Lessons Learned from Incorporating Climate Considerations in the Three Rivers Watershed-Based Plan

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Abstract. The South Carolina Department of Health and Environmental Control has recently incentivized planners to incorporate climate change projections into watershed-based plans. Methods for doing so vary by geography, specific basin-level conditions, and available resources. This short communication documents an early example developed by a collaborative team including a council of governments, private contractor, and university researchers. We outline steps taken to construct climate change scenarios, incorporate them into a basin-level model, and develop a holistic approach to climate adaptation and resilience for the Three Rivers Watershed-Based Plan in the Columbia, South Carolina, metropolitan area. We present lessons learned about integrating appropriate climate change scenarios with hydrological tools and incorporating a community development strategy that addresses freshwater pollution and integrates cobenefits and equitable adaptation frameworks into the watershed-based planning process.

INTRODUCTION

Through funding provided by the United States Environmental Protection Agency’s (EPA) Drinking Water State Revolving Fund (DWSRF) for Source Water Protection (SWP), the South Carolina Department of Health and Environmental Control (SCDHEC) offers watershed-based plan (WBP) development grants to address surface water pollutants affecting public drinking water (SCDHEC 2022a). All WBPs must include, at minimum, the nine elements specified by the EPA for watershed-based plan development guidance. Requirements for these grants include incorporating conservation as a recommendation and that the WBPs must consider potential impacts of climate change, acknowledging that changes in temperature, precipitation, sea level, and other variables could alter water supply and quality. Integrating resiliency and adaptation planning into watershed-based plans should help ensure proposed best management practices (BMPs) take more intense watershed disturbances and their impacts into consideration (SCDHEC 2022b). Beyond that, SCDHEC’s requirements follow no single formula and face several challenges: First, how to choose from many available climate change scenarios. Second, how to select an effective tool to measure the hydrologic and water quality responses to climate change within operational constraints. Third, how to develop a holistic approach to climate adaptation and resilience in the context of a WBP.

We address these questions by describing the development of the Three Rivers Watershed-Based Plan—a collaborative effort between the Central Midlands Council of Governments, McCormick Taylor, and the Carolinas Integrated Sciences & Assessments (CISA) team at the University of South Carolina to meet SCDHEC’s requirement of incorporating climate change into a WBP. This short communication describes our effort to do so for an environmentally- and economically-important urban watershed. We focus on three key components: developing a future climate scenario, deploying a watershed model to measure response to future scenarios, and creating local resilience through climate-ready planning (Figure 1). We document key lessons learned that
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might aid other planners and engineers in incorporating climate considerations in watershed-based planning elsewhere.

The Three Rivers Watershed includes portions of the Saluda, Broad, and Congaree Rivers encompassing 55.6 square miles of the Columbia, South Carolina, metropolitan area (SCDHEC 2022c). It is a freshwater source for almost 400,000 residents (SCDHEC 2022c). The watershed itself has an estimated population of 94,480 and is expected to grow by 46% by 2050 (CMCOG 2018). The watershed area includes portions of several highly urbanized HUC-12 subwatersheds, with 28% of the land cover (10,127 acres) estimated as impervious surfaces. These surfaces are within of mostly medium- and low-density residential housing and commercial areas (18%, 13%, and 13% of the entire watershed, respectively) (CMCOG et al. 2018). The watershed extends across seven different political jurisdictions with varying degrees of community development, water quality management, and technical and financial capacity to address water quality issues.

**CREATING CLIMATE CHANGE SCENARIOS**

Our decisions regarding climate change scenarios centered on two fundamental questions: What climate variables mattered to the stormwater modeling tools used in the study? What is the sensitivity of the basin to changes in climate relative to nonclimatic variables that may also change in future decades?

The climate specialists chose scenarios from the current Sixth Climate Model Intercomparison Project (CMIP6), based on climate model projections of total annual precipitation during the historic period. We gathered historical precipitation data for a long-term National Weather Service Coop station (Columbia USC) and from South Carolina Climate Division 6 (NCEI, 2022), then pulled all available CMIP6 data from the appropriate grid cells in South Carolina. We used Shared Socioeconomic Pathway 5 (SSP5), representing a high greenhouse gas emissions future (Hausfather, 2018). We compared yearly historical precipitation totals against CMIP6 model output for the period 1895–2020 to measure bias. We also examined the range of projected annual precipitation for the twenty-first century from all CMIP6 model output (Figure 2). Based on the analysis of 10 CMIP6 models available at the time of our analysis (December 2020), we increased the average annual rainfall from 46 to 60 inches for use in a midcentury (~2050) scenario, a range that considered the climatological average (46 inches) as well as wetter historical years, and that incorporated the trends of the CMIP6 model projections.

