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Sensitivity and exposure of brook trout (*Salvelinus fontinalis* habitat to climate change

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Sensitivity and Exposure of Brook Trout (*Salvelinus fontinalis*) Habitat to Climate Change

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Abstract

Predicting coldwater fisheries distributions under various climate scenarios is of interest to many fisheries managers and researchers. Larger scale models have been useful in highlighting the potential large scale threat. However, the error associated with these models makes predictions of the persistence of individual cold water fisheries problematic. Most of this error is associated with predicted air and water temperatures which typically are simple elevation and location (latitude/longitude) models with simple caveats such as 1°C increase in air temperature equals 0.8°C increase in water temperatures. I directly measured paired air and water temperatures in watersheds containing reproducing populations of brook trout in Virginia during the critical summer period (July 1 to September 30) in both 2009 and 2010. I developed a classification system using sensitivity (change in the daily maximum water temperature from a 1°C increase in the daily maximum air temperature) and exposure metrics (frequency; duration; and magnitude of daily maximum water temperatures > 21°C) that classified brook trout populations into four categories: High Sensitivity-High Exposure; High Sensitivity-Low Exposure; Low Sensitivity-High Exposure and Low Sensitivity- Low Exposure. I found that my paired air and water temperature relationships were highly variable among sites and were a useful metric for classifying the sensitivity and exposure of individual brook trout populations to various climate change scenarios. I identified many (25%) Low Sensitivity- Low Exposure brook trout populations that appear to be resilient to climate change. The median sensitivity (0.39°C) in this study was much lower than the assumed rate (0.80°C) used in many regional models that predicted a complete extirpation of brook trout in Virginia. Several GIS generated metrics (sample area; %

riparian canopy; solar insolation ; % groundwater; elevation; % watershed in forest cover) were useful for predicting (accuracy approximately 75%) sensitivity and exposure values. Directly measuring paired air and water temperature relationships can reduce the error of large scale models. I recommend that managers making investment decisions in protecting and restoring brook trout use my direct measurement approach when they cannot afford to make a Type I or Type II error.

Introduction

Although no known brook trout *Salvelinus fontinalis* populations have been extirpated due to climate change effects (Hudy et al. 2008), several studies have identified the potential threat of air temperature increases in dramatically reducing the current range of brook trout in the eastern United States (Meisner 1990; Flebbe 1994; Clark et al. 2001; Flebbe et al. 2006). While useful in highlighting the potential threat from increases in air temperature, the errors (Type I or Type II) associated with models using secondary data (predicted air temperatures (PRISM 2007); and predicted water temperature response relative to predicted air temperature) makes predictions of the persistence of individual brook trout populations under various climate change scenarios problematic (Johnson 2003). Models using secondary data often ignore site-specific landscape characteristics that may influence the relationship between air and water temperatures. Predictions of habitat loss based on models that assume a simple positive direct relationship between air and water temperature across all habitats are likely to be overly pessimistic (Meisner 1990; Flebbe 1994; Keleher and Rahel 1996; Rahel et al. 1996; Clark et al. 2001; Flebbe et al. 2006; Rieman et al. 2007; Williams et al. 2009). Some brook trout habitats may persist even under the most pessimistic climate change scenarios due to localized landscape conditions.

Variability in the relationship between water temperature and air temperature can be quantified (Cluis 1972; Pilgrim et al. 1998; Mohseni and Stefan 1999; Isaak and Hubert 2001; Johnson 2003) and has the potential to be effectively used by managers to rank the resistance of individual brook trout populations to various climate change scenarios. Identifying brook trout habitats that are more resistant than others to water temperature increases from air temperature increases is an important step in prioritizing the restoration and conservation work of the Eastern Brook Trout Joint Venture (EBTJV) (EBTJV 2006). Pilot studies and earlier research (Fink 2008) suggest that the relationship between air and water temperature is (1) highly variable at the current brook trout population scale and (2) influenced by local conditions and their interactions (i.e. elevation, aspect, topography shading, riparian cover, latitude, longitude, insolation and ground water sources). The influence of these characteristics at localized scales appears to play a more important role than expected in stream thermal stability (Meisner 1990; Pilgrim et al. 1998; Moore et al. 2005; Wehrly et al. 2007; Fink 2008).

I focused on metrics associated with daily maximum water temperature (Huff et al. 2005; Wehrly et al. 2007) during the critical period for this study because (1) increases in air temperature (and presumed increases in water temperature) have the highest probability occurrence in various climate change scenarios (IPCC 2007); (2) daily maximum water temperature metrics for presence and absence of reproducing populations of brook trout are known (Stoneman and Jones 1996; Picard et al. 2003; Wehrly et al. 2003; Huff et al. 2005; Wehrly et al. 2007); and (3) I believe lethal water temperature effects from climate change will likely have an immediate and dramatic effect on existing brook trout populations.

The specific objectives of this study are to (1) quantify the variability in the daily maximum air and daily maximum water temperature responses during the water temperature stress period (July 1 to September 30) for brook trout populations in Virginia; (2) develop a classification system using sensitivity and exposure metrics that will be of use to managers in prioritizing their work for brook trout; and (3) develop a model to predict classification categories (sensitivity and exposure) based on land use metrics.

Methods

Study Area, Sample Unit Delineation and Selection

My research includes all habitats with reproducing populations of brook trout in Virginia. Brook trout presence-absence data from the EBTJV (Mohn and Bugas 1980; EBTJV 2006; Hudy et al. 2008) were overlaid on catchments from the National Hydrography Plus (NHD+) dataset (USGS 2008) to produce a dataset of catchments containing reproducing populations of brook trout. Contiguous catchments containing brook trout were then dissolved into individual watersheds or "habitat patches" of brook trout. Contiguous catchments that contained dams impassable to brook trout were further broken down into separate patches. Each patch was presumed to be genetically isolated from other patches by either distance barriers (physical, habitat/thermal) or invasive species (to include stocked waters). A total of 272 patches were found in Virginia (Figure 1).

Candidate landscape metrics hypothesized to be important to potential air temperature and water temperature relationships were summarized in a Geographic Information System (GIS) for the pour-point and centroid of all brook trout patches (Table 1). Values for all candidate landscape metrics are listed in Appendix A1. The pour-point is the intersection of the most downstream stream segment in the NHD+ dataset and the brook trout occupied catchment boundary. The centroid location of the brook trout habitat patch was determined by a GIS, and then adjusted in the field to the closest stream segment (Figure 2).

Table 1. Candidate landscape metrics summarized for watersheds above each sample point. A "derived" source refers to a personally calculated metric. Metrics in **bold** used for cluster analysis.

Candidate Landscape Metrics	Units	Source
Total Annual Solar Insolation in riparian sample area	**kWh**	**derived (Fu and Rich 1999)**
Sample point Elevation	**m**	**derived**
Sample point 30-year Mean Max Temp	**Celsius**	**PRISM 2007**
% Groundwater (BFI) flow in sample area	**% of patch**	**USGS 2003**
% Forest Area in sample area	**% of patch ha**	**USGS 2009**
Sample Area	ha	derived
Sample Area in riparian corridor	ha	derived (100m buffer NHD+)
Mean Canopy Cover in sample area	% of patch	USGS 2009
Mean Canopy Cover riparian corridor of sample area	% of patch	USGS 2009
Land Use Area by Category in sample area	% of patch ha	USGS 2009
Land Use Area by Category in sample area	% of patch ha	USGS 2009
Geology Type and Category in sample area		DMME 2008
Sample Point Latitude, Longitude	Decimal Deg.	derived
Stream Length	km	derived
% Forest In Sample Area Riparian Corridor	% ha	USGS 2009
% Groundwater flow in sample riparian corridor	% of patch	USGS 2003
Total Annual Solar Insolation in sample area	kWh	Fu and Rich 1999
Total Annual Solar Insolation per stream km	kWh/km	derived (Fu and Rich 1999)
Total Annual Solar Insolation per stream km in riparian corridor	kWh/30mpixel	derived (Fu and Rich 1999)
Total Annual Solar Insolation (July 1-Sept. 30)	kWh/30mpixel	derived (Fu and Rich 1999)
Total Annual Solar Insolation in riparian corridor (July 1-Sept. 30)	kWh/30mpixel	derived (Fu and Rich 1999)
Total Annual Solar Insolation per stream km (July 1-Sept. 30)	kWh/km	derived (Fu and Rich 1999)
Total Annual Solar Insolation in riparian corridor per stream km (July 1-Sept. 30)	kWh/km	derived (Fu and Rich 1999)
Total Annual Solar Insolation*Canopy Cover per stream km	kWh/km	derived (Fu and Rich 2002)
Total Annual Solar Insolation*Canopy Cover in riparian corridor per stream km	kWh/km	derived (Fu and Rich 2002)
Total Annual Solar Insolation*Canopy Cover per stream km (July 1-Sept. 30)	kWh/km	derived (Fu and Rich 2002)
Total Annual Solar Insolation*Canopy Cover in riparian corridor per stream km (July 1-Sept. 30)	kWh/km	derived (Fu and Rich 2002)
Mean Annual Solar Insolation in sample area	kWh/30mpixel	derived (Fu and Rich 2002)
Mean Annual Solar Insolation in riparian corridor	kWh/30mpixel	derived (Fu and Rich 2002)
Mean Annual Solar Insolation*Canopy Cover	kWh/30mpixel	derived (Fu and Rich 2002)
Mean Annual Solar Insolation*Canopy Cover in riparian corridor	kWh/30mpixel	derived (Fu and Rich 2002)
Mean Solar Insolation*Canopy Cover (July 1-Sept. 30)	kWh/30mpixel	derived (Fu and Rich 2002)
Mean Solar Insolation*Canopy Cover in riparian corridor (July 1-Sept. 30)	kWh/30mpixel	derived (Fu and Rich 2002)
Mean Solar Insolation in Sample Area (July 1-Sept. 30)	kWh/30mpixel	derived (Fu and Rich 2002)
Mean Solar Insolation in riparian corridor (July 1-Sept. 30)	kWh/30mpixel	derived (Fu and Rich 2002)

A cluster analysis (Ward's Method; SAS 2000) was used to group the 272 patches into 9 groups (Figure 1) (see Table 1 for grouping metrics). General grouping of the clusters are in Table 2. I then randomly selected 50 patches proportionally from the 9 groups to ensure a representative sample of habitats.

Table 2. Explanation of how patches were grouped into clusters based on patch metrics.

Cluster	Riparian Solar	Sample Point Elevation	Sample Point Max Air Temp	% Forest Sample Area	%BFI
1	Low	Low	High	High	Low
2	Low	Low	High	High	Low
3	Low	Medium	Medium	High	Low
4	Low	Medium	Medium	Medium	Medium
5	Medium	High	Low	High	Low
6	Medium	High	Medium	Low	Low
7	High	Medium	High	High	Medium
8	High	High	Medium	Low	Low
9	Medium	High	Low	Low	High

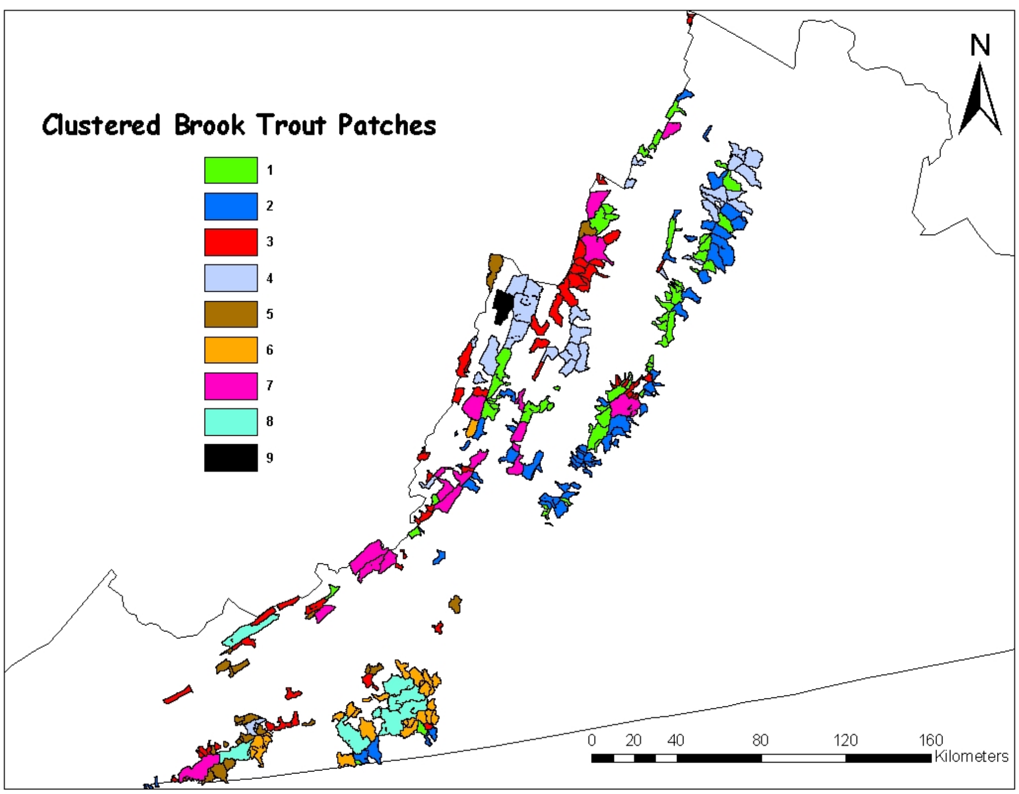

Figure 1. Unique brook trout habitat patches (N=272) in the state of Virginia clustred into 9 groups based on physical habitat metrics (see Table 1 for metrics).

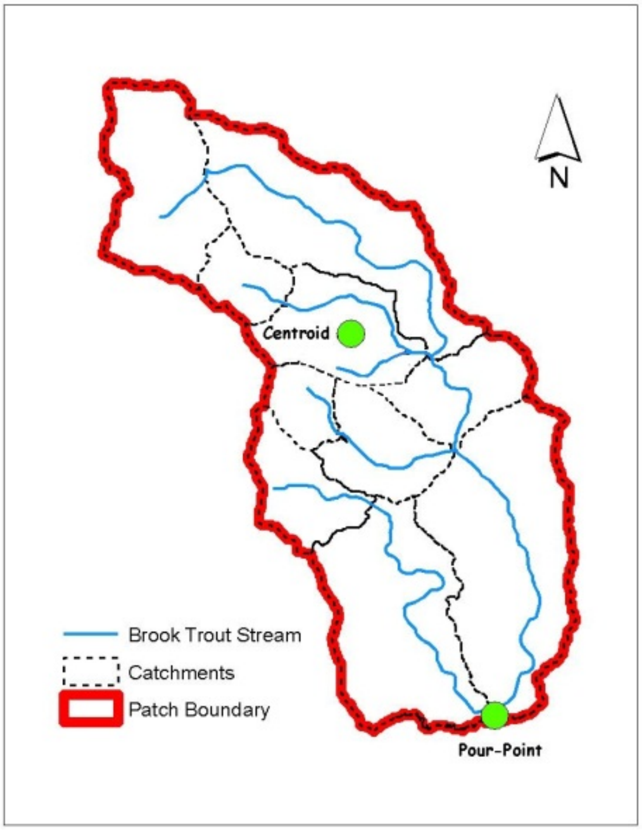

Figure 2. Contiguous catchments containing brook trout were dissolved into "patches" of brook trout habitat. Paired air and water temperature thermographs were placed at pour point and at the stream section nearest to the centroid to directly measure water temperature responses to air temperatures.

Sampling Protocol

Paired (air and water) thermographs (HOBO Watertemp Pro v2; accuracy 0.2˚C; drift <0.1 annually; Onset Computer Corporation 2008) were placed at the pour point and at the centroid of each sampled patch**.** All thermographs were set to record every 30 min (Dunham et al. 2005; Huff et al. 2005) from July 1st through September 30th for both 2009 and 2010 (Stoneman and Jones 1996), thus encompassing the most likely period when water temperatures are stressful or potentially lethal (> 21ºC) for brook trout in Virginia. Thermographs were calibrated pre and post-deployment following methods summarized in Dunham et al. (2005). Due to the possibility that stream channels may become dry during summer low flow periods, water temperature thermographs were placed near maximum residual pool depths (Lisle 1987). A shield was used to reduce direct ultraviolet light contact with air temperature thermographs (Dunham et al. 2005; Wise et al. 2010). The raw 30 minute air and water temperature data was screened for outliers and summarized as daily maximums for most analyses. Outliers were primarily from dry stream channels. A Standard Operating Procedures guide was created for field crews (Appendix A2).

Data Analysis

Sensitivity and exposure metrics were created for analysis using daily maximum air and water temperature. Sensitivity is defined as the change in the daily maximum water temperature (DMAXW) from a 1°C increase in the daily maximum air temperature (DMAXA). Because this sensitivity varies throughout the DMAXA range for a given site, I report the median change for each sample location as a single sensitivity metric. In addition, a standardized exposure score was developed for each site from the DMAXW values. I chose 21°C DMAXW as my exposure value based on previous work from Rahel et al. (1996), as well as 21°C being a median value among several studies defining thermal maxima for brook trout (Eaton et al. 1995; Eaton and Scheller 1996; Johnstone and Rahel 2003). Duration (number of consecutive days above 21°C), frequency (proportion of days above 21°C) and magnitude (average DMAXW of all DMAXW days over 21°C) for the sample period were calculated for each site. The three measures of exposure were then combined into a single measure by standardizing each exposure measure ((x-mean)/SD) and taking the average. Because a number of sites have zero values of exposure, the index was adjusted so that the minimum value is zero.

I combined sensitivity and exposure scores into a conceptual classification system with four categories: (high sensitivity-high exposure (HS-HE); high sensitivity-low exposure (HS-LE); low sensitivity-high exposure (LS-HE) and low sensitivity-low exposure (LS-LE) (Figure 3). The quadrant in which each site appeared was defined by the sensitivity and exposure values of each site (Figure 3). For example, the LS-LE category contains sites that consistently have low exposure to water temperature > 21°C and are most resistant to increased water temperature from air temperature increases. These sites have stable stream temperatures with daily maximums never reaching or exceeding 21°C. The HS-HE category contains sites with high exposure to water temperature > 21°C and are most sensitive to increased water temperature from increased air temperature.

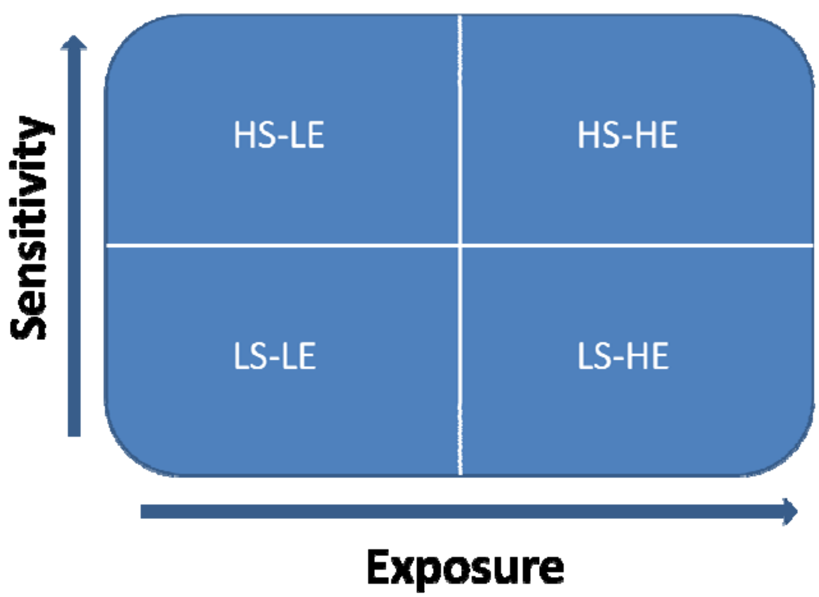

Figure 3. Proposed conceptual classification system for classifying brook trout habitats. LS-LE are least vulnerable to climate change, HS-LE are somewhat vulnerable, LS-HE are moderately vulnerable, and HS-HE are most vulnerable to climate change.

Predictions

Multiple linear regression was used to predict sensitivity values from land use metrics. Due to a large number of sites with exposure values of zero, logistic regression was used to predict exposure values from land use metrics. The measured sensitivity and exposure values were then compared to the predicted to determine model accuracy.

Results

Sensitivity

In 2009, the sensitivity response of DMAXW to a 1°C increase in DMAXA had a median of 0.38°C among all sites and air temperature ranges (Figure 4). However, there was considerable variation both among sites and temperature ranges. For example a 1°C DMAXA increase from 16 to 17°C averaged a 0.52°C increase in DMAXW but ranged from 0.13 to 0.98°C, while a 1°C increase in DMAXA from 25 to 26°C averaged 0.35°C with a range of 0.10 to 0.82°C (Figure 4).

In 2010, the sensitivity metric had a median of 0.40°C. Sensitivity within a site was significantly less (mean difference -0.069) (T test; $t = -5.01$; $p < 0.0001$) in 2010 than in 2009 (Figure 5). The two sensitivity years were correlated (Spearman Correlation; $r = 0.690$; $p < 0.0001$) (Figure 5). Individual sensitivity scores for both years are found in Appendix A3.

Exposure

Exposure metrics varied among sites in 2009; duration averaged 11.11 d; frequency averaged 23.4% and magnitude above 21°C averaged 1.78°C. Exposure metrics varied among sites in 2010; duration averaged 19.81 d; frequency averaged 46.5%; magnitude above 21°C averaged 3.78°C.

Exposure in 2010 was greater than exposure in 2009 (T test; $t = 6.24$; $p < 0.0001$) with a site mean of 0.34 exposure units greater. This was expected because of a 1.43°C mean air temperature increase in 2010 (Figure 6). The two exposure years measured were highly correlated (Spearman Correlation; $r = 0.911$; $p < 0.0001$) (Figure 7). Individual exposure scores for both years are found in Appendix A3.

Classification

The cutoffs for sensitivity/exposure classification categories were: > 0.38°C high sensitivity, ≤ 0.38°C low sensitivity; > 0 = high exposure, ≤ 0 = low exposure. I chose the median sensitivity as an arbitrary cutoff value simply because the variation within and among air temperature bins was so great (Figure 4). The exposure cutoff was set to zero because exposure values greater than zero indicate stress to brook trout (DMAXW >21°C). The 2009 Sensitivity-Exposure classification categorized 42.3% of sites as (HS-HE); 33.3% (LS-LE); 5.1% (HS-LE); 19.2% (LS-HE) (Figure 8).The 2010 Sensitivity-Exposure classification categorized 40.3% of sites as (HS-HE); 9.1% (LS-LE); 2.6% (HS-LE); 48.1% (HS-LE) (Figure 9).

Sensitivity was lower in 2010 than 2009 and 36.0% of sites changed classification group (Table 3). Thirteen sites became less sensitive changing from HS to LS, and 9 sites became more sensitive changing from LS to HS (Table 3). Conversely, exposure was higher in 2010 than 2009 and 26.0% of sites changed classification group. Zero sites experienced less exposure, but 16 sites experienced higher exposure changing from LE to HE (Table 3). Classification categories for all sites are shown in Table 4.

Prediction

In 2009, the measured sensitivity and exposure values matched the predicted values 77.8% of the time but varied by category. Percentages for prediction categories matching true categories between 2009 and 2010 were similar among the HS-HE and

Table 3. Sensitivity/Exposure classification percentages and differences 2009-2010

Sensitivity/Exposure Difference 2009-2010		
	Sensitivity	**Exposure**
Change	36%	26%
No Change	64%	73%
Less	13 sites	0 sites
More	9 sites	16 sites

Sensitivity/Exposure Classifications 2009-2010		
	2009	**2010**
HS-HE	42%	40%
HS-LE	5%	3%
LS-HE	19%	48%
LS-LE	34%	9%

HS-LE categories; however, higher exposure values in 2010 changed prediction accuracy among the LS-HE and LS-LE categories (Table 5). Predicted and true categories for each site from 2009 and 2010 are shown in Appendix A4.

