

Annual Report
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Project Title: Nature-based infrastructure for enhancing climate resiliency of groundwater resources in South Florida: An integrated modeling approach

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1. Summary

The first year of the project focused on establishing the foundational framework required for enhancing climate resiliency of groundwater resources in South Florida. A major milestone was then the completion of Task 1 and submission of a manuscript to journal, which has since progressed to the peer-review stage and is currently under moderate revision in Environmental Research Communications. An abstract derived from this work was also accepted for oral presentation at the AGU25 Meeting and presented on December 17, 2025. Task 2 has progressed from the initial phase to the development of a geospatial-based multi-criteria framework for evaluating nature-based infrastructure (NBI), integrating rule-based screening and decision-support tools to support flood mitigation and groundwater recharge. Task 3 has also progressed from the initial GitHub-hosted platform to the development of an AI-enabled, web-based dashboard, including collaboration with Florida Gulf Coast University (FGCU) software engineering students. This effort incorporates Large Language Models (LLMs) and Generative AI tools to improve accessibility and usability of groundwater and climate data. For Task 4, outreach and education activities included a seminar at FGCU, engagement with the Seminole Tribe, discussions with Naples City Council members on flood mitigation and resiliency planning, and integration of project themes into the Environmental Data Science course at FGCU. Additional dissemination efforts included presentations at the AGU25 Meeting and the 34th Annual Southwest Florida Water Resources Conference, and other events expanding engagement with both the scientific community and regional stakeholders.

2. Overview of the project

The project was funded for the period of 06/01/2024 - 05/31/2027, aims to enhance the climate resiliency of groundwater resources through nature-based infrastructure (NBI) in South Florida. The project will use an integrated modeling approach to assess the impact of climate change on water resources and develop adaptive solutions. With a particular focus on developing and evaluating nature-based infrastructure features for mitigating climate change impacts on groundwater resources in South Florida, this project aims to develop a modeling framework that can be used to develop a groundwater climate adaptation plan. The overarching hypothesis of this project is that understanding the dynamic and co-evolving water-ecology-human system is important for effective evaluation of NBIFs. The specific objectives of this project are as follows:

- Task 1 Impact Assessments: Assess the impacts of multiple climate factors on various groundwater related hydrological and ecological features under future climate and management scenarios.

- Task 2 Impact Mitigation: Evaluate NBIFs to mitigate the impact of climate change on water resources in south Florida.
- Task 3 Web-based Platform: Develop the platform for data management, analytics, and visualization to improve the access, understanding, and application of the project results for water resources management and community engagement.
- Task 4 Outreach Campaign and Education: Promote citizen awareness of the importance of water resources and engagement in sustainable management practices under climate change.

3. Progress

Key activities undertaken during the one-year period include recruitment postdoctoral researcher, literature review, team members meetings, development of a platform channel, and running of the USGS Biscayne and Southern Everglades Coastal Transport (BISECT) model, engaging communities and stakeholders. During the period of 03/14/2025–09/15/2025, we have made the following progress.

3.1. Progress on Task 1: Impact Assessments

Recruitment of postdoctoral researcher: The first phase of the project was the successful recruitment of a highly qualified postdoctoral researcher Dr. Mewcha Amha Gebremedhin: (<https://scholar.google.com/citations?user=X6LMEFUAAAAJ&hl=en>) who has just completed his PhD on Water Resources Management in the Faculty of Geo-Information Science and Earth Observation (ITC) at University of Twente, the Netherlands. His PhD research focused on analysis of surface water-groundwater interactions using in-situ data, satellite-derived products, and numerical modeling. His expertise extends to groundwater sustainability, climate change, ecosystems, and land use/land cover dynamics: Dr. Gebremedhin, who started his position on October 1, 2024. is integral to the project's research, particularly in assessing the impacts of climate change on groundwater resources and exploring the potential of nature-based infrastructure solutions. His expertise in integrated hydrological modeling, focused on surface-groundwater interaction, will drive the next phase of the modeling approach and data analysis. Additionally, a workstation was purchased using the allocated budget to support Dr. Gebremedhin's research activities.