**SELECTING A WATERSHED MODEL**

Several factors influenced the water quality model selection. As part of the grant, we needed to evaluate water quality for the entire watershed with a particular focus on protecting source water (intakes for the cities of Columbia, Cayce, and

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Figure 1. A visual representation of how climate considerations were incorporated into the Three Rivers Watershed-Based Plan. The team used the watershed treatment model (WTM) and built climate considerations into multiple report sections. The middle panel shows the three major components, and the right panel shows the subsections where this work appears in the final plan document.
West Columbia water systems are in the watershed. The model minimally needed to calculate bacteria loads, as this particular pollutant is the primary cause of impairments in waterways in the study area. It also needed to estimate nitrogen, phosphorus, and suspended solids loads as each could have additional impacts and trigger treatment requirements for potable water. We needed a flexible tool that could be implemented efficiently. The entire project from stakeholder engagement, watershed analysis, pollutant source analysis, climate and source water protection considerations, management recommendations, and report writing had to be completed in 18 months. We needed to make changes and adjustments to the models across 11 subwatersheds, considering response to three different scenarios in each:

1. Existing land use conditions and mean annual precipitation amount
2. Future retrofit scenarios, in which the management measures are applied to reduce pollutant loads below current conditions
3. Future climate scenarios, incorporating changes in land use, increased bacteria concentrations in runoff, and increased precipitation within the study area

 Ultimately, the water resources consultants leading the modeling effort selected the watershed treatment model (WTM) from the Center for Watershed Protection (Caraco, 2016). The WTM is a steady-state spreadsheet modeling tool best utilized for the rapid assessment and quantification of various watershed treatment options and management measures. Its only explicit climate input is annual precipitation. Pollutant loads for sediment, nutrients, fecal bacteria, and runoff volume respond linearly to this input (Figure 3). The WTM calculates stormwater runoff volume and pollutant loading on an annual basis and will not simulate seasonal loads or the short-term variability of pollutant loads due to shorter periods of climate variability. For existing conditions in the watershed, the WTM evaluates sources (such as land use, septic systems, sanitary sewer overflows, and livestock) and has the capacity to include the benefits of both existing stormwater infrastructure (for the Three Rivers Watershed-Based Plan we only included large wet ponds and riparian buffers due to the scale of the subwatersheds) and nonstructural practices (such as riparian buffers and pet waste education). The future retrofit scenarios applied the same annual precipitation and sources as existing conditions but augmented the practices with additional stormwater best
management practices (BMPs including wet ponds, bioretention, stormwater wetlands, or filters), programs (such as impervious area/rooftop disconnection, improved riparian buffer maintenance and protection, and pet waste education), and proposed redevelopment of older communities (to bring stormwater management up to current requirements). The final scenario evaluated in the WTM was the impact of future climate on land use, annual precipitation, and bacteria concentrations in stormwater runoff for the current land use condition (e.g., no additional management measures implemented). The purpose of this analysis was to illustrate how water quality will be affected if no changes take place in the watershed as undeveloped areas are converted to suburban/urban land use, annual precipitation increases, and bacteria concentrations rise.

The first two scenarios (current conditions and current conditions with additional treatment options) used a routine methodology that can be examined in the final plan. Future climate conditions required a different approach. Here, the team focused on changing three inputs to the WTM: land cover, bacteria concentration in runoff, and mean annual precipitation.

For land cover, the team utilized a future land use data-set developed as part of the US Geological Survey (USGS) LandCarbon project, matching the time frame (2050) and emissions profile (high emissions, A1B / SSP5) of our climate scenario (Sohl et al., 2018). The USGS land use categories have 11 different undeveloped land use categories and one “developed” category (that would encompass seven of the specific land use categories that are input into the WTM). To determine proportions of roadways, industrial, commercial, and residential developed areas in the future land use, the first step was to calculate the distribution of developed and undeveloped land for the current conditions. For each subwatershed the current land uses were separated into “developed” and “undeveloped.” The total area for these two types was calculated separately and then used to calculate the percent of each land use. For example, commercial area percentage is calculated as its respective area divided by the total developed area (including only commercial, residential, roadway, and industrial land uses). The forest percentage is, likewise, its respective area divided by the total undeveloped area for that subwatershed. The percentage of each of the current land use types was then multiplied by the future developed or undeveloped area for each subwatershed.

