TEMPERATURE AND RELATIVE HUMIDITY GRADIENTS OF INTERMITTENT AND PERENNIAL TRIBUTARIES IN NORTHERN CALIFORNIA

A Thesis

Presented

to the Faculty of

California State University, Chico

In Partial Fulfillment

of the Requirement for the Degree

Master of Science

in

Geosciences

Hydrology/Hydrogeology Option

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by

Eric Hillman Tharsing Willard

Summer 2009

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ABSTRACT

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Perennial and intermittent tributary streams are extensive components of the stream networks across landscapes. Riparian zones surrounding streams are important components of the bio-scape. Four tributary streams (Two perennial and Two intermittent) were sampled, in the Southern Cascade region of California using methods developed to infer effects of harvesting on microclimatic gradients from stream to upland. These methods were modified to observe the effects of flow on temperature and relative humidity gradients. The objectives of this study are: (1) to characterize flow of perennial and intermittent tributary streams of Big Chico Creek using temperature and stage methods; (2) identify differences in temperature and relative humidity at intermittent and perennial sites during different flow conditions; (3) describe effects of perennial and intermittent stream classes on temperature and relative humidity gradients and (4) compare changes in gradients from stream to upland between stream classes. Five temperature and relative humidity loggers were installed along transects running from stream to upland positions at each stream. Linear regressions of relative changes along transects were used to quantify gradients. One and two-way ANOVA were used to determine statistical differences in gradients and relative changes along transects respectively. This was done between stream classes, transects, and transects and Stations for appropriate time periods. Results point to distinct temperature and relative humidity gradients for perennial and intermittent streams (0.0195 and 0.0102 C/m), during daytime dry conditions, while the intermittent stream is dry and the perennial is still flowing. For the same time period significant differences exist between stream Stations and all other Stations (7.5m to 45m) along the perennial transect, while intermittent statistical differences don't exist until near upland Stations (30m to 60m). The study indicates that perennial and intermittent streams have distinctive temperature and relative humidity conditions above the stream during the peak daytime, when the intermittent ceases to flow and the perennial continues to flow. Additional site specific data are needed for various site conditions in order to determine if generalizations can be made about these stream classes.

CHAPTER I

INTRODUCTION

Water is one part of the climatic equation, it acts as a balance or feedback mechanism, which inhibits or enables changes in relative humidity and temperature near the ground surface (Geiger, 1965; Oke, 1987; Webb and Zhang, 1997; Brosofske et al., 1997; Danehy and Kirpes, 2000; Olson et al., 2007). Intermittent streams are defined as streams whose channels contain flowing surface water for a fraction of the year. Contrarily, a perennial stream flows all year long. Much of the research done on forestry and riparian zones has been conducted on larger and higher order streams (Moore et al., 2005). This study focuses on small headwater tributary streams which have a narrow zone of riparian vegetation (Hagan et al., 2006). The ability of an environment to maintain biodiversity can be linked to air temperature and relative humidity (Rosenberg et al., 1983). Surface water modifies an environment's air temperature and relative humidity by acting as both a reservoir, and source for energy through daily and annual periods (Geiger, 1965). Water has been shown to be an efficient thermal sink during warm days or summers; or thermal source during cool nights or winters (Danehy and Kirpes, 2000; Moore et al., 2005; Hannah et al., 2008).

All animals rely on the ability to maintain body temperature within natural limits (Rosenberg et al., 1983). This is true especially for poikilotherms (cold blooded species) which rely on ambient heat to regulate internal temperatures (Huey, 1991).

Relative humidity is one control of the rate at which evaporation and transpiration take place, affecting the ability of evaporative cooling by both flora and fauna. Approximately 1% of water taken up by plants is used for metabolic processes and the rest is passed through from roots to leaves acting to cool the plant as transpiration takes place (Rosenberg et al., 1983). Temperature and relative humidity are limiting physiological factors, important to proper riparian ecosystem function, and are important habitat indicators (Gregory et al., 1991; Chen et al., 1999; Danehy and Kirpes, 2000; Moore et al., 2005).

Specific objectives of this study were to:

1) Characterize flow conditions of perennial and intermittent tributary streams of Big Chico Creek using temperature and stage methods.

2) Identify differences in temperature and relative humidity at intermittent and perennial sites during different flow conditions

3) Characterize relative humidity gradients (RHG) and temperature gradients (TG) of perennial and intermittent streams using transect methods developed to observe effects of harvesting on microclimatic gradients. Gradients were characterized along specific spatial (stream to upland) and during archetypical temporal periods (flowing, transitional, dry). Linear regression slopes referred to as TG and RHG of relative change in temperature and relative humidity from stream values were compared using a one-way ANOVA to determine statistical differences between means (P<.05).

4) Characterize temperature and relative humidity changes from stream on a Station by Station basis. Changes along transects were analyzed using a two-way ANOVA to determine which Stations were significantly different (P<.05).

Characterization of specific temperature and relative humidity conditions adjacent perennial and intermittent tributary streams is a step toward understanding potential management practices that might attenuate perturbations of these distinguishable stream types. Results indicate that during peak daytime hours in the canyon setting of northern California perennial stream temperature and humidity gradients experience greater gradients, i.e., steeper TG and RHG, directly following cessation of flow at the intermittent stream, and continued substantial flow at the perennial stream. During the same time period air temperature and relative humidity above intermittent streams are statistically similar to riparian air temperature, while the perennial streams are different from both riparian and upland conditions. This is believed to be partially a result of surface water availability along perennial streams.

CHAPTER II

LITERATURE REVIEW

Direct connection between riparian zones and streams provide aquatic and terrestrial organisms with ready access to water. For this reason, riparian zones are ecologically vital areas of the landscape. Streams, and their surrounding riparian ecosystems, form a continuous network across the landscape. These networks provide critical habitat for 67% of plant species and 70% of vertebrates in the Pacific Northwest (Dong et al., 1998). As much as 80% of these systems have disappeared across North America and Europe in the last 200 years (Naiman and Décamps, 1997).

Riparian zones hold a unique position in the landscape which provides critical habitat by virtue of an extensive land-water ecotone. In semi arid environments, riparian zones ecological value is disproportionate to their areal extent (Kondolf et al., 1996). Riparian microclimatic variability in solar radiation, air temperature, and wind speed can influence migration of flying insects. Soil temperature and moisture can affect soil microbial activity. Temperature, solar radiation and humidity affect plant growth by influencing physiological processes such as photosynthesis, respiration, seed germination, mortality, and enzyme activity. Ecosystem processes such as decomposition, nutrient cycling, succession, and productivity are also partly dependent on these variables (Chen et al., 1999).

In microclimatic studies, physical scale of interest determines if landscape, vegetation, aspect, slope, or seasonal effects need to be taken into consideration, or if they can be ignored. For example, relationships between canopy cover and ground surface temperature were most apparent on a scale of 200m (r^2 = -0.74), and less so on scales down to 10 m (r^2 = -0.09) (Chen et al., 1999).

Variability of microclimates has been looked at extensively by studies concerned with forestry practices, and their effects on riparian microclimates. Microclimatic controls on stream temperature, soil temperature, air temperature, direct radiation have been of particular interest (Moore et al., 2005). Riparian microclimates are a consequence of overlap and transition from aquatic to terrestrial environments (Chen et al., 1999). Riparian zones provide shade and water, which in the semi-arid environment of northern California are often limited. Riparian summer daytime temperatures in the forests environment of the Pacific Northwest are typically lowest near the stream and increase with distance traveled along a transect extending perpendicular from a stream into the upland (Brosofske et al., 1997; Dong et al., 1998; Welsh et al., 2005). The steepest gradient of both temperature and relative humidity occur within the first 10 to 32 m (Moore et al., 2005; Olson et al., 2007) and changes are often insignificant beyond those distances. Summer nighttime variation was more pronounced, with statistical differences existing between all adjacent stations. During this time temperatures were observed to highest at the stream for two of five transects (Brosofske et al., 1997).

Effects of forest harvesting on the riparian temperature and relative humidity gradients from stream to upland indicate increased variability of temperature and relative humidity associated with different post harvest buffer widths (Dong et al., 1998). Forest canopies reduce diurnal air temperature range when compared to large open areas (Chen et al., 1999). Maximum temperature differences between open and forested areas existed during the daytime and ranged from +3 to +6°C or more between open and forested areas (open maximum temperature – forested maximum temperature) (Moore et al., 2005). At night minimum temperatures in the forest are typically 1°C higher than open areas (Moore et al., 2005). In order mitigate for observed increases in stream temperature, forestry practices in recent years have included the preservation of a narrow strand of riparian vegetation (buffer) for maintaining species composition and ecological function of riparian zones (Chen et al., 1999). Studies of buffer effects on air temperature at the stream in northern California indicate reductions at the rate of about 1.6°C per 10m buffer width (Moore et al., 2005). Streams with buffers of 150 m had stream temperatures as much as 6°C lower than streams without buffers (Moore et al., 2005). Standardized values indicate that harvesting at 17 m or more from stream results in an increase of 2-4°C at the stream, and a decrease in relative humidity of 2.5 – 13.8 % (Chen et al., 1999).

Relative humidity and temperature have an inverse relationship. A static amount of water vapor in the atmosphere, subjected to higher temperature will result in lower relative humidity (Anderson, 1936). This leads to relative humidity being highest during the night, the time when actual vapor pressure is likely lowest, and the lowest relative humidity during the day, when actual vapor pressure is likely the highest (Figure 1) (Rosenberg et al., 1983).

Relative humidity within the riparian zone is dependent on temperature, wind speed, radiation, and vapor pressure (Chen et al., 1999). Relative humidity gradients exist within riparian zones, with different studies accounting for different gradients. Relative

