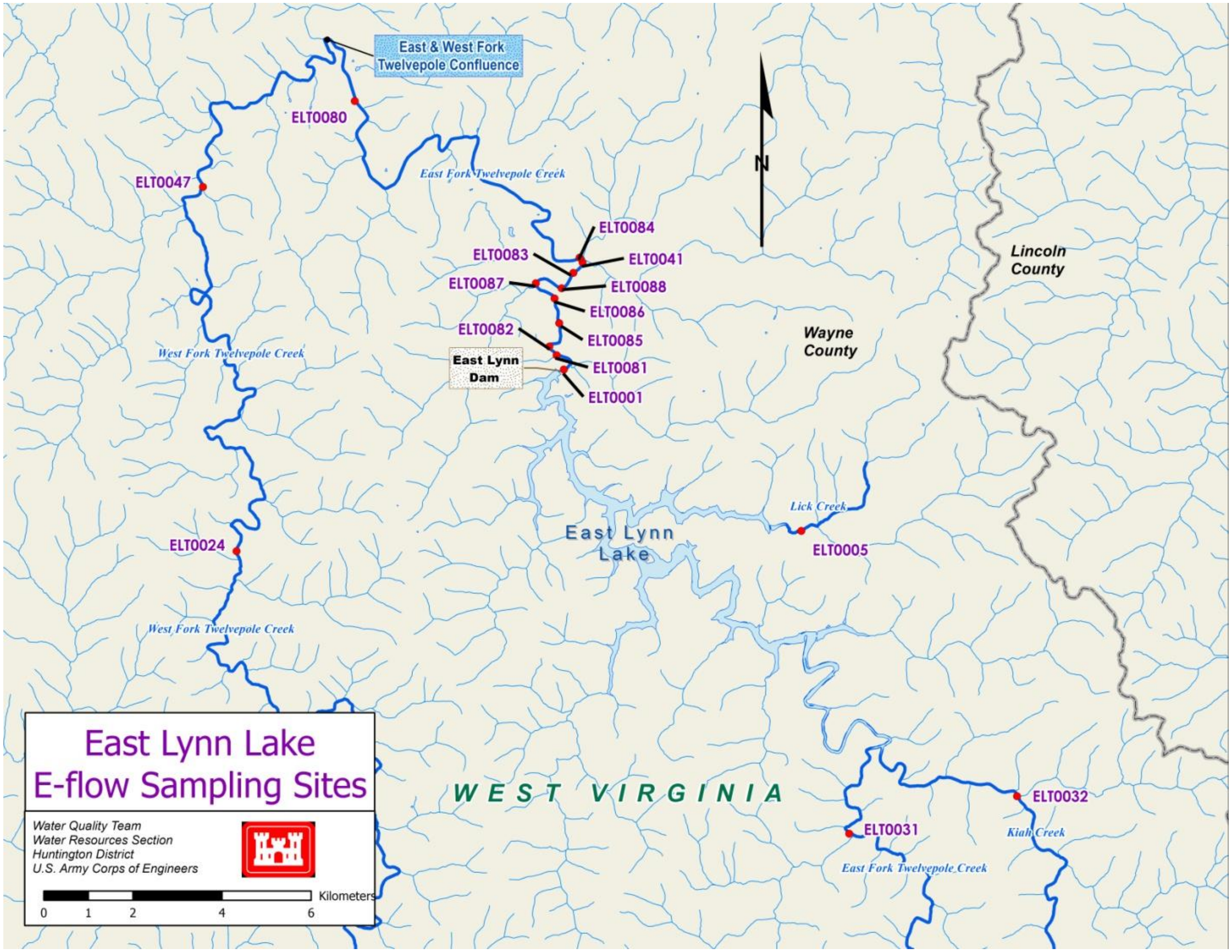


Figure 2. Sampling locations.

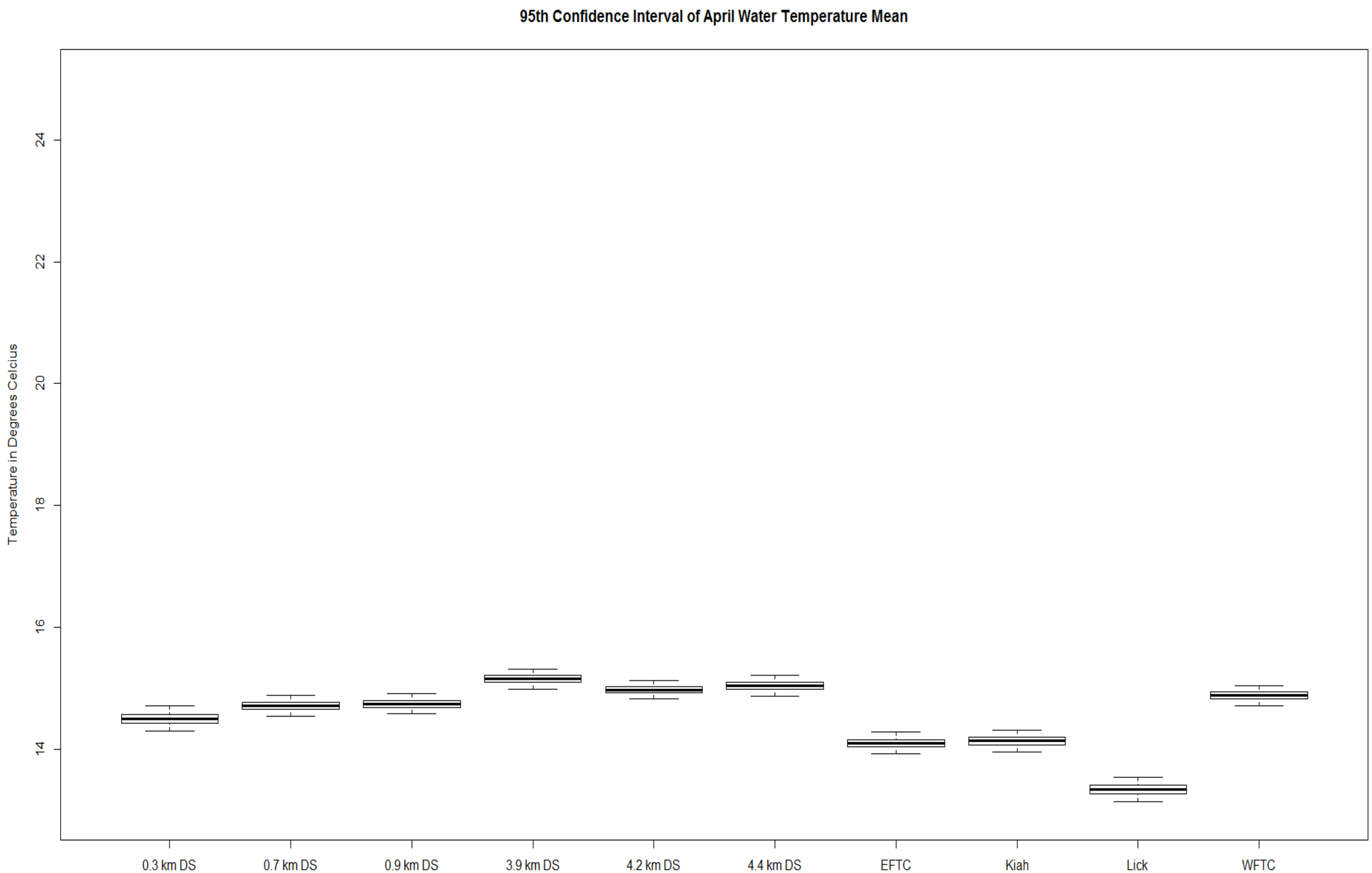


Figure 3. 95th Confidence interval of bootstrapped April water temperature means below East Lynn Lake.

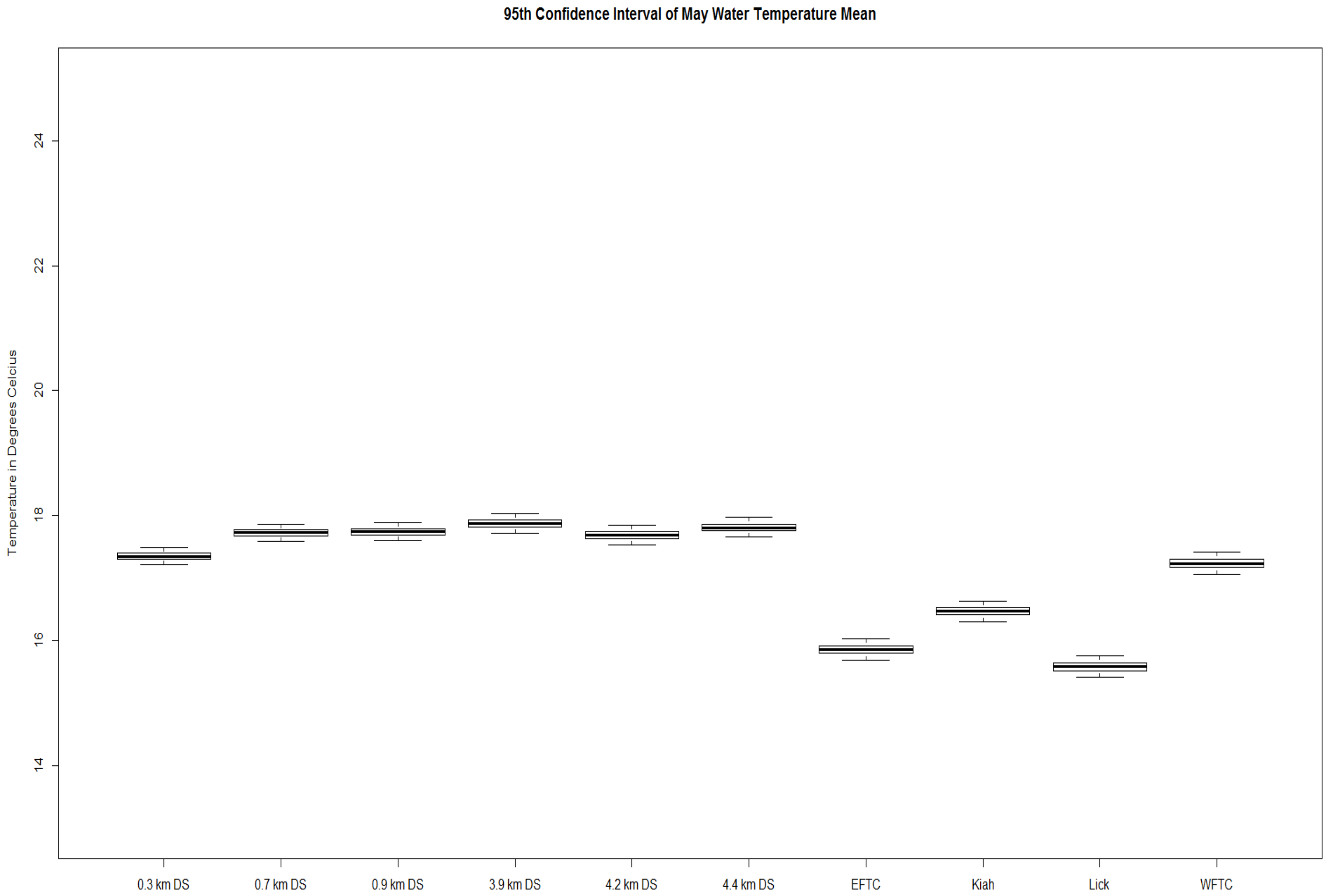


Figure 4. 95th Confidence interval of bootstrapped May water temperature means below East Lynn Lake.