Literature review: A comprehensive literature review was conducted to evaluate climate models relevant to the project, focusing on those that accurately simulate future scenarios for precipitation, temperature, and sea-level rise. It also examined the application and debates surrounding nature-based infrastructure, with particular attention to their effectiveness in enhancing groundwater resiliency in South Florida. The findings will guide the selection of data and methods for subsequent project phases. Results of the review,

along with the project plan, were presented at our first all-hands meeting for group discussion:https://mewcha1.github.io/NBI/_downloads/a6ab29693bebffa2fb4452b61d8706e2/EPA_RP_Presentation.pdf.

All-hands meeting: The first all-hands meeting was held on November 20, 2024, with all project team members in attendance to discuss goals and assign responsibilities following progress on Task 1. During the meeting, the PI introduced the project's vision and outlined its broader objectives, while the postdoc presented the initial research plan. This plan focuses on assessing the impacts of multiple climate factors on groundwater-related hydrological and ecological features and evaluating nature-based infrastructures to mitigate climate change impacts on water resources in South Florida under future climate and management scenarios. Team members provided valuable feedback to refine the research approach, and the session successfully clarified individual roles and agreed on immediate next steps.

Downscaled climate data: A literature review was conducted to assess the availability of downscaled climate data for South Florida. Multiple General Circulation Models (GCMs) were reviewed for resolution and accuracy, leading to the selection of a dynamically downscaled dataset with finer spatial resolutions. Python code was developed to visualize average yearly spatial data for precipitation, minimum temperature, and maximum temperature across South Florida. The data, including baseline (1980–2019) and near-future (2020–2059) projections under the SSP585 scenario, was sourced from multiple GCMs (https://hydrosourc.ornl.gov/data/datasets/9505v3_1/ory). Visualization maps for average precipitation and temperature variables for both periods are now available on the project web platform (<https://mewcha1.github.io/NBI>). This progress is a step towards better understanding the climate dynamics in South Florida, specifically in relation to how changes in temperature and rainfall patterns could impact the region.

This task is to develop comprehensive set of climate scenarios that include future climate forcings (mainly precipitation) and sea-level rise projections from CMIP6 data under different Shared Socioeconomic Pathways, particularly data from High Resolution Model Intercomparison Project and Coordinated Regional Downscaling Experiment. These two projected data are basic inputs to the USGS Biscayne and Southern Everglades Coastal Transport (BISECT). Accordingly, the daily high-resolution downscaled hydro-climate projections over the conterminous United States (CONUS) was utilized, which integrates multiple General Circulation Models (GCMs) from the CMIP6 dataset. The Daymet and Livneh meteorological datasets were used as reference observation for the downscaling process.

Validation of downscaled precipitation: Data validation was performed to evaluate the performance of the climate models compared with in-situ observation and select the best performing climate model for the study area. The performance evaluation is targeted to enhance the spatio-temporal representation of hydrological processes, improving model accuracy. Similar to the rainfall projections, this study also incorporated sea level rise (SLR) projections specific to South Florida, using NASA's Sea Level Projection Tool. This tool provides localized SLR data from the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6), enabling precise visualization and analysis. The python code to visualize the validation process for some in-situ locations of precipitation in the southern Florid is updated in the web platform (<https://mewcha1.github.io/NBI>).

Exploration of the BISECT model: Exploration of the USGS BISECT model has been carried out. This model is crucial for the project as it integrates surface water and groundwater systems through a density-dependent flow approach, which is vital for managing water resources in the context of climate change and sea-level rise. The initial setup for the model has focused on establishing a baseline and future climate scenarios, including the impacts of sea-level rise on the region's groundwater resources. Originally, the BISECT model was calibrated using several state variables. In this project, a testing stage of the model has been made for validation with independent daily data from the baseline climate data. The model's test performance has been assessed through both graphical and statistical analyses, ensuring its ability to replicate observed conditions. Preliminary results of the model, mainly the spatial groundwater levels and groundwater salinity have been updated in the project web platform (<https://mewcha1.github.io/NBI>).

