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A Spatially Distributed Investigation of Stream Water Temperature in a Contemporary Mixed-Land-Use Watershed

Jason P. Horne
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A Spatially Distributed Investigation of Stream Water Temperature in a Contemporary Mixed-Land-Use Watershed

Jason Horne

**Thesis submitted to the
Davis College of Agriculture, Natural Resources and Design
at West Virginia University**

in partial fulfillment of the requirements for the degree of

**Master of Science in
Environmental, Soil and Water Sciences**

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Division of Plant and Soil Sciences

Morgantown, West Virginia

2020

Keywords: stream water temperature; land use; hydrology; experimental watershed

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ABSTRACT

A Spatially Distributed Investigation of Stream Water Temperature in a Contemporary Mixed-Land-Use Watershed

Jason Horne

Stream water temperature is an important physical variable that influences many biological and abiotic water quality processes. The land-use/land-cover (LULC) types and corresponding variability in stream water temperature (Tw) processes in contemporary mixed-land-use watersheds necessitate research to advance management and policy decisions. Water temperature was analyzed from 21 gauging sites using a nested-scale experimental watershed study design. Results showed that forested land use was significantly negatively correlated ($\alpha = 0.05$) with mean and maximum Tw. Agricultural land use was significantly positively correlated ($\alpha = 0.05$) with maximum Tw except during the spring season. Mixed development and Tw were significantly correlated ($\alpha = 0.05$) at quarterly and monthly timescales. Correlation trends in some reaches were reversed between the winter and summer seasons, contradicting previous research. During the winter season, mixed development showed a negative relationship with minimum Tw and mean Tw. During the summer season, higher minimum, maximum, and mean Tw correlations were observed relative to the winter season. Advanced understanding generated through this high-resolution investigation improves land managers' ability to improve conservation strategies in freshwater aquatic ecosystems of contemporary watersheds.

The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

A Spatially Distributed Investigation of Stream Water Temperature in a Contemporary

Mixed-Land-Use Watershed

presented by Jason P. Horne,

a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

A handwritten signature in black ink, appearing to read "Jason A. Hubbart", written over a horizontal line.

Dr. Jason A. Hubbart

A handwritten signature in black ink, appearing to read "Elliott Kellner", written over a horizontal line.

Dr. Elliott Kellner

A handwritten signature in blue ink, appearing to read "Kirsten Stephan", written over a horizontal line.

Dr. Kirsten Stephan

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CHAPTER I

A SPATIALLY DISTRIBUTED INVESTIGATION OF STREAM WATER TEMPERATURE IN A CONTEMPORARY MIXED-LAND-USE WATERSHED

Background

Stream water temperature (Tw) affects abiotic and biotic processes in aquatic ecosystems (Caissie, 2006; Webb et al., 2008). Abiotic variables influenced by Tw include dissolved oxygen concentration, chemical reaction rates, viscosity, density, and surface tension (Webb, 1996). Biological processes influenced by Tw include the growth rate of fish (Coutant, 1999) and rates of primary production in some autotrophic species (Winder and Sommer, 2012). Water temperature therefore impacts multiple trophic levels of the aquatic food web, including periphyton, benthic macroinvertebrates, and fishes (Pollock et al., 2009). This is of further relevance given that many aquatic organisms (e.g., mottled sculpin (*Cottus bairdii*), *Escherichia coli*, flathead mayfly (*Heptageniidae sp*)) have specific tolerance ranges for Tw (Coutant, 1999). Water temperature tolerances/preferences also directly affect species distributions and population densities, thus affecting important industries (i.e. fishing) (Martin and Petty, 2009; Petty et al., 2014; Petty et al., 2012). Globally, water temperature has traditionally received less attention relative to other water quality parameters, such as suspended sediment and water chemistry (Webb et al., 2008). However, the ecohydrological importance of Tw and susceptibility to anthropogenic disturbance make it a critical variable of concern for resource managers (Coutant, 1999; Poole and Berman, 2001).

The landscape of most contemporary watersheds consists of many different land-use land-cover types (LULC) that influence air temperature, rainfall-runoff temperatures, and therefore receiving water temperature (Borman and Larson, 2003; Kellner et al., 2018; Mustafa et al., 2018). These LULC types also influence groundwater surface water interactions influencing Tw (Story et al., 2003). Many studies have shown that incident shortwave radiation is the variable of greatest influence on stream Tw (Gravelle and Link, 2007; Moore et al., 2006; Pollock et al., 2009). Vegetation intercepts incoming shortwave radiation, reducing the amount of radiation reaching the surface thereby reducing surface temperatures (Moore et al., 2006; Oke, 1987; Pollock et al., 2009). For example, Webb and Zhang (1997, 1999) showed that incident shortwave radiation accounted for 70% of a stream's thermal inputs, whereas other significant sources of energy come from longwave radiation emitted by atmospheric water vapor, and advected energy from the

stream bed and bank. Inter-catchment variations in aspect, elevation, and catchment size have also been shown to differentially affect Tw (Webb and Nobilis, 1997).

Ta-Tw Relationship

Ambient air temperature (Ta) has been shown to have a substantial influence on Tw (O'Driscoll and DeWalle, 2006; Rice et al., 2011; Sinokrot and Stefan, 1993). This is important because the Ta and Tw relationship could mask impacts of land-use on Tw. Research has shown conclusively that, as water moves downstream, it is impacted less by the various inflows from runoff/tributaries, and more so by ambient air temperature (Ta) (O'Driscoll and DeWalle, 2006; Sinokrot and Stefan, 1993). However, it should also be stated that land-use also influences Ta in addition to Tw (Moore et al., 2005). Rice et al. (2011) showed that increasing watershed urbanization causes the Tw and Ta relationship to break down. Tw begins to deviate from Ta as energy and mass accumulate from surrounding mixed development LULC types. This is, in some instances, offset given that higher channel volumes downstream are often sufficient enough to attenuate thermal inputs (Caissie, 2006; Gu et al., 1999). Thus, stream inputs (e.g., groundwater, surface runoff, tributaries) from surrounding land-use types may have a greater influence upstream near headwaters relative to downstream and during periods of low(er) flow relative to periods of flooding (Webb et al. 2008). Ultimately, water volume and Ta are not the only influencing factors affecting Tw, and the impacts of complex LULC must be considered (Moore et al., 2006; Pollock et al., 2009; Rice et al., 2011; Younus et al., 2000; Zeiger and Hubbart, 2015).

Groundwater Tw Interactions

Surface-subsurface exchanges through groundwater inputs can contribute to a waterbody's thermal regime (Marzadri et al., 2013; Webb et al., 2008). Story et al. (2003), observed that groundwater inflows into a stream were responsible for approximately 40% of the gross cooling of Tw when passing from open to shaded regions. Researchers often assume that groundwater influences Tw in smaller first order tributaries more so than the mainstem. These groundwater inputs can lower Tw variability of smaller-scale streams at both a daily and seasonal scale (Marzadri et al., 2013; Webb et al., 2008). The lowering of stream Tw variability in these cases typically comes from the groundwater's constant temperature compared to the variable surface Tw (Marzadri et al., 2013). However, this is not always the case and groundwater inputs into smaller scale streams can increase Tw variability if groundwater

temperatures are drastically different from overlying Tw (Anderson et al., 2010). This increase in Tw variability due to groundwater inflow can vary on both a seasonal and diel scale (O'Driscoll and DeWalle, 2006). For example, modeling research by Herb and Stefan (2011) in a Minnesota cold water stream observed that groundwater input increased daily and monthly Tw variability. Groundwater temperature variability also depends on characteristics of the underlying aquifer (e.g., aquifer material, confined vs unconfined). Similar to surface waters aquifers often display seasonal temperature variations (Marzadri et al., 2013).

Forested LULC Types

Forested land use is commonly associated with lower Tw fluctuations and lower overall Tw, particularly in warmer months (Moore et al., 2005). Increases in stream temperature are commonly observed subsequent to the removal of riparian buffers or riparian zone (RZ) (Bulliner and Hubbart, 2013; Gravelle and Link, 2007; Imhoff et al., 2010; Johnson and Almlöf, 2016; Johnson and Jones, 2011; Moore et al., 2005). This finding was attributed primarily to the function of vegetative stream buffers to attenuate thermal inputs through interception of incoming shortwave radiation (Gregory et al., 1991; Naiman and Décamps, 1997). Although interception of incoming shortwave radiation by the forest canopy is the primary regulating variable influencing Tw in forested LULCs, it is not the sole influencing variable (Moore et al., 2005). Energy exchanges set by the RZ boundary conditions influence Tw, and at the same time, Tw is one of the boundary conditions influencing riparian microclimates boundary conditions (Moore et al., 2005). Forest canopies influence the thermal and moisture conditions below canopy by not only reducing solar radiation but also intercepting precipitation, reducing wind speeds, and increasing longwave radiation to the forest floor (Moore et al., 2005; Oke, 1987; Xuhui, 2018). Typically forest canopies reduce the diel fluctuation of ambient air temperatures (Ta) compared to open areas associated with some agricultural and mixed development LULCs (Johnson and Jones, 2011; Moore et al., 2005; Oke, 1987; Pollock et al., 2009; Xuhui, 2018). The canopy can also influence conditions such as relative humidity and vapor pressure deficits (Moore et al., 2005). For example, during a summer day, relative humidity tends to be 5 to 25 percent higher in the forest because of the homogenous vapor pressure within an air mass and the lower daytime temperatures under forest canopies (Moore et al., 2005).

Agricultural LULC Types

Agricultural land-use types are typically associated with higher T_w (Younus et al., 2000; Horne and Hubbart, 2020). This may be due to turbid waters, subsurface lateral flow and increased shortwave radiation. For example, turbid water associated with agricultural land-use practices has been shown to have higher concentrations of total suspended solids (TSS) and, thus, higher T_w relative to clear water due to particulate matter heat adsorption (Boyde et al., 2016; Oke, 1987). Younus et al. (2000) created a numerical model to compute free surface flow hydrodynamics and coupled stream temperature dynamics in an agricultural watershed. Model results showed that an increase in subsurface lateral flow and shortwave radiation were the most significant contributors to the stream heat budget (Younus et al., 2000). Interestingly, the influence of subsurface flow on the stream heat budget was comparable to shortwave radiation (Younus et al., 2000). This strong influence by subsurface flow is attributable to water being heated while infiltrating and percolating through the surface soil during periods of bare fields and high quarterly radiation. Oke (1987) noted that crops can provide some shade through increased shortwave interception and reduce runoff volumes through transpiration. This is as contrast with the period after harvest when runoff volumes are higher and the soil is exposed to greater amounts of shortwave radiation causing soils to reach higher temperatures (Campbell and Norman, 1998; Hatfield et al., 2001; Oke, 1987; Younus et al., 2000). Similar heating processes, associated with runoff, also occur in mixed development LULC types (Kinouchi et al., 2007; Palmer and Nelson, 2007; Zeiger and Hubbart, 2015).

Mixed Development LULC Types

Previous research showed that mixed development LULC types increase the volume of heated runoff entering adjacent streams during summer precipitation events (Herb et al., 2008; Rice et al., 2011; Zeiger and Hubbart, 2015). This has been attributed to stormwater runoff contacting heated impervious surfaces (Herb et al., 2008; Palmer and Nelson, 2007; Paul and Meyer, 2001; Zeiger and Hubbart, 2015). As heated runoff enters adjacent water bodies, it can result in a thermal surge (Herb et al., 2008; Rice et al., 2011; Zeiger and Hubbart, 2015). Thermal surges were characterized as a 1°C increase in T_w within fifteen minutes following a rain event (Rice et al., 2011; Zeiger and Hubbart, 2015). For example, Rice et al. (2011) supported this finding, showing a linear relationship between percent impervious surface and mean thermal surge amplitude, where surges of 3.3°C were observed in areas with 75% impervious surface cover. Zeiger and Hubbart (2015) observed surge increases of 4°C lasting for up to five hours in work conducted in the central United

States. Thermal point source inputs in mixed development land-use types, particularly those from stormwater or wastewater outlets, can also impact Tw. Kinouchi et al. (2007) showed a positive correlation between increasing annual Tw and an increase in volume of heated wastewater input from wastewater treatment plants. This increase was 0.1-0.2°C/year resulting in an overall increase in 4.2°C over twenty years. Other research showed that mixed-development (urban) areas can increase subsurface temperatures through above ground (urban heat island effect) to below ground advection (Menberg et al., 2013; Oke, 1987; Zeiger and Hubbart, 2015).

Tw Research in Appalachia

The Appalachian region of the United States is an example of a physiographically complex region with high relief relative to surrounding areas (Raitz, 2019). Factors such as higher relief alter the rate of runoff from surrounding land-use types relative to flatter terrain (Zajíček et al., 2011). Although previous Tw studies have been conducted in other physiographically complex regions, such as the Rocky Mountains of the United States, the Appalachian region differs due to being geologically older and more weathered (Blackwelder, 1914). Thus, a region such as Appalachia is well suited to advance existing knowledge gaps in the relationship between land-use types and Tw. Furthermore, in recent years Appalachia, in particular the state of West Virginia, has been impacted by increased flood frequency largely attributed to an increase in percent mixed development land-use type. As mixed development land-use types expand they often replace forested land-use types (LeBlanc et al., 1997). This is important because previous research showed these two land-use classifications have distinct effects on Tw (Webb et al. 2008). Furthermore, the interactions between competing mixed land-use types are largely unknown. Thus, studies in a contemporary mixed-land-use watershed designed to assess land-use impacts on hydrologic variables, including Tw, are needed in general (globally) and in the region (specifically) (Hubbart et al. 2019).

The Nested Experimental Watershed Study Design

Using the experimental watershed study design in a contemporary mixed-land-use watershed, researchers can separate a larger catchment in to individual sub-catchments, enabling quantification of specific land use impacts on variables of interest (Hewlett et al., 1969; Hubbart et al., 2019; Kellner et al., 2018; Kellner and Hubbart, 2017a; Tetzlaff et al., 2017). The paired and nested-scale experimental watershed study design approach was initially developed by forestry

researchers analyzing the effects of silvicultural practices and road building on stream hydrology and water quality (Gravelle and Link, 2007; Hubbart et al., 2007). The approach is used much less frequently than other methodology. This is primarily attributed to the noted high cost of instrumentation, often the time-consuming nature of data collection, difficulty in transferring results, and unrepresentativeness as being prohibitive to implementation (Hewlett et al., 1969; Kellner and Hubbart, 2017a; Tetzlaff et al., 2017). Although some of these perceived problems are not unfounded, the inherent advantages of an experimental watershed study design far outweigh the potential disadvantages (Hewlett et al., 1969; Kellner and Hubbart, 2017a; Tetzlaff et al., 2017). The experimental watershed study design has been shown to effectively characterize and quantify both hydrologic and water quality perturbation (Hewlett et al., 1969; Hubbart et al., 2019; Tetzlaff et al., 2017). It also is effective at addressing both site-specific management questions and assist further model development, validation, and calibration (Hewlett et al., 1969; Hubbart et al., 2019; Tetzlaff et al., 2017).