Figure 3. The simplicity of the WTM is indicated via the linear relationships shown here between annual precipitation and five key variables: total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), fecal bacteria, and runoff volume. Each line shows the model output that corresponds with different inputs of annual precipitation for one of the subwatersheds.
of each of the seven land uses for developed area remains the same, but their respective area increases to reflect the larger overall developed area (Table 1).

We considered the changing bacteria loads associated with elevated ambient temperatures and higher yearly precipitation, reviewing existing studies in comparable locations to estimate the shift in stormwater bacteria concentrations (SCDHEC, 2022d). The climate scenarios assumed an annual precipitation of 60 inches and a 15% increase in bacteria concentration in runoff. Separate scenarios were run to determine (1) the resulting load from the increase in annual rainfall alone, (2) an increase in bacteria concentration to 23,000 MPN/100 mL alone, and (3) the combined effects of increased rainfall and bacteria concentration.

Due to budget and time constraints, we conducted these additional climate scenarios only in the Fourteenmile Creek subwatershed (Figure 4). This subwatershed was selected because it was the least developed, and thus had the highest likelihood of future development (in current conditions 78% of the Fourteenmile Creek is developed and it is anticipated that it will increase to 90%, with approximately 54% of rural and forested land converted to developed land uses). We believe that this subwatershed is well positioned to demonstrate the effectiveness of management strategies. Projected land use changes alone increased the annual bacteria load by 13%. This, added to a 15% increase in bacteria concentrations due to climate considerations, created bacteria loads that were 28% higher than current conditions. Future land use with higher annual rainfall increased the annual bacteria load by 44%. With all three factors (land use, precipitation, and bacteria concentrations) applied, annual bacteria load was projected to be 64% higher than the current load. This is consistent with a similar study based on climate and land use changes in the Chesapeake Bay (Alamdari et al., 2022), which found that the combined effects of climate and land use/land cover change showed the largest increase in runoff and nutrient loading. This analysis illustrates the challenges that local jurisdictions face when trying to select effective stormwater management practices and policies to provide water quality benefits.

With our work, we have included nonstructural measures (such as pet waste education and improved buffer maintenance) as well as repairs to existing sanitary sewer and septic systems. Our analysis suggests that additional pollution load reduction targets from the LDC in the WTM to guide management scenarios for each of the subwatersheds. The first set of recommendations applied to all subwatersheds included nonstructural measures (such as pet waste education and improved buffer maintenance) as well as repairs to existing sanitary sewer and septic systems. Subsequently, the subwatersheds draining to the Saluda River, which tend to be more rural and suburban, required approximately 20–30% of their watershed areas to be retrofitted with new stormwater BMPs (bioretention cells, filter BMPs, constructed wetlands, wet ponds, and infiltration practices) to achieve the 51% bacteria load reduction estimated from the LDC to approximate compliance with federal and state water quality standards. By contrast, the subwatersheds draining to the Congaree River, which tend to be more urbanized, required 40–53% of their watershed areas to be retrofitted with new stormwater BMPs to achieve the necessary 63% bacteria load reduction for current conditions. The additional pollutant loads associated with future land use and climate impacts will require even larger portions of each subwatershed to be retrofitted to effectively reduce bacteria loads.

### CREATING LOCAL RESILIENCE THROUGH CLIMATE READY PLANNING

Resiliency in watershed management requires a holistic approach that connects relevant stakeholders and considers socioeconomic conditions, the environment, best practices, and available financial tools. While the development of the plan began in 2020, the Three Rivers Watershed Stakeholder Group has met since 2016 to discuss bacterial contamination issues. This includes municipal separate storm sewer systems (MS4s) from the watershed’s seven political jurisdictions and a water quality advocacy group. This coordination provided a watershed-wide analysis of existing conditions, identified potential monitoring locations for bacteria sources, and improved the understanding of water quality conditions.