Output: A major milestone achieved under Task 1 has progressed to the peer-review stage. The manuscript titled “Groundwater–surface water interaction and salinity responses to projected rainfall and sea-level rise in South Florida” is currently under moderate revision in Environmental Research Communications (Gebremedhin et al. 2025). The study applies the density-dependent BISECT model to simulate integrated climate impacts. Key findings indicate that groundwater levels rise in low-lying areas by the end of the century, increasing flood risk, while both surface water and groundwater salinity are projected to rise significantly, threatening the Biscayne Aquifer and freshwater-dependent ecosystems such as the Everglades. Inland saltwater intrusion is expected to expand, reaching concentrations up to 40 g L⁻¹ in some areas, while groundwater-driven evapotranspiration declines due to waterlogging and ecosystem shifts. These projections highlight the urgent need for integrated, nature-based adaptation strategies to protect freshwater resources and ecological resilience in South Florida. Building on this, Task 2 of the project will focus on developing an evaluation framework for Nature-Based Solutions (NBS), ensuring their proper implementation and effectiveness as adaptation strategies.

3.2. Progress on Task 2: Impact Mitigation

Gray2Green (G2G) tool: Anticipated climate impacts that NBIFs would mitigate include flooding due to shallow groundwater compounded with sea-level rise impacting urban areas. This was investigated in Bonita Bay in southwest Florida, which is highly susceptible to flooding due to its low elevation, shallow groundwater, and proximity to tidal waters. We developed a novel GIS method that integrates environmental drivers such as precipitation, sea-level rise and groundwater levels with infrastructure systems such as design storms, nature-based infrastructure, and land use changes. This approach will provide a framework for evaluating various NBIFs for developing tailored flood mitigation strategies to improve groundwater climate resiliency. Our work was published as a peer review paper in *Frontiers in Water* (Tsegaye et al., 2024). Building on the G2G tool, Task 2 is focused on developing a Framework for Integrated NBS Evaluation. This framework combines risk assessment, hydrological and groundwater modeling, spatial analysis, and stakeholder engagement to identify priority hotspots, design and test NBS scenarios, and evaluate their performance using metrics indicators such as flood reduction and groundwater. By linking scientific assessments with practical decision support, the framework ensures that NBS strategies are not only technically robust but also socially supported and economically viable, laying the foundation for effective long-term adaptation planning.

A geospatial-based multi-criteria suitability framework: A framework has been developed to support the implementation of nature-based infrastructure (NBI) for flood mitigation and groundwater recharge enhancement. A comprehensive review of existing geospatial and decision-support approaches was conducted to identify methods for integrating hydrological, environmental, and spatial datasets into NBI planning. This review highlighted the need for transitioning from feasibility-based site identification to performance-based prioritization of NBI interventions. Based on this, a Python-based geospatial workflow was developed to process high-resolution geospatial datasets. These datasets were integrated to map existing hydrological conditions and identify potential areas suitable for NBI implementation. This progress represents a critical step toward developing scalable tools to support flood mitigation planning and groundwater resiliency in South Florida. This task integrates rule-based spatial screening (G2G) with multi-criteria decision analysis (MCDA) to evaluate and prioritize NBI implementation under current and future hydrological conditions. The framework incorporates multiple controlling factors, including runoff generation potential, soil infiltration capacity, slope, drainage proximity, and storage efficiency. The rule-based component defines feasible areas based on engineering and environmental constraints such as groundwater depth, slope thresholds, proximity to impervious surfaces, and exclusion zones. These feasible areas are then evaluated using the MCDA approach to rank locations according to their expected hydrological performance.

This integrated framework enables the identification of optimal NBI placement areas that maximize stormwater runoff reduction and groundwater recharge.

Validation of NBI suitability framework: The robustness of the framework was evaluated through sensitivity analysis by systematically varying the weights of key criteria and assessing changes in spatial prioritization outcomes.

Exploration of hydrological performance: The framework incorporates stormwater runoff estimation to quantify runoff generation and evaluate the effectiveness of NBI practices in reducing runoff volumes and enhancing storage. Storage-based runoff reduction was estimated for different NBI practices, allowing comparison between rule-based feasible implementation and performance-based prioritized implementation.

Output: A major milestone under Task 2 is the development of a geospatial decision-support framework that integrates rule-based screening and MCDA-based prioritization for NBI planning. A manuscript based on this work is currently in preparation for submission to a peer-reviewed journal (Gebremedhin et al., In-Preparation) and for presentations at conferences including AGU Fall Meeting 2026 and to stakeholders.

