2023

Rad Rivers in Rad Places: Characterizing the Historical and Future Whitewater Resources in Select Regions of the United States

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Recommended Citation

Shafer, Melissa D., "Rad Rivers in Rad Places: Characterizing the Historical and Future Whitewater Resources in Select Regions of the United States" (2023). *Graduate Theses, Dissertations, and Problem Reports*. 11764.
https://researchrepository.wvu.edu/etd/11764

Rad Rivers in Rad Places: Characterizing the Historical and Future Whitewater Resources in Select Regions of the United States

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

In partial fulfillment of the requirements for the degree of
Master of Science in Forestry in Forest Hydrology

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2023

Keywords: Boatable days, whitewater recreation, climate change

ABSTRACT

Rad Rivers in Rad Places: Characterizing the Historical and Future Whitewater Resources in Select Regions of the United States

Melissa Shafer

Outdoor recreation is a highly profitable industry in the United States. In 2021, outdoor recreation accounted for $454.0 billion, or 1.9% of the current-dollar gross domestic product for the nation. Many states have benefited financially from focusing on promoting their outdoor recreation and natural resources. Whitewater (WW) paddling has been a recreational activity since the 1950s. In 2007 there were an estimated 1.2 million participants in whitewater kayaking. As of 2020, that number increased to 2.6 million, doubling the number of participants. WW resources can be leveraged to reshape local and regional economies. The framework developed in this study provides stakeholders with a powerful tool for quantifying boatable days now and into the future. Any stakeholder can use the boatable day analysis framework to help determine when and where to prioritize whitewater recreation, economic development, and investment by understanding the asset historically and into the future. Boatable days were calculated for select whitewater runs throughout seven whitewater regions. The results show that boatable days range from plentiful to infrequent across the regions. Given the strong seasonality of hydrology throughout the regions because of altered precipitation characteristics in terms of seasonal timing, frequency, and intensity, seasonal boatable days are more informative for understanding when the whitewater runs are boatable and for how long. Whether emissions match the RCP4.5 or RCP8.5 scenario in the future, changes are similar, though the magnitude and direction of change vary between regions.

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1.1 Introduction

Outdoor recreation is a huge contributor to the economy of the United States. In 2021, outdoor activities generated $454.0 billion, or 1.9% of the current-dollar gross domestic product for the nation (BEA, 2020). Eighteen states have stimulated their economies from developing and promoting their outdoor recreation and natural resources through Offices of Outdoor recreation (Outdoor Recreation Roundtable, 2022). Utah, for example, has shifted its economy away from uranium mining, oil shale, and natural gas extraction to focusing on recreational resources (Traywick & Recht, 2019) by establishing an Office of Outdoor Recreation. The office aids communities in creating new recreational infrastructure, inventorying outdoor recreation assets, and matching contributions of money and volunteers from companies to develop trails, parks, and other projects (Utah Department of Natural Resources, 2022). The city of Duluth in Michigan approved a property tax in 2011 that raises $2.6 million/year to support parks and recreation development, a cost to the homeowner of approximately $60 a year for the average-priced home. Another tax of 0.5% on lodging, restaurants, and bars generates $1.2 million a year to fund new hiking, mountain biking, cross-country skiing, horseback riding trails, and launch centers for canoes and kayaks (Roelofs, 2016). The Roanoke Outside Foundation in Virginia actively promotes the area's natural resources to entice businesses to set their roots in the region. The foundation highlights state incentives, low business costs, ideal population, regional benefits, and workforce talent to support its claims that the area is perfect for economic growth (Roanoke Outside Foundation, 2022). As a result, these states have seen increased population growth, recruitment, and youth retention (United States Census Bureau, 2022). Recreational counties, as defined by the United States Department of Agriculture's Economic Research Service, have higher net migration rates, faster growth in earnings per job, and higher household income among newcomers (Headwaters Economics, 2019). This trend stands across metro, micro, and rural county designation. These statistics highlight the possibility for states, regions, and counties to advance economic development initiatives by developing and promoting their outdoor recreation resources.

Whitewater recreation is an important growing sector of the recreation economy. In 2007, there were an estimated 1.2 million participants in whitewater kayaking. As of 2020, that number expanded to 2.623 million, doubling the number of participants (Outdoor Foundation, 2022). The sport is defined as the navigation of whitewater (WW) rivers using kayaks, canoes, and rafts. Whitewater rapids are fast stretches of water, bubbly or aerated, and unstable currents in whitewater rivers (Phillips, 2012). Three factors are needed to produce WW: topographic gradient, ample rainfall, and streamflow (Shelby, Brown, & Taylor, 1992). High-elevation mountain regions of the US contain these conditions to create WW. Abundant rainfall in a region generates runoff and contributes to streamflow. The minimum boatable level is a specific streamflow required for each whitewater section to be safe and fun to paddle. Streamflow or river stage below the minimum threshold makes the river difficult or impossible to paddle. Above the minimum level, recreation quality rises with flow, levels off at some intermediate-range, and then drops as the flow continues to increase (Brown, Taylor, & Shelby, 1992). The streambed's topography determines the rapids' difficulty through gradient, constriction, and obstruction. The non-profit organization, American Whitewater (AW), provides the American version of a rating system to compare river difficulty (American Whitewater, 2005). This rating system is a guide to understanding the complexity of a river section, the skill needed, and in some cases, the consequences of paddling.

The National Whitewater Inventory (NWI) from AW provides GIS line segments of WW runs which characterizes the spatial concentration of whitewater resources for the United States and several other countries (American Whitewater, 2019). American Whitewater is generally considered the most complete inventory of whitewater available in the US. The NWI dataset contains the run's name, class, length, and minimum boatable flow thresholds. Whitewater sections are defined as parts of a river that have a high number of whitewater rapids. These sections may have long stretches of flatwater, but due to the accessibility of the river, may be unavoidable from a logistics standpoint. A river may have multiple sections of whitewater, for instance, the Youghiogheny River in Maryland and Pennsylvania contains Top Yough, the Upper Yough and Lower Yough. The total number of runs (or sections) and miles of WW sections vary by state (Table 1), with every state in the US has at least one whitewater section. California, Washington, New York, Oregon, and West Virginia are the top states based on the number of runs (Table 1-2). California, Oregon, Idaho, Washington, and New York have the highest number of miles. There is a consistency of high-ranking states in both classifications, with California taking first in both instances. The Pacific Northwest (Oregon and Washington), West Virginia, Colorado, and Pennsylvania are in the top ten in both categories.

Table 1-1: Ranking of all the states in the contiguous United States based on the number of runs and total miles obtained from the National Whitewater Inventory (NWI) from American Whitewater

Rank	State	Total Runs	Rank	State	Total miles
1	California	348	1	California	3950
2	Washington	345	2	Oregon	3056
3	New York	337	3	Idaho	2726
4	Oregon	309	4	Washington	2483
5	West Virginia	260	5	New York	2125
6	Colorado	226	6	Colorado	2040
7	Virginia	219	7	West Virginia	1944
8	Wisconsin	216	8	Virginia	1939
9	Pennsylvania	196	9	Maine	1938
10	North Carolina	195	10	Pennsylvania	1710
11	Tennessee	191	11	Arkansas	1438
12	Maine	190	12	Montana	1345
13	Arkansas	168	13	North Carolina	1322
14	Idaho	161	14	Texas	1315
15	Georgia	136	15	Tennessee	1303
16	Michigan	127	16	Utah	1237
17	Texas	109	17	Wisconsin	1234
18	New Hampshire	104	18	Georgia	829
19	Montana	97	19	Arizona	748
20	Minnesota	92	20	Michigan	721
21	Ohio	89	21	Wyoming	709
22	Alabama	87	22	Minnesota	626
23	Wyoming	77	23	Kentucky	615
24	Kentucky	76	24	Alaska	589
25	Maryland	76	25	New Mexico	524
26	Vermont	72	26	New Hampshire	466
27	Utah	71	27	Maryland	455
28	South Carolina	71	28	Vermont	439
29	Massachusetts	42	29	Missouri	434
30	Missouri	39	30	Alabama	431
31	Arizona	33	31	Ohio	362
32	Illinois	32	32	South Carolina	316
33	Indiana	31	33	Oklahoma	272
34	Alaska	30	34	Massachusetts	169
35	New Mexico	28	35	New Jersey	118
36	Connecticut	28	36	Connecticut	106
37	Oklahoma	26	37	Illinois	105
38	New Jersey	25	38	Indiana	91
39	Iowa	18	39	Nebraska	89
40	South Dakota	12	40	Nevada	79
41	Florida	6	41	South Dakota	75
42	Hawaii	5	42	Iowa	45
43	Nebraska	4	43	Hawaii	34
44	Nevada	4	44	Mississippi	27
45	North Dakota	3	45	Florida	22
46	Louisiana	3	46	North Dakota	16
47	Kansas	3	47	Delaware	16
48	Mississippi	2	48	Louisiana	13
49	Delaware	2	49	Rhode Island	6
50	Rhode Island	1	50	Kansas	1

Easily accessible runs generate more revenue than remote wilderness runs due to the proximity of communities, concessions, and services (English & Bowker, 1996). Assessing WW resources from the concentration perspective (number of WW sections/area) provides essential insights that state summaries obfuscate. For example, evaluating WW resources through a concentration lens can help prioritize investment and development of amenities and services (lodging, guide, and shuttle services) around these clusters (Johnson & Beale, 2002) (Mayfield, 2006). Increased amenities and services can help counties obtain recreational county status. Recreational counties attract new residents and higher incomes (Headwaters Economics, 2019). Including whitewater concentration and other outdoor recreation will help promote these areas to potential relocating individuals, who may place outdoor recreation as a high priority when choosing a new place to call home (Christensen, 2021). As a result, Zegre et al. (2021) developed heat maps that show the concentration of WW resources throughout the contiguous 48 states (Figure 1-1).

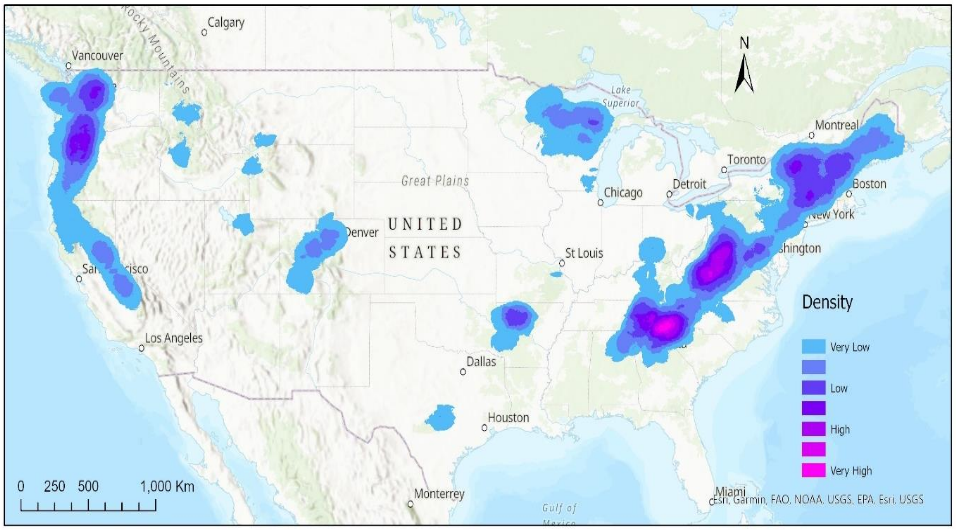

Figure 1-1: Concentration of whitewater runs in the contiguous US. WW concentrations are plotted as a heat map. Count per 50 square miles shows the density of whitewater runs.

In the United States, WW resources are unequally distributed, which makes them a valuable and rare resource (Figure 1-1). The concentration analysis highlights 'whitewater regions' associated with mountain areas in the US due to the high levels of precipitation, runoff, and topographic gradient of high elevations relative to lower lying areas. The central and southern Appalachian Regions have the greatest concentration of WW runs, followed by other mountainous regions in the northeastern US, such as the Adirondacks, Green, and White Mountains. The Cascade Mountains in the Pacific Northwest, which extends down to California from Washington and Oregon, also contain high whitewater densities while most of the runs in California are found in the Sierra Nevada Mountains. The western slope of the southern Rocky Mountains provides the terrain and runoff to support WW runs in Colorado. The Crown and High Divide section of the Rocky Mountains create ideal conditions for high concentrations of WW in Idaho. Table 1-3 shows the regions and corresponding states with the highest concentration of WW sections in the continental United States.

Table 1-2: Whitewater regions of interest and corresponding states, number of runs and miles, and percentages. Percentages are based on the number of runs and mileages in the state compared to the total number of miles in the contiguous United States (American Whitewater, 2019). This table differs from Figure 1-1 in that it is not from a concentration standpoint, but an overall region aspect.

Region	State(s)	Total No. runs	Total miles	% of runs in the lower 48 states	% of mileage in the lower 48 states
California	California	348	3951	7%	9%
Central Appalachian Mountains	Maryland	76	455	2%	1%
	Pennsylvania	196	1711	4%	4%
	West Virginia	260	1745	5%	4%
Colorado	Colorado	225	2019	4%	5%
Idaho	Idaho	161	2727	3%	6%
Northeast	Connecticut	28	107	1%	0%
	Maine	190	1939	4%	5%
	Massachusetts	42	170	1%	0%
	New Hampshire	104	467	2%	1%
	New York	337	2126	7%	5%
	Vermont	72	439	1%	1%
Pacific Northwest	Oregon	309	3056	6%	7%
	Washington	345	2484	7%	6%
Southeast	Alabama	87	431	2%	1%
	Georgia	136	830	3%	2%
	North Carolina	195	1323	4%	3%
	Tennessee	191	1304	4%	3%
	Total	3302	27284	66%	64%

Understanding how often and when whitewater resources can be utilized will provide insight into which rivers have the greatest opportunities for use. This is measured in boatable days (Mayfield M. W., 2006). Providing boatable day analysis is another meaningful metric for deciding where and when to prioritize whitewater recreation economic development and investment. In the past twenty years, research has emerged regarding the importance of understanding boatable days historically and in the future. Historically, recent studies have focused on providing quantitative data for whitewater river sections of the US, and most have focused on a few river sections or one region. In 2006, Mayfield conceived the metric of boatable days (Mayfield, 2006). Three rivers were analyzed in the southeast US to provide quantifiable data regarding whitewater to regional economists. In 2016, Fey and Stafford analyzed boatable days for the San Miguel River in southwest Colorado to assess how changing water rights would affect boating opportunities (Fey & Stafford, 2016). The following year, Fey, Stafford, and Vaske studied boatable days for the Cataract Canyon on the Colorado River to provide frequency and timing information to outfitters and resource managers (Stafford, Fey, & Vaske, 2017). To potentially understand the effects of climate change on boatable days in the Sierra Nevada in California, Ligare et al. analyzed 128 whitewater runs on the western slopes for future whitewater boatable days (Ligare, Viers, Null, Rheinheimer, & Mount, 2012). Understanding what whitewater will look like in the future will help ensure economic development and investment will be directed towards resilient whitewater communities.

To strategically develop the WW economy, decision-makers must understand their whitewater assets now and in the future. Water cycle changes are increasingly becoming influenced by climatic responses to emissions of greenhouse gases (Allan R. P., et al., 2020). The warming of the atmosphere is causing temperature, precipitation, and evapotranspiration (ET) changes. Extremes in precipitation alter the runoff generated, while higher temperatures alter snow accumulation, snowmelt, and ET. Uncertainty exists about the severity of change around these factors. However, General Circulation Models (GCMs) agree that the changing climate will alter precipitation events, timing, frequency, and intensity elevating inter-seasonal variability on water levels and flows (Brice, 2017). The GCMs also predict evapotranspiration changes which will affect whitewater. Higher temperatures will increase the rate of ET; plants will increase transpiration resulting in more water loss at a higher frequency. Snowpack is a reservoir for fresh water in the western states. As the snow melts, freshwater becomes available. However, with increasing temperatures, there will be less snow overall. Available snow will begin to melt earlier in the year (Reidmiller, et al., 2018). These predicted changes in the water cycle would have significant impacts on whitewater.

Whitewater recreation is highly dependent on streamflow; any streamflow changes can alter the number of boatable days (Mayfield, 2006). Given the dependence of WW boating on minimum streamflow levels, and the number of days that a river section can be paddled per year or season, referred here as boatable days, can be used to quantify the temporal aspect of WW resources. The potential changes in boatable days could drastically impact rural economies. That is why it is essential for stakeholders within whitewater-dense regions to understand how this natural resource and economic driver will change in the future.

This thesis aims to characterize select WW runs within WW regions to understand how often and when these runs can be paddled and the potential implications of future climate change for the WW economy. This was accomplished by quantifying historical boatable days across years and seasons for a select number of runs throughout WW regions. Publicly available datasets were used from AW’s National Whitewater Inventory (NWI), the United States Geological Survey, the California Department of Water Resources, and the Colorado Division of Water Resources. With the knowledge of historical whitewater, we can then attempt to determine what WW will look like in the future. Two simple change factors were calculated for the climate scenarios RCP4.5 and RCP8.5 from 2025 to 2049, using historic data from 1981-2010 (Hostetler & Alder, 2016). The change factors were applied to historical annual and seasonal boatable days. This work aims to provide information to stakeholders, who, in turn, will be able to anticipate and possibly mitigate climate change effects on an unevenly distributed, unique resource of the United States.

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Chapter 2: Whitewater Boating, Now and into the Future: Insights from 152 Classic Whitewater Runs in the Continental United States

2.1 Introduction

Whitewater (WW) paddling has been a recreational activity since the 1950s. In the 1970s, the pastime was made an Olympic sport (Policky & Costello, 2018). In 2007, there were an estimated 1.2 million participants in whitewater kayaking. As of 2021, that number increased to 2.6 million, doubling the number of participants (Outdoor Foundation, 2022). Despite the growth, little recent research has been done on the effects of whitewater recreation on communities. Previous research has reported documented changes in local economies in dense whitewater areas. In 1992, the Gauley River in West Virginia produced $4.68 million and created 208 jobs (English & Bowker, 1996). Another study estimated that rafting tourism on the New, Gauley, and Cheat rivers in West Virginia generated $41.3 million in 1995. In Tennessee, sixteen scheduled whitewater releases on the Cheoah River generates an estimated $3 million yearly (Mayfield, 2006). And more recently, Maples and Bradley found that commercial and non-commercial paddlers traveling to the Nantahala and Pisgah National forests generated over $39 million in revenue (Maples & Bradley, 2017). The same researchers found that paddlers traveling to three national forests in Colorado spent $4.7 million, supported 22 jobs, and $538,000 in job income to pursue paddling opportunities (Maples & Bradley, 2018). In 2020, over 112,000 individuals paid commercial outfitters in West Virginia to raft 13 river sections (WV DNR, 2020). As highlighted, whitewater enthusiasts have a direct impact on the local economy. However, there is still a need to have data to attract participants and businesses of recreational activities to a particular area.

Three factors are needed to produce WW: topographic gradient, ample rainfall, and streamflow (Shelby, Brown, & Taylor, 1992). Areas with these characteristics tend to be in mountainous regions, which makes the resource unequally distributed in the United States. States with these characteristics are ideal for developing or increasing their mountain adventure tourism, which includes whitewater boating (Baltescu, Stancioiu, & Pargaru, 2011). Areas containing outdoor recreation assets are also ideal for attracting remote workers to relocate (Christensen, 2021). Having detailed information about the outdoor recreation assets of an area, community developers can focus on highlighting rural communities' unique characteristics to recruit relocating individuals and retain their youth, overall stimulating the local economies (Johnson & Beale, 2002)(Andresen, 2012). But to do so, decision-makers, planners, and businesses need detailed information on the number of WW runs and how often they can be boated.