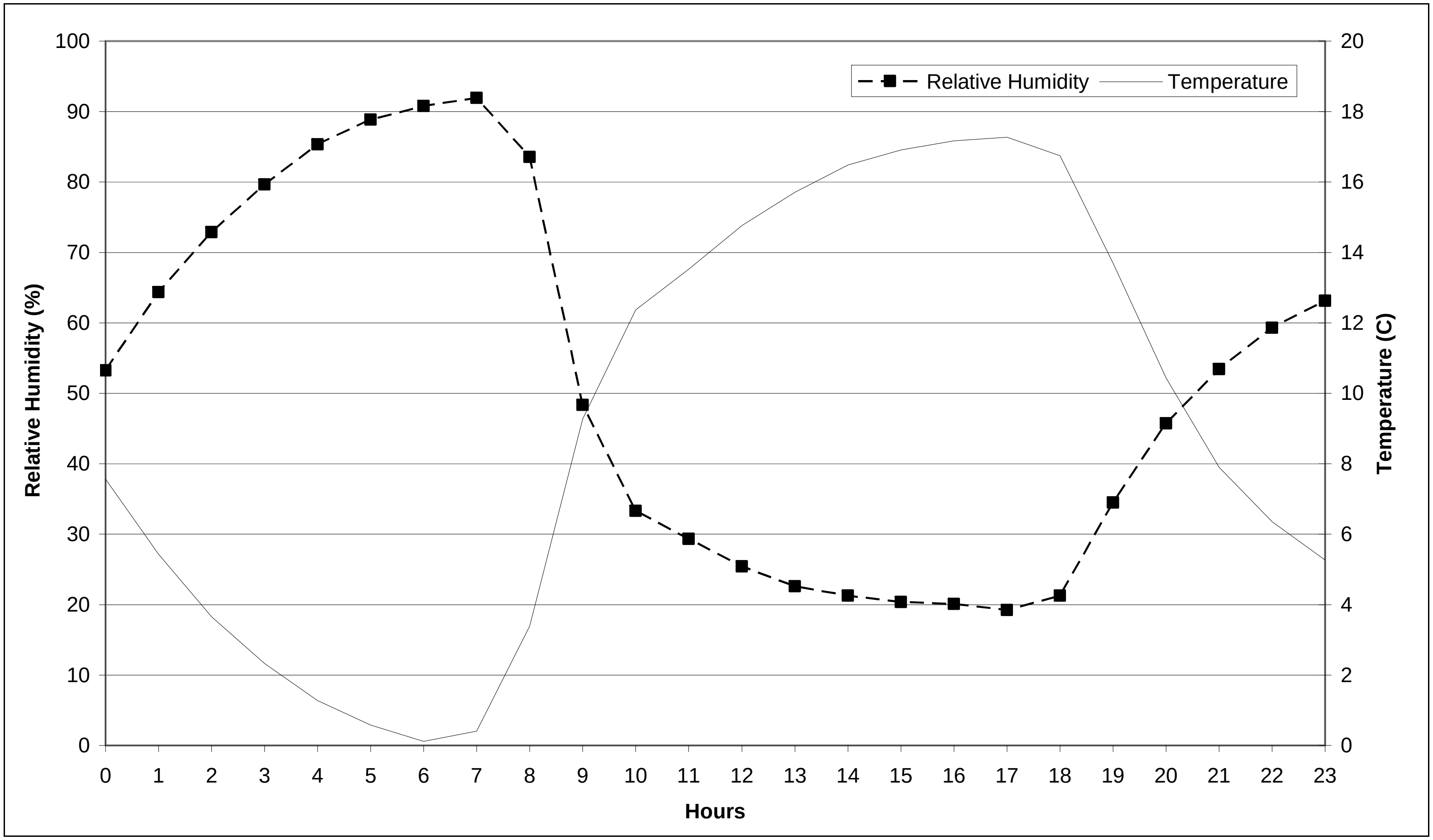


Figure 1. Temperature and relative humidity diurnal relationship. The x axis measures hours, and temperature and relative humidity are on the y axis. As temperature increases relative humidity experiences an exponential decrease.

humidity differences ended within 31m in a study done by Brosofske et al. in an old growth Douglas-Fir forest in western Washington, and a study done by Danehy and Kirpes in eastern Oregon and Washington forests found changes halted after 10m, this was attributed to steep topography (Brosofske et al., 1997; Danehy and Kirpes, 2000).

CHAPTER III

METHODS

The current study location is adjacent to perennial and intermittent tributaries in the Big Chico Creek Ecological Reserve (BCCER). The BCCER is located 240 km northeast of San Francisco California, and 13 km northeast of Chico California (Figure 2).

The BCCER is located in the Big Chico Creek Canyon. The ecological reserve covers an area of 16 km^2, and ranges in elevation from 210 m at channel bottom, to 670 m at the highest canyon ridge top. The overstory vegetation at the study sites included blue oak, canyon live oak, digger pine, grey pine, buckbrush, manzanita, ponderosa pine, maple, and canyon blue oak. Overstory density varied from the upland forest to the riparian. Soil types ranged from loamy through moderately fine soils, from very shallow to moderately deep (United States Department of Agriculture, Natural Resources Conservation Service, 2009)

Big Chico Creek flows from north to south though the BCCER and is fed by numerous tributaries. Tributary streams were chosen based on stream size, stream flow regime, topographical relief, and vegetation. The stream width varied from 1 to 2 m, elevations from 270 to 320 m, LAI ranged from 0 to 2.16; but was only measured for 3 of 4 streams due to time limitations. Relative topographical relief from stream to upland

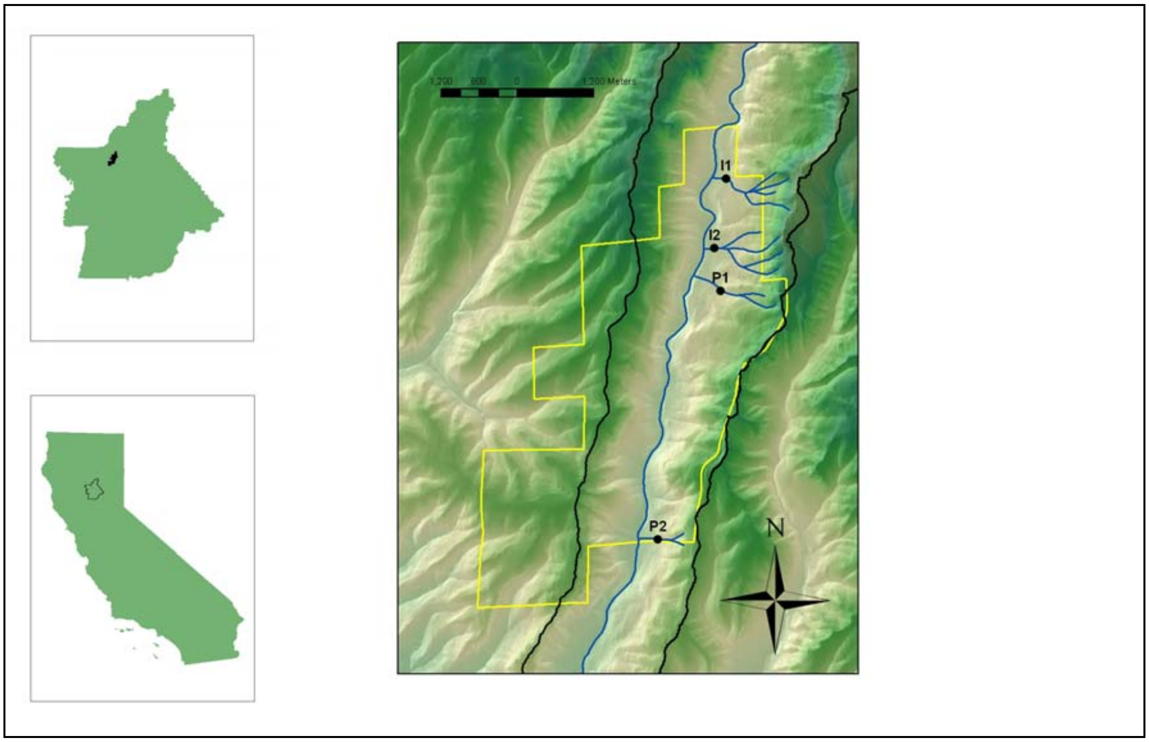


Figure 2. Location of study. From top to bottom left to right; GIS map of Butte County with the BCCER in black, California with Butte County outlines, and a hillslope shaded map of Big Chico Creek Canyon (black), the BCCER is outlined in white. I1 I2 P1 and P2 are the locations of established transects within the BCCER. (Original figures created using Arc GIS by Eric Willard.)

varied from .026 to .16. All streams flowed from east to west, down the eastern canyon slopes (Table 1).

2008 was the second consecutive year of drought in California. Extremely dry conditions persisted into the summer and both perennial streams had minimal flow by the end of the study. On the 16th of June photographs of the P2 stream indicate no flow (Figure 3), however notes from the visit to the site the next day report minimal flowing water. Visits to the perennial sites in September revealed both perennial streams were dry.

TABLE 1. TRIBUTARY CHARACTERISTICS. THE FOUR TRANSECTS LOCATED ALONG FOUR TRIBUTARY STREAMS IN THE BIG CHICO CREEK CANYON OF NORTHERN CALIFORNIA

Stream Name	Distance to Big Chico Creek	Aspect	Stream Type	Transect Length	Stream Width	Stream Elevation	Station 1 LAI	Station 5 LAI	Transect Topographic Slope from Stream to Upland
I1	170 m	W=270°	Intermittent	60m	2 m	300 m	2.16	0	0.026
I2	170 m	W=270°	Intermittent	60m	2.5 m	280 m	0.75	0.35	0.145
P1	480 m	W=270°	Perennial	45m	1 m	320 m	1.73	0.75	0.166
P2	290 m	W=270°	Perennial	45m	1 m	270 m	Na	Na	0.144

Figure 3. Photo of P2 no flow on the 16th of June.

The following methods were applied in conducting air temperature and relative humidity gradient analysis on perennial and intermittent streams: (1) transects were established extending perpendicular to both intermittent and perennial streams, (2) flow was monitored using temperature methods and a stream stage methods in combination, (3) SAS and JMP Statistical software were used to create regression models of the relative humidity and temperature gradients. One and Two way ANOVA were used to determine interaction of variables, along specified spatial, and during representative temporal periods.

Perennial and Intermittent Transects

At each stream, a transect was established perpendicular to the channel, extending from stream to upland. Transects were composed of 5 monitoring Stations (1-5). At each Station, relative humidity and temperature were recorded. The first Station was located in the middle of the stream channel (Station 1), the next Station was located 7.5 m away from the stream edge (Station 2), the next Station 15 m from stream edge (Station 3), the next 30 m from the stream edge (Station 4), and the final site was placed in the upland environment (Station 5), which ranged from 45 m to 60 m away from Station 1 depending on vegetation (Figure 4).

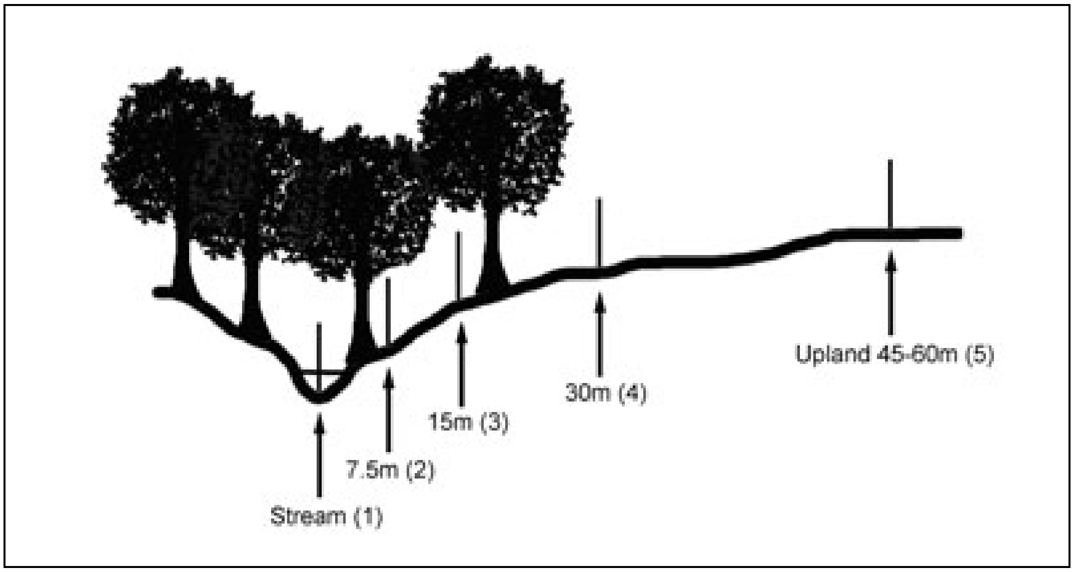


Figure 4. Transect diagram. Transects were established across four streams in the BCCER (I1, I2, P1 and P2). Figure 4 is a cross section of the stream and transect. Spacing of Stations from stream to upland create transects which extend North, perpendicular to all streams.

Transect grade was measured with a hand held clinometer at each station. Leaf Area Index (LAI) was also measured at each station, with the exception of P2 transect. Each transect station consisted of a 2 m tall post, with a HOBO H8 Pro Temp/RH data logger housed in a protective radiation shield attached to the post (Figure 5). Each logger was set to record relative humidity and temperature every five minutes, in order to observe maximums and minimums.

Figure 5. Relative humidity and temperature station. In the foreground is the solar radiation shield which houses the RH/Temp HOBO Pro at 2m height.