Statement of Need

There is an ongoing need for high-resolution studies in contemporary watersheds that include multiple land use practices (Hubbart et al., 2019; Petersen and Hubbart, 2020; Zeiger et al., 2016). Unlike West Run Watershed, other study watersheds in the Appalachian region, such as those in the Fernow Experimental Forest, are less instrumented and comprise homogenous land use. In addition, there is a lack of watershed-scale studies that utilize the experimental watershed study design in Appalachia, or elsewhere. The use of high-resolution observed data provides a greatly needed investigation increasing confidence in underlying processes, both physical and chemical, occurring on the landscape (Kellner et al., 2018; New et al., 2002). At the time of this research, no previous studies gathering high-resolution Tw have been conducted in the Appalachian region of the United States using an experimental watershed study design. The lack of such studies may be in part due to the experimental watershed study design's criticisms (Hewlett et al., 1969; Hubbart et al., 2019; Tetzlaff et al., 2017). However, such studies will advance spatial and temporal understanding and therefore improve management decisions in contemporary (municipal) watersheds (Kellner et al., 2018; New et al., 2002).

Objectives

The overall objective of this study was to use an experimental watershed study design to investigate land-use practices impacts on Tw, particularly maximum Tw, spatially and temporally in a representative contemporary mixed-land-use watershed. Specific objectives included quantifying, a) annual, b) quarterly, and c) monthly relationships between LULC and Tw.

Hypotheses

- 1.) H₀: Land-use practices in West Run Watershed will have no significant effect on stream Tw at each timescale
H_a: Land-use practices in West Run Watershed will have significant effects on stream Tw at each timescale
- 2.) H₀: There will not be a significant relationship between LULC and Tw between quarters and months.
H_a: There will be a significant relationship between LULC and Tw between quarters and months
- 3.) H_a: There will be a significant relationship between LULC and Tw between quarters and months. H₀: There will not be a significant difference .in daily maximum Tw across different sites between quarters and months.
H_a: There will be a significant difference in daily maximum Tw across different sites between quarters and months

Materials and Methods

Study Site

West Run Watershed (WRW) is located in the Monongahela Watershed and categorized as a Hydrologic Group D watershed (HUC #05020003) located near Morgantown, West Virginia, USA. The watershed spans 23 km², and the main drainage, West Run Creek, drains directly into the Monongahela River. The channel of West Run, according to habitat surveys, lacks sinuosity in many reaches and possesses a low channel slope of 1.1%, with back watering (flooding) near the terminus (WVWRI, 2008). Average net radiation in Morgantown from 1981-2010 was 130.68 W/m² (Arguez

et al. 2012). The average recorded precipitation depth in Morgantown is approximately 1096 mm/yr (1981-2010). Precipitation falls throughout the year but increases in quantity during the spring and summer months (Kutta and Hubbart, 2019a). Previous studies showed that precipitation has significantly ($p=0.01$) increased in the Appalachian region by 2.2% over the past 111 years (Kutta and Hubbart, 2019a; Petersen et al., 2018). Precipitation is frequently generated via frontal storm convergence systems, but during the summer months in particular, precipitation also occurs via orographic and / or convective processes (Kutta and Hubbart, 2019b).

The current population of Morgantown is 30,539. Overall land-use in West Run Watershed is 19.4% agriculture, 42.7% forest, and 37.7% mixed development, with the portion of agricultural land-use mainly comprising animal husbandry (i.e., cattle), and crop fields (i.e., corn, soybeans, cover crops) (Kellner et al., 2018; Petersen et al., 2018). The presence of different land-use types, coupled with regular land-use manipulation via human development, justifies WRW categorization as a representative contemporary mixed-land-use watershed (Kellner et al., 2018). In addition, a combination of agricultural, mining, and industrial land-uses in and surrounding WRW have contributed to ongoing land and water resource degradation (Kellner et al., 2018). Given the potential for legacy effects of historic land-use land practices including, but not limited to, historical mining operations, those practices need to be chronicled and included in analyses of work (Kellner and Hubbart, 2017b; Petersen and Hubbart, 2020). West Run Watershed has a history of surface and subsurface coal mining, particularly in the headwaters of the watershed, and peaking in the 1930s, 40s, and 50s (West Virginia Water Research Institute, 2008). Mining practices ceased by the late 1950s, however, evidence of those operations remains apparent by means of acid mine drainage (AMD). During the 1940s, the population increased by 8,870 from approximately 16,000 individuals at an annual growth rate of 4.36% per year (United States Census Bureau, 2020). During the 1940s, mixed development areas such as the Walter L. Bill Hart Field (i.e., Morgantown Municipal Airport) were constructed in West Run (West Virginia Department of Transpiration, 2008). By the late 1950's, population in Morgantown decreased by 3030 as mining activities decreased. Population surged in the decade to follow (i.e., the 1960's) reaching 29,431 (United States Census Bureau, 2020). Since the 1960s, the population has remained at approximately 30,000 individuals. However, since the 1970s, the LULC composition of West Run Watershed has continued to change.

Comparing Historical LULC data from 1992, 2011, to the most recent LULC data (2018), mixed development areas increased from 18.2% in 1992 to 37.8% in 2018, replacing forested (54.3% in 1992 to 42.8% in 2018) and agricultural (27.4% in 1992 to 19.2% in 2018) LULC (WVGIS Tech Center, 2020). Anecdotally observed by the project managers of the watershed-based plan for West Run of the Monongahela River, the increase in urban sprawl stemming from the surrounding city of Morgantown continues to increase the severity and frequency of flooding (WVWRI, 2008).

Figure 1. Land use and land cover of West Run Watershed (WRW), West Virginia, USA including 22 nested gauging sites and corresponding sub-basins.

Climate Data

During the study period, climate data were recorded at 30-minute time intervals using research-grade climate instrumentation located within approximately 100 m of Site #13 (Figure 1). Climate

variables (recorded at a height of 3 m) included precipitation (TE525 Tipping Bucket Rain Gauge), average air temperature and relative humidity (Campbell Scientific HC2S3 Temperature and Relative Humidity Probe), average wind speed (Met One 034B Wind Set instrument), and net radiation (Campbell Scientific NR01 Four-Component Net Radiation Sensor).

LULC Data

LULC was derived from National Agricultural Imaging Program (NAIP) 2018 data. Initially, LULC types included 16 different assignments. For the current work, each of the original 16 LULC types was further grouped (lumped) into one of four LULC categories Mixed-Developed, Agriculture, Forested, and Open water (Table 1). Forested land-use practices are the most abundant land use classification in the WRW. For the current work, land-use land-cover types grouped in the Forested category included mature vegetation and also mine grass classification, which is assumed to have succeeded to an intermediate successional stage (Grime, 1998, 1973). This assumption was validated through onsite inspection of these areas. Agricultural land-use practices were those classifications associated with early successional stages (i.e., low vegetation) or pastures and fields. Mixed development land-use practices included mixed development and all other LULC classifications associated with urban areas and/or impervious surfaces (e.g. barren, roads, impervious) (Table 2) (Booth et al., 2016; Paul and Meyer, 2001; Rice et al., 2011; Walsh et al., 2005). Using Arc GIS, watershed and sub-catchment boundaries were delineated, and LULC data incorporated. Each pixel representing 5m^2 was counted and converted to km^2 and used to estimate percent LULC for each subcatchment draining to each monitoring site (Table 2 and Figure 2).

Table 1. Original LULC classifications from the 2018 NAIP data and the reclassification developed for use when analyzing Tw and LULC relationships in West Run Watershed, West Virginia, USA.

Reclassified	Original LULC Classification
Mixed Development	Roads, Impervious, Mixed development, Barren
Agriculture	Low vegetation, Hay pasture, Cultivated crops
Forested	Mine grass, Forest, Mixed mesophytic forest, Dry mesic oak forest, Dry oak forest, Small stream riparian habitats
Open water	Water, River floodplains, and Palustrine Emergent Wetlands

Figure 2. (a) Proportion LULC of sub-catchment and associated sites, (b) LULC area of sub-catchment and each associated site in West Run Watershed, West Virginia, USA. Sites 3, 4, 6, 10, 13, 18, 19, 21, 22 are on the main stem; all other sites are at the mouths of tributaries.

Table 2. Sub-basin area (km²) and proportional contribution to West Run Watershed (% in parenthesis), West Virginia, USA from NAIP (2018). Area (km²) and percent of sub-basin (% in parenthesis) are given for each LULC type for each site. Site 22 LULC areas and proportions represent WRW as a whole. Cumulative open water (0.295 km²) was excluded.

Site	Sub-basin Area	Land Use / Land Cover		
		Mixed Development	Agriculture	Forested
1	0.3 (1.3)	0.2 (53.2)	0.1 (38.7)	0.0 (8.1)
2	0.3 (1.3)	0.0 (13.6)	0.0 (12.2)	0.2 (74.2)
3	1.9 (8.0)	0.4 (22.4)	0.3 (16.7)	1.1 (61.3)
4	2.5 (10.7)	0.6 (25.9)	0.4 (14.9)	1.5 (59)
5	0.4 (1.6)	0.1 (23.4)	0.1 (25.5)	0.2 (51.1)
6	3.7 (16.0)	0.9 (23.9)	0.6 (17.2)	2.2 (58.7)
7	0.8 (3.4)	0.1 (16.3)	0.2 (28.6)	0.4 (54.9)
8	1.6 (6.7)	0.5 (30.8)	0.3 (16.5)	0.8 (52.4)
9	2.3 (9.8)	0.6 (23.9)	0.4 (19.3)	1.2 (52.8)
10	6.2 (26.6)	1.5 (24.9)	1.1 (18.4)	3.5 (56.5)
11	1.8 (7.5)	0.3 (18.2)	0.7 (41.9)	0.7 (39.2)
12	1.2 (7.5)	0.4 (31.8)	0.4 (33.7)	0.4 (34.5)
13	10.5 (45.3)	2.8 (26.8)	2.7 (25.8)	5.0 (47.1)
14	3.4 (14.4)	0.5 (16.2)	0.9 (26.4)	1.9 (56.9)
15	1.0 (4.2)	0.7 (70.3)	0.1 (10.3)	0.2 (19.4)
16	0.2 (1.1)	0.0 (5.4)	0.1 (58.7)	0.1 (35.2)
17	0.7 (3.2)	0.0 (4.8)	0.1 (9.4)	0.6 (85.8)
18	16.4 (70.6)	4.3 (26.0)	4.1 (24.9)	8.0 (48.9)
19	18.9 (81.2)	5.6 (29.4)	4.2 (22.5)	9.0 (47.9)
20	3.4 (14.7)	3.0 (89.2)	0.1 (4.2)	0.2 (6.6)
21	22.9 (98.7)	8.7 (38.1)	4.5 (19.5)	9.7 (42.2)
22	23.2 (100.0)	8.8 (37.7)	4.5 (19.4)	9.9 (42.7)

Data Analysis

At each of the twenty-two stream monitoring sites a Solinst Levellogger Gold pressure transducer was installed between the fall of 2016 and fall of 2017. Each site was equipped with a Solinst Levellogger Gold pressure transducer that logged and stored Tw (°C) data, with an accuracy of $\pm 0.05^{\circ}\text{C}$, and stage (water depth, cm), with an accuracy of ± 0.3 cm, at five-minute intervals. Data analyses included descriptive statistics (5 min data) of annual, quarterly, and monthly Tw data over the 2018 annual year for each site except for Site 22 due to potential backwatering with the Monongahela River. Quarterly time steps were delineated as; January 1st – March 31st (Quarter 1), April 1st – June 30th (Quarter 2), July 1st – September 30th (Quarter 3),

and October 1st – December 31st (Quarter 4). Data post processing included estimation of erroneous data or missing points (< 0.2% of total data) by averaging between data points on either side of a gap, or by linear interpolation (Helsel and Hirsch, 1992).

The Tw data were shown to be non-normally distributed using the Anderson-Darling test (Kellner et al., 2018). Therefore, correlations between land use and Tw variables (i.e., mean Tw, maximum Tw, minimum Tw, and Tw standard deviation) were determined (Appendix E) using the Spearman Rank correlation coefficient test ($\alpha=0.05$) generating Spearman's Rank Correlation Coefficients (rs). The open water land-use type was excluded from analyses due to its negligible coverage relative to other land use types in the watershed. Three separate analyses were run including a) all sites b) tributaries only (i.e., sites 1, 2, 5, 7, 8, 9, 11, 12, 14, 15, 16, 17, 20), and c) mainstem West Run Creek only (i.e., sites 3, 4, 6, 10, 13, 18, 21) to assess effects of surrounding land-use practices on tributaries vs. mainstem sites.

Due to the detrimental influence maximum Tw can potentially have on aquatic biological/geochemical processes, a comparison of daily maximum Tw was conducted on a site by site basis using a Kruskal Wallis ANOVA with a post hoc analysis (Boyde et al., 2016; Caissie, 2006). The independent variable in this Kruskal Wallis ANOVA was Site and the dependent variable the daily maximum Tw. The Kruskal Wallis ANOVA was run for each separate time step (i.e., annual, quarterly, monthly). The post hoc analysis consisted of multiple Mann-Whitney U test comparing individual sites on a site by site basis (Helsel and Hirsch, 2020). To control for potential Type I errors while executing the multiple comparisons, a Dunn-Bonferroni correction was implemented (Helsel and Hirsch, 2020).

Multiple Principal Component Analyses (PCA) were conducted to illustrate the relationship between LULC types and Tw variables at an annual, quarterly, and monthly timescale, again excluding open water (Bro and Smilde, 2014). Using OriginPro Pro 9b Academic (OriginLab Corporation), correlation biplots were generated. Due to the use of observed Tw data, no autoscaling preprocessing was needed to compare Tw and LULC data in the PCA analysis. However due to the use of differing units (i.e., proportions (%) and temperature (°C)) a correlation matrix was used rather than a covariate matrix (Bro and Smilde, 2014). Following the Kaiser Guttman criterion, Eigenvalues greater than one were accepted as principle components above the threshold of importance (Bro and Smilde, 2014).

Finally, a preliminary investigation of LULC thresholds (i.e., tipping points) (Lenton, 2013) was conducted to elucidate potential tipping points in WRW. This investigation compared cumulative LULC proportion from headwaters to terminus, and Tw for each of Tw variables, also cumulative, during the 2018 annual year. Cumulative Tw variables (plotted as y-axis 1) were calculated by adding mean, maximum, or minimum Tw at each site, progressing numerically from the headwater to the terminus. Cumulative LULC proportion (plotted as y-axis 2) were calculated by adding successive LULC proportions (0-1) at each site, progressing numerically from the headwater to the terminus. Cumulative LULC proportions can exceed 100% ($100\%=1$) with the addition of successive sites. Both y-axes use logarithmic scaling and the x-axis, as stated, displays the numeric progression of sites (1-21). Points of intersection between cumulative LULC and Tw variables may elude to potential tipping point. If the analysis hints towards the existence of tipping points, these data could potentially be valuable information used to guide land management decisions or policies regarding LULC-Tw relations.

Results

Climate during Study

Total precipitation recorded in West Run Watershed over the 2018 annual year was 1378 mm, which was 282 mm higher than average annual precipitation (1096 mm) over the previous 111 years (Arguez et al., 2012; Petersen et al., 2018). The largest precipitation event observed in a 30-min window was 22.9 mm, occurring on September 9 (Figure 3b). The largest continuous precipitation event (83.2 mm) began on September 8th at 18:00 and lasted until September 9 at 16:30 (Figure 3b). Mean air temperature (T_a) during the 2018 annual year was 11.6 °C, which was 0.2 °C higher than the average annual temperature (11.4 °C) in West Virginia between 1990-2016 (Kutta and Hubbart, 2019a). The coldest (-24.8 °C) and warmest (34.6 °C) recorded air temperature occurred January 1 at 8:00 and July 1 at 17:00, respectively (Figure 3a). Maximum net radiation was 1100 W/m² recorded on May 7 at 12:00. Mean near surface (1.5 m) net radiation was 139.5 W/m², which was 8.82 W/m² higher than the mean annual net radiation in Morgantown between 1981 and 2010 (130.68 W/m²) (Appendix A) (Arguez et al., 2012).

