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A Simulation of Water Temperature in the Upper Grande Ronde Basin with Future Climate Change Scenarios

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Abstract

Stream temperature is an important environmental variable for the freshwater stages of salmon and other coldwater fishes. For this study, we used a water temperature model of the Upper Grande Ronde River basin, an area of ongoing and potential salmon habitat restoration in NE Oregon. The Heat Source model, a deterministic approach to simulate thermodynamics in a stream network, was calibrated to late summer (August) conditions using empirical data collected in 2010. We employed this model to simulate future climate and stream flow conditions based on an ensemble of global climate models for two future emission scenarios (A1B and B1) and three periods (2020s, 2040s, and 2080s). The simulations showed substantial increases to daily mean and maximum temperatures in future periods, which are important to consider in salmon and riparian restoration efforts.

Keywords: Climate change, water temperature, model

1. Introduction

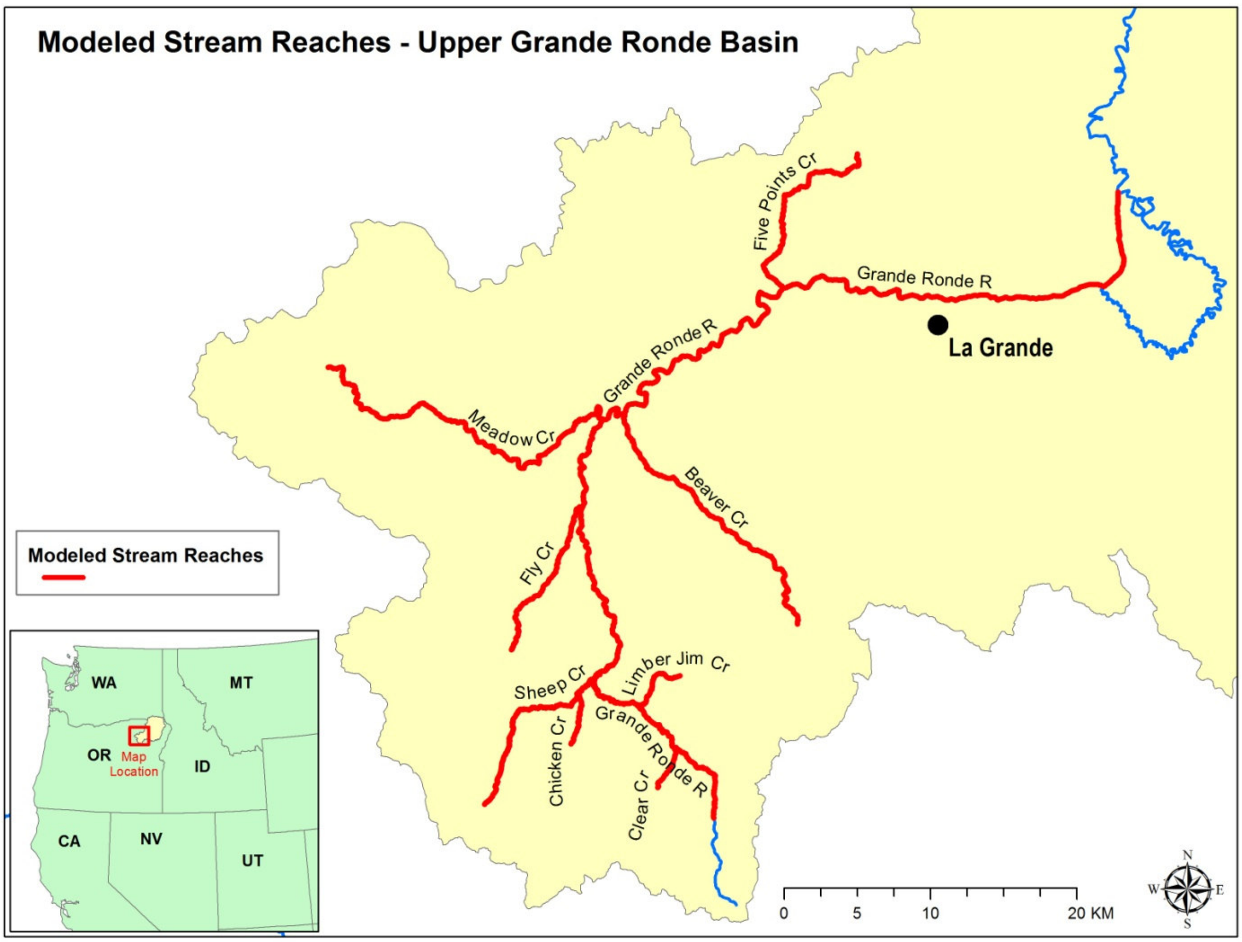
There is a strong scientific consensus that climate change has been caused by the release of heat-trapping greenhouse gases into the atmosphere during the 20th century and will likely accelerate during the 21st century, even though the rate of change is uncertain (Oreskes 2004; IPCC 2007). Global climate models forecast that the climate of the Pacific Northwest will warm significantly during the 21st century, and related research shows that this warming will significantly alter stream flow patterns and water quality (Stewart et al. 2004; Regonda et al. 2005, Elsner et al. 2010). Climate change has been identified as a major threat to salmon and steelhead in the Columbia River Basin of the U.S. (Mote et al. 2003; Mantua et al. 2010). The need to assess and adapt to future climate change is an important objective for stakeholders and managers of salmon and steelhead in the region (ISAB 2007; UWCIG 2008). Water temperature will almost certainly increase with climate change in salmon-bearing streams and rivers (Crozier, et al. 2008), and this is of concern because it is one of the most vulnerable habitat variables influencing the growth and survival of salmon and other coldwater fishes (McCullough 1999).