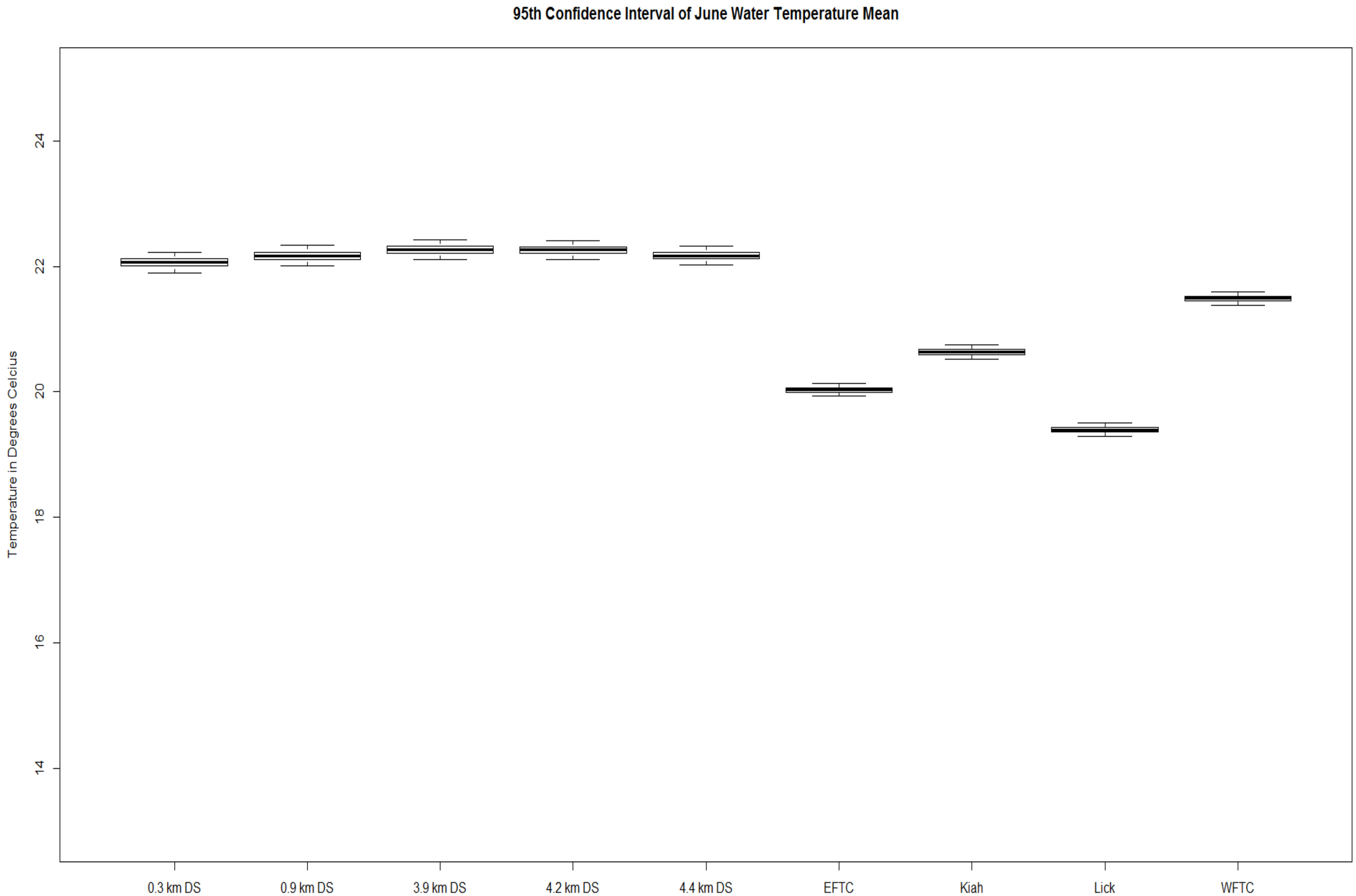

Figure 5. 95th Confidence interval of bootstrapped June water temperature means below East Lynn Lake.

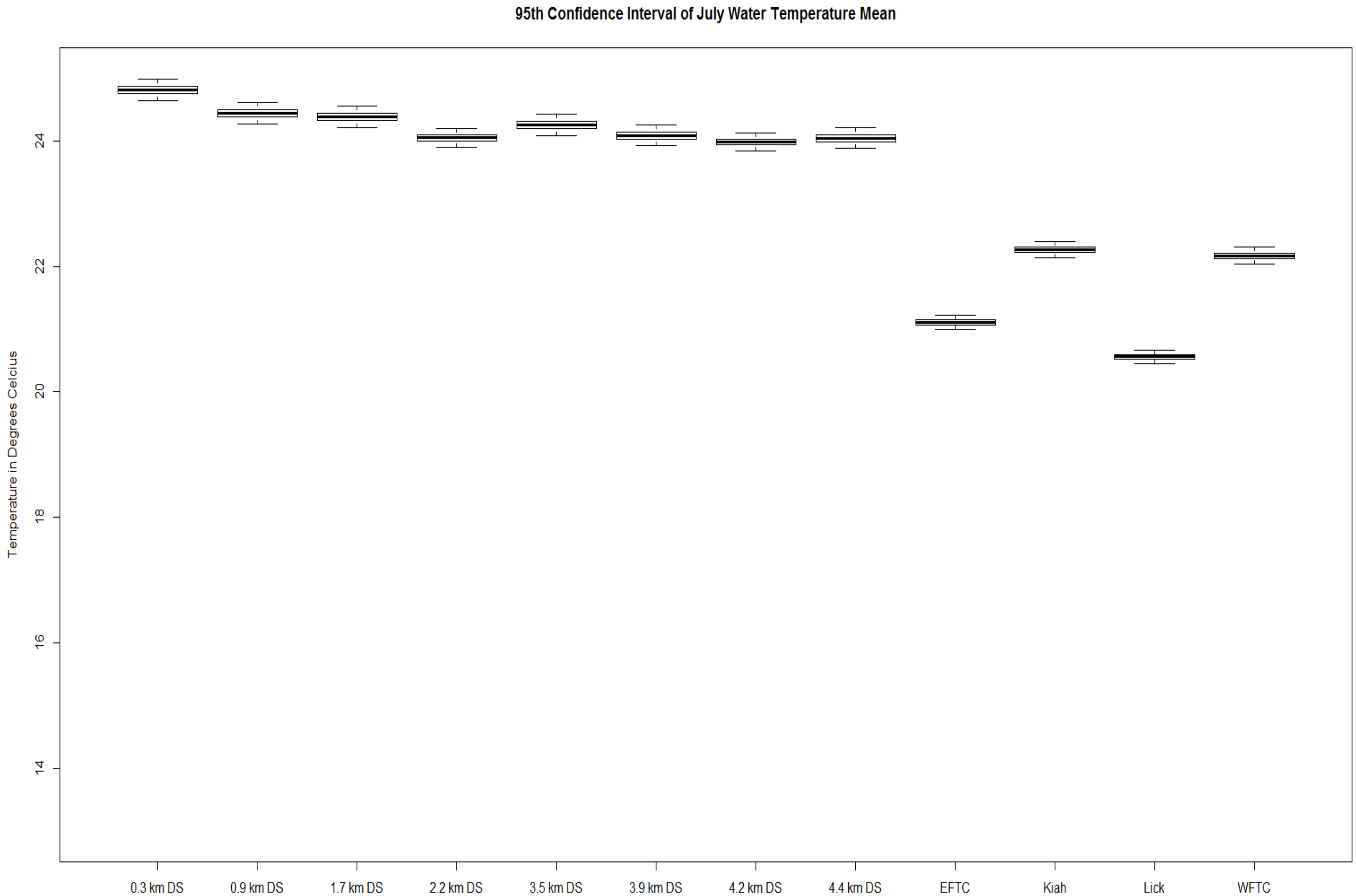


Figure 6. 95th Confidence interval of bootstrapped July water temperature means below East Lynn Lake.

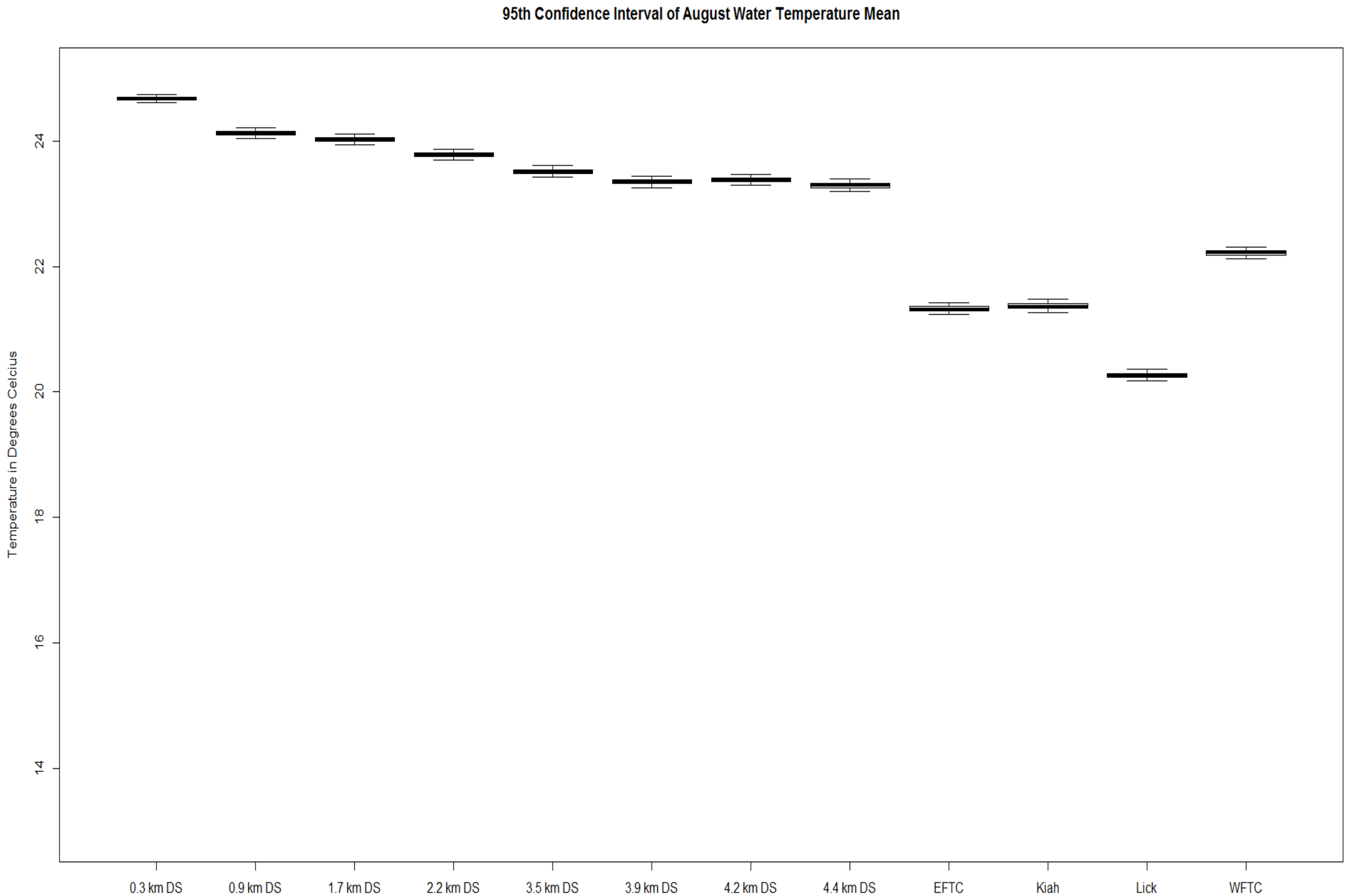


Figure 7. 95$^{th}$ Confidence interval of bootstrapped August water temperature means below East Lynn Lake.