Figure 3. Thirty-minute (a) time-series of air temperature (Ta) and Tw during the 2018 annual year and (b) time-series of precipitation during the 2018 annual year collected from a climate station located near site #13 (Figure 1) in West Run Watershed, West Virginia, USA.

Annual Stream Water Temperature

Annual average water temperature (Tw) across all sites varied by 2.4 °C with a maximum of 12.5 °C at site #11 (dominant LULC Agriculture; 41.9%) and a minimum of 10.1 °C at site #17 (dominant LULC Forested; 85.8%) (Table 3). The lowest recorded Tw (-3.0 °C) occurred at Site #16, (dominant LULC Agriculture; 58.7%), at 6:45 on January 7, and the highest recorded Tw (27.4 °C) occurred at Site #5, (dominant LULC Forested; 51.1%) at 16:05 on July 3. Site #5 includes the Morgantown Municipal Airport, one of the largest expanses of impervious surface covers in the watershed. Both were recorded less than a week after the lowest (-24.8 °C) and highest recorded Ta (34.6 °C). A timeseries for all 22 sites is included in Appendix B.

Spearman correlations of all twenty-one sites across the entire annual year indicated a significant ($p=0.01$) positive correlation ($r_s= 0.6$) between maximum Tw and Agriculture LULC area, and a negative correlation ($r_s= -0.5$) between maximum Tw and Forest LULCs ($p=0.03$).

Site by site comparisons indicated that maximum Tw at site #1 was significantly different from site #5, #11, #12, and #15 (Table 4) (Appendix C). Maximum Tw at site #2 was significantly different from sites #14, #15, #18, #19, #21. Maximum Tw at site #3 was significantly different from site #5, #11, #12, and #15. Maximum Tw at site #4 was significantly different from site #5, #11, #12, and #15. Maximum Tw at site #5 was significantly different from site #17. Maximum Tw at site #17 was significantly different from site #5, #6, #11 , #12 , #14, #15, #18, #19, #21 (Table 4).

Table 3. Descriptive statistics of stream water temperature (°C), annually by site, quarterly (all sites), and monthly (all sites) collected in West Run Watershed, West Virginia, USA, over the 2018 annual year.

Sites/Season/Month	Mean	Standard Deviation	Minimum	Maximum
Site #1	10.9	4.4	-0.3	22.2
Site #2	10.5	5.4	-0.2	20.6
Site #3	10.8	6.1	-0.5	21.6
Site #4	10.5	6.7	-1.9	22.8
Site #5	11.9	7.6	-0.6	27.4
Site #6	11.7	7.1	-0.7	25.9
Site #7	11.2	6.7	-2.9	23.2
Site #8	11.5	6.0	-1.1	22.3
Site #9	11.8	6.5	-1.2	23.4
Site #10	11.3	7.1	-1.1	23.5
Site #11	12.5	6.2	1.2	27.3
Site #12	11.3	7.9	-1.3	27.4
Site #13	11.4	7.0	-1.3	23.7
Site #14	11.4	7.5	-1.1	26.4
Site #15	12.4	6.7	-1.1	24.1
Site #16	10.8	7.0	-3.0	26.7
Site #17	10.1	6.9	-1.4	21.5
Site #18	12.0	7.3	-0.9	24.8
Site #19	11.8	7.6	-1.1	26.3
Site #20	11.3	7.6	-2.0	23.8
Site #21	11.7	7.7	-1.2	25.8
Site #22	11.7	7.2	-0.6	22.3
Quarter 1	3.2	3.8	-3.0	14.0
Quarter 2	14.0	4.7	1.6	27.3
Quarter 3	19.2	2.2	12.5	27.4
Quarter 4	8.5	4.6	-1.4	22.8
January	1.4	2.3	-3.0	8.3
February	5.5	3.2	-2.6	14.0
March	4.6	2.5	-1.4	13.2
April	4.6	2.5	-1.4	13.2
May	9.2	3.3	1.6	23.4
June	16.1	2.3	9.0	24.2
July	18.0	2.5	10.3	27.4
August	19.3	2.1	12.8	26.3
September	19.6	1.9	13.2	27.1
October	18.2	2.1	12.5	26.7
November	7.4	2.7	1.0	15.3
December	4.9	2.2	-1.4	11.4
Annual	11.4	6.9	-3.0	27.4

Table 4. Site by site comparison of annual maximum (parenthetic) daily Tw, along with dominant LULC, at twenty-one sites at West Run Watershed, West Virginia, USA, over the 2018 annual year. Mix Dev represents the LULC type mixed development. Only significant ($\alpha = 0.05$) results from the analysis are shown.

Site Comparison			<i>p</i> -Value ($\alpha = 0.05$)
WRW 1 (22.2 °C) Mix Dev (53.2%)	vs.	WRW 5 (27.4 °C) Forested (51.1%)	0.02
	vs.	WRW 11 (27.3 °C) Agriculture (41.9%)	0
	vs.	WRW 12 (27.4) Forested (34.5%)	0
	vs.	WRW 15 (24.1 °C) Mix Dev (70.3%)	0.01
WRW 2 (20.6 °C) Forested (74.2%)	vs.	WRW 5 (27.4 °C) Forested (51.1%)	0
	vs.	WRW 6 (25.9 °C) Forested (58.7%)	0
	vs.	WRW 9 (23.4 °C) Forested (52.8%)	0.01
	vs.	WRW 11 (27.3 °C) Agriculture (41.9%)	0
	vs.	WRW 12 (27.4 °C) Forested (34.5%)	0
	vs.	WRW 14 (26.4 °C) Forested (56.9%)	0
	vs.	WRW 15 (24.1 °C) Mix Dev (70.3%)	0
	vs.	WRW 18 (24.8 °C) Forested (48.9%)	0
	vs.	WRW 19 (26.3 °C) Forested (47.9%)	0
	vs.	WRW 21 (25.8 °C) Forested (42.2%)	0.01
	vs.	WRW 5 (27.4 °C) Forested (51.1%)	0.01
WRW 3 (21.6 °C) Forested (61.3%)	vs.	WRW 11 (27.3 °C) Agriculture (41.9%)	0
	vs.	WRW 12 (27.4 °C) Forested (34.5%)	0
	vs.	WRW 15 (24.1 °C) Mix Dev (70.3%)	0.01
WRW 4 (22.8 °C) Forested (59%)	vs.	WRW 5 (27.4 °C) Forested (51.1%)	0.01
	vs.	WRW 11 (27.3 °C) Agriculture (41.9%)	0
	vs.	WRW 12 (27.4 °C) Forested (34.5%)	0
	vs.	WRW 15 (24.1 °C) Forested (85.8%)	0.01
WRW 5 (27.4 °C) Forested (51.1%)	vs.	WRW 17 (21.5 °C) Forested (85.8%)	0
WRW 6 (25.9 °C) Forested (58.7%)	vs.	WRW 17 (21.5 °C) Forested (85.8%)	0.01
WRW 11 (27.3 °C) Agriculture (41.9%)	vs.	WRW 17 (21.5 °C) Forested (85.8%)	0
WRW 12 (27.4 °C) Forested (34.5%)	vs.	WRW 17 (21.5 °C) Forested (85.8%)	0
WRW 14 (26.4 °C) Forested (56.9%)	vs.	WRW 17 (21.5 °C) Forested (85.8%)	0.01
WRW 15 (24.1 °C) Mix Dev (70.3%)	vs.	WRW 17 (21.5 °C) Forested (85.8%)	0
WRW 17 (21.5 °C) Forested (85.8%)	vs.	WRW 18 (24.8 °C) Forested (48.9%)	0.01
	vs.	WRW 19 (26.9 °C) Forested (47.9%)	0.02
	vs.	WRW 21 (25.8 °C) Forested (42.2%)	0.02

Quarterly Stream Water Temperature

Seasonal Tw regimes showed that quarter 1 (January 1st – March 31st) had the lowest minimum Tw (-3.0 °C, Site #16), a mean of 3.2 °C, a maximum Tw of 14.0 °C (Site #12), and a standard deviation of 3.8 °C (Table 3, Figure 4). Quarter 2 (April 1st – June 30th) included the highest standard deviation (4.7 °C), and a mean Tw 14.6 °C, a maximum Tw of 27.3 °C (Site #11), and a minimum Tw of 1.6 °C (Site #17). Quarter 3 (July 1st – September 30th) had the highest mean Tw (19.2 °C) and maximum Tw (27.4 °C) (Site #12) with a standard deviation of 2.2 °C, and a minimum of 12.5 °C (Site #4).

Significant Spearman's correlation coefficients ($\alpha=0.05$) between LULC types and maximum Tw occurred during quarter 1, 3, and 4 (Table 5). Agriculture LULC showed a significant positive correlation to maximum Tw during quarter 1 ($p=0.03$) and quarter 3 ($p=0.01$). Forested LULC showed a significant negative correlation to maximum Tw during quarter 3 ($p=0.04$).

The Kruskal Wallis ANOVA showed maximum daily Tw across all 21 sites differed significantly ($p=0.00$). The post hoc analysis showed that the most significant differences were observed in quarter 3 with 130 significant differences between sites (all, $p \leq 0.04$). Quarter 4 had three significant differences, the lowest number of returned significant differences of all four quarters. All three of the returned significant differences involved site #1 (vs. site #4 ($p=0.01$), vs. #5 ($p=0.05$), vs. #17 ($p=0.00$)).

Figure 4. Five-minute water temperature data shown on a (a) site by site, (b) quarterly, and (c) monthly basis collected from 22 gauging sites in West Run Watershed, West Virginia, USA; during the 2018 annual year.

Monthly Stream Water Temperature

January included the lowest minimum Tw (-3.0°C) (Site #16), with a standard deviation of 2.4°C (all 21 sites), and a mean Tw of 1.4°C (all 21 sites), and a maximum of 8.3°C (Site #8) (Table 3). May included the highest standard deviation (3.3°C), with a mean Tw of 21.8°C , a maximum of 23.4°C (Site #12), and a minimum of 1.6°C (Site #17). July included the highest maximum Tw (27.4°C) (Site #12), with a mean Tw of 16.1°C , a minimum Tw of 10.3°C (Site #17), and a standard deviation of 2.3°C . September included the highest mean Tw (19.6°C), a minimum Tw of 13.2°C (Site #17), a maximum Tw of 27.1°C (Site #16), and a standard deviation of 1.9°C (Table 3).

Significant spearman's correlation coefficients ($\alpha=0.05$) between LULC types and maximum Tw occurred during February, April, June, July, August, September, October, November, and December. Agriculture LULCs showed a significance positive correlation to maximum Tw during February ($p=0.03$), June ($p=0.03$), August, ($p=0.04$), September($p=0.05$), November ($p=0.03$), and December ($p=0.05$). Forested LULCs showed a significance negative correlation to maximum Tw during August ($p=0.01$), September ($p=0.00$), and December ($p=0.02$). Mixed development LULCs showed a significant positive correlation to maximum Tw during August, ($p=0.01$), September ($p=0.00$), and November ($p=0.04$) (Table 5).

LULC and Tw analysis using all sites showed 12 significant ($\alpha=0.05$) correlations to Tw variables. The Kruskal Wallis ANOVA showed maximum daily Tw across all 21 sites differed significantly during all twelve months ($p=0.00$). The post hoc analysis showed the most significant differences occurred in July, with 108 significant differences ($p \leq 0.04$). Both February and October had no significant differences between sites (Appendix C).

Table 5. Spearman correlations between LULC types and maximum Tw of all 21 sites, mainstem, and tributaries of West Run Watershed, West Virginia, USA, during the 2018 annual year. Positive correlations indicate an increase in Tw with increasing LULC and negative correlations indicate a decrease in Tw with increasing LULC. Bold values are significant correlations at $\alpha=0.05$. Q – quarter.

All Sites																
	Q 1	Q 2	Q 3	Q 4	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mixed Development	0.0	0.1	0.0	-0.1	0.2	0.1	0.0	0.0	0.2	0.1	0.1	0.2	0.2	-0.1	0.3	0.3
Agriculture	0.5	0.4	0.5	0.4	0.3	0.5	0.3	0.3	0.3	0.4	0.5	0.5	0.4	0.4	0.3	0.5
Forested	-0.1	-0.2	-0.5	-0.3	-0.3	-0.2	-0.3	-0.1	-0.3	-0.2	-0.3	-0.4	-0.5	-0.3	-0.4	-0.5

Mainstem																
	Q 1	Q 2	Q 3	Q 4	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	0.0	0.4	0.5	0.4	-0.6	0.0	0.2	0.6	0.6	0.4	0.5	0.9	0.9	0.4	0.6	-0.1
Agriculture	0.5	0.3	0.5	0.8	-0.2	0.5	0.4	0.5	0.4	0.3	0.5	0.7	0.7	0.8	0.8	0.7
Forested	-0.3	-0.5	-0.6	-0.6	0.5	-0.3	-0.4	-0.7	-0.7	-0.5	-0.6	-0.9	-0.9	-0.6	-0.7	-0.2

Tributaries																
	Q 1	Q 2	Q 3	Q 4	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mixed Development	0.0	0.1	0.1	-0.2	0.2	0.1	-0.1	-0.3	0.3	0.3	0.4	0.3	0.3	0.1	0.6	0.4
Agriculture	0.5	0.3	0.4	0.3	-0.1	0.4	0.2	0.2	0.5	0.6	0.6	0.6	0.6	0.5	0.6	0.4
Forested	0.0	0.0	-0.4	-0.1	-0.4	0.4	0.2	0.4	0.3	0.5	0.3	0.2	0.1	0.3	0.4	0.2

PCA

As stated previously, PCAs included in this work are for illustrative purposes, strictly. Given the nature of data used in this analysis, further elaboration of each Principle component's composition will not be included. Annual time-series comparisons between LULC areas and Tw variables all showed two Eigenvalues above the threshold of importance. If all variables ($n=4$) exerted equal influence for the annual PCA the loading values would be 0.5 (i.e., $\sqrt{1/n}$) (Bro and Smilde, 2014; Kellner et al., 2018). For mean Tw annual PCA, PC1 had an Eigenvalue of 2.0 and explained 50.4% of the variance and PC2 had an Eigenvalue of 1.2 and explained 31.0% of the variance (Figure 7). For the minimum Tw annual PCA, PC1 had an Eigenvalue of 1.8 and explained 45.1% of the variance and PC2 had an Eigenvalue of 1.2 and explained 30.5% of the

variance. For the maximum Tw annual PCA, PC1 had an Eigenvalue of 1.8 and explained 45.8% of the variance and PC2 had an Eigenvalue of 1.7 and explained 41.8% of the variance.