The Grande Ronde River is a major tributary of the Snake River, flowing for most of its 340 km path through NE Oregon before joining the Snake River in SE Washington (Nowack 2004). Its basin is 10,360 km² in area, and has its headwaters near Anthony Lake in the Blue Mountains. This modeling effort occurs on select reaches (Figure 1) of the Upper Grande Ronde Basin (UGRB), which is located mostly upstream of the city of La Grande, and includes a mix of private land ownership and national forest. This area is typified by cold winters with ample snow in its headwaters areas, and hot, dry summers. The tributaries of the UGRB are primarily fed by snowmelt, with peak flows occurring during the spring, and base flows occurring during the late summer. The Grande Ronde basin once supported abundant salmon runs that were major sources of food to native tribes in the area (Ashe et al. 2000). Coho have since been extirpated from the basin and the production potential of other salmon runs, including Spring Chinook and Summer Steelhead, are severely compromised by habitat degradation (Nowack 2004). Water quality concerns include temperature, sedimentation, and habitat modification. High water

temperature in particular has a detrimental effect on salmon in the UGRB, and it has been shown that improved management strategies could help mitigate these temperatures (ODEQ 2000).

A Columbia River Inter-Tribal Fish Commission (CRITFC) Project "Monitoring Recovery Trends in Key Spring Chinook Habitat" (CRITFC - Grande Ronde) is performing ongoing research to monitor Spring Chinook habitat and to investigate restoration potential in the UGRB (McCullough et al. 2011). This work involves on-the-ground field sampling and monitoring in coordination with NOAA Fisheries, the Confederated Tribes of the Umatilla Reservation (CTUIR), Oregon Department of Fish and Wildlife, and the US Forest Service, as well as data compilation and analysis.

Figure 1: Modeled Stream Reaches, Upper Grande Ronde Basin



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2. Methods

For this study we employed a deterministic water temperature model, Heat Source (ODEQ 2010), to simulate water temperature and flow dynamics in the major streams of the Upper

Grande Ronde River Basin (Figure 1). The base model was calibrated by Watershed Sciences, Inc. using ground-level hourly stream temperature, discharge, and geometry measurements collected at discrete locations throughout the basin by the CRITFC-Grande Ronde project field crew, the CTUIR, and the US Forest Service. Remotely sensed, continuous data collected by Watershed Sciences for the CRITFC-Grande Ronde project were also incorporated into the model, including LiDAR data to measure stream channel elevation and riparian canopy, and thermal infrared (TIR) data to capture a snapshot of peak daily water temperatures throughout the stream network. The model was calibrated for a 3-week period between August 6, 2010 and August 27, 2010 with this data. This period was chosen to best represent late summer conditions, when water temperatures are typically highest and stream discharge is low, and salmonids are consequently at risk.

The calibrated model incorporates stream channel geometry, hydrology, and riparian vegetation to simulate stream temperature and flow at regular intervals throughout the stream network. Climatic data, including air temperature, cloud cover, relative humidity, and wind speed were recorded by the National Weather Service at the La Grande airport and by the US Forest Service at the J Ridge remote automated weather station in the UGRB. These climatic data were incorporated into model calibration by Watershed Sciences, using lapse rates to correct for elevation differences between the location of the meteorological instruments and the stream sites.

Once calibrated, the August 2010 conditions were simulated as separate but linked models for each stream. These models use a 1-minute time step with hourly input data at a 50-meter distance step, producing hourly outputs at a 100-meter distance step throughout the stream network. These 2010 models were then adjusted by us for future climate change scenarios.