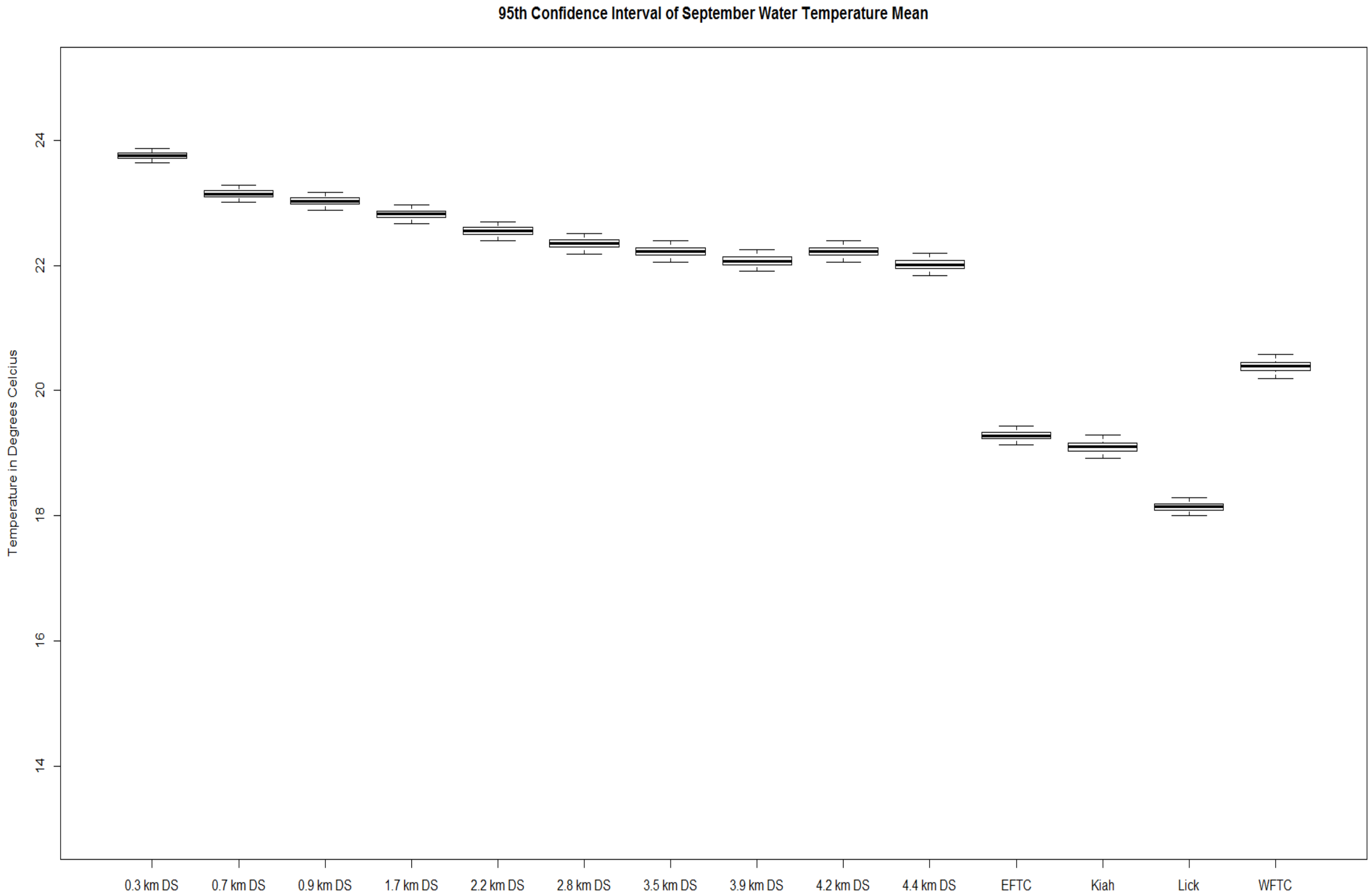


Figure 8. 95th Confidence interval of bootstrapped September water temperature means below East Lynn Lake.

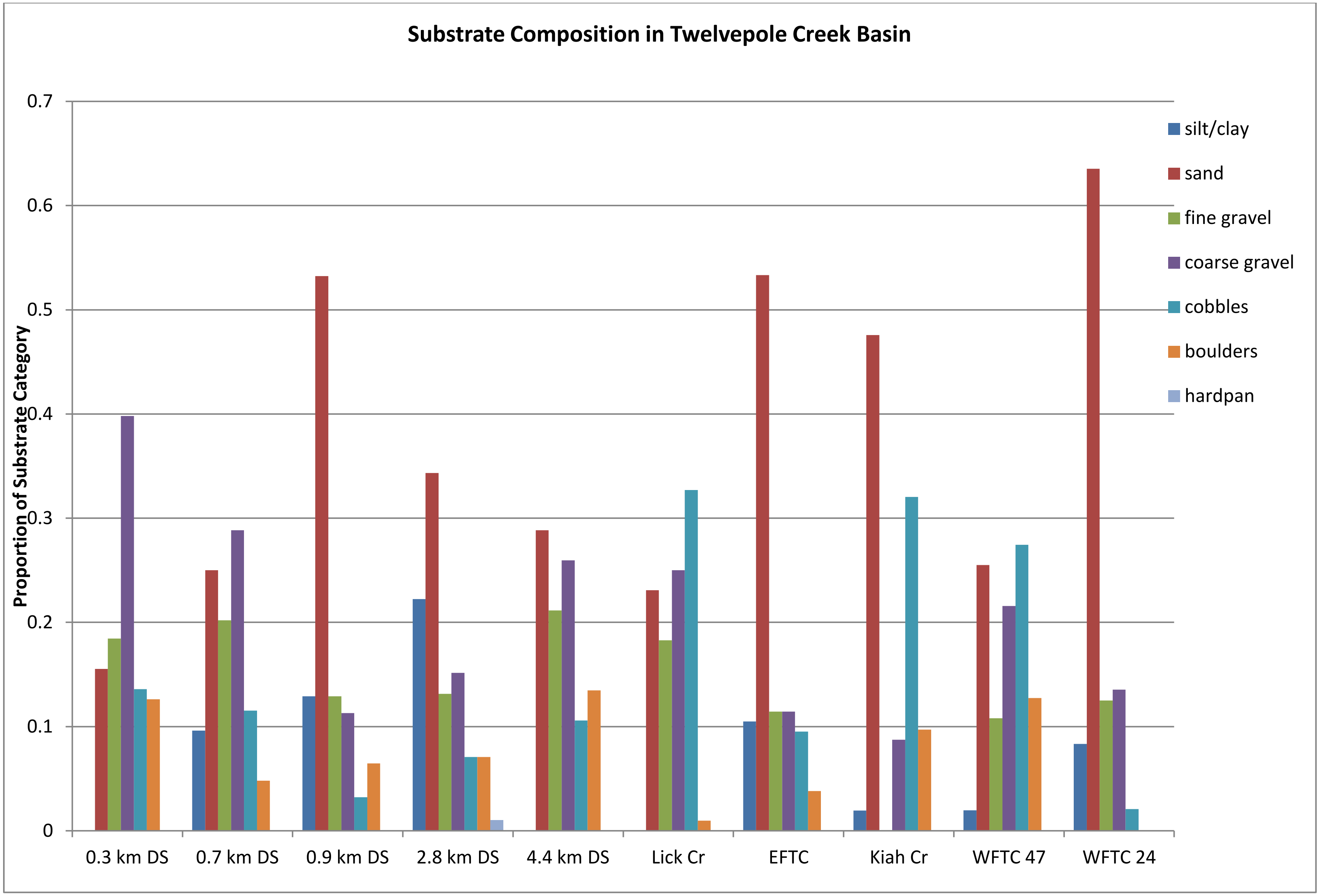


Figure 9. Substrate proportions at sample locations.

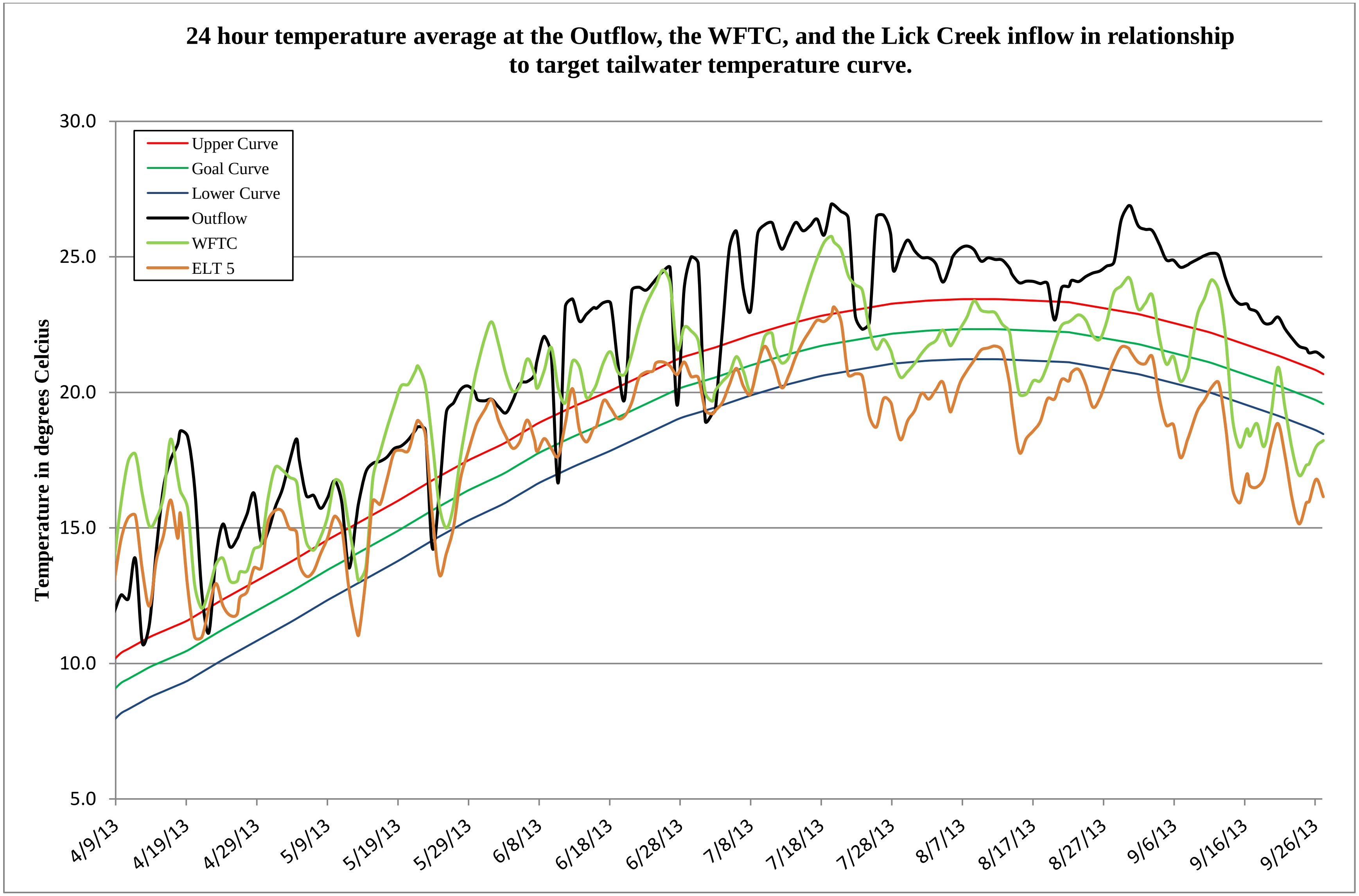


Figure 10. 24 hour temperature average at the Outflow, the WFTC, and the Lick Creek between April and September.