Metrics that significantly predicted sensitivity in 2009 were Sample Area ($F = 9.63$; $df = 77$; $p < 0.0001$); Mean Annual Solar Insolation in sample area ($F = 9.31$; $df = 776$; $p = 0.002$), with a model $r^2 = 0.25$ (Table 6). Metrics that significantly predicted sensitivity in 2010 were Stream Length ($F = 14.95$; $df = 76$; $p = 0.0002$); Mean Canopy Cover in riparian corridor ($F = 16.81$; $df = 76$; $p = 0.0001$); % Groundwater flow in sample area ($F = 17.64$; df = 76; $p < 0.0001$); Mean Solar Insolation in sample area (July 1-Sept 30) ($F = 21.25$; df = 76; $p < 0.0001$) with a model $r^2 = 0.36$ (Table 6).

Metrics that significantly predicted exposure in 2009 were Sample Area (Wald $Chi^2 = 7.33$; df = 23; $p = 0.006$); %Forest in sample area (Wald $Chi^2 = 4.43$; df = 23; $p = 0.03$); Sample Point Elevation (Wald $Chi^2 = 11.38$; df = 23; $p < 0.001$) (Table 6). Only one metric significantly predicted exposure in 2010, Mean Solar Insolation*Canopy Cover in riparian corridor (July 1-Sept 30) (Wald $Chi^2 = 0.67$; df = 25; $p = 0.01$) (Table 6).

Table 4. Sensitivity/Exposure categories 2009-2010. Categories are listed in consecutive year for comparison. Pop# = Patch ID; Site C = centroid, p = pour-point; Sens09-10 = Sensitivity 2009 or 2010; Exp09-10 = Exposure 2009 or 2010; S-E Class = Sensitivity-Exposure category. **Bold** indicates category changes between 2009 and 2010**.** Table includes only sites with complete 2009 and 2010 data.

.

POP#	Site	Sens09	Sens10	Exp09	Exp10	S-E Class09	S-E Class10
23	C	LS	LS	LE	**HE**	LSLE	**LSHE**
26	C	HS	**LS**	HE	HE	HSHE	**LSHE**
27	C	LS	LS	LE	LE	LSLE	LSLE
33	C	HS	HS	HE	HE	HSHE	HSHE
39	C	LS	**HS**	HE	HE	LSHE	**HSHE**
40	C	LS	**HS**	LE	**HE**	LSLE	**HSHE**
61	C	LS	**HS**	LE	**HE**	LSLE	**HSHE**
63	C	HS	HS	HE	HE	HSHE	HSHE
64	C	HS	HS	HE	HE	HSHE	HSHE
72	C	LS	**HS**	LE	**HE**	LSLE	**HSHE**
84	C	LS	**HS**	LE	**HE**	LSLE	**HSHE**
87	C	LS	**HS**	LE	LE	LSLE	**HSLE**
105	C	LS	LS	LE	LE	LSLE	LSLE
106	C	LS	LS	HE	HE	LSHE	LSHE
143	C	LS	LS	HE	HE	LSHE	LSHE
168	C	HS	**LS**	HE	HE	HSHE	**LSHE**
172	C	HS	HS	HE	HE	HSHE	HSHE
174	C	LS	LS	LE	LE	LSLE	LSLE
182	C	LS	LS	HE	HE	LSHE	LSHE
185	C	LS	LS	LE	**HE**	LSLE	**LSHE**
220	C	LS	LS	HE	HE	LSHE	LSHE
229	C	LS	LS	HE	HE	LSHE	LSHE
234	C	HS	HS	HE	HE	HSHE	HSHE
247	C	LS	LS	HE	HE	LSHE	LSHE
260	C	HS	HS	LE	**HE**	HSLE	**HSHE**
262	C	LS	LS	LE	LE	LSLE	LSLE
273	C	LS	**HS**	LE	**HE**	LSLE	**HSHE**
276	C	LS	**HS**	LE	**HE**	LSLE	**HSHE**
298	C	HS	HS	HE	HE	HSHE	HSHE
307	C	HS	**LS**	HE	HE	HSHE	**LSHE**
308	C	LS	LS	LE	LE	LSLE	LSLE
312	C	HS	HS	HE	HE	HSHE	HSHE
315	C	HS	HS	HE	HE	HSHE	HSHE
19	P	LS	LS	HE	HE	LSHE	LSHE
27	P	HS	HS	HE	HE	HSHE	HSHE
30	P	LS	**HS**	HE	HE	LSHE	**HSHE**
39	P	HS	**LS**	HE	HE	HSHE	**LSHE**
40	P	LS	LS	HE	HE	LSHE	LSHE
63	P	HS	**LS**	LE	**HE**	HSLE	**LSHE**

Table 4. Sensitivity/Exposure categories 2009-2010 continued

POP_	**Site**	**Sens09**	**Sens10**	**Exp09**	**Exp10**	**S-E Class09**	**S-E Class10**
64	**P**	HS	**LS**	HE	HE	HSHE	**LSHE**
72	**P**	LS	LS	LE	**HE**	LSLE	**LSHE**
77	**P**	LS	LS	LE	**HE**	LSLE	**LSHE**
84	**P**	LS	LS	LE	**HE**	LSLE	**LSHE**
102	**P**	LS	LS	LE	LE	LSLE	LSLE
105	**P**	LS	LS	HE	HE	LSHE	LSHE
106	**P**	HS	HS	HE	HE	HSHE	HSHE
112	**P**	HS	**LS**	HE	HE	HSHE	**LSHE**
143	**P**	LS	LS	HE	HE	LSHE	LSHE
168	**P**	HS	**LS**	HE	HE	HSHE	**LSHE**
172	**P**	HS	HS	HE	HE	HSHE	HSHE
174	**P**	HS	**LS**	HE	HE	HSHE	**LSHE**
182	**P**	HS	HS	HE	HE	HSHE	HSHE
185	**P**	HS	**LS**	HE	HE	HSHE	**LSHE**
220	**P**	HS	**LS**	HE	HE	HSHE	**LSHE**
229	**P**	LS	**HS**	HE	HE	LSHE	**HSHE**
234	**P**	HS	**LS**	HE	HE	HSHE	**LSHE**
247	**P**	LS	LS	HE	HE	LSHE	LSHE
260	**P**	LS	**HS**	LE	**HE**	LSLE	**HSHE**
273	**P**	LS	LS	LE	**HE**	LSLE	**LSHE**
298	**P**	HS	HS	HE	HE	HSHE	HSHE
307	**P**	HS	HS	HE	HE	HSHE	HSHE
308	**P**	HS	HS	HE	HE	HSHE	HSHE
312	**P**	HS	HS	HE	HE	HSHE	HSHE
315	**P**	HS	HS	LE	**HE**	HSLE	**HSHE**
319	**P**	HS	**LS**	HE	HE	HSHE	**LSHE**

Table 5. Sensitivity/Exposure Prediction percentages. Percentages shown are the predicted % correct for each category.

Sensitivity/Exposure Prediction percentages 2009-2010		
Category	**2009**	**2010**
HS-HE	57.7%	59.7%
HS-LE	94.9%	97.4%
LS-HE	80.7	51.9%
LS-LE	77.7%	90.9%
Overall	77.8%	74.3%

Table 6. Metrics used to predict Sensitivity/Exposure in 2009-2010. Sensitivity metrics were calculated using multiple linear regression, and exposure metrics were calculated using logistic regression.

Sensitivity 2009	Model r^2 = 0.25		
Metric	**F value**	**df**	**p-value**
Intercept	105.96	77	< 0.0001
Sample Area	9.63	77	0.002
Mean Annual Solar Insolation	9.31	77	0.003
***Canopy in Riparian Corridor**			

Sensitivity 2010	Model r^2 = 0.36		
Metric	**F value**	**df**	**p-value**
Intercept	18.35	76	< 0.0001
Stream Length	14.95	76	0.0002
%Canopy in Riparian Corridor	16.81	76	0.0001
Mean %groundwater	17.64	76	< 0.0001
Mean Solar Insolation (July 1-Sept 30)	21.25	76	< 0.0001

Exposure 2009			
Metric	**Wald Chi^2**	**df**	**p-value**
Intercept	7.33	23	0.006
Sample Area	4.43	23	0.03
%Forest in sample area	4.7	23	0.03
Sample Point Elevation	11.38	23	<0.001

Exposure 2010			
Metric	**Wald Chi^2**	**df**	**p-value**
Intercept	0.67	25	0.41
Solar Insolation*Canopy (July 1-Sept 30) in Riparian per Stream km	5.9	25	0.01

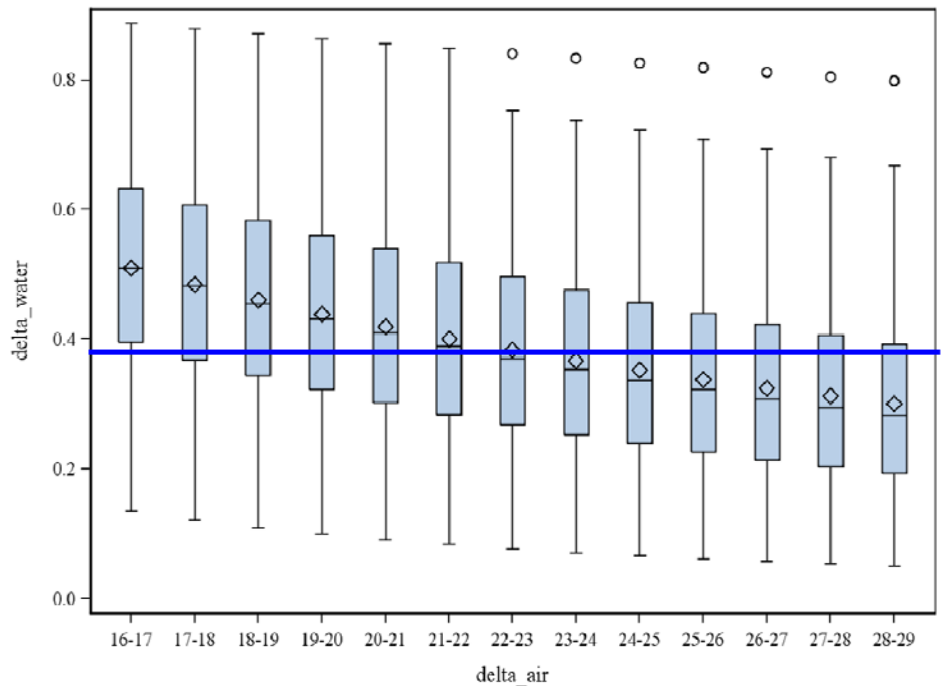

Figure 4. Box plots of the response of daily maximum water temperatures to a 1°C increase in daily maximum air temperature (by one degree bins from 16 to 28 °C) during July 1 through September 30, 2009. The solid line represents the median Δ 0.38°C for 2009. Whiskers represent the 5th and 95th percentiles; circles represent outliers; diamonds represent means; solid line in boxes represent medians.

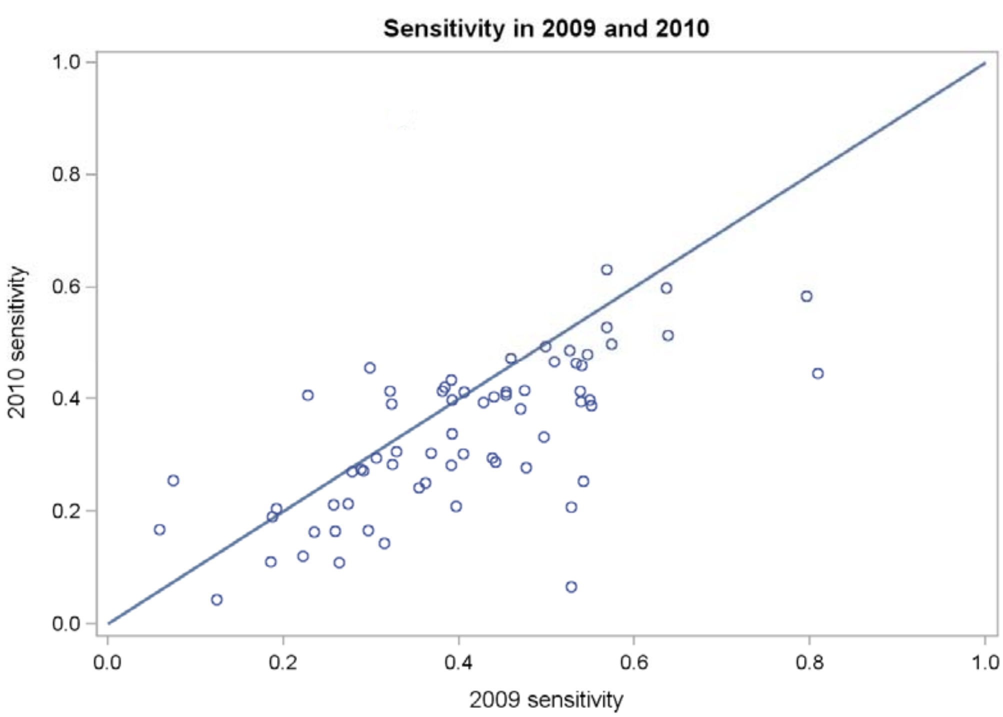

Figure 5. A plot of the 2009 and 2010 sensitivity scores by site. Circles below the solid line indicate sites where sensitivity was lower in 2010 than in 2009. The mean difference at a site was 0.069 °C lower in 2010 than in 2009.

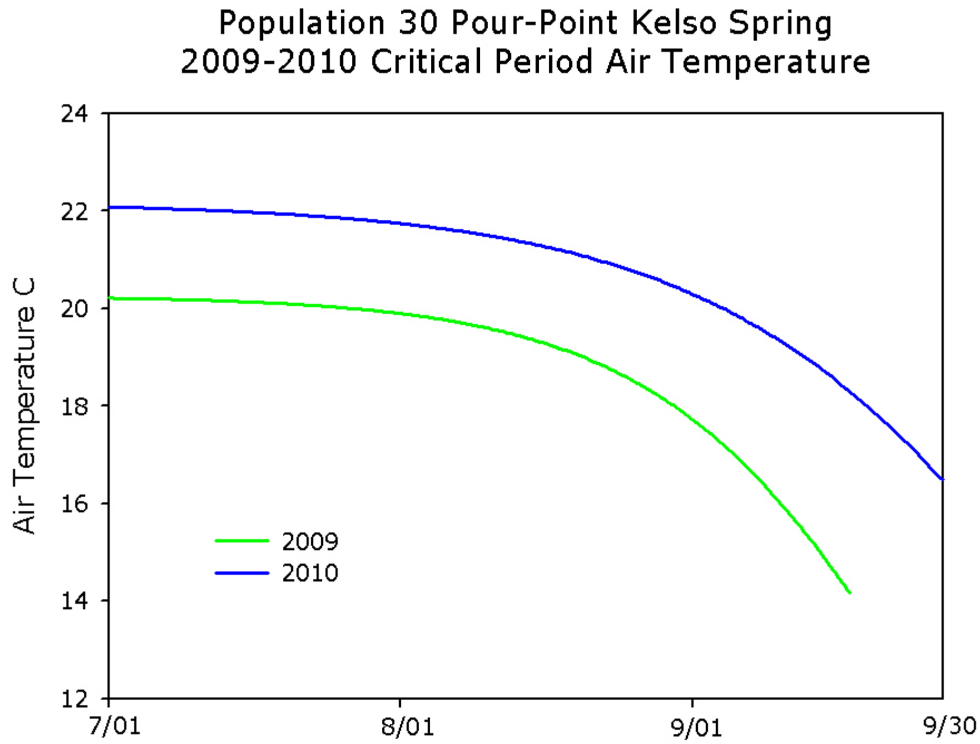

Figure 6. Difference in air temperatures between 2009 and 2010 at a typical site. Mean air temperature increase (2009-2010) among all sites was 1.43 °C.

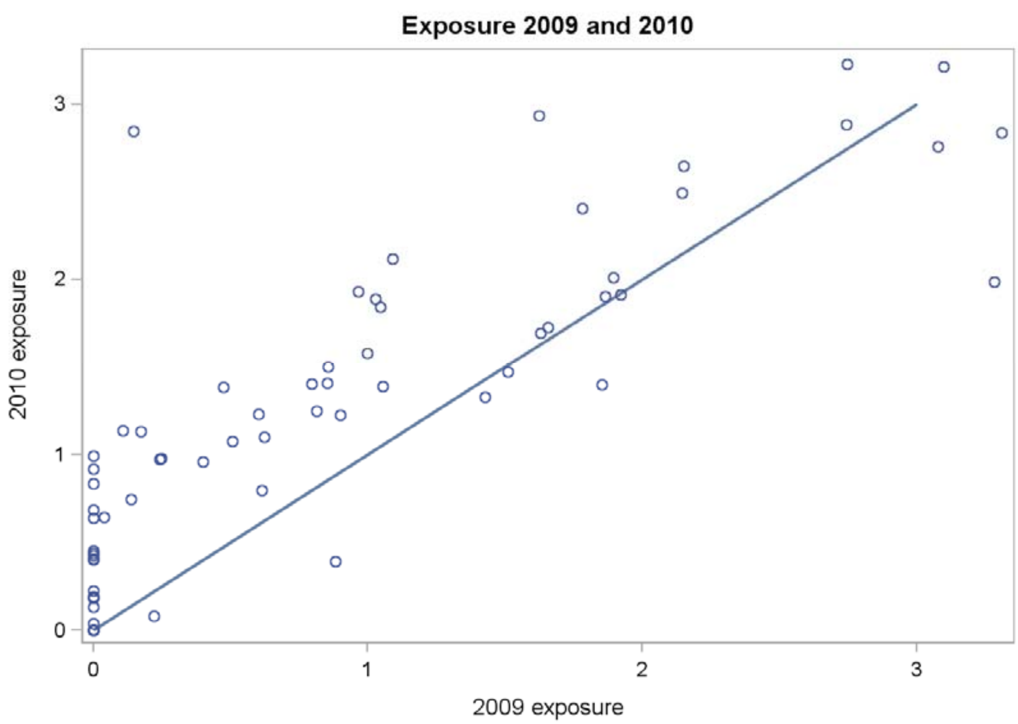

Figure 7. A plot of the 2009 and 2010 exposure scores by site. Circles below the solid line indicate sites where exposure was lower in 2009 than in 2010. The mean difference at a site was 0.34 exposure units higher in 2010 than in 2009.

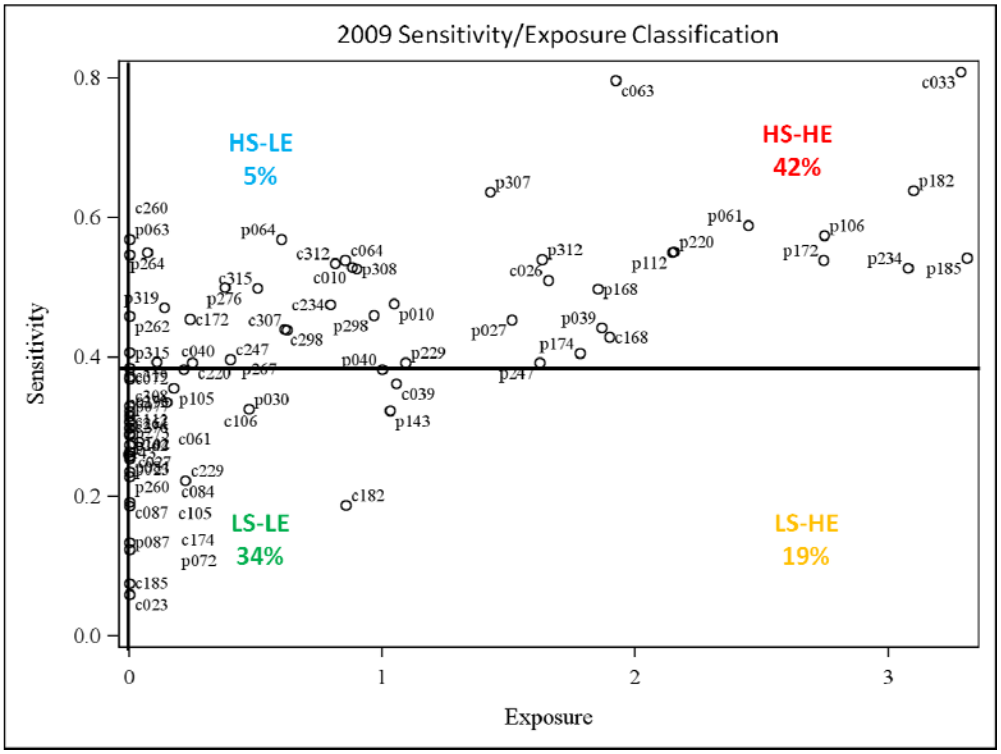

Figure 8. 2009 Sensitivity/Exposure Classification. Sensitivity ≤ 0.38 = low sensitivity, > 0.38 = high sensitivity. Exposure ≤ 0 = low exposure, > 0 = high exposure.

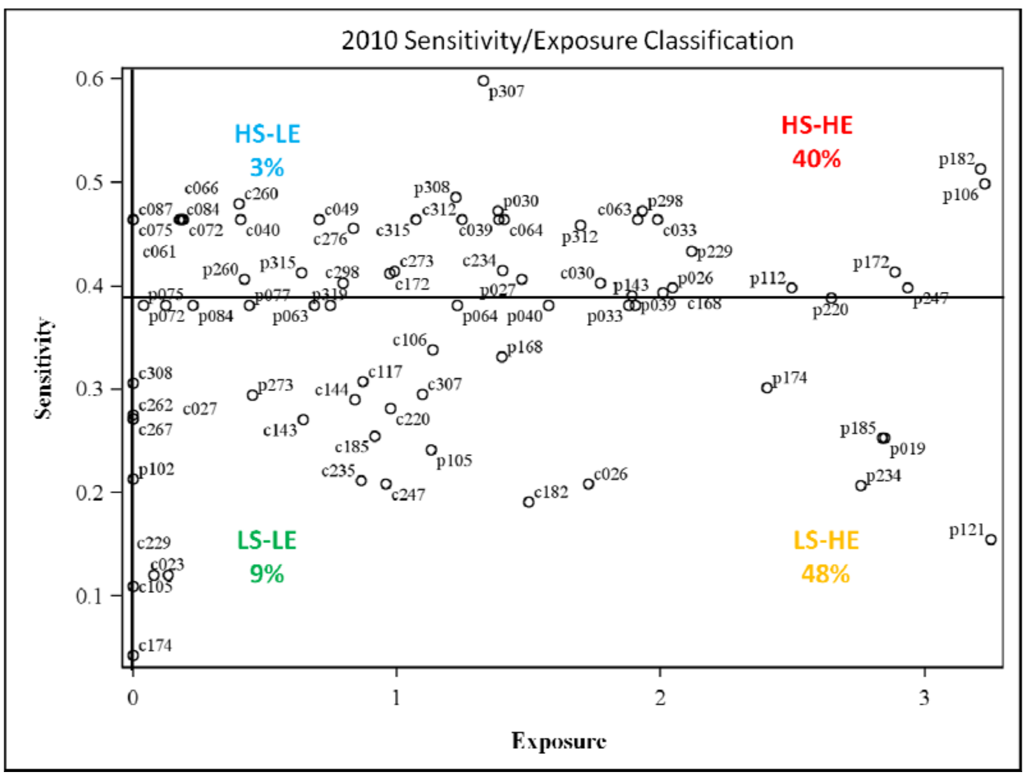

Figure 9. 2010 Sensitivity/Exposure Classification. Sensitivity ≤ 0.38 = low sensitivity, > 0.38 = high sensitivity. Exposure ≤ 0 = low exposure, > 0 = high exposure.