For future climate change simulations, we used scenario information from the University of Washington Climate Impacts Group (UWCIG 2010). These included two sets of scenario families, A1B and B1, to reflect higher and lower end projected emissions of greenhouse gases during the 21st century, and consequently higher and lower rates of air temperature increases from gas concentrations in the atmosphere. The A1B scenario family lies near the high end of the spectrum of projected changes to emissions, and assumes "very high economic growth, global population peaking mid-century and then declining, and energy needs being met by a balance of fossil fuels and alternative technologies" (UWCIG 2010). The B1 Scenario family lies near the lower end of the spectrum, and "assumes global population growth peaks by mid-century and then declines, a rapid economic shift towards service and information economies, and the introduction of clean and resource-efficient technologies." Both scenario families are considered equally likely to occur during the 21st century, and therefore provide a good projected range of possible outcomes in climate change modeling efforts. Each scenario family includes the averaged results of 20 global climate models run with the respective scenario, weighted by each model's ability to replicate 20th century climate in the Pacific Northwest.

Three time periods were modeled using these scenario families: the 2020s (2010-2039 simulation), the 2040s (2030-2059 simulation), and the 2080s (2070-2099 simulation). The scenario families provided estimates of changes in air temperature from a baseline period (1971-2000) to these future time periods. In order to correlate these changes to the 2010 year, it was necessary to correlate the August 1971-2000 average to August 2010. We performed a GIS analysis with PRISM climate data (PRISM Climate Group 2012), calculating the difference in air temperature between these two time spans, and then adjusted the future climate change scenarios

from a 2010 baseline (Table 1). August 2010 was slightly cooler (-.62 °C) than average August conditions during the 1971-2000 period.

Table 1: Change in August Air Temperature from 2010 (°C)

Scenario Family	A1B	B1
2020s	+ 1.38	+ 1.08
2040s	+ 2.57	+ 1.86
2080s	+ 4.68	+ 3.01

Projected changes to stream discharge under these future climate change scenarios were obtained from the Hydrologic Climate Change Scenarios Project for Stream discharge at USGS gage station #4012 (Grande Ronde River at La Grande), near the bottom of the study area (UWCIG 2010). August flows under the climate change scenarios at this gage were related to flows at the same gage in 2010 for the August period to produce flow adjustments. These adjustments were applied to all tributaries and the main stem Grande Ronde River in the water temperature model (Table 2). Ideally, we would differentiate these changes at different sites throughout the study area based on continuous flow gages in the different streams or with a proven method based on watershed characteristics, but this information was not readily available in the Upper Grande Ronde river basin so these fixed adjustments were applied to flow in all streams throughout the study area.

Table 2: Change in August Stream Discharge from 2010 (%)

Scenario Family	A1B	B1
2020s	94%	102%
2040s	87%	94%
2080s	80%	86%

One model was used for each stream of the UGRB (See modeled streams in Figure 1). The 2010 models were adjusted by changing the air temperature and flow values using the adjustments in Tables 1 and 2 at each input site of each model. The Sheep Creek and Grande Ronde River models are downstream of other contributing tributaries, so it was also necessary to change the input stream flow and water temperature values using the mouths of the tributaries that enter those models (Chicken Creek to Sheep Creek, and all other creeks to the Grande Ronde River). Output flows at diversions on the Grande Ronde River were left unchanged. Additionally, an initial stream temperature was required at the upstream boundary of each stream in the simulation, in order to initiate its model. We tested several different correlations for best performance between air temperature and flow to boundary area water temperature in multiple models. Previous 6-hour air temperature was determined to be the best predictor of stream

temperature at these upstream boundaries. For each stream, a regression was thus developed in the 2010 models between the 6-hour previous air temperature and upstream water temperature. When air temperatures were adjusted for future climate change scenarios, these regressions were used to calculate the revised boundary water temperatures.

The models were run for each of the six climate change scenarios (A1B, B1: 2020s, 2040s, and 2080s), producing hourly stream temperatures at all study nodes. We formatted these results in a series of computational spreadsheets to derive summary statistics (Mean, Minimum, Maximum, Mean Daily Maximum, and Mean Daily Minimum water temperatures) at each node throughout the network, and as averages for the entire study area. These statistical results were compiled into a single spreadsheet format, and also a GIS layer for mapping and spatial analysis, using the longitude/latitude coordinates of each study node.

3. Results and Discussion

As expected, simulated mean and maximum daily temperatures at most sites show an increasing trend towards the latter part of the 21st century, and the rate and magnitude of increase is larger in the A1B scenario than the B1 scenario (Figures 2 and 3). On average, the magnitude of increase from 2010 to the 2080s is greater for mean daily maximum temperature (+2.7 °C, +1.8 °C for the A1B and B1 scenarios respectively) than for mean daily mean temperature (+2.0 °C, +1.3 °C), and least for mean daily minimum water temperature (+1.7 °C, +1.0 °C) (Tables 4-6), meaning that daytime peak water temperatures were found to increase more rapidly than nighttime low temperatures in the simulations.