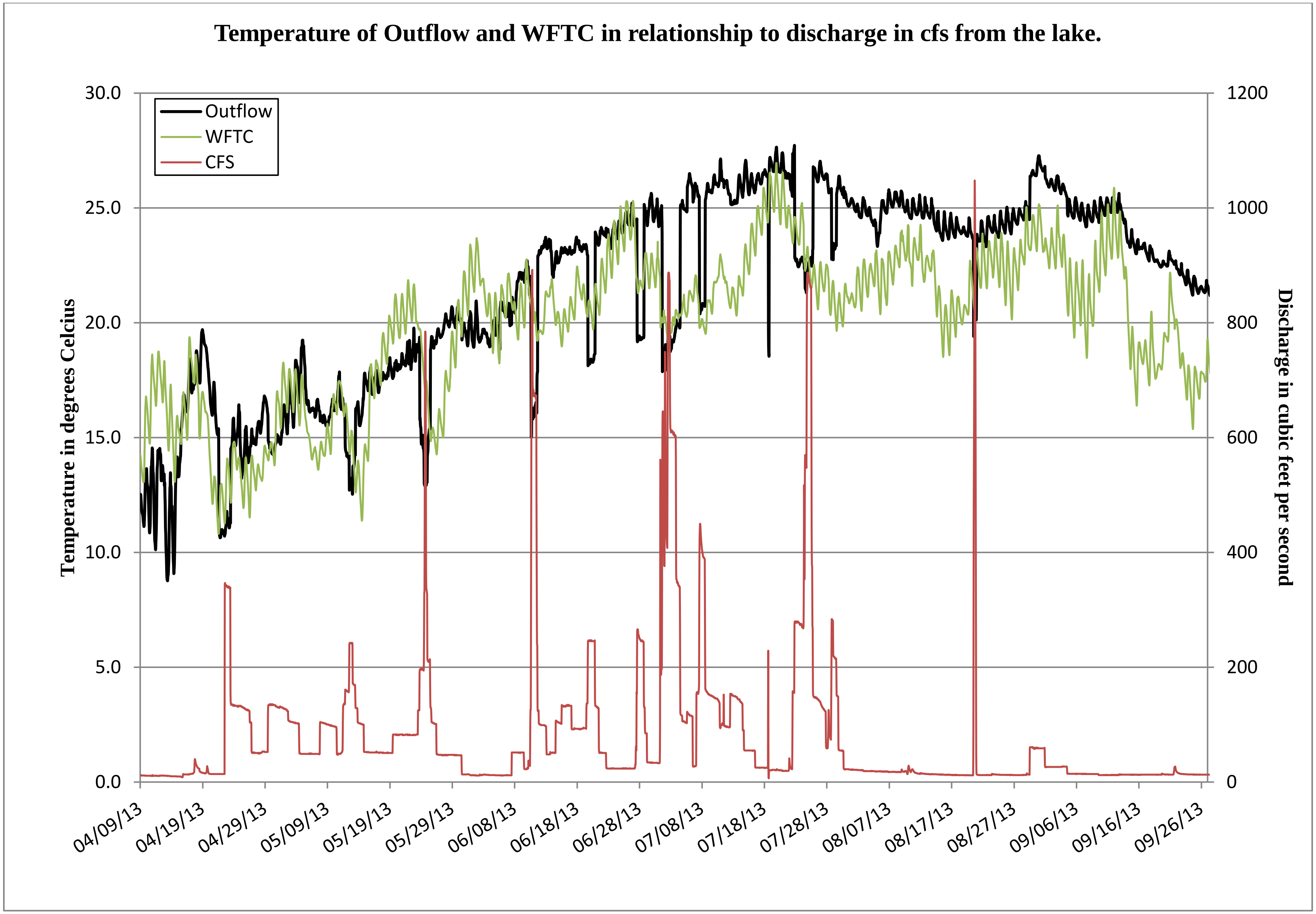


Figure 11. Temperature of Outflow and WFTC in relationship to discharge in cfs from the lake.

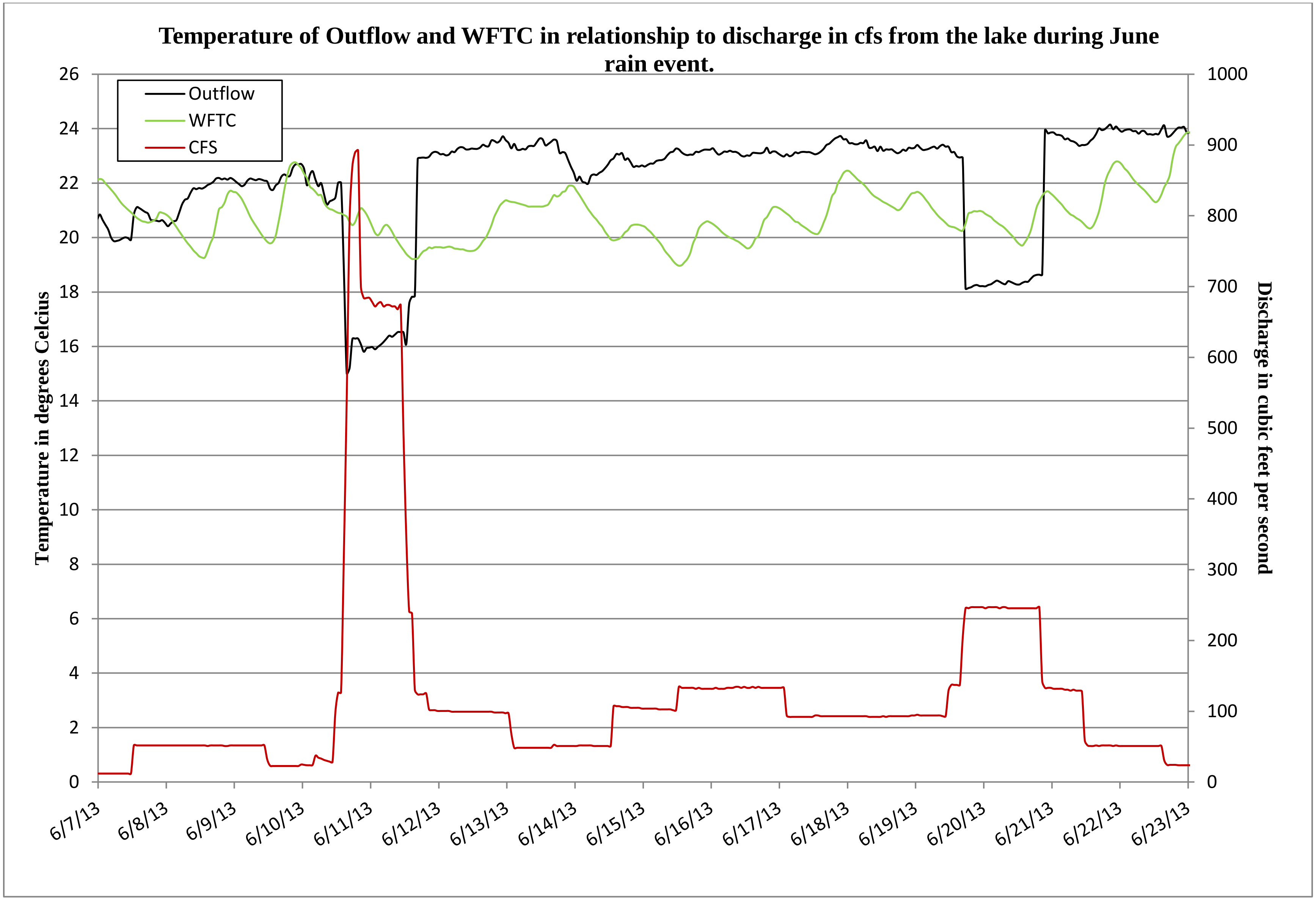


Figure 12. Temperature of Outflow and WFTC in relationship to discharge in cfs from the lake during June rain event.