In the past twenty years, research has emerged regarding the importance of understanding whitewater historically and in the future. Historically, studies have focused on providing quantitative data for whitewater river sections of the US, and most focus only on a few river sections or one region. In 2006, Mayfield formulated the metric of boatable days (Mayfield, 2006). Mayfield analyzed three rivers in the southeast US to provide quantifiable whitewater data to regional economists. In 2016, Fey and Stafford analyzed boatable days for the San Miguel River in southwest Colorado to assess how changing water rights would affect boating opportunities (Fey & Stafford, 2016). The following year, Fey, Stafford, and Vaske studied boatable days for the Cataract Canyon on the Colorado River to provide frequency and timing information to outfitters and resource managers (Stafford, Fey, & Vaske, 2017).

Changes in the water cycle are increasingly influenced by climatic responses to greenhouse gas emissions (Allan R. P., et al., 2020). The warming of the atmosphere causes changes in temperature, precipitation, and evapotranspiration (ET). Extremes in precipitation alter the runoff generated, while higher temperatures change snow accumulation, snowmelt, and ET. Uncertainty exists about the severity of change around these factors. However, General Circulation Models (GCMs) results are uniform. The changing climate will alter precipitation events, timing, frequency, and intensity elevating inter-seasonal variability in water levels and flows (Brice, 2017). GCMs also predict evapotranspiration changes affecting whitewater (Hayhoe, et al., 2018). Higher temperatures will increase the rate of ET; plants will increase transpiration resulting in more water loss at a higher frequency.

Snowpack is a reservoir for fresh water in the western states, and as the snow melts, freshwater becomes available. With increasing temperatures, there also will be less snow overall, and any available snow will melt earlier in the year (Reidmiller, et al., 2018). The predicted changes in the water cycle components will significantly impact whitewater. Whitewater recreation is highly dependent on streamflow. Therefore, any changes to streamflow will result in alterations of boatable days (the number of days a river section is considered runnable per year or season) (Mayfield, 2006). The potential changes in boatable days could drastically impact rural economies. As such, it is essential for stakeholders within whitewater-dense regions to understand how this natural resource and the economic driver could change in the future with continued warming.

It appears that Ligare et al., 2012 is the first to explicitly study the possible effects of climate change on boating opportunities. Using a spatially explicit, one-dimensional rainfall-runoff model, Ligare et al., 2012 examined how 128 whitewater runs in the Sierra Nevada Mountains in California could change under future warming. Simulations of future climate and streamflow were produced by increasing the air temperature by 2˚C, 4˚C, and 6˚C with assumed no changes in precipitation. They found that the average number of boatable weeks per year increased with moderate warming (2˚C) but declined with a more severe warming (4˚C and 6˚C) scenario. Runs in both low- and high-elevation watersheds are susceptible to climate change. However, runs in the central Sierra Nevada showed increased boatable weeks. Elevation and run type (e.g., creek, gorge, river) were the best predictors of sensitivity to changes in climate. More recently, Bowman et al., 2020 quantified boatable days on the Franklin and Collingwood Rivers in the Tasmanian Wilderness World Heritage Area in Australia to identify commercial rafting opportunities and changes over time. The authors examined historical trends in rainfall to determine how climate change could affect future boatable days. For the 70-year study period, no evident decrease in BDs was found, which was believed to be from the large base flows originating from the porous rocks in the area’s geology. However, with steady decreases in precipitation, this water source will likely begin to disappear, resulting in fewer boating days.

While Ligare et al., 2012 and Bowman, 2020 provide insight into the potential impact of climate change on boating opportunities in WW, inference to other locations is limited due to the spatial variability of streamflow-generating boating flows and the magnitude and trajectory of climate change around the world. Furthermore, rainfall-runoff models such as the one used by Ligare et al. are complex, requiring expert modeling knowledge that may not be accessible to non-scientific stakeholders. To address this, a framework was developed that can be used by the community to explore the potential effects of climate change on WW resources anywhere in the US, provided there is publicly available gauge information.

This study aims to provide insight into select whitewater runs throughout the contiguous United States sensitivity to changes in climate. This is achieved by 1. Developing a framework that can quantify boatable days for any location in the United States using publicly available data; 2. Quantifying boatable days at annual and seasonal timescales across a historical period (2000-2020); 3. Under two different climate scenarios, evaluate the sensitivity of boatable days for a future period (2025-2049). This is accomplished by using a change factor calculated as the ratio of future (2025-2049) runoff to historical (1981-2010) from the National Climate Change Viewer (NCCV) (Alder & Hostetler, 2013) (Hostetler & Alder, 2016). The change factor was then applied to the historical annual and seasonal boatable days. This work aims to provide information to stakeholders, who, in turn, will be able to anticipate and possibly mitigate climate change effects on an unevenly distributed, unique resource of the United States. Understanding the resource better, can help prioritize whitewater's preservation while promoting the economic benefits and helping the surround communities.

2.2 Methods

2.2.1 Study Regions

Whitewater-dense regions of the United States were identified using the concentration heat map approach by Zegre et al. (2021) (Figure 2-1). The results of the density heat map analysis were used to identify whitewater regions of the contiguous United States that contain disproportionately high concentrations of whitewater resources through number of miles and number of sections, of which seven were used for boatable day analysis. The whitewater regions used in the current study were California (CA), the Central Appalachian Mountains (CAM), Colorado (CO), Idaho (ID), the Northeast (NE), the Pacific Northwest (PNW), and the Southeast (SE). The mountain ranges within these regions contain high concentrations of WW. The WW of California is mainly located in the northern portion of the state in the Sierra Nevada Mountain range and the southern part of the Cascade Mountains. The Central Appalachian Mountain region includes the states of West Virginia, a portion of western Maryland, and southwestern Pennsylvania. Colorado has significant runs in the southern Rockies, while Idaho's WW sections are mainly within the Rockies' Crown and High Divide sections. The Northeast region contains the Adirondacks, Green, and the White Mountains and includes the states of New York, Massachusetts, Connecticut, New Hampshire, Vermont, and Maine. The Pacific Northwest runs are primarily in the Cascade Mountains of Washington and Oregon. Finally, the Southeast contains the southern portion of the Appalachian Mountains, specifically the Great Smoky Mountains, and includes western North Carolina and South Carolina, eastern Tennessee, Alabama, and northern Georgia.

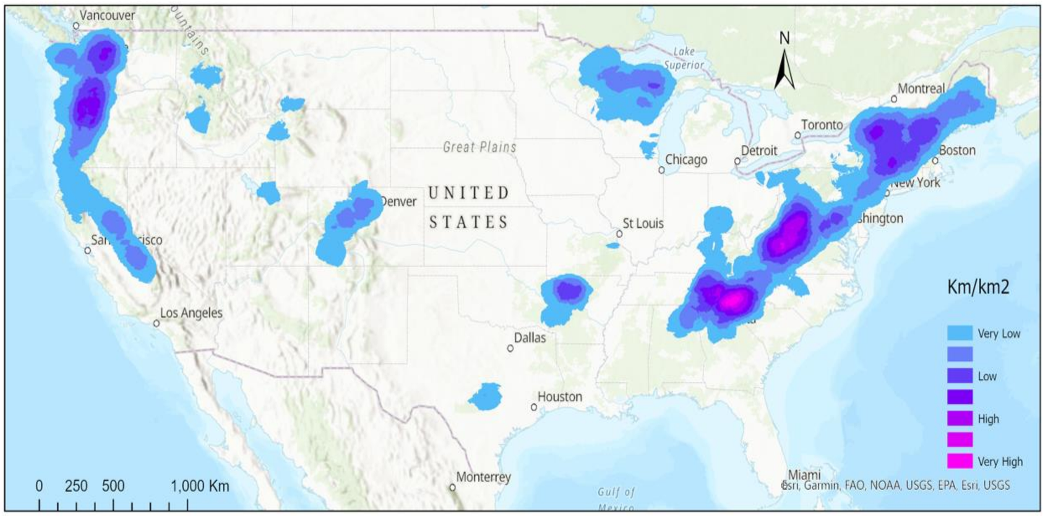

Figure 2-1: Concentration of whitewater runs in the contiguous US by section. WW concentrations are plotted as a heat map. Count per 50 square miles sees the density of whitewater runs.

Within each region, runs were selected that are known to be important for local paddlers and paddle tourists alike (Davis, Davis, & Friends, 2010). Rivers were also selected based on publicly available and complete historical flow data, The time period required to be considered complete historical flow data was 2001 to 2021. In all, 152 river sections were analyzed (see Table 2-1 and Appendix A). With 32 runs, the Pacific Northwest had the most runs analyzed, followed by Central Appalachian Mountains (27), Colorado (21), the Southeast (21), the Northeast (20), Idaho (17), and California (14) (Table 2-1). A wide range of whitewater classes were analyzed in this study; 10 Class IIs, 38 class IIIs, 60 class IVs, and 44 class Vs.

Precipitation and elevation, two essential characteristics of whitewater rivers, are highlighted to understand better how these factors affect whitewater. USGS Digital Elevation Model data are displayed in Figure 2-2 (U.S. Geological Survey, 2022). Prism precipitation data for each region is shown in Figure 2-3 (PRISM Climate Group, Oregon State University, 2022). Both were processed and analyzed using ArcGIS Pro.

California - While California has an abundance of whitewater runs throughout the state, most runs are concentrated in the Sierra Nevada Mountains and southern Cascades. These mountain ranges contain drastic elevation changes (Fig. 3). The Central Valley lies 3 m above sea level and rises quickly upwards to 4,412 m. The mountainous region of California has a temperate climate zone. Precipitation varies greatly. In the north, precipitation averages 900 mm per year, and in the south, 675 mm per year. However, rainfall increases with elevation, so the highest peaks in the Sierra Nevada and Klamath Mountains receive upwards of 12.5 meters of snowfall yearly. The hydrologic regime of the whitewater region of northern California is coastal (Moore & Wondzell, 2005), where streamflow relies heavily on rainfall and rain on snow. The maritime exposure leads to a high proportion of winter precipitation falling as rain, especially at lower elevations, which results in high stream discharges. Peak flows generally occur in spring and summer due to snowmelt, but rain-on-snow events can generate peak flows nearly year-round. Low flows tend to occur in late summer or early autumn.

<u>Central Appalachian Mountains</u> - Elevations in the Central Appalachian Mountains range from 94 m to 1466 m, with an average elevation of 458 m. What this area lacks in overall height, it makes up for elevation change with deeply dissected topography and rolling hills. Mean annual precipitation ranges from 1,652 mm in the mountains to 842 mm in the rain shadow to the east. Snowfall ranges from less than 510 mm in the south to more than 1,620 mm in the eastern mountains. The dendritic streamflow network is extensive throughout the Appalachia Plateau west of the Continental Divide and ridge and valley to the east. Streamflow is dominated by base flow and rainfall. Humid mountainous areas have shallow permeable soils and impermeable bedrock. Limited water storage in the soil is available; therefore, streamflow reacts swiftly to precipitation (Young, Krolak, & Phillippe, 1986). The deciduous forests produce a powerful seasonal effect on runoff and paddling opportunities. During the leaf-off dormant season, when ET is reduced, base flows increase, requiring less precipitation for rivers to run. During the growing season, May to October (Adams, et al., 2012), base flows are reduced from water loss to the atmosphere through ET, requiring more precipitation for paddling.

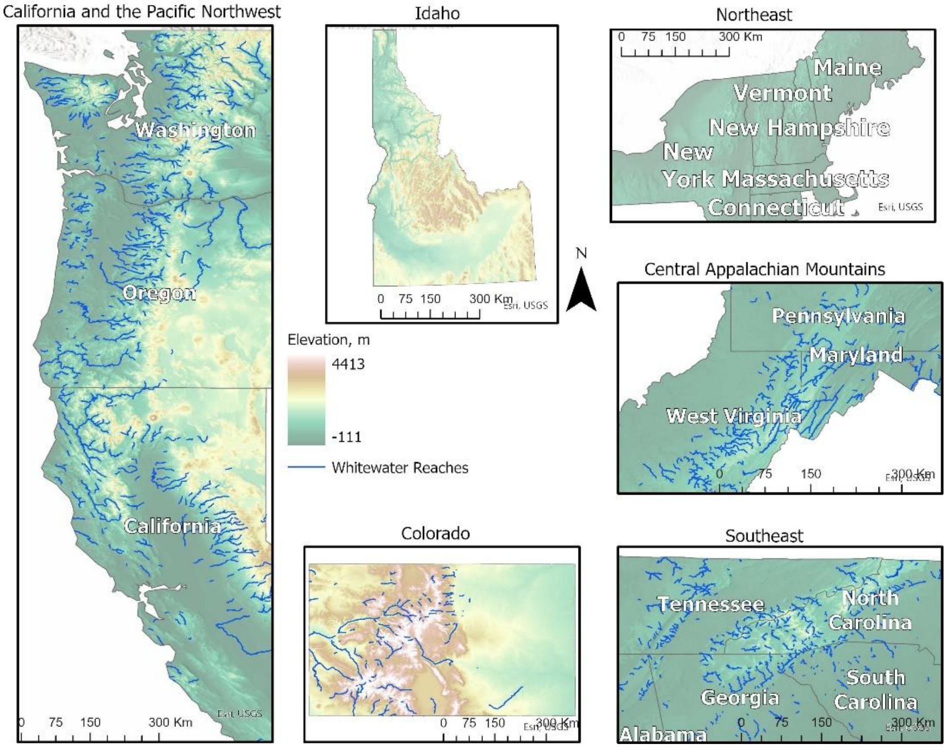

Figure 2-2: Elevation and whitewater reaches of the seven regions in the contiguous United States examined in this study. Elevation data were obtained through the ArcGIS PRO living atlas from the USGS's 3D Elevation Program, which is in 30 m (1 arc-second). Whitewater reach information were provided by American Whitewater's National Whitewater Inventory (NWI).

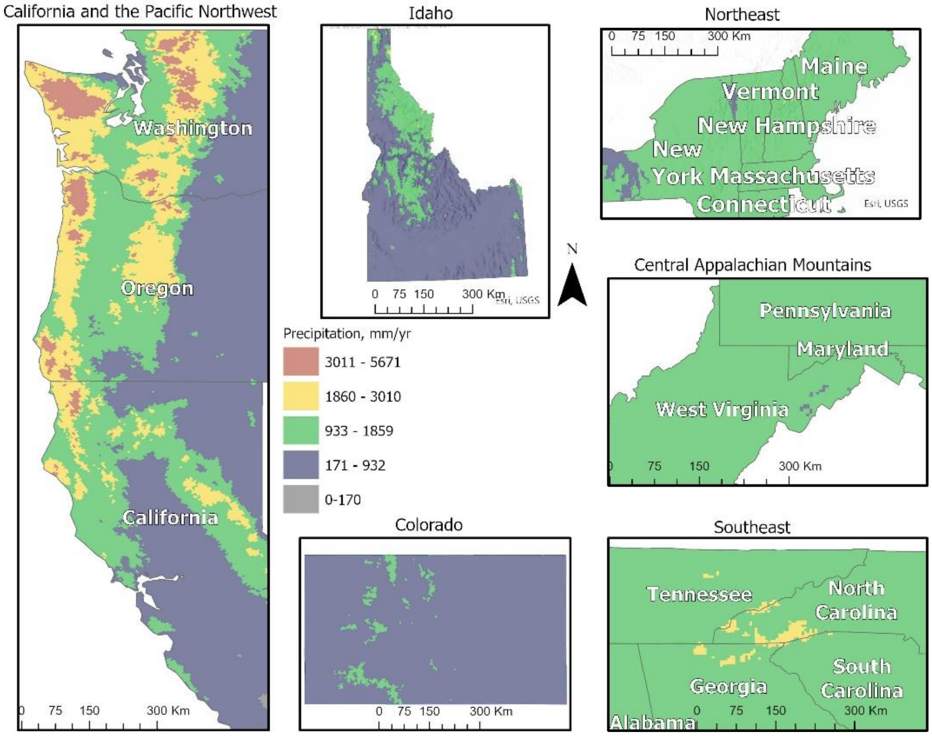

Figure 2-3: Mean annual precipitation for the seven WW regions. 30-yr Normal Precipitation for 1991-2020 precipitation data were obtained from the PRISM Climate Group. Copyright ©2023, PRISM Climate Group, Oregon State University. https://prism.oregonstate.edu.

<u>Colorado</u> - Most WW rivers in Colorado lie in the state's western portion in the Rocky Mountains, where the elevation ranges from 1,011 m to 4,326 m. Precipitation varies considerably. Overall, the average annual rainfall is 405 mm per year. However, 927 mm of rain is received per year in the western portion of the state. The Colorado River Basin hydrology is a primarily snowmelt-driven system (Gonzalez, et al., 2018). Snow accumulates in the higher elevations in the winter months, providing a "white reservoir." As temperatures warm in the summer, melting occurs slowly enough to recharge the soil and supply water to the river systems' channels. Warm-season precipitation is mainly lost due to evapotranspiration (ET), resulting in little summer precipitation making it to aquifers and streams (National Research Council, 2007).

<u>Idaho</u> - Many WW runs of Idaho occur in the western and northern areas, in the Rockies' Crown and High Divide portions. Elevation ranges from 152 m to 4,052 m. In these mountainous regions, streams are in deeply incised, narrow valleys. Topographic relief usually exceeds 1524 m. Topography strongly influences precipitation, with an average of 481 mm per year. Idaho has an interior hydrologic regime that relies heavily on snowmelt. Winters are colder due to the continental climatic system and higher basal elevation, and snow accumulates throughout the winter. As increased temperatures occur in the spring and summer, snowmelt is the cause of the seasonal peak flows. Summer rainstorms occasionally generate peak flows (May, et al., 2018).

<u>Northeast</u> - The Northeast has a much lower elevation range than the west. New York's highest elevation is 1,638 m, while Maine's tallest peak is 1,694 m. However, the northeastern states have very low minimum elevations allowing for steep slopes that produce whitewater. Precipitation averages 1037 mm to 2183 mm of rain per year, with higher amounts falling in the mountainous regions. Streamflow is

dominated by base flow and rainfall. The areas containing most WW runs are humid mountainous areas with permeable soils and impermeable bedrock, causing limited soil water storage (U.S. Geological Survey, 2003). As a result, streamflow responds quickly to precipitation with rapid rising and falling storm flow hydrograph limbs in catchments with limited soil storage (Young, Krolak, & Phillippe, 1986). The mixed deciduous forests dictate a strong seasonal influence on runoff and paddling opportunities. During the dormant season, when forest ET is reduced, base flows increase, requiring less precipitation input for rivers to run. During the growing season, May to October (Adams, et al., 2012), base flows are diminished from water loss to the atmosphere through ET, requiring more precipitation for paddling. This region contains multiple states, two of which appear in the top 10 states for WW (New York and Maine).

<u>Pacific Northwest</u> - The Cascade Mountains in the Pacific Northwest have a wide elevation range from 0 m to 4,202 m. The western portion of the mountains receives upwards of 5671 mm/year of precipitation. The proximity of the mountains to the oceans causes the coastal hydrologic regime, which generates the most rainfall than anywhere else in the United States (May, et al., 2018)(Moore & Wondzell, 2005). The mountains effectively sever the maritime western coastal climate creating an orographic effect, causing the area east of the Cascade Mountains to be dry with an average annual rainfall of 1088 mm/year. The streamflow of this region relies heavily on rainfall and rain-on-snow. The maritime exposure leads to a high proportion of winter precipitation falling as rain, especially at lower elevations, which results in high stream discharges. Peak flows generally occur in spring-summer due to snowmelt, but rain-on-snow events can generate peak flows nearly year-round. Low flows tend to occur in late summer or early autumn.