When examining these results, it is important to consider that a single model is used to simulate average expected climate in each of the future periods (2020s, 2040s, and 2080s). Because the future period simulations are constructed with mean changes to air temperature and stream flow in a multiyear period, they do not reflect the year-to-year climate variability that will certainly occur around these averages. For example, a simulated daily maximum temperature of 23°C (A1B) and 22°C (B1) at a particular site in a 2040s scenario, predicts that the mean daily maximum temperature in August at this site in the 2040s will likely be between 22-23°C, but the actual daily maximum will vary around this value from year-to-year and also on a daily basis, and higher water temperatures can be expected to occur in years that are warmer or drier than average.

Figure 2: Simulated Mean Daily Mean Water Temperature (°C) at All Sites

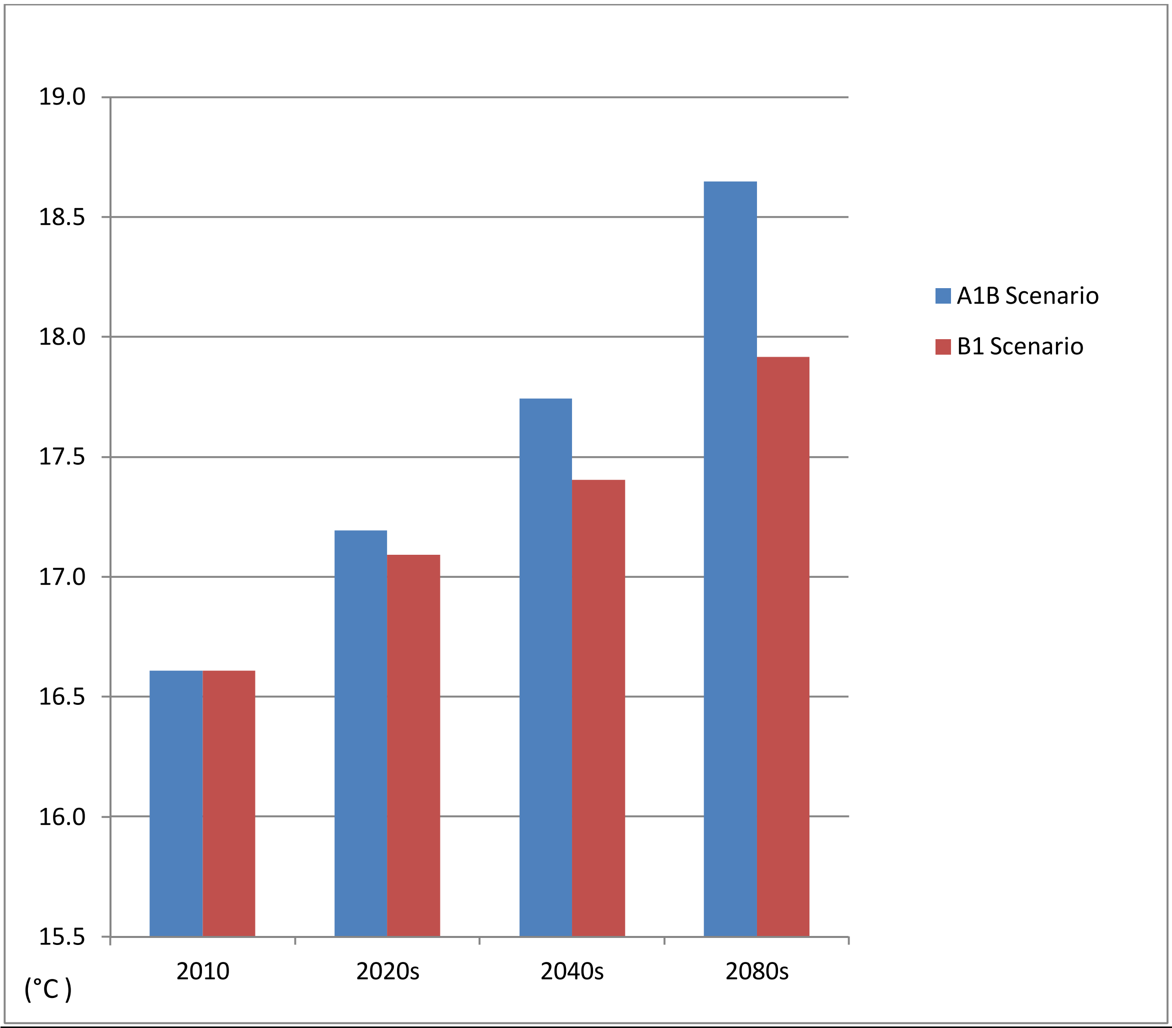


Figure 3: Simulated Mean Daily Maximum Water Temperature (°C) at All Sites

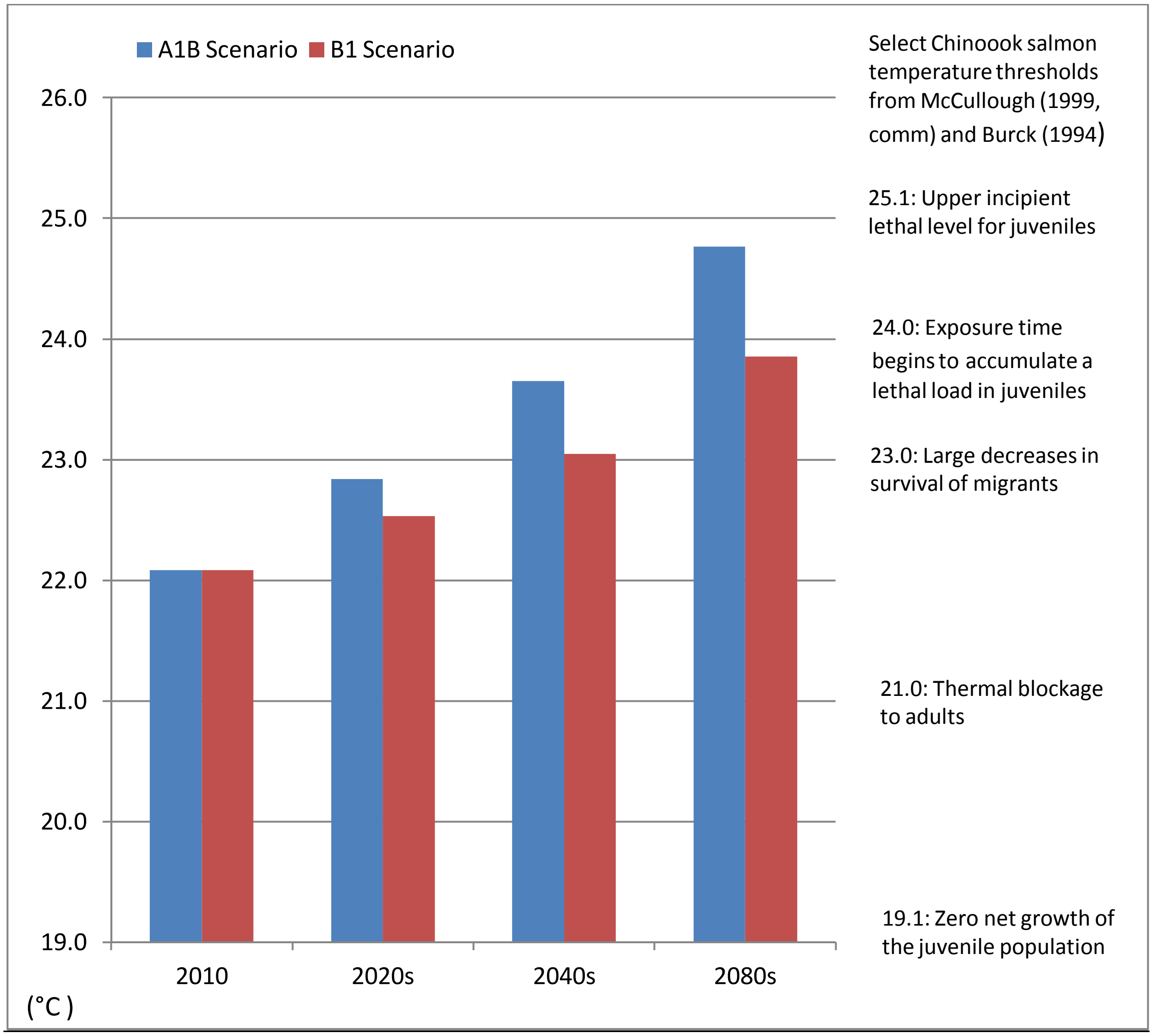


Table 4: Change in Mean Daily Mean Water Temperature (°C) from 2010

Scenario Family	2020s	2040s	2080s
A1B	+ 0.6	+ 1.1	+ 2.0
B1	+ 0.5	+ 0.8	+ 1.3

Table 5: Change in Mean Daily Maximum Water Temperature (°C) from 2010

Scenario Family	2020s	2040s	2080s
A1B	+ 0.8	+ 1.6	+ 2.7
B1	+ 0.4	+ 1.0	+ 1.8

Table 6: Change in Mean Daily Minimum Water Temperature (°C) from 2010

Scenario Family	2020s	2040s	2080s
A1B	+ 0.5	+ 0.9	+ 1.7
B1	+ 0.5	+ 0.7	+ 1.0