Four streams, two perennial and two intermittent, were monitored. Stream site names are as follows I1, I2, P1,or P2. I stands for intermittent, and P for perennial (Figure 2). Four sites (I1, I2, P1, P2) were monitored for six months from the middle of February 2008 to the middle of June 2008 (Table 2).

Instrumentation

The HOBO H8 Pro Temp/RH logger has an internal temperature sensor mounted inside the front of the loggers case. The sensor measures ambient air temperature over the operating range of, -30° to 50° C (22° to 122° F) with a response

TABLE 2. OUTLINE OF FLOW CONDITIONS, MONTHS, WEEKS, AND DAYS OF STUDY. TOP TO BOTTOM RELATES DIFFERENT TIME SCALES OF THE STUDY SHOWING FLOW CONDITIONS DURING THE MONTHS, WEEKS, AND DAYS OF THE STUDY.

Flow Condition	Flowing						Transitional				Dry						
Month	Feb		Mar					Apr				May				Jun	
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Days	18-24	25-2	3-9	10-16	17-23	24-30	31-6	7-13	14-20	21-27	28-4	5-11	12-18	19-25	26-1	2-8	9-15

time of less than 35 minutes (typical to 90%) in still air. The accuracy of the measurements taken with the logger depends on the temperature of the environment. Accuracy is specified by the manufacturer as ± .3° C (.5 F°) within the optimal operating temperature range of 0° to 50° C (32° to 122° F). Past these boundaries the accuracy of the temperature sensor decreases exponentially.

The HOBO RH sensor is mounted on the face of the logger. The sensor measures the capacitance of a small water absorbent polymer. As water is absorbed on the polymer its capacitance increases. Designer specifications indicate the RH sensor has an accuracy of ±3% over a temperature range of 0° to 50° C° (32° F to 122° F). The range of the sensor is 0 to 100% RH. It can read up to 104.1% in a condensing environment. While the sensor is saturated data is invalid. The RH response time is less than 5 minutes typical to a 90% change (independent of temp). Temporary drift of up to 3% can occur when the average humidity is above 70%. Additional irreversible drift may occur after repeated exposure of sensor to condensing environments (100% RH or greater).

Stream Stage and Temperature Methods and Instruments Used to Monitor Flow Timing

Due to resource limitations only two streams were chosen for monitoring stream flow timing. Based on topography and elevation, P1 and I2 were the most comparable transects, of contrasting stream classes (intermittent vs. perennial). In addition to relative humidity and temperature, stream stage was monitored. Stream stage and temperature in the stream thalweg and on the bank were monitored on an hourly basis.

Two methods for monitoring stream discharge were employed, temperature methods, and stage measurement. The intention at stream P1 was to monitor a continuous flowing environment. Temperature methods have been shown capable of inferring flow timing (Constantz et al., 2001). The instruments used to measure temperature were HOBO temperature data loggers encapsulated in watertight PVC cases (Figure 6, A).

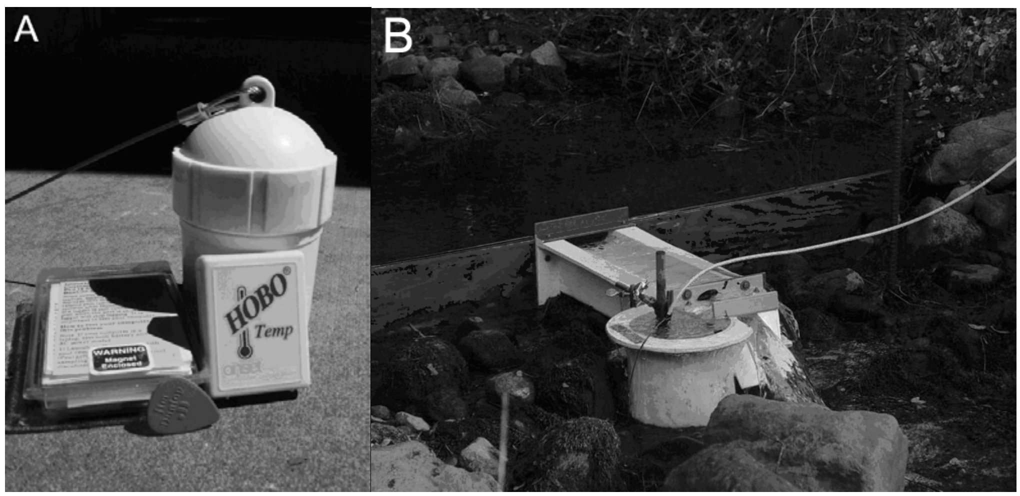


Figure 6. Flow monitoring equipment. A) Onset HOBO temperature logger and PVC capsule. B) Dam flume and weir with stilling well and pressure transducer installed at I2 stream. (Photos Taken By Eric Willard.)

At streams P1 and I2 temperature loggers were placed in the thalweg of the stream channels, and on the bank adjacent to the channel. The two loggers record a temperature on an hourly basis. The amplitude of the diurnal temperature wave indicates the variation of temperature. During flow events the amplitude of the in stream temperature wave is smaller than the amplitude of the bank temperature logger (Constantz et al., 2001). When the stream flow ceases, the two waves should closely resemble one another (Figure 7).

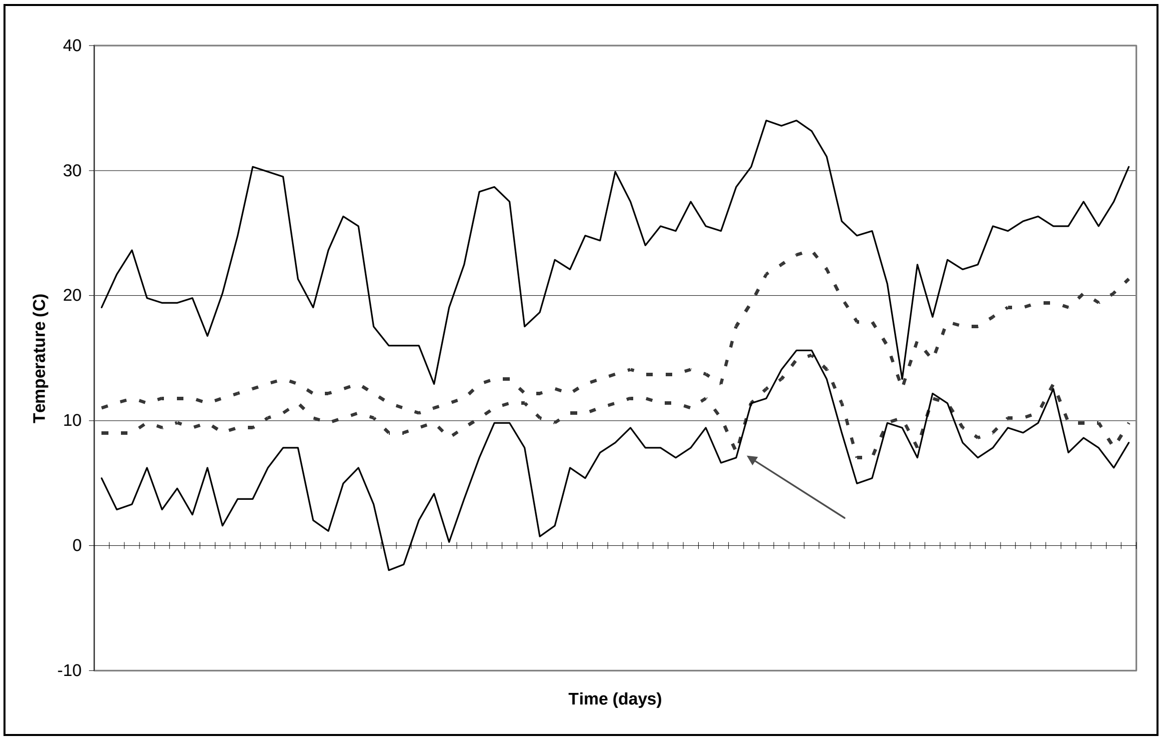


Figure 7. Graph of temperature methods for stream flow inference. X-axis is time in days, y-axis is temperature in C. Comparison of bank minimum and maximum temperature (solid lines) and creek thalweg (dotted lines) allows inference of flow timing. Emersion of the creek temperature logger results in a marked increase in minimum and maximum temperature. The arrow points to the day when the minimum and maximum temperature of the creek logger experiences a marked increase in minimum and maximum daily temperatures.

Stream I2's flow was also measured using a .4 ft H flume, which was installed in the channel upstream of Station 1 (Figure 6, B). A pressure transducer measured the depth of flow stage through the flume on an hourly basis. This provided data of flow quantity in the intermittent stream channel.

Flow Delineation

Flow condition is structured around the flow timing of intermittent stream I2. Delineating flow data into reasonable periods indicative of various flow conditions are based on both temperature and stream stage methods. Results indicate lagged correlatation of stream flow timing between stage and temperature methods (Figure 8).

The creek temperature logger was placed in the thalweg of the stream. As the stream flow attenuated the creek left behind small pools of water. The creeks temperature logger was underwater for an extended period after the flume stopped filling with water. For this reason, stage methods indicate more precisely when the stream channel stopped flowing, and temperature methods indicate when the channel is clear of standing water. Both methods indicate complete dewatering of the channel within a day of one another (Figure 8).

Stream I2 had elevated stages during the months of February and March, which are considered the period of flowing conditions at all streams. During the month of April flow in stream I2 is attenuating, this period is considered a transitional flow condition. Dry conditions in March and April led to cessation of flow at I2 during the ninth week of the study (Figure 8). May and June are months when both intermittent streams are not flowing, and are considered the dry or no flow condition.

Stage methods used in determining flow timing indicate early the ninth week of the study Mid April as the beginning of no flow conditions at I2 (Figure 8). A small rainfall event induced flow during the tenth week. Evaporation, transpiration, and infiltration quickly halted the flow again in the following week (11) (Figure 8). Visits to the northern most intermittent stream (I1) suggest an even earlier drying, perhaps late March or early April (Figure 9).