Discussion

My direct measurement approach produced markedly different predictions of future brook trout distributions than models that used secondary data to predict the relationship between air and water temperatures (Meisner 1990; Flebbe 1994; Clark et al. 2001; Flebbe et al. 2006). In most cases, my direct measurement approach identified more brook trout watersheds (25%) that are not sensitive, and currently not vulnerable to many predicted air temperature increases. The secondary data models predict complete extirpation for many scenarios. While typical secondary data sources (maximum air temperature and elevation) used in regional models to predict water temperature are useful, my direct measurement approach reduces the risk of Type I or Type II error. Air temperature increases from the various climate change scenarios can be applied to the site specific air-water temperature relationship curves instead of secondary data model averages to better predict brook trout persistence.

I found considerable variability between 2009 and 2010 in sensitivity. The lower sensitivity in 2010 may have been a response to stream flow differences between 2009 (average precipitation year) and 2010 (drought year). In 2010, groundwater contributed a greater percentage of stream flow possibly lowering sensitivity.

Other explanations for fluctuations of sensitivity and exposure may be found in the land use characteristics at each site. For example, sample site c33 had the highest sensitivity/exposure values for 2009 (HS-HE category), but its values declined in 2010. Site c33 had low percent canopy cover with shallow water which may explain the differences between years. Greater surface water inputs in 2009 may have increased the variation in the sensitivity/exposure values in 2009.

Both sensitivity and exposure prediction models could potentially be improved by sampling a larger geographic area encompassing a greater range of landscape metrics. Repeated paired air and water temperature data over several years that includes different temperature and hydrologic trends could also improve the prediction models. A lack of long-term temperature data coupled with a narrow geographic range of sample sites may explain why different land use metrics predicted sensitivity and exposure between years. Improved sensitivity and exposure models would allow managers to predict sensitivity and exposure from any point on a map and summarize responsive landscape metrics and values upstream of the point of interest. The applications of this type of model may span across disciplines.

I recommend that when managers make long term planning decisions, such as choosing among populations of brook trout for preserving genetic information, or for making investments in habitat restoration, that they develop site specific air-water temperature relationships instead of relying on existing secondary data models. Combined with my sensitivity-exposure classification system, the direct measurement approach gives managers a tool to assess potential persistence of individual brook trout habitats under various climate change scenarios. I recommend their use when the potential for costs of an error (either Type I or Type II) from the secondary data models are high.

Although climate change effects other than air temperature (i.e. rainfall, floods, droughts, changes in land cover, spawning times, invasive species, etc.) are important, the low predictability of these metrics (both in magnitude and direction) at this time make it difficult for managers to incorporate this information into the decision making process. Predictions of increasing air temperatures have the highest reliability (IPCC 2007), and these increases may pose the highest risk of change to the current distribution of brook trout.

Appendix

A 1. Landscape Metric Values. Type (c = centroid, p = pour-point), Lat/Long (decimal degrees), Area (km^2), Stream_LEN (km), Maxtemp (Celsius), Elev (m), Forest and Canopy (%), BFI (%), all Solar metrics (kWh, or kWh/km); Missing Values (-999). See Table 1 for explanation of metric titles.

POP#	Type	LAT	LONG	AREA	Stream_LEN	Maxtemp	Elev	Forest%
10	**C**	38.73346556	79.04022583	32.4	22.9	16.3	580	98.2
19	**C**	38.42111285	79.1991183	16.5	3.3	16.6	644	99.3
23	**C**	38.20593758	79.26200604	11.3	1.3	17.0	609	97.8
26	**C**	38.10949313	79.30571523	35.6	9.8	18.1	512	93.3
27	**C**	38.17807336	79.45710783	13.9	7.8	17.4	599	96.3
30	**C**	37.9927401	79.42595154	2.5	1.7	18.8	449	100
33	**C**	37.98028769	79.62592875	17.7	12.9	18.9	418	96.4
39	**C**	37.7363163	79.74129299	7.3	6.9	19.1	384	96.5
40	**C**	37.75050653	79.91645196	13.8	8.1	17.3	508	86.2
49	**C**	37.93645201	79.80711347	10.4	10.9	17.3	603	96
61	**C**	38.31638684	79.35220278	23.8	5.9	16.2	712	100
63	**C**	38.37584998	79.64005552	31.5	6.3	15.6	824	39.4
64	**C**	38.44221798	79.5390406	19.1	6.6	15.6	791	56.3
66	**C**	38.51485169	79.64728827	27	13.5	13.1	994	92.8
72	**C**	37.71317689	79.98509481	7.2	8.9	17.0	670	79.5
75	**C**	37.72223412	80.18311132	5	3.8	17.5	574	99.3
77	**C**	37.7980823	80.19433938	13.3	7.1	16.8	669	94.2
84	**C**	37.48588356	80.28700769	2	-999.0	18.0	577	99.5
87	**C**	37.35488489	80.41423433	3.6	4.5	17.6	703	98.5
102	**C**	37.56700764	79.47649509	8.6	8.2	18.9	396	99.1
105	**C**	37.50786217	79.46863521	5.7	3.2	17.4	574	98.9
106	**C**	37.52976391	79.55216708	5	3.4	18.0	448	96.1
112	**C**	37.72581378	79.19955038	13.2	11.2	17.9	508	98.6
117	**C**	37.9295325	79.10548054	18.1	16.2	16.5	633	99.3
121	**C**	37.9744455	79.04651259	3.2	3.1	17.5	604	100
143	**C**	37.8923228	78.93564239	4.5	3.2	18.7	474	90.6
144	**C**	37.90149839	78.97063348	2.7	1.9	17.9	577	93
168	**C**	37.83180144	78.97359137	6.2	5.6	18.7	325	92.7
172	**C**	37.85577075	79.06740909	35	37.4	17.7	436	90.8
174	**C**	38.09641778	78.80804636	9.3	3.0	18.1	467	96.5
182	**C**	38.21193307	78.67785797	16.4	8.3	19.0	317	96.3
185	**C**	38.26833271	78.61204636	18.5	4.8	18.9	304	94.2
220	**C**	38.45098109	78.69294346	8.8	6.2	18.4	452	98.9
229	**C**	38.59741922	78.42443012	12.7	6.0	19.1	352	93
234	**C**	38.41723999	78.43709953	24.2	10.4	18.5	365	98.3
235	**C**	38.36938796	78.46858816	12.3	5.0	18.8	339	97.4
247	**C**	38.6571723	78.28225913	9.7	0.4	18.6	325	90.7
257	**C**	36.73067015	81.58716585	4.4	3.5	16.7	816	99.9
260	**C**	36.7358386	81.49324201	17.9	14.5	16.8	805	96.5
262	**C**	37.04298095	81.46103681	15.9	11.2	17.7	751	83.3
264	**C**	36.75282746	81.37324275	6.1	5.5	15.9	916	95.6
267	**C**	36.83263457	81.3445178	2.8	2.1	16.3	936	97.2
273	**C**	36.67898172	81.35310606	6.7	5.7	17.0	852	62.2
276	**C**	36.68964786	81.43143964	36.5	31.9	16.8	870	91.6
298	**C**	36.67592391	80.8113441	59.2	41.5	17.7	730	65.6
307	**C**	36.8951448	80.42961731	4.2	3.5	17.2	742	71.2
308	**C**	36.83813578	80.39188013	2.4	1.4	16.6	829	71.1
312	**C**	36.81239102	80.49770686	45.5	27.3	17.1	770	70.2
315	**C**	36.75959978	80.37217076	4.7	4.0	16.4	895	53.2
319	**C**	36.71224572	80.48310424	2.4	1.8	16.8	829	47.2

A1. Landscape Metric Values continued.

POP#	Type	Forest%_Corr	Canopy%	Canopy%_Corr	Mean_BFI	Mean_BFI_Corr
10	**C**	95.8	78.0	77.8	43.0	43.0
19	**C**	100	79.3	80.8	45.0	45.0
23	**C**	84.8	74.0	82.5	48.4	48.0
26	**C**	81.7	77.4	71.9	47.0	46.7
27	**C**	86.6	83.1	83.8	40.5	40.5
30	**C**	100	88.2	88.4	42.7	42.6
33	**C**	92.6	83.0	76.8	41.4	41.0
39	**C**	99.6	81.3	82.4	45.7	45.9
40	**C**	74.9	66.2	60.7	45.8	45.8
49	**C**	96.7	76.6	81.8	42.7	42.5
61	**C**	100	89.4	83.9	44.0	43.8
63	**C**	10.6	34.4	14.4	39.9	40.0
64	**C**	23.9	47.8	29.6	39.5	39.6
66	**C**	93.6	71.3	73.1	38.1	38.1
72	**C**	61.8	64.5	49.0	45.0	45.0
75	**C**	99.8	82.3	78.1	45.0	45.0
77	**C**	82.8	79.6	68.2	44.0	44.0
84	**C**	-999	77.9	-999.0	48.0	-999.0
87	**C**	100	85.4	84.7	48.9	49.0
102	**C**	97.5	84.8	85.2	47.0	47.0
105	**C**	100	85.7	84.9	49.0	49.0
106	**C**	97.5	88.2	88.8	48.7	48.6
112	**C**	93.3	76.1	71.4	49.0	49.0
117	**C**	100	83.0	85.0	51.3	51.2
121	**C**	100	80.6	79.4	51.2	51.3
143	**C**	89.3	73.6	77.6	53.0	53.0
144	**C**	86.8	75.2	76.6	53.0	53.0
168	**C**	79.4	74.6	60.5	52.4	52.6
172	**C**	87.5	76.3	74.4	50.3	50.4
174	**C**	98.6	83.3	86.3	47.9	48.0
182	**C**	97.5	80.3	77.8	44.1	44.2
185	**C**	94.6	77.1	72.7	43.8	43.6
220	**C**	98.9	80.3	80.2	44.3	44.3
229	**C**	78.4	82.1	73.9	47.0	47.1
234	**C**	92	78.9	81.0	45.6	45.7
235	**C**	97.7	79.3	79.5	44.6	44.5
247	**C**	49.3	81.1	82.0	48.0	48.0
257	**C**	99.3	93.7	92.4	55.0	55.0
260	**C**	95.5	90.1	87.9	55.0	55.0
262	**C**	89.8	82.8	82.5	51.9	51.9
264	**C**	99.7	89.8	93.3	54.0	54.0
267	**C**	85	89.6	88.9	54.0	54.0
273	**C**	68	56.6	63.2	54.0	54.0
276	**C**	88.3	85.8	82.6	55.0	55.0
298	**C**	69.8	60.4	63.5	59.9	59.9
307	**C**	57.5	64.5	53.3	49.7	49.7
308	**C**	90.3	64.3	82.3	51.2	51.0
312	**C**	67.4	64.2	62.8	52.2	52.3
315	**C**	43	47.7	40.3	54.0	54.0
319	**C**	38	44.8	39.1	56.4	56.6

A1. Landscape Metric Values continued.

POP#	Type	Solar_ann_can_mean	Solar_ann_can_km	Solar_ann_can_mean_Corr
10	**C**	292.5	459,343.8	292.8
19	**C**	285.3	1,565,319.7	253.0
23	**C**	360.1	3,361,364.5	231.7
26	**C**	314.6	1,267,097.8	385.6
27	**C**	230.4	454,856.5	221.7
30	**C**	154.2	250,020.5	157.2
33	**C**	227.5	347,624.7	307.4
39	**C**	247.2	291,986.0	233.2
40	**C**	463.2	874,400.1	520.5
49	**C**	333.0	354,683.5	248.3
61	**C**	143.7	648,573.8	210.6
63	**C**	924.4	5,121,047.0	1201.7
64	**C**	737.7	2,382,621.4	979.5
66	**C**	414.6	920,063.2	379.1
72	**C**	494.2	442,631.4	708.7
75	**C**	232.4	343,578.1	288.3
77	**C**	282.0	587,822.2	433.6
84	**C**	324.1	-999.0	-999.0
87	**C**	210.9	188,222.7	220.0
102	**C**	201.5	236,642.3	190.8
105	**C**	201.1	398,003.1	209.5
106	**C**	145.2	234,604.3	131.1
112	**C**	337.0	440,083.8	397.8
117	**C**	232.8	288,760.1	197.3
121	**C**	252.6	286,971.0	249.9
143	**C**	379.2	596,152.4	309.5
144	**C**	370.0	587,224.6	343.8
168	**C**	346.1	427,290.1	537.2
172	**C**	327.0	339,475.5	344.6
174	**C**	224.4	777,262.3	181.4
182	**C**	269.9	593,500.8	291.2
185	**C**	308.3	1,325,332.9	353.3
220	**C**	268.5	426,318.2	260.4
229	**C**	231.3	549,254.7	334.8
234	**C**	290.5	754,666.4	253.2
235	**C**	284.1	772,388.6	276.8
247	**C**	250.3	6,032,788.4	239.1
257	**C**	85.5	116,941.0	104.0
260	**C**	142.3	194,703.8	176.9
262	**C**	258.7	406,729.3	259.1
264	**C**	149.5	182,382.6	100.8
267	**C**	157.2	236,959.8	165.8
273	**C**	640.5	838,297.1	538.9
276	**C**	207.0	263,575.4	254.9
298	**C**	577.4	916,144.0	525.3
307	**C**	510.7	681,728.2	671.0
308	**C**	508.4	935,071.9	248.5
312	**C**	522.4	968,070.9	534.4
315	**C**	768.2	1,019,589.3	878.5
319	**C**	815.2	1,200,005.4	894.3

A1. Landscape Metric Values continued.

POP#	Type	Solar_ann_can_km_Corr	Solar_crit_can_mean	Solar_crit_can_km
10	**C**	64,222.2	97.2	152,712.4
19	**C**	58,527.0	91.8	503,813.0
23	**C**	57,743.3	115.3	1,076,625.9
26	**C**	86,577.1	100.7	405,421.7
27	**C**	50,310.1	74.9	147,793.5
30	**C**	38,210.3	52.4	84,924.4
33	**C**	69,004.0	75.8	115,778.6
39	**C**	52,477.3	83.6	98,790.8
40	**C**	116,896.1	151.0	285,151.0
49	**C**	55,185.5	104.5	111,262.8
61	**C**	47,989.8	47.0	212,355.5
63	**C**	270,175.5	290.7	1,610,732.6
64	**C**	220,745.3	231.2	746,866.4
66	**C**	83,275.3	127.2	279,999.6
72	**C**	156,621.8	158.7	142,089.0
75	**C**	66,715.6	79.3	117,271.4
77	**C**	98,018.5	91.3	188,635.5
84	**C**	-999.0	99.2	-999.0
87	**C**	50,173.8	65.9	58,856.5
102	**C**	42,839.1	68.0	79,886.5
105	**C**	48,883.8	63.9	125,545.7
106	**C**	30,454.4	52.9	84,537.4
112	**C**	88,712.8	106.9	139,576.6
117	**C**	43,648.3	75.9	94,199.2
121	**C**	58,368.4	86.5	98,226.7
143	**C**	70,692.4	118.0	185,529.9
144	**C**	82,185.0	110.9	176,000.5
168	**C**	121,505.4	113.5	140,163.6
172	**C**	76,230.5	106.1	110,195.7
174	**C**	42,168.3	74.1	256,815.6
182	**C**	65,627.0	87.7	192,746.0
185	**C**	80,725.6	101.7	436,977.1
220	**C**	58,756.1	87.2	138,385.7
229	**C**	75,905.9	79.2	188,014.9
234	**C**	56,578.1	93.7	243,470.1
235	**C**	63,855.7	91.9	249,966.3
247	**C**	72,818.6	83.5	2,012,701.0
257	**C**	24,027.4	28.5	38,996.2
260	**C**	39,347.6	44.7	61,230.7
262	**C**	57,669.9	78.0	122,609.6
264	**C**	22,729.6	46.3	56,490.1
267	**C**	39,628.9	47.4	71,413.8
273	**C**	120,458.7	197.1	257,947.4
276	**C**	55,477.2	64.6	82,209.7
298	**C**	116,152.9	179.6	285,044.5
307	**C**	154,586.2	160.7	214,565.1
308	**C**	61,707.2	161.6	297,183.2
312	**C**	118,990.7	162.5	301,216.5
315	**C**	202,985.5	237.3	314,972.9
319	**C**	216,576.9	250.8	369,213.6

A1. Landscape Metric Values continued.

POP#	Type	Solar_crit_can_mean_corr	Solar_crit_can_km_Corr	Solar_ann_mean
10	**C**	98.1	21,531.3	1,287.9
19	**C**	85.2	19,709.2	1,351.7
23	**C**	77.8	19,379.8	1,353.1
26	**C**	125.2	28,106.7	1,382.5
27	**C**	72.1	16,361.4	1,333.5
30	**C**	51.5	12,513.2	1,301.8
33	**C**	103.3	23,180.0	1,319.0
39	**C**	78.5	17,677.9	1,285.8
40	**C**	175.9	39,499.7	1,352.8
49	**C**	81.1	18,034.4	1,370.3
61	**C**	71.3	16,241.8	1,336.7
63	**C**	379.3	85,275.0	1,398.4
64	**C**	312.0	70,322.5	1,401.8
66	**C**	119.1	26,157.7	1,418.6
72	**C**	228.3	50,452.5	1,381.2
75	**C**	97.7	22,606.2	1,301.9
77	**C**	142.0	32,107.3	1,362.3
84	**C**	-999.0	-999.0	1,462.5
87	**C**	69.0	15,728.8	1,436.4
102	**C**	66.3	14,896.9	1,243.8
105	**C**	67.5	15,753.6	1,384.1
106	**C**	50.3	11,681.5	1,227.4
112	**C**	128.1	28,556.7	1,394.5
117	**C**	67.0	14,824.3	1,347.5
121	**C**	91.6	21,388.2	1,270.9
143	**C**	100.2	22,893.4	1,408.3
144	**C**	104.5	24,971.7	1,448.7
168	**C**	176.4	39,906.5	1,335.1
172	**C**	114.4	25,305.0	1,324.2
174	**C**	61.1	14,206.3	1,324.3
182	**C**	98.4	22,166.9	1,344.7
185	**C**	121.3	27,720.1	1,328.0
220	**C**	87.8	19,799.6	1,338.6
229	**C**	115.4	26,154.4	1,253.5
234	**C**	84.0	18,777.1	1,336.9
235	**C**	90.8	20,942.4	1,329.5
247	**C**	79.5	24,213.4	1,292.0
257	**C**	34.4	7,954.1	1,342.8
260	**C**	54.8	12,187.1	1,384.4
262	**C**	79.2	17,631.1	1,472.9
264	**C**	30.5	6,874.3	1,438.6
267	**C**	50.4	12,044.5	1,480.8
273	**C**	167.0	37,328.8	1,459.9
276	**C**	79.0	17,205.9	1,432.2
298	**C**	165.7	36,646.3	1,442.2
307	**C**	211.7	48,775.0	1,408.4
308	**C**	80.2	19,925.1	1,413.7
312	**C**	168.6	37,547.1	1,427.3
315	**C**	271.1	62,646.8	1,462.2
319	**C**	276.3	66,920.3	1,445.4

A1. Landscape Metric Values continued.

POP#	Type	Solar_ann_km	Solar_ann_mean_Corr	Solar_ann_km_Corr
10	**C**	2,022,875.5	1,285.8	281,508.0
19	**C**	7,416,494.2	1,317.7	305,976.1
23	**C**	12,630,849.1	1,314.8	327,604.0
26	**C**	5,567,018.5	1,368.1	307,994.2
27	**C**	2,632,631.6	1,324.0	298,752.5
30	**C**	2,111,137.8	1,354.5	330,135.9
33	**C**	2,015,345.8	1,305.6	291,561.0
39	**C**	1,520,651.4	1,291.2	291,556.7
40	**C**	2,553,865.1	1,275.0	285,714.3
49	**C**	1,459,669.1	1,358.2	301,652.7
61	**C**	6,039,569.1	1,316.8	296,930.7
63	**C**	7,741,745.4	1,396.4	316,601.2
64	**C**	4,530,895.5	1,392.1	313,504.7
66	**C**	3,148,089.9	1,384.1	303,297.2
72	**C**	1,237,032.1	1,368.6	301,998.9
75	**C**	1,916,790.4	1,309.9	299,960.2
77	**C**	2,839,222.6	1,369.3	309,726.4
84	**C**	-999.0	-999.0	-999.0
87	**C**	1,292,332.5	1,437.0	329,674.1
102	**C**	1,460,532.4	1,221.5	274,145.1
105	**C**	2,739,306.5	1,358.8	317,059.7
106	**C**	1,982,639.8	1,170.2	271,842.4
112	**C**	1,819,161.4	1,381.2	309,583.4
117	**C**	1,675,074.5	1,316.4	293,292.3
121	**C**	1,447,577.3	1,206.7	280,722.0
143	**C**	2,213,973.7	1,360.6	315,025.3
144	**C**	2,299,299.5	1,460.2	349,048.7
168	**C**	1,648,174.2	1,365.5	309,852.5
172	**C**	1,376,234.8	1,307.8	289,295.7
174	**C**	4,587,595.2	1,291.4	298,891.6
182	**C**	2,959,811.6	1,304.7	295,576.6
185	**C**	5,708,498.0	1,245.9	288,585.8
220	**C**	2,125,268.2	1,289.4	290,478.5
229	**C**	2,975,902.0	1,251.5	283,494.4
234	**C**	3,472,481.7	1,321.6	295,460.4
235	**C**	3,610,723.2	1,312.0	301,106.8
247	**C**	31,124,300.1	1,324.1	403,303.5
257	**C**	1,837,049.9	1,367.3	317,508.1
260	**C**	1,894,591.8	1,437.2	319,923.3
262	**C**	2,333,232.4	1,461.4	327,464.4
264	**C**	1,754,568.3	1,494.1	337,637.3
267	**C**	2,266,099.5	1,440.2	342,779.2
273	**C**	1,910,659.6	1,450.1	323,630.6
276	**C**	1,820,654.6	1,440.6	314,127.2
298	**C**	2,293,269.5	1,424.1	314,692.8
307	**C**	1,879,961.9	1,419.3	329,401.6
308	**C**	2,570,897.9	1,407.8	342,796.1
312	**C**	2,642,163.6	1,421.8	316,176.8
315	**C**	1,940,693.0	1,462.8	338,011.8
319	**C**	2,101,034.0	1,452.2	351,681.6

A1. Landscape Metric Values continued.

POP#	Type	Solar_crit_mean	Solar_crit_km	Solar_crit_mean_Corr	Solar_crit_km_Corr
10	**C**	441.717	693,785.4	441.6	96,877.2
19	**C**	443.204	2,431,752.3	442.9	102,443.5
23	**C**	444.056	4,145,183.5	444.0	110,625.9
26	**C**	444.984	1,791,999.7	445.0	99,905.2
27	**C**	444.11	876,798.1	444.0	100,746.6
30	**C**	445.247	722,076.4	445.4	108,307.9
33	**C**	445.456	680,643.4	445.3	99,954.2
39	**C**	447.128	528,157.9	447.1	100,637.8
40	**C**	447.146	844,135.0	447.0	100,390.8
49	**C**	446.334	475,436.7	446.2	99,189.3
61	**C**	443.691	2,002,714.2	443.5	101,069.5
63	**C**	443.238	2,455,589.7	443.1	99,618.2
64	**C**	443	1,430,763.4	443.0	99,833.1
66	**C**	443.053	975,450.1	443.0	97,309.3
72	**C**	447.37	400,662.6	447.3	98,865.4
75	**C**	447.152	661,187.4	447.1	103,441.6
77	**C**	447.006	923,427.7	447.0	101,041.1
84	**C**	448.54	-999.0	-999.0	-999.0
87	**C**	451.213	402,733.7	451.3	102,925.9
102	**C**	447.958	526,002.0	447.9	100,575.7
105	**C**	448.55	881,335.9	448.4	104,620.4
106	**C**	448.113	716,258.5	448.0	104,077.2
112	**C**	447.547	584,532.2	447.4	99,761.5
117	**C**	446.584	554,025.9	446.5	98,792.0
121	**C**	445.468	506,130.7	445.2	103,998.8
143	**C**	446.765	702,365.3	446.6	102,019.0
144	**C**	446.838	709,208.6	446.9	106,820.9
168	**C**	446.946	551,736.6	447.0	101,109.9
172	**C**	446.795	463,905.8	446.7	98,815.3
174	**C**	444.977	1,541,422.4	445.0	103,438.1
182	**C**	443.996	976,190.1	443.9	100,035.3
185	**C**	443.764	1,907,624.1	443.6	101,357.0
220	**C**	442.939	703,242.6	442.8	99,894.2
229	**C**	442.358	1,050,234.4	442.1	100,215.4
234	**C**	443.163	1,151,112.0	443.0	98,994.5
235	**C**	443.175	1,205,030.3	443.1	102,229.7
247	**C**	441.982	10,652,116.5	442.0	134,629.3
257	**C**	453.804	620,859.9	453.7	104,846.6
260	**C**	453.861	621,121.5	453.9	100,967.9
262	**C**	452.733	711,691.0	452.6	100,741.3
264	**C**	453.888	553,585.6	453.9	102,322.8
267	**C**	453.606	683,563.5	453.6	108,389.3
273	**C**	453.998	594,184.4	454.0	101,479.4
276	**C**	454.006	577,997.2	454.0	98,820.5
298	**C**	453.998	720,401.1	454.0	100,379.2
307	**C**	453.036	604,727.2	453.1	104,381.9
308	**C**	453.178	833,563.9	453.0	112,509.0
312	**C**	453.579	840,530.3	453.5	100,972.4
315	**C**	453.993	602,540.0	454.0	104,905.4
319	**C**	453.999	668,337.4	454.0	109,948.3

A1. Landscape Metric Values continued.