Substantial research has documented ill effects on both juvenile and adult salmonids from higher water temperatures. McCullough et al. (2001) examined existing literature on the effects of high water temperature on salmonids. Each salmonid species and life stage has an optimum temperature range. Thermal stress at high temperatures above these ranges can cause lethal and sub lethal effects over short and long periods, and the emergence and metabolic growth rates of juveniles are directly influenced by temperature. The optimal temperature range for growth of juvenile Chinook during summer was found to occur in a range between 15°C and 20°C. These optimum growth rates are predicated on an abundant availability of food, which may not be the case; when food is limited, optimum growth temperatures are consequently lower. Brett et al. (1982) found that juvenile Chinook feeding begins to decline in water temperatures above 23°C, and ceases at 25°C. Tests of the survival of 0+ age Chinook migrants in Lookingglass Creek, a tributary to the lower Grande Ronde River in early August found large decreases in survival at water temperatures above 23°C (Burck 1994). Thermal blockages to adult Chinook salmon (*O. tshawytscha*), steelhead, and rainbow trout have been documented when maximum daily water temperatures exceed 21°C in the Clearwater River (Stabler 1981), 21.1°C in the Tucannon River (Bumgarner et al. 1997), and between 21°C and 22°C in the Willamette River (Alabaster 1988). In the Grande Ronde River, Ebersole et al. (2001) found that rainbow trout densities declined to zero at a temperature of approximately 24°C.