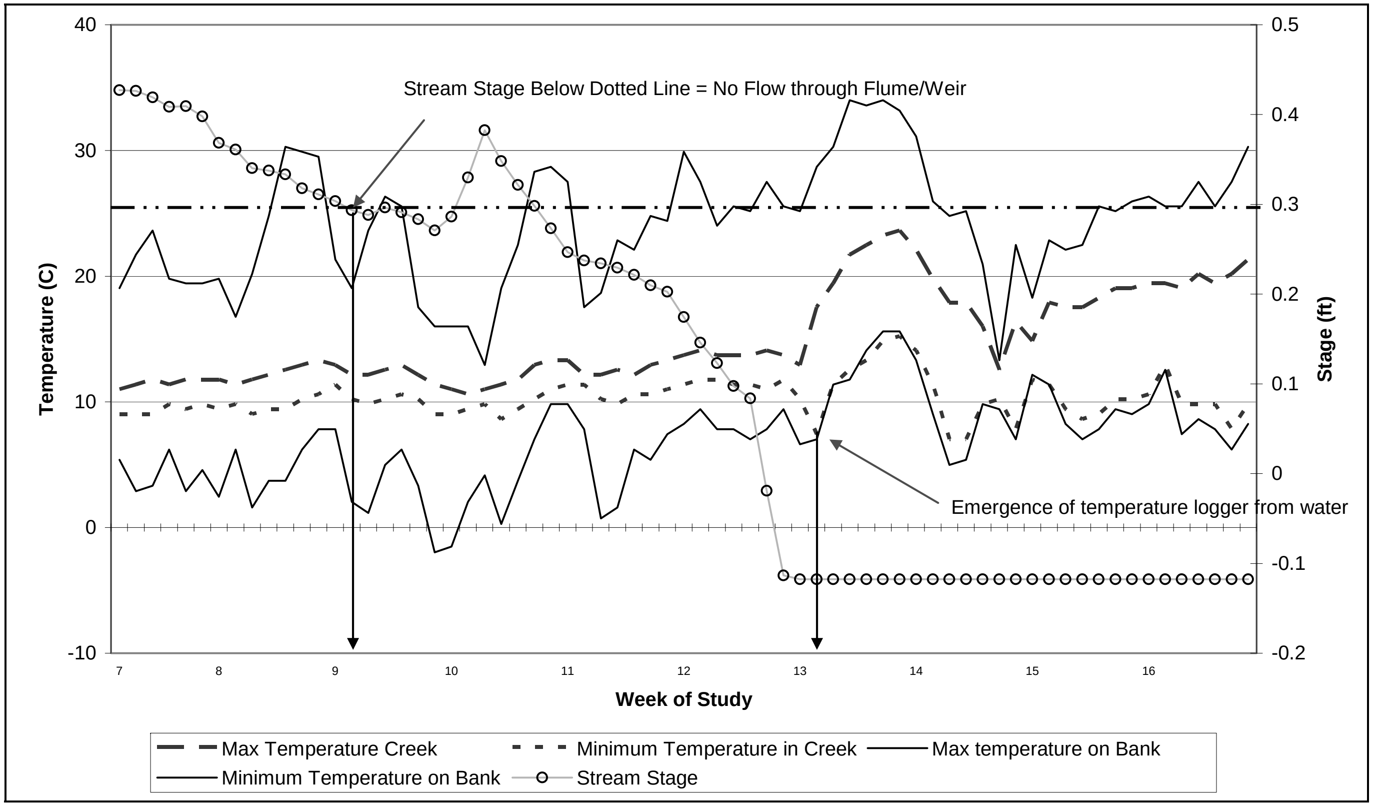


Figure 8. Minimum/maximum temperature of creek and bank loggers and stream stage graphs. This graph combines temperature and stage methods to infer flow condition of I2 intermittent stream. X-axis represents weeks of study, y-axis represents temperature for minimum and maximum lines and depth for stream stage. If stream stage drops below the horizontal grey dashed line that represents the inlet height (0.3 ft) of stilling well; is an indication of cessation of flow. Further stream stage measurements below this level indicate evaporation of water from stilling well. Negative values indicate complete evaporation of water in the weir.

Figure 9. Photo I1 stream dry. Photo was taken on April 7th stream bed completely dry indicate early drying of I1 stream.

CHAPTER IV

DATA ANALYSIS

Daily Minimum, Maximum, Standard Deviation

Intermittent and perennial stream minimum, maximum, and standard deviations were determined on a daily basis at Station 1. An ANOVA was run on the data to see if the temperatures and relative humidity varied between intermittent and perennial streams. This was done for all three flow conditions (Flowing, Transitional, Dry).

Relative Change from Stream

Gradient analyses used relative averages Equation, each station along the transect was averaged for a time period indicative of night and day temperatures, 0400-0800 and 1400-1800 respectively. Representative hours of day and night were determined on a monthly basis through analysis of average temperature waves during each month at each stream. Air temperature and relative humidity at Station 1 were used as references (S_1). The average at Station 1 was subtracted from the average value of each Station for the given night/day period (Equation 1).[1]

$$S_{x\,(rel\ avg)} = S_{x\,(avg)} - S_{1(avg)} \tag{1}$$

[1] Relative change equation was used to determine the average relative change in temperature and relative humidity from stream temperature and relative humidity during night time and daytime peaks.

where $S_{x\ (avg)}$ is the average air temperature given at Station x, and x can equal 1 through 5. $S_{1\ (avg)}$ represents the average air temperature at Station 1. Values calculated represent relative changes in temperature not absolute temperatures, and are associated with distances from the stream (Figure 10). The same process was used to determine the changes in relative humidity. Using the relative change data linear regressions were produced using the regression procedure within the SAS program. Each regression was forced through the origin. Creating linear equations representing the TG (temperature gradients) and RHG (relative humidity gradients) along each transect. Then TG and RHG were grouped or separated for comparison.

ANOVA, Linear Regression of Temperature (TG) and Relative Humidity (RHG) Gradients

The null hypothesis of the experiment states TG from stream to upland are larger adjacent to perennial streams than intermittent streams, after intermittent streams have ceased to flow, and while perennial streams continue to flow. The alternate hypothesis states that TG from stream to upland are not larger adjacent to perennial streams than intermittent streams, after intermittent streams cease to flow, and while perennial streams continue to flow.

In order to test the hypothesis, slopes obtained from the regression analyses were run through a one-way ANOVA to determine if the slopes were statistically different ($P \leq .05$). Time periods were representative of day or night, week and flow condition of the stream channel. Flow characteristics were determined from the stage data of the weir in the I2 channel. Perennial and intermittent stream data were grouped in the initial analysis, then in order to determine specific differences at each stream slope was analyzed individually. For simplicity sake most reported results are those obtained from combined data (i.e., all perennial transects combined, all intermittent transects combined, flow conditions classified as flowing, transitional and dry).

Two Way ANOVA by Station and Transect

A two-way ANOVA was used to determine significance of effects. Stream transect, Station, and a cross of both terms were used to determine significant differences between Stations, between transects, and between transects and Stations. Tukey HSD (Honestly Significant Difference) comparison was used to determine statistical differences ($P < .05$). This analysis is used for monthly and weekly periods, in order to compare P1 and I2 transects specifically.

Relative Humidity at Station 1

The final analysis investigated the number of hours a day that relative humidity was <20% <50% and >80%. The hours were counted at Station 1 for each stream. Accumulated hours were then compared on a weekly basis using a one-way ANOVA to determine statistical differences by stream type ($P \leq .05$).

CHAPTER V

RESULTS

Daily Minimum, Maximum, Standard Deviation Temperature and Relative Humidity at Station 1

Statistical results indicate significant temperature differences ($P<.05$) occurred due to stream classification (intermittent, perennial) effects. Daily minimum temperature differences between stream classes ($P<.05$) existed for all flow conditions (Table 3).

As expected due to the inverse relationship of temperature and relative humidity relative humidity maximums are statistically different during all flow conditions. Daily minimum temperatures were on average 1.8° C lower for intermittent streams than perennial streams. Maximum temperatures between stream classes were not statistically different during any of the flow environments (Table 2). Intermittent stream Stations averaged greater temperature standard deviation during transitional and dry conditions ($P<.05$), but were indistinguishable during conditions of flow.

Perennial versus Intermittent Stream TG and RHG One-way ANOVA

Flow Condition

Statistical analysis of TG (temperature gradients) and RHG (relative humidity gradients) along perennial and intermittent streams reveals intrinsic variations associated with seasonal changes in flow. Daytime TG and RHG increase from flowing stream

TABLE 3. ONE-WAY ANOVA USING TUKEYS HSD FOR DAILY MAXIMUM, MINIMUM AND STANDARD DEVIATION RELATIVE HUMIDITY AND TEMPERATURE, BY FLOW CONDITION. MEANS WITH THE SAME LETTER ARE NOT STATISTICALLY SIGNIFICANTLY DIFFERENT (P<0.05).

Temperature											
Flowing - Feb, Mar											
Min T				**Max T**				**STD T**			
Level			Mean	Level			Mean	Level			Mean
P	A		4.155	P	A		17.38521	I	A		4.873
I		B	2.732	I	A		17.20304	P	A		4.460
Transitional- Apr											
MinT				**Max T**				**STD T**			
Level			Mean	Level			Mean	Level			Mean
P	A		5.377	I	A		20.93324	I	A		6.096
I		B	3.63	P	A		20.74185	P		B	5.372
Dry- May, Jun											
Min T				**Max T**				**STD T**			
Level			Mean	Level			Mean	Level			Mean
P	A		10.93	I	A		27.31148	I	A		6.580
I		B	8.659	P	A		26.90117	P		B	5.559

Relative Humidity											
Flowing- Feb Mar											
Min RH				**Max RH**				**STDRH**			
Level			Mean	Level			Mean	Level			Mean
P	A		41.27	I	A		95.03256	I	A		18.28
I	A		40.8	P		B	92.25814	P	A		17.09
Transitional- Apr											
Min RH				**Max RH**				**STDRH**			
Level			Mean	Level			Mean	Level			Mean
P	A		24.54	I	A		89.76167	I	A		22.91
I	A		23.02	P		B	85.13333	P		B	19.94
Dry- May, Jun											
Min RH				**Max RH**				**STDRH**			
Level			Mean	Level			Mean	Level			Mean
P	A		24.5	I	A		84.58778	I	A		20.2
I	A		22.72	P		B	78.12778	P		B	16.14

conditions to dry stream conditions for intermittent and perennial stream classes (see Figure 10, A and B). However, intermittent streams do not experience the same magnitude of increase as perennial streams. Nighttime TG and RHG changes are minimal between different flow conditions (Figure 10, C and D).

Daytime. TG stream classification effects were significant (*P*<.05) for both flowing, and dry environments (see Table 4). However during the transition period TG were not statistically differentiated. During dry conditions both TG and RHG were greater for perennial than intermittent streams (Table 4).

Nighttime. TG was not statistically different between stream classes except during flowing conditions (Table 4). Nighttime RHG were different between stream classes during all flow conditions (Table 4).

Weekly-Daytime

TG ANOVA indicates 7 weeks (3, 6, 7, 10, 11, 12, 13, and 17) which have statistically significant differences between stream classes (Figure 11, A). During the weeks 10, 11, 12 and 13, the intermittent streams are both dry while the perennial streams continue to flow. RHG ANOVA indicate 10 weeks (1 and 9-17) had statistically significant differences (Figure 11, B). During weeks 9-17 perennial streams average a greater negative RHG, indicating a greater decrease in relative humidity from stream to upland. Visits to P1 revealed minimal flow during week 17 (Figure 12, B).

Nighttime

TG ANOVA indicates only two weeks (2 and 3) that have statistically significant differences between groupings of intermittent and perennial transects (Figure 13, A). During these weeks, the perennial transects average a steeper TG than intermittent transects. The RHG ANOVA for similar periods indicate 12 weeks (1-5,7,11,14,16,17) with significantly steeper RHG at the perennial transects (Figure 13, B).