<u>Southeast</u> - The Southeastern region contains the Smokey Mountains encompassing most of the area's WW. Elevation ranges from 248 m to 2,013 m, making them some of the tallest mountains in the Appalachian chain. Annual rainfall averages 1593-2183 mm/year, with some areas receiving upwards of 2817 mm/year. The basins in western North Carolina vary from low elevations with gentle slopes, deep soils, and low rainfall to high peaks with steep slopes, shallow soils, and increased rainfall (Post & Jones, 2001). Streamflow and baseflow are highly variable in this regime. Annual baseflow response to precipitation is moderate to high, while annual quick flow response to rainfall is low to moderate. The deciduous forest canopies play an important, temporally, and spatially varying role. In the leafless winters, the trees play a role in interception, whereas in the summer, they exert a strong hydrologic influence through water uptake and ET.

Table 2-1: Seven whitewater regions of interest and the states corresponding to each region. The number of runs analyzed, total runs, total mileage, and corresponding percentages for each state and region. Information was obtained from the NWI.

Region	State(s)	No. runs analyzed (State)	No. runs analyzed (region)	Total No. runs	Total miles	% of runs in the lower 48 states	% of mileage in the lower 48 states
California	California	14	14	348	3951	7%	9%
Central Appalachian Mountains	Maryland	2	27	76	455	2%	1%
	Pennsylvania	1		196	1711	4%	4%
	West Virginia	24		260	1745	5%	4%
Colorado	Colorado	21	21	225	2019	4%	5%
Idaho	Idaho	17	17	161	2727	3%	6%
Northeast	Connecticut	3	20	28	107	1%	0%
	Maine	4		190	1939	4%	5%
	Massachusetts	1		42	170	1%	0%
	New Hampshire	2		104	467	2%	1%
	New York	9		337	2126	7%	5%
	Vermont	1		72	439	1%	1%
Pacific Northwest	Oregon	9	32	309	3056	6%	7%
	Washington	23		345	2484	7%	6%
Southeast	Alabama	3	21	87	431	2%	1%
	Georgia	1		136	830	3%	2%
	North Carolina	10		195	1323	4%	3%
	Tennessee	7		191	1304	4%	3%
	Total	152	152	3302	27284	66%	64%

2.2.2 Data and Analysis

Minimum boatable flow thresholds were obtained from the NWI. The National Whitewater Inventory (NWI) from AW provides GIS line segments of WW runs which characterizes the spatial concentration of whitewater resources for the United States and several other countries (American Whitewater, 2019). American Whitewater is generally considered the complete inventory of whitewater available in the US. The NWI dataset contains the run's name, class, length, and minimum boatable flow thresholds. Whitewater sections are defined as parts of a river that have a high number of whitewater rapids. These sections may have long stretches of flatwater, but due to the accessibility of the river, may be unavoidable from a logistics standpoint. A river may have multiple sections of whitewater, for instance, the Youghiogheny River in Maryland and Pennsylvania contains Top Yough, the Upper Yough and Lower Yough. The NWI includes the river section, gauge information, and minimum streamflow threshold for boating (see appendix A). Each river section has a minimum boatable level. Levels below the minimum threshold make the river difficult to paddle or impassable. Above this minimum level, recreation quality rises with the flow, levels off at some intermediate range, and then drops as the flow continues to increase (Brown, Taylor, & Shelby, 1992). Minimum levels reported in the NWI are either volumetric streamflow (length^3/time) or stage (length/time). For this study, where minimum boatable thresholds were reported as stage in the NWI, published stage-streamflow rating curves for the gauge were used to determine minimum thresholds in volumetric streamflow. This study did not consider the maximum boatable thresholds because levels are objective, differ by activity and skill level, and have changed over time (Fey & Stafford, 2016).

While Zegre et al. demonstrated the power of using instantaneous maximum streamflow for quantifying boatable days, mean daily streamflow (Qmean) was used in this study since the data are publicly available for gaging stations throughout the US. Furthermore, published Qmean data are quality assured/quality controlled, and the USGS reconstructs missing data. As a result, Qmean timeseries data are complete (Zegre, et al., 2021). Streamflow data from January 2000 to December 2020 (21 years) was obtained for the corresponding river section from the United States Geological Survey (USGS) stream gauging network (U.S. Geological Survey, 2021), the Colorado Division of Water Resources (CODWR)(Colorado Division of Water Resources, 2022), and the California Department of Water Resources (CDEC) (CA Department of Water Resources, 2022).

Future boatable days were simulated using runoff data from the USGS National Climate Change Viewer (NCVV). NCCV uses climate information from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (Alder & Hostetler, 2013) and consists of climate and water balance products contained in the 5th Climate Model Intercomparison Program (CMIP5). The NCCV contains climate data from 20 global general circulation models (GCM) and data for ensemble mean models for mean, maximum, and minimum temperature. Data is also available for precipitation, vapor pressure deficit, runoff, snow, soil storage, and evaporate deficit. Data is available for the historical period of 1981 to 2010 and future climatology periods of 2025 to 2049, 2050 to 2074, and 2075 to 2099. Timescales for the available data are viewed as annual, seasonal, or monthly.

Due to the coarse nature of the data supplied through AR5, the Multivariate Adaptive Constructed Analogs (MACA) method was applied to statistically downscale maximum and minimum air temperature and precipitation from 20 of the CMIP5 models to create the MACAv2-METADATA that is biased corrected. The MACAv2-METADATA provides two Representative Concentration Pathways (RCP) greenhouse gas (GHG) emission scenarios developed for AR5. The NCCV contains historical and future climate projections of these 20 downscaled models for two RCP emissions scenarios, RCP4.5 and RCP8.5. RCP4.5 is one of the possible emissions scenarios where the atmospheric GHG concentrations stabilize, representing a best-case scenario regarding climate change. RCP8.5 is an aggressive emissions scenario where GHGs continue to rise unchecked, leading to intense warming of the Earth. Temperature and precipitation data from the MACAv2-METADATA models were applied to a physically based monthly water balance model to simulate changes in the water balance for the contiguous US, which provides runoff and other water and energy balance information (Hostetler & Alder, 2016).

Future (2025-2049) runoff for RCP4.5 and RCP8.5 were acquired for each HUC8 watershed (Figure 2-4). HUCs are hierarchical watershed area units based on surface hydrologic features in a standard, uniform geographical framework. Each hydrologic boundary is determined from topography and represents a drainage divide between the various levels of units. Future BD were estimated using a change factor that describes relative changes in future and historic runoff that was calculated by dividing the future runoff by historical runoff (Anandhi, et al., 2011). Future boatable days were calculated by multiplying historic boatable days by the respective change factors to generate the change in boatable days for each river section. The difference in boatable days was then applied to historical days to generate future boatable days.

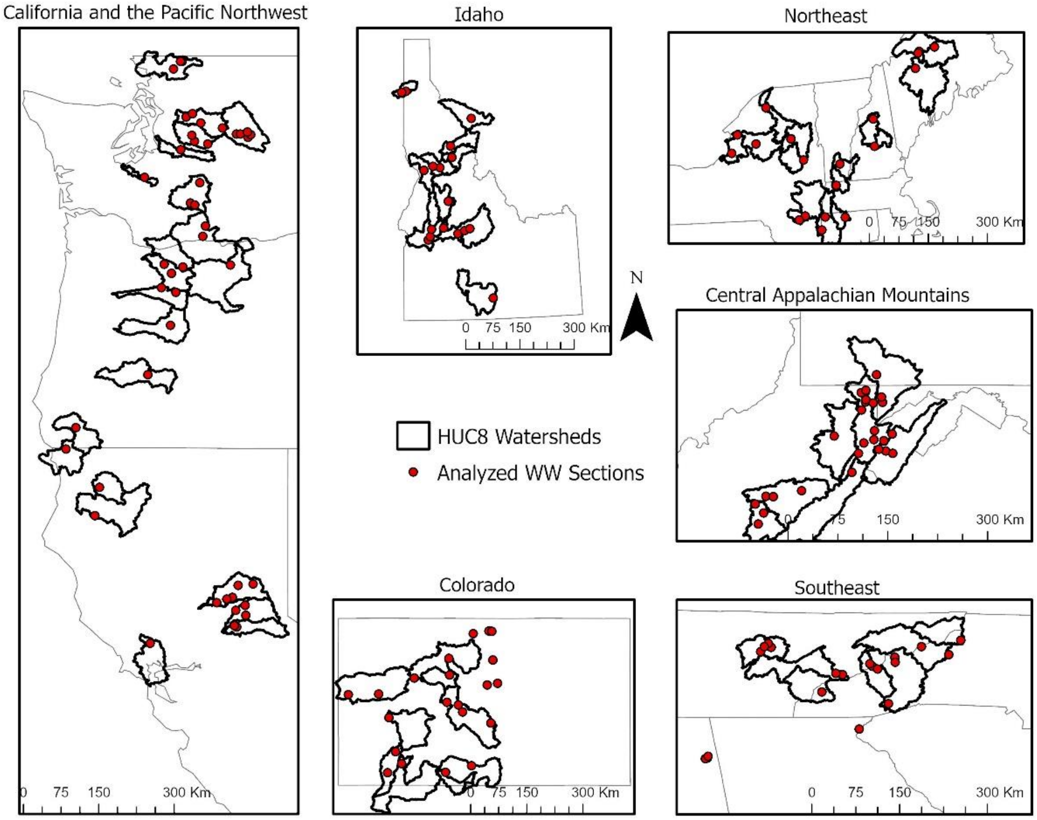

Figure 2-4: The seven whitewater regions, selected whitewater put-in locations, and the HUC8 watersheds used to assess climate change implications on whitewater. HUC8s stand for Hydrologic Unit Code hierarchical units of watershed areas that are based on surface hydrologic features in a standard, uniform geographical framework. Each hydrologic boundary is determined from topography and represents a drainage divide between the various levels of units. HUC data was downloaded from the USGS TNM National Hydrography Dataset (NHD). Put In locations were derived from the NWI.

Each run's number of boatable days was calculated using R’s open-source coding software (R Core Team, 2021). Historical mean daily streamflow data for sections that contained USGS gauges were downloaded directly into R using the dataRetrival package (De Cicco, Lorenz, Hirsch, Watkins, & Johnson, 2018). Historical data from the California Department of Water Resources California Data Exchange Center (CDEC) or the Colorado Department of Water Resources (CODWR) was downloaded through the related site and, if necessary, processed to provide mean daily streamflow and loaded into the program. The raw data was manipulated and re-formatted for ease of use using the packages lubridate (Spinu, et al., 2021), dplyr (Wickham, Francois, Henry, & Muller, 2017), padr (Thoen, 2021), hydroTSM (Zambrano-Bigiarini, 2020), tidyr (Wickham & RStudio, 2021), stringer (Wickham H., 2022), and trend (Pohlert, 2020) The minimum boatable threshold was set. The data was run to provide multiple files of information. First, a file of boatable days of every month for the 21 years (January 2010 to December 2020) was created. The average boatable days for each month were calculated and saved to file. Next, the average boatable days for each year were calculated and saved to a CSV file. The yearly average boatable days across the timeframe of interest were then calculated from the 21-year boatable day file. The workflow for the coding process is shown in Figure 2-5. Seasonal analysis of the whitewater sections was completed by aggregating monthly streamflow by season. Seasons were defined as winter (December, January, February); spring (March, April, May); summer (June, July, August); and fall (September, October, November). The change factors in runoff from the NCCV were applied to the historical annual and seasonable boatable days for the two emission scenarios to predict future boatable days.

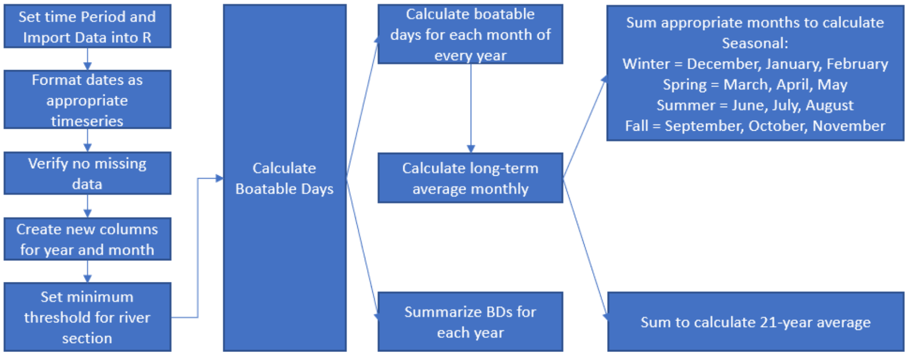

Figure 2-5: Workflow for calculating historical annual and seasonal boatable days of the selected whitewater runs of interest using R. Raw data was downloaded from the appropriate agency (USGS, CODWR, or CDEC), formatted for ease of manipulation, and verified. The minimum threshold for the analyzed river was set to calculate boatable days. Boatable days for each month of every year were calculated and then processed to show long-term average monthly boatable days.

2.3 Results

2.3.1 Annual Boatable Days

Summary statistics for historical annual boatable days for each region are shown in Figure 2-6 and summarized in Table 2-2. All the map legends use the natural breaks (jenks) division method for the classifications. Natural Breaks are based on natural grouping inherent in the data (Chen, Yang, Li, Zhang, & Lv, 2013). Therefore, the legends change from map to map. On average, the Pacific Northwest had the greatest number of boatable days, with 204 days/year, and ranged from 8 days/year to 365 days/year. Idaho had the next highest average boatable days at 192 days/year with a range of 5 days/year to 365 days/year, followed by California with 170 days/year with a range of 58 days/year to 328 days/year. The Northeast had an average of 168 days/year and a range of 11 days/year to 365 days/year. The remaining regions were the Central Appalachian Mountains with 160 average days/year having a range of 11 days/year to 365 days/year, Colorado with 144 average days/year with a 37 days/year to 309 days/year range, and the Southeast with 130 average days/year and a range of 9 days/year to 355 days/year. Figure 2-7 shows the historical annual boatable days for the 152 river sections spatially throughout the seven regions.

Table 2-2: Results for historical and future annual and seasonal boatable day analysis. Yearly and seasonal future and historical runoff data were collected from the National Climate Change Viewer (NCCV) (Alder & Hostetler, 2013), which was used to calculate the change factor (noted as CF in table) for runoff for each river section. The change factor was then applied to the historical results. This table shows the average change factor for the region. The average change in and future boatable days were averaged from the results of each river section in the region (this information can be found in Appendix #).*

Region	Season	Historical Boatable Days (2010-2020)	Scenario RCP4.5				ScenarioRCP8.5			
			CF*	Change in Boatable Days	Future Boatable Days	Relative Change in Boatable days from Historical (%)	CF*	Change in Boatable Days	Future Boatable Days	Relative Change in Boatable days from Historical (%)
Pacific Northwest	Winter	54	0.22	12	66	22	0.27	15	69	27
	Spring	67	0.04	3	70	5	0.05	3	70	5
	Summer	45	-0.24	-11	34	-24	-0.30	-14	32	-30
	Fall	37	-0.03	-1	36	-3	-0.06	-2	35	-6
	Annual	204	0.01	2	206	1	0.01	2	206	1
Idaho	Winter	31	0.49	10	36	16	0.63	13	38	23
	Spring	70	0.01	0	70	0	0.01	0	70	0
	Summer	61	-0.25	-16	46	-25	-0.28	-17	44	-28
	Fall	30	-0.06	-1	29	-3	-0.05	-1	29	-3
	Annual	192	0.00	-1	190	-1	0.01	1	192	0
California	Winter	51	0.11	6	56	10	0.17	9	59	16
	Spring	68	0.01	1	69	1	0.04	3	71	4
	Summer	32	-0.23	-8	24	-25	-0.24	-9	23	-28
	Fall	18	-0.04	-1	18	-4	-0.01	0	18	-3
	Annual	170	0.00	-1	169	-1	0.03	5	175	3
Northeast	Winter	48	0.20	9	53	10	0.21	10	53	10
	Spring	55	-0.05	-2	53	-4	-0.04	-2	52	-4
	Summer	31	-0.09	-3	29	-9	-0.06	-2	29	-8
	Fall	34	-0.09	-3	30	-11	-0.11	-4	30	-11
	Annual	168	0.00	0	167	0	0.00	0	168	0
Central Appalachian Mountains	Winter	49	0.05	2	51	5	0.05	2	51	5
	Spring	54	-0.05	-3	51	-5	-0.02	-1	53	-2
	Summer	28	-0.07	-2	26	-7	-0.05	-1	27	-5
	Fall	29	-0.11	-3	26	-10	-0.09	-3	26	-10
	Annual	160	-0.03	-5	155	-3	-0.01	-3	158	-1
Colorado	Winter	17	0.57	11	19	11	0.80	15	20	17
	Spring	42	0.11	5	45	7	0.11	5	46	9
	Summer	60	-0.22	-13	47	-22	-0.23	-13	47	-22
	Fall	25	-0.13	-3	22	-13	-0.11	-3	22	-13
	Annual	144	-0.03	-5	139	-3	-0.02	-3	142	-2
Southeast	Winter	46	-0.04	-2	43	-6	-0.03	-2	44	-4
	Spring	42	-0.06	-3	40	-6	-0.01	0	42	-1
	Summer	20	-0.06	-1	19	-6	0.00	0	20	0
	Fall	22	-0.07	-1	21	-5	0.49	3	25	14
	Annual	130	-0.06	-7	123	-5	-0.02	-2	128	-2

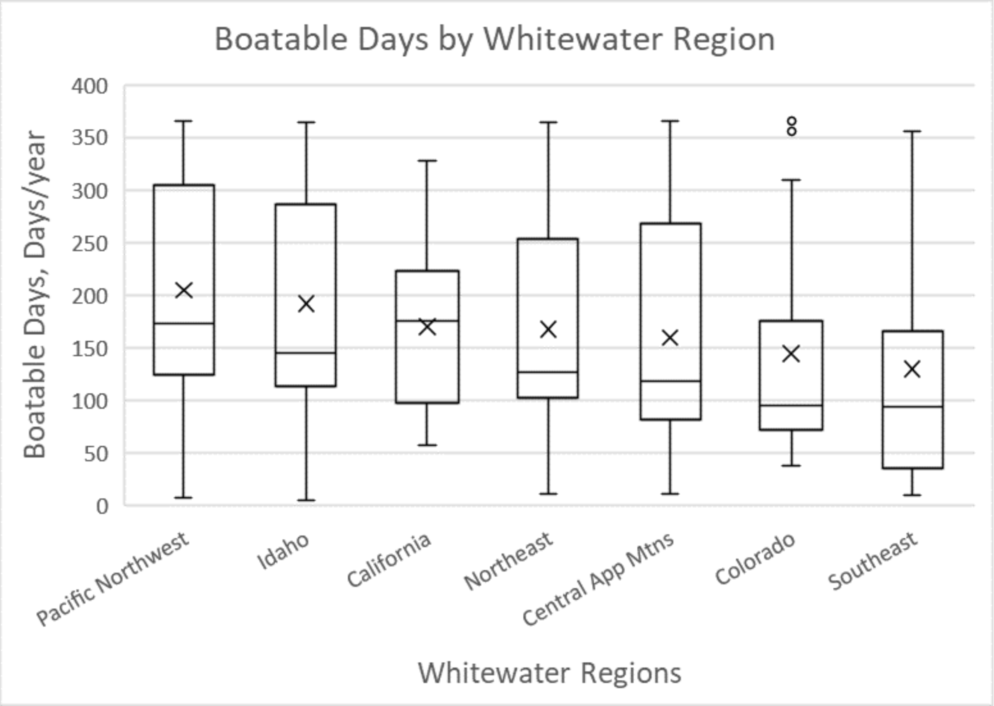

Figure 2-6: Mean (x), median (line), and historical annual boatable days range for each region over a 21 year period. The lower whisker indicates the minimum number of boatable days for each region, the top whisker shows the maximum result of days, and open circle denoted outlier (Colorado).