POP#	Type	LAT	LONG	AREA	Stream_LEN	Maxtemp	Elev	Forest%
10	**P**	38.76674573	78.94244552	80.2	56.5	17.9	434.0	90.2
19	**P**	38.39453846	79.16115255	41.2	12.7	17.7	539.0	99.0
23	**P**	38.20193918	79.18157282	59.5	20.0	18.6	451.0	81.1
26	**P**	38.08505197	79.34999072	61.2	15.1	18.4	471.0	90.4
27	**P**	38.19128776	79.41995877	32.8	11.5	17.9	548.0	95.3
30	**P**	37.99210535	79.43787903	4.2	4.9	19.0	416.0	99.2
33	**P**	37.9947288	79.63072547	24.1	18.1	19.2	392.0	94.3
39	**P**	37.71845881	79.78962212	35.3	29.6	19.9	313.0	96.3
40	**P**	37.7873588	79.88445261	40.2	25.6	20.1	348.0	91.3
49	**P**	37.90481234	79.80202986	42.3	36.4	18.9	441.0	95.0
61	**P**	38.24035891	79.33633806	55.4	16.3	17.8	551.0	94.0
63	**P**	38.2915511	79.66145357	101.4	23.6	16.5	687.0	66.5
64	**P**	38.48224968	79.50864962	69.6	17.2	16.4	712.0	71.1
66	**P**	38.57521123	79.59112866	71.6	54.4	15.3	803.0	96.0
72	**P**	37.72857699	79.99925476	11.9	12.6	18.2	496.0	87.1
75	**P**	37.73925854	80.18793649	9.3	9.0	18.5	485.0	97.4
77	**P**	37.78140203	80.19731781	18.5	13.2	17.1	630.0	96.1
84	**P**	37.47254675	80.27843252	17.2	19.6	18.6	500.0	95.7
87	**P**	37.34133181	80.41293661	6.5	6.2	17.7	623.0	88.4
102	**P**	37.59455629	79.50928751	16.7	15.9	20.4	247.0	93.5
105	**P**	37.49899469	79.44846509	8.7	5.4	19.3	361.0	94.5
106	**P**	37.54398523	79.61602573	30.9	25.5	20.1	272.0	96.2
112	**P**	37.680233	79.22143424	27	22.3	19.8	289.0	97.0
117	**P**	37.93036053	79.16255653	41	37.3	18.3	487.0	98.0
121	**P**	37.99945708	79.04187262	4.7	6.2	18.7	461.0	99.2
143	**P**	37.88463815	78.89905469	7.4	7.1	19.9	229.0	89.6
144	**P**	37.8860236	78.97204664	5.6	4.0	18.2	415.0	91.4
168	**P**	37.8113102	79.00158135	13.5	14.7	20.1	242.0	87.1
172	**P**	37.82735947	79.01030851	115.4	100.4	19.8	261.0	91.5
174	**P**	38.09756208	78.85022916	16.3	7.1	18.8	395.0	92.3
182	**P**	38.17101747	78.67388794	29.7	13.4	19.3	231.0	88.9
185	**P**	38.23885196	78.56975052	31.1	12.9	19.2	213.0	88.1
220	**P**	38.4202862	78.66159661	16.9	10.9	18.9	303.0	81.2
229	**P**	38.6562804	78.46127391	44.2	14.7	19.1	244.0	57.2
234	**P**	38.33864541	78.40585369	59.7	25.3	19.3	189.0	89.2
235	**P**	38.34268978	78.45835509	25.1	15.7	19.0	238.0	93.8
247	**P**	38.65779762	78.21764121	28.1	7.0	19.1	195.0	86.9
257	**P**	36.75752564	81.57498463	8.3	8.9	18.1	707.0	89.6
260	**P**	36.74517123	81.49365742	4.4	3.2	17.4	773.0	96.7
262	**P**	37.03362587	81.48199673	25.1	23.2	17.8	680.0	80.5
264	**P**	36.77355256	81.40361397	18.1	15.8	17.6	797.0	89.4
267	**P**	36.82651337	81.28976452	23	19.2	17.7	757.0	86.0
273	**P**	36.6540272	81.36632711	11.9	9.5	17.4	762.0	64.3
276	**P**	36.66180357	81.37837121	93.5	87.6	17.5	771.0	79.5
298	**P**	36.74480538	80.87907806	134.3	99.6	17.9	675.0	54.6
307	**P**	36.90420321	80.39797584	42	42.8	17.5	693.0	64.4
308	**P**	36.85785313	80.38808792	26	20.1	17.3	754.0	69.9
312	**P**	36.78451403	80.59562456	106.3	75.8	17.6	685.0	75.3
315	**P**	36.73924587	80.37784012	16.1	12.4	16.4	866.0	43.0
319	**P**	36.69110958	80.52096141	12.6	7.7	17.2	773.0	48.6

A1. Landscape Metric Values continued.

POP#	Type	Forest%_Corr	Canopy%	Canopy%_Corr	Mean_BFI	Mean_BFI_Corr
10	**P**	87.4	70.4	68.3	42.8	42.8
19	**P**	97.1	79.3	77.7	45.0	45.0
23	**P**	69.1	63.5	60.3	48.9	49.4
26	**P**	71.3	76.1	61.0	46.1	46.3
27	**P**	76.9	81.6	69.8	41.1	41.0
30	**P**	99.4	87.8	87.6	42.2	41.8
33	**P**	83.2	79.9	69.3	41.0	40.7
39	**P**	89.5	77.2	72.6	45.3	45.4
40	**P**	83.3	74.8	69.9	45.2	45.2
49	**P**	93.4	80.0	80.8	42.4	42.4
61	**P**	83.8	83.1	70.6	43.4	43.5
63	**P**	20.4	54.9	27.5	39.6	39.6
64	**P**	38.3	58.6	39.4	40.2	40.1
66	**P**	96.1	77.0	78.1	38.0	38.0
72	**P**	70.6	73.4	59.9	45.0	45.0
75	**P**	95.3	81.5	76.8	45.0	45.0
77	**P**	90.1	81.0	75.4	44.0	44.0
84	**P**	94.2	76.6	76.3	48.0	48.0
87	**P**	86.6	73.4	72.7	48.9	49.0
102	**P**	89.3	79.4	77.9	47.0	47.0
105	**P**	94.2	80.5	76.3	49.1	49.2
106	**P**	92.9	88.2	86.6	48.3	48.4
112	**P**	88.9	76.2	67.8	49.0	49.0
117	**P**	97.2	82.2	83.0	50.8	50.8
121	**P**	99.1	79.9	78.7	51.7	51.9
143	**P**	82.8	70.4	68.3	53.0	53.0
144	**P**	80.6	74.5	73.3	53.0	53.0
168	**P**	76.5	69.6	58.7	52.8	52.8
172	**P**	86.4	75.6	73.1	51.5	51.6
174	**P**	85.4	79.0	68.8	48.6	49.1
182	**P**	78.3	72.7	61.8	44.2	44.2
185	**P**	72.3	71.5	53.0	43.9	43.8
220	**P**	76.8	64.1	61.5	44.2	44.2
229	**P**	45.4	48.6	38.7	46.5	46.5
234	**P**	77.2	72.9	63.3	45.3	45.3
235	**P**	87.4	76.5	70.6	44.9	44.9
247	**P**	38.8	74.6	36.6	47.9	47.7
257	**P**	86.1	83.2	78.1	55.0	55.0
260	**P**	95.8	90.3	87.9	55.0	55.0
262	**P**	89.4	82.7	84.1	51.9	51.9
264	**P**	87.4	84.3	84.0	54.0	54.0
267	**P**	79.7	78.0	74.3	54.2	54.1
273	**P**	71.8	58.3	65.2	54.0	54.0
276	**P**	74.7	74.2	69.5	54.5	54.5
298	**P**	59.2	49.4	52.3	59.4	59.3
307	**P**	60.8	57.9	50.3	50.1	50.0
308	**P**	68.5	64.2	77.4	51.8	51.6
312	**P**	66.9	68.3	61.0	53.5	53.6
315	**P**	46.9	38.2	40.8	54.7	54.8
319	**P**	43.5	45.6	42.6	57.1	57.3

A1. Landscape Metric Values continued.

POP#	Type	Solar_ann_can_mean	Solar_ann_can_km	Solar_ann_can_mean_Corr
10	**P**	395.9	623,149.0	416.0
19	**P**	282.1	1,017,174.0	292.7
23	**P**	493.9	1,630,029.0	529.5
26	**P**	331.7	1,489,128.0	506.4
27	**P**	247.3	782,161.0	399.6
30	**P**	164.3	157,035.0	165.9
33	**P**	269.4	398,482.0	400.2
39	**P**	305.2	404,825.0	363.2
40	**P**	338.3	590,655.0	390.6
49	**P**	284.4	367,626.0	263.5
61	**P**	228.9	864,286.0	383.8
63	**P**	630.9	3,013,824.0	1,018.9
64	**P**	576.8	2,594,336.0	832.9
66	**P**	324.8	474,551.0	298.3
72	**P**	364.6	380,936.0	557.8
75	**P**	241.5	279,959.0	307.9
77	**P**	264.6	455,694.0	337.2
84	**P**	335.9	326,314.0	342.3
87	**P**	364.4	425,818.0	365.0
102	**P**	274.0	320,067.0	282.4
105	**P**	273.5	494,374.0	255.3
106	**P**	153.8	206,793.0	172.4
112	**P**	330.1	443,719.0	433.0
117	**P**	237.4	288,953.0	222.5
121	**P**	262.9	224,457.0	273.5
143	**P**	408.9	477,495.0	404.4
144	**P**	367.5	562,074.0	362.9
168	**P**	423.1	432,693.0	559.7
172	**P**	333.2	425,790.0	354.2
174	**P**	284.5	724,512.0	399.9
182	**P**	367.7	904,123.0	497.6
185	**P**	378.4	1,012,995.0	613.6
220	**P**	481.6	833,670.0	495.0
229	**P**	671.8	2,238,150.0	795.2
234	**P**	363.3	951,619.0	480.0
235	**P**	313.7	558,448.0	384.5
247	**P**	331.8	1,483,321.0	804.6
257	**P**	238.3	247,862.0	292.6
260	**P**	139.7	940,393.0	175.2
262	**P**	260.6	312,164.0	239.8
264	**P**	229.3	292,368.0	223.7
267	**P**	312.5	415,054.0	363.6
273	**P**	600.9	834,282.0	478.6
276	**P**	378.3	447,658.0	443.8
298	**P**	730.3	1,092,299.0	680.8
307	**P**	604.9	659,114.0	664.0
308	**P**	522.6	753,306.0	544.1
312	**P**	455.6	710,306.0	555.4
315	**P**	911.5	1,298,920.0	868.6
319	**P**	804.2	1,462,326.0	831.6

A1. Landscape Metric Values continued.

POP#	Type	Solar_ann_can_km_Corr	Solar_crit_can_mean	Solar_crit_can_km
10	**P**	91,208.0	130.8	207,046.4
19	**P**	64,631.0	91.6	330,014.8
23	**P**	117,887.0	161.9	534,270.4
26	**P**	110,570.0	106.5	481,885.5
27	**P**	88,745.0	81.6	258,006.3
30	**P**	37,215.0	54.2	51,765.8
33	**P**	88,022.0	89.6	133,265.4
39	**P**	80,182.0	101.8	135,036.5
40	**P**	87,011.0	112.6	196,889.8
49	**P**	57,740.0	89.4	115,405.3
61	**P**	85,576.0	74.9	282,909.4
63	**P**	223,825.0	200.0	955,951.3
64	**P**	184,998.0	183.3	823,957.0
66	**P**	65,078.0	101.8	150,663.1
72	**P**	122,064.0	119.1	125,206.8
75	**P**	69,091.0	82.8	95,999.4
77	**P**	73,643.0	85.0	146,336.5
84	**P**	75,656.0	104.8	102,205.1
87	**P**	80,862.0	120.0	140,180.2
102	**P**	61,466.0	92.2	107,589.1
105	**P**	59,187.0	87.3	157,848.5
106	**P**	37,832.0	52.9	71,608.9
112	**P**	94,083.0	106.4	143,303.9
117	**P**	49,094.0	79.7	97,252.8
121	**P**	61,436.0	89.4	76,374.5
143	**P**	87,631.0	132.3	154,518.5
144	**P**	80,551.0	114.1	174,446.8
168	**P**	122,852.0	135.7	138,766.5
172	**P**	78,465.0	109.0	139,483.8
174	**P**	87,313.0	93.5	238,260.0
182	**P**	109,786.0	121.4	298,331.9
185	**P**	136,505.0	126.4	339,910.2
220	**P**	110,123.0	158.8	274,902.5
229	**P**	176,343.0	227.2	757,131.1
234	**P**	106,610.0	120.0	314,277.6
235	**P**	85,267.0	104.3	185,670.6
247	**P**	178,248.0	112.5	502,667.5
257	**P**	64,788.0	76.3	79,357.2
260	**P**	189,465.0	44.2	297,534.3
262	**P**	52,133.0	78.5	94,584.9
264	**P**	49,073.0	71.3	91,284.9
267	**P**	80,294.0	99.6	133,121.2
273	**P**	104,160.0	189.4	267,514.9
276	**P**	97,049.0	117.2	138,970.4
298	**P**	149,009.0	229.8	344,642.4
307	**P**	144,820.0	190.8	209,170.4
308	**P**	121,252.0	162.4	233,155.4
312	**P**	121,925.0	143.8	224,767.1
315	**P**	193,759.0	280.4	403,553.4
319	**P**	184,044.0	247.1	449,306.0

A1. Landscape Metric Values continued.

POP#	Type	Solar_crit_can_mean_corr	Solar_crit_can_km_Corr	Solar_ann_mean
10	**P**	139.9	30,787.8	1,284.6
19	**P**	97.9	21,811.4	1,336.1
23	**P**	176.0	39,524.1	1,353.8
26	**P**	172.2	37,811.4	1,374.0
27	**P**	131.5	29,495.2	1,317.3
30	**P**	54.3	12,004.5	1,316.6
33	**P**	133.8	29,433.7	1,321.9
39	**P**	122.0	27,061.6	1,313.7
40	**P**	133.4	29,691.5	1,309.0
49	**P**	84.6	18,434.4	1,345.4
61	**P**	127.7	28,555.6	1,334.2
63	**P**	321.8	70,939.1	1,388.3
64	**P**	267.3	58,777.7	1,380.8
66	**P**	97.2	21,244.9	1,388.0
72	**P**	180.8	39,664.7	1,339.5
75	**P**	100.5	22,249.4	1,298.5
77	**P**	110.9	23,885.1	1,367.2
84	**P**	105.4	23,347.2	1,429.5
87	**P**	115.5	25,506.6	1,426.9
102	**P**	98.1	21,348.0	1,269.8
105	**P**	90.5	22,043.6	1,375.3
106	**P**	59.9	13,038.5	1,280.3
112	**P**	142.1	30,774.5	1,363.5
117	**P**	75.8	16,654.8	1,306.9
121	**P**	91.8	21,543.3	1,295.9
143	**P**	137.0	30,107.5	1,391.8
144	**P**	111.6	23,948.3	1,390.9
168	**P**	184.2	39,799.7	1,341.4
172	**P**	120.2	26,617.8	1,314.4
174	**P**	136.6	29,490.0	1,315.7
182	**P**	168.3	36,828.8	1,325.1
185	**P**	208.3	46,400.5	1,322.9
220	**P**	168.3	37,804.5	1,342.2
229	**P**	269.9	59,325.1	1,269.7
234	**P**	161.8	35,767.7	1,325.3
235	**P**	128.0	28,365.2	1,335.3
247	**P**	276.7	61,775.9	1,280.4
257	**P**	95.2	21,250.2	1,360.0
260	**P**	54.6	58,732.1	1,377.7
262	**P**	72.0	15,532.7	1,483.5
264	**P**	71.2	15,747.8	1,419.8
267	**P**	114.8	25,410.7	1,446.4
273	**P**	157.7	33,891.2	1,453.9
276	**P**	138.4	30,279.7	1,446.5
298	**P**	216.8	47,557.4	1,429.6
307	**P**	225.0	56,852.9	1,419.0
308	**P**	102.4	15,371.6	1,408.0
312	**P**	176.4	38,828.8	1,418.6
315	**P**	269.0	59,464.2	1,471.1
319	**P**	258.3	56,321.4	1,448.9

A1. Landscape Metric Values continued.

POP#	Type	Solar_ann_km	Solar_ann_mean_Corr	Solar_ann_km_Corr
10	**P**	2,033,959.8	1,273.5	280,950.4
19	**P**	4,816,629.2	1,301.0	291,275.5
23	**P**	4,465,245.3	1,338.3	301,447.5
26	**P**	6,218,765.3	1,339.9	296,746.4
27	**P**	4,166,588.5	1,318.3	296,702.6
30	**P**	1,258,912.9	1,354.0	306,588.0
33	**P**	1,966,217.1	1,309.7	292,141.6
39	**P**	1,742,499.3	1,311.1	291,523.6
40	**P**	2,294,500.1	1,298.9	290,835.2
49	**P**	1,736,969.8	1,357.2	297,581.5
61	**P**	5,039,981.8	1,329.3	299,035.9
63	**P**	6,630,981.3	1,365.8	302,111.8
64	**P**	6,207,995.3	1,365.4	300,825.7
66	**P**	2,053,696.5	1,339.5	292,572.7
72	**P**	1,404,246.0	1,320.5	287,915.0
75	**P**	1,497,324.9	1,303.0	292,665.1
77	**P**	2,360,830.3	1,360.7	298,960.2
84	**P**	1,393,903.1	1,410.5	318,218.8
87	**P**	1,667,180.7	1,416.0	320,508.6
102	**P**	1,484,319.1	1,260.7	277,673.6
105	**P**	2,487,001.7	1,348.2	353,247.2
106	**P**	1,734,784.4	1,258.7	274,360.5
112	**P**	1,832,961.1	1,338.1	291,449.6
117	**P**	1,594,468.7	1,272.1	279,440.8
121	**P**	1,105,611.0	1,273.7	304,988.8
143	**P**	1,625,284.7	1,328.0	296,963.2
144	**P**	2,127,256.1	1,390.8	313,508.0
168	**P**	1,371,796.6	1,351.6	292,909.3
172	**P**	1,683,649.8	1,279.6	283,091.3
174	**P**	3,351,207.2	1,283.9	282,508.6
182	**P**	3,253,805.1	1,296.1	287,797.6
185	**P**	3,559,861.4	1,266.9	285,192.5
220	**P**	2,323,120.9	1,294.8	292,713.7
229	**P**	4,231,047.6	1,267.9	284,005.0
234	**P**	3,470,183.0	1,298.5	288,896.6
235	**P**	2,375,065.3	1,298.3	290,291.6
247	**P**	5,721,346.9	1,285.6	294,354.5
257	**P**	1,414,777.1	1,380.3	313,763.0
260	**P**	9,273,661.0	1,416.0	1,530,022.3
262	**P**	1,787,884.3	1,460.9	318,785.8
264	**P**	1,829,933.5	1,429.5	315,995.9
267	**P**	1,933,663.7	1,429.9	319,263.6
273	**P**	2,053,336.0	1,433.5	311,379.3
276	**P**	1,717,762.8	1,439.4	314,609.3
298	**P**	2,142,819.9	1,403.0	308,518.8
307	**P**	1,556,029.0	1,398.1	354,495.6
308	**P**	2,012,346.4	1,395.1	208,416.5
312	**P**	2,216,059.0	1,398.5	307,686.3
315	**P**	2,117,038.9	1,460.2	324,804.6
319	**P**	2,606,725.3	1,430.8	318,325.2

A1. Landscape Metric Values continued.

POP#	Type	Solar_crit_mean	Solar_crit_km	Solar_crit_mean_Corr	Solar_crit_km_Corr
10	**P**	441.7	699,394.3	441.6	97,221.4
19	**P**	443.2	1,596,543.3	442.9	98,643.0
23	**P**	444.0	1,465,425.0	444.0	99,691.9
26	**P**	445.0	2,013,493.7	445.0	97,725.7
27	**P**	444.1	1,404,614.2	444.0	99,614.3
30	**P**	445.2	425,460.0	445.3	98,467.6
33	**P**	445.5	662,563.2	445.3	97,928.4
39	**P**	447.1	593,043.3	447.1	99,147.1
40	**P**	447.1	782,135.0	447.0	99,484.4
49	**P**	446.3	576,188.0	446.2	97,238.0
61	**P**	443.7	1,675,944.0	443.6	99,171.4
63	**P**	443.3	2,118,474.5	443.1	97,685.3
64	**P**	443.0	1,991,777.9	443.0	97,396.7
66	**P**	443.1	655,564.0	443.1	96,793.0
72	**P**	447.4	470,386.3	447.3	98,132.6
75	**P**	447.2	518,412.6	447.1	99,037.4
77	**P**	447.0	769,945.4	447.0	96,245.4
84	**P**	448.5	437,320.7	448.4	99,306.4
87	**P**	451.1	527,114.6	451.2	99,669.9
102	**P**	448.0	522,983.8	447.9	97,452.0
105	**P**	448.4	810,942.8	448.3	109,181.9
106	**P**	448.2	606,341.5	448.1	97,606.9
112	**P**	447.4	602,575.8	447.3	96,836.7
117	**P**	446.5	544,741.1	446.4	98,140.8
121	**P**	445.3	380,223.5	445.1	104,482.8
143	**P**	446.6	521,546.3	446.4	98,110.2
144	**P**	446.7	683,215.8	446.6	95,817.2
168	**P**	447.0	457,075.7	447.0	96,563.1
172	**P**	446.7	571,805.8	446.6	98,927.8
174	**P**	445.0	1,133,390.6	444.9	96,084.6
182	**P**	444.0	1,090,949.7	444.0	97,156.4
185	**P**	443.7	1,193,469.0	443.6	98,833.3
220	**P**	443.0	766,723.1	442.9	99,470.2
229	**P**	442.2	1,473,223.9	442.0	97,153.7
234	**P**	443.1	1,160,515.5	443.0	97,952.6
235	**P**	443.1	788,823.9	443.1	98,227.8
247	**P**	442.0	1,975,729.5	442.0	98,673.4
257	**P**	453.8	472,114.8	453.8	101,311.3
260	**P**	453.9	3,054,986.7	453.8	487,842.1
262	**P**	452.7	545,608.7	452.6	97,627.2
264	**P**	453.9	580,810.8	453.9	100,355.7
267	**P**	453.4	606,175.2	453.3	100,367.7
273	**P**	454.0	641,174.9	454.0	97,558.1
276	**P**	454.0	538,299.0	454.0	99,300.3
298	**P**	454.0	681,007.3	454.0	99,606.3
307	**P**	453.1	496,826.5	453.0	114,481.2
308	**P**	453.2	650,547.5	453.1	68,027.6
312	**P**	453.5	708,648.5	453.4	99,791.4
315	**P**	454.0	653,343.3	454.0	100,358.9
319	**P**	454.0	825,573.2	454.0	98,995.4

A2. Thermograph Deployment SOPs

Standard Operating Procedures for Field Deployment of Thermographs Used in Climate Change Monitoring of Eastern Wild Trout Habitat

Version 1.2; Onset HOBO Water Temp Pro V2
05/2010

USFS Fish and Aquatic Ecology Unit

Brad Trumbo

Purpose:

Standard Operating Procedures (SOP) are necessary *in the field* for proper site location of air and water temperature sensors, anchoring of each HOBO to a stationary streamside object, suitable anchoring equipment, running/hiding anchoring apparatus along streambed, placing tree tags, photographs and documentation of HOBO placement. Following SOPs for each sample site will expedite the deployment process, as well as simplify finding the site and HOBOs upon returning to collect data and apparatus.