Mean and maximum Quarterly time-series comparisons between LULC areas showed three Eigenvalues above the threshold of importance. The minimum Tw Quarterly time-series comparisons between LULC areas showed two Eigenvalues above the threshold of importance. If all variables ($n=7$) exerted equal influence the loading values would equal 0.38. For the mean Tw quarterly PCA, PC1 had an Eigenvalue of 2.9 and explained 40.9% of the variance and PC2 had an Eigenvalue of 2.0 and explained 28.4% of the variance. For the minimum Tw quarterly PCA, PC1 had an Eigenvalue of 2.5 and explained 35.3% of the variance and PC2 had an Eigenvalue of 1.8 and explained 25.6% of the variance. For the maximum Tw quarterly PCA, PC1 had an Eigenvalue of 3.4 and explained 47.9% of the variance and PC2 had an Eigenvalue of 1.8 and explained 26.3% of the variance.

Monthly time-series comparison between LULC areas and Tw variables all showed four Eigenvalues above the threshold of importance (Appendix D). If all variables ($n=15$) exerted equal influence the loading values would equal 0.26. For the mean Tw monthly PCA, PC1 had an Eigenvalue of 6.2 and explained 41.3% of the variance and PC2 had an Eigenvalue of 5.5 and explained 36.8% of the variance. For the minimum Tw monthly PCA, PC1 had an Eigenvalue of 6.4 and explained 42.9% of the variance and PC2 had an Eigenvalue of 3.4 and explained 22.6% of the variance. For the maximum Tw monthly PCA, PC1 had an Eigenvalue of 7.5 and explained 49.7% of the variance and PC2 had an Eigenvalue of 2.7 and explained 17.8% of the variance.

Figure 5. Results of principle component analysis, showing biplots of extracted principle components of annual water temperature data (mean (a), maximum (c), and minimum (e)), and biplots with extracted principle components of quarterly water temperature data (mean (b), maximum (d), and minimum (f)) collected during the 2018 annual year at the 21 monitoring sites of West Run Watershed, WV, USA; and their corresponding LULC area (km²).

Discussion

Climate during Study

Climate variables (e.g., T_a , precipitation, net radiation) recorded in West Run Watershed over the 2018 annual year were within the range of historic climate of West Virginia (i.e., 1900-2016) (Kutta and Hubbart, 2019a). Average mean temperature ($11.6\text{ }^{\circ}\text{C}$) differed only slightly (1.7%) from historic (1900-2016) averages observed in West Virginia from 1900-2016 ($11.4\text{ }^{\circ}\text{C}$). Typical of the climate in West Run Watershed, no dry season was observed during the 2018 annual year, but somewhat more of the total precipitation fell during quarters two and three than in one and four (Petersen and Hubbart, 2020). However, during the study period there was above average (20.5% higher) total precipitation relative to the historic (1900-2016) average (1096 mm) (“Fourth National Climate Assessment,” n.d.). Thus, the 2018 findings may not be representative of average precipitation years.

Stream Water Temperature LULC Relations

The null hypotheses of hypothesis 1, 2, and 3 were rejected given results from the Tw-LULC analyses and the site-by-site analysis. In general, results from the Spearman’s analysis (Table 5, Appendix E) showed that an increase in the proportion of forested LULC types is negatively correlated to mean and maximum Tw at all three temporal scales (i.e., annual, quarterly, monthly) as confirmed in previous studies (Beschta and Taylor, 1988; Johnson and Jones, 2011; Moore et al., 2006). These results follow the same conclusions made by previous researchers that showed that forest harvest (e.g., clear-cuts / canopy removal) increase Tw (Gravelle and Link, 2007; Johnson and Jones, 2011; Moore et al., 2006; Pollock et al., 2009). Additionally, although not surprising, during the winter season, a positive correlation was observed between the proportion of forest LULC and minimum Tw. This correlation was likely related to canopy insulation during winter months (Moore et al., 2006; Oke, 1987). Moore et al. (2005) suggested that riparian vegetation insulates Tw by lowering convective heat loss to the above atmosphere, and thus warmer Tw. In the current work, positive correlations between maximum Tw and percent forest LULC were observed in specific tributaries (Table 5). These results contradict findings of previous research (Beschta and Taylor, 1988; Moore et al., 2005;

Pollock et al., 2009) which found as forested LULC proportions increase Tw decreases. However, when sites 8 and 9 were removed from the data pool, correlations trends reverted to the expected negative correlation (Beschta and Taylor, 1988; Moore et al., 2005; Pollock et al., 2009). For sites 8 and 9 of the current work, the positive correlation may be attributed to the high proportion forest in the subcatchment but mixed development LULC types at both sites 8 and 9 directly adjacent to the stream.

Results from the Spearman's analysis (Table 5, Appendix E) showed mixed development LULC types were significantly correlated to mean, minimum, and maximum Tw with variable effects throughout the year. While results of the mixed development–Tw analysis were similar to results of past research, the high number of both sampling sites and sampling frequency of this study provide needed validation for results of previous research (Rice et al., 2011; Zeiger et al., 2016; Zeiger and Hubbart, 2015). Interestingly, Spearman's results (Table 5, Appendix E) showed a negative correlation between mixed development LULC types and minimum, maximum, and mean Tw during the winter and early spring months (e.g., January, February, March, April, November, December), indicating overall lower Tw. These findings contradict results of other research analyzing the relationship between mixed development LULC and Tw. Rice et al. (2011) showed that mean Tw increased during the winter season in heavily urbanized catchments of Boone, North Carolina. Alternatively to Rice et al. (2011), lower Tw correlated to mixed development during cooler months (e.g., January, February, March, April, November, December) could be explained by runoff from impervious surfaces, which during these months is often lower in temperature than Tw of surrounding streams. Qun et al. (2016) showed a negative correlation between urban impervious surface and land surface temperatures (i.e., lower surface temperatures) during winter daytimes. Conflicting results might be further explained by the complex physiographic mosaic of the study watershed in which mixed development LULC types are broken up by forested and agricultural LULC types at varying relative positions on the landscape, thus leaving room for future investigations.

Although not always significant, agricultural LULC types had a positive Spearman's correlation, with maximum Tw in every quarter and month, except January (Table 5). These findings may be, at least in part, due to increased soil shortwave radiation exposure during periods when fields are bare, increased subsurface lateral flow rates, and/or the removal of riparian vegetation as per findings of previous literature (Macedo et al., 2013; Story et al., 2003; Younus

et al., 2000). Interestingly, a potential relationship appeared between maximum Tw and crop absence. Typically, in the study watershed, certain crops (e.g., triticale, rye, and hay) are planted in spring and harvested between May and early July (U.S. Department of Agriculture, 1997), exposing fields and potentially explaining the observed trend in Table 5. Therefore, the potential relationship between crop absence and maximum Tw could be explained, at least in part, by increased shortwave interception and reduced runoff volumes through evapotranspiration and interception of precipitation by crops (Oke, 1987; Xuhui, 2018). In addition, after harvest the relationship becomes significant because runoff volumes increase and the soil is exposed to greater amounts of shortwave radiation thereby reaching higher temperatures (Hatfield et al., 2001; Oke, 1987; Younus et al., 2000). Furthermore, during these periods water contacting or infiltrating into the soil is heated and transported to surrounding streams through subsurface lateral flows (Younus et al., 2000).

LULC Tw Tipping Points

Decreasing forested LULC proportion influenced Tw variables in the current investigation. As the percent of forested LULC types decreased below 74.2%, associated maximum Tw began to increase (thus a potential tipping point). Below 61.1%, Forested LULC mean Tw began to either increase or decrease depending on the time of year (Table 5., Appendix E), and below 52.2% Forested LULC the minimum Tw of associated streams began to increase or decrease again depending on the time of year. The increase or decrease is based on the significant Spearman's correlations which vary quarterly and monthly (Table 5., Appendix E). Mixed development LULC types were the second LULC to influence Tw.

Figure 6. Average annual Tw variables (mean Tw, minimum Tw, and maximum Tw) vs. Cumulative LULC types (forested, agriculture, and mixed development) (1=100%) moving from the headwaters to the terminus in West Run Watershed, West Virginia, USA, during the 2018 annual year.

As the percent of mixed development LULC types increased above 14%, associated mean Tw increased (thus a potential mixed development tipping point). Above 24.1% mixed development maximum Tw began to either increase or decrease depending on the time of year, and above 26.8% mixed development the minimum Tw of streams began to increase or decrease (depending on the time of year). Agricultural LULC types also influenced Tw significantly. As the percent of agriculture LULC types increased above 14.9% associated maximum Tw began to increase. Above 16.0% agriculture LULC mean Tw begins increase and above 26.4% agriculture LULC the minimum stream Tw began to increase or decrease (time of year dependent).

Summary and Conclusion

Influencing both abiotic and biotic processes, Tw is a water quality parameter of interest to land use managers, policy makers, and water quality experts. Tw influences abiotic processes such as the settling rates of suspended particles and biotic processes such as gas exchange rates in aquatic organisms (Boyde et al., 2016). Although the subject of Tw is a frequent topic of past literature the relation to land-use in a contemporary mixed land-use watershed is largely unknown. Research over Tw relations to surrounding land use is often limited to proximal areas (i.e., riparian buffer) to the waterbody being researched or conducted in watersheds consisting of a homogenous LULC type. The homogenous LULC assumption is often not viable due to the contemporary nature of anthropogenic development and expansion in many watersheds. Instead most watersheds are closer to the complex mosaic of LULC types in a contemporary mixed land-use watershed like West Run Watershed. Therefore, research in watersheds like West Run can provide insight into LULC change impacts on water quality parameters such as Tw. No previous research investigating stream water temperature (Tw) in contemporary watersheds has used such a high temporal and spatial sampling regime as that included in the current investigation. In addition, using a paired and nested-scale experimental watershed study design allowed for separation of the watershed into subsections designated with associated land-use practices. Implementation of the experimental design used in the current research is necessary to provide both validation for previous results and the discovery of temporal variation in LULC-Tw integrated processes. In the current work, the relationship between LULC types and Tw was investigated in the Appalachian region of the eastern United States. The analysis used five-minute Tw time-series data collected at 21 nested sites using an experimental watershed study design. Results indicated that LULC has varying effects on Tw both spatially and temporally. In this research, the forested LULC type displayed a negative correlation to mean and maximum Tw in the spring and summer months. Throughout the year forested LULC type displayed an overall lowered Tw variability. A significant ($p=0.01$) positive relation between agricultural LULCs and maximum water temperature was observed during this research. LULC types associated with the agricultural classification are often associated with the removal of riparian buffer strips and the exposure of soil to shortwave radiation for some period when no crops are present during the annual year (Borman and Larson, 2003b; Wiebe and Gollehon, 2007; Younus et al., 2000). Both factors shown in previous research to increase Tw through increased

shortwave radiation exposure and increased temperature of subsurface lateral flows entering neighboring streams (Younus et al., 2000). Mixed-development LULC types, associated with impervious surfaces, are frequently observed to have a positive relation with mean, maximum, and Tw standard deviation in the literature (Kinouchi et al., 2007; Palmer and Nelson, 2007; Rice et al., 2011; Zeiger and Hubbart, 2015). The relationship between Mixed-development and Tw variables analyzed in this thesis varied throughout the year depending on the season and month, similar to findings of primary literature (Palmer and Nelson, 2007; Rice et al., 2011; Zeiger and Hubbart, 2015). During the winter months a negative correlation with minimum Tw was observed. This negative relationship correlates to an overall lower minimum Tw. This relationship is likely attributed to surface runoff being cooled when contacting impervious surfaces during these colder months (Qun et al. 2016). Alternatively, during the summer months, a positive relationship was shown between mixed-development LULC types and all Tw variables. These results correlated to elevated Tw with higher overall variability similar to those of previous work (Palmer and Nelson, 2007; Rice et al., 2011; Zeiger and Hubbart, 2015). Although results are specific to the study watershed, the finding of tipping points shows LULC thresholds that, when exceeded, may begin to impact associated Tw. These relationships likely exist in all watersheds, particularly contemporary municipal watersheds. Results of this thesis investigation highlighted the variable temporal impacts surrounding LULC types can have on Tw in a contemporary mixed land-use watershed. Many of these results were likely only elucidated due to the high temporal and spatial resolution of data collected at the twenty-one sites in West Run Watershed. Conclusions made by past researchers were both supported and expanded upon through the interpretation and analysis of these data. The alternative hypotheses of this thesis, established through results of other Tw literature, were supported. These results will advance decision making success of land managers and policymakers concerned with the health of aquatic ecosystems. In particular, the high-resolution (n=21) study design presented in this work facilitates identification of upland mitigation sites and corresponding greater certainty in fiscal investment outcomes.

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CHAPTER II

EXPLORATORY WORK

Thermal Surges

Given the impact that maximum Tw can have on stream ecosystems, a preliminary investigation of thermal surge events was conducted. A relationship between impervious surface cover and stream water temperature surges has been shown in past studies often associated with urban stream syndrome (Anderson et al., 2010; Caldwell et al., 2015; Ficklin et al., 2012; Herb et al., 2008a; Herb and Stefan, 2011; Palmer and Nelson, 2007a; Ren et al., 2003; Rice et al., 2011; Segura et al., 2015; Sun et al., 2015; Webb et al., 2008; Wei et al., 2018; Zeiger and Hubbart, 2015). This is important due to the increasing sprawl of mixed development LULCs in West Run Watershed, potentially increasing the symptoms of urban stream syndrome in the future.

Arbitrarily selected precipitation events were targeted to analyze the effects of precipitation events on stream Tw surges. As per Zeiger and Hubbart (2015), Rice et al. (2011), and Anderson et al. (2010), a Tw surge is defined as higher than 1.0 °C increase within 15-min time interval. In Zeiger and Hubbart (2015), surge duration was calculated as the time from the beginning of the Tw surge until Tw returned to pre-surge temperature. For the current work, during each event, surge duration, maximum Tw increase, surge lag time, rate of Tw increase, and total precipitation were measured. Replicating the work of Zeiger and Hubbart, (2015) a stacked comparison of Tw on the y-axis and time on the x-axis will be created to show the lag time from precipitation event to observed temperature surge upon entrance, and the thermal plume created as the warmer water enters the watershed and moves through the watershed (Figure 7).

H₀: Storm surges will not be detected following precipitation events in West Run Watershed

H_a: Storm surges will be detected following precipitation events in West Run Watershed

Five thermal surge events were identified, randomly chosen, and isolated from the 2018 Tw annual data by looking for a 1.0 C° increase within a 15 min period following summer precipitation events. Between all five precipitation events mean precipitation, Tw surge, surge

duration, rate of Tw increase, and lag time were 14.26 mm, 2.46 °C, 4.64 hours, 0.1 °C, and 8 mins, respectively (Table 6). The largest precipitation event occurred on July 31st at 14:05

Figure 7. Stream water temperature surges sensed at sites in West Run Creek following summer precipitation event during the summer of 2018. Black circles mark the peak Tw surges and

arrows track the Tw surge as it moves downstream. (a) Stream water temperature surge one occurring on 06/17 at 04:15 (15.1mm precipitation event) moving through West Run Creek. (b) Stream water temperature surge two occurring on 07/25 at 12:00 (13.5mm precipitation event) moving through West Run Creek. (c) Stream water temperature surge three occurring on 07/16 at 13:00 (19.4mm precipitation event) moving through West Run Creek. (d) Stream water temperature surge four (left) occurring on 08/16 at 15:55 (11.7mm precipitation event) and stream water temperature surge five (right) occurring on 08/16 at 16:15 (11.7mm precipitation).

Table 6. Descriptive statistics of stream water temperature surges identified during Quarter 3 of the 2018 annual water temperature data collected at West Run Watershed, West Virginia, USA.