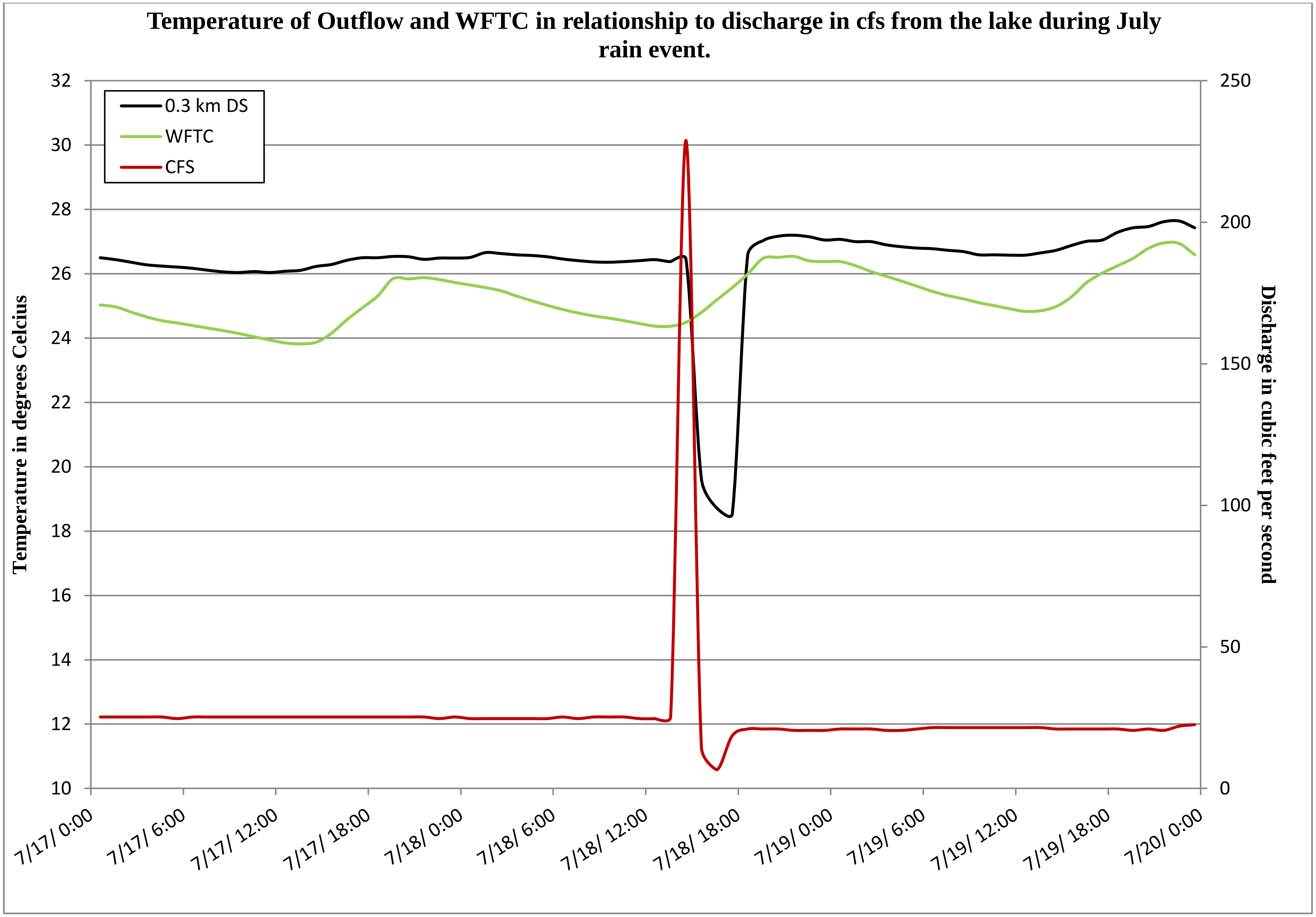


Figure 13. Temperature of Outflow and WFTC in relationship to discharge in cfs from the lake during July rain event.

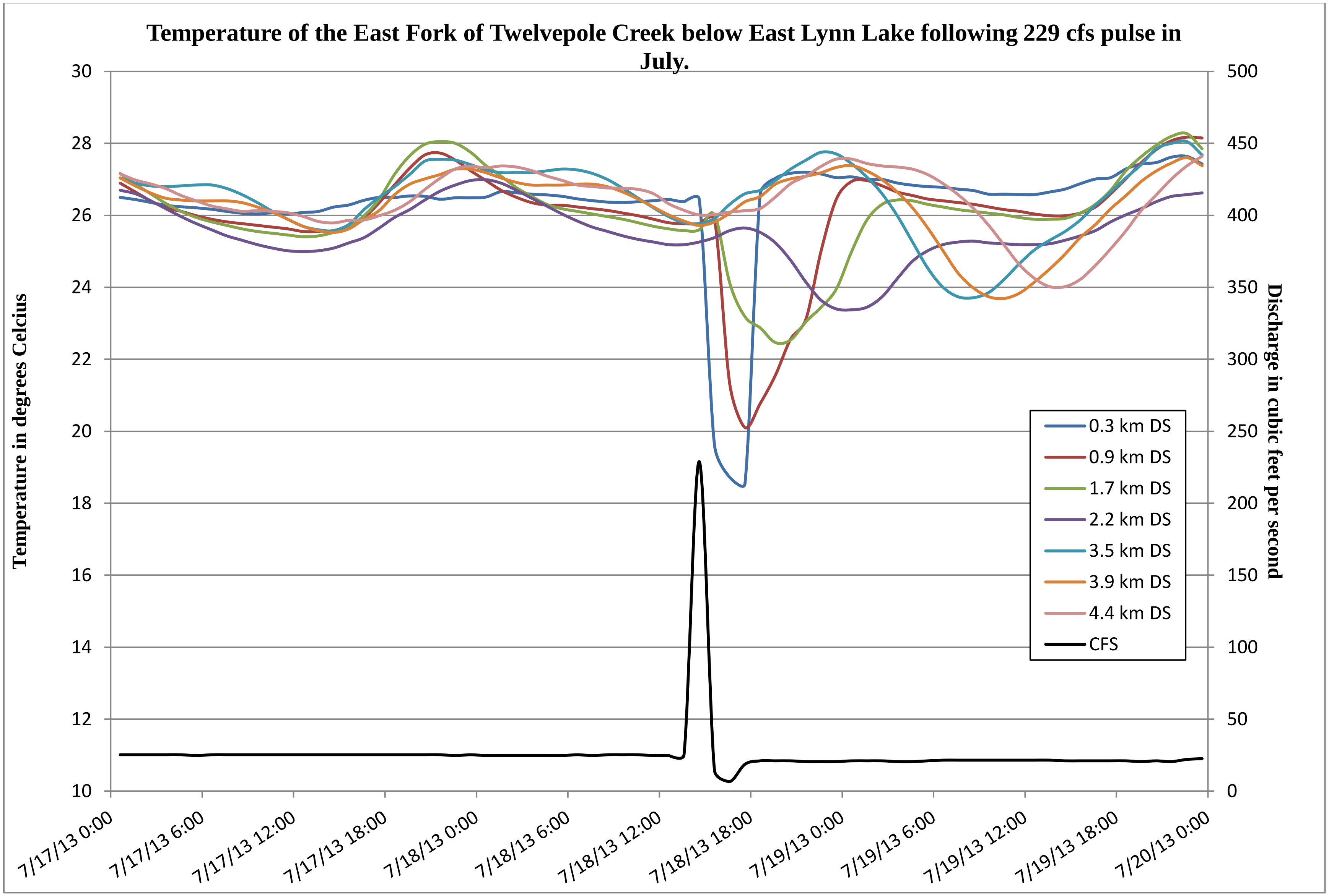


Figure 14. Temperature of the East Fork of Twelvepole Creek below East Lynn Lake following 229 cfs pulse in July.

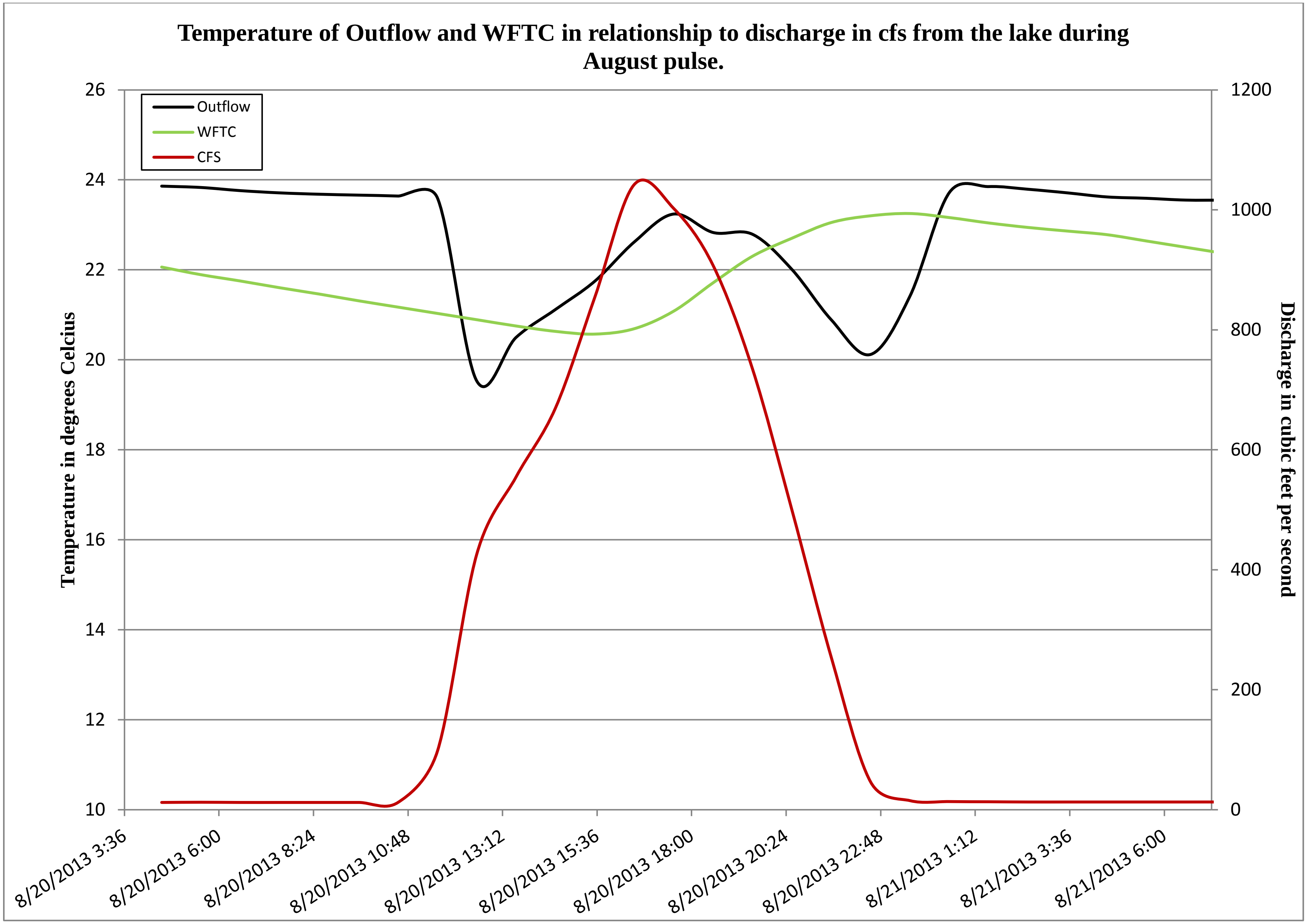


Figure 15. Temperature of Outflow and WFTC in relationship to discharge in cfs from the lake during August pulse.