One challenge was incorporating climate resilience into an ongoing planning process. We synthesized the wealth of available climate adaptation literature and settled on two frameworks that were robust, easy to communicate, and reinforced other strategic goals. The Three Rivers Watershed Stakeholder Group aided the team by providing feedback on the frameworks prior to incorporating them into the plan. The frameworks were connected to the EPA 9 Elements

<table>
<thead>
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<th>Land Use</th>
<th>Existing Condition (2021)</th>
<th>Future Condition (2050)</th>
</tr>
</thead>
<tbody>
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<td>30.5%</td>
<td>13.8%</td>
</tr>
<tr>
<td>Developed</td>
<td>69.5%</td>
<td>86.2%</td>
</tr>
</tbody>
</table>
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The first framework selected was co-benefits, an approach that evaluates the benefits of an adaptation project across multiple domains (Diringer et al., 2020). Watershed BMPs can have social, environmental, or public health benefits that extend beyond their role in controlling stormwater or improving water quality. For example, a rain garden can provide pollinator habitat and passive recreation, and urban tree plantings can help offset urban heat island effects. This framework enables an alternative way to visualize the co-benefits of green infrastructure BMPs, including climate resilience.

The second framework selected was equitable adaptation, which focuses on removing social and environmental barriers so the entire community can thrive and become more resilient (USCAN, 2022). While managing climate change risks in a way that emphasizes equity is challenging for local planners, ignoring systemic inequalities (e.g., redlining; Nelson, 2022; City of Columbia, 2022) can have cascading effects that affect residents and hinder implementation of a watershed-based plan (Jacobs and Street, 2020; Schell et al., 2020). An example from the Chesapeake Bay Watershed demonstrates how a GIS-focused method can generate equity-centered decision-making criteria for locating and prioritizing watershed BMPs (Chesapeake Bay Program, 2022).

At the time of writing, the Stakeholder Group is prioritizing riparian buffer protection and septic tie-in projects at the headwaters of the Three Rivers Watershed. This area, along with bacterial contamination issues, contains a burgeoning greenway trail system and high outdoor recreation value. By focusing on this subarea, the Stakeholder Group hopes to leverage additional cobenefits and tap into alternative, competitive funding sources that address more than stormwater and bacterial contamination management.

LESSONS LEARNED

Here we document several lessons learned in the process of incorporating climate change projections into watershed-based plans.
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Figure 5. Pollutant loads for all WTM scenarios by subwatershed; percentages indicate the increase from current conditions to future development and climate conditions without additional stormwater retrofits. Note that the response of bacteria load to future development and climate change is higher in rural and suburban subwatersheds than in highly developed subwatersheds such as Rocky Branch Creek. This is most likely due to the already highly impaired status of this subwatershed.

LESSON 1: LET HISTORIC CLIMATE VARIABILITY AND CHANGE IN THE BASIN PROVIDE CONTEXT FOR CLIMATE CHANGE SCENARIOS

Analyzing the century-long instrumental record allowed us to assess climate model bias since the models include 1950–2005 “control runs.” It also allowed baseline hydrologic simulation across the range of previously recorded precipitation values, thus improving basin model calibration, and providing a measure of sensitivity to past climate variability and change. Such a baseline puts response to projected changes in a useful context to prepare for anticipated conditions and foster a vibrant and resilient watershed.