	Date (Time)	Total Precipitation (mm)	Surge Amplitude (°C)	Rate of increase (°C/min)	Lag Time (mins)	Surge Duration (hours)
Surge #1	6/17 (4:15)	15.1	2.8	0.1	10	1.8
Surge #2	7/25 (12:40)	13.6	1.7	0.1	10	10.6
Surge #3	7/31 (14:05)	19.4	2.1	0.1	5	2.5
Surge #4	8/16 (15:55)	11.7	1.4	0.1	0	0.3
Surge #5	8/16 (16:15)	11.7	4.3	0.1	15	8

at Site #11, with a total of 19.4 mm of precipitation falling over 4.5 hours, resulting in a surge increasing Tw by 2.1 °C lasting 2.5 hours (Figure 7). The largest Tw surge increase of 4.3 °C occurred on August 16th at 16:15 at Site #1, dominate LULC mixed development (0.1 km²) with a total of 11.7 mm of precipitation falling over 1.0 hour, producing a surge lasting 8 hours. Two thermal surges were observed during the August 16th event, both observed at Site #3, dominate LULC Forested (1.1 km²). The longest surge duration occurred on July 25th at 12:40 at Site #13, dominate LULC Forested (5.0 km²) with a total of 13.6 mm of precipitation falling over 2 hours, resulting in a surge increase Tw by 1.7 °C lasting 10.6 hours.

The analysis of temperature surges was limited in this study. A rating curve for each site to estimate flow is needed for further investigation. However, our hypothesis was rejected when locating and isolating these five events. Other multiple surges were identified but left for quantitation and analysis in future research. Furthermore, multiple surge events occurring simultaneously in the watershed were observed and only able to be identified because of the large number of sampling sites. The topic of multiple surges occurring simultaneously has been

studied minimally in past literature and needs to be investigated. This investigation showed thermal surges in the study watershed, and therefore presents future research opportunities into the investigation of thermal surge dynamics. Furthermore, the potential correlation between summer thermal surge events and agricultural LULC types should be investigated. The relationship between mixed-development, particularly impervious surfaces, frequently appears in the Tw literature. However, the relationship to agricultural LULC types is not well understood. Future studies analyzing thermal surges in WRW could potentially advance the decision-making success of land managers and policy makers concerned with the health of aquatic ecosystems.

Relationship of Stream Distance and Tw

Ambient air temperature (Ta) has been shown to have a substantial influence on Tw (O'Driscoll and DeWalle, 2006; Rice et al., 2011; Sinokrot and Stefan, 1993). Research has shown conclusively that, as water moves downstream, it is impacted less by the various inflows from runoff/tributaries, and more so by ambient air temperature (Ta) (O'Driscoll and DeWalle, 2006; Sinokrot and Stefan, 1993). However, it should also be stated that land-use also influences Ta in addition to Tw (Moore et al., 2005). Rice et al. (2011) showed that increasing watershed urbanization causes the Tw and Ta relationship to break down. Tw begins to deviate from Ta as energy and mass accumulate from surrounding mixed development LULC types. This is, in some instances, offset given that higher channel volumes downstream are often sufficient enough to attenuate thermal inputs (Caissie, 2006; Gu et al., 1999). Thus, stream inputs (e.g., groundwater, surface runoff, tributaries) from surrounding land-use types may have a greater influence upstream near headwaters relative to downstream and during periods of low(er) flow relative to periods of flooding (Webb et al. 2008).

A linear relationship between stream distance and descriptive statistics from sites along the main channel was fit using simple linear regression to validate results from past research where stream distance was showed to have a significant correlation with Tw variables (e.g., mean, minimum, maximum, and standard deviation) (Anderson et al., 2010; Mohseni and Stefan, 1999; Poole and Berman, 2001; Stefan and Preud'homme, 1993). Ta recorded at a climate station near site #13 was assumed homogenous across the entire watershed.

H₀: There will be no significant relationship between distance from headwaters and Tw variables (mean, maximum, minimum, standard deviation)

H_a: There will be a significant relationship between distance from headwaters and Tw variables (mean, maximum, minimum, standard deviation)

The linear relationship fit between mean ($p=0.04$), maximum ($p=0.03$), and standard deviation ($p=0.01$) showed significance at an $\alpha=0.05$ to stream distance from the headwaters of West Run Creek, similar to studies looking at relations between stream distance downstream and Tw (Figure 8) (Anderson et al., 2010; Mohseni and Stefan, 1999; Poole and Berman, 2001; Stefan and Preud'homme, 1993; Torgersen et al., 1999) In all three cases, the relationship had a positive correlation and R-squared values of 0.68, 0.57, and 0.71, respectively. Minimum Tw did not have a significant relationship ($p=0.90$) to distance downstream from headwater.

Figure 8. Mean (a), standard deviation (b), maximum (c), and minimum (d) water temperature collected at main stem gauging sites of West Run Watershed, West Virginia, USA; plotted against stream distance from headwaters of West Run Creek. Percent mixed development LULC is also plotted against stream distance from headwaters. A reference line for mean Ta over the entire 2018 annual year is included in mean plot (a).

Given these results the null hypothesis was rejected. These results are important because they align with the conclusions of past researchers that as parcels of water move downstream, T_w tends to increase (Anderson et al., 2010; Bogan et al., 2003; Herb et al., 2008; Palmer and Nelson, 2007; Rice et al., 2011). This increase is attributed to equilibration with atmospheric conditions and/or compounding effects of urbanization (Figure 8) (Anderson et al., 2010; Rice et al., 2011; Zeiger and Hubbart, 2015). Overlying T_a affects rates of sensible heat transfer to or from adjacent streams depending on initial temperature deficits (Bogan et al., 2003). These temperature deficits between T_a and T_w occur due to the atmosphere's lower heat capacity relative to liquid water (Bogan et al., 2003; Mohseni and Stefan, 1999; Poole and Berman, 2001). Furthermore, stream water further downstream tends to have higher thermal inertia due to larger volumetric streamflow and is less affected by incoming surface runoff, tributary inflows, overlying T_a , and groundwater inputs (Johnson, M. Wilby, 2007; Mwedzi et al., 2016; Poole and Berman, 2001; Rice et al., 2011; Sinokrot and Gulliver, 2000). This higher thermal inertia means surrounding land-use types should have a smaller effect on T_w . However, Rice et al. (2011) observed the compounding effect of urban areas, associated with the mixed development LULC types increase T_w prevailing over dampening effects caused by higher thermal inertia. Furthermore, downstream sub-basins of West Run Watershed have lower portions of forested LULC areas and greater mixed development and agricultural LULCs (Figure 2.) an additional reason explaining why both mean, maximum, and standard deviation of T_w increases with distance downstream (Rice et al., 2011).

Future Work

Given the finding of thermal surge events occurring in West Run Watershed these thermal surge events should be further investigated. Future research should be conducted to quantify all surge events over not only the 2018 annual year but also 2017 and 2019 annual years for which T_w data exists. The Incorporation of two additional annual year passes the three-year threshold needed to classify the research investigate as an investigation of West Run Watershed's thermal regime. The three years of data should elucidate the interactions occurring between surrounding LULC types and thermal surge dynamics (e.g., surge amplitude, surge frequency, surge duration). The 2017 and 2019 annual years were not incorporated into this investigation due to ongoing 2019 data collection during the investigation and lack of post processing of 2017 data. As stated, surges were detected at not just a single location in the

watershed, but multiple locations throughout the watershed during the same precipitation event. In the current literature, there is a lack of information regarding these multi-surge events. The current literature attributes surge events to urban area and impervious surfaces associated with mixed-development LULC types (Anderson et al., 2010; Rice et al., 2011; Zeiger and Hubbart, 2015). Given the significant relation between maximum water temperature and agricultural LULC types, the potential impact of agriculture LULCs on thermal surge dynamics should also be investigated in for future research. Furthermore, the creation of a thermal surge model in West Run Watershed to predict surge likelihood and severity would be a good avenue for future research and be a beneficial tool for land managers. Climatic conditions prior to precipitation events like incident shortwave radiation have been shown to be an influencing factor on surge occurrence and severity (i.e., surge amplitude and surge duration). Creating a model which incorporates variables such as shortwave radiation flux, percent impervious surfaces, amount of precipitation, spatial precipitation variability, and topographic slope may allow researcher to predict thermal surge likelihood and severity.

The high-resolution data acquired via direct measurements of Tw in West Run Watershed could be used to validate the numerous existing Tw models. Numerous Tw models have been developed to predict Tw. For example, effective models in predicting Tw exist which use only overlying air temperature (Mohseni and Stefan, 1999; Stefan and Preud'homme, 1993). Other models such as the SNTMP model or SWAT model incorporate other variables (e.g., streamflow, ground water temperature, hyporheic water temperature, and net heat exchange by radiation, turbulent exchange, and conduction across the water surface and bed) (Herb et al., 2008; Moore et al., 2005). The validation and further development of both simple and complex existing models provides another potential avenue for scientific advances and future research.

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APPENDIX A CLIMATE DURING STUDY PERIOD

Figure A1. Time-series of ambient air temperature (Ta) and average net radiation across the 2018 annual year collected from a climate station located in West Run Watershed, West Virginia, USA

Figure A2. Time-series of relative humidity and precipitation across the 2018 annual year collected from a climate station located in West Run Watershed, West Virginia, USA

Figure A3. Time-series of ambient air temperature (Ta) and precipitation across the 2018 annual year collected from a climate station located in West Run Watershed, West Virginia, USA

APPENDIX B
GAUGING SITE TW TIMESERIES

Figure B1. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #1 located in West Run Watershed, West Virginia, USA.

Figure B2. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #2 located in West Run Watershed, West Virginia, USA.

Figure B3. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #3 located in West Run Watershed, West Virginia, USA.

Figure B4. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #4 located in West Run Watershed, West Virginia, USA.

Figure B5. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #5 located in West Run Watershed, West Virginia, USA.

Figure B6. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #6 located in West Run Watershed, West Virginia, USA.

Figure B7. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #7 located in West Run Watershed, West Virginia, USA.

Figure B8. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #8 located in West Run Watershed, West Virginia, USA.

Figure B9. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #9 located in West Run Watershed, West Virginia, USA.

Figure B10. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #10 located in West Run Watershed, West Virginia, USA.

Figure B11. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #11 located in West Run Watershed, West Virginia, USA

Figure B12. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #12 located in West Run Watershed, West Virginia, USA

Figure B13. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #13 located in West Run Watershed, West Virginia, USA

Figure B14. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #14 located in West Run Watershed, West Virginia, USA

Figure B15. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #15 located in West Run Watershed, West Virginia, USA.

Figure B16. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #16 located in West Run Watershed, West Virginia, USA.

Figure B17. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #17 located in West Run Watershed, West Virginia, USA

Figure B18. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #18 located in West Run Watershed, West Virginia, USA

Figure B19. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #19 located in West Run Watershed, West Virginia, USA

Figure B20. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #20 located in West Run Watershed, West Virginia, USA

Figure B21. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #21 located in West Run Watershed, West Virginia, USA

Figure B22. Time-series of steam water temperature across the 2018 annual year recorded at gauging site #22 located in West Run Watershed, West Virginia, USA

APPENDIX C
SITE BY SITE ANALYSIS RESULTS

Site Comparison	MEAN p-value	MAX p-value	MIN p-value
WRW #1 (°C) "WRW #5 (°C)"		0.02	
WRW #1 (°C) "WRW #11 (°C)"		0.00	
WRW #1 (°C) "WRW #12 (°C)"		0.00	
WRW #1 (°C) "WRW #15 (°C)"	0.02	0.01	
WRW #2 (°C) "WRW #5 (°C)"	0.01	0.00	
WRW #2 (°C) "WRW #6 (°C)"		0.00	
WRW #2 (°C) "WRW #9 (°C)"		0.01	
WRW #2 (°C) "WRW #11 (°C)"		0.00	
WRW #2 (°C) "WRW #12 (°C)"		0.00	
WRW #2 (°C) "WRW #14 (°C)"		0.00	
WRW #2 (°C) "WRW #15 (°C)"	0.00	0.00	0.01
WRW #2 (°C) "WRW #18 (°C)"	0.01	0.00	
WRW #2 (°C) "WRW #19 (°C)"	0.03	0.00	
WRW #2 (°C) "WRW #21 (°C)"	0.04	0.01	
WRW #3 (°C) "WRW #5 (°C)"		0.01	
WRW #3 (°C) "WRW #11 (°C)"		0.00	
WRW #3 (°C) "WRW #12 (°C)"		0.00	
WRW #3 (°C) "WRW #15 (°C)"	0.01	0.01	
WRW #4 (°C) "WRW #5 (°C)"		0.01	
WRW #4 (°C) "WRW #11 (°C)"		0.00	
WRW #4 (°C) "WRW #12 (°C)"		0.00	
WRW #4 (°C) "WRW #15 (°C)"	0.00	0.01	0.00
WRW #5 (°C) "WRW #17 (°C)"	0.00	0.00	0.02
WRW #6 (°C) "WRW #17 (°C)"	0.03	0.01	
WRW #9 (°C) "WRW #17 (°C)"	0.03		
WRW #11 (°C) "WRW #15 (°C)"			0.01
WRW #11 (°C) "WRW #17 (°C)"		0.00	
WRW #12 (°C) "WRW #15 (°C)"			0.01
WRW #12 (°C) "WRW #17 (°C)"		0.00	
WRW #14 (°C) "WRW #17 (°C)"		0.01	
WRW #15 (°C) "WRW #16 (°C)"	0.04		0.04
WRW #15 (°C) "WRW #17 (°C)"	0.00	0.00	0.00
WRW #17 (°C) "WRW #18 (°C)"	0.00	0.01	0.02
WRW #17 (°C) "WRW #19 (°C)"	0.01	0.02	
WRW #17 (°C) "WRW #21 (°C)"	0.02	0.02	

Figure C1. Results of site by site annual comparison using a Kruskal Wallis ANOVA with a post hoc analysis of mean, maximum, and minimum daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown.