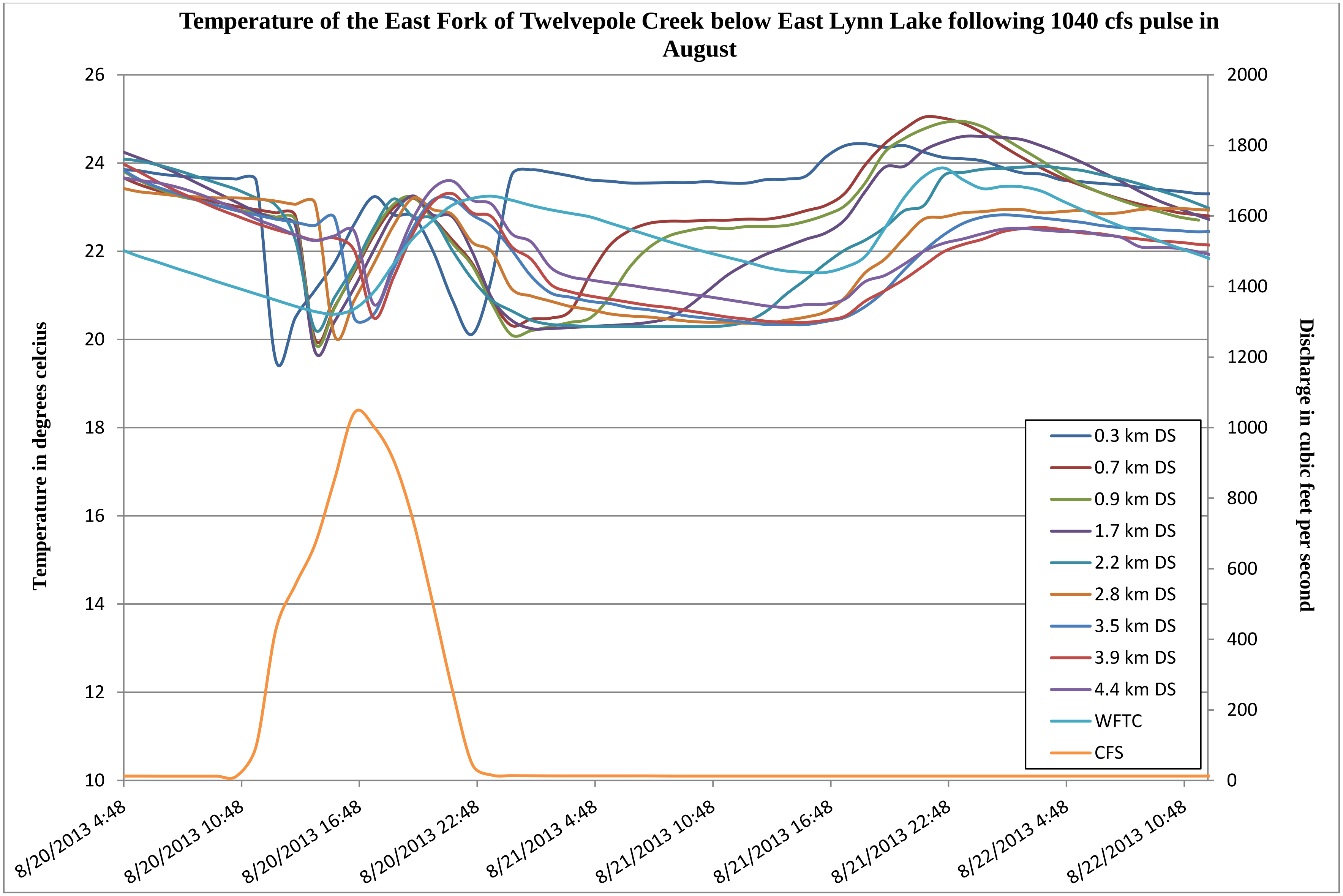


Figure 16. Temperature of the East Fork of Twelvepole Creek below East Lynn Lake following 1040 cfs pulse in August.

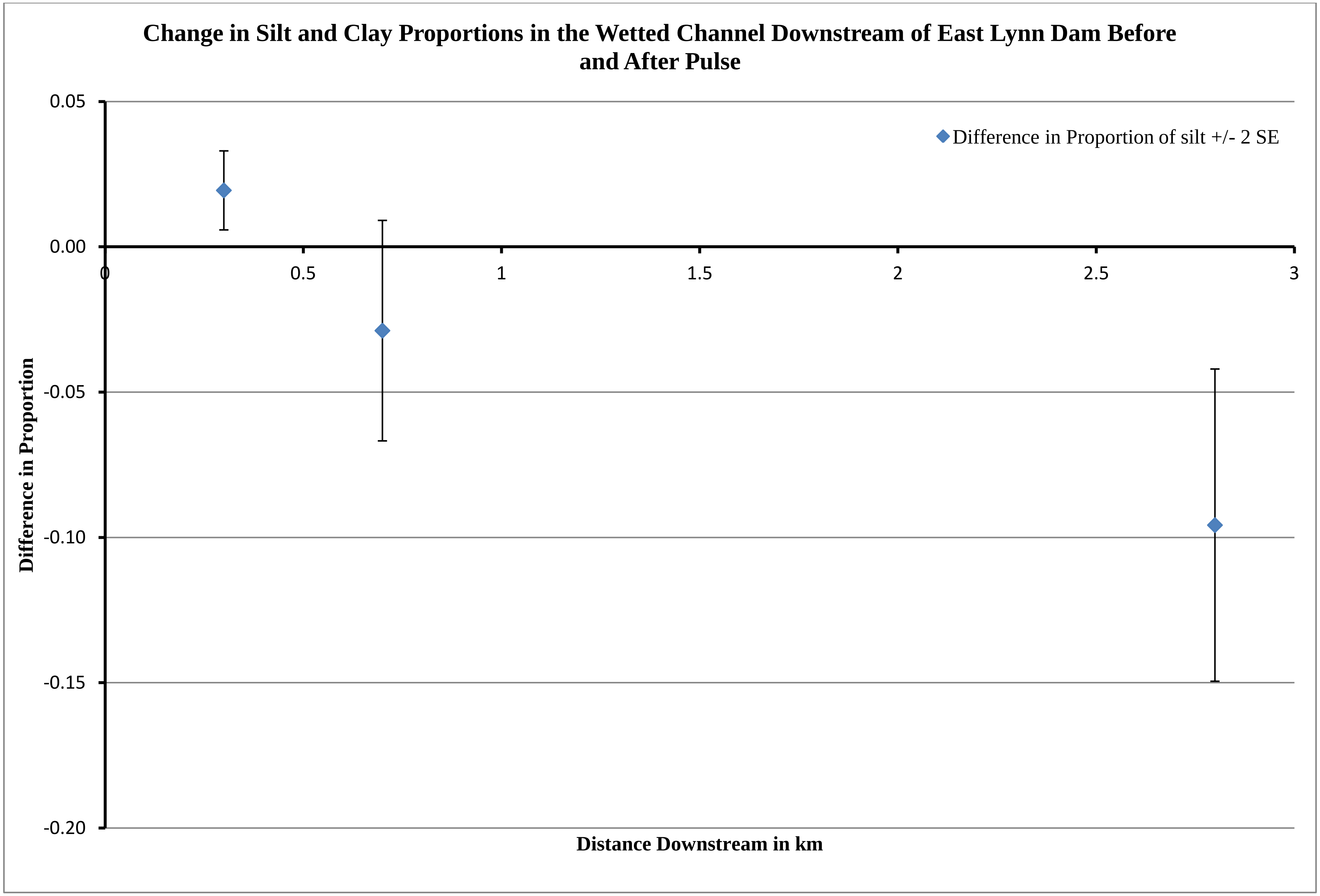


Figure 17. Change in silt and clay proportions in the wetted channel downstream of East Lynn Dam before and after pulse.

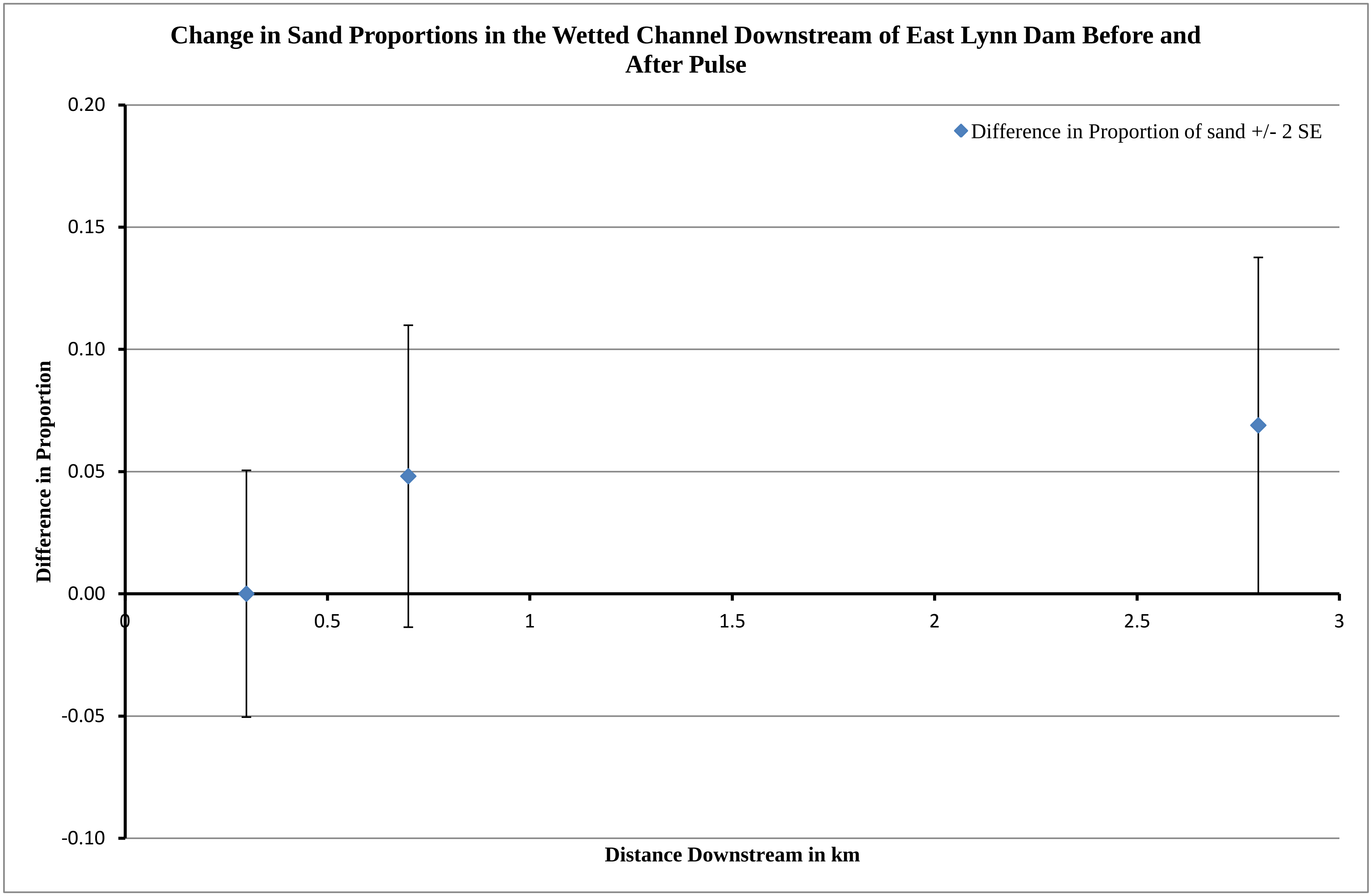


Figure 18. Change in sand proportions in the wetted channel downstream of East Lynn Dam before and after pulse.