Key Words: Centroid, Pour-point, Patch, Site, HOBO, Residual Pool

I. HOBO Calibration

1) Launch HOBOs and set in ambient air for 1 hour recording a temperature every 1 minute

2) After 1 hour, stop and readout the HOBOs. Plot the data for each HOBO to be sure each one recorded data within the same data range

3) Re-launch HOBOs and place in ice for 1 hour recording a temperature ever 1 minute.

4) Repeat Step 2

II. Site Location

1) Before departing headquarters, it is necessary to have a route plan as to which site are to be set. The use of a handheld GPS unit, as well as a map will allow for more expedient travel

2) Handheld GPS units should be pre-programmed with "theoretical" centroid and pour-point locations for each patch. Theoretical centroid points will not likely be directly overtop of stream segments on the GPS unit. It is necessary to determine the closest stream segment to the centroid point as the site for deploying HOBOs in each patch.
    - The goal should be to navigate to the closest possible location to the "theoretical" centroid and pour-point in the GPS unit
    - IF the point falls WITHIN, or requires passing THROUGH PRIVATE property, try to contact the landowner.
    - If a remote site and landowner cannot be contacted, one of the following options should be based upon best professional judgment:
        - a site may be set as close as possible to the theoretical site where access is granted or public land is available
        - in cases of danger or serious inconvenience a new patch may be randomly selected for sampling

3) Once a site is located, HOBOs placed in the water should be placed near maximum residual pool depth. Residual depth is defined as "the difference in depth or bed elevation between a pool and the downstream riffle crest" (Lisle 1987).
    - Pools with at least knee depth should be selected when possible to ensure the HOBO will be submersed throughout late summer

III. Setting In-stream HOBOs

1) Copper wire (coated 14ga.) has been used with great success in Virginia. It is necessary to use some type of extremely tough material for attaching HOBOs to the stream bank, etc., since debris will likely catch on, and greatly stress the material

2) Protective rubber boots with caps should be used to set HOBOs in water to prevent surfaces and serial numbers from being worn off. Friction between substrate particles and the clear surface where data is transferred could be damaged causing potential data lost

3) Once maximum residual pool depth has been located, determine what stream bank structure will be used to anchor the HOBO. Be certain the tree, root, boulder, log etc. is PERMANENT

4) Secure wire tightly around structure wrapping wire back upon itself a minimum of five wraps

5) Estimate the length of wire necessary to reach the location where the HOBO is to be placed

6) Cut wire to length leaving extra length for movement around substrate. Attach HOBO, and place HOBO in stream
   - Place HOBO FIRMLY under a rock large enough to be stationary with high flow
     - DO NOT bury HOBO into substrate
   - Lay wire along substrate burying it under rocks, etc. It is necessary to have wire hidden as well as possible from human detection, but more importantly from debris such as leaves that may catch and dislodge the HOBO

7) Use handheld GPS to collect a "Waypoint" while standing where the HOBO was placed. These coordinates are required for future mapping and locating the HOBO
   - Rename the waypoint to the patch number, centroid or pour-point, air or water
     - Example: 172CW = Patch 172 Centroid, Water

8) Place a tree tag in plain view of the HOBO attachment point from the most likely direction of approach
   - Tree tag placement has proven to be highly beneficial when finding set HOBOs since it offers a visual cue to the submerged HOBO

IV. Setting Air Temperature HOBOs

1) Carry copper wire for attachment, PVC shield to reduce direct UV contact with HOBO (Dunham et al. 2005; Wise et al. 2010), tree tags and GPS unit for air set

2) If possible, locate a tree within 50m of stream set, upslope (Dunham et al. 2005), away from stream
   - Not all sites will offer "upslope" areas, or a 50m wide buffer zone. Use best professional judgment to find a suitable area

3) Use GPS unit to locate NORTH aspect/compass direction

4) Run wire through PVC shield cap, attach HOBO to wire, and then attach wire to tree at approximately head height
    - Head height may vary depending upon who is setting the HOBO. Keep in mind that someone else may be checking the HOBO at a later date; therefore, anyone greater than 6 feet in height should set HOBOs at shoulder height

5) Use handheld GPS to collect a "Waypoint" while standing where the HOBO was placed. These coordinates are required for future mapping and locating the HOBO

6) Place a tree tag in plain view of the HOBO attachment point from the most likely direction of approach

V. Site/HOBO Documentation

1) A "Site Description" datasheet should be completely filled out upon setting HOBOs at a site, and a "Status Report" should be filled out when checking HOBOs at each site.

2) Site Description datasheet requirements:
    - Date
    - Time
    - Stream/Site Name and Number
    - Pour-point or Centroid
    - Datum and UTM zone
    - Serial Number for both In-Stream and Near-Stream HOBOs
    - GPS coordinate for both In-Stream and Near-Stream HOBOs
    - Driving direction and drive time from headquarters (may be filled in at the office)
    - Hiking directions, time, and distance from vehicle
    - Physical description of location of both In-Stream and Near-Stream HOBOs with photo numbers noted
        - Should include tree tag placement and what the HOBO was attached to

3) Status Report requirements:
    - Date
    - Time
    - Stream/Site Name and Number
    - Pour-point or Centroid check
    - Serial Number for both In-Stream and Near-Stream HOBOs
    - Checklist of HOBO conditions such as Near-Stream shield intact, In-Stream rubber boot intact, In-Stream HOBO submersed, etc.
    - Comments area
    - Replacement HOBO Serial Number (if a HOBO is missing or damaged)

VI. Site Photography

This may appear to be common sense, but guidelines may actually result in better quality, more useful photos.

1) Understand how to use your camera thoroughly

2) Take photos of In-Stream and Near-Stream HOBO locations from the most likely direction of approach

3) Be certain the person taking photos is far enough from the site that recognizable landmarks such as unique trees or boulders, etc. may be included in the photo.

4) Be certain the person taking photos is close enough to the site that landmarks and tree tags are recognizable

5) Photos organized by date and camera (given there are multiple crews working) are easily matched to the "Site Description" datasheet by photo number for future reference

VI. Definitions

Patch: unique brook trout habitat area being studied defined by researcher and GIS
Centroid: central area of patch designated a point defined by GIS. Centroid site within each patch is defined as the closest stream segment to the actual centroid point of the patch
Pour-Point: downstream-most point where brook trout exist within each patch defined by the intersection of the stream layer and patch boundary in GIS
Site: Actual centroid or pour-point location within a patch where HOBOs are placed

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Wise, L. M., B. A. Trumbo and M. Hudy. 2010. Determining Drift in Electronic Temperature Sensors Used in Climate Change Modeling. James Madison University undergraduate research (un-published).

A 3. Sensitivity/Exposure Classification Values 2009-2010. Type c = centroid, p = pour-point, HS = high sensitive, LS = low sensitive, HE = high exposure, LE = low exposure

POP#	Type	Sens2009	Sens2010	Exp2009	Exp2010
10	**C**	0.528		0.881	
19	**C**				
23	**C**	0.059	0.120	0.000	0.132
26	**C**	0.509	0.209	1.657	1.725
27	**C**	0.235	0.272	0.000	0.000
30	**C**		0.403		1.771
33	**C**	0.809	0.494	3.285	1.987
39	**C**	0.362	0.494	1.056	1.385
40	**C**	0.384	0.494	0.000	0.407
49	**C**		0.494		0.704
61	**C**	0.297	0.494	0.000	0.188
63	**C**	0.797	0.494	1.923	1.910
64	**C**	0.539	0.494	0.854	1.405
66	**C**		0.494		0.174
72	**C**	0.368	0.494	0.000	0.190
75	**C**		0.494		0.000
77	**C**				
84	**C**	0.259	0.494	0.000	0.182
87	**C**	0.192	0.494	0.000	0.000
102	**C**				
105	**C**	0.264	0.109	0.000	0.000
106	**C**	0.392	0.338	0.108	1.136
112	**C**	0.308		0.000	
117	**C**		0.308		0.870
121	**C**				
143	**C**	0.279	0.271	0.038	0.643
144	**C**		0.289		0.841
168	**C**	0.428	0.394	1.897	2.007
172	**C**	0.454	0.412	0.241	0.973
174	**C**	0.124	0.043	0.000	0.000
182	**C**	0.187	0.191	0.856	1.500
185	**C**	0.075	0.254	0.000	0.916
220	**C**	0.391	0.281	0.247	0.976
229	**C**	0.223	0.120	0.220	0.079
234	**C**	0.475	0.415	0.795	1.401
235	**C**		0.211		0.864
247	**C**	0.396	0.209	0.398	0.956
257	**C**				
260	**C**	0.546	0.479	0.000	0.400
262	**C**	0.289	0.275	0.000	0.000
264	**C**	0.291		0.000	
267	**C**		0.272		0.000
273	**C**	0.322	0.414	0.000	0.989
276	**C**	0.298	0.456	0.000	0.833
298	**C**	0.440	0.403	0.614	0.794
307	**C**	0.438	0.295	0.624	1.096
308	**C**	0.329	0.295	0.000	0.000
312	**C**	0.534	0.464	0.814	1.247
315	**C**	0.499	0.494	0.507	1.073
319	**C**	0.372		0.000	

A3. Sensitivity/Exposure Classification Values 2009-2010 continued.

POP#	Type	Sens2009	Sens2010	Exp2009	Exp2010
10	**P**	0.476		1.046	
19	**P**	0.335	0.253	0.148	2.848
23	**P**	0.254		0.000	
26	**P**		0.398		2.043
27	**P**	0.453	0.407	1.510	1.471
30	**P**	0.324	0.472	0.473	1.383
33	**P**		0.381		1.879
39	**P**	0.442	0.381	1.866	1.901
40	**P**	0.381	0.381	0.999	1.575
49	**P**				
61	**P**	0.589		2.448	
63	**P**	0.569	0.381	0.000	0.685
64	**P**	0.568	0.381	0.602	1.227
66	**P**				
72	**P**	0.186	0.381	0.000	0.040
75	**P**		0.381		0.125
77	**P**	0.315	0.381	0.000	0.438
84	**P**	0.257	0.381	0.000	0.225
87	**P**	0.134		0.000	
102	**P**	0.274	0.213	0.000	0.000
105	**P**	0.355	0.242	0.175	1.130
106	**P**	0.574	0.498	2.747	3.226
112	**P**	0.549	0.398	2.145	2.494
117	**P**				
121	**P**		0.155		3.251
143	**P**	0.323	0.390	1.029	1.890
144	**P**	0.288		0.000	
168	**P**	0.497	0.331	1.852	1.396
172	**P**	0.539	0.414	2.744	2.885
174	**P**	0.405	0.301	1.781	2.402
182	**P**	0.638	0.513	3.099	3.212
185	**P**	0.541	0.253	3.311	2.837
220	**P**	0.551	0.388	2.153	2.645
229	**P**	0.391	0.433	1.091	2.115
234	**P**	0.528	0.207	3.079	2.757
235	**P**				
247	**P**	0.392	0.398	1.623	2.936
257	**P**				
260	**P**	0.228	0.407	0.000	0.423
262	**P**	0.459		0.000	
264	**P**	0.549		0.071	
267	**P**	0.382		0.216	
273	**P**	0.306	0.295	0.000	0.450
276	**P**	0.499		0.376	
298	**P**	0.459	0.472	0.965	1.930
307	**P**	0.636	0.599	1.426	1.328
308	**P**	0.526	0.486	0.900	1.222
312	**P**	0.540	0.459	1.631	1.694
315	**P**	0.406	0.413	0.000	0.637
319	**P**	0.470	0.381	0.138	0.746

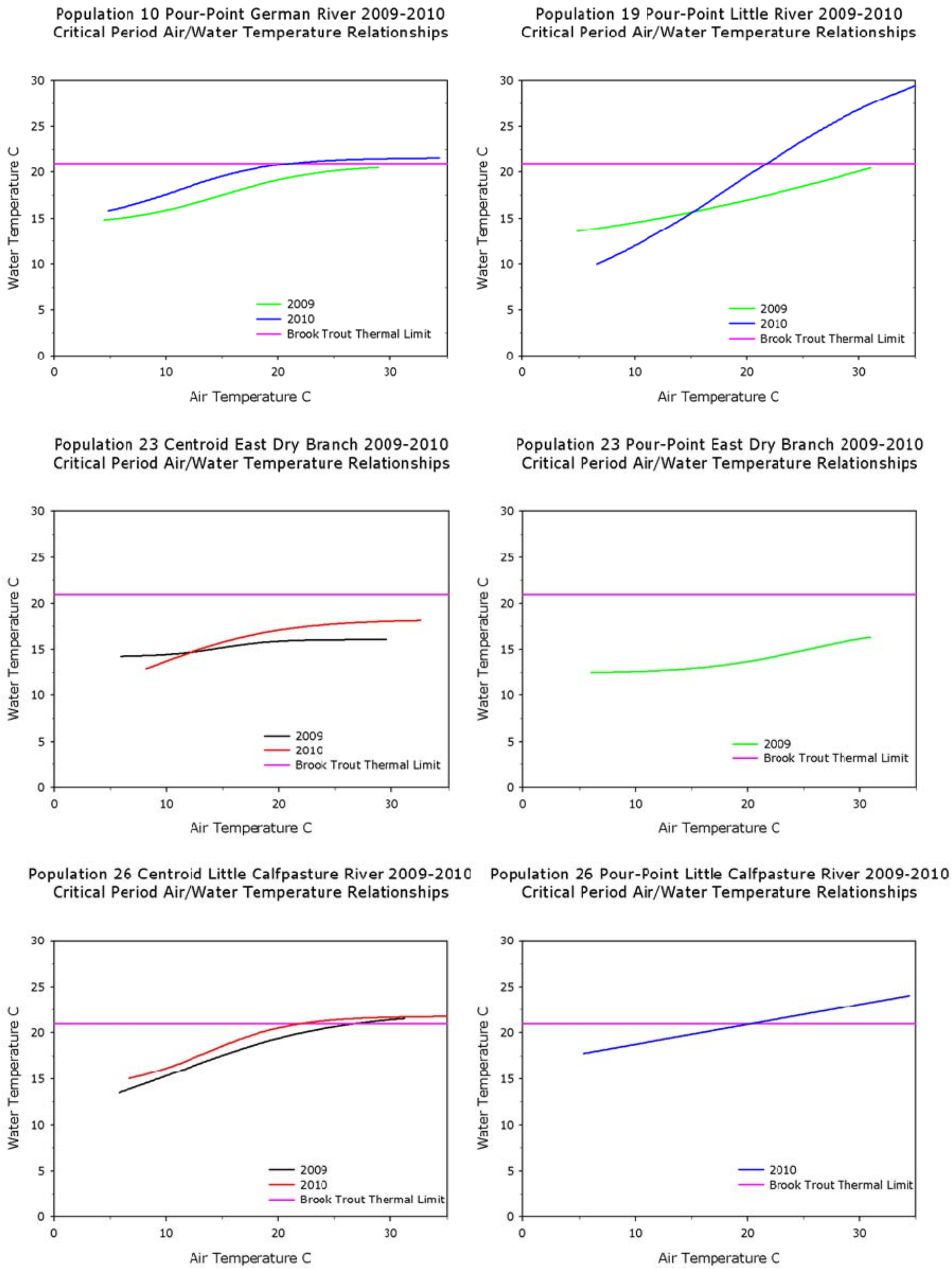
A4. Sensitivity/Exposure Classification Prediction 2009-2010. **Bold** indicates site predictions matching true classification**.**

POP#	Type	S-E Class09	P-Class09	S-E Class10	P-Class10
23	**C**	LSLE	**LSLE**	LSHE	**LSHE**
26	**C**	HSHE	**HSHE**	LSHE	**LSHE**
27	**C**	LSLE	**LSLE**	LSLE	LSHE
33	**C**	HSHE	LSHE	HSHE	**HSHE**
39	**C**	LSHE	**LSHE**	HSHE	LSHE
40	**C**	LSLE	LSHE	HSHE	LSHE
61	**C**	LSLE	**LSLE**	HSHE	LSHE
63	**C**	HSHE	**HSHE**	HSHE	**HSHE**
64	**C**	HSHE	**HSHE**	HSHE	**HSHE**
72	**C**	LSLE	HSLE	HSHE	**HSHE**
84	**C**	LSLE	**LSLE**	HSHE	HSLE
87	**C**	LSLE	**LSLE**	HSLE	LSHE
105	**C**	LSLE	**LSLE**	LSLE	LSHE
106	**C**	LSHE	**LSHE**	LSHE	**LSHE**
143	**C**	LSHE	**LSHE**	LSHE	**LSHE**
168	**C**	HSHE	LSHE	LSHE	**LSHE**
172	**C**	HSHE	**HSHE**	HSHE	LSHE
174	**C**	LSLE	LSHE	LSLE	LSHE
182	**C**	LSHE	**LSHE**	LSHE	**LSHE**
185	**C**	LSLE	LSHE	LSHE	**LSHE**
220	**C**	LSHE	**LSHE**	LSHE	**LSHE**
229	**C**	LSHE	**LSHE**	LSHE	**LSHE**
234	**C**	HSHE	LSHE	HSHE	LSHE
247	**C**	LSHE	**LSHE**	LSHE	**LSHE**
260	**C**	HSLE	LSLE	HSHE	LSHE
262	**C**	LSLE	**LSLE**	LSLE	LSHE
273	**C**	LSLE	**LSLE**	HSHE	**HSHE**
276	**C**	LSLE	**LSLE**	HSHE	LSHE
298	**C**	HSHE	**HSHE**	HSHE	LSHE
307	**C**	HSHE	HSLE	LSHE	HSHE
308	**C**	LSLE	**LSLE**	LSLE	LSHE
312	**C**	HSHE	**HSHE**	HSHE	**HSHE**
315	**C**	HSHE	HSLE	HSHE	**HSHE**
19	**P**	LSHE	HSHE	LSHE	**LSHE**
27	**P**	HSHE	**HSHE**	HSHE	LSHE
30	**P**	LSHE	**LSHE**	HSHE	LSHE
39	**P**	HSHE	**HSHE**	LSHE	HSHE
40	**P**	LSHE	HSHE	LSHE	HSHE
63	**P**	HSLE	HSHE	LSHE	HSHE
64	**P**	HSHE	**HSHE**	LSHE	HSHE
72	**P**	LSLE	LSHE	LSHE	HSHE
77	**P**	LSLE	**LSLE**	LSHE	HSHE
84	**P**	LSLE	LSHE	LSHE	**LSHE**
102	**P**	LSLE	LSHE	LSLE	LSHE
105	**P**	LSHE	**LSHE**	LSHE	**LSHE**
106	**P**	HSHE	LSHE	HSHE	LSHE
112	**P**	HSHE	**HSHE**	LSHE	**LSHE**
143	**P**	LSHE	**LSHE**	LSHE	**LSHE**
168	**P**	HSHE	**HSHE**	LSHE	**LSHE**

A4. Sensitivity/Exposure Classification Prediction 2009-2010 continued.

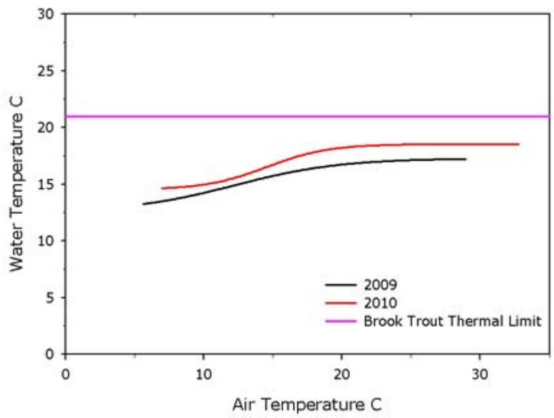
POP_	Type	S-E Class09	P-Class09	S-E Class10	P-Class10
172	**P**	HSHE	**HSHE**	HSHE	**HSHE**
174	**P**	HSHE	LSHE	LSHE	**LSHE**
182	**P**	HSHE	**HSHE**	HSHE	LSHE
185	**P**	HSHE	**HSHE**	LSHE	**LSHE**
220	**P**	HSHE	LSHE	LSHE	**LSHE**
229	**P**	LSHE	HSHE	HSHE	LSHE
234	**P**	HSHE	**HSHE**	LSHE	**LSHE**
247	**P**	LSHE	HSHE	LSHE	**LSHE**
260	**P**	LSLE	**LSLE**	HSHE	LSHE
273	**P**	LSLE	**LSLE**	LSHE	HSHE
298	**P**	HSHE	**HSHE**	HSHE	**HSHE**
307	**P**	HSHE	**HSHE**	HSHE	**HSHE**
308	**P**	HSHE	**HSHE**	HSHE	**HSHE**
312	**P**	HSHE	**HSHE**	HSHE	**HSHE**
315	**P**	HSLE	HSHE	HSHE	**HSHE**
319	**P**	HSHE	**HSHE**	LSHE	**LSHE**

A5. Paired air/water temperature relationships 2009-2010 for pour-point and centroid sample sites. Pink line at 21°C is brook trout thermal tolerance limit. Missing sites or plots missing curves are due to missing data from thermograph loss, animal destruction , etc.

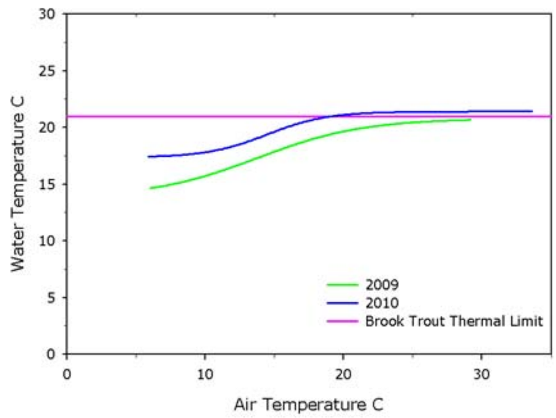


A5. Paired air/water temperature relationships 2009-2010 continued.