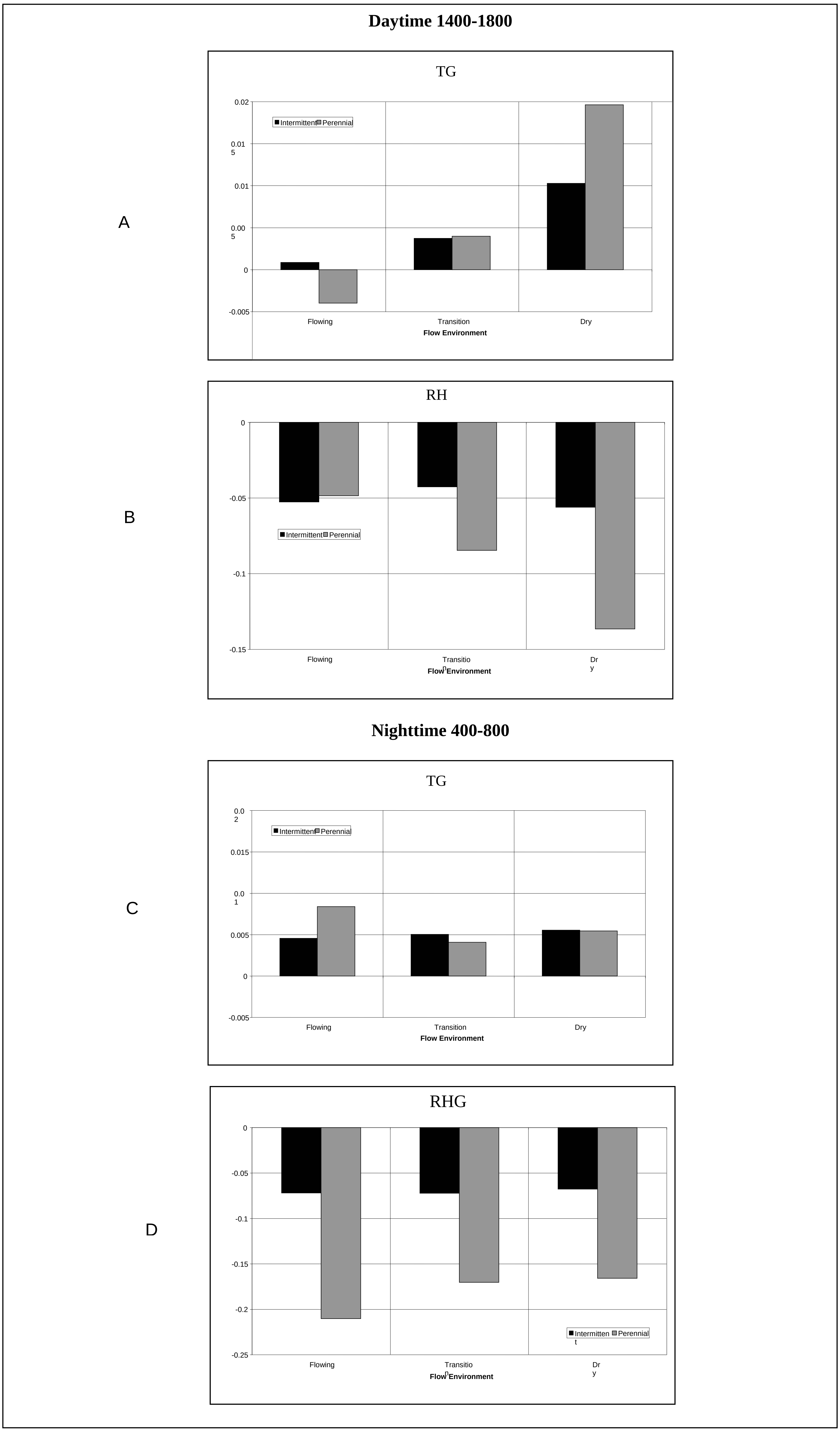


Figure 10. Graphs of intermittent and perennial average TG and RHG by flow condition. Y-axis of A and C represent TG (C/m) and RHG (%/m) for B and D. The x-axis represents different flow conditions (flowing transitional and dry). A and B are during peak daytime hours, and C and D are during peak night hours.

TABLE 4. RHG AND TG ONE-WAY ANOVA (P<.05) BY FLOW CONDITION AND NIGHT DAY PEAK HOURS. MEANS WITH THE SAME LETTER ARE NOT STATISTICALLY DIFFERENT. I STANDS FOR INTERMITTENT AND P FOR PERENNIAL. RESULTS ARE COMPARED USING TUKEYS HSD (P<.05) BY TIME OF DAY (NIGHT, DAY), STREAM CLASS (INTERMITTENT, PERENNIAL), AND FLOW CONDITION (FLOWING, TRANSITIONAL, DRY).

Daytime (1400-1800)								**Nighttime (400-800)**							
RHG				**TG**				**RHG**				**TG**			
Flowing								**Flowing**							
Level			Mean	Level			Mean	Level			Mean	Level			Mean
P	A		-0.049	I	A		0.0009	I	A		-0.072	P	A		0.0084
I	A		-0.053	P		B	-0.004	P		B	-0.21	I		B	0.0045
Transitional								**Transitional**							
Level			Mean	Level			Mean	Level			Mean	Level			Mean
I	A		-0.043	P	A		0.004	I	A		-0.072	I	A		0.005
P		B	-0.085	I	A		0.0037	P		B	-0.17	P	A		0.0041
Dry								**Dry**							
Level			Mean	Level			Mean	Level			Mean	Level			Mean
I	A		-0.057	P	A		0.0195	I	A		-0.068	I	A		0.0056
P		B	-0.138	I		B	0.0102	P		B	-0.166	P	A		0.0054

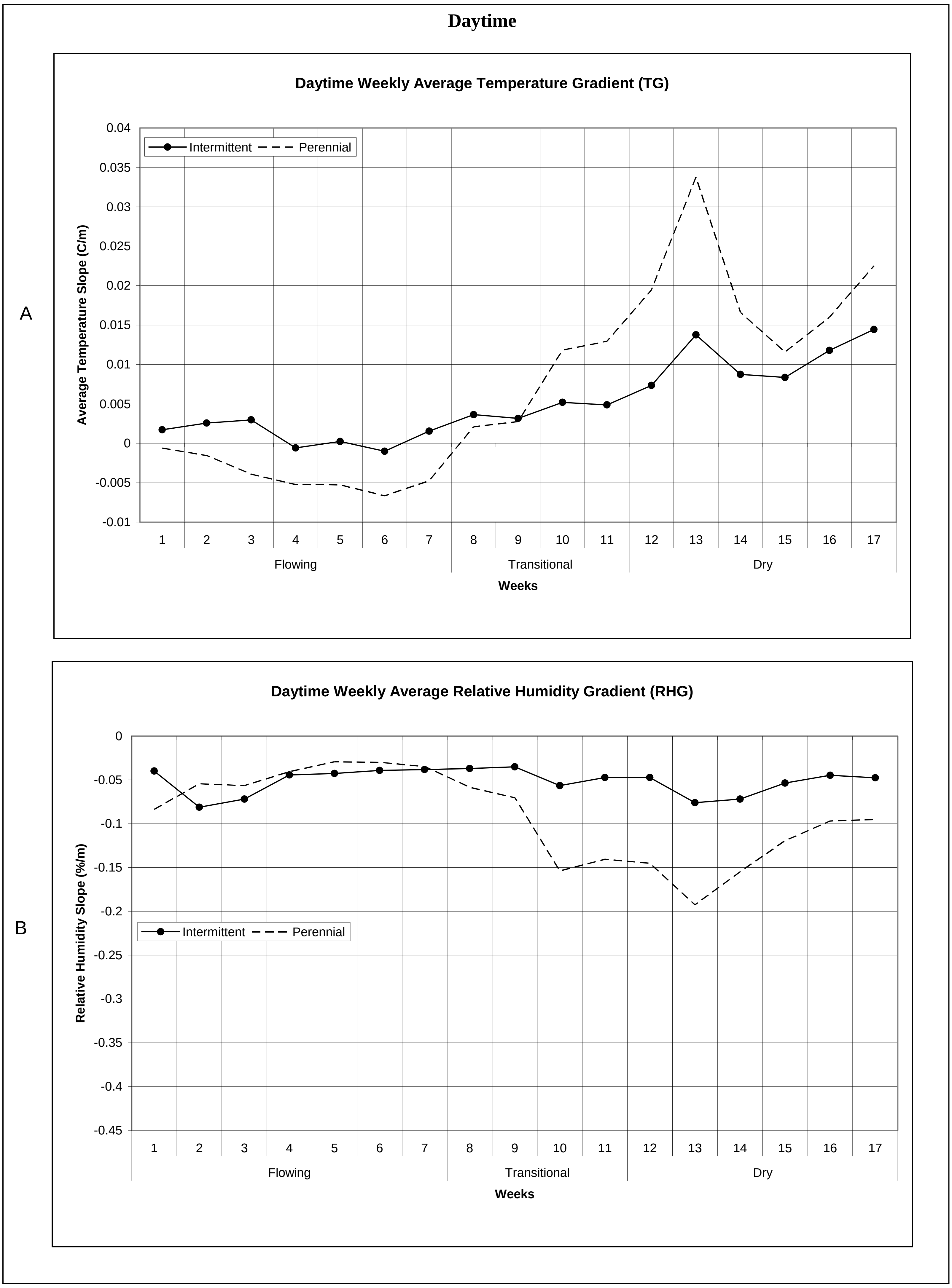


Figure 11. Weekly daytime TG and RHG graphs. A) Weekly daytime TG for two classes of streams perennial and intermittent. The y-axis measures average weekly TG (C°/m). The x-axis indicates weeks (seven day period) of the study from February 18th to June 14th along with flow condition (flowing, transitional, dry). B) is similar to graph A) but the y-axis represents RHG (%/m) rather than TG.

A

B

C

Figure 12. Perennial photos during May, June, and September 2008. A) Photo of perennial flow on the 10th of May. B) Photo of perennial flow on the 16th of June C) Photo of Perennial Stream 27th of September.

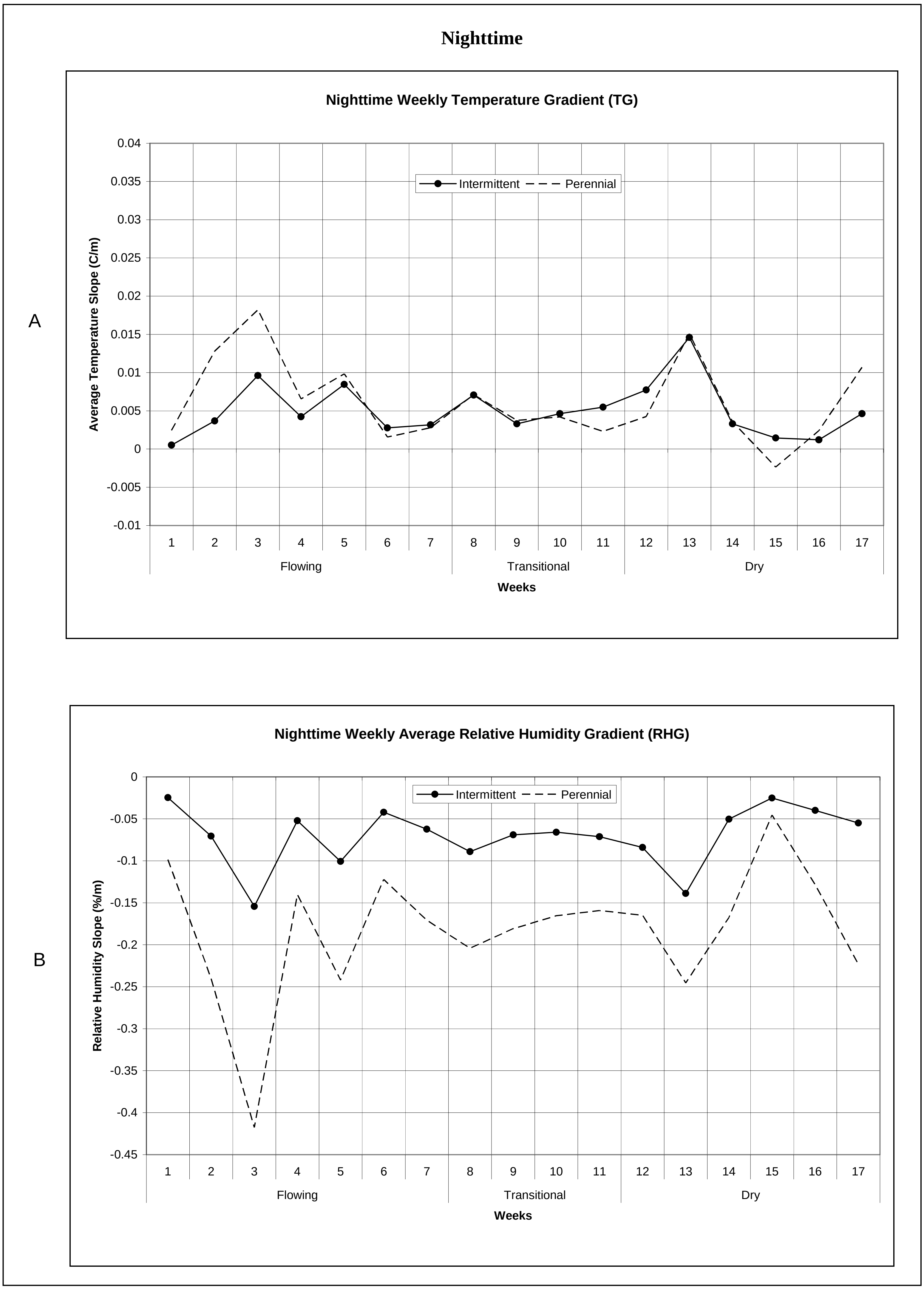


Figure 13. Weekly nighttime TG and RHG graphs. A) Weekly nighttime TG and B) Weekly nighttime RHG. A) Displays average weekly TG for two stream classes perennial and intermittent. The Y axis measures average weekly TG (C°/m). The X axis measures weeks (seven day period) of the study from February 18th to June 14th along with flow condition (flowing, transitional, dry) B) is similar to graph A) but uses RHG (%/m) rather than TG.