Mapping the results of the water temperature simulations illustrates how mean and maximum water temperatures may be expected to change across the watershed in the future. In the 2010 simulation, mean daily temperatures at 73% of study nodes are below 18°C, but in the 2080s simulation, only 37% (A1B) - 51% (B1) of study nodes are modeled to be below this temperature (Figure 4). Water temperatures above 23°C can have lethal and non-lethal impacts on salmon. In the 2010 simulation, 50% of the study nodes had a mean daily maximum temperature above this threshold. In the 2020s simulation, 55% (B1) - 59% (A1B) of study nodes had temperatures above this threshold, in the 2040s simulation, 62% (B1) - 67% (A1B) did, and in the 2080s simulation, 68% (B1) - 74% (A1B) had values above this level (Figure 5). Maximum temperatures signify the highest temperature simulated during the study period. In 2010, 21% of the study nodes, primarily on the main stem Grande Ronde, were modeled to reach

temperatures above 28°C, but by the 2080s simulation, 43% (B1) - 52% (A1B) are modeled to exceed this threshold, including locations in Five Point Creek, Meadow Creek, Fly Creek, Sheep Creek, and Chicken Creek (Figure 6).

Several other analyses are possible with these data to examine potential trends in future water temperatures in the UGRB. These may include consideration of potential impacts to salmon and other aquatic species, as well as habitat restoration activities that could best mitigate these effects. A spreadsheet with combined statistical results and a GIS layer containing these results are available for download from the CRITFC website at http://fishery.critfc.org/FiSci/CRITFCDataDownload.aspx. Please contact the study author if more detailed data including hourly simulations are desired.