	Q1	Q2	Q3	Q4	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value
WRW #1 (°C) "WRW #2 (°C)"							0.02									0.01
WRW #1 (°C) "WRW #3 (°C)"	0.01		0.01				0.01									0.00
WRW #1 (°C) "WRW #4 (°C)"	0.00		0.00	0.00	0.00		0.00				0.04					0.00
WRW #1 (°C) "WRW #5 (°C)"	0.00	0.00	0.00	0.01	0.00		0.00		0.00	0.00	0.00	0.00	0.00		0.01	0.00
WRW #1 (°C) "WRW #6 (°C)"	0.00	0.00	0.00		0.01		0.00		0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #7 (°C)"	0.00		0.00		0.00		0.01				0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #8 (°C)"			0.00										0.03			
WRW #1 (°C) "WRW #9 (°C)"			0.00						0.01	0.00	0.00	0.00	0.00			
WRW #1 (°C) "WRW #10 (°C)"	0.00		0.00	0.05	0.00		0.00		0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #11 (°C)"	0.00	0.01	0.00	0.00	0.00		0.00		0.00	0.00	0.00	0.00	0.00		0.01	0.00
WRW #1 (°C) "WRW #12 (°C)"	0.00	0.01	0.00	0.00	0.00		0.00		0.00	0.00	0.00	0.00	0.00		0.01	0.00
WRW #1 (°C) "WRW #13 (°C)"	0.00		0.00		0.00		0.05		0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #14 (°C)"	0.00	0.02	0.00	0.03	0.00		0.00		0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #15 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #1 (°C) "WRW #16 (°C)"	0.00		0.00	0.01	0.00		0.00				0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #17 (°C)"	0.00		0.00	0.00	0.00		0.00								0.00	0.00
WRW #1 (°C) "WRW #18 (°C)"	0.00	0.00	0.00		0.00				0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #19 (°C)"	0.00	0.00	0.00	0.04	0.00		0.00		0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #20 (°C)"	0.00	0.01	0.00	0.01	0.00		0.00		0.00	0.00	0.00	0.00	0.00		0.04	0.00
WRW #1 (°C) "WRW #21 (°C)"	0.00	0.00	0.00	0.02	0.00		0.00		0.00	0.00	0.00	0.00	0.00			0.00
WRW #2 (°C) "WRW #4 (°C)"			0.00		0.00											
WRW #2 (°C) "WRW #5 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #6 (°C)"		0.01	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #7 (°C)"			0.00								0.01	0.00	0.01			
WRW #2 (°C) "WRW #8 (°C)"			0.00													
WRW #2 (°C) "WRW #9 (°C)"			0.00						0.02	0.04	0.00	0.00	0.00			
WRW #2 (°C) "WRW #10 (°C)"			0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #11 (°C)"		0.02	0.00		0.00				0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #12 (°C)"		0.02	0.00		0.00				0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #13 (°C)"			0.00						0.01	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #14 (°C)"			0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #15 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #16 (°C)"			0.00		0.01						0.00	0.00	0.01			
WRW #2 (°C) "WRW #17 (°C)"	0.01		0.00				0.02									
WRW #2 (°C) "WRW #18 (°C)"		0.01	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #19 (°C)"		0.00	0.00		0.03				0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #20 (°C)"		0.04	0.00		0.00				0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #21 (°C)"		0.00	0.00		0.01				0.00	0.00	0.00	0.00	0.00			
WRW #3 (°C) "WRW #5 (°C)"		0.01	0.00						0.00	0.00	0.00	0.00	0.01			
WRW #3 (°C) "WRW #6 (°C)"			0.00								0.00	0.00				
WRW #3 (°C) "WRW #7 (°C)"			0.00													
WRW #3 (°C) "WRW #9 (°C)"			0.00								0.02	0.02				
WRW #3 (°C) "WRW #10 (°C)"			0.00								0.00	0.01				
WRW #3 (°C) "WRW #11 (°C)"			0.00							0.00	0.00	0.00				
WRW #3 (°C) "WRW #12 (°C)"			0.00							0.00	0.00	0.00				
WRW #3 (°C) "WRW #13 (°C)"			0.00								0.00	0.00				

Figure C2. Results of site by site quarterly and monthly comparison using a Kruskal Wallis ANOVA with a post hoc analysis of mean daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown. (Part 1)

	Q1	Q2	Q3	Q4	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value
WRW #3 (°C) "WRW #14 (°C)"			0.00								0.00	0.00				
WRW #3 (°C) "WRW #15 (°C)"			0.00						0.02	0.01	0.00	0.00	0.00			
WRW #3 (°C) "WRW #16 (°C)"			0.00													
WRW #3 (°C) "WRW #17 (°C)"							0.02									
WRW #3 (°C) "WRW #18 (°C)"			0.00							0.01	0.00	0.00	0.01			
WRW #3 (°C) "WRW #19 (°C)"			0.00						0.01	0.00	0.00	0.00				
WRW #3 (°C) "WRW #20 (°C)"			0.00		0.04					0.02	0.00	0.00	0.01			
WRW #3 (°C) "WRW #21 (°C)"			0.00						0.00	0.00	0.00	0.00	0.02			
WRW #4 (°C) "WRW #5 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #4 (°C) "WRW #6 (°C)"			0.00						0.04		0.00	0.01				
WRW #4 (°C) "WRW #8 (°C)"	0.01						0.00									
WRW #4 (°C) "WRW #9 (°C)"			0.02				0.00									
WRW #4 (°C) "WRW #10 (°C)"			0.00													
WRW #4 (°C) "WRW #11 (°C)"			0.00							0.00	0.00	0.00				
WRW #4 (°C) "WRW #12 (°C)"			0.00							0.00	0.00	0.00				
WRW #4 (°C) "WRW #13 (°C)"			0.00													
WRW #4 (°C) "WRW #14 (°C)"			0.00								0.00	0.00				
WRW #4 (°C) "WRW #15 (°C)"	0.00	0.05	0.00		0.01		0.00		0.00	0.00	0.04	0.00	0.01			
WRW #4 (°C) "WRW #18 (°C)"			0.00						0.04	0.00	0.00	0.00				
WRW #4 (°C) "WRW #19 (°C)"		0.05	0.00						0.00	0.00	0.00	0.00				
WRW #4 (°C) "WRW #20 (°C)"			0.00							0.02	0.01	0.00				
WRW #4 (°C) "WRW #21 (°C)"		0.03	0.00						0.00	0.00	0.00	0.00				
WRW #5 (°C) "WRW #7 (°C)"		0.02	0.00						0.00	0.00	0.00					
WRW #5 (°C) "WRW #8 (°C)"			0.00						0.01	0.00	0.00	0.00				
WRW #5 (°C) "WRW #9 (°C)"			0.00							0.01	0.01					
WRW #5 (°C) "WRW #10 (°C)"			0.03													
WRW #5 (°C) "WRW #16 (°C)"		0.00	0.00						0.00	0.00	0.00					
WRW #5 (°C) "WRW #17 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #6 (°C) "WRW #7 (°C)"											0.02					
WRW #6 (°C) "WRW #8 (°C)"			0.00								0.00					
WRW #6 (°C) "WRW #12 (°C)"												0.02				
WRW #6 (°C) "WRW #16 (°C)"			0.04						0.00		0.02					
WRW #6 (°C) "WRW #17 (°C)"		0.01	0.00						0.00	0.00	0.00	0.01				
WRW #7 (°C) "WRW #11 (°C)"		0.01	0.00							0.01	0.00	0.05				
WRW #7 (°C) "WRW #12 (°C)"		0.01	0.00							0.01	0.00	0.05				
WRW #7 (°C) "WRW #14 (°C)"		0.03	0.01								0.01					
WRW #7 (°C) "WRW #15 (°C)"			0.01						0.01	0.01						
WRW #7 (°C) "WRW #18 (°C)"			0.00							0.01	0.00	0.02				
WRW #7 (°C) "WRW #19 (°C)"			0.00						0.00	0.00	0.00	0.04				
WRW #7 (°C) "WRW #20 (°C)"			0.04							0.04						
WRW #7 (°C) "WRW #21 (°C)"			0.00						0.00	0.00	0.00	0.03				
WRW #8 (°C) "WRW #9 (°C)"			0.04													
WRW #8 (°C) "WRW #10 (°C)"			0.01													
WRW #8 (°C) "WRW #11 (°C)"	0.00		0.00				0.00			0.01	0.00	0.00				
WRW #8 (°C) "WRW #12 (°C)"	0.00		0.00				0.00			0.01	0.00	0.00				
WRW #8 (°C) "WRW #13 (°C)"			0.00								0.01					

Figure C2 (cont.). Results of site by site quarterly and monthly comparison using a Kruskal Wallis ANOVA with a post hoc analysis of mean daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown. (Part 2)

	Q1	Q2	Q3	Q4	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value
WRW #8 (°C) "WRW #14 (°C)"			0.00				0.00				0.00	0.00				0.03
WRW #8 (°C) "WRW #15 (°C)"			0.00							0.01	0.00	0.00				
WRW #8 (°C) "WRW #16 (°C)"	0.03						0.00									
WRW #8 (°C) "WRW #17 (°C)"	0.00						0.00									0.00
WRW #8 (°C) "WRW #18 (°C)"			0.00							0.01	0.00	0.00				
WRW #8 (°C) "WRW #19 (°C)"			0.00							0.00	0.00	0.00				
WRW #8 (°C) "WRW #20 (°C)"	0.00		0.00				0.00			0.04	0.00	0.00				0.03
WRW #8 (°C) "WRW #21 (°C)"			0.00						0.05	0.00	0.00	0.00				
WRW #9 (°C) "WRW #11 (°C)"	0.01		0.01				0.00									
WRW #9 (°C) "WRW #12 (°C)"	0.01		0.01				0.00									
WRW #9 (°C) "WRW #16 (°C)"							0.00									
WRW #9 (°C) "WRW #17 (°C)"	0.00		0.02				0.00		0.00							0.03
WRW #9 (°C) "WRW #18 (°C)"			0.00								0.01					
WRW #9 (°C) "WRW #19 (°C)"			0.00								0.01					
WRW #9 (°C) "WRW #20 (°C)"	0.02						0.00									
WRW #9 (°C) "WRW #21 (°C)"			0.00								0.01					
WRW #10 (°C) "WRW #17 (°C)"									0.00	0.01						
WRW #10 (°C) "WRW #17 (°C)"			0.00													
WRW #10 (°C) "WRW #18 (°C)"			0.00													
WRW #10 (°C) "WRW #19 (°C)"			0.01													
WRW #10 (°C) "WRW #21 (°C)"			0.01													
WRW #11 (°C) "WRW #15 (°C)"	0.00				0.00		0.00									
WRW #11 (°C) "WRW #16 (°C)"			0.00						0.01	0.01	0.00	0.01				
WRW #11 (°C) "WRW #17 (°C)"			0.00						0.00	0.00	0.00	0.00				
WRW #12 (°C) "WRW #15 (°C)"	0.00				0.00		0.00									
WRW #12 (°C) "WRW #16 (°C)"			0.00						0.01	0.01	0.00	0.01				
WRW #12 (°C) "WRW #17 (°C)"			0.00						0.00	0.00	0.00	0.00				
WRW #13 (°C) "WRW #17 (°C)"			0.00				0.01		0.00	0.01	0.02					
WRW #13 (°C) "WRW #18 (°C)"			0.02													
WRW #13 (°C) "WRW #21 (°C)"			0.03													
WRW #14 (°C) "WRW #15 (°C)"	0.01															
WRW #14 (°C) "WRW #16 (°C)"			0.00						0.02		0.01					
WRW #14 (°C) "WRW #17 (°C)"			0.00						0.00	0.00	0.00	0.00				
WRW #15 (°C) "WRW #16 (°C)"	0.00		0.00		0.03		0.00		0.00	0.01						
WRW #15 (°C) "WRW #17 (°C)"	0.00	0.00	0.00	0.02	0.00		0.00	0.02	0.00	0.00	0.01	0.00	0.04		0.03	0.01
WRW #15 (°C) "WRW #20 (°C)"	0.00				0.00		0.00									
WRW #15 (°C) "WRW #21 (°C)"	0.05				0.04											
WRW #16 (°C) "WRW #18 (°C)"			0.00						0.00	0.01	0.00	0.00				
WRW #16 (°C) "WRW #19 (°C)"			0.00						0.00	0.00	0.00	0.01				
WRW #16 (°C) "WRW #20 (°C)"			0.01						0.02							
WRW #16 (°C) "WRW #21 (°C)"		0.05	0.00						0.00	0.00	0.00	0.01				
WRW #17 (°C) "WRW #18 (°C)"		0.00	0.00				0.00		0.00	0.00	0.00	0.00				
WRW #17 (°C) "WRW #19 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #17 (°C) "WRW #20 (°C)"		0.02	0.00						0.00	0.00		0.00				
WRW #17 (°C) "WRW #21 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #19 (°C) "WRW #20 (°C)"											0.00					

Figure C2 (cont.). Results of site by site quarterly and monthly comparison using a Kruskal Wallis ANOVA with a post hoc analysis of mean daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown. (Part 3)

SITE COMPARISON	Q1	Q2	Q3	Q4	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value
WRW #1 (°C) "WRW #2 (°C)"																0.01
WRW #1 (°C) "WRW #3 (°C)"	0.03						0.00									0.00
WRW #1 (°C) "WRW #4 (°C)"	0.00		0.00	0.01	0.00		0.00				0.00					0.00
WRW #1 (°C) "WRW #5 (°C)"		0.00	0.00	0.04	0.00				0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #6 (°C)"		0.00	0.00		0.03				0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #7 (°C)"			0.00		0.02					0.04	0.00	0.00	0.01			
WRW #1 (°C) "WRW #8 (°C)"			0.00													
WRW #1 (°C) "WRW #9 (°C)"		0.01	0.00						0.01	0.00	0.00	0.00	0.00			
WRW #1 (°C) "WRW #10 (°C)"	0.03	0.00	0.00		0.00				0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #11 (°C)"	0.01	0.00	0.00		0.00				0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #12 (°C)"	0.01	0.00	0.00		0.00				0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #13 (°C)"		0.01	0.00		0.00				0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #14 (°C)"	0.00	0.00	0.00		0.00				0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #15 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #1 (°C) "WRW #16 (°C)"	0.00		0.00		0.00		0.04				0.00	0.00				0.00
WRW #1 (°C) "WRW #17 (°C)"	0.00		0.00	0.00	0.00		0.00			0.00						0.00
WRW #1 (°C) "WRW #18 (°C)"		0.00	0.00		0.01				0.00		0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #19 (°C)"	0.01	0.00	0.00		0.00				0.00	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #20 (°C)"	0.00		0.00		0.00		0.00			0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #21 (°C)"	0.00	0.00	0.00		0.00				0.00	0.00	0.00	0.00	0.00		0.04	0.00
WRW #2 (°C) "WRW #4 (°C)"			0.00								0.00					
WRW #2 (°C) "WRW #5 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #6 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #7 (°C)"			0.00								0.00	0.00	0.00			
WRW #2 (°C) "WRW #8 (°C)"			0.03													
WRW #2 (°C) "WRW #9 (°C)"		0.05	0.00						0.01	0.04	0.00	0.00	0.00			
WRW #2 (°C) "WRW #10 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #11 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #12 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #13 (°C)"		0.02	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #14 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #15 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #16 (°C)"			0.00								0.00	0.00	0.03			
WRW #2 (°C) "WRW #17 (°C)"			0.03													
WRW #2 (°C) "WRW #18 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #19 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #20 (°C)"			0.00		0.04					0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #21 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #3 (°C) "WRW #5 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.01			
WRW #3 (°C) "WRW #6 (°C)"		0.02	0.00						0.00	0.00	0.00	0.00				
WRW #3 (°C) "WRW #7 (°C)"			0.00													
WRW #3 (°C) "WRW #9 (°C)"			0.00									0.03				
WRW #3 (°C) "WRW #10 (°C)"			0.00									0.02				
WRW #3 (°C) "WRW #11 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #3 (°C) "WRW #12 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #3 (°C) "WRW #13 (°C)"			0.00								0.00	0.00				

Figure C3. Results of site by site quarterly and monthly comparison using a Kruskal Wallis ANOVA with a post hoc analysis of maximum daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown. (Part 1)