Daytime results support the null hypothesis, that greater TG exist adjacent to perennial streams during no flow conditions of intermittent streams; and while perennial streams continue to flow. Results are highly dependent on homogeneity of numerous inputs, such as topography influencing the channeling of air masses (Chen et al., 1999) and canopy cover affecting direct solar radiation (Oke, 1987). Flow condition effects on TG and RHG seem to be apparent during peak daytime hours. For simplicity sake the rest of the analysis will focus on daytime conditions.

Transect

The following analysis is to show the level of variation within stream classes. P1 and P2 transect TG were significantly different from one another during all flow condition analysis, except during the transitional flow condition, this is true for I1 and I2 as well (Table 5).

P1 and P2 transect relative humidity slopes were significantly different from one another during all analysis. I1 and I2 relative humidity slopes were not statistically different during the flowing environment, but were for all other flow environments (Table 5). These significant amounts of variation within stream classes' points out the need for larger sample sizes of tributary streams.

Small tributary stream TG are influenced by multiple environmental variables, including topographic slope to upland, LAI, and relative position in the watershed. Landform appears to modify the RHG and TG from streams to uplands at transect I1, where topographic slope to upland was .026 (Table 5). The average TG and RHG for I1 were the lowest of all transects during dry conditions, averaging .0059 C°/m, and -.019 %/m respectively. Some of the differences in TG and RHG between intermittent and

TABLE 5. ONE-WAY ANOVA OF TG AND RHG DURING PEAK DAY TIME HOURS (1400-1800). DATA WAS ANALYZED BY TRANSECT DURING DIFFERENT FLOW ENVIRONMENTS: FLOWING, FEB, MAR; TRANSITIONAL, APR AND DRY MONTH, MAY, JUN. INTERMITTENT STREAMS DENOTED BY I1, I2; AND PERENNIAL STREAMS DENOTED BY P1, P2. STREAMS WITH DIFFERENT LETTERS ARE NOT STATISTICALLY DIFFERENT (*P*<0.05).

Flowing									
	RHG					TG			
Level				Mean	Level				Mean
P2	A			-0.024	I1	A			0.008
I2		B		-0.051	P2		B		0.000
I1		B	C	-0.054	I2			C	-0.007
P1			C	-0.073	P1			C	-0.008
Transitional									
	RHG					TG			
Level				Mean	Level				Mean
I1	A			-0.020	P1	A			0.005
P2	A			-0.034	I1	A			0.005
I2		B		-0.065	P2	A			0.003
P1			C	-0.135	I2	A			0.002
Dry									
	RHG					TG			
Level				Mean	Level				Mean
I1	A			-0.019	P1	A			0.023
P2		B		-0.076	P2		B		0.016
I2		B		-0.094	I2		B		0.015
P1			C	-0.199	I1			C	0.006

perennial streams can probably be attributed to topographic and canopy cover. Focusing on two transects with similar topography reduces this variation and allows for a closer look at the effect of stream flow on temperature and RH.

Two Way ANOVA – I2 and P1 Transects

Monthly

Direct comparisons of I2 and P1 reveals distinct variation during the transition from month to month. After March transect I2 has progressively higher average change in temperature every month at every Station. In contrast, transect P1 reaches a maximum difference between stream temperature and other locations along its transect during the month of May (Figure 14).

During June, the relative temperature change decreases at stations 2 and 3 along the P1 transect, but increase along the I2 transect. The peak change in temperature during May correlates with cessation of flow at I2 and continued flow at the perennial site. Photographic evidence shows minimal flow occurring in the perennial stream on June 16th (Figure 13, B). The decreased relative change in temperatures at Stations 2 and 3 during June is possibly the result of decreased availability of water for evapotranspiration to cool the air at Station 1 above the stream.

During the month of May and June relative air temperature rises sharply from Station 1 of the P1 transect then levels out and shows no statistical differences until Station 5. Station 1 is significantly statistically different ($P<.05$) from all other perennial Stations. I2 Station 1 during the month of May shows no statistical differences until Stations 4 and 5 along its transect. During the month of June I2 is statistically different from Stations 3, 4, and 5.

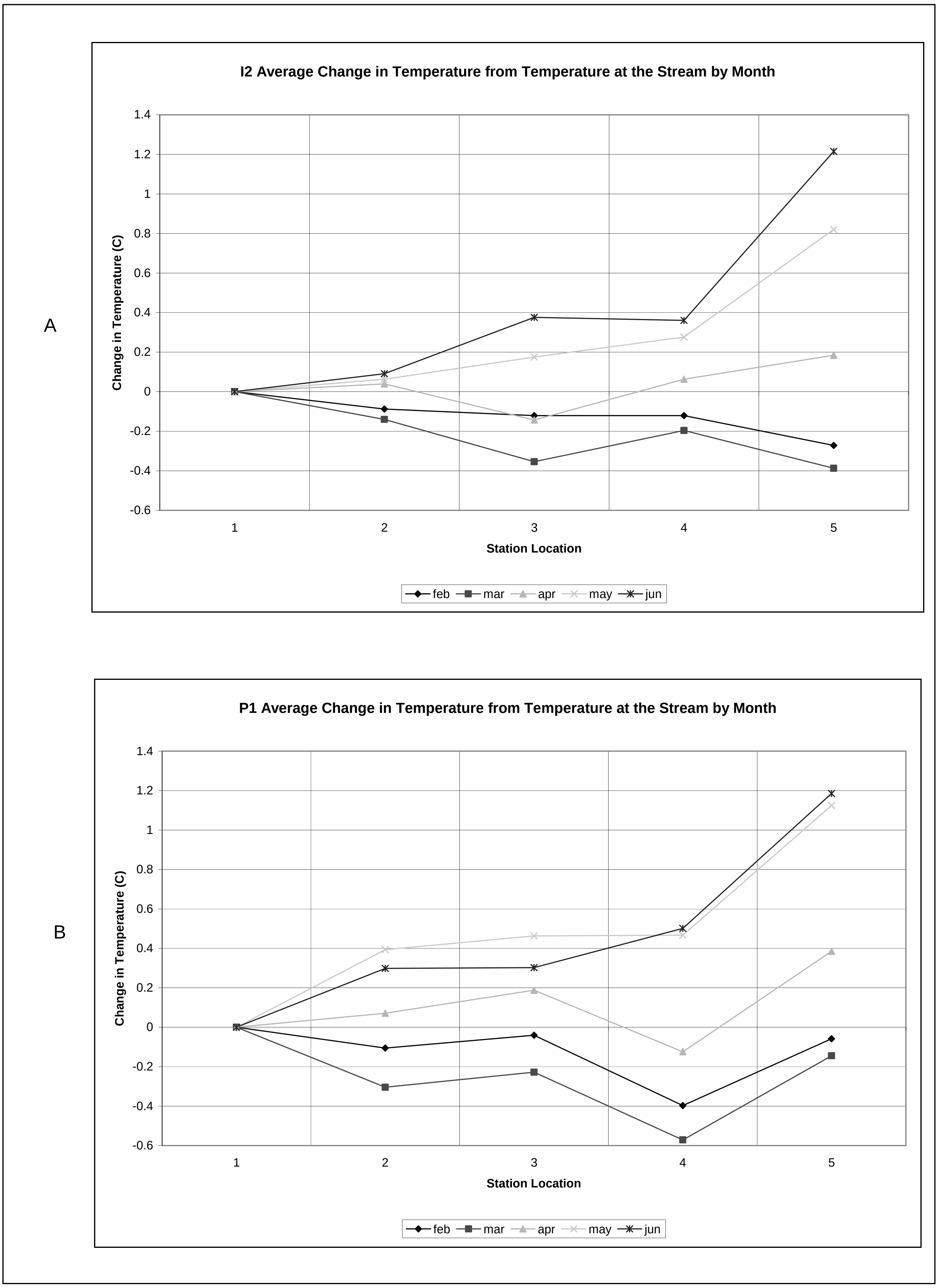


Figure 14. Average monthly relative change in temperature. The monthly relative change in temperature from stream temperature, during the daytime, by month. Graph A is from the transect I2, Graph B is from the transect P1. X-axis represents Stations along the transect, and the y-axis represents relative changes in temperature from stream temperature.

Weekly

Weekly analysis magnifies the similarities and differences during each week of the study between these two transects. Every week that the intermittent stream is flowing, the relative temperature lines cross one another (Figure 15).

During the tenth, eleventh, twelfth, thirteenth and fourteenth weeks of the study the intermittent creek reaches minimal flow and the two lines separate. This separation is maintained for five weeks during which maximum temperatures reach the high 30s C° (100s F). Hot weather combined with drought conditions attenuates and all but depletes the flow of the perennial streams. By the fifteenth week relative variation in temperature for each stream closely resemble one another again. During the 12^{th} and 13^{th} weeks separation reaches a maximum, and perennial stream temperature is statistically different (p<.05) from all other stations along the transect (Figure 15). I1 temperature at Station 1 during the 12^{th} week is significantly different (P<.05) from Station 5, and the thirteenth week Stations 4 and 5.A similar pattern exists for relative humidity as well (Figure 16).

The average temperature change from Station 1 for P1 is greater during the weeks following cessation of flow through the flume at Stream I2 (Figure 17). The correlation of attenuating flow and separation of average temperature change exhibits the predicted effect of surface water on air temperature above the stream.