LESSON 2: CHOOSE CLIMATE SCENARIOS WITH AN APPROPRIATE BALANCE OF FEASIBILITY AND REQUIRED SPECIFICITY

Watershed-based plans incorporating climate change scenarios should consider both what is feasible for the planning task and what level of specificity is required (Figure 6). Users have access to a suite of climate projections and must choose among individual general circulation models (or an ensemble of them), emissions scenarios, and climate variables most relevant for them. They also can choose a level of data processing from sources that synthesize climate model output to those that provide raw output. Examples of the former include the summary text and graphs found in regional reports like the National Climate Assessment (USGRP, 2018), State Climate Summaries (NOAA et al., 2022a), and the U.S. Climate Resilience Toolkit (USGRP, 2022). Examples of the latter provide direct portals to download climate model data, such as downscaled CMIP5 data through the Applied Climate Information System (NOAA Regional Climate Centers, 2022) or CMIP6 data through the KNMI Climate Explorer (KNMI, 2022). Interactive dashboards provide a compromise between these two extremes, allowing users tools to query and extract specific data for their needs. Examples include the NOAA Climate Explorer (NOAA, 2022b), Neighborhoods at Risk tool (Headwaters Economics, 2022), and the Climate and Hazard Mitigation Planning (CHaMP) tool (USDN et al., 2022).
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At the time of our project, CMIP5 data had been regionally evaluated against past observations, bias-corrected, gridded, aggregated across space, was readily available and used widely in national and state climate reports (USGRP, 2018; NOAA, 2022a). We chose to use CMIP6 output because we could extract annual precipitation from the most recent climate model runs with reasonable effort and could compare it with both historical values and previous versions of climate change scenarios. Such buffering created a robust range of future projections. More sophisticated hydrological models might require additional climate inputs, demanding considerably more effort to gather and evaluate data.

LESSON 3: COLLABORATE TO BUILD CLIMATE INTO EXISTING MANAGEMENT TOOLS
Although the WTM is a simple model, and not specifically created to model future climate conditions, it allows adjustment to basic inputs to highlight the synergistic effects of land use, temperature, and precipitation. Despite its simplicity, our results mirror those from another basin using the more complex Storm Water Management Model (SWMM; Alamdari et al., 2022). With additional time, we hope to model other climate-related impacts such as decreased stormwater storage capacity or shifts in groundwater depth. Understanding which climate data to use to model both historic and future conditions, and where to obtain them, has not been commonly discussed in stormwater design manuals and zoning regulations (the basis of consultants’ engineering design requirements). In addition, climate scientists don’t always know the sensitivity of the tools used to measure the response to climate variability and change. Our partnership experience highlights the benefits of interdisciplinary relationships across the fields of engineering, planning, and climatology.

LESSON 4: ADOPT CLIMATE PLANNING FRAMEWORKS THAT BEST ADDRESS COMMUNITY NEEDS
The plan served as a framework to fulfill the watershed-based planning process established by the EPA and addressed source water and climate change considerations from freshwater bacterial contamination in the watershed. But there was an additional need to communicate the plan’s water quality

Figure 6. Planners can use a variety of climate scenarios ranging from accessible reports that synthesize climate model output to interactive dashboards allowing prescribed model output to direct download of specific model output.
assessments and recommendations and connect them to local community development goals. The equitable adaptation and cobenefits frameworks proved critical in clarifying certain community and economic development concepts to the Three Rivers Watershed Stakeholder Group. The cobenefits concept illustrated how water quality improvements can provide systemic cost savings beyond the scope of a project. The equitable adaptation framework educated stakeholders on the benefits of integrating socioeconomic information into the project and showed how water quality remediation and stormwater management are not applied equally across an area.

SUMMARY

Water quality improvement projects go beyond treating surface water pollution. These projects can be part of a holistic community development strategy that treats freshwater pollution while addressing persistent environmental justice and economic development issues. This will become increasingly important as watershed communities face unequal costs (Wing et al., 2022). Integrating the cobenefits and equitable adaptation framework into the watershed-based planning process incentivized the inclusion of alternative funding sources to those typically tied to water quality remediation, such as FEMA hazard mitigation assistance grants or other federal funding that falls within the Justice40 Initiative (The White House, 2022).

The Three Rivers Watershed demonstrates how a holistic approach to watershed-based planning may provide additional financial and water quality management benefits. The approach taken here is one of the first examples to follow SCDHEC’s new guidance on climate considerations, and we hope that planners across South Carolina can incorporate some of our lessons regarding climate scenarios, watershed models, and local resilience. The Three Rivers Watershed-Based Plan will be made available through the DHEC Watershed Atlas (SCDHEC, 2022c) and on their funded watershed-plans website (SCDHEC, 2022d). Ours is just one approach. Planners in other South Carolina geographies may focus on other frameworks or ways to approach climate adaptation. The Adaptation Clearinghouse (2022) lists several other examples from the water sector. Planners can use our example in concert with others to decide which ideas best suits their community’s needs and addresses the climate impacts in their watersheds. In the case of the Three Rivers Watershed Stakeholder Group, using climate and social equity considerations will refine their grant funding applications by highlighting the broader community implications of water quality and stormwater remediation projects.

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