SITE COMPARISON	Q1	Q2	Q3	Q4	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value
WRW #3 (°C) "WRW #14 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.02			
WRW #3 (°C) "WRW #15 (°C)"		0.02	0.00						0.00	0.01	0.01	0.00	0.00			
WRW #3 (°C) "WRW #16 (°C)"			0.00													
WRW #3 (°C) "WRW #18 (°C)"			0.00							0.01	0.00	0.00	0.02			
WRW #3 (°C) "WRW #19 (°C)"		0.03	0.00						0.01	0.00	0.00	0.00				
WRW #3 (°C) "WRW #20 (°C)"			0.00									0.03				
WRW #3 (°C) "WRW #21 (°C)"		0.03	0.00						0.01	0.00	0.00	0.00	0.03			
WRW #4 (°C) "WRW #5 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #4 (°C) "WRW #6 (°C)"		0.02	0.00						0.00							
WRW #4 (°C) "WRW #8 (°C)"							0.02									0.03
WRW #4 (°C) "WRW #10 (°C)"									0.04							
WRW #4 (°C) "WRW #11 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #4 (°C) "WRW #12 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #4 (°C) "WRW #13 (°C)"			0.04													
WRW #4 (°C) "WRW #14 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #4 (°C) "WRW #15 (°C)"	0.03	0.02	0.00				0.04		0.00				0.01			
WRW #4 (°C) "WRW #18 (°C)"			0.00								0.03	0.00				
WRW #4 (°C) "WRW #19 (°C)"		0.04	0.00						0.00	0.02	0.00	0.00				
WRW #4 (°C) "WRW #21 (°C)"		0.03	0.00						0.00	0.03	0.00	0.00				
WRW #5 (°C) "WRW #7 (°C)"		0.02	0.00						0.00	0.00	0.00	0.04				
WRW #5 (°C) "WRW #8 (°C)"		0.02	0.00						0.00	0.00	0.00	0.00				0.02
WRW #5 (°C) "WRW #9 (°C)"			0.00							0.00	0.00					
WRW #5 (°C) "WRW #10 (°C)"			0.00								0.00					
WRW #5 (°C) "WRW #13 (°C)"			0.01								0.01					
WRW #5 (°C) "WRW #15 (°C)"											0.00					
WRW #5 (°C) "WRW #16 (°C)"		0.00	0.00						0.00	0.00	0.00	0.01				
WRW #5 (°C) "WRW #17 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #5 (°C) "WRW #20 (°C)"			0.00						0.01		0.00					
WRW #6 (°C) "WRW #8 (°C)"			0.00								0.00	0.01				
WRW #6 (°C) "WRW #11 (°C)"			0.00									0.00				
WRW #6 (°C) "WRW #12 (°C)"			0.00									0.00				
WRW #6 (°C) "WRW #16 (°C)"									0.02	0.02						
WRW #6 (°C) "WRW #17 (°C)"		0.00	0.00						0.00	0.00	0.00					
WRW #7 (°C) "WRW #8 (°C)"			0.02													
WRW #7 (°C) "WRW #11 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #7 (°C) "WRW #12 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #7 (°C) "WRW #14 (°C)"			0.00								0.00					
WRW #7 (°C) "WRW #17 (°C)"			0.02													
WRW #7 (°C) "WRW #18 (°C)"			0.00								0.04					
WRW #7 (°C) "WRW #19 (°C)"			0.00								0.00					
WRW #7 (°C) "WRW #21 (°C)"			0.00								0.00					
WRW #8 (°C) "WRW #9 (°C)"			0.00													
WRW #8 (°C) "WRW #10 (°C)"			0.00													
WRW #8 (°C) "WRW #11 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.02			
WRW #8 (°C) "WRW #12 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.02			
WRW #8 (°C) "WRW #13 (°C)"			0.00								0.00	0.00				
WRW #8 (°C) "WRW #14 (°C)"			0.00							0.00	0.00	0.00				0.05
WRW #8 (°C) "WRW #15 (°C)"			0.00								0.02	0.00	0.05			

Figure C3 (cont.). Results of site by site quarterly and monthly comparison using a Kruskal Wallis ANOVA with a post hoc analysis of maximum daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown. (Part 2)

SITE COMPARISON	Q1	Q2	Q3	Q4	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value
WRW #8 (°C) "WRW #16 (°C)"			0.04													
WRW #8 (°C) "WRW #17 (°C)"																0.00
WRW #8 (°C) "WRW #18 (°C)"			0.00								0.00	0.00				
WRW #8 (°C) "WRW #19 (°C)"			0.00							0.03	0.00	0.00				
WRW #8 (°C) "WRW #20 (°C)"	0.01		0.00				0.00									0.05
WRW #8 (°C) "WRW #21 (°C)"			0.00							0.03	0.00	0.00				
WRW #9 (°C) "WRW #11 (°C)"			0.00						0.05	0.00	0.00	0.00				
WRW #9 (°C) "WRW #12 (°C)"			0.00						0.05	0.00	0.00	0.00				
WRW #9 (°C) "WRW #14 (°C)"			0.00								0.00					
WRW #9 (°C) "WRW #17 (°C)"			0.00						0.01							
WRW #9 (°C) "WRW #18 (°C)"			0.01													
WRW #9 (°C) "WRW #19 (°C)"			0.01													
WRW #9 (°C) "WRW #20 (°C)"							0.03				0.01					
WRW #9 (°C) "WRW #21 (°C)"			0.00								0.01					
WRW #10 (°C) "WRW #11 (°C)"			0.00								0.00	0.00				
WRW #10 (°C) "WRW #12 (°C)"			0.00								0.00	0.00				
WRW #10 (°C) "WRW #14 (°C)"			0.00								0.01					
WRW #10 (°C) "WRW #17 (°C)"		0.01	0.00						0.00	0.00						
WRW #10 (°C) "WRW #19 (°C)"			0.04													
WRW #10 (°C) "WRW #21 (°C)"			0.02													
WRW #11 (°C) "WRW #13 (°C)"			0.00								0.00	0.00				
WRW #11 (°C) "WRW #15 (°C)"			0.00		0.04						0.00	0.03				
WRW #11 (°C) "WRW #16 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #11 (°C) "WRW #17 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #11 (°C) "WRW #20 (°C)"		0.02	0.00						0.00		0.00	0.00				
WRW #12 (°C) "WRW #13 (°C)"			0.00								0.00	0.00				
WRW #12 (°C) "WRW #15 (°C)"			0.00		0.04						0.00	0.03				
WRW #12 (°C) "WRW #16 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #12 (°C) "WRW #17 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00	0.00		
WRW #12 (°C) "WRW #20 (°C)"		0.02	0.00						0.00	0.00	0.00	0.00				
WRW #13 (°C) "WRW #17 (°C)"			0.00						0.00	0.00	0.00	0.01				
WRW #14 (°C) "WRW #15 (°C)"											0.05					
WRW #14 (°C) "WRW #16 (°C)"			0.00						0.00	0.00	0.00	0.04				
WRW #14 (°C) "WRW #17 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.01			
WRW #14 (°C) "WRW #20 (°C)"			0.01								0.00					
WRW #15 (°C) "WRW #16 (°C)"									0.00							
WRW #15 (°C) "WRW #17 (°C)"	0.03	0.00	0.00						0.00	0.00	0.04	0.00	0.00			0.02
WRW #15 (°C) "WRW #20 (°C)"	0.01						0.00									
WRW #16 (°C) "WRW #17 (°C)"			0.04													
WRW #16 (°C) "WRW #18 (°C)"			0.00							0.05	0.05					
WRW #16 (°C) "WRW #19 (°C)"			0.00						0.03	0.01	0.00					
WRW #16 (°C) "WRW #21 (°C)"			0.00						0.02	0.01	0.00					
WRW #17 (°C) "WRW #18 (°C)"		0.01	0.00						0.00	0.00	0.00	0.00	0.01			
WRW #17 (°C) "WRW #19 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00				
WRW #17 (°C) "WRW #20 (°C)"			0.00							0.01						
WRW #17 (°C) "WRW #21 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.02			
WRW #19 (°C) "WRW #20 (°C)"											0.02					
WRW #20 (°C) "WRW #21 (°C)"			0.04								0.02					

Figure C3 (cont.). Results of site by site quarterly and monthly comparison using a Kruskal Wallis ANOVA with a post hoc analysis of maximum daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown. (Part 3)

	Q1	Q2	Q3	Q4	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value
WRW #1 (°C) "WRW #2 (°C)"																0.02
WRW #1 (°C) "WRW #3 (°C)"	0.01		0.00													0.00
WRW #1 (°C) "WRW #4 (°C)"	0.00		0.00	0.00	0.00		0.00	0.01			0.04				0.05	0.00
WRW #1 (°C) "WRW #5 (°C)"	0.00	0.00	0.00	0.00	0.00		0.00		0.00	0.00	0.00	0.00	0.00		0.00	0.00
WRW #1 (°C) "WRW #6 (°C)"	0.00		0.00		0.01		0.00			0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #7 (°C)"	0.00		0.00		0.00		0.00				0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #8 (°C)"			0.00		0.02						0.00	0.00	0.00			
WRW #1 (°C) "WRW #9 (°C)"	0.04		0.00							0.00	0.00	0.00	0.00			
WRW #1 (°C) "WRW #10 (°C)"	0.00		0.00	0.00	0.00		0.00			0.00	0.00	0.00	0.00		0.02	0.00
WRW #1 (°C) "WRW #11 (°C)"	0.00		0.00	0.00	0.00		0.00	0.00		0.00	0.00	0.00	0.00		0.00	0.00
WRW #1 (°C) "WRW #12 (°C)"	0.00		0.00	0.00	0.00		0.00	0.00		0.00	0.00	0.00	0.00		0.00	0.00
WRW #1 (°C) "WRW #13 (°C)"	0.00		0.00	0.05	0.00		0.01			0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #14 (°C)"	0.00		0.00	0.00	0.00		0.00			0.00	0.00	0.00	0.00		0.02	0.00
WRW #1 (°C) "WRW #15 (°C)"		0.02	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #1 (°C) "WRW #16 (°C)"	0.00		0.00	0.00	0.00		0.00	0.02		0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #17 (°C)"	0.00		0.00	0.00	0.00		0.00	0.00		0.00	0.00	0.00	0.00		0.00	0.00
WRW #1 (°C) "WRW #18 (°C)"	0.00		0.00		0.01		0.00		0.03	0.00	0.00	0.00	0.00			0.00
WRW #1 (°C) "WRW #19 (°C)"	0.00		0.00	0.01	0.00		0.00		0.00	0.00	0.00	0.00	0.00		0.02	0.00
WRW #1 (°C) "WRW #20 (°C)"	0.00		0.00	0.00	0.00		0.00		0.00		0.00	0.00	0.00		0.00	0.00
WRW #1 (°C) "WRW #21 (°C)"	0.00	0.03	0.00	0.00	0.00		0.00		0.00		0.00	0.00	0.00		0.01	0.00
WRW #2 (°C) "WRW #4 (°C)"	0.00		0.02		0.00											
WRW #2 (°C) "WRW #5 (°C)"		0.00	0.00						0.00	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #6 (°C)"			0.00							0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #7 (°C)"			0.00		0.00						0.02	0.00	0.01			
WRW #2 (°C) "WRW #8 (°C)"			0.00										0.05			
WRW #2 (°C) "WRW #9 (°C)"			0.00										0.00			
WRW #2 (°C) "WRW #10 (°C)"			0.00		0.01						0.00	0.00	0.01			
WRW #2 (°C) "WRW #11 (°C)"	0.00		0.00		0.00		0.00				0.00	0.00	0.02			
WRW #2 (°C) "WRW #12 (°C)"	0.00		0.00		0.00		0.00				0.00	0.00	0.02			
WRW #2 (°C) "WRW #13 (°C)"			0.00		0.00						0.00	0.00	0.04			
WRW #2 (°C) "WRW #14 (°C)"	0.01		0.00								0.00	0.00	0.00			
WRW #2 (°C) "WRW #15 (°C)"			0.00						0.01	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #16 (°C)"	0.00		0.00		0.00						0.00	0.00	0.01			
WRW #2 (°C) "WRW #17 (°C)"	0.00		0.00		0.02		0.00				0.04					
WRW #2 (°C) "WRW #18 (°C)"			0.00							0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #19 (°C)"			0.00		0.00				0.01	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #20 (°C)"	0.00		0.00		0.00				0.01	0.00	0.00	0.00	0.00			
WRW #2 (°C) "WRW #21 (°C)"	0.01		0.00		0.00				0.00	0.00	0.00	0.00	0.00			
WRW #3 (°C) "WRW #4 (°C)"					0.00											
WRW #3 (°C) "WRW #5 (°C)"			0.00							0.00	0.00	0.00	0.02			
WRW #3 (°C) "WRW #6 (°C)"			0.00								0.00	0.00				
WRW #3 (°C) "WRW #7 (°C)"			0.00													
WRW #3 (°C) "WRW #9 (°C)"			0.00													
WRW #3 (°C) "WRW #10 (°C)"			0.00								0.01	0.04				
WRW #3 (°C) "WRW #11 (°C)"	0.00		0.00		0.00		0.00				0.00	0.01				

Figure C4. Results of site by site quarterly and monthly comparison using a Kruskal Wallis ANOVA with a post hoc analysis of minimum daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown. (Part 1)

	Q1	Q2	Q3	Q4	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value
WRW #3 (°C) "WRW #12 (°C)"	0.00		0.00		0.00		0.00				0.00	0.01				
WRW #3 (°C) "WRW #13 (°C)"			0.00								0.00					
WRW #3 (°C) "WRW #14 (°C)"			0.00								0.00	0.02				
WRW #3 (°C) "WRW #15 (°C)"			0.00								0.00	0.00	0.00			
WRW #3 (°C) "WRW #16 (°C)"			0.00		0.01		0.04									
WRW #3 (°C) "WRW #17 (°C)"	0.00						0.00									
WRW #3 (°C) "WRW #18 (°C)"			0.00								0.00	0.00				
WRW #3 (°C) "WRW #19 (°C)"			0.00							0.03	0.00	0.00				
WRW #3 (°C) "WRW #20 (°C)"	0.04		0.00		0.00					0.02	0.00	0.00	0.03			
WRW #3 (°C) "WRW #21 (°C)"			0.00							0.02	0.00	0.00				
WRW #4 (°C) "WRW #5 (°C)"		0.01	0.00						0.01	0.00	0.00	0.00	0.02			
WRW #4 (°C) "WRW #6 (°C)"			0.00								0.00	0.00				
WRW #4 (°C) "WRW #8 (°C)"	0.00						0.00									
WRW #4 (°C) "WRW #9 (°C)"	0.02		0.01		0.05		0.01									
WRW #4 (°C) "WRW #10 (°C)"			0.00													
WRW #4 (°C) "WRW #11 (°C)"			0.00								0.03					
WRW #4 (°C) "WRW #12 (°C)"			0.00								0.03					
WRW #4 (°C) "WRW #13 (°C)"			0.00													
WRW #4 (°C) "WRW #14 (°C)"			0.00													
WRW #4 (°C) "WRW #15 (°C)"	0.00		0.00		0.00		0.03			0.00	0.01	0.00	0.00			
WRW #4 (°C) "WRW #16 (°C)"			0.04													
WRW #4 (°C) "WRW #18 (°C)"			0.00							0.01	0.00	0.00				
WRW #4 (°C) "WRW #19 (°C)"			0.00							0.00	0.00	0.00				
WRW #4 (°C) "WRW #20 (°C)"			0.00							0.00	0.00	0.00	0.02			
WRW #4 (°C) "WRW #21 (°C)"			0.00						0.04	0.00	0.00	0.00				
WRW #5 (°C) "WRW #7 (°C)"		0.05	0.01						0.01	0.00	0.04					
WRW #5 (°C) "WRW #8 (°C)"			0.00							0.00	0.00					
WRW #5 (°C) "WRW #11 (°C)"							0.00									
WRW #5 (°C) "WRW #12 (°C)"							0.00									
WRW #5 (°C) "WRW #15 (°C)"															0.04	
WRW #5 (°C) "WRW #16 (°C)"		0.03	0.04						0.00	0.00						
WRW #5 (°C) "WRW #17 (°C)"		0.00	0.00					0.00	0.00	0.00	0.02					
WRW #6 (°C) "WRW #7 (°C)"											0.04					
WRW #6 (°C) "WRW #8 (°C)"			0.00								0.00					
WRW #6 (°C) "WRW #11 (°C)"	0.04				0.05											
WRW #6 (°C) "WRW #12 (°C)"	0.04				0.05											
WRW #6 (°C) "WRW #17 (°C)"			0.00						0.03	0.03	0.02	0.04				
WRW #7 (°C) "WRW #15 (°C)"	0.03		0.01		0.04					0.00						
WRW #7 (°C) "WRW #18 (°C)"			0.00							0.00	0.00					
WRW #7 (°C) "WRW #19 (°C)"			0.00							0.00	0.00					
WRW #7 (°C) "WRW #20 (°C)"			0.00							0.00	0.00					
WRW #7 (°C) "WRW #21 (°C)"			0.00						0.03	0.00	0.00					
WRW #8 (°C) "WRW #11 (°C)"	0.00			0.02	0.03		0.00	0.00							0.05	0.01
WRW #8 (°C) "WRW #12 (°C)"	0.00			0.02	0.03		0.00	0.00							0.05	0.01
WRW #8 (°C) "WRW #14 (°C)"	0.05						0.00									0.05