3.3. Progress on Task 3: Web-based Platform

The postdoctoral researcher developed web-based platform our project using Jupyter-Book and hosted on GitHub (<https://mewcha1.github.io/NBI/>), which serves as a platform for sharing project data (Gebremedhin, 2024). In parallel, we are developing an AI-enabled dashboard as an interactive data tool for stakeholders, and the public. We are collaborating with software engineering students Michael Alvear, Luis Cabrera, Mark Schwartz, and Christopher Smith at FGCU, and we are developing this dashboard as their capstone project. A key design feature is the incorporation of AI-powered insights, leveraging Large Language Models (LLMs) chat interface. This functionality will enable users to interact with project outputs through natural language queries and instantly receiving visualized, data-driven responses. The dashboard will also allow users to search, extract, visualize, and download datasets for their specific area of interest in various formats. This will ensure that project findings are not only accessible but also actionable for a wide range of end-users, from technical experts to community members. By bridging scientific modeling with user-friendly AI tools, the dashboard will enhance transparency, support evidence-based decision-making, and strengthen stakeholder engagement in climate resilience planning. The students presented their work at the 34th Annual Southwest Florida Water Resources Conference and won third place in a poster competition. This work has also been presented to other regional events (see Task 4). A manuscript on the development of AI-enabled, LLM-based tools for democratizing groundwater and climate data is currently under preparation (Alvear et al., In-preparation).

3.4. Progress on Task 4: Outreach Campaign and Education

Outreach event: Our first community engagement event was a seminar talk delivered by the PI about sustainable groundwater management at coastal aquifer. The talk was delivered to a seminar class at The Water School at FGCU with about 30 students and was attended by many faculty and staff members at FGCU in person, and by the project team from Florida Student University and University of Florida including their students and postdocs online. The total audience was more than 60 people both in-person and online. The one-hour seminar highlighted the PI work on groundwater sustainability, including this EPA-funded project on nature-based infrastructure for enhancing climate resiliency of groundwater resources in South Florida. We posted the event flyer and slide on our project web-platform: <https://mewcha1.github.io/NBI/Presentations.html>.

Community engagement with the Seminole Tribe: We made an engagement with the Seminole Tribe of Florida as part of our outreach campaign. In 16-17 June 2025, we visited Immokalee, Brighton Reservation, and Big Cypress, where we presented preliminary results from Task 1 and discussed broader environmental and hydrological research themes of mutual interest. The meetings provided an opportunity to share our findings on groundwater–surface water interactions and climate change impacts, while also learning from the Tribe about local hydrology, land use, and environmental priorities. These discussions helped identify potential areas for future collaboration and community-driven research directions. As part of this trip, we also conducted fieldwork from 18-20 June 2025 at the University of Florida Immokalee site. This effort was focused on installing all-in-one meteorological monitoring instrument and soil moisture sensors, to enable continuous monitoring of atmospheric and subsurface soil moisture dynamics.

Engagement with Naples: We presented Task 1 results to a Naples City Council member and their team, followed by a series of discussions both at the Council office and at FGCU. These conversations focused on adaptation strategies for flood mitigation, particularly in response to sea-level rise and tidal flooding. Council members expressed concerns about planning for rising the Gulf waters and referenced IPCC projections, highlighting questions on whether to raise coastal roads, prepare for more frequent “rainy day flooding,” and develop long-term resiliency plans. Our studies directly address these concerns by linking climate projections with localized flood risk assessments. With ongoing follow-up communication, we are planning to implement aspects of Task 2 in Naples, engaging stakeholders to co-develop NBS evaluation frameworks tailored for flood mitigation and coastal adaptation. We developed and introduced a collaborative, modeling-based simulation–optimization framework that combines stakeholder participation with state-of-the-art hydrologic modeling and advanced evolutionary optimization techniques. This integrative framework is designed to support decision-making for complex water resource and climate resilience

challenges, ensuring both technical rigor and stakeholder relevance. The work is detailed in a manuscript currently in review, moderate revision (Elshall, Gebremedhin, et al., In-Review).