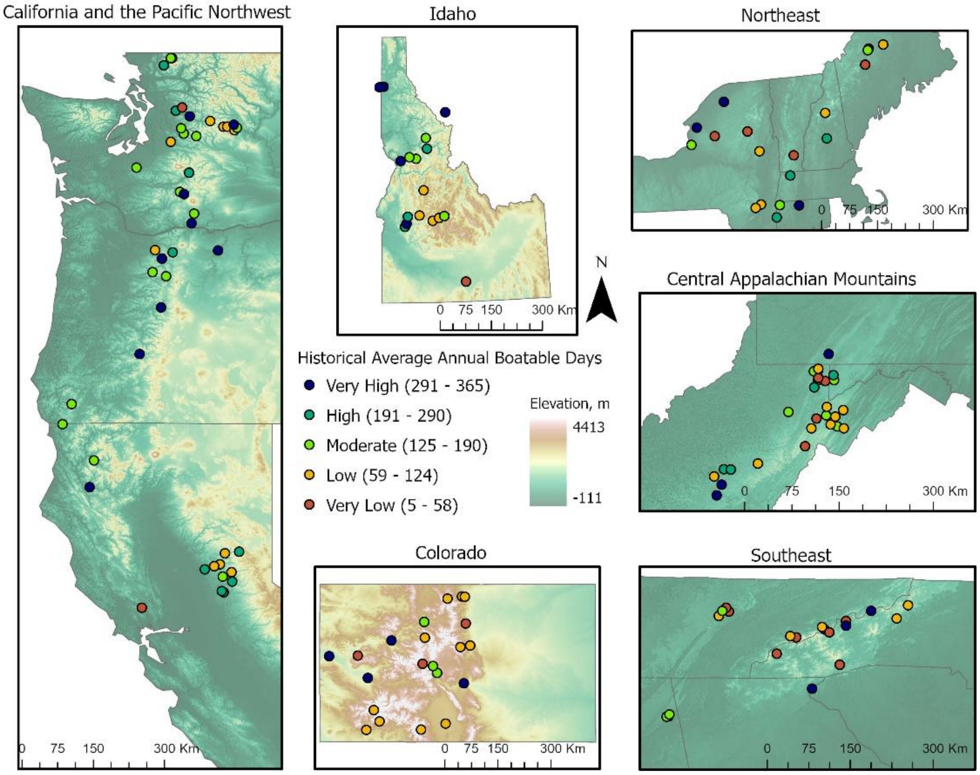

Figure 2-7: Historical (2011 to 2021) average annual boatable days for 152 whitewater runs across the seven regions of the US. Yearly averages were calculated from publicly available data from the USGS, CODWR, and the CDEC.

Figures 2-8 and 2-9 show the annual boatable days based on change factors (Table 2-2) for RCP4.5 and RCP8.5, respectively. Results were binned into four season categories based on the year's four quarters. Future boatable days in the Pacific Northwest averaged of 206 days/year for both RCP4.5 and RCP8.5 (range of 8 to 365 days/year), which results in a 1% relative increase for both scenarios when compared to historical averages. Future average boatable days for Idaho across the region were 192 days/year for RCP4.5 (a range of 5 to 365 days/year) and 194 days/year for RCP8.5 (a range of 5 to 365 days/year), respectively, corresponding to no change for RCP4.5 and a 1% decrease for RCP8.5. The Central Appalachian Mountains' future average boatable days averaged 155 days/year for RCP4.5 (a range of 10 to 357 days/year) to 158 days/year for RCP8.5 (a range of 10 to 363 days/year), corresponding to 3% fewer days to 1% fewer days, respectively. In the Northeast region, average boatable days for the future were 168 days/year for RCP4.5 (a range of 11 to 363 days/year) and RCP8.5 (a range of 11 to 365 days/year), corresponding to no average change for either scenario. California annual average boatable days for the future were 170 days/year for RCP4.5 (a range of 58 to 328 days/year) and 175 days/year for RCP8.5 (a range of 60 to 335 days/year), corresponding to no change and a 3% increase in boatable days, respectively. Colorado’s average boatable days for the future period were 140 days/year for RCP4.5 (a range of 35 to 357 days/year) and 141 for RCP8.5 (a range of 36 to 365 days/year), which resulted in a 3% and 2% decrease in days, respectively. Finally, boatable days across the Southeast averaged 122 days/year for RCP4.5 (a range of 9 to 340 days/year) and 127 days/year for RCP8.5 (a range of 9 to 357 days/year), corresponding to a 6% decrease and a 2% increase, respectively.

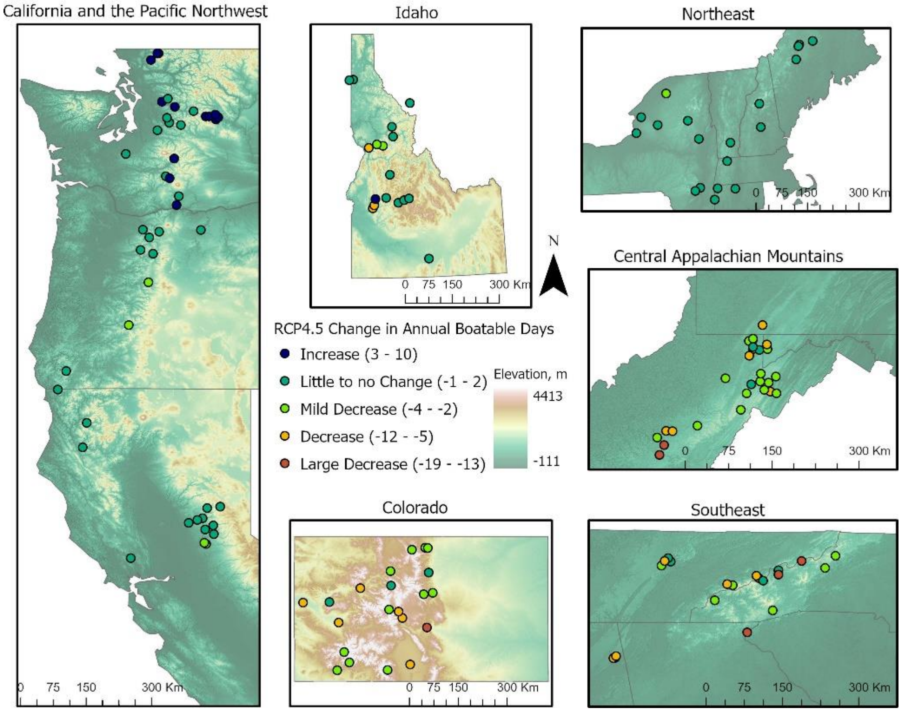

Figure 2-8: Future (2026-2049) average annual boatable days for 152 whitewater runs across seven whitewater regions based on the RCP4.5 low emission scenario.

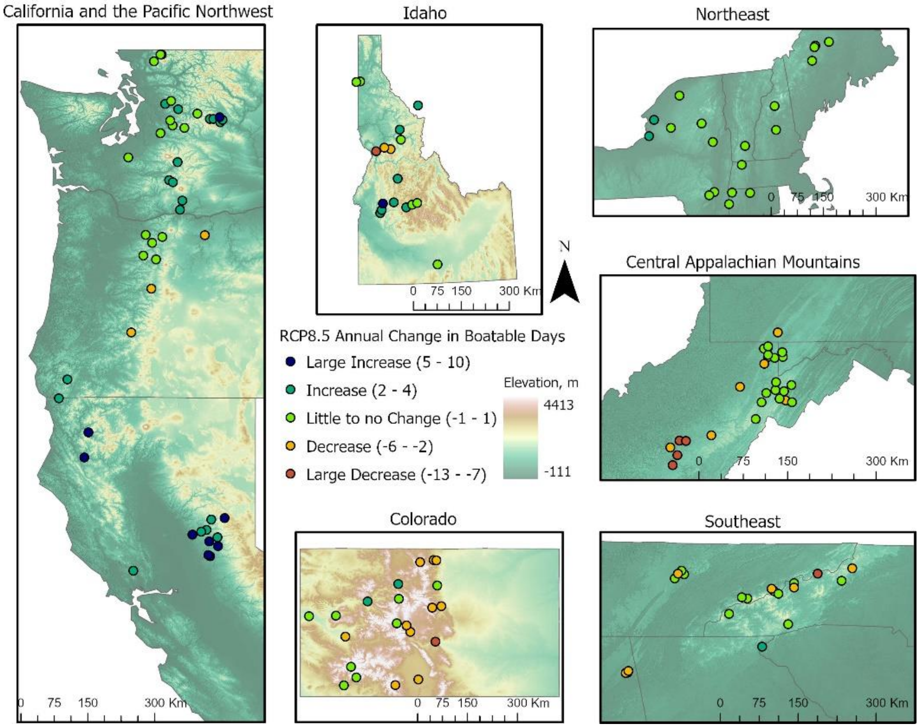

Figure 2-9: Future (2026-2049) average annual boatable days for 152 whitewater runs across seven whitewater regions based on the RCP8.5 high emission scenario for.

2.3.2 Seasonal Boatable Days

Historical seasonal analysis was completed for each river section to provide insight into the timing and frequency of boatable days across seasons (Table 2-2 and Figure 2-11). For each season, generally comprised of three months, there were 91, 92, 92, and 91 days for winter, spring, summer, and fall, respectively for which boating is possible. Boatable days were greatest in the Pacific Northwest during winter, averaging 54 days out of 91 (60%) and ranging between 36 and 88 days. For the Spring, the region averaged 67 days out of 92 (73%), ranging from 37 to 92 days. The average summer boatable days for the region was 47 days out of 92 (49%), ranging from 0 to 92 days/season. In the fall, average boatable days were calculated as 38 days out of 91 (41%), and the range was 2 to 91 days/season.

Idaho had an average of 31 days out of 91 (34%) in the winter, ranging from 0 to 90 days. In the spring, the area had high boatable days, with an average of 70 days of 92 (76%), ranging from 4 to 92 days. Idaho had the highest average for summer, with 61 days out of 92 (66%) and a range of 1 to 92 days. The fall averaged 30 days out of 91 days (33%), and the range was 0 to 91 days.

California's average winter boatable days of 51 days out of 91 (56%). The range was 22 to 85 days. In the spring, the region saw 68 days out of 92 (74%) on average and a range of 24 to 92 days. The summer averaged 32 days out of 92 (35%), and the range was 0 to 88 days. In the fall, the average was 18 days out of 91 (20%), and the range was 1 to 63 days.

The Northeast had an average of 48 days out of 91 (53%) for the winter, ranging from 0 to 90 days. 55 days out of 92 (60%) was the average for the spring, ranging from 7 to 92 days. The region saw an average of 31 days out of 92 (34%) in the summer, and the range was 2 to 92 days. Fall averaged 34 days out of 91 (37%), ranging from 2 to 91 days.

The Central Appalachian Mountains had an average winter boatable days of 49 days out of 91 (54%), ranging from 4 to 90 days. The spring analysis resulted in an average of 54 days out of 92 (59%) and a range of 4 to 92 days. 28 days out of 92 (30%) were averaged for the summer, ranging from 1 to 92 days. In the fall, the area averaged 32 days out of 91 (32%). The range calculated was 1 to 91 days.

Colorado had the lowest number of winter boatable days, with an average of 17 days out of 91 (19%) and a range of 0 to 90 days. The spring resulted in boatable days of 42 days out of 92 (46%). The range was 7 to 92 days. 60 days out of 92 (65%) was averaged for summer, ranging from 14 to 92 days. The fall averaged 25 days out of 91 (27%) and ranged from 0 to 91 days.

The Southeast had an average of 46 days out of 91 (50%), ranging from 5 to 90 days for the winter. The spring saw an average of 42 days out of 92 (46%), ranging from 3 to 92 days. 20 days out of 92 (22%) was the average for the summertime in the region, with a range of 1 to 90 days. Finally, the fall saw an average of 22 days out of 91 (24%), ranging from 1 to 83 days.

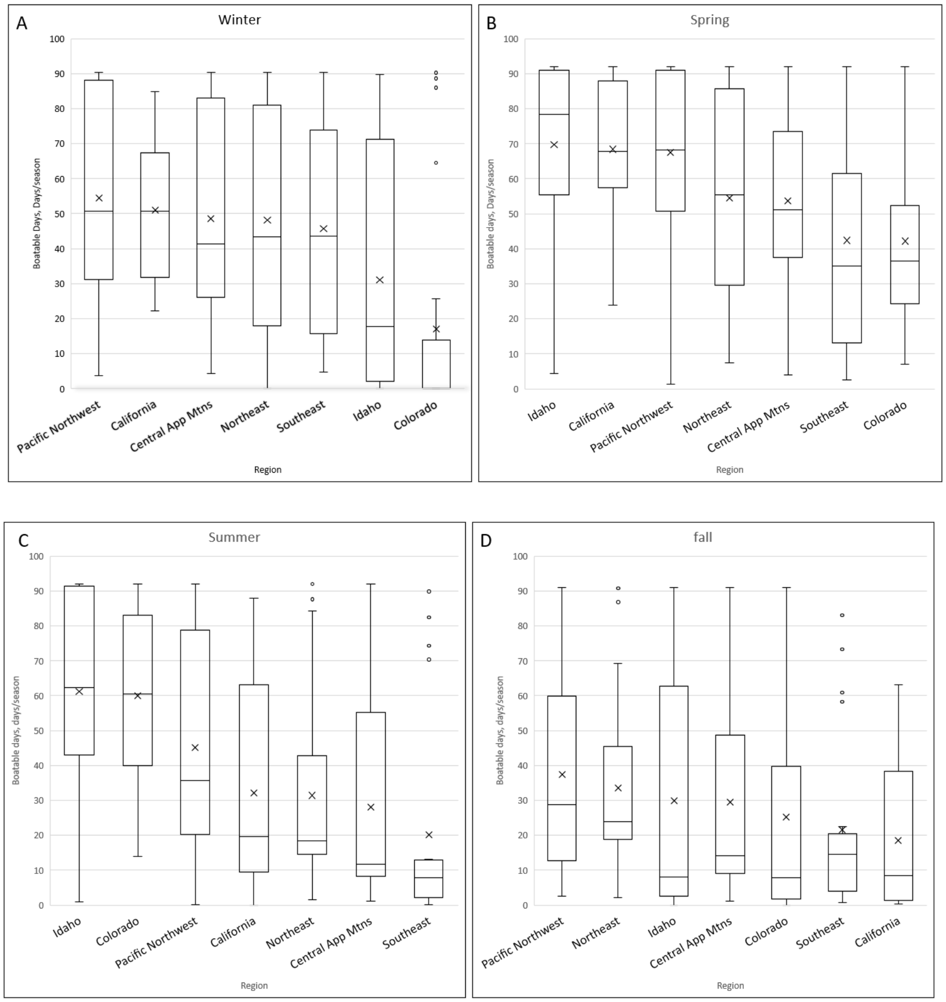

Figure 2-10: Mean (x), median (line), and range of historical seasonal boatable days for each region. The lower whisker indicates the minimum number of boatable days for each region, while the top whisker shows the maximum result of days. Winter (Figure 10A) is defined by December, January, and February, Spring (Figure 10B) by March, April, and May, Summer (Figure 10C) by June, July, and August, and fall (Figure 10D) by September, October, and November. Outliers are denoted by open circles.

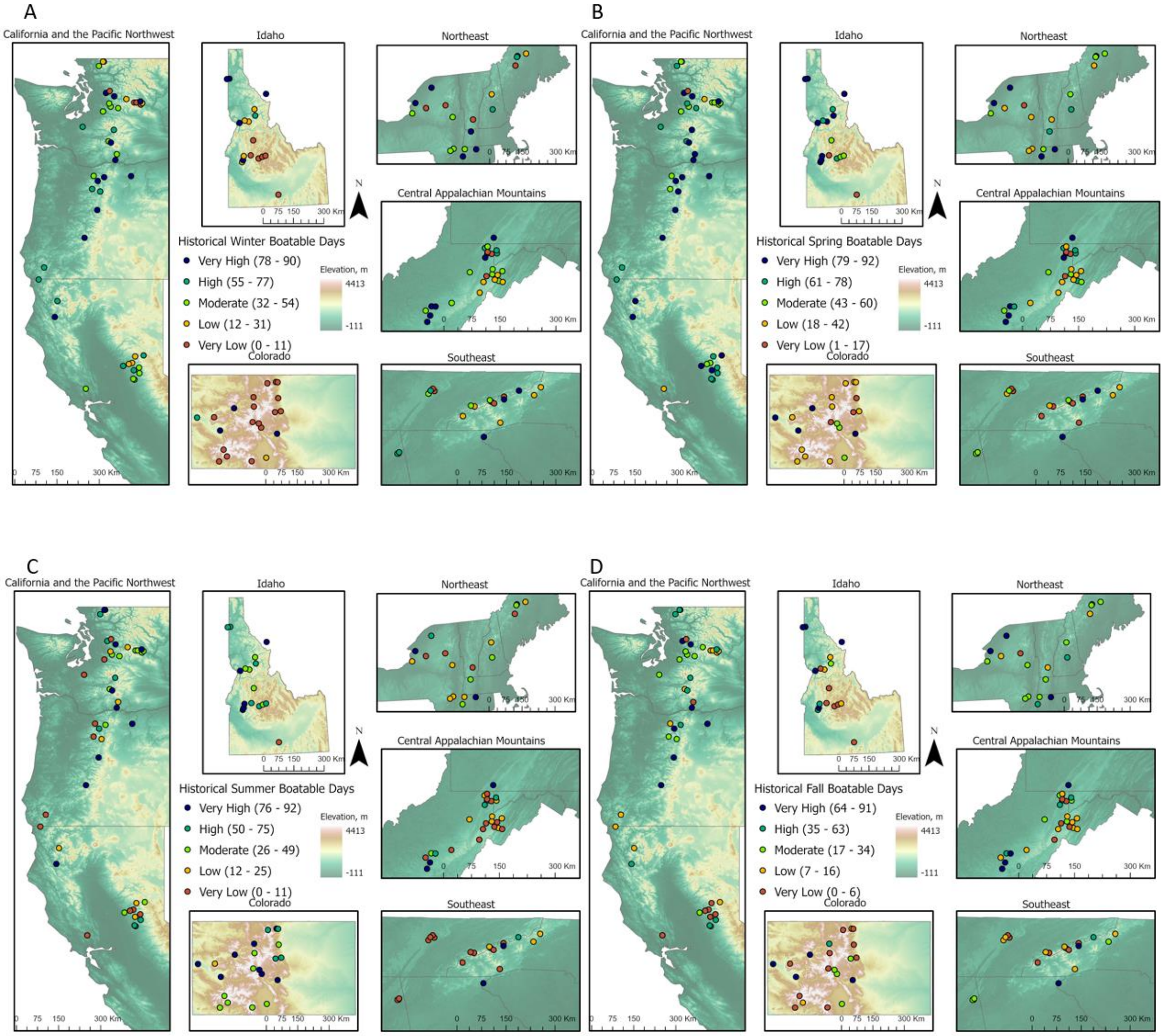

Figure 2-11: Average seasonal historical boatable days of 152 whitewater river sections in seven Whitewater regions. Figure 11A shows the average boatable days for winter (December, January, and February). Figure 11B shows the average boatable days for the spring (March, April, and May). Figure 11C represents the average boatable days calculated for the summer (June, July, and August). Figure 11D shows the average boatable days for each river section for the Fall (September, October, and November).