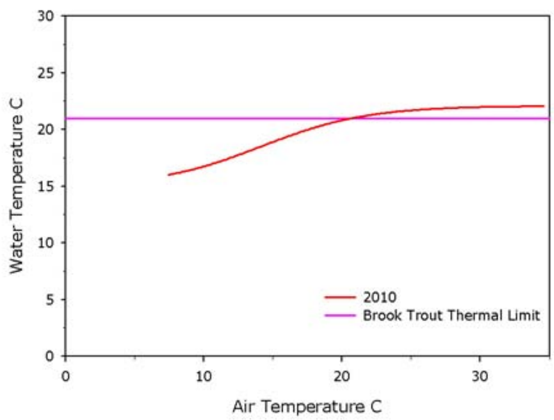
Population 27 Centroid Hamilton Branch 2009-2010
Critical Period Air/Water Temperature Relationships



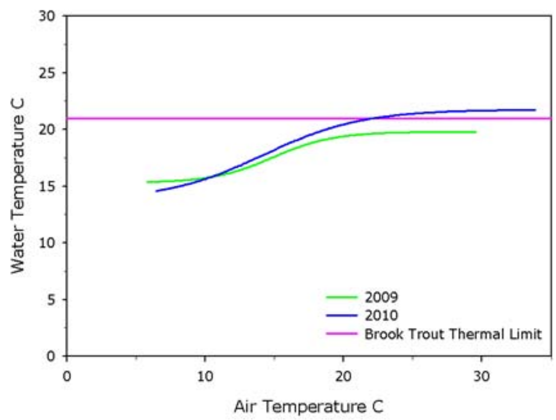
Population 27 Pour-Point Hamilton Branch 2009-2010
Critical Period Air/Water Temperature Relationships



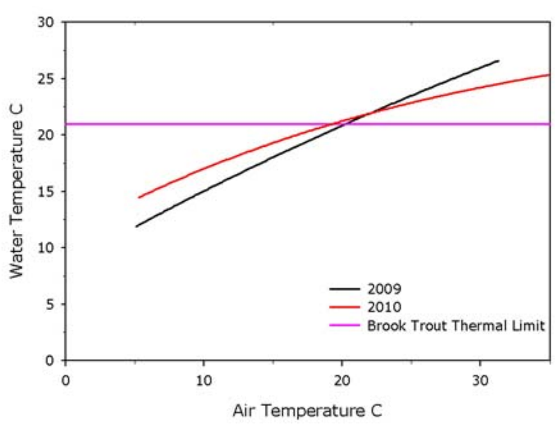
Population 30 Centroid Kelso Spring 2009-2010
Critical Period Air/Water Temperature Relationships



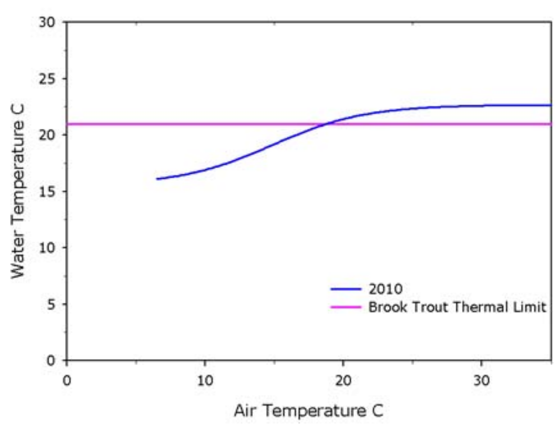
Population 30 Pour-Point Kelso Spring 2009-2010
Critical Period Air/Water Temperature Relationships



Population 33 Centroid Lick Run 2009-2010
Critical Period Air/Water Temperature Relationships

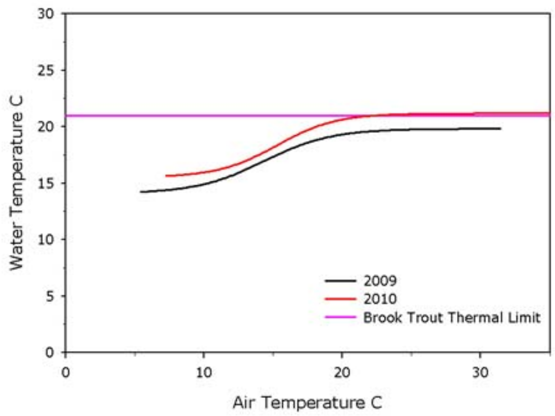


Population 33 Pour-Point Lick Run 2009-2010
Critical Period Air/Water Temperature Relationships

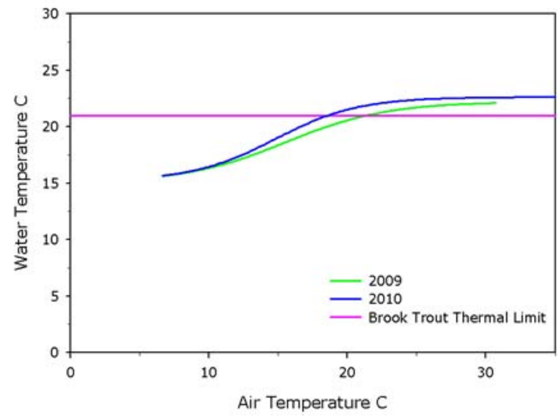


A5. Paired air/water temperature relationships 2009-2010 continued.

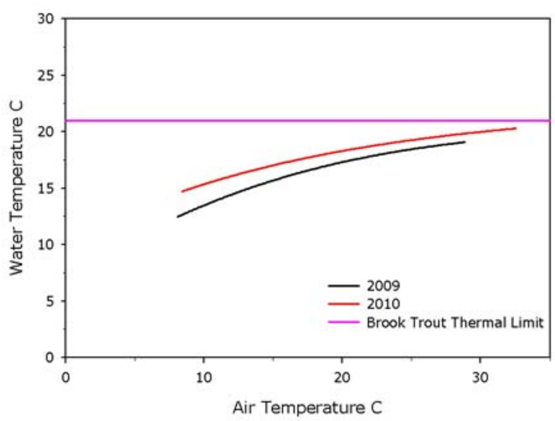
Population 39 Centroid Sinking Creek 2009-2010
Critical Period Air/Water Temperature Relationships



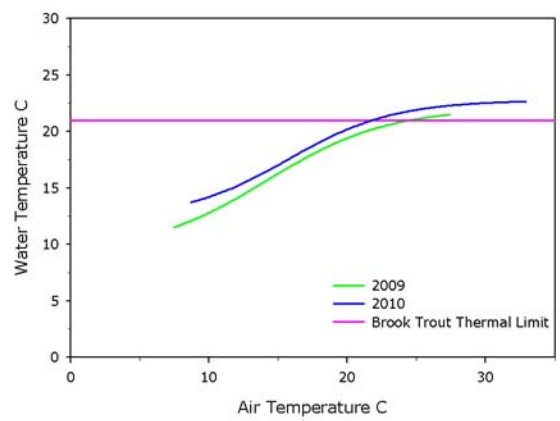
Population 39 Pour-Point Sinking Creek 2009-2010
Critical Period Air/Water Temperature Relationships



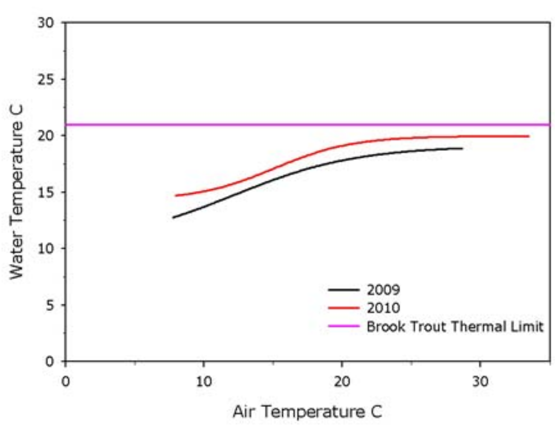
Population 40 Centroid Karnes Creek 2009-2010
Critical Period Air/Water Temperature Relationships



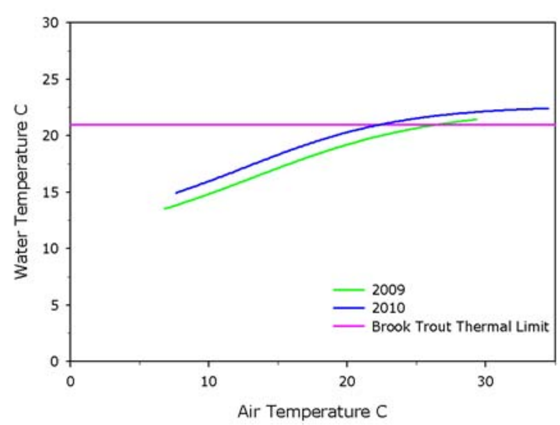
Population 40 Pour-Point Karnes Creek 2009-2010
Critical Period Air/Water Temperature Relationships



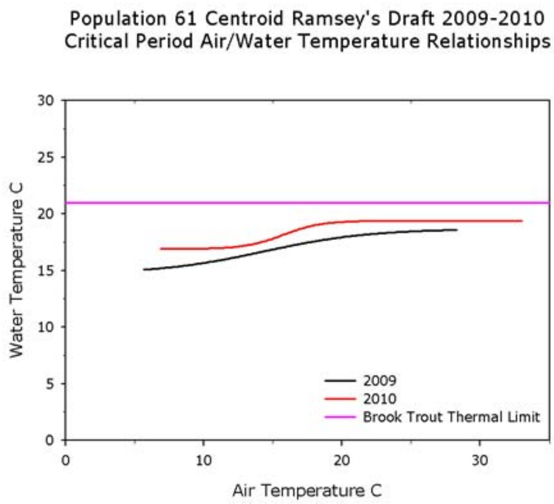
Population 49 Centroid Wilson Creek 2009-2010
Critical Period Air/Water Temperature Relationships

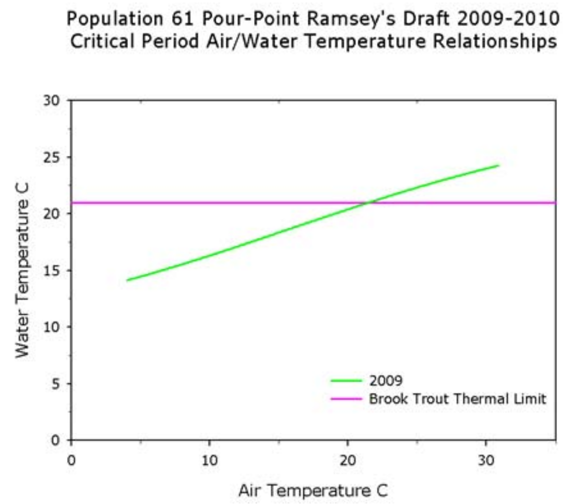


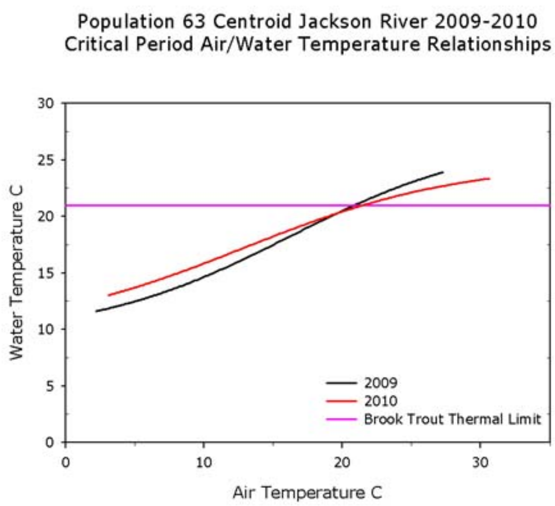
Population 49 Pour-Point Wilson Creek 2009-2010
Critical Period Air/Water Temperature Relationships

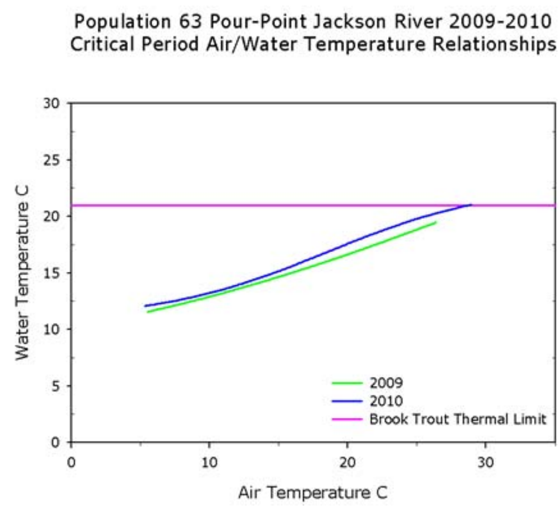


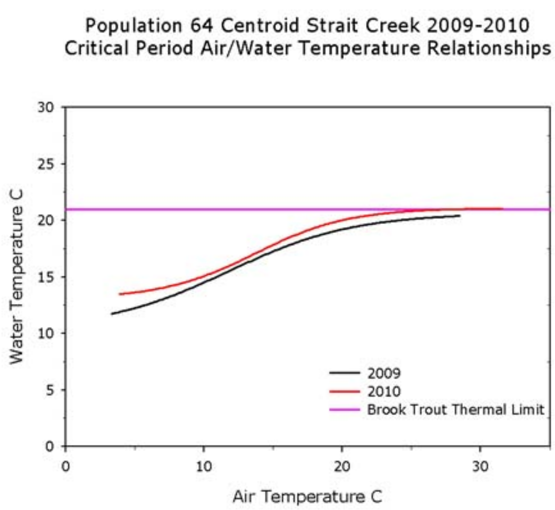
A5. Paired air/water temperature relationships 2009-2010 continued.

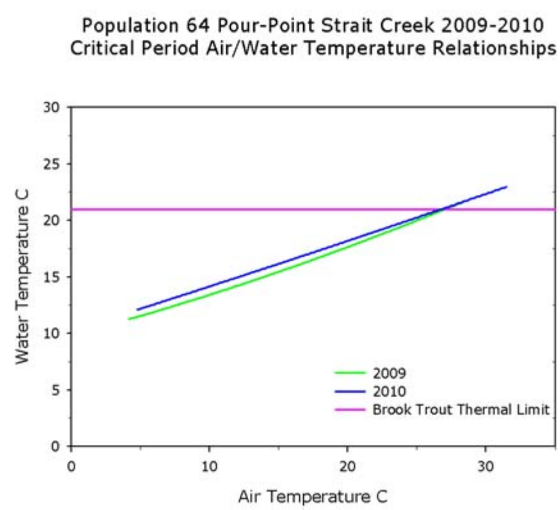




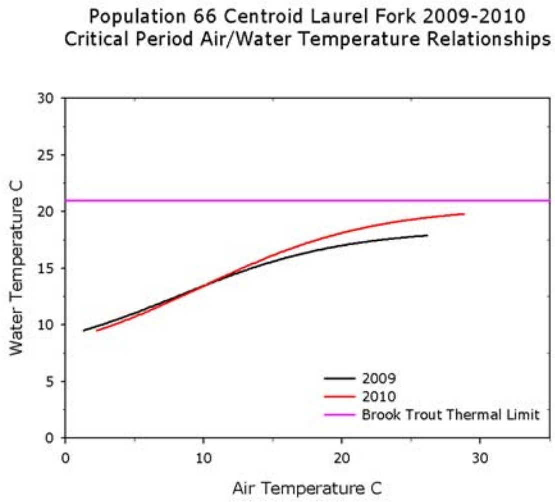


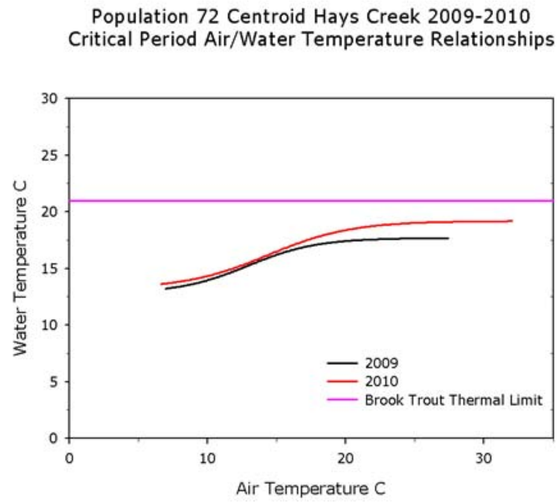


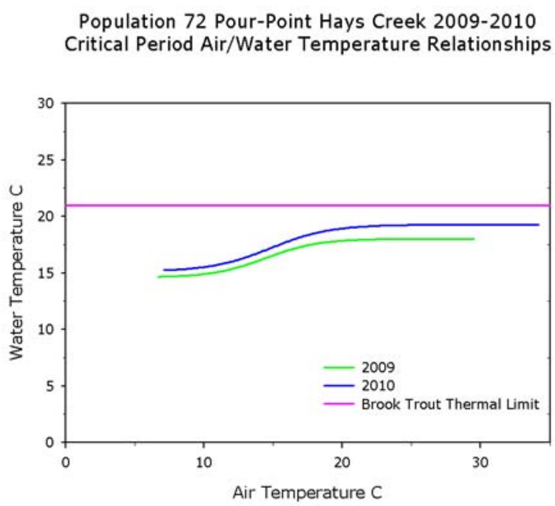


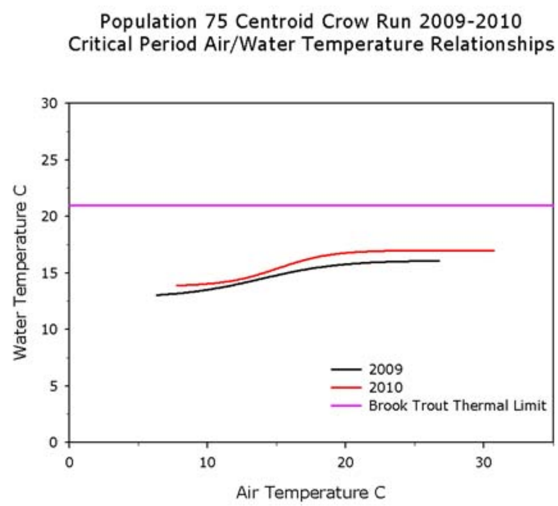


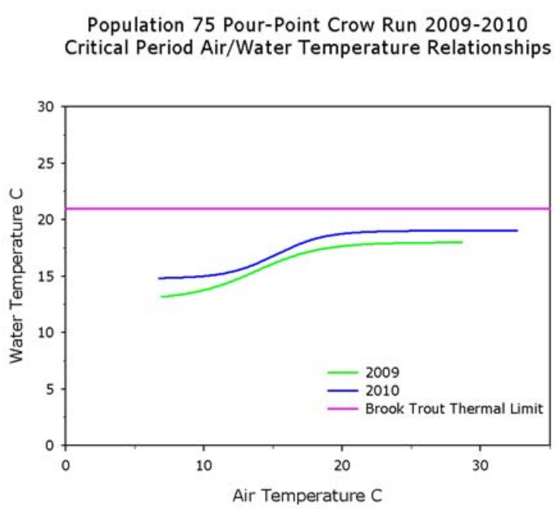
A5. Paired air/water temperature relationships 2009-2010 continued.

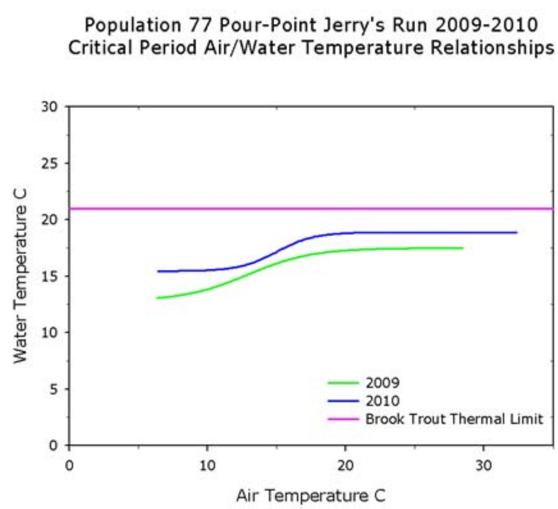






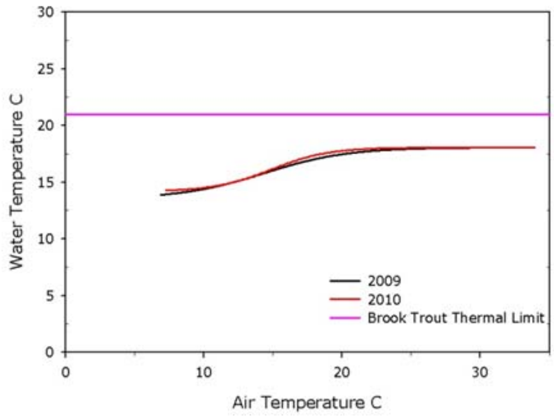




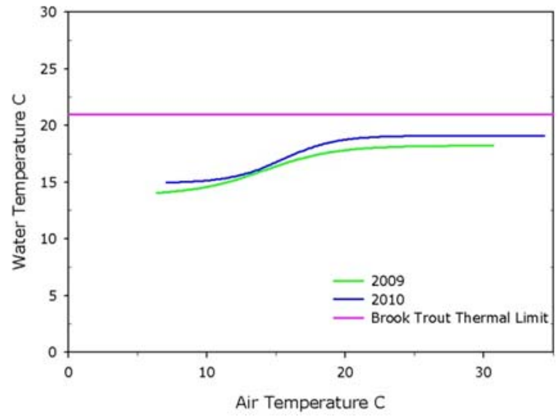


A5. Paired air/water temperature relationships 2009-2010 continued.

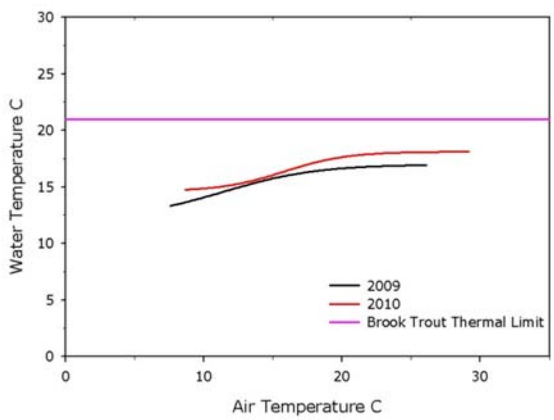
Population 84 Centroid Granny's Creek 2009-2010
Critical Period Air/Water Temperature Relationships



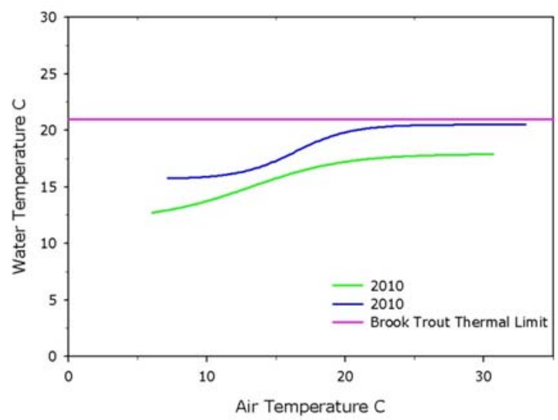
Population 84 Pour-Point Granny's Creek 2009-2010
Critical Period Air/Water Temperature Relationships



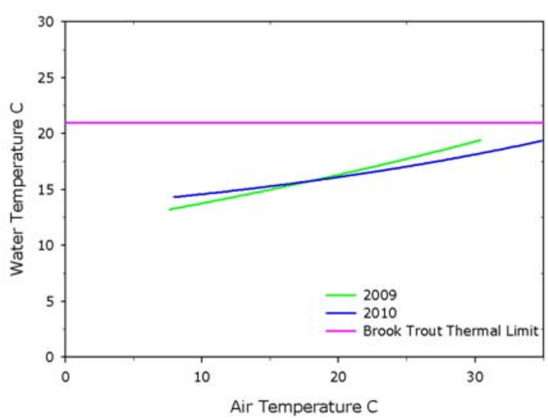
Population 87 Centroid Laurel Creek 2009-2010
Critical Period Air/Water Temperature Relationships



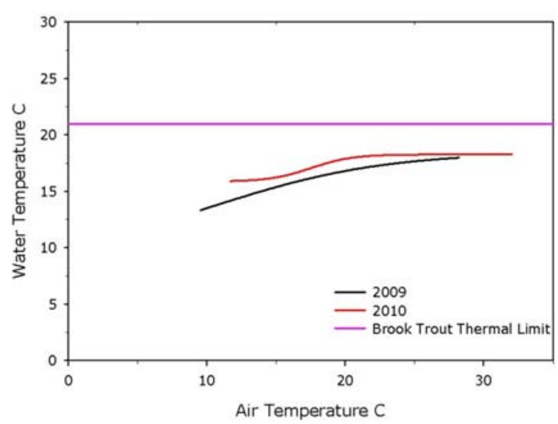
Population 87 Pour-Point Laurel Creek 2009-2010
Critical Period Air/Water Temperature Relationships



Population 102 Pour-Point East Fork Elk Creek 2009-2010
Critical Period Air/Water Temperature Relationships

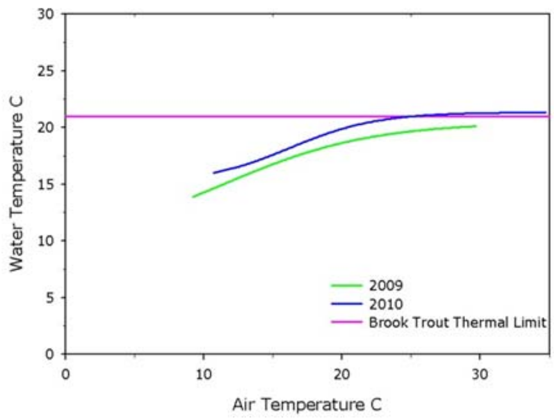


Population 105 Centroid Reed Creek 2009-2010
Critical Period Air/Water Temperature Relationships

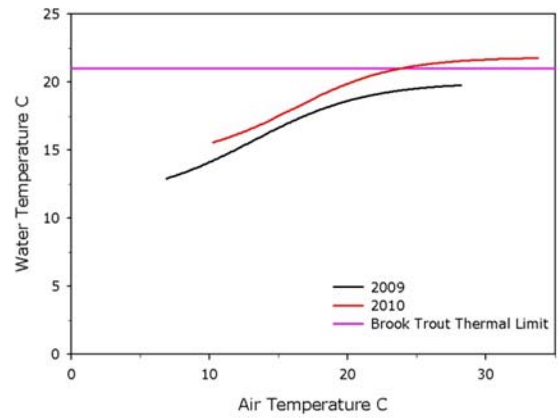


A5. Paired air/water temperature relationships 2009-2010 continued.