Educational activities: We integrated our project into the Environment Data Science course that is offered by the college of engineering at FGCU. This course introduces water and environmental data analysis using Python to upper-level undergraduate students and graduate students from both engineering and Earth science (<https://aselshall.github.io/eds>). In the course, students use Python packages such as Xarray and Google Earth Engine to analyze climate data, land use, and land cover change data to address water resource and environmental issues. The course is project-based and with service-learning opportunities, allowing students to apply data science methods to real-world problems. By incorporating our EPA project, we provided students with project ideas related to nature-based solutions and regional groundwater climate resiliency: <https://aselshall.github.io/eds/HW/project#3-service-learning-optional>. This integration not only offers students valuable experiential learning opportunities but also enables them to earn service hours while contributing to the sustainable management of water resources under climate change in South Florida. This progress is reported in two conference papers and (Badir & Elshall, 2025; Elshall & Badir, 2025a) and two manuscripts, one already published (Elshall & Badir, 2025b) and the other is under review (Elshall, Badir, et al., In-Review).

Conference presentations and scientific dissemination: As part of our dissemination efforts, from Task 1 we delivered an oral presentation at the AGU25 Meeting and presented on December 17, 2025, in New Orleans (Gebremedhin et al., 2025). The presentation increased visibility of the project and facilitated engagement with the international scientific community. This engagement provided an opportunity to disseminate project findings and receive feedback from peers working on similar challenges in climate–water interactions worldwide. The project’s Task 3 output was also presented at the 34th Annual Southwest Florida Water Resources Conference (Alvear et al., 2026). The presentation focused on the development of AI-driven tools using Large Language Models for democratizing groundwater and climate data, linking Task 3 technological advancements with outreach objectives. This engagement strengthened connections with multiple regional stakeholders and water resource professionals and received recognition by winning the 3rd place in poster contest. In addition, this work was presented at other events including the FGCU AI Day (Mar 12, 2026), and Critical Infrastructure & Resilient Communities Summit at FGCU (Mar 13, 2026). The students also submitted an abstract to Eagle, which is FGCU's largest annual showcase event featuring the most highly regarded student projects of the year in which they will present research and demonstrate the AI-powered dashboard on April 17, 2026.

4. Challenges and solutions

While initial test runs have been conducted, further work is required to address uncertainties in model post-processing and refine key driving forces. Ongoing efforts are focused on improving model accuracy and reliability, ensuring that it effectively captures the complex interactions governing coastal hydrology. In addition to addressing technical challenges, we have been working with USGS collaborators to improve the accuracy and reliability of the BISECT model simulations. On the engagement side, translating technical findings into actionable strategies for stakeholders, such as local governments and tribal communities, requires continuous communication. To address this, we expanded outreach through presentations, discussions, and web-based tools that make results more accessible. Early stakeholder input has already helped shaping the direction of Task 2 by highlighting local concerns about sea-level rise, flooding, and long-term adaptation planning.

5. Future work plan

- Advancing Task 2 through continued development and refinement of the integrated NBI evaluation framework.
- Advancing Task 3 by continuing the development of the web-based dashboard and AI-powered tools, incorporating Large Language Models (LLMs) and Generative AI, interfaces to enhance the accessibility and usability of groundwater and climate data.
- Preparing additional manuscripts and presentations to further disseminate project findings and support knowledge transfer.
- Addressing reviewer comments and revising the Task 1 manuscript.

6. Conclusion

The project has successfully progressed from its foundational phase into research, modeling, framework development, and expanded stakeholder engagement. Task 1 has produced scientific outputs, with the primary manuscript advancing through peer-review revisions and dissemination through conference presentation. Task 2 has progressed to the development of a geospatial, multi-criteria framework for evaluating nature-based infrastructure (NBI), providing a scalable framework for flood reduction and recharge enhancement. Task 3 has also made progress with the development of a web-based platform and corresponding manuscript development. Task 4 has further strengthened outreach and dissemination efforts, including engagement with local stakeholders and the broader scientific community through conferences and collaborative activities. Together, these integrated efforts enhance both the scientific foundation and practical applicability of the project, supporting data-driven strategies for improving groundwater resiliency under

climate change in South Florida. The papers and manuscripts produced under this funding are available at the project website: <https://mewcha1.github.io/NBI/Publication.html>

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