Future seasonal boatable days based on RCP4.5 and RCP8.5 are summarized in Table 2-2 and Figures 2-12 and 13. Winter in the Pacific Northwest averages 66 days for RCP4.5, with a range of 5 to 91 days/year and a relative change of 22%. RCP8.5 averaged 69 days/season (a change of 27%), with a range of 5 to 91 days/season. Spring also sees an increase in boatable days for the region, with a 4% increase for RCP4.5 and RCP8.5 (70 days). The range is 2 to 92 days for both scenarios. In the summer, there is a large decrease in boatable days, averaging 34 days for RCP4.5 and 32 days for RCP8.5, corresponding to 24% and 30% declines, respectively. The range for the summer is 0 to 72 days for RCP4.5 and 0 to 68 days for RCP8.5. Fall averages for boatable days are 36 days for RCP4.5 (a range of 2 to 89 days) and 35 days for RCP8.5 (a range of 2 to 85 days), corresponding to a decrease of 3% and 6%, respectively.

Idaho boatable day averages for the winter are 36 days for RCP4.5 and 38 days for RCP8.5, corresponding to an increase of 16% and 23%, respectively. The range for this season is 0 to 91 days for both scenarios. Spring resulted in an average of 70 days for both scenarios, resulting in a 0% change in boatable days. The range for the spring season is 4 days to 92 days for both scenarios. Idaho is expected to see a large decrease in boatable days for the summer. Averages of 46 days and 44 days for RCP4.5 and RCP8.5 correspond to the decline in boatable days by 25% and 28%, respectively. The range for summer was 1 day to 70 days for both scenarios. The fall brings averages of 29 days for RCP4.5 and RCP8.5, corresponding to a relative change of 3%. The range for this season is 0 to 89 days for both scenarios.

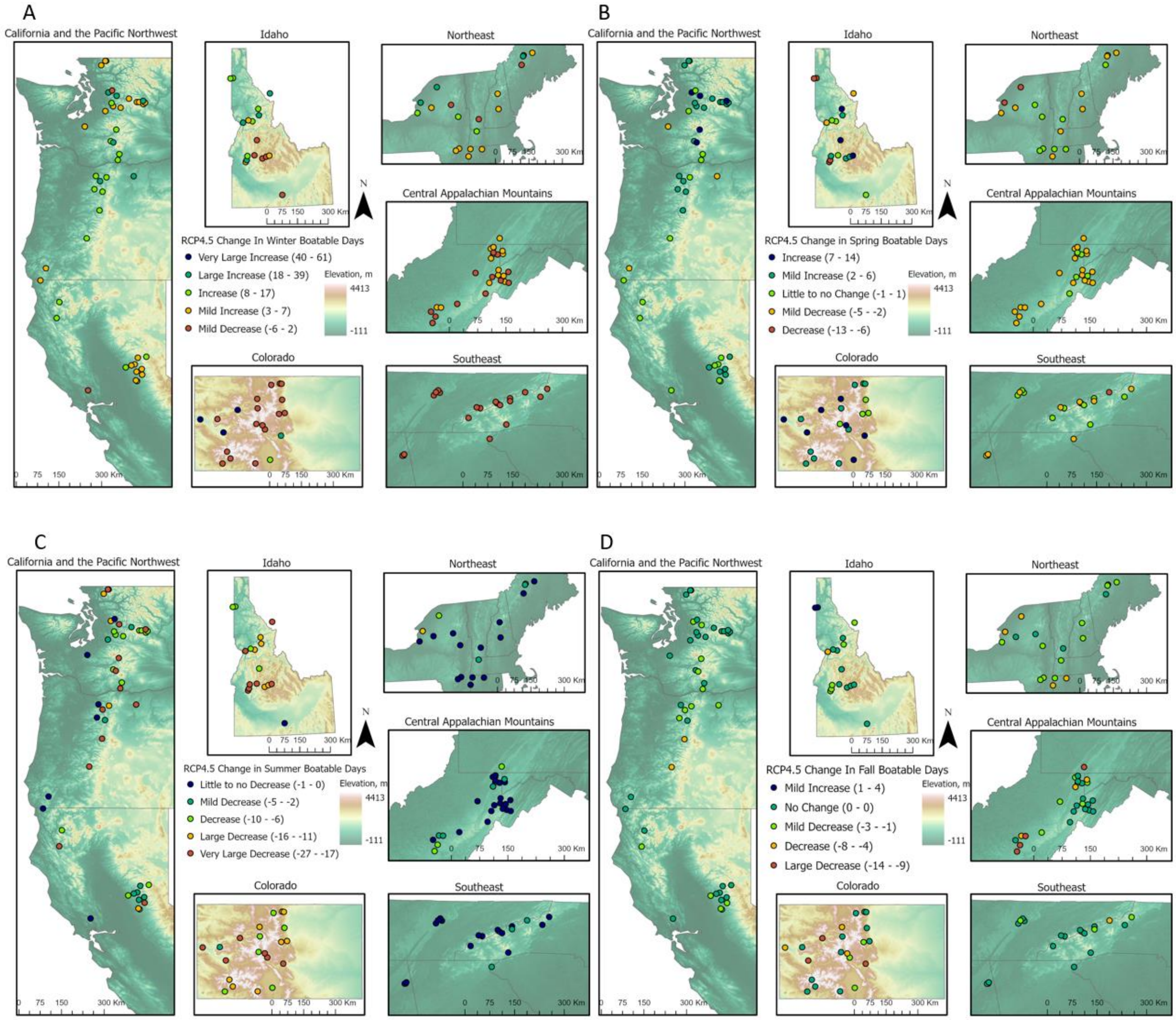

Figure 2-12: Relative changes in boatable days across seasons for the 152 whitewater river sections in seven Whitewater regions based on the RCP4.5 low emission scenario. Figure 12A shows the difference in boatable days for the winter (December, January, and February). Figure 12B shows the change in boatable days for spring (March, April, and May). Figure 12C represents the change in boatable days calculated for the summer (June, July, and August). Figure 12D shows the difference in boatable days for each river section for the Fall (September, October, and November).

For California, there was an average of 56 days for RCP4.5 and 59 days for RCP8.5 in the winter, corresponding to a 10% and a 16% increase in boatable days, respectively. The region's boatable days ranged from 25 to 91 days for RCP4.5 and 26 to 91 days for RCP8.5. Minimal increases in boatable days occurred in California's spring season, with an average of 69 days and 71 days for RCP4.5 and RCP8.5, respectively. This increases boatable days by 1% for RCP4.5 and 4% for RCP8.5. The range observed was 23 to 92 days for RCP4.5 and 24 to 92 days for RCP8.5. The greatest decrease in boatable days occurred during the summer, with an average of 24 days for RCP4.5 to 23 days for RCP8.5, which corresponds to a reduction of 25% and 28%, respectively. The range for this season is 0 to 64 days for RCP4.5 and 0 to 61 days for RCP8.5. Finally, the fall resulted in average boatable days of 18 days for RCP4.5 and RCP8.5, which is no change compared to the historical average. A range of 0 to 60 days is observed for California in the fall for both scenarios.

The Northeast is expected to see increases in winter boatable days of 10% for RCP4.5 and RCP8.5, which corresponds to average seasonal days of 53 days for both scenarios. Boatable days range from 0 to 91 days for both scenarios in the winter. The spring also sees a decrease of boatable days, with an average of 53 days (a decrease of 4%) for RCP4.5 and RCP8.5. The range for this season is 7 to 91 days for both scenarios. The average seasonal summer boatable days were 29 for RCP4.5 and RCP8.5, corresponding to a 9% decline. A range of 1 to 83 days for RCP4.5 and 1 to 86 days for RCP8.5. The fall season generates seasonal averages of 30 days for RCP4.5 and RCP8.5. This translates into a decrease of 11%. The range for the fall is 2 to 81 days for RCP4.5 and 2 to 80 days for RCP8.5.

The Central Appalachian Mountain's future winter boatable days averaged 51 days for both RCP4.5 and RCP8.5 scenarios, corresponding to an increase of 5% for the season. The range of boatable days was 5 to 91 days for both scenarios. The region's spring sees a decrease in boatable days, averaging 51 and 53 days for RCP4.5 and RCP8.5, respectively. This results in a 4% and 5% decrease for scenarios RCP4.5 and RCP8.5, respectively. This season's range of boatable days was 4 to 92 days for RCP4.5 and 4 to 92 days for RCP8.5. Summer in the Central Appalachian Mountains resulted in average boatable days of 26 days for RCP4.5 and 27 days for RCP8.5, corresponding to a decrease of 7% and 5%, respectively. The range for this season was 1 day to 86 days for RCP4.5 and 1 to 88 days for RCP8.5. In the fall, this region's average seasonal boatable days were 26 days RCP4.5 and RCP8.5, which decreased the boatable days by 10%. The range for this season is 1 day to 81 days for RCP4.5 and 1 to 82 days for RCP8.5.

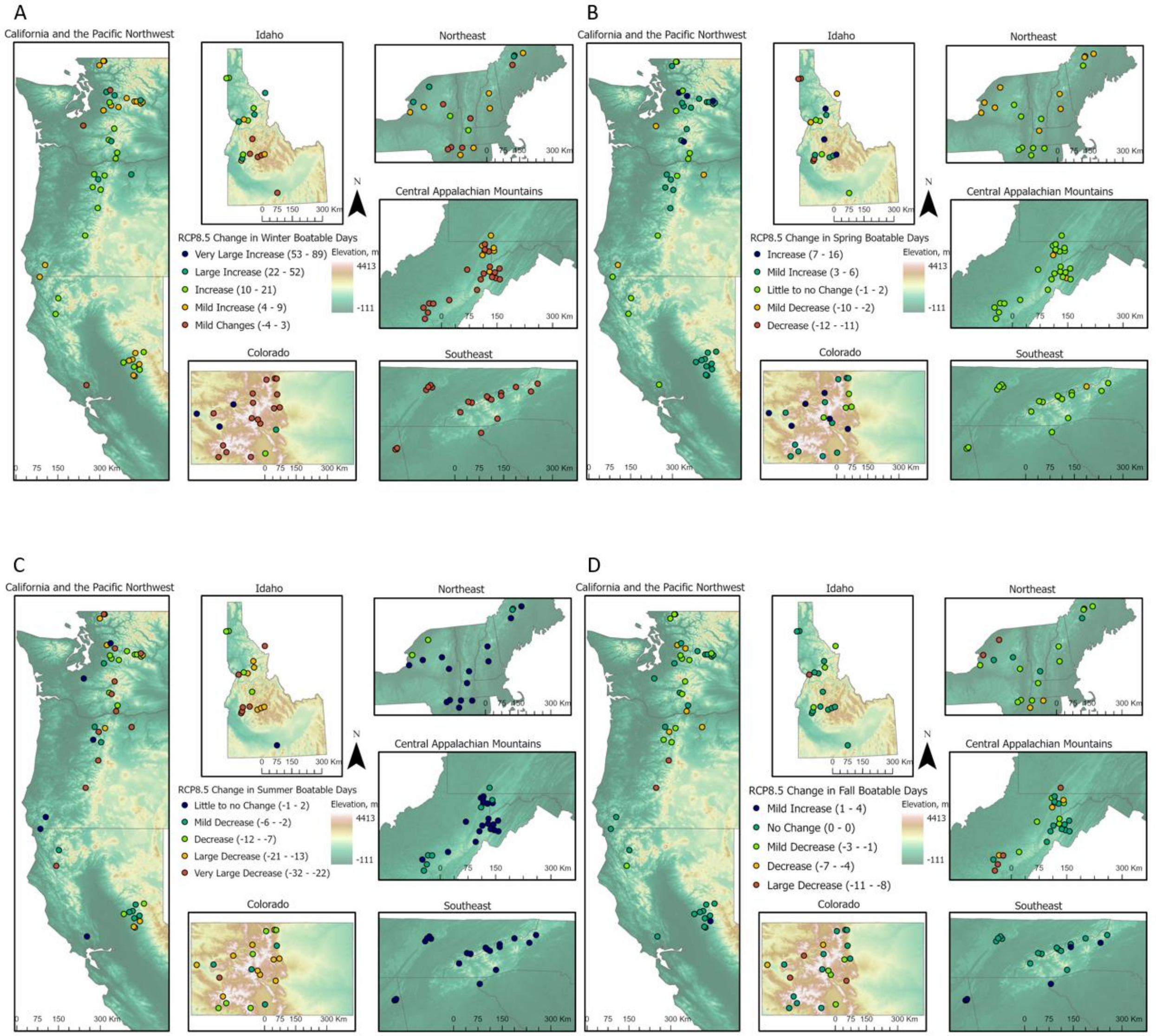

Figure 2-13: Maps of change in boatable days for the four seasons of 152 whitewater river sections in seven Whitewater regions based on the RCP8.5 high emission scenario. Figure 13A shows the difference in boatable days for the winter (December, January, and February). Figure 13B shows the change in boatable days for the spring (March, April, and May). Figure 13C represents the change in boatable days calculated for the summer (June, July, and August). Figure 13D shows the change in boatable days for each river section for the Fall (September, October, and November).

Seasonal changes for Colorado show average boatable days for the winter of 19 days and 20 days for RCP4.5 and RCP8.5, corresponding to an increase of 11% and 17%, respectively. The range for this season was 0 to 91 days for both scenarios. Spring in Colorado will see an average of 45 days for RCP4.5 and 46 days for RCP8.5, a relative change of 7% and 9%. The range for this season is 8 to 92 days for both scenarios. The summer results in lower average boatable days for the season, with 47 days for RCP4.5 and RCP8.5, a 22% decrease. The range for this season is 11 to 74 days for both scenarios. Finally, the fall analysis shows seasonal averages of 22 days for RCP4.5 and RCP8.5, corresponding to a 13% change. The range for this season is 0 to 79 days for RCP4.5 and 0 to 81 days for RCP8.5.

The Southeast sees average boatable days of 43 days for RCP4.5 and 44 days for RCP8.5 in the wintertime, a relative change of 6% and 4%, respectively. The range for this season in the Southeast is 5 to 87 days for RCP4.5 and 5 to 89 days for RCP8.5. The spring seasonal averages calculate 40 days for RCP4.5 (a decrease of 6%) and 42 days for RCP8.5 (a reduction of 1%). The range for this season is 2 to 87 days for RCP4.5 and 3 to 92 days for RCP8.5. The summer average boatable days were 19 days for RCP4.5 (a decrease of 6%) and 20 days for RCP8.5, which is no change from historical boatable days. The range for this season was 0 to 86 days for RCP4.5 and 0 to 91 days for RCP8.5. Finally, the fall season averaged 21 days for RCP4.5 and 25 days for RCP8.5, corresponding to a decrease of 5% and an increase of 14%, respectively. The range for the fall was 1 to 82 days for RCP4.5 and 2 to 87 days for RCP8.5.

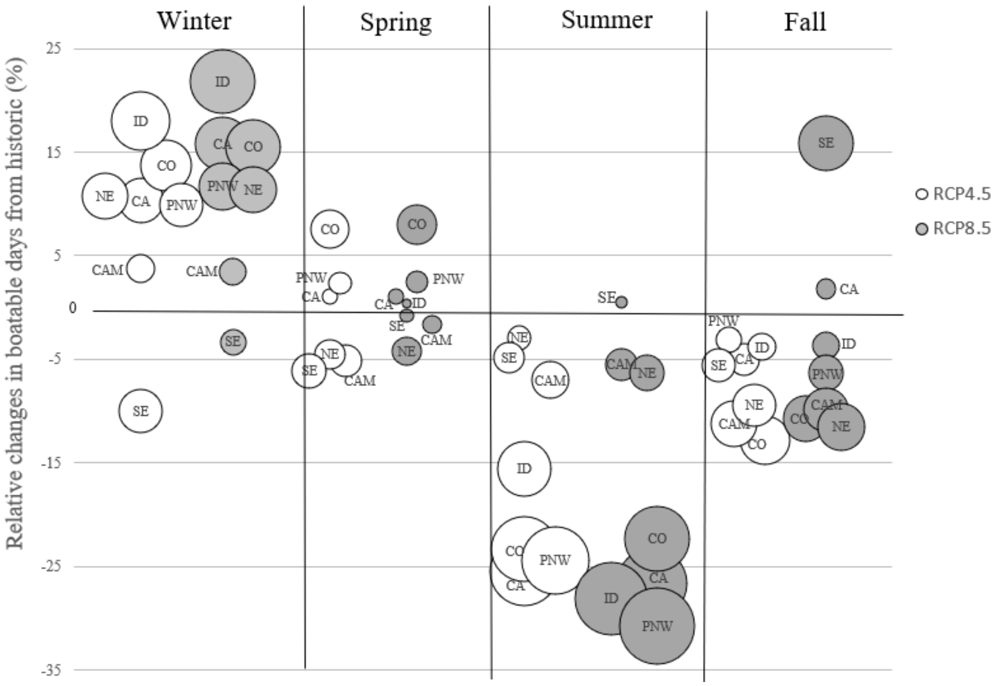

*Figure 2-14: The average relative changes for seven whitewater regions. The size of the bubble equals the magnitude of change. Relative change shows the difference in future boatable days when compared to historical and is calculated by subtracting the historical boatable days from the future boatable days, then dividing by the historical. The result is expressed in a percentage (Relative change = (Future boatable days – Historical boatable days) / Historical Boatable days *100). The seven whitewater regions of interest are the Pacific Northwest (PNW), Idaho (ID), California (CA), the Northeast (NE), the Central Appalachian Mountains (CAM), and the Southeast (SE). The four seasons of the year are shown. They are defined as winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and fall (September, October, and November).*

2.4 Discussion

2.4.1 Historical Boatable Days

The framework developed in this study provides stakeholders with a tool for quantifying boatable days now and into the future that can be used to determine when and where to prioritize whitewater recreation promotion and development to access, economic development, and investment into supporting amenities and concessions. The use of publicly available streamflow (U.S. Geological Survey, 2021) (Colorado Division of Water Resources, 2022) (CA Department of Water Resources, 2022), minimum flow thresholds (American Whitewater, 2019), and climate data (Alder & Hostetler, 2013) are available to characterize boatable days for any whitewater run in the United States. The USGS and state stream gauge networks provide historical daily streamflow timeseries data for a vast network of streams that can be used to develop baseline boatable day information. Using the NCCV, the potential sensitivity of WW runs to future climate can be assessed for different scenarios. While the 152 runs analyzed in this study account for only a small fraction (3%) of runs in the American Whitewater NWI, the results provide important insights into how whitewater recreation throughout the nation could be changing principally due to climate change. This research also provides a national look at the whitewater inventory and boatable days when compared to recent historical studies (Fey & Stafford, 2016) (Mayfield M. , 2006) (Stafford, Fey, & Vaske, 2017).

The results of this thesis quantify, for the first time, boatable days for whitewater runs throughout the seven whitewater regions. The results show that boatable days range from plentiful to infrequent across the regions. On average, the Pacific Northwest had the greatest number of days annually, followed by Idaho, California, the Northeast, the Central Appalachian Mountains, Colorado, then finally, the Southeast. Whitewater is abundant in these areas due to the vast river networks, ample precipitation, and the steep gradient from mountain ranges. Rainfall is important in the Pacific Northwest for the western Cascades runs, while snowmelt is crucial for the high Cascades. In California, snowmelt is vital, especially in dam release runs, but rainfall is important for northern California runs. Snowmelt is critical for Colorado (Gonzalez, et al., 2018) and Idaho (May, et al., 2018). Many boatable days here are delivered from peak snowmelt (freshet) from the ‘white reservoir,’ which is the annual spring rise of streams in cold climates because of melting snow (Bales, et al., 2006). Rainfall is relatively evenly distributed throughout the year in the Central Appalachian Mountains, the Northeast (Dupigny-Giroux, et al., 2018), and the Southeast (Carter, et al., 2018). Snowpack in the Central Appalachian Mountains and the Southeast is transient, and therefore in most years, not overly important but plays a more considerable role in the Northeast.