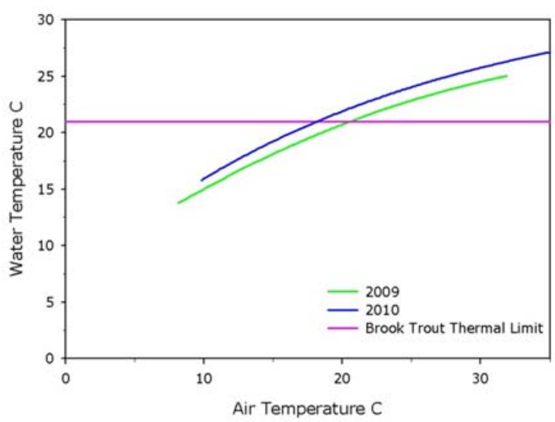
Population 105 Pour-Point Reed Creek 2009-2010
Critical Period Air/Water Temperature Relationships



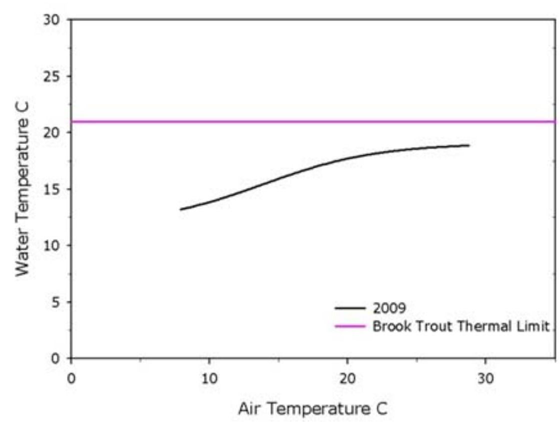
Population 106 Centroid North Creek 2009-2010
Critical Period Air/Water Temperature Relationships



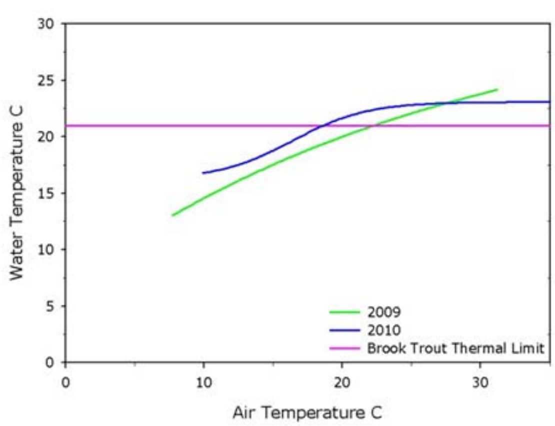
Population 106 Pour-Point North Creek 2009-2010
Critical Period Air/Water Temperature Relationships



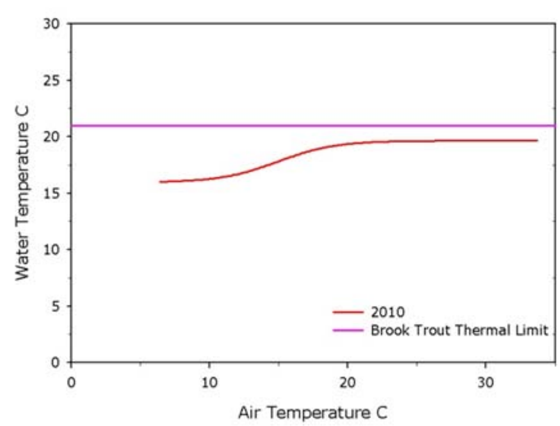
Population 112 Centroid Buffalo River 2009-2010
Critical Period Air/Water Temperature Relationships



Population 112 Pour-Point Buffalo River 2009-2010
Critical Period Air/Water Temperature Relationships

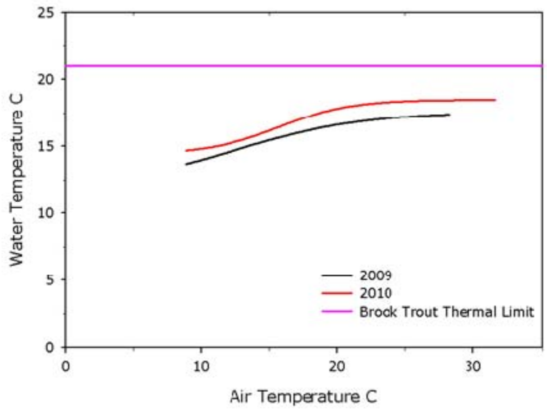


Population 117 Centroid St Mary's River 2009-2010
Critical Period Air/Water Temperature Relationships

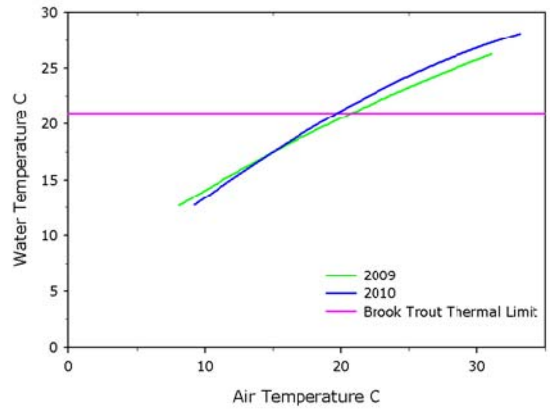


A5. Paired air/water temperature relationships 2009-2010 continued.

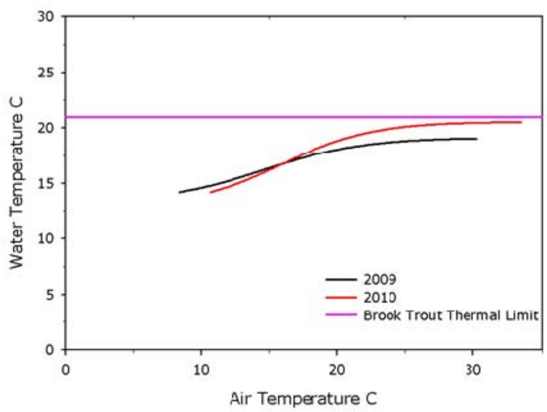
Population 121 Centroid John's Run 2009-2010
Critical Period Air/Water Temperature Relationships



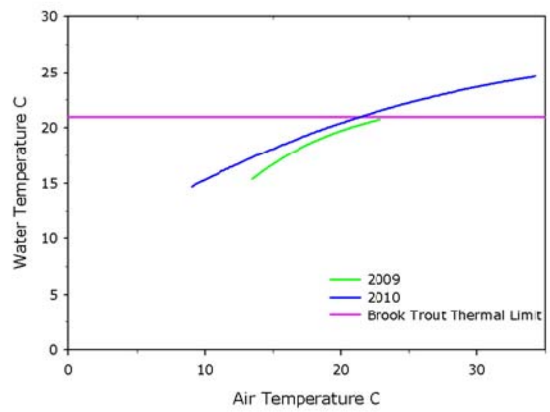
Population 121 Pour-Point John's Run 2009-2010
Critical Period Air/Water Temperature Relationships



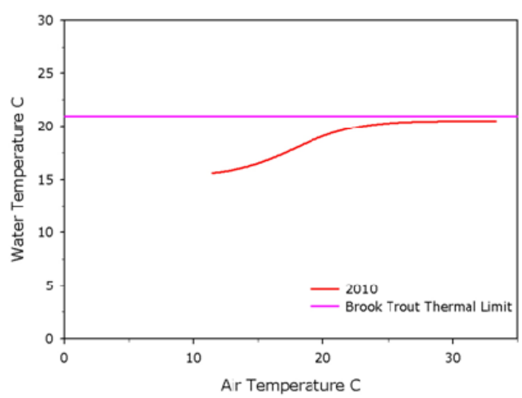
Population 143 Centroid Spruce Creek 2009-2010
Critical Period Air/Water Temperature Relationships



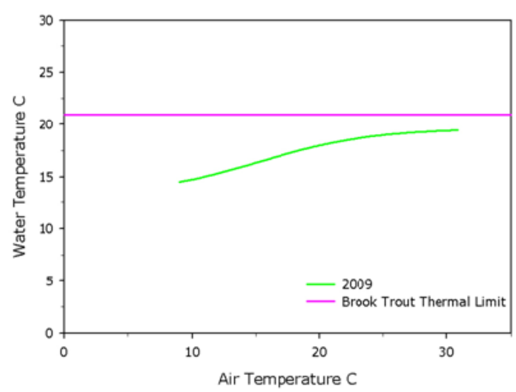
Population 143 Pour-Point Spruce Creek 2009-2010
Critical Period Air/Water Temperature Relationships



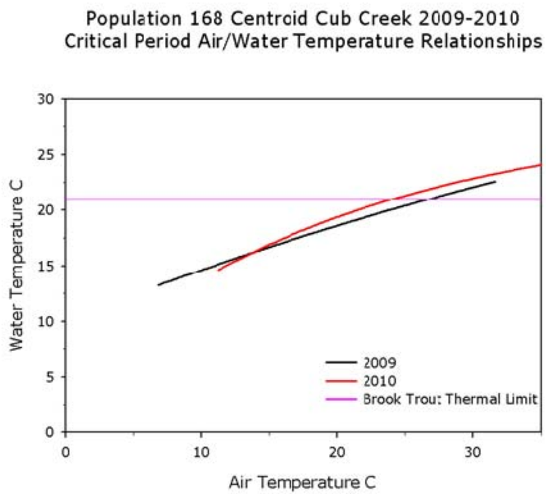
Population 144 Centroid South Fork Rockfish River 2009-2010
Critical Period Air/Water Temperature Relationships

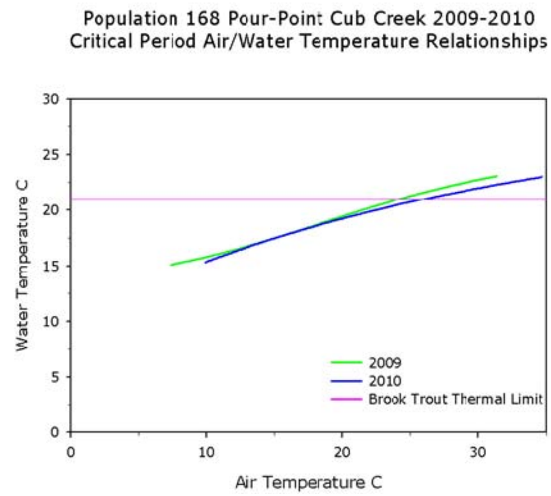


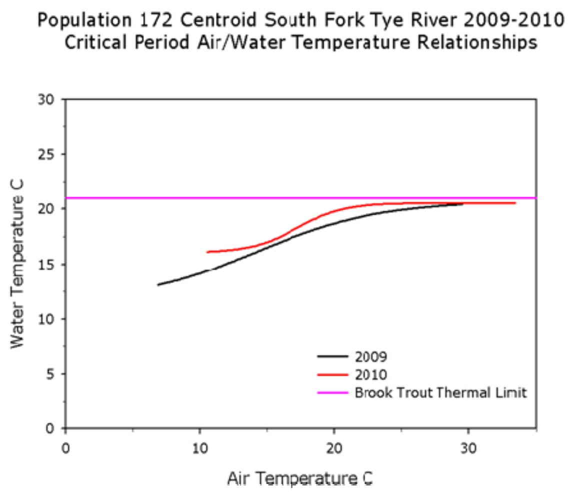
Population 144 Pour-Point South Fork Rockfish River 2009-2010
Critical Period Air/Water Temperature Relationships

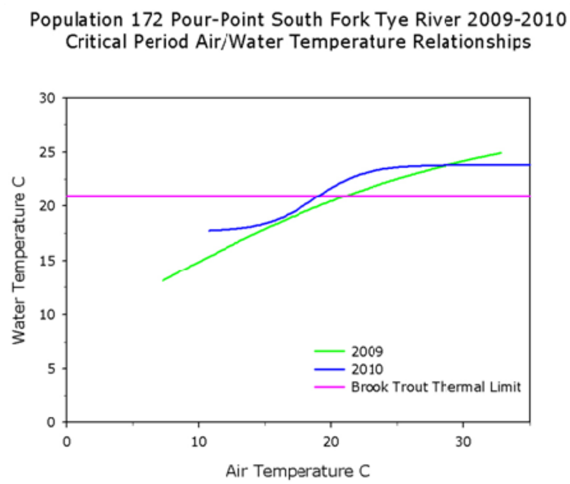


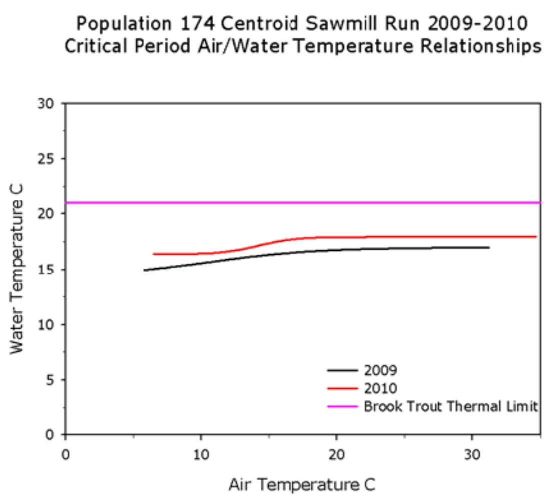
A5. Paired air/water temperature relationships 2009-2010 continued.

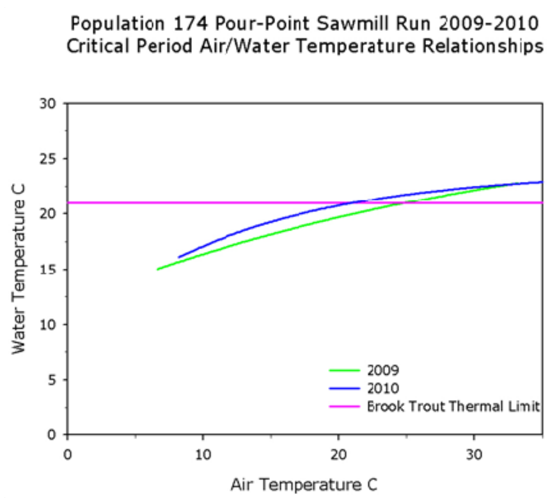






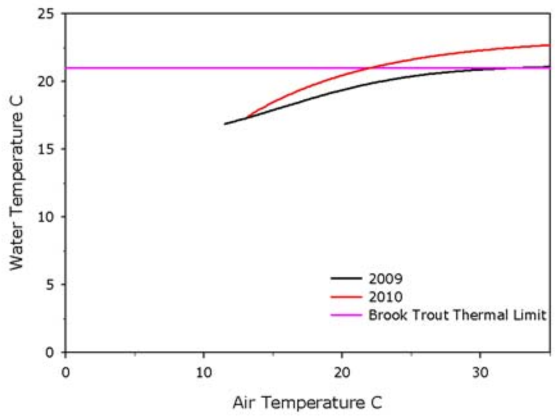




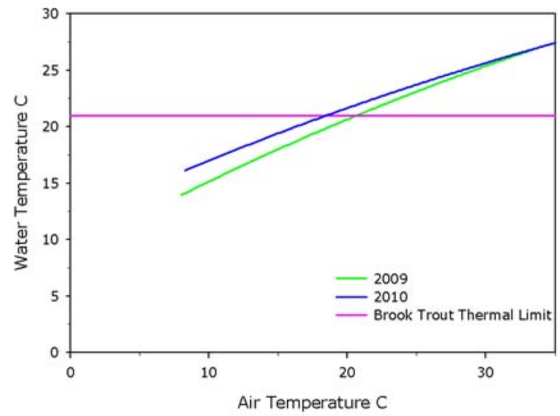


A5. Paired air/water temperature relationships 2009-2010 continued.

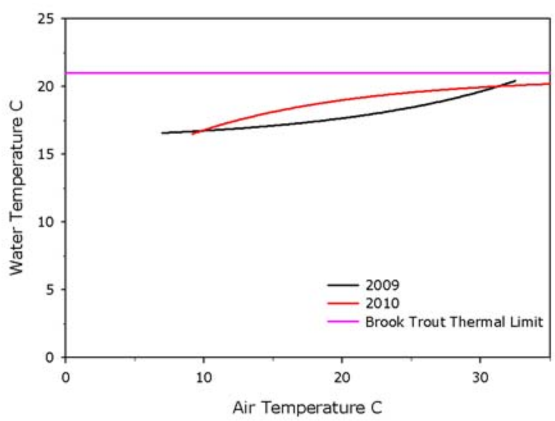
Population 182 Centroid Doyle's River 2009-2010
Critical Period Air/Water Temperature Relationships



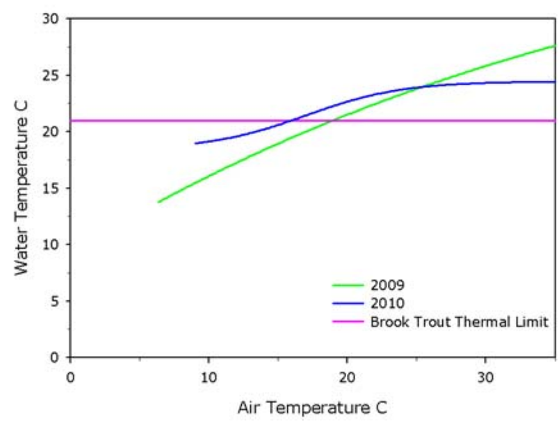
Population 182 Pour-Point Doyle's River 2009-2010
Critical Period Air/Water Temperature Relationships



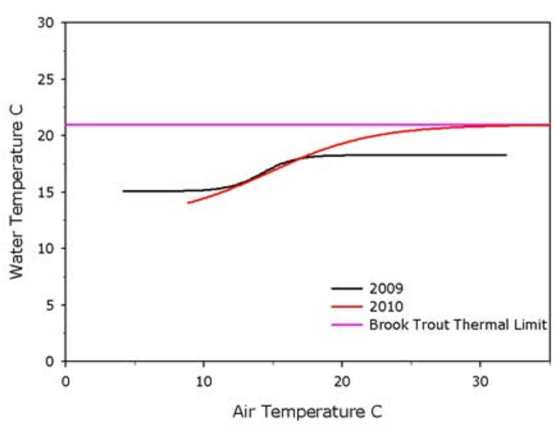
Population 185 Centroid Lynch River 2009-2010
Critical Period Air/Water Temperature Relationships



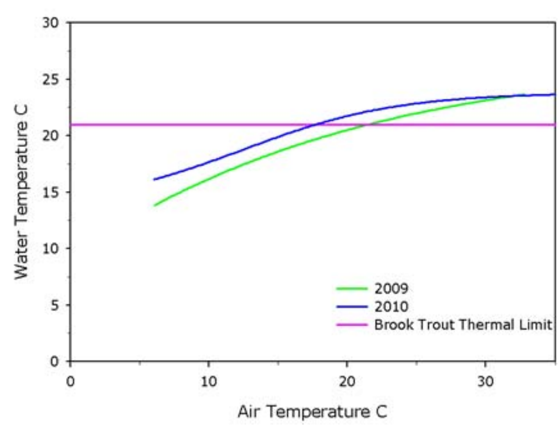
Population 185 Pour-Point Lynch River 2009-2010
Critical Period Air/Water Temperature Relationships



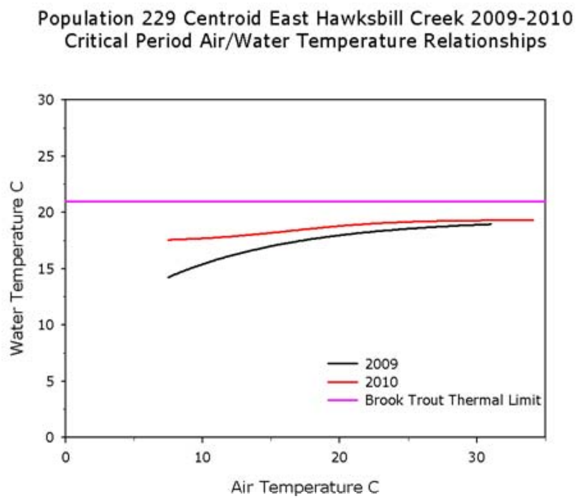
Population 220 Centroid Boone Run 2009-2010
Critical Period Air/Water Temperature Relationships

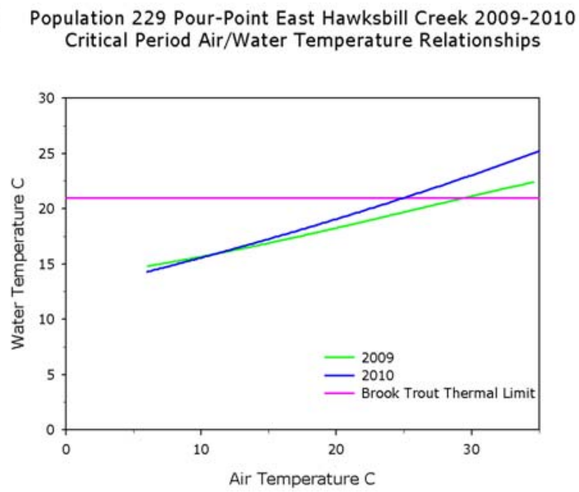


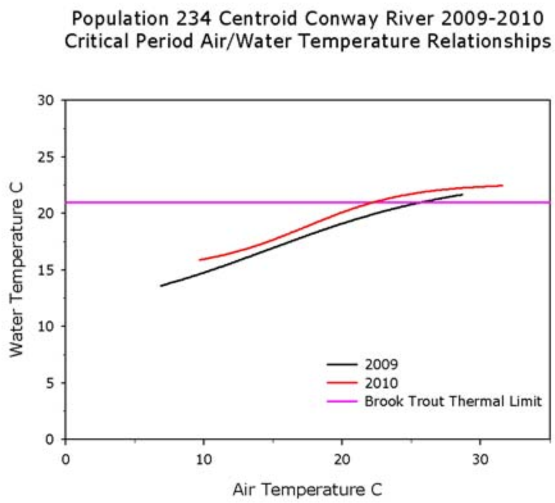
Population 220 Pour-Point Boone Run 2009-2010
Critical Period Air/Water Temperature Relationships

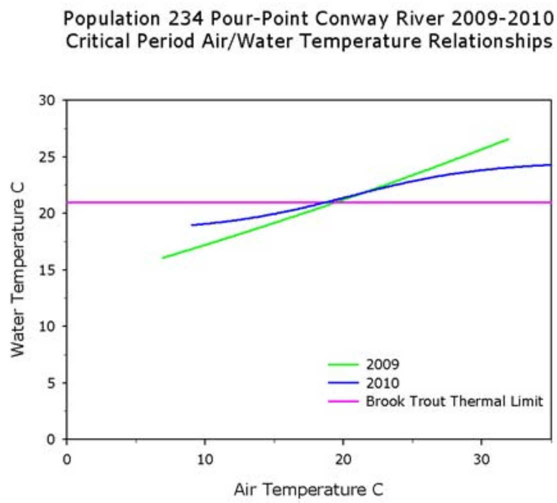


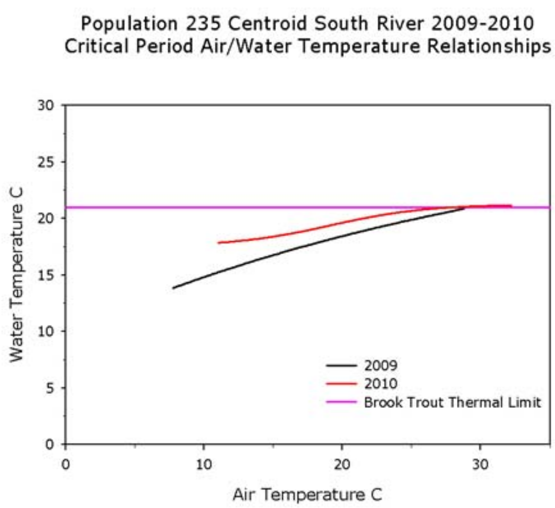
A5. Paired air/water temperature relationships 2009-2010 continued.