Figure C4 (cont.). Results of site by site quarterly and monthly comparison using a Kruskal Wallis ANOVA with a post hoc analysis of minimum daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown. (Part 2)

	Q1	Q2	Q3	Q4	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value	p-value
WRW #8 (°C) "WRW #15 (°C)"			0.00									0.04				
WRW #8 (°C) "WRW #16 (°C)"	0.00						0.00									
WRW #8 (°C) "WRW #17 (°C)"	0.00			0.03			0.00	0.00								0.00
WRW #8 (°C) "WRW #18 (°C)"			0.00								0.00	0.00				
WRW #8 (°C) "WRW #19 (°C)"			0.00							0.01	0.00	0.00				
WRW #8 (°C) "WRW #20 (°C)"	0.00		0.00		0.04		0.00			0.00	0.00	0.00				0.02
WRW #8 (°C) "WRW #21 (°C)"			0.00				0.05			0.00	0.00	0.00				
WRW #9 (°C) "WRW #11 (°C)"	0.00				0.01		0.00	0.02								
WRW #9 (°C) "WRW #12 (°C)"	0.00				0.01		0.00	0.02								
WRW #9 (°C) "WRW #16 (°C)"	0.02						0.00									
WRW #9 (°C) "WRW #17 (°C)"	0.00						0.00	0.00								0.03
WRW #9 (°C) "WRW #18 (°C)"			0.00													
WRW #9 (°C) "WRW #19 (°C)"			0.01													
WRW #9 (°C) "WRW #20 (°C)"	0.01		0.00		0.01											
WRW #9 (°C) "WRW #21 (°C)"			0.00													
WRW #10 (°C) "WRW #18 (°C)"			0.01													
WRW #10 (°C) "WRW #19 (°C)"			0.02													
WRW #10 (°C) "WRW #20 (°C)"			0.01													
WRW #10 (°C) "WRW #21 (°C)"			0.01													
WRW #11 (°C) "WRW #13 (°C)"							0.05									
WRW #11 (°C) "WRW #15 (°C)"	0.00			0.00	0.00		0.00	0.00							0.00	
WRW #11 (°C) "WRW #18 (°C)"	0.02							0.01								
WRW #12 (°C) "WRW #13 (°C)"							0.05									
WRW #12 (°C) "WRW #15 (°C)"	0.00			0.00	0.00		0.00	0.00							0.00	
WRW #12 (°C) "WRW #18 (°C)"	0.02							0.01								
WRW #13 (°C) "WRW #17 (°C)"							0.01									
WRW #13 (°C) "WRW #18 (°C)"			0.00													
WRW #13 (°C) "WRW #19 (°C)"			0.01													
WRW #13 (°C) "WRW #20 (°C)"			0.00													
WRW #13 (°C) "WRW #21 (°C)"			0.00													
WRW #14 (°C) "WRW #15 (°C)"	0.00															
WRW #15 (°C) "WRW #16 (°C)"	0.00		0.04		0.00		0.01		0.03							
WRW #15 (°C) "WRW #17 (°C)"	0.00	0.01	0.00	0.01	0.04		0.00	0.00	0.00	0.00		0.02			0.00	0.02
WRW #15 (°C) "WRW #19 (°C)"	0.02								0.02							
WRW #15 (°C) "WRW #20 (°C)"	0.00				0.00				0.03							
WRW #15 (°C) "WRW #21 (°C)"	0.00				0.01											
WRW #16 (°C) "WRW #18 (°C)"			0.00								0.03					
WRW #16 (°C) "WRW #19 (°C)"			0.00							0.03	0.03					
WRW #16 (°C) "WRW #20 (°C)"			0.00							0.02	0.04					
WRW #16 (°C) "WRW #21 (°C)"			0.00					0.00	0.01	0.01						
WRW #17 (°C) "WRW #18 (°C)"		0.03	0.00						0.01	0.00	0.00	0.00				
WRW #17 (°C) "WRW #19 (°C)"		0.02	0.00						0.00	0.00	0.00	0.00				
WRW #17 (°C) "WRW #20 (°C)"		0.03	0.00						0.00	0.00	0.00	0.00				
WRW #17 (°C) "WRW #21 (°C)"		0.01	0.00						0.00	0.00	0.00	0.00				
WRW #8 (°C) "WRW #14 (°C)"	0.05						0.00									0.05

Figure C4 (cont.). Results of site by site quarterly and monthly comparison using a Kruskal Wallis ANOVA with a post hoc analysis of minimum daily Tw collected at twenty-one sites located in West Run Watershed, West Virginia, USA. Only significant ($\alpha=0.05$) p-value are shown. (Part 3)

APPENDIX D MONTHLY PCA FIGURES

Figure D1. Results of principle component analysis, showing biplots of extracted principle components of mean monthly water temperature data collected during the 2018 annual year at the 22 monitoring sites of West Run Watershed, WV, USA; and their corresponding LULC area (km²)

Figure D2. Results of principle component analysis, showing biplots of extracted principle components of maximum monthly water temperature data collected during the 2018 annual year at the 22 monitoring sites of West Run Watershed, WV, USA; and their corresponding LULC area (km²)

Figure D3. Results of principle component analysis, showing biplots of extracted principle components of minimum monthly water temperature data collected during the 2018 annual year at the 22 monitoring sites of West Run Watershed, WV, USA; and their corresponding LULC area (km²)

APPENDIX E

TW – LULC SPEARMAN’S CORRELATIONS (MEAN, MINIMUM, STANDARD DEVIATION)

Further analysis into the Tw-LULC relationship was conducted using a Spearman’s correlations between mean, minimum, and standard deviation of Tw but not included in the published work (Horne and Hubbart, 2020). Correlations between LULC and Tw were done at the annual, quarterly, and monthly time scale mirroring the published research. The open water LULC type was excluded from analyses due to its negligible areal coverage relative to other land use types. Three separate analyses were run using all sites, only tributaries (i.e., sites 1, 2, 5, 7, 8, 9, 11, 12, 14, 15, 16, 17, 20) , and only mainstem sites (i.e., sites 3, 4, 6, 10, 13, 18, 21) looking for varying effects of surrounding LULCs on tributaries vs. mainstem sites. Correlations at the annual timescale showed no significant ($\alpha=0.05$) correlation to mean, minimum or standard deviation of Tw.

Table E1. Spearman correlations between LULC types and mean, minimum, and standard deviation of Tw at all 21 sites, mainstem, and tributaries of West Run Watershed, West Virginia, USA; during the 2018 annual year. Positive correlations indicate an increase in Tw with increasing LULC and negative correlations indicate a decrease in Tw with increasing LULC. Bold values are significant correlations at $\alpha=0.05$.

All Sites																
Mean Correlation	Q 1	Q 2	Q 3	Q 4	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	0.1	0.4	0.3	0.2	0.0	0.1	0.3	0.4	0.5	0.4	0.2	0.3	0.4	0.3	0.1	0.1
Agriculture	0.1	0.1	0.2	0.1	0.0	0.2	0.2	0.2	0.0	0.1	0.2	0.2	0.0	0.0	0.1	0.2
Forested	-0.1	-0.4	-0.4	-0.2	0.1	-0.1	-0.2	-0.4	-0.3	-0.4	-0.3	-0.5	-0.5	-0.3	-0.1	-0.1
Min Correlation	Q 1	Q 2	Q 3	Q 4	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	-0.1	0.1	0.2	0.0	0.1	0.0	-0.1	-0.1	-0.4	-0.4	-0.3	-0.1	-0.2	-0.1	-0.1	0.0
Agriculture	0.1	0.1	-0.1	0.1	0.0	-0.1	-0.1	-0.1	-0.1	0.1	-0.1	0.0	0.1	0.0	-0.1	-0.1
Forested	0.1	-0.1	-0.3	0.1	-0.2	0.0	0.0	0.1	0.4	0.3	0.5	0.2	0.3	0.1	0.0	-0.1
SD Correlation	Q 1	Q 2	Q 3	Q 4	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	0.2	0.2	0.0	0.2	0.4	0.2	-0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.3
Agriculture	0.2	0.1	0.5	0.0	-0.2	0.3	0.2	0.1	0.2	0.2	0.3	0.2	0.5	0.0	0.0	-0.2
Forested	-0.3	-0.2	-0.2	-0.2	-0.3	-0.2	-0.2	-0.1	-0.1	-0.1	0.0	-0.2	-0.3	-0.2	-0.1	-0.3
Mainstem																

Mean Correlation	Q 1	Q 2	Q 3	Q 4	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	-0.6	0.7	0.7	-0.2	-0.6	-0.6	-0.2	0.6	0.6	0.6	0.7	0.7	0.6	0.5	-0.5	-0.7
Agriculture	0.1	0.6	0.7	0.5	0.0	0.1	0.6	0.7	0.4	0.5	0.7	0.7	0.6	0.6	0.3	0.0
Forested	0.3	-0.8	-0.7	0.0	0.4	0.3	0.0	-0.6	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	0.2	0.5
Min Correlation	Q 1	Q 2	Q 3	Q 4	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	-0.5	-0.7	0.4	-0.8	-0.5	-0.5	-0.5	-0.7	0.5	0.5	0.6	0.6	0.4	0.0	-0.8	-0.8
Agriculture	-0.1	-0.1	0.5	-0.4	-0.1	0.1	0.3	-0.1	0.6	0.4	0.7	0.4	0.5	0.5	-0.2	-0.4
Forested	0.4	0.4	-0.4	0.7	0.4	0.3	0.2	0.4	-0.5	-0.5	-0.6	-0.7	-0.4	-0.1	0.6	0.7
SD Correlation	Q 1	Q 2	Q 3	Q 4	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	0.7	0.6	0.8	0.7	0.6	0.8	0.5	0.7	0.1	0.3	0.7	0.9	0.7	0.7	0.7	0.8
Agriculture	0.5	0.3	0.6	0.5	0.0	0.6	0.2	0.5	0.3	0.3	0.2	0.7	0.5	0.5	0.6	0.6
Forested	-0.8	-0.7	-0.8	-0.8	-0.3	-0.8	-0.5	-0.8	-0.3	-0.5	-0.5	-0.9	-0.7	-0.7	-0.8	-0.8

Tributaries

Mean Correlation	Q 1	Q 2	Q 3	Q 4	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	0.3	0.5	0.3	0.4	0.0	0.0	0.3	0.4	0.6	0.5	0.4	0.5	0.6	0.7	0.2	0.1
Agriculture	0.3	0.0	0.1	0.2	-0.2	-0.1	-0.1	0.1	0.3	0.3	0.6	0.5	0.3	0.4	0.0	-0.1
Forested	-0.2	-0.4	-0.3	-0.2	-0.2	-0.3	-0.2	0.0	0.0	0.2	0.4	0.3	0.1	0.3	-0.2	-0.3
Min Correlation	Q 1	Q 2	Q 3	Q 4	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	0.1	0.3	0.2	0.2	0.0	0.0	-0.1	-0.1	-0.3	-0.4	-0.6	0.0	-0.4	-0.1	-0.1	0.0
Agriculture	0.1	0.1	-0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.0	-0.3	-0.1	0.0	0.1	0.1	0.1
Forested	0.1	-0.2	-0.2	-0.1	0.0	0.3	0.2	0.3	0.3	0.1	-0.2	-0.3	0.0	0.1	0.3	0.2
SD Correlation	Q 1	Q 2	Q 3	Q 4	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Mixed Development	0.1	0.1	-0.1	0.1	0.2	0.0	-0.1	0.1	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.2
Agriculture	0.1	-0.1	0.5	-0.2	-0.1	0.4	0.3	0.4	0.5	0.6	0.7	0.4	0.8	0.1	0.4	0.2
Forested	-0.1	-0.2	-0.1	-0.2	-0.3	0.2	0.1	0.4	0.4	0.4	0.2	0.0	0.4	0.1	0.4	0.2

Isolated mainstem at West Run Creek sites at the quarterly timescale showed eleven significant ($p=0.05$) correlations, whereas the all sites analysis showed one significant ($p=0.05$) correlations, and isolated tributaries showed no significant. For example, Tw standard deviation showed a significant positive correlation to mixed development during three of the four quarters when isolating mainstem sites, whereas there were no significance correlations returned from the all sites analysis at $\alpha=0.05$. The main forested monitoring sites analysis had the most significant

spearman correlations. For example, during quarter 1 (January 1st – March 31st) both mixed development and forested LULC types showed significant ($p=0.05$) spearman correlations to Tw standard deviation, whereas in the all sites neither were significant at $\alpha=0.05$. During the second quarter mean Tw showed significant ($p=0.05$) correlations to both forested and mixed development LULC types, and mixed development showed significant ($p=0.05$) negative correlations to minimum Tw. In quarter 3 Forested LULC types and mean Tw showed a significant negative correlation, and both mixed development and forested LULC types showed significance ($p=0.01$) to Tw standard deviation. During quarter 4 (October 1st – December 31st) mixed development LULC types showed a significant ($p=0.02$) negative correlation to minimum Tw and mixed development LULC types showed significant ($p=0.04$) correlations to Tw standard deviation.

LULC and Tw analysis at the monthly timescale using all sites showed six significant ($\alpha=0.05$) correlations to Tw variables. LULC and Tw analysis using only mainstem sites showed twenty significant ($\alpha=0.05$) correlations to Tw variables. LULC and Tw analysis using only tributaries sites showed eight significant ($\alpha=0.05$) correlations to Tw variables. Some significant monthly correlation included positive correlations between mixed development and mean Tw for all sites in months April through October. Which then switched to a negative correlation in the months November through March. Mixed development also showed a positive correlation with the standard deviation of Tw through the year for mainstem sites with the highest spearman's correlation in August. Forested LULC types also showed a negative correlation to Tw standard deviation throughout the year with the highest spearman's correlation in August.