Given the strong seasonality of hydrology throughout the regions because of altered precipitation characteristics in terms of seasonal timing, frequency, and intensity (Allan R. , et al., 2020), seasonal boatable days provide important insights for understanding when the WW runs are boatable and for how long. For the winter, areas with mixed precipitation (falling as rain or snow) resulted in sustained streamflow throughout the season. These areas include Pacific Northwest, California, the Northeast, the Central Appalachian Mountains, and the Southeast. Idaho and Colorado fall at the bottom of the ranking due to the precipitation falling as snow (Gonzalez, et al., 2018) (May, et al., 2018). As winter turns to spring and temperatures increase, this causes snowmelt in the high elevations to enter the river networks, creating more streamflow and, therefore, more boating opportunities. Idaho has the highest number of boatable days in the spring, followed California, the Pacific Northwest, the Northeast, Central Appalachian Mountains, Southeast, and Colorado. Freshet in the inner mountain west occurs during spring and summer. As a result, Idaho and Colorado have the greatest number of boating days. This period is also when tree water use is at its maximum. Forests play a prominent role in regulating streamflow through ET (Condon, Atchley, & Maxwell, 2020). A significant drop in boatable days is seen in these forested areas, including California, the Northeast, the Central Appalachian Mountains, and the Southeast. The Pacific Northwest also sees fewer days during the summer, but the coastal hydrological regime maintains many boatable days. In the fall, there are fewer boatable days in the snow-driven environments of Idaho and Colorado because snowmelt that had been stored and released from reservoirs is depleted. Regions affected by ET from forests show a rise in boatable days. Results from the seasonal analysis can be used for promulgating policy aimed at enhancing the WW recreation economy, reducing risk for business decisions, and planning by boaters.

Dams that regulate rivers play in important role. New York and Massachusetts in the Northeast and North Carolina in the Southeast contain more than 1,000 dams, that regulate streamflow. Colorado, California, Alabama, and South Carolina in the Southeast have between 500 and 1,000 dams (Federal Emergency Management Agency, 2013). Dam releases from reservoirs also generate streamflow over the summer in areas with little precipitation (FERC, 2022). Dam releases across the nation, for instance, in the Northeast (the Dryway) and Southeast (the Green and the Ocoee), skewed the boatable day analysis by not having historically publicly available data on highly utilized prominent rivers. Ligare et al, 2012 found in the Sierra Nevada Mountains of California that dam-regulated rivers have more resiliency than unregulated rivers (Ligare, Viers, Null, Rheinheimer, & Mount, 2012) but this of course is predicated on future water resources availability. Future Boatable Days

Climate change has important implications for how often and when WW rivers can be boated. Figure 2-13 shows the difference in boatable days for the near future (2025-2049). The effects of both climate change scenarios are similar, meaning the future of boating will look different than in the past whether carbon dioxide emissions are mitigated under RCP4.5 or continue to increase under RCP8.5 (Hayhoe, et al., 2018). The annual changes in boatable days are minimal across all seven regions. These changes are less than 2% of total annual boatable days and are negligible compared to year-to-year historical variation. However, climate models show that there will be shifts in seasonal precipitation, runoff, and evaporative deficit (Konapala, Mishra, Wada, & Mann, 2020). Information on how these factors will change for each region can be found in Appendix B. Annual analysis is not a compelling measure of how climate change will affect whitewater recreation and will not be discussed in greater detail. The shifts in seasonal boating will significantly impact opportunities and the economies that rely on them.

The magnitude and direction of future changes in boatable days relative to the historic period showed variation across space and time (Figure 2-14). The regions clustered in the seasonal responses to future changes in climate suggest similar controls on boatable streamflow. For example, California, Colorado, Idaho, and the Pacific Northwest (the western regions) show similar results of increases in the winter and spring. The western regions see relatively large changes in winter and spring boatable days (Hostetler & Alder, 2016). Warming temperatures in the winter will cause the white reservoir to release earlier, generating higher runoff, resulting in increased boatable days in the winter and spring (Bales, et al., 2006) (May, et al., 2018). Anecdotal references suggest the timing of dam releases is already shifting due to the earlier melting of snow in these mountainous regions. Average winter precipitation is projected to increase, generating more runoff (Hostetler & Alder, 2016). Colorado can expect larger increases in boatable days for the winter season than is documented in this study. Many river sections in the region freeze in winter, which results in gauges reporting a zero-flow reading and no historical boatable days for the season. Overall, eleven river sections in Colorado had zero historical winter boatable days.

Another issue with the future analysis for winter and spring was that some river sections throughout the United States (every region except for the Southeast) were projected to have more boatable days than days in a season. This is caused by the a large change factor being applied to a river that already had many boatable days in a season historically. These sections were manually changed to the maximum number of available days. This increase in boatable days can translate into high streamflows, resulting in some rivers being too high for safe navigation (Brown, Taylor, & Shelby, 1992). Further investigation into maximum boatable levels regarding potential climate change would be beneficial but was out of scope for this research. Summer boatable days are expected to decrease drastically for the western regions (Bales, et al., 2006). An overall decrease in precipitation coupled with an increased temperature and evaporative deficit reduces the runoff, lowering river levels and boatable days.

The eastern regions showing similar results from climate change are the Northeast and Central Appalachian regions (Figures 2-12 and 2-13), with warmer temperatures present in the Central Appalachian region (Dupigny-Giroux, et al., 2018). Warming temperatures in winter will affect precipitation (more instances of precipitation falling as rain than snow). Earlier snowmelt, and little evapotranspiration from the leaf-off season of trees, will result in more runoff in the winter, providing more boatable days. Small increases in precipitation in spring, summer, and fall combat the increased evaporation changes from warmer temperatures, resulting in small decreases in the runoff and causing mild losses to boatable days (Kramer, et al., 2015). Heavy Precipitation events are expected to increase in the Northeast and Central Appalachian Mountain regions. These intense rainstorms (events above the 99th percentile of daily values) have increased by 55% since 1958 (Hayhoe, et al., 2018). Extreme rain events can greatly impact boatable days, especially for the drier summer and fall seasons.

Boatable days are projected to decreases in the Southeast due to decreases in rainfall. The Southeast saw consistent albeit small declines in boatable days for every season, and both scenarios, except for summer and fall under RCP8.5. The Southeast is one of the areas of the United States that has seen minimal warming over the past 120 years (Carter, et al., 2018). This minimal warming may account for the relatively low potential changes from the shifting climate. However, extreme precipitation events counteracted by prolonged drought are expected in this region. The water balance model (Wolock & McCabe, 1999) applied to the MACAv2-METADATA does not capture extreme events such as intense precipitation and floods (Hostetler & Alder, 2016). Therefore, the Southeast may expect greater variation in rainfall and runoff than is illuminated through the METADATA and this research.

The eastern regions of the United States, the Central Appalachian Mountains, the Northeast, and the Southeast, see greater resilience to climate change, as observed in this study. These regions are relatively stable, despite seeing mostly decreases in boatable days. Changes are small compared to the western regions, which supports investing in the whitewater economy. The Central Appalachian Mountains are less sensitive to changes throughout the year than other regions. These findings indicate that the region would benefit from developing new businesses to utilize the region's stability. Summer is usually a time of high use for rivers due to the warmer temperatures, dam releases from reservoirs, and snowmelt. The decrease in summer boatable days across every region suggests planning for dam release scheduling adaptations, and tourism participation shifts should be considered now. Declines in boatable days in the summer could be detrimental to the commercial boating industry (Buckley, 2017). Large reductions and inconsistent boatable days would make scheduling visitors on their vacations difficult (Giddy, Fitchett, & Hoogendoorn, 2017). Whitewater recreation could still boost the economy; however, business plans may have to focus on more than just whitewater (Baltescu, Stancioiu, & Pargaru, 2011). Outfitters and resorts may consider offering multiple forms of adventure tourism to supplement activities if a river is below the minimum boatable level. Dams on certain sections could mitigate climate change effects on boatable days (Buckley, 2017).

2.5 Conclusion

Whether emissions match the RCP4.5 or RCP8.5 scenario in the future, changes are similar, though the magnitude and direction of change vary between regions. With inevitable climate change and the growing consensus that most climate model projections are accurate, changes in whitewater will occur. To what degree will depend on how we proceed with releasing greenhouse gases into the atmosphere. The western regions of California, Colorado, Idaho, and the Pacific Northwest will see significant changes in boating opportunities. The winter and spring will see large increases in precipitation and earlier melting of the white reservoir. In contrast, the summer and fall will drastically decrease boatable days due to a warmer and drier climate. The Northeast and the Central Appalachian Mountains are getting warmer and wetter.

With climate change looming over everyday life, the community of stakeholders must make knowledgeable decisions about this natural resource that will most certainly be affected by climate change. It is the hope that with this research, decision-makers in these regions will have the framework to focus, facilitate, and inform decision-making. Such actions as prioritizing business in different seasons, nature-based mitigation to stabilize streamflow, and perhaps adjusting WW releases to optimize participation and sustain instream ecosystem processes should be the focus of all involved with the recreational activity. Finally, changes in local land use, land cover, and water management will also play a massive role in how rivers change (Hayhoe, et al., 2018). To help mitigate changes in river hydrology, jurisdictions and tenures across river landscapes need to work collectively to make various decisions and actions to lessen the consequences and implications for river environments (Kakoyannis & Stankey, 2002). This research aims to provide previously unavailable data about whitewater recreation that will facilitate more integrative, holistic, and comprehensive thinking about utilizing, protecting, and promoting this resource.

This research provides the first robust analytical framework for consistently quantifying the whitewater resources as seen through boatable days. The results of the boatable day analysis provide insight into which rivers have the greatest opportunities for use and can be meaningful for deciding where and when to prioritize whitewater recreation economic development and investment. These whitewater-rich areas can promote their assets by providing recreational activities after a workday. What the future holds for the climate and whitewater depends greatly on natural variability and human-induced change. If current levels of greenhouse gases stabilize at their current levels, temperatures are projected to increase an additional 0.6˚C (Hayhoe, et al., 2018).

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Chapter 3: Conclusion

This research provides the first robust analytical framework for consistently quantifying the whitewater resources as seen through boatable days. The results of the boatable day analysis provide insight into which rivers have the greatest opportunities for use and can be meaningful for deciding where and when to prioritize whitewater recreation economic development and investment. These whitewater-rich areas can promote their assets by providing recreational activities after a workday. These and other rural communities can also benefit from reshaping their economies from unsustainable natural resource extraction to a sustainable outdoor recreation economy (Quaranta, Citro, & Salvia, 2016). To develop a whitewater economy, detailed information on the concentration of whitewater rivers and how often they can be boated is critical information that can be used by communities, planners, businesses, and decision-makers. The flexible and scalable approach outlined in this study can be used to understand better whitewater resources and economic potential in other areas of the US. This work may not prove ground-breaking for the seasoned paddler. However, the true impact of this is the ability to quantitatively emphasize to government officials, political leaders, land managers, businesses, and community members the active role whitewater recreation plays in state and local economic vitality.

Water security is increasingly becoming a significant concern in the US. Clean freshwater is essential to communities, agriculture, and ecosystems to ensure a happy and healthy population. Human recreational usage is a sub-division of this research dedicated to understanding the intricacies of recreation and its economic impact (Brown, Taylor, & Shelby, 1992) (Duffield, Brown, & Allen, 1994) (English & Bowker, 1996) (Sims, Hodges, & Scruggs, 2004) (Stafford, Fey, & Vaske, 2017). With climate change looming over everyday life, the community of stakeholders must make knowledgeable decisions about this natural resource that will most certainly be affected by climate change. It is the hope that with this research, decision-makers in these regions will have the framework to focus, facilitate, and inform decision-making.

To further this research, a greater analysis of the historical boatable days could show trends in the abundance of boatable days. Are sections and regions seeing decreases or increases in boatable days? Potential for further research could be investigating boatable days of regulated rivers with whitewater recreation worked into the licensing instead of dammed rivers that do not. Such research could leverage future recreational releases to be included in dam operations. Also, a greater look into the watersheds containing the whitewater sections of interest could provide insight into how often rivers run. Is there a size constraint on the size of the watershed? Do watersheds with particular geology and landcover provide more boatable days? This research offers new hydrologic knowledge and understanding for stakeholders, decision-makers, legislators, and resource managers to utilize a unique region-specific natural resource. Future research using this framework could be used to study fishing days. Lower flow is better for fishing, coupled with stocking and temperature would help round out the approach to river development. This framework could also be used to look at non-river activities such as mountain biking days, and skiable days. Finally, a more in-depth look into this boatable analysis could shed light on commercial vs non-commerical river section boatable days, and river difficulty as a seasonal breakdown.

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Chapter 4: Appendices

4.1 Appendix A: General information for the 152 whitewater sections of interest

Section Information							
Region	State	River Name	Top Difficulty	gauge	Gauge Owner	Minimum Threshold	stage-discharge rating
CA	CA	American, Middle Fork (Oxbow Bend)	IV	OXB	CDEC	700	n/a
CA	CA	American, S. Fork (Chili Bar)	III	CBR	CDEC	800	n/a
CA	CA	American, S. Fork (The Gorge)	III	CBR	CDEC	900	n/a
CA	CA	Trinity, Burnt Ranch Gorge	V	11527000	USGS	500	n/a
CA	CA	Yuba	III	YRS	CDEC	700	n/a
CA	CA	American, N. Fork (Chamberlain Falls)	IV	11427000	USGS	300	n/a
CA	CA	American, N. Fork (Giant Gap)	V	11427000	USGS	700	n/a
CA	CA	Napa	III	11458000	USGS	200	n/a
CA	CA	Salmon, Nordheimer Run	V	11522500	USGS	1000	n/a
CA	CA	Smith, North Fork (Low Divide Road to Gasquet)	V	11532500	USGS	2000	n/a
CA	CA	Yuba, N. Fork (Goodyear)	IV	11413000	USGS	800	n/a
CA	CA	Yuba, N. Fork (Plum)	V	11413000	USGS	250	n/a
CA	CA	Yuba, S. Fork (Edwards to Purdon)	IV	JBR	CDEC	500	n/a
CA	CA	Yuba, S. Fork 49 to Bridgeport	V	JBR	CDEC	500	n/a
CAM	WV	Gauley, Lower	IV	3192000	USGS	1000	n/a
CAM	WV	Gauley, Upper	V	3189600	USGS	400	n/a
CAM	WV	New River Dries	IV	3185400	USGS	10500	n/a
CAM	PA	Youghiogheny, Lower	III	3081500	USGS	1.1ft	n/a
CAM	MD	Youghiogheny, Upper	V	3076500	USGS	2.9ft	450
CAM	WV	Daugherty Run	V	3070500	USGS	8ft	1977
CAM	WV	Little Sandy	IV	3070500	USGS	6ft	666
CAM	WV	Otter Creek	IV	3065000	USGS	3000	n/a
CAM	WV	Red Creek	IV	3066000	USGS	300	n/a
CAM	WV	Roaring Creek	IV	3070500	USGS	7.5ft	1573

CAM	WV	Seneca Creek, (Lower)	III	1606000	USGS	5.75ft	716
CAM	WV	Big Sandy, Lower	V	3070500	USGS	5ft	257
CAM	WV	Big Sandy, Upper	III	3070500	USGS	5.75ft	537
CAM	WV	Blackwater, Lower	V	3066000	USGS	250	n/a
CAM	WV	Blackwater, Upper	V	3066000	USGS	250	n/a
CAM	WV	Cheat Canyon	IV	3070260	USGS	11ft	724
CAM	WV	Cheat Narrows	III	3069500	USGS	450	n/a
CAM	WV	Cheat, Dry Fork	III	3065000	USGS	2.8ft	694
CAM	WV	Cheat, Shavers Fork (Bemis to Bowden)	IV	3068800	USGS	5.2ft	570
CAM	WV	Cranberry, Lower	IV	3187500	USGS	3.5ft	268
CAM	WV	Greenbrier River	II	3182500	USGS	4.5ft	2032
CAM	WV	Middle Fork Audra State Park to Tygart River Confluence	*IV*	3052000	USGS	3.2ft	341
CAM	WV	New River Gorge	IV	3185400	USGS	500	n/a
CAM	WV	New, Upper	III	3185400	USGS	1.25ft	707
CAM	WV	Potomac, North Fork of South Branch (Hopeville)	III	1606000	USGS	5.2ft	355
CAM	WV	Potomac, S. Branch (Smokehole)	III	1605500	USGS	2.5ft	229
CAM	MD	Youghiogheny, Top	V	3075500	USGS	180	n/a
CO	CO	Arkansas, Brown's Canyon	III	7091200	USGS	300	n/a
CO	CO	Arkansas, The Numbers	IV	7091200	USGS	200	n/a
CO	CO	Gore Canyon, Colorado River	V	9058000	USGS	700	n/a
CO	CO	Boulder Creek	IV	BOCOROCO0	CODWR	150	n/a
CO	CO	Clear Creek (lower)	IV	6719505	USGS	189	n/a
CO	CO	Clear Creek of the Ark	V	CCACCRCO0	CODWR	150	n/a
CO	CO	Gore Creek	III	9066510	USGS	150	n/a
CO	CO	Plateau Creek	IV	9105000	USGS	200	n/a
CO	CO	South Platte, North Fork (Bailey)	V	PLABAICO0	CODWR	200	n/a
CO	CO	Vallecito Creek	V	9352900	USGS	1.6ft	144
CO	CO	Animas	III	9361500	USGS	1000	n/a
CO	CO	Animas, Upper	V	9359020	USGS	300	n/a
CO	CO	Arkansas, Royal Gorge	IV	ARKWELCO0	CODWR	150	n/a
CO	CO	Cache La Poudre (Big South Campground)	V	CLAFTCCO0	CODWR	300	n/a

CO	CO	Cache La Poudre (Narrows)	V	CLAFTCCO0	CODWR	150	n/a
CO	CO	Cache La Poudre (Upper Mish to park)	III	CLAFTCCO0	CODWR	250	n/a
CO	CO	Colorado, Ruby - Horsethief	II	9163500	USGS	2500	n/a
CO	CO	Conejos (The Pinnacles)	II	CONPLACO0	CODWR	150	n/a
CO	CO	Gunnison	III	9128000	USGS	280	n/a
CO	CO	Rio Grande	II	RIOALACO0	CODWR	200	n/a
CO	CO	Shoshone, Colorado River	IV	9070500	USGS	500	n/a
ID	ID	Deadwood (rese to end of road)	V	13236500	USGS	400	n/a
ID	ID	Snake (Milner Mile)	V	13087995	USGS	10000	n/a
ID	ID	Spokane	III	12419000	USGS	700	n/a
ID	MT	Clark Fork, Alberton Gorge	IV	12354500	USGS	1200	n/a
ID	ID	Clear Water, S. Fork (Golden Canyon)	V	13338500	USGS	400	n/a
ID	ID	Clear Water, S. Fork (Mickey Mouse)	IV	13338500	USGS	600	n/a
ID	ID	Lochsa (Upper)	IV	13337000	USGS	400	n/a
ID	ID	Lochsa, (Lower)	IV	13337000	USGS	1500	n/a
ID	ID	Payette (Lower Main)	II	13247500	USGS	1200	n/a
ID	ID	Payette (Upper Main)	III	13247500	USGS	800	n/a
ID	ID	Payette, N. Fork , Upper (Smiths Ferry to Banks)	V	13246000	USGS	400	n/a
ID	ID	Payette, S. Fork (Grandjean)	IV	13235000	USGS	600	n/a
ID	ID	Salmon (Lower Gorge)	IV	13317000	USGS	3000	n/a
ID	ID	Salmon (Stanley to Old Sunbeam Dam)	IV	13296500	USGS	800	n/a
ID	ID	Salmon (The Day Stretch)	III	13296500	USGS	600	n/a
ID	ID	Salmon, E. Fork of S. Fork, Vibika Creek to Johnson Creek	IV	13313000	USGS	250	m/a
ID	ID	Selway (Lower)	III	13336500	USGS	1000	n/a