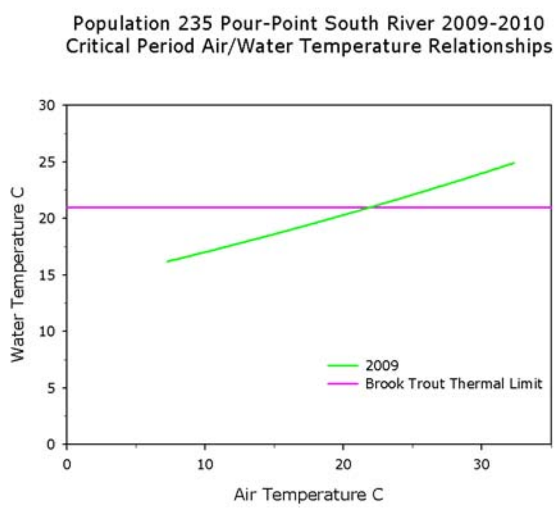




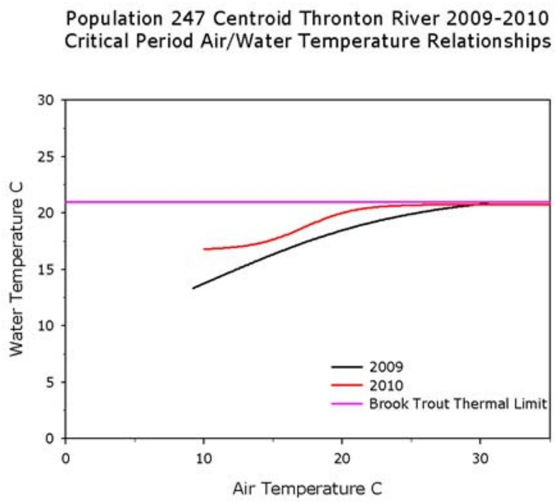


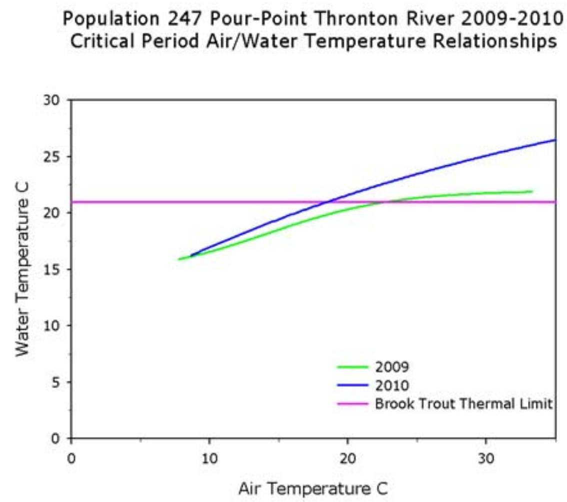


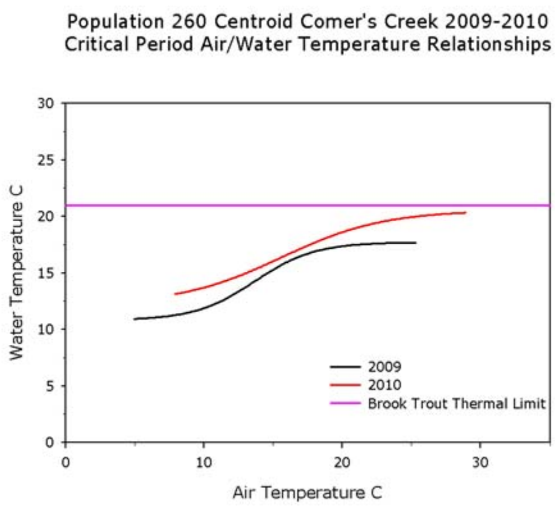


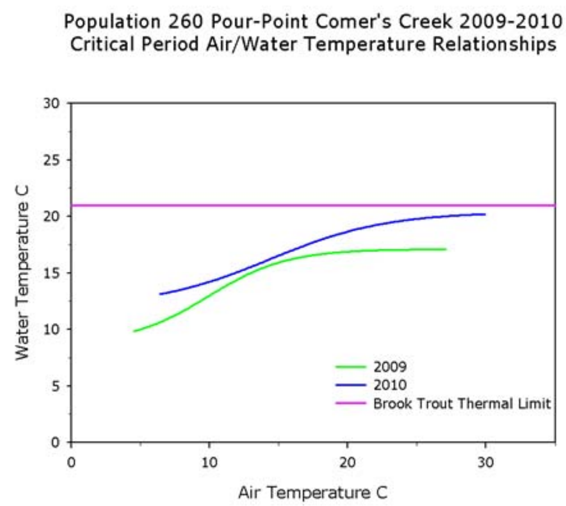


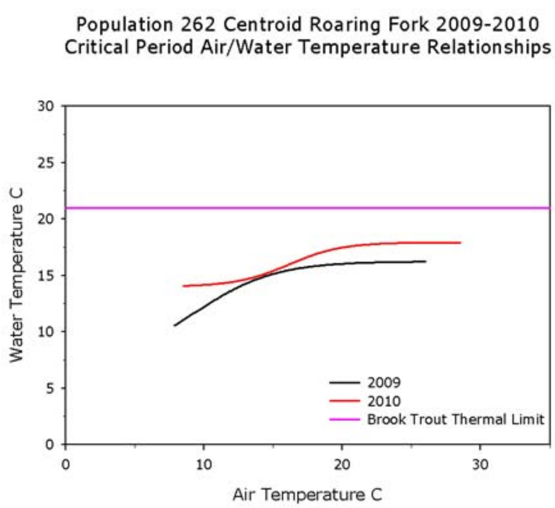
A5. Paired air/water temperature relationships 2009-2010 continued.

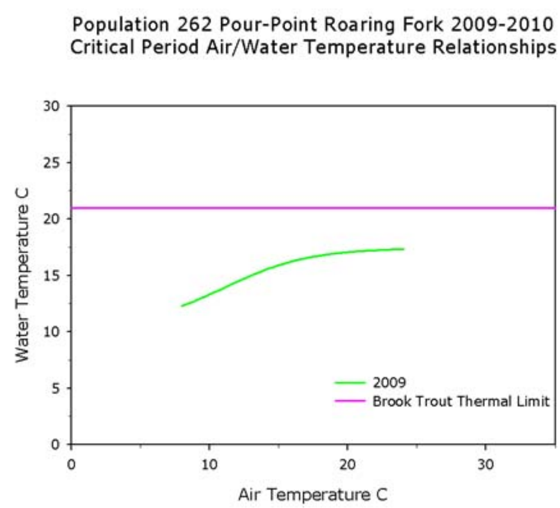




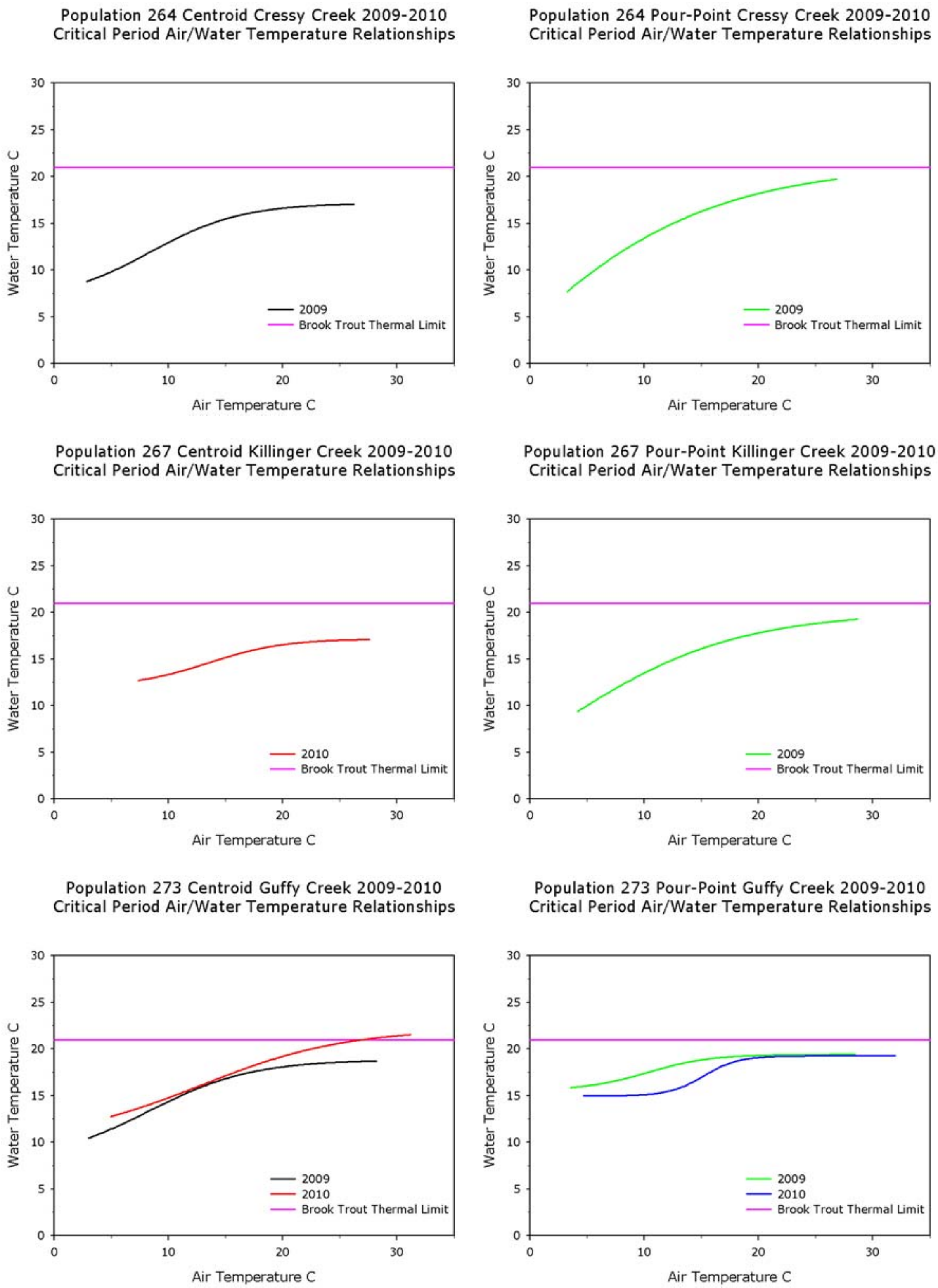




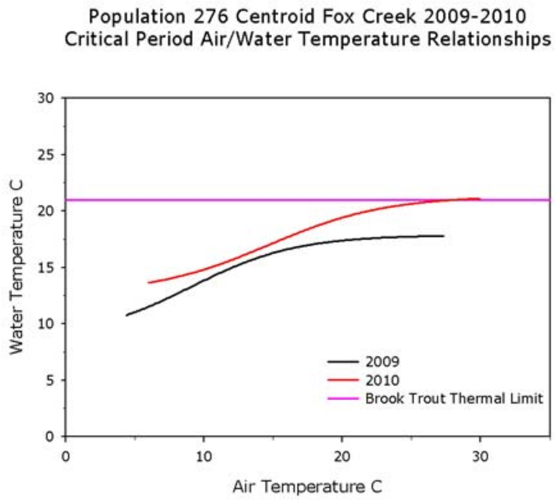


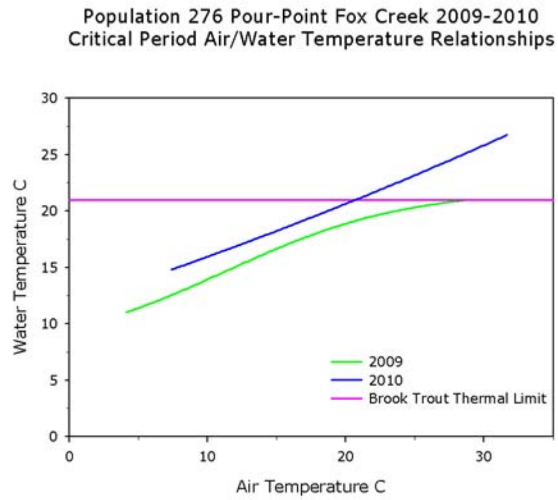


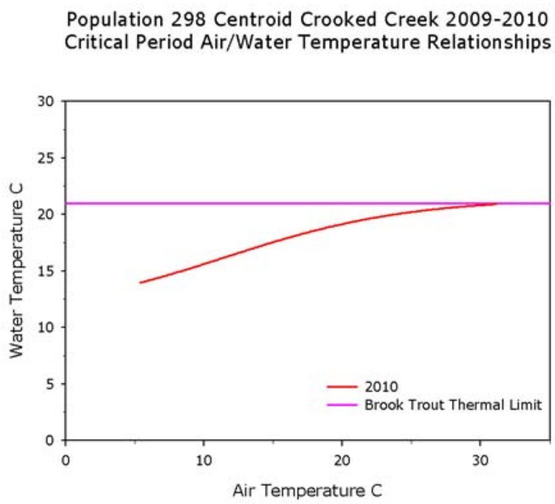
A5. Paired air/water temperature relationships 2009-2010 continued.

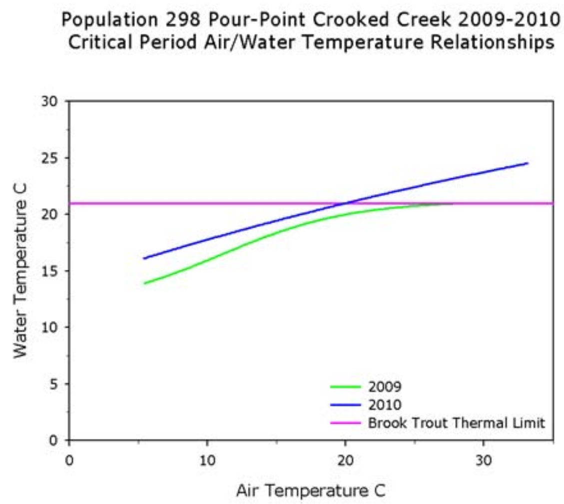


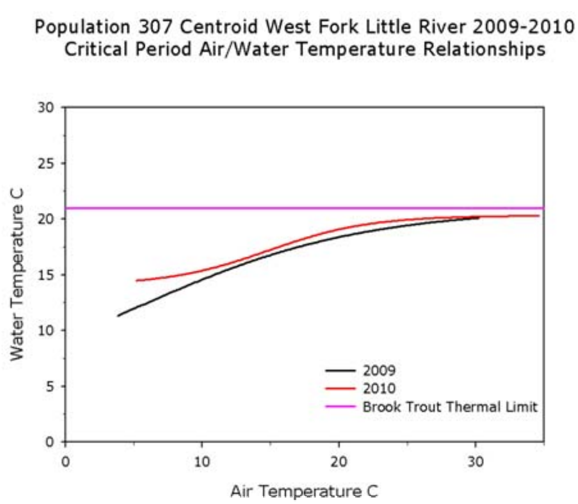
A5. Paired air/water temperature relationships 2009-2010 continued.

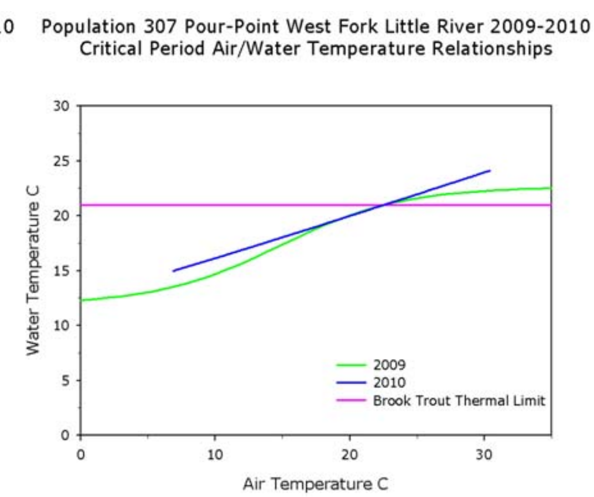




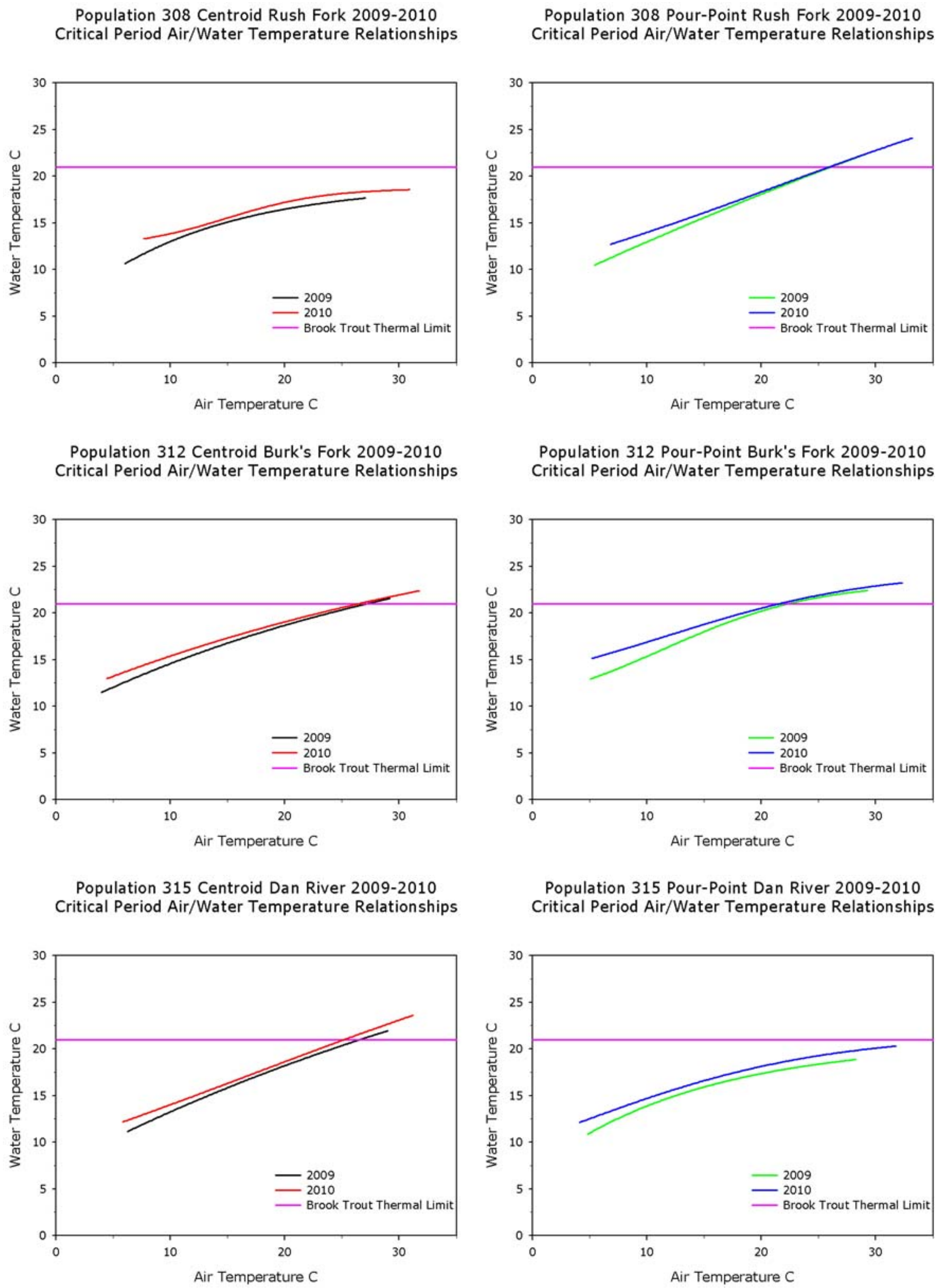




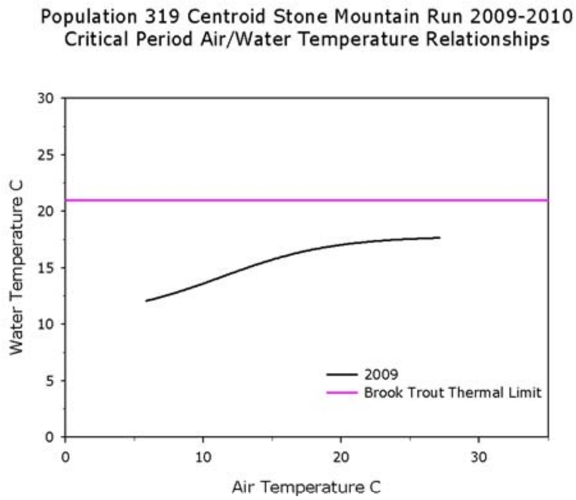


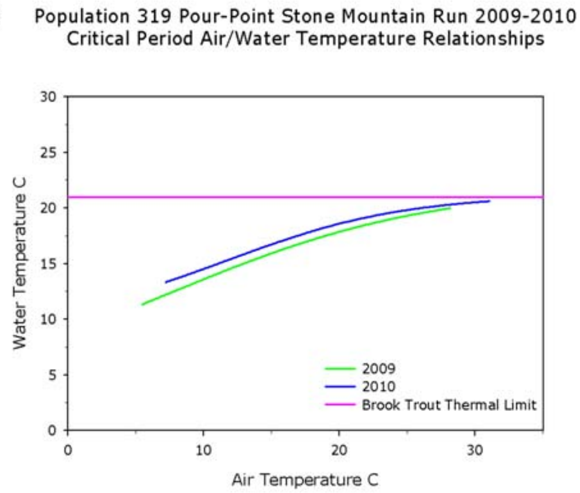


A5. Paired air/water temperature relationships 2009-2010 continued.



A5. Paired air/water temperature relationships 2009-2010 continued.





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