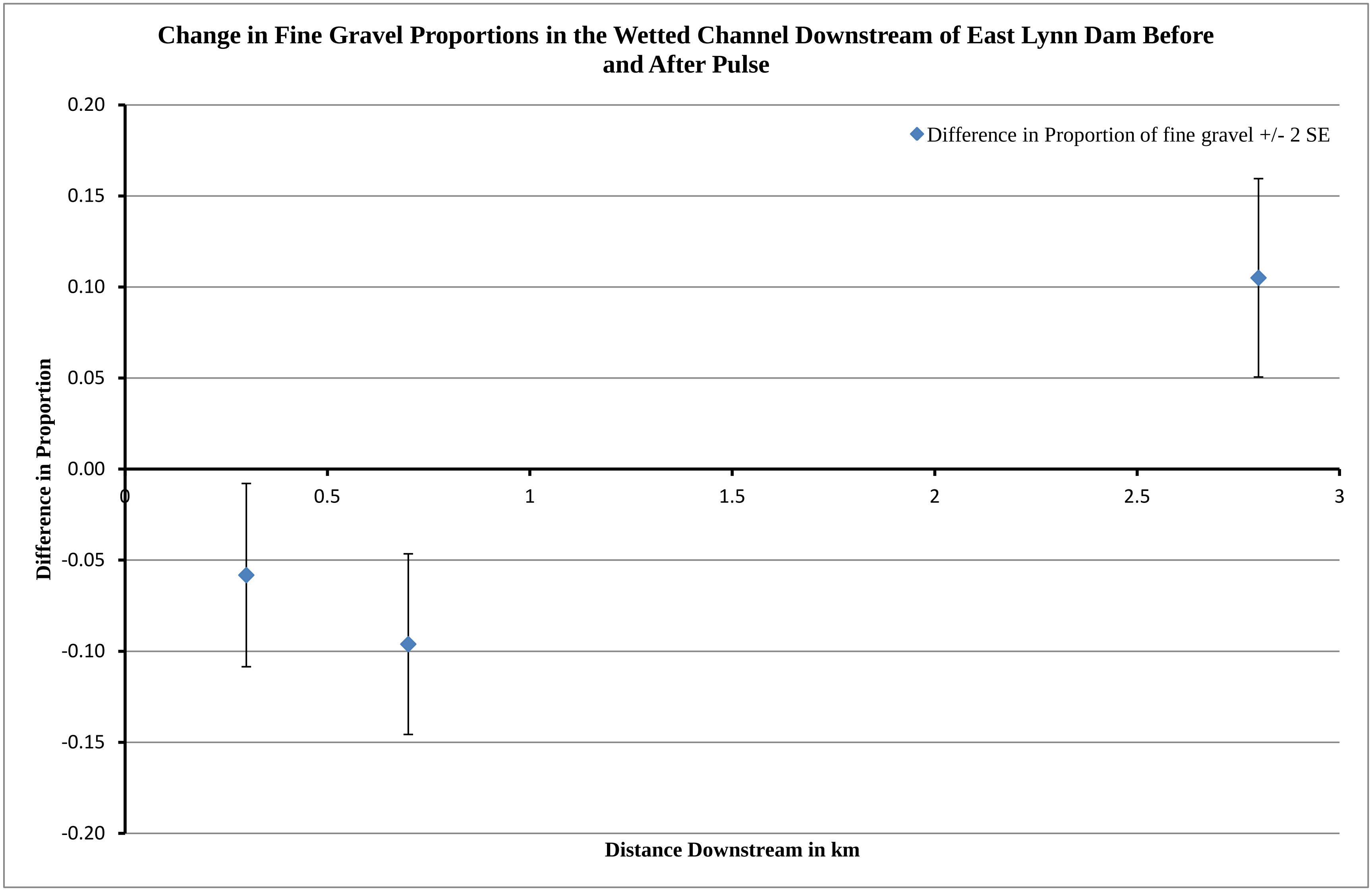


Figure 19. Change in fine gravel proportions in the wetted channel downstream of East Lynn Dam before and after pulse.

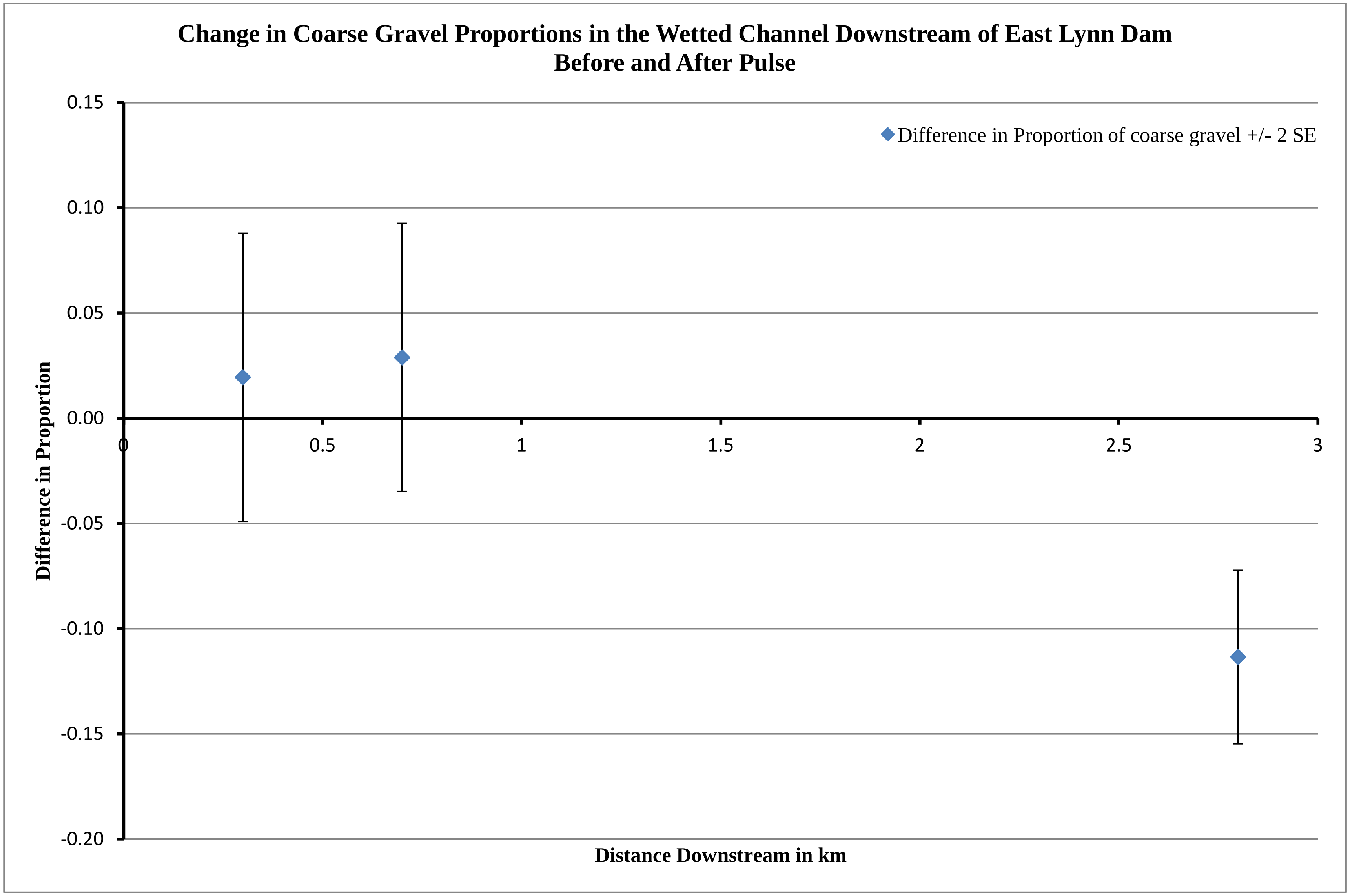


Figure 20. Change in coarse gravel proportions in the wetted channel downstream of East Lynn Dam before and after pulse.

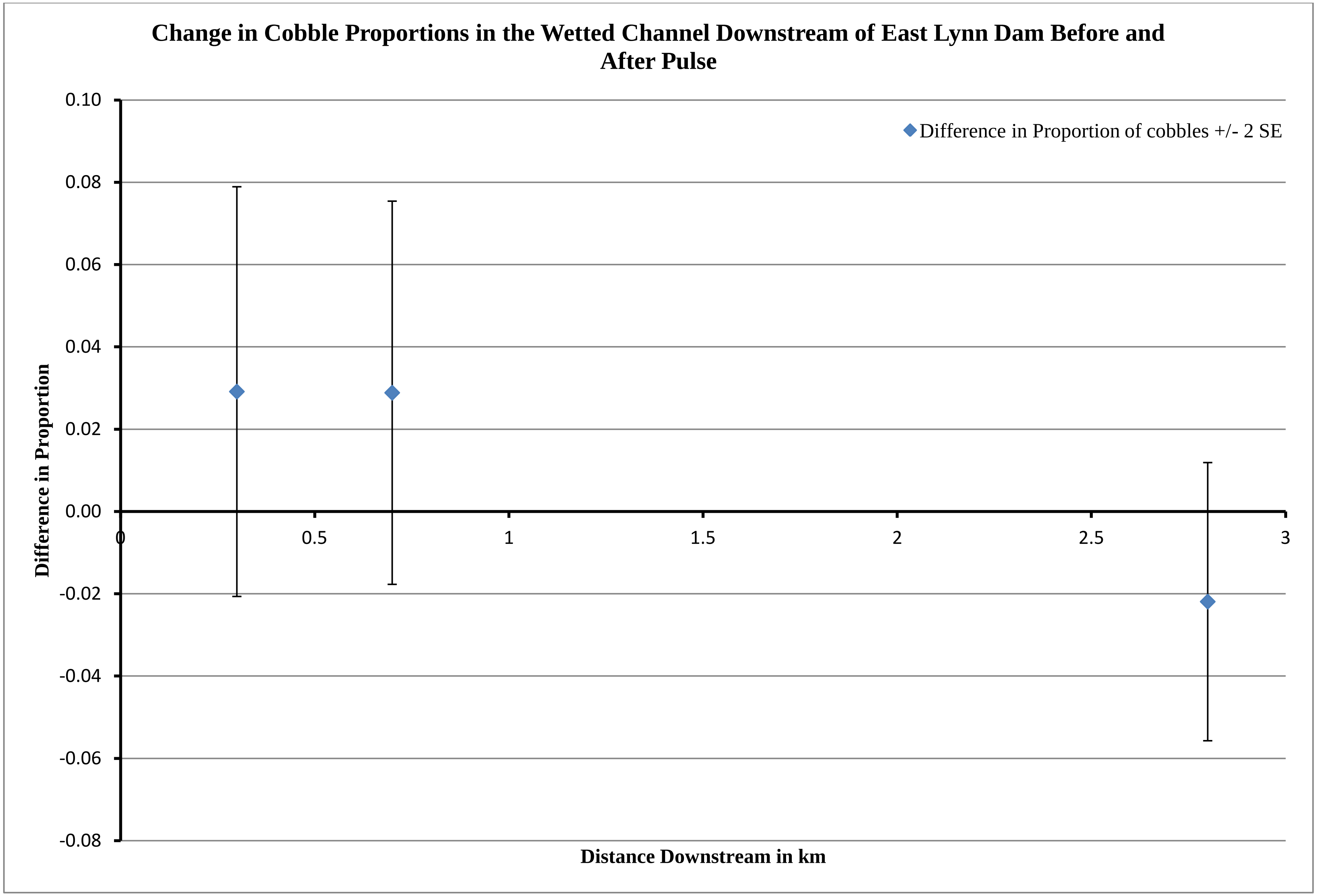


Figure 21. Change in cobble proportions in the wetted channel downstream of East Lynn Dam before and after pulse.