Figure 4: Mean Daily Mean Water Temperature

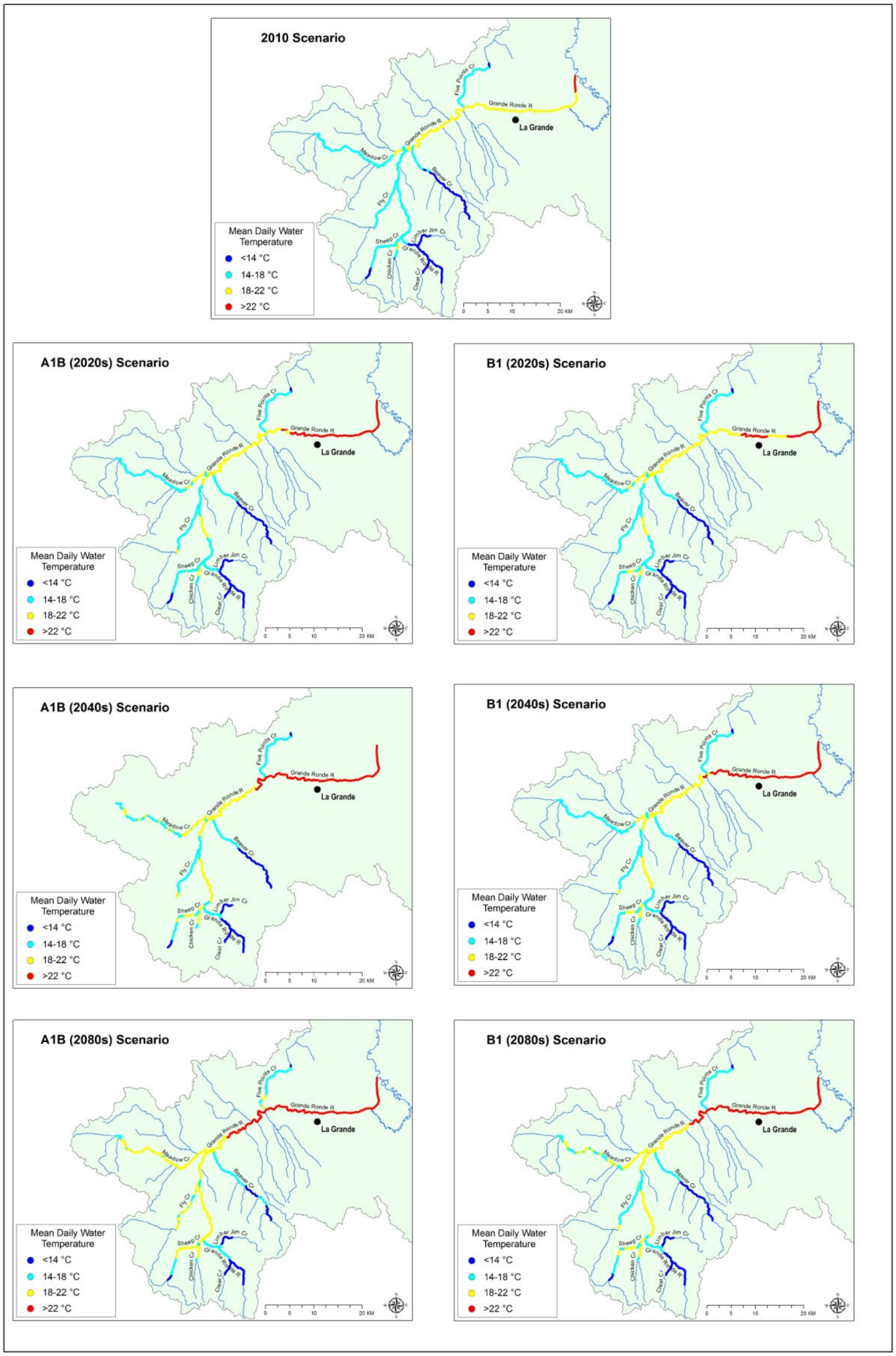


Figure 5: Mean Daily Maximum Water Temperature

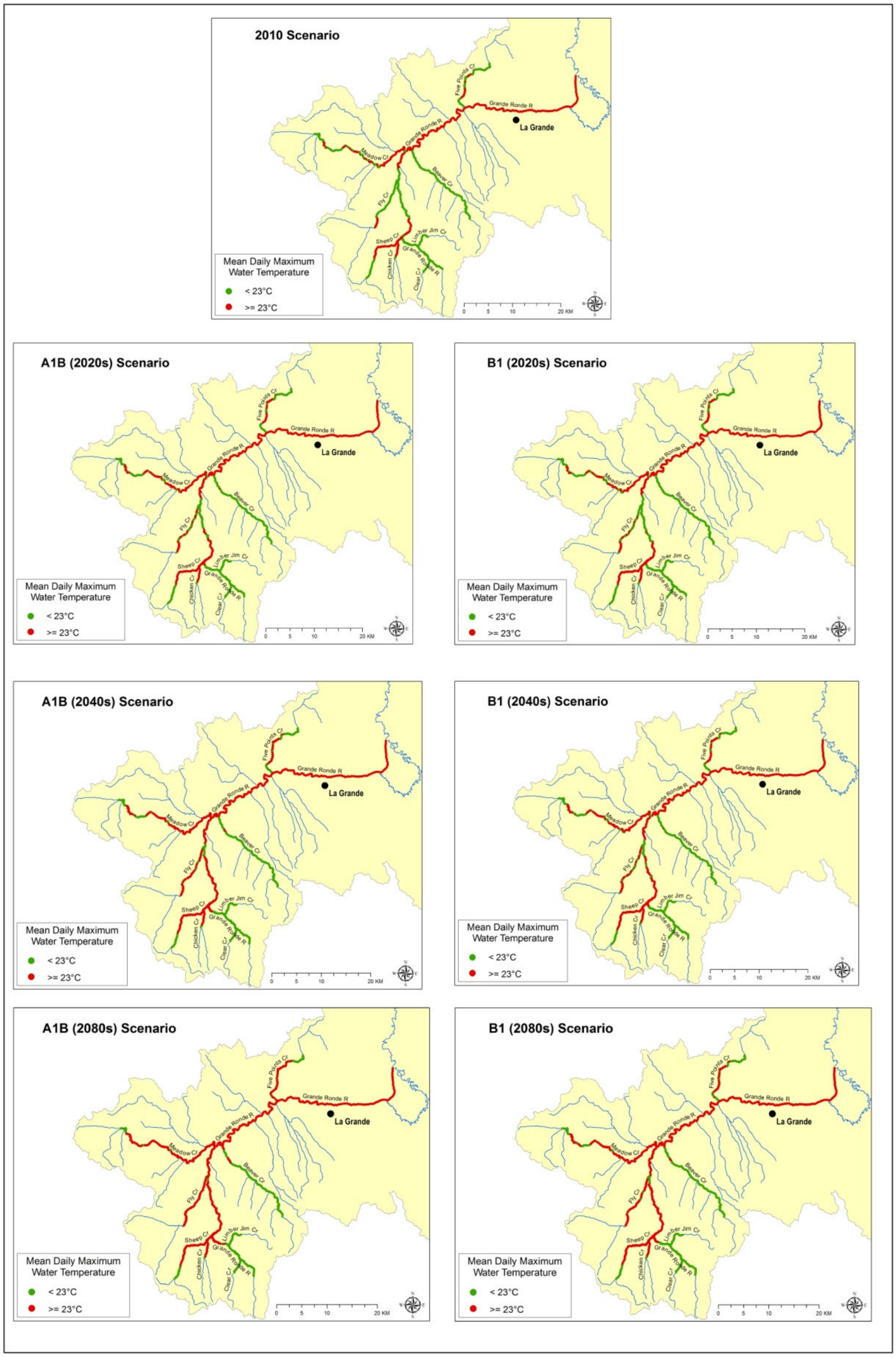