Relative Humidity (RH) at Station 1

The number of hours a day that the relative humidity (RH) is >80 <50 and <20 reveal no statistical variation between samples except in the month of April (P<.05)

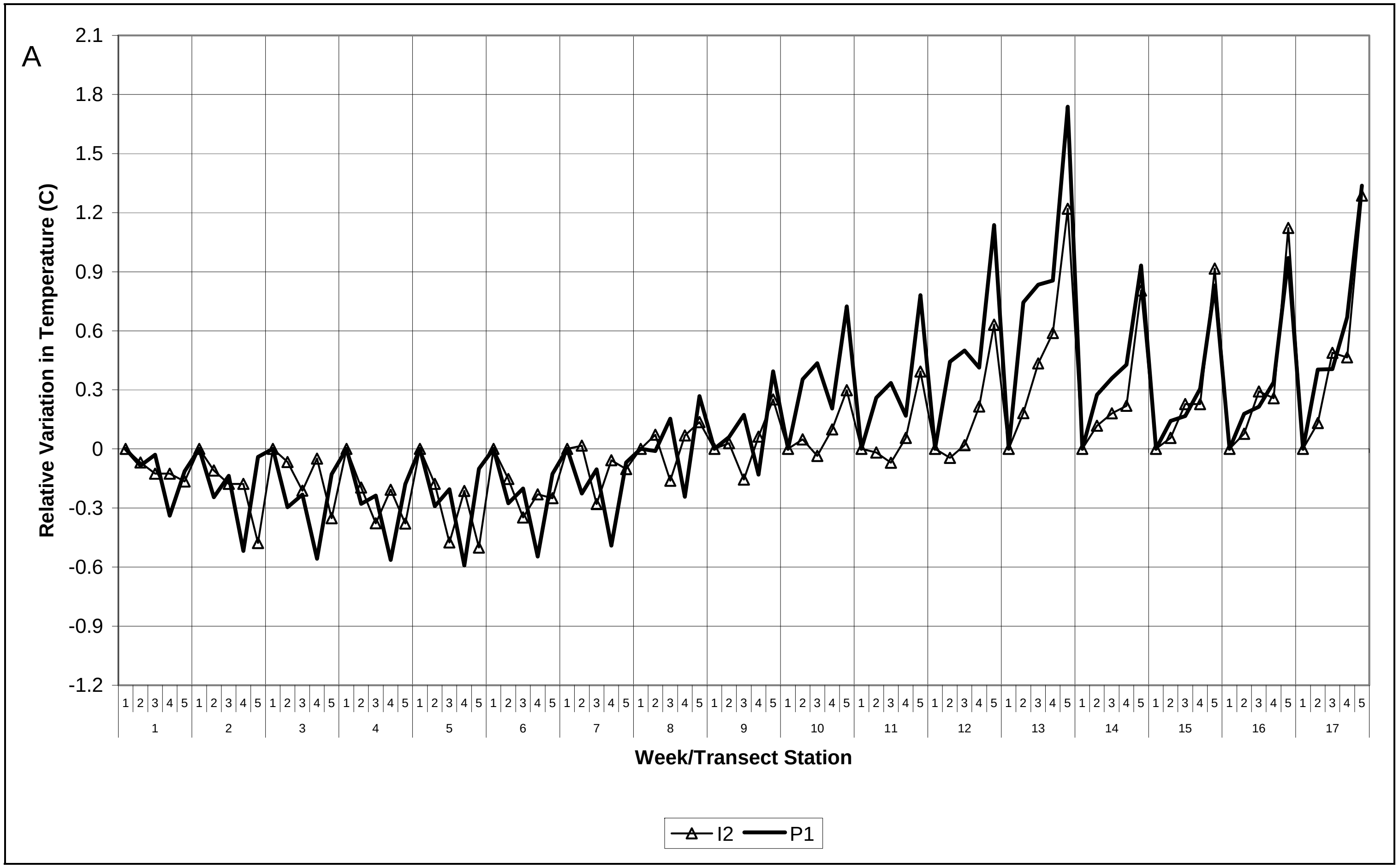


Figure 15. Weekly temperature change from stream to uplands along P1 and I2 transects. Weeks are denoted by the lowest number on the X axis (1-17), and Stations are denoted by numbers next to the X axis (1-5). Y-axis represents the relative change in temperature from stream temperature.

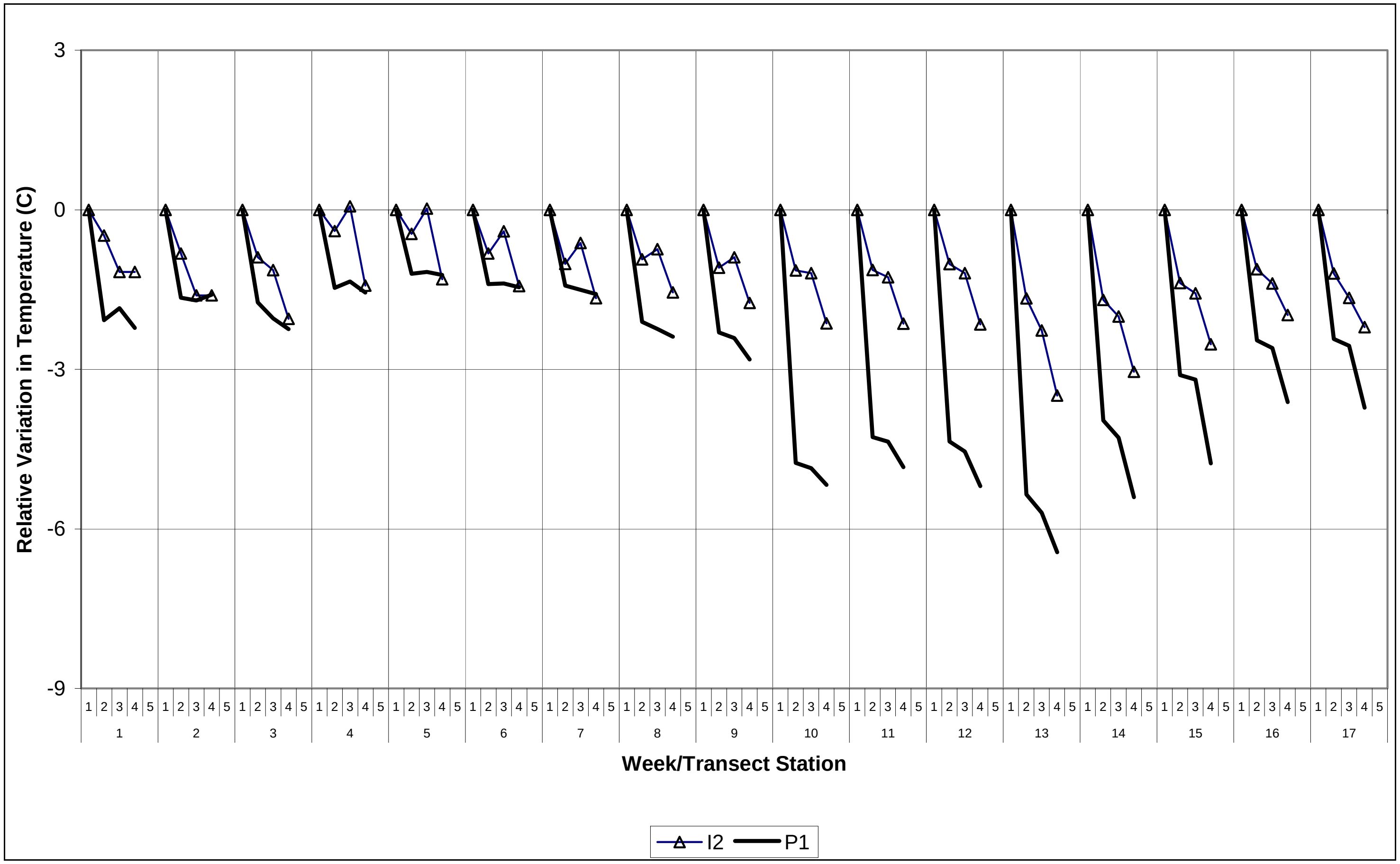


Figure 16. Weekly relative humidity change from Station 1 to Station 4 along P1 and I2 transects, excluding Station 5. Weeks are denoted by the lowest number on the X axis (1-17), and Stations are denoted by numbers next to the X axis (1-5). Y-axis represents the relative change in relative humidity from stream relative humidity. Station 5 was not used in relative humidity analysis due to faulty logger.

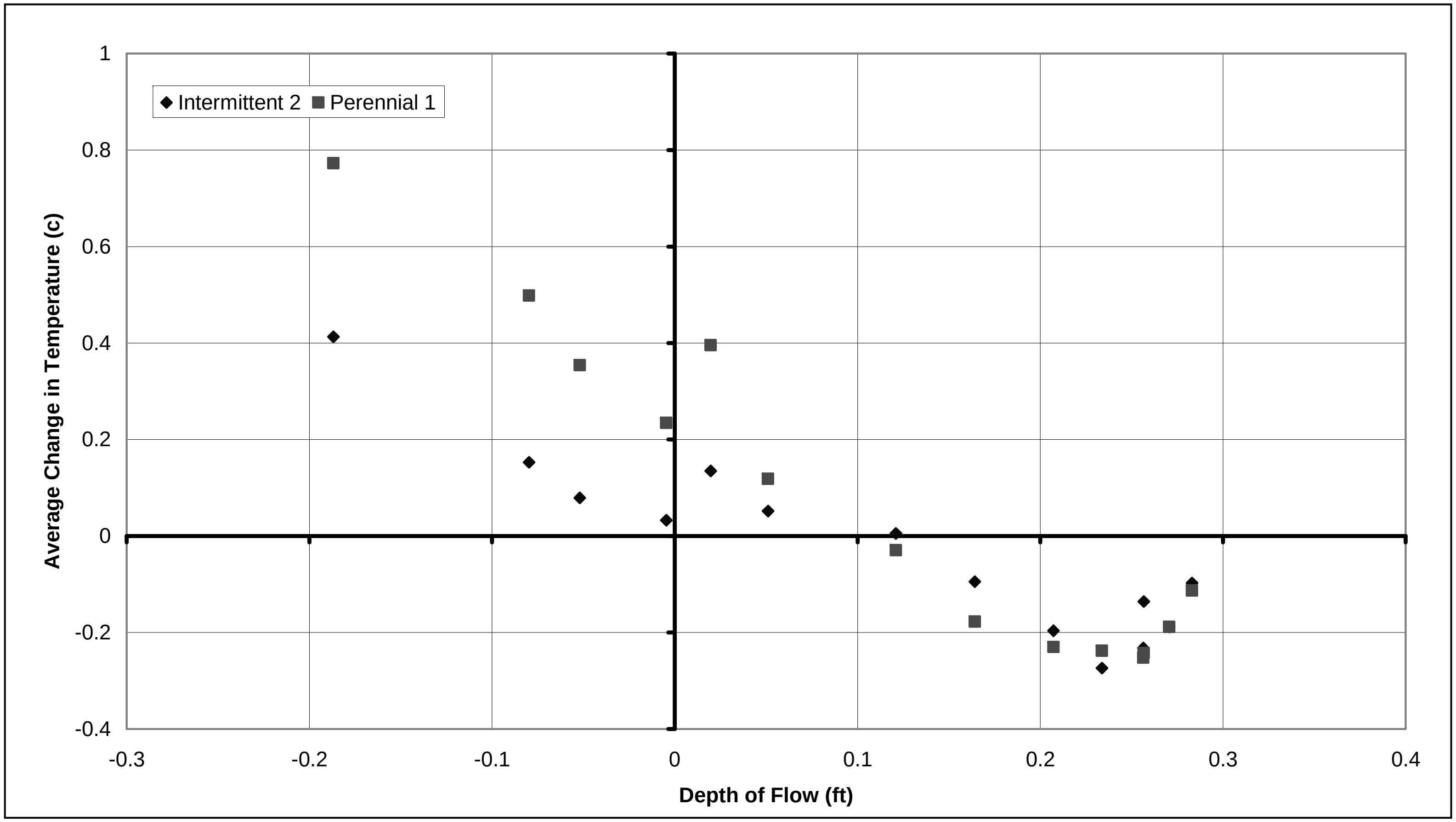


Figure 17. Average temperature from stream to upland at perennial 1 and intermittent 2 versus depth of flowing water. I1 and P2 weekly average change in temperature (C) from stream temperature plotted on the y axis, and stage (ft) of water in stilling well on the x axis.

(Table 6). During April intermittent streams average more hours per day with relative humidity is greater than 80%, compared with the perennial stream. This is attributed to the lower minimum temperatures at those transect locations. Intermittent Station 1 sites show larger numbers of hours per day with relative humidity less than 20% during the months of April, May and June; yet maximum temperatures at all stream locations were shown to be similar (Table 2).