NE	NY	Esopus Creek, Glenerie Falls to Saugerties (Lower-Lower)	IV	1364500	USGS	500	n/a
NE	NY	Esopus Creek, Spillway to Tongore Rd. (Lower)	IV	1364500	USGS	500	n/a
NE	CT	Housatonic (Bulls Bridge)	IV	1200500	USGS	800	n/a
NE	CT	Housatonic (Rattlesnake)	IV	1199000	USGS	1200	n/a
NE	NY	Hudson, Indian River to North River (Gorge)	IV	1315000	USGS	2.8ft	419
NE	NY	Indian (Hudson trib.)	V	1315000	USGS	800	n/a
NE	ME	Kennebec (Gorge)	IV	1042500	USGS	350	n/a
NE	ME	Kennebec (Lower)	III	1042500	USGS	2400	n/a
NE	NY	Raquette, Stone Valley	V	4266500	USGS	500	n/a
NE	NY	Sacandaga, Stewarts Bridge Res to Hudson River	III	1325000	USGS	4.8ft	3130
NE	NY	Salmon (Lake Ontario)	III	4250200	USGS	750	n/a
NE	VT	West River (Salmon Hole)	III	1155500	USGS	1000	n/a
NE	NH	Winnipesaukee (Lower Winni)	III	1081000	USGS	400	n/a
NE	MA	Deerfield, Fife Brook	II	1168500	USGS	700	n/a
NE	NY	Black, Watertown to Brownville (Black River Canyon)	V	4260500	USGS	1000	n/a
NE	CT	Farmington (Tville)	III	1189995	USGS	1.2ft	315
NE	NY	Independence, Donnattsburgh Road to Old Pine Grove Road	V	4256000	USGS	350	n/a
NE	NH	Pemigewasset, East Branch	IV	1074520	USGS	300	n/a
NE	ME	Pleasant, W. Branch (Gulf Hagas)	V	1031300	USGS	200	n/a
NE	ME	Sandy Stream	V	1047000	USGS	2000	n/a

PNW	OR	Deschutes L. ’” ’Sherar’s Falls to Columbia River	III	14103000	USGS	3000	n/a
PNW	WA	Spokane (Upper)	II	12419000	USGS	1000	n/a
PNW	WA	Sultan, Powerhouse to fishing access	IV	12138160	USGS	350	n/a
PNW	WA	Sultan, Upper	IV	12137800	USGS	400	n/a
PNW	OR	Umpqua, North 2. Soda Springs to Deadline Falls	III	14316500	USGS	500	n/a
PNW	OR	Breitenbush	IV	14179000	USGS	400	n/a
PNW	OR	Eagle Creek (Fish Hatchery to Eagle Creek Road)	IV	14209500	USGS	2000	n/a
PNW	WA	Icicle Creek Upper	III	12458000	USGS	700	n/a
PNW	WA	Icicle Creek, rico	V	12458000	USGS	700	n/a
PNW	WA	Icicle Creek, Lower	IV	12458000	USGS	700	n/a
PNW	WA	Nooksack, N. Fork	IV	12205000	USGS	500	n/a
PNW	OR	Opal Creek - Santiam, Little North (Classic Opal)	IV	14182500	USGS	600	n/a
PNW	WA	Tye, Upper	V	12134500	USGS	5000	n/a
PNW	WA	Cispus, Upper	III	14231900	USGS	900	n/a
PNW	WA	Cispus, Upper Upper	V	14231900	USGS	400	n/a
PNW	OR	Clackamas (Power Station to North Fork Reservoir)	IV	14209500	USGS	700	n/a
PNW	WA	Deschutes	II	12079000	USGS	150	n/a
PNW	WA	Green River Gorge	IV	12106700	USGS	1000	n/a
PNW	OR	Illinois 2 - Miami Bar to Oak Flat (31 miles)	IV	14377100	USGS	500	n/a
PNW	OR	McKenzie 4. Paradise to Finn Rock	II	14162500	USGS	600	n/a
PNW	WA	Nooksack, Middle Fork	V	12208000	USGS	350	n/a
PNW	WA	Nooksack, N. Fork	III	12205000	USGS	600	n/a
PNW	WA	Ohanepecosh	V	14226500	USGS	700	n/a
PNW	OR	Salmon (split falls to wilderness trailhead)	V	14137000	USGS	500	n/a
PNW	WA	Skykomish)	III	12134500	USGS	700	n/a
PNW	WA	Snoqualmie, Middle Fork (Middle-Middle)	IV	12141300	USGS	1000	n/a

PNW	WA	Snoqualmie, N. Fork (Erinie's Canyon)	V	12142000	USGS	400	n/a
PNW	WA	Snoqualmie, S. Fork (Fall in the Wall)	V	12143400	USGS	220	n/a
PNW	WA	Wenatchee	III	12459000	USGS	2500	n/a
PNW	WA	Wenatchee (Tumwater Canyon)	V	12459000	USGS	800	n/a
PNW	WA	White Salmon (The Green Truss)	V	14123500	USGS	1000	n/a
PNW	WA	White Salmon, Lower Gorge	III	14123500	USGS	300	n/a
SE	NC	Cheoah	V	351706800	USGS	400	n/a
SE	NC	Pigeon (Gorge)	III	3460795	USGS	300	n/a
SE	NC	Pigeon (Lower)	II	3460795	USGS	1200	n/a
SE	NC	Pigeon Dries	V	3460795	USGS	3200	n/a
SE	NC	Big Laurel	IV	3453000	USGS	450	n/a
SE	TN	Clear Creek, Lilly to Nemo	IV	3539778	USGS	180	n/a
SE	TN	Daddy's Creek	IV	3539600	USGS	300	n/a
SE	NC	French Broad, North Fork	IV	3439000	USGS	350	n/a
SE	TN	Island	IV	3539600	USGS	1650	n/a
SE	NC	Linville	V	2138500	USGS	1.7ft	190
SE	TN	Little Clear Creek	IV	3539778	USGS	1200	n/a
SE	NC	Watauga	IV	3479000	USGS	200	n/a
SE	GA	Chattooga, section 4	IV	2177000	USGS	0.9ft	123
SE	NC	French Broad (Bernard to Hot Springs)	IV	3453500	USGS	700	n/a
SE	AL	Little River Canyon	IV	2399200	USGS	175	n/a
SE	AL	Little River Canyon (Chairlift)	III	2399200	USGS	250	n/a
SE	AL	Little River Canyon(Suicide)	V	2399200	USGS	250	n/a
SE	TN	Little, bridge to sinks	III	3497300	USGS	2.8ft	600
SE	TN	Little, sinks to elbow	IV	3497300	USGS	2.4ft	350
SE	NC/TN	Nolichucky	IV	3465500	USGS	500	n/a
SE	TN	Obed Junction to Nemo	IV	3540500	USGS	1000	n/a

4.2 Appendix B: Historical and future boatable day results from both scenarios for each river section of interest.

Region	River Name	HUC8	Historical Boatable Days					RCP4.5 Boatable Days					RCP8.5 Boatable Days				
			Annual	Winter	Spring	Summer	Fall	Annual	Winter	Spring	Summer	Fall	Annual	Winter	Spring	Summer	Fall
CA	American, Middle Fork (Oxbow Bend)	North Fork American	233	54	68	75	36	231	60	70	55	34	240	64	73	55	37
CA	American, N. Fork (Chamberlain Falls)	North Fork American	170	59	87	19	5	170	66	90	14	5	176	70	92	14	5
CA	American, N. Fork (Giant Gap)	North Fork American	118	34	73	9	2	117	39	75	7	2	122	41	77	7	2
CA	American, S. Fork (Chili Bar)	South Fork American	221	48	62	63	48	218	53	62	48	45	227	56	64	48	47
CA	American, S. Fork (The Gorge)	South Fork American	217	46	61	63	46	215	51	62	48	44	223	54	64	48	46
CA	Napa	San Pablo Bay	58	34	24	0	0	58	34	23	0	0	60	36	24	0	0
CA	Salmon, Nordheimer Run	Salmon	180	66	85	20	8	181	77	85	14	8	185	80	86	14	8
CA	Smith, North Fork (Low Divide Road to Gasquet)	Smith	154	71	66	3	15	154	74	64	2	15	155	75	65	2	14
CA	Trinity, Burnt Ranch Gorge	Trinity	328	85	92	88	63	328	92	90	64	60	335	92	92	61	60
CA	Yuba	Upper Yuba	228	76	91	39	23	227	85	92	29	21	235	90	92	29	22
CA	Yuba, N. Fork (Goodyear)	Upper Yuba	103	22	67	12	1	102	25	69	9	1	106	26	70	9	1
CA	Yuba, N. Fork (Plum)	Upper Yuba	202	66	90	39	8	201	73	91	29	8	208	78	92	29	8
CA	Yuba, S. Fork (Edwards to Purdon)	Upper Yuba	84	27	46	10	1	83	30	47	7	1	86	32	48	7	1
CA	Yuba, S. Fork 49 to Bridgeport	Upper Yuba	84	27	46	10	1	83	30	47	7	1	86	32	48	7	1
CAM	Cheat Canyon	Cheat	280	87	89	56	47	274	92	85	52	42	278	92	88	53	42
CAM	Cheat Narrows	Cheat	284	85	91	58	51	278	91	86	54	45	282	91	89	55	45
CAM	Cheat, Dry Fork	Cheat	142	48	58	17	19	139	52	55	16	17	141	52	57	16	17
CAM	Cheat, Shavers Fork (Bemis to Bowden)	Cheat	83	25	38	9	11	82	27	36	8	10	83	27	37	9	10
CAM	Cranberry, Lower	Gauley	101	34	42	11	15	98	35	40	10	13	98	35	41	10	13
CAM	Daugherty Run	Cheat	11	4	4	1	1	10	5	4	1	1	10	5	4	1	1
CAM	Greenbrier River	Greenbrier	42	15	20	3	4	41	15	19	2	4	41	15	20	2	4
CAM	Little Sandy	Cheat	68	26	28	6	8	67	28	26	6	7	67	28	27	6	7
CAM	Lower Big Sandy	Cheat	179	64	71	20	22	175	69	68	19	20	177	69	70	19	20
CAM	Lower Blackwater	Cheat	99	35	40	11	13	97	38	38	10	12	98	38	39	11	12
CAM	Lower Gauley	Gauley	263	82	80	39	62	255	85	76	36	55	256	85	79	36	56
CAM	Middle Fork of the Tygart, Audra	Tygart Valley	135	50	54	14	17	132	52	52	13	15	133	51	54	13	16

	Section																	
CAM	New River Dries	Lower New	101	32	48	10	11	97	32	45	9	10	98	32	48	9	10
CAM	New River Gorge	Lower New	365	90	92	92	91	348	88	87	86	81	353	88	92	87	82
CAM	New, Upper	Lower New	365	90	92	92	91	348	88	87	86	81	353	88	92	87	82
CAM	Otter Creek	Cheat	16	6	7	2	1	16	7	7	1	1	16	7	7	1	1
CAM	Potomac, North Fork of South Branch (Hopeville)	South Branch Potomac	144	50	68	12	14	138	52	63	11	13	142	51	65	12	13
CAM	Potomac, S. Branch (Smokehole)	South Branch Potomac	89	26	47	7	9	85	27	44	7	8	88	27	45	7	9
CAM	Red Creek	Cheat	77	27	32	9	9	76	30	30	8	8	77	30	31	9	8
CAM	Roaring Creek	Cheat	16	7	6	2	2	16	7	6	2	1	16	7	6	2	1
CAM	Seneca Creek (Lower)	South Branch Potomac	70	22	37	5	6	67	23	34	5	6	69	22	36	5	6
CAM	Upper Big Sandy	Cheat	91	34	38	9	10	89	37	36	8	9	90	37	37	8	9
CAM	Upper Blackwater	South Branch Potomac	99	35	40	11	13	95	36	37	10	12	97	36	39	11	13
CAM	Upper Gauley	Gauley	282	86	62	55	79	273	88	59	51	70	275	88	61	51	71
CAM	Youghiogheny, Lower	Youghiogheny	365	90	92	92	91	357	92	88	85	80	363	92	91	88	82
CAM	Youghiogheny, Top	Youghiogheny	182	63	71	24	24	178	66	68	22	21	181	66	70	23	22
CAM	Youghiogheny, Upper	Youghiogheny	245	61	71	65	48	240	64	68	60	42	244	64	70	62	43
CO	Animas	Animas	70	0	36	32	3	67	0	39	22	2	69	0	39	22	2
CO	Arkansas, Brown's Canyon	Arkansas Headwaters	147	0	43	86	18	139	0	49	69	15	142	0	49	68	16
CO	Arkansas, Royal Gorge	Arkansas Headwaters	365	90	92	92	91	346	92	92	73	77	352	92	92	72	80
CO	Arkansas, The Numbers	Arkansas Headwaters	179	0	59	92	29	169	0	66	73	25	173	0	67	72	25
CO	Boulder Creek	St. Vrain	48	0	9	38	1	47	0	10	32	1	47	0	10	31	1
CO	Cache La Poudre (Big South Campground)	Cache La Poudre	88	0	26	61	1	86	0	29	50	1	86	0	30	50	1
CO	Cache La Poudre (Narrows)	Cache La Poudre	124	2	37	78	8	121	3	41	65	7	121	3	41	64	7
CO	Cache La Poudre (Upper Mish to park)	Cache La Poudre	96	0	28	65	2	93	0	31	54	2	93	0	32	53	2
CO	Clear Creek (lower)	Upper South Platte	85	0	22	60	2	81	0	23	48	2	81	0	22	46	2
CO	Clear Creek of the Ark	Arkansas Headwaters	37	0	7	30	0	35	0	8	24	0	36	0	8	24	0
CO	Colorado, Ruby - Horsethief	Colorado Headwaters-Plateau	309	65	82	80	83	303	92	88	62	76	309	92	89	62	76
CO	Conejos (The Pinnacles)	Conejos	71	0	21	43	6	68	0	25	32	5	68	0	25	31	5
CO	Gore Canyon, Colorado River	Colorado Headwaters	172	0	42	80	50	169	0	48	64	44	174	0	49	63	45
CO	Gore Creek	Eagle	72	0	30	42	0	71	0	35	32	0	73	0	35	32	0
CO	Gunnison	Upper Gunnison	356	86	89	92	89	346	92	92	69	78	351	92	92	68	80

CO	Plateau Creek	Colorado Headwaters - Plateau	52	0	37	14	1	51	0	39	11	1	52	0	40	11	1
CO	Rio Grande	Alamosa-Trinchera	120	26	46	28	21	115	37	53	21	18	115	43	52	21	18
CO	Shoshone, Colorado River	Colorado Headwaters	363	89	92	92	91	357	92	92	74	79	365	92	92	73	81
CO	South Platte, North Fork (Bailey)	Upper South Platte	105	1	17	68	19	100	1	17	54	16	100	1	17	52	16
CO	Upper Animas	Animas	79	0	30	45	4	76	0	34	31	3	78	0	34	31	3
CO	Vallecito Creek	Upper San Juan	92	0	41	43	8	89	0	43	31	8	90	0	43	31	8
ID	Clark Fork, Alberton Gorge	Middle Clark Fork	365	90	92	92	91	365	92	89	66	89	365	92	88	63	89
ID	Clear Water, S. Fork (Golden Canyon)	South Fork Clearwater	168	24	86	49	8	163	35	85	37	7	163	37	85	35	7
ID	Clear Water, S. Fork (Mickey Mouse)	South Fork Clearwater	133	12	78	39	3	129	18	77	29	3	129	19	77	28	3
ID	Deadwood (rese to end of road)	South Fork Payette	86	1	10	72	2	87	2	11	51	2	88	2	11	49	2
ID	Lochsa (Upper)	Lochsa	145	18	77	43	7	146	26	85	31	7	147	28	85	29	7
ID	Lower Lochsa	Lochsa	145	18	77	43	7	146	26	85	31	7	147	28	85	29	7
ID	Payette (Lower Main)	Payette	241	22	86	92	42	235	27	74	69	40	244	28	75	70	42
ID	Payette (Upper Main)	Payette	354	84	92	92	86	345	92	79	69	82	358	92	80	70	86
ID	Payette, N. Fork , Upper (Smiths Ferry to Banks)	North Fork Payette	229	16	82	92	39	231	24	86	68	37	235	27	86	65	37
ID	Payette, S. Fork (Grandjean)	South Fork Payette	122	3	64	54	2	123	4	68	38	2	126	5	69	36	2
ID	Salmon (Lower Gorge)	Lower Salmon	357	87	92	91	88	348	92	89	70	82	348	92	90	67	79
ID	Salmon (Stanley to Old Sunbeam Dam)	Upper Salmon	105	1	52	49	4	104	1	58	35	3	105	1	58	34	4
ID	Salmon (The Day Stretch)	Upper Salmon	136	4	59	62	12	135	8	65	45	11	137	9	66	44	11
ID	Salmon, E. Fork of S. Fork - Vibika Creek	South Fork Salmon	94	1	52	40	2	95	1	58	30	1	96	1	59	29	1
ID	Selway (Lower)	Lower Selway	243	59	90	64	31	244	84	92	47	28	244	90	92	45	28
ID	Snake (Milner Mile)	Upper Snake-Rock	5	0	4	1	0	5	0	4	1	0	5	0	4	1	0
ID	Spokane	Upper Spokane	331	90	92	65	84	331	92	81	56	88	331	92	80	54	84
NE	Black (Black River Canyon)	Black	357	90	92	88	87	357	92	86	75	79	358	92	86	76	77
NE	Deerfield, Fife Brook	Deerfield	209	81	66	29	34	209	92	63	26	31	209	92	63	27	30
NE	Esopus Creek (Lower-Lower)	Middle Hudson	117	39	39	15	24	116	42	38	14	22	116	42	38	15	21
NE	Esopus Creek (Lower)	Middle Hudson	117	39	39	15	24	116	42	38	14	22	116	42	38	15	21
NE	Farmington (Tville)	Farmington	332	86	92	84	69	332	92	90	83	64	330	92	91	86	62