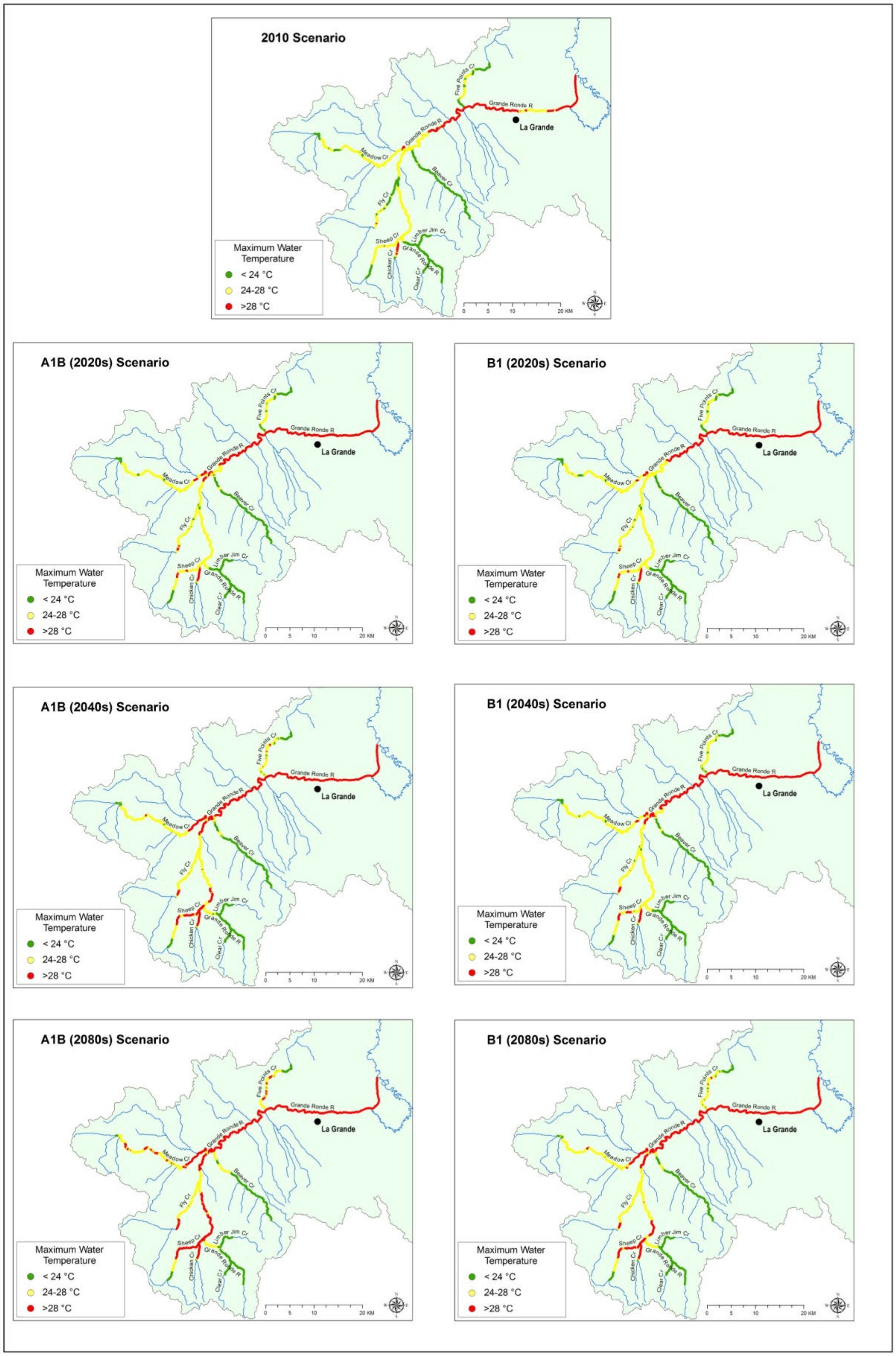


Figure 6: Maximum Water Temperature



4. Acknowledgements

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