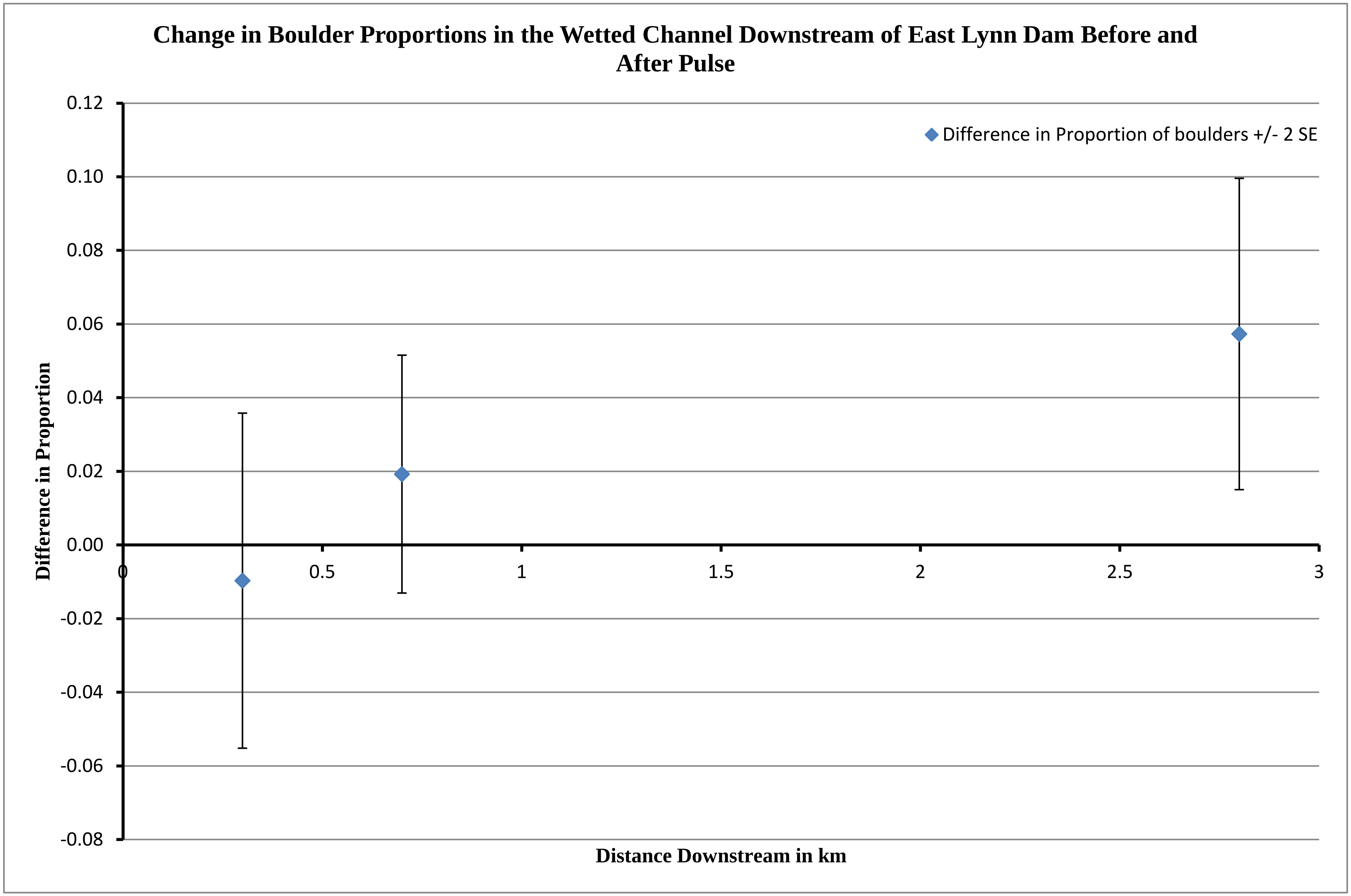


Figure 22. Change in boulder proportions in the wetted channel downstream of East Lynn Dam before and after pulse.

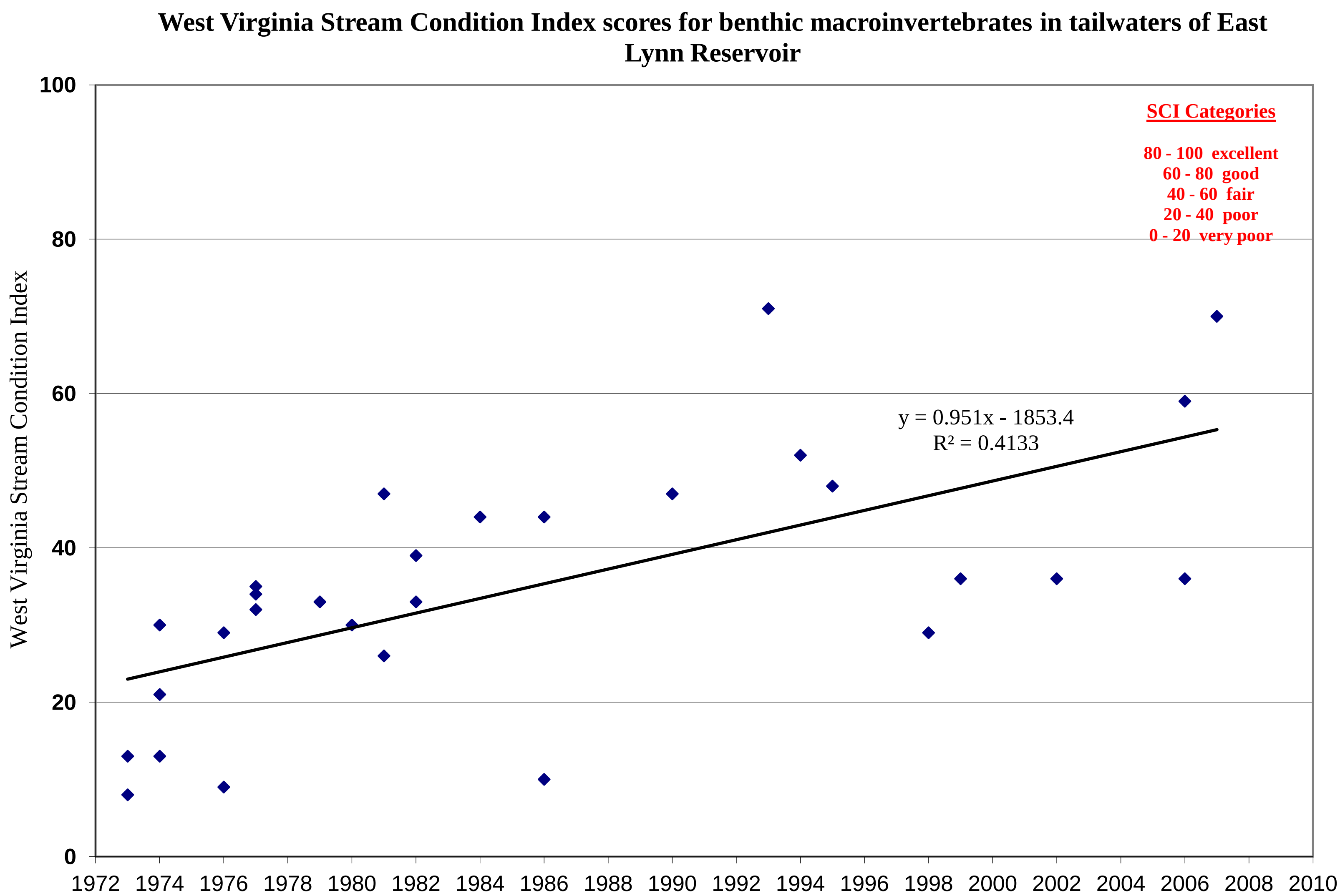


Figure 23. West Virginia Stream Condition Index scores for benthic macroinvertebrates in tailwaters of East Lynn Reservoir.

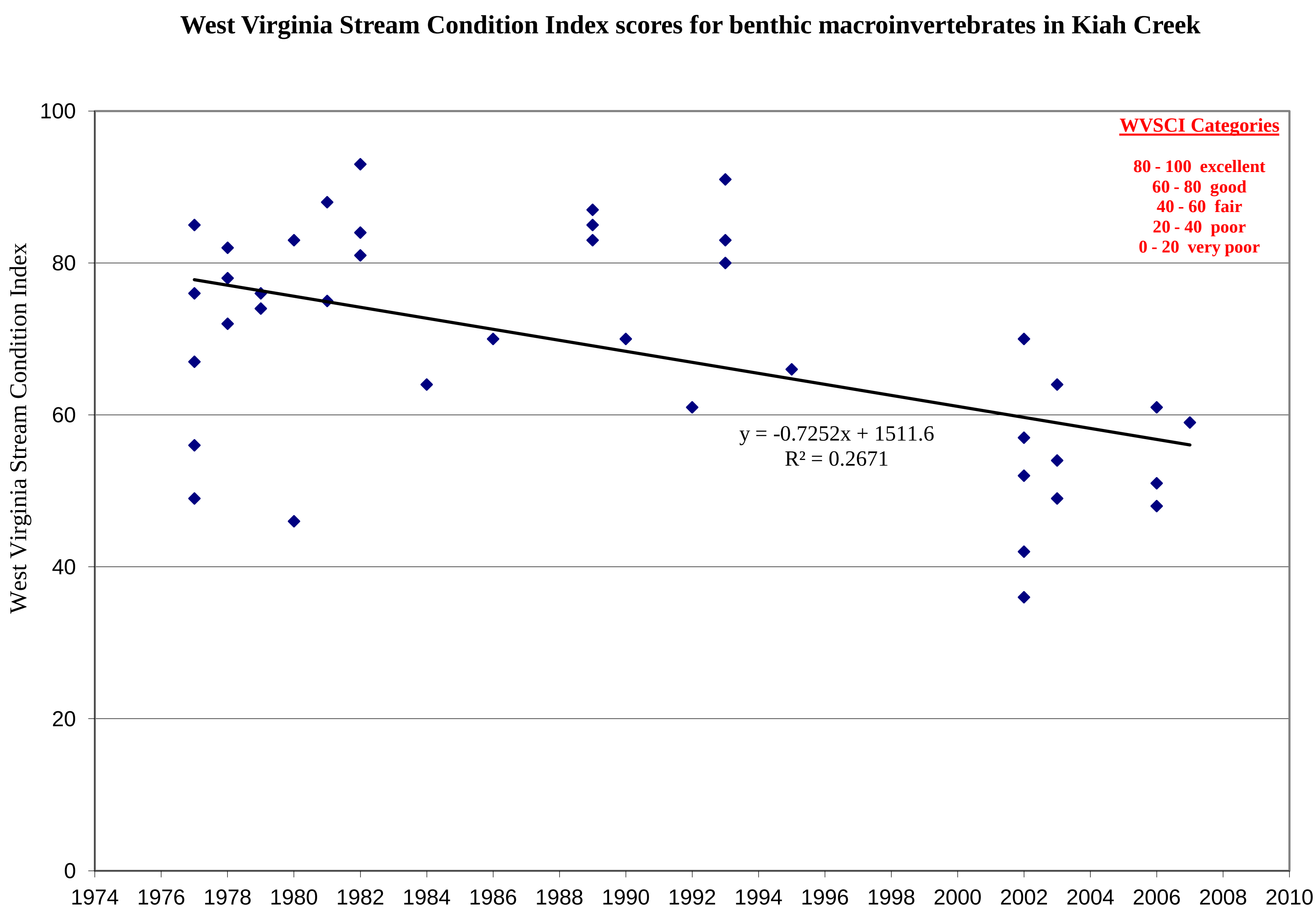


Figure 24. West Virginia Stream Condition Index scores for benthic macroinvertebrates in Kiah Creek.