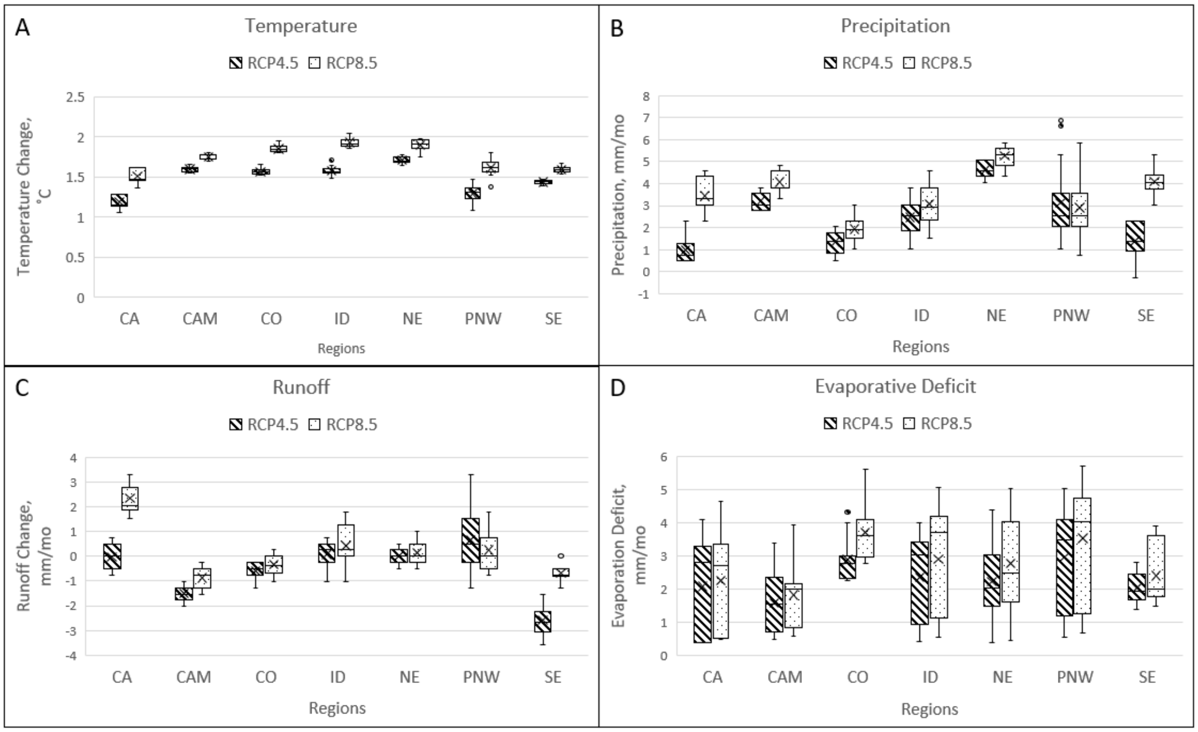
NE	Housatonic (Bulls Bridge)	Housatonic	261	81	88	44	48	260	86	86	43	44	260	85	87	45	42
NE	Housatonic (Rattlesnake)	Housatonic	129	38	51	19	21	129	40	50	18	20	129	40	50	19	19
NE	Hudson, Indian River to North River (Gorge)	Upper Hudson	100	33	30	18	19	99	41	28	16	17	99	42	28	16	17
NE	Independence	Black	58	11	30	6	11	58	14	28	5	10	58	14	28	5	10
NE	Indian (Hudson trib.)	Upper Hudson	11	0	7	2	2	11	0	7	1	2	11	0	7	1	2
NE	Kennebec (Gorge)	Upper Kennebec	365	90	92	92	91	363	92	88	80	81	365	92	88	82	80
NE	Kennebec (Lower)	Upper Kennebec	189	63	58	37	31	188	85	56	32	28	189	88	56	32	27
NE	Pemigewasset, East Branch	Pemigewasset	123	17	58	22	25	123	21	55	20	23	124	21	55	21	23
NE	Pleasant, W. Branch (Gulf Hagas)	Piscataquis	111	20	53	15	24	112	26	50	13	22	112	26	50	13	21
NE	Raquette, Stone Valley	Raquette	313	89	90	67	67	311	92	83	58	59	311	92	83	58	58
NE	Sacandaga, Stewarts Bridge Res to Hudson River	Sacandaga	109	50	25	16	19	110	61	23	14	17	110	62	23	15	17
NE	Salmon (Lake Ontario)	Salmon-Sandy	145	48	59	14	24	146	56	55	13	22	148	57	56	13	22
NE	Sandy Stream	Lower Kennebec	37	4	22	4	7	37	5	21	4	6	38	5	21	4	6
NE	West River (Salmon Hole)	West - Connecticut	41	8	23	4	6	41	10	21	4	6	41	10	21	4	6
NE	Winnipesaukee (Lower Winni)	Merrimack	229	75	77	39	37	230	81	75	38	35	229	81	75	40	34
PNW	Breitenbush	North Santiam	178	63	79	18	17	178	75	83	13	16	178	79	84	12	16
PNW	Cispus, Upper	Upper Cowlitz	160	46	68	32	14	162	57	73	23	13	162	60	73	21	13
PNW	Cispus, Upper Upper	Upper Cowlitz	311	86	91	83	51	315	92	92	60	49	314	92	92	55	48
PNW	Clackamas (Power Station to North Fork Reservoir)	Clackamas	318	90	92	66	70	317	92	92	45	66	317	92	92	41	63
PNW	Deschutes	Deschutes	164	74	64	4	22	164	76	61	3	23	163	76	61	3	22
PNW	Deschutes L. Sherar's Falls to Columbia River	Lower Deschutes	365	90	92	92	91	365	92	88	65	89	361	92	88	60	84
PNW	Eagle Creek (Fish Hatchery to Eagle Creek Road)	Clackamas	118	44	59	6	9	118	53	61	4	9	118	55	61	4	8
PNW	Green River Gorge	Duwamish	113	40	45	8	20	113	45	45	6	19	113	46	44	6	19
PNW	Icicle Creek Upper	Wenatchee	95	7	44	36	7	98	10	49	28	7	98	11	49	25	7
PNW	Icicle Creek, rico	Wenatchee	95	7	44	36	7	98	10	49	28	7	98	11	49	25	7
PNW	Icicle Creek, Lower	Wenatchee	95	7	44	36	7	98	10	49	28	7	98	11	49	25	7
PNW	Illinois 2 - Miami Bar to Oak Flat (31 miles)	Illinois	173	77	76	6	15	175	82	73	4	15	175	84	74	4	14
PNW	McKenzie 4. Paradise to Finn Rock	Mckenzie	365	90	92	92	91	364	92	92	71	85	363	92	92	66	82

PNW	Nooksack, Middle Fork	Nooksack	212	44	64	64	41	216	51	66	50	40	213	52	66	45	39
PNW	Nooksack, N. Fork	Nooksack	231	36	56	87	52	236	41	59	68	52	233	42	58	61	51
PNW	Nooksack, N. Fork	Nooksack	190	26	45	79	40	194	30	47	62	40	191	31	47	56	38
PNW	Ohanepecosh	Upper Cowlitz	262	73	84	68	37	265	89	90	50	36	265	92	91	45	35
PNW	Opal Creek (Classic Opal)	North Santiam	145	57	60	6	23	145	68	63	4	21	145	71	63	4	20
PNW	Salmon (split falls to wilderness trailhead)	Lower Columbia-Sandy	266	88	91	49	38	265	92	92	37	36	264	92	92	34	35
PNW	Skykomish	Skykomish	332	90	92	79	71	338	92	92	59	68	335	92	92	53	67
PNW	Snoqualmie, Middle Fork (Middle-Middle)	Snoqualmie	154	37	59	30	29	156	44	63	22	28	155	46	63	20	27
PNW	Snoqualmie, N. Fork (Erinie's Canyon)	Snoqualmie	167	45	64	25	33	169	54	68	19	32	167	56	69	17	31
PNW	Snoqualmie, S. Fork (Fall in the Wall)	Snoqualmie	162	37	69	28	29	164	44	73	21	28	162	46	74	19	27
PNW	Spokane (Upper)	Upper Spokane	314	89	92	55	79	314	92	81	46	82	314	92	80	45	79
PNW	Sultan, Powerhouse to fishing access	Skykomish	290	88	83	51	67	295	92	92	38	65	293	92	92	34	63
PNW	Sultan, Upper	Skykomish	8	4	1	0	2	8	5	2	0	2	8	5	2	0	2
PNW	Tye, Upper	Skykomish	97	20	37	22	18	99	25	42	17	17	98	26	42	15	17
PNW	Umpqua, North 2. Soda Springs to Deadline Falls	North Umpqua	365	90	92	92	91	361	92	91	72	85	362	92	92	68	82
PNW	Wenatchee	Wenatchee	131	14	59	46	12	135	19	65	35	11	135	20	65	32	11
PNW	Wenatchee (Tumwater Canyon)	Wenatchee	299	79	90	79	50	309	92	92	61	49	309	92	92	56	49
PNW	White Salmon (The Green Truss)	Middle Columbia-Hood	162	51	80	25	6	163	60	80	19	6	163	63	80	18	5
PNW	White Salmon, Lower Gorge	Middle Columbia-Hood	365	90	92	92	91	369	92	92	68	88	365	92	92	63	85
SE	Big Laurel	Upper French Broad	19	7	8	2	2	18	7	8	2	2	19	7	8	2	2
SE	Chattooga, section 4	Tugaloo	355	90	92	90	83	340	87	87	86	82	357	89	92	91	87
SE	Cheoah	Lower Little Tennessee	38	16	16	2	4	36	16	14	2	4	38	16	15	2	4
SE	Clear Creek, Lilly to Nemo	Emory	149	68	57	8	16	141	65	55	7	14	146	65	58	8	16
SE	Daddy's Creek	Emory	91	44	35	4	8	86	42	33	4	7	89	42	35	4	17
SE	French Broad (Bernard to Hot Springs)	Upper French Broad	337	89	92	82	73	320	85	86	79	70	333	87	91	83	75
SE	French Broad, North Fork	Upper French Broad	57	23	17	8	10	54	22	16	8	9	57	22	16	8	10
SE	Island	Emory	9	5	3	0	1	9	5	3	0	1	9	5	3	0	3
SE	Linville	Upper Catawba	77	25	24	11	17	74	23	23	11	17	76	24	24	12	19
SE	Little Clear Creek	Emory	18	9	6	1	2	17	9	6	1	2	17	9	6	1	8

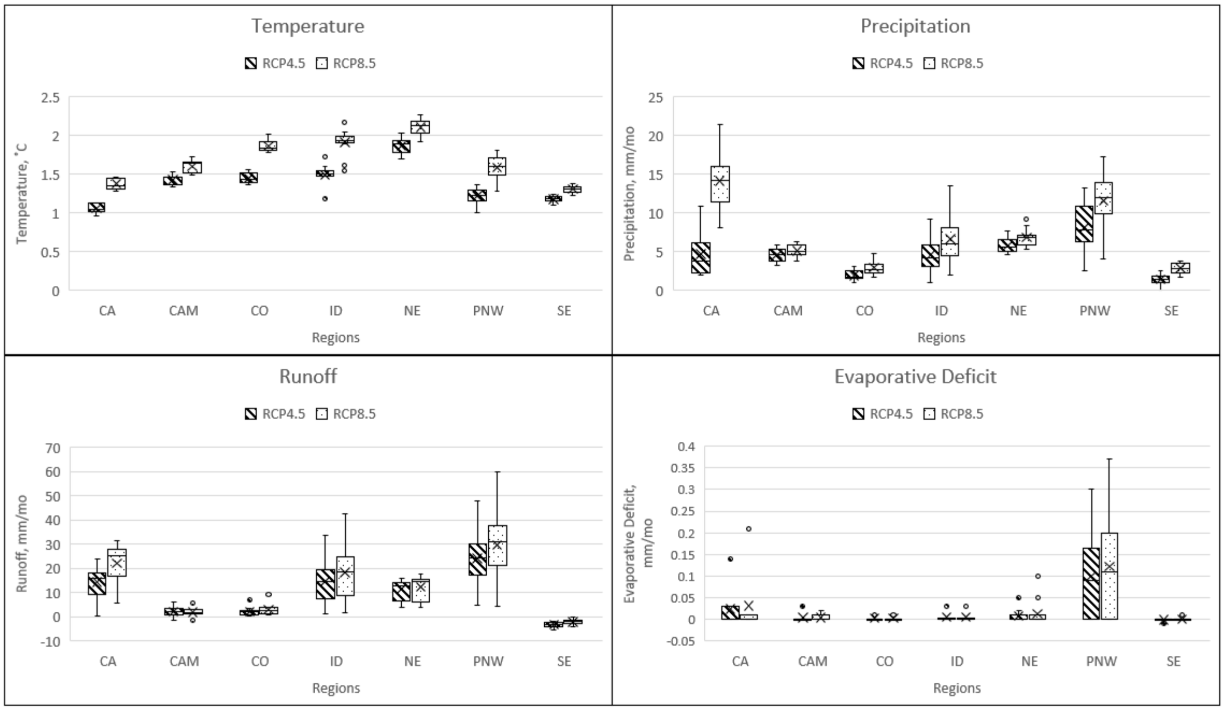
SE	Little River Canyon	Upper Coosa	180	79	66	13	23	167	73	62	12	21	177	75	66	13	24
SE	Little River Canyon (Chairlift)	Upper Coosa	151	69	56	8	18	141	64	53	7	17	148	65	56	8	20
SE	Little River Canyon(Suicide)	Upper Coosa	151	69	56	8	18	141	64	53	7	17	148	65	56	8	20
SE	Little, bridge to sinks	Watts Bar Lake	32	15	11	2	4	30	15	10	2	3	31	15	11	2	4
SE	Little, sinks to elbow	Watts Bar Lake	87	37	34	6	10	82	36	31	6	9	86	36	33	6	10
SE	Nolichucky	Nolichucky	305	85	91	70	58	287	82	84	67	54	297	83	88	70	58
SE	Obed Junction to Nemo	Emory	139	64	54	8	14	132	61	52	7	12	137	61	55	8	13
SE	Pigeon (Gorge)	Pigeon	311	86	90	74	61	295	84	83	70	56	305	85	88	74	60
SE	Pigeon (Lower)	Pigeon	116	44	45	13	15	110	42	42	12	13	114	43	44	13	14
SE	Pigeon Dries	Pigeon	10	5	3	1	2	10	5	2	1	2	10	5	3	1	2
SE	Watauga	Watauga	94	31	35	12	15	89	30	33	12	14	91	30	34	12	15

4.3 Appendix C: Annual and seasonal hydrological changes for the seven regions

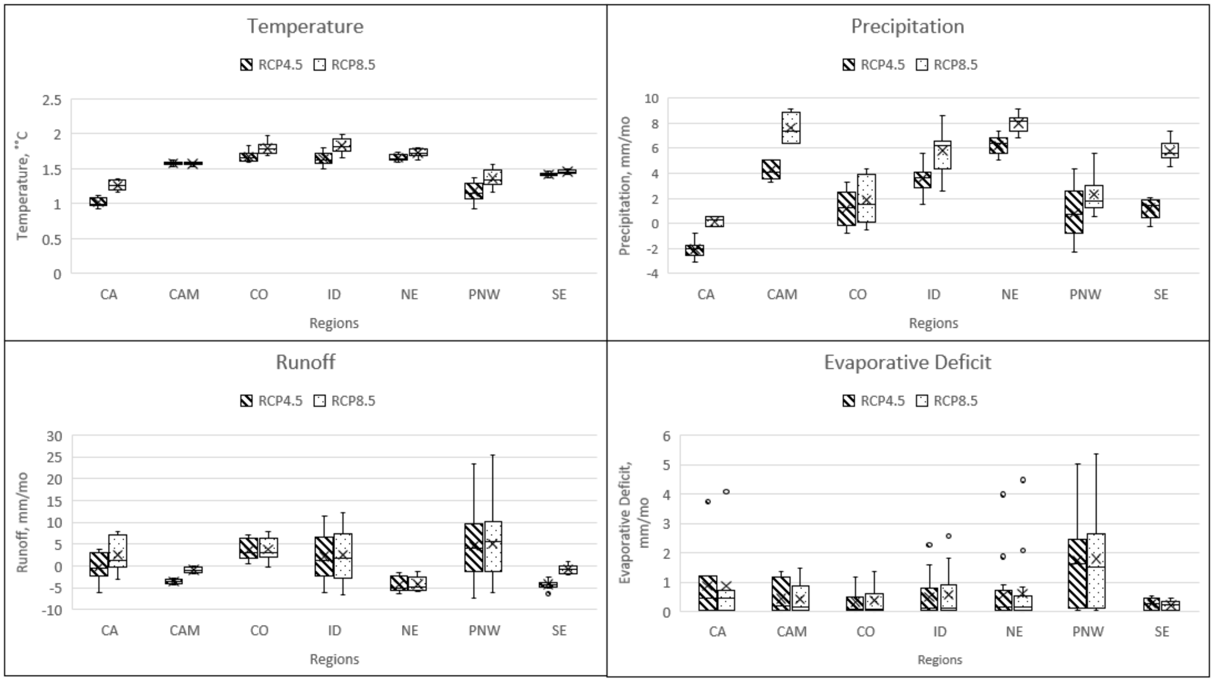
Annual Climatic and Hydraulic Changes for the Seven Regions



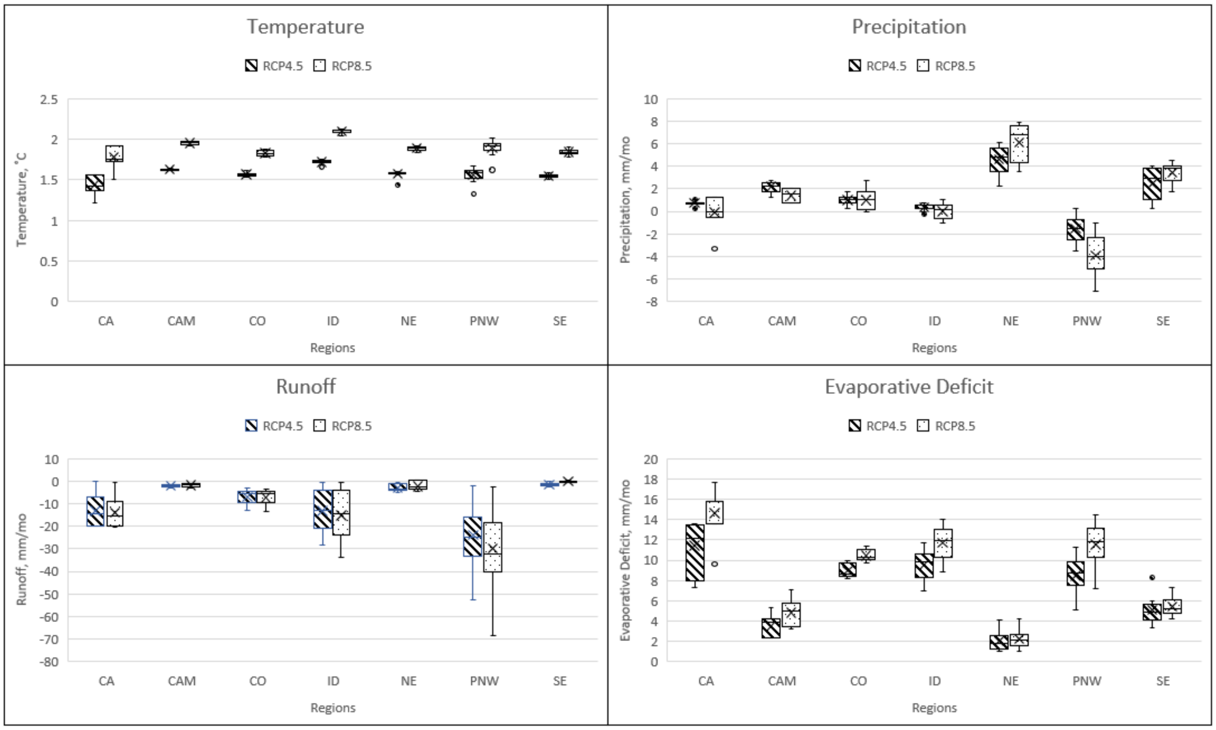
Winter Climate and Water Cycle Changes for the Seven Regions



Spring Climate and Water Cycle Changes for the Seven Regions



Summer Climate and Water Cycle Changes for the Seven Regions



Fall Climate and Water Cycle Changes for the Seven Regions