TABLE 6. AVERAGE NUMBER OF HOURS A DAY AT STATION1 THAT RELATIVE HUMIDITY IS GREATER THAN 80% LESS THAN 50% AND LESS THAN 20%.

	Perennial			**Intermittent**		
Month	RH>80	RH<50	RH<20	RH>80	RH<50	RH<20
Feb	19.4	1.2	0.0	19.6	1.5	0.0
Mar	8.2	5.9	0.4	9.6	6.0	0.4
Apr	4.5	8.9	0.6	6.2	9.1	0.8
May	3.5	9.0	0.6	4.9	9.0	1.3
Jun	0.4	16.9	4.0	0.9	14.9	5.1

CHAPTER VI

SUMMARY AND CONCLUSIONS

Daily average maximum temperature 2m directly above the stream was not statistically different between perennial and intermittent streams. However, it should be noted that during both transitional and dry conditions the perennial streams averaged .2 and .4°C lower maximum air temperature respectively. This may be a function of evaporative cooling both through transpiration and direct evaporation; and is on the edge of instrument precision. Daily average minimum temperature was higher at perennial streams during all flow conditions. Standard deviation of temperature was similar during flowing conditions; however, during transitional and dry conditions standard deviation temperature is higher at intermittent streams.

Daily average maximum relative humidity is lower during all flowing environments at the perennial stream. Relative humidity is intrinsically related to temperature, lower minimum temperatures at intermittent streams produce an exponential increase in RH (Rosenberg et al., 1983) near intermittent streams. Daily average minimum relative humidity were not statistically different during any of the three flow conditions. However, it should be noted that perennial daily minimum relative humidity was consistently higher than the intermittent minimum RH. During flowing conditions average daily standard deviation of relative humidity are statistically similar. Transitional and dry conditions lead to greater standard deviation of relative humidity at the intermittent streams.

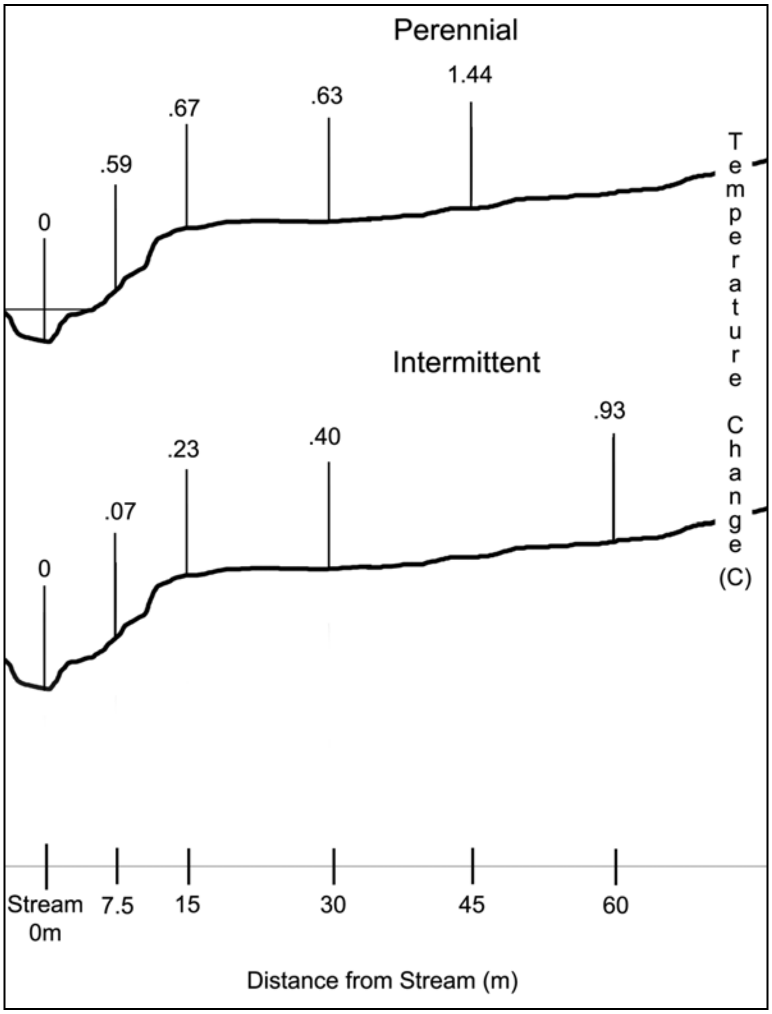
Both temperature (TG) and relative humidity gradients (RHG) were found to have seasonal variation associated with flow condition during the daytime. TG and RHG during the daytime for intermittent streams are statistically lower than perennial streams during dry conditions. This implies that intermittent channels are subject to temperatures which more closely approximate upland temperatures and relative humidity than perennial streams once they have ceased to flow. While perennial streams house substantial flow, this difference should continue. During daytime hours and transitional flow conditions the TG of intermittent and perennial streams were not statistically different, but RHG was, with perennial streams averaging a higher gradient than that of intermittent streams. During flow conditions TG for intermittent streams were higher than perennial streams, which had a negative gradient. During flowing conditions the RHG were not statistically different between stream classes. The abundance of water, and minimal solar radiation associated with flowing conditions are likely the reason for little variation of RHG during this period. An ANOVA of TG and RHG by transect, revealed strong influences on a transect by transect basis. The three streams with similar average topographical slope to upland mirrored one another during all weeks. However strongly contrasting topography at I1 is probably responsible for much of the variability of the intermittent streams RHG and TG found in group analysis.

Variation of temperature along transects I2 and P1 allowed a direct comparison of intermittent and perennial class streams on a station by station basis. I2 statistical variation was only apparent at Station 5 during week 12, and Stations 4 and 5 during week 13. P1 statistical variation began at Station 2 and was significantly different from all other Stations. Weeks 12 and 13 correlated with the cessation of stream flow at the intermittent stream I2, and continue flow at the P1.

Changes in temperature along transects at their greatest were 2.4°C, and on average 0.13°C. The instruments which were used to measure these changes are only accurate to ± .3°C. Instrument accuracy is a limitation of this study along with limitation of available sites. Further investigations into temperature and relative humidity gradients around perennial and intermittent streams should investigate closer to the stream, as an unnecessary distance was traveled away from streams in order to determine at stream effects on temperature and relative humidity. It would also be beneficial to have measurements at multiple levels, lapse rates are present over bodies of water and land (Oke, 1987), and it is possible that changes in air temperature are greater at levels closer to the surface.

In conclusion, relative humidity and temperature conditions at intermittent channels after they have stopped flowing are likely to be similar to riparian and upland conditions compared to perennial channels which contain substantial flowing surface water (Figure 18).

Predicted temperatures based on linear regressions reveal subtle differences between intermittent and perennial tributaries. The size of the streams attribute to the magnitude with which they affect the temperature gradient from stream to upland (Figure 19).



- Perennial TG = 0.0195 (C°/m)
- Intermittent TG= 0.0102 (C°/m)
- Intermittent subdued TG is a feature of reduced evaporative cooling at the intermittent stream.
- Perennial stream surface water evapotranspiration creates a temperature which significantly varies from the riparian and upland stations during summer peak daytime. The result is a steeper temperature gradient at the perennial stream than the intermittent stream.

Figure 18. Actual intermittent and perennial average change in temperature during weeks 12 and 13. Diagram based on daytime (1400 -1800) average change in temperature from stream temperature during the 12th and 13th weeks of the study. During this period intermittent stream (I2) is completely dry and the perennial stream continues to flow. Perennial represents averages of P1 and Intermittent represents averages of I2.

The observed temperature and humidity variations adjacent to perennial and intermittent tributary streams give rise to new questions regarding implications of stream type and seasonal inputs into the riparian energy balance.

1. What percentage of the river heat budget is latent heat of vaporization along small tributary streams during the summer daytime hours responsible for?

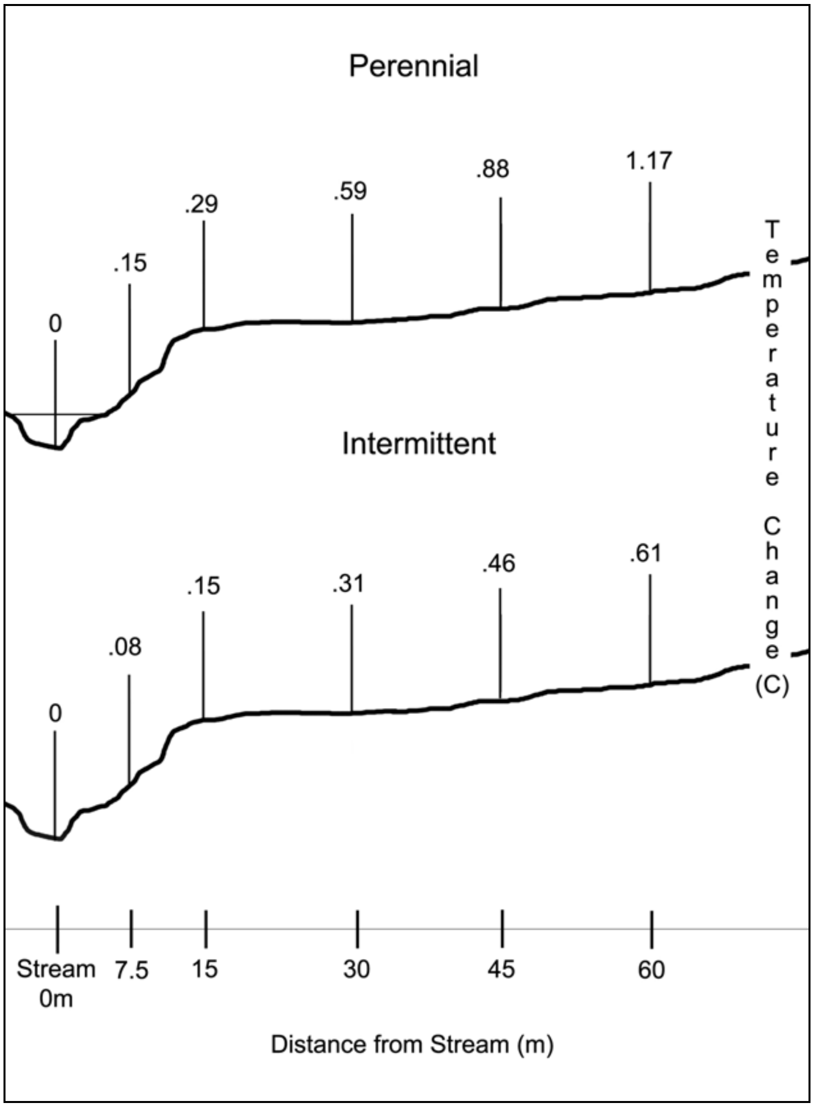
2. Do the findings of this study apply to small tributaries in general in this region?

3. Is the influence of the stream on air temperature and relative humidity stronger closer to the surface (e.g., 1m or .5m)?

4. Are tributary perennial streams capable of providing extended cool moist air along the complete extent of the stream network?

5. How do the differences between intermittent and perennial air temperature and relative humidity found in this study translate to real differences in habitat viability for local flora and fauna?

Perennial streams compared to intermittent streams appear to have relatively lower temperatures at the stream compared to riparian and upland temperatures. More physical and biological research on these extensive, and mostly unprotected stream classes should help to improve the physical understanding of these important ecosystems.



- Perennial TG = 0.0195 (C°/m)
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Figure 19. Predicted intermittent and perennial change in temperature derived from TG data. Diagram based on daytime TG data during dry conditions. Perennial on top, and intermittent on the bottom. Temperature change by Station was calculated using TG × Distance. Similar distances from the stream were used as the Stations used in the study.

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