OAK RIDGE National Laboratory

Assessing the Vulnerability of Coastal Aquifers in Arrowsic Island, ME

Intern: Aninditha(Anin) Nair
Mentor: Dr. Melissa Allen-Dumas

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Assessing the Vulnerability of Coastal Aquifers to Saltwater Intrusion in Arrowsic Island, ME

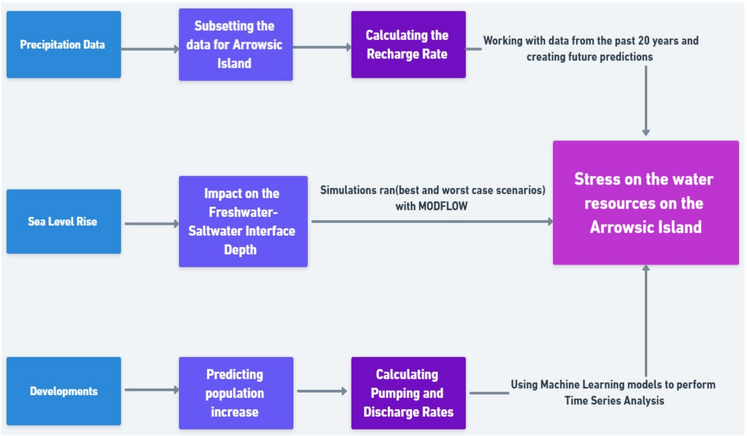
Aninditha Nair
Mentor: Dr. Melissa Allen-Dumas

OAK RIDGE National Laboratory | Ohio Wesleyan University | U.S. DEPARTMENT OF ENERGY

Introduction

More than 40% of Maine's citizens depend on groundwater for their main source of water, with Arrowsic Island largely dependent on bedrock aquifers for freshwater. This project evaluates the vulnerability of coastal aquifers to saltwater intrusion in Arrowsic and the town's capability to meet the water demands of the future. We examine three components of projected water quality and quantity for the island: changes in precipitation patterns, sea level rise and increases in population. Data for the project includes measured, historical and projected precipitation and temperature, historical and projected population scenarios based on potential affordable housing unit development on the island, and three sea level rise scenarios: no change, 3 ft rise and 6 ft rise. By validating historical data and generating plausible future projections, we will develop a portfolio of analyses to help Arrowsic's residents make best management decisions for the island's aquifer water resources.

Methodology



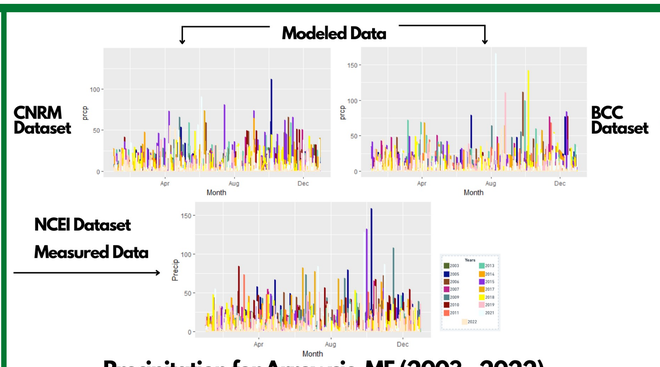
Precipitation

- Visualized the observed National Centers for Environmental Information (NCEI) precipitation data(mm) spanning from 2003 to 2022
- Generated plots for six distinct models derived from the 9505 dataset – **ACCESS, BCC, CNRM, MPI, MRI, NOR** and incorporating four different variations **– DBCCA-Daymet & Livneh** and **RegCM – Daymet & Livneh**. Subsequently, we identified two models(**CNRM** and **BCC**) that exhibited the closest resemblance to the observed data.
- Based on the correlation between historical data and the projected model data we estimated the future precipitation and temperature.

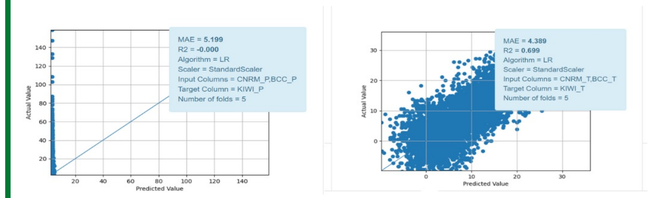
Development

- Created three projected population scenarios based on current population and housing data from Census Block Group Data(Tigerline), Maine's Affordable Housing Unit document and Arrowsic's current regulations.
- Low: **12% increase** per block based on the baseline increase seen every decade in Arrowsic
- Mid: Adding **4 people** (2 houses) to each block
- High: Adding **8 people** (4 houses) to each block

Results

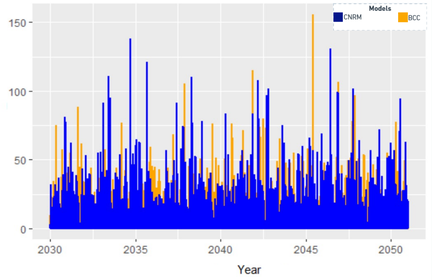


Precipitation for Arrowsic, ME (2003 - 2022)

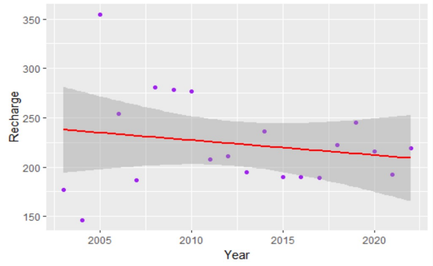


Precipitation **Temperature**

Linear Regression using CNRM and BCC as independent variables and the NCEI (measured) data as the dependent variable.



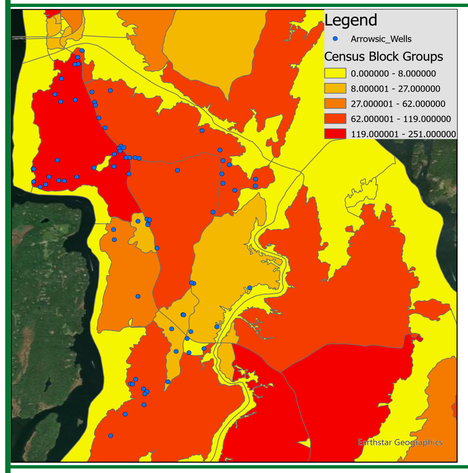
Precipitation for Arrowsic, ME (2030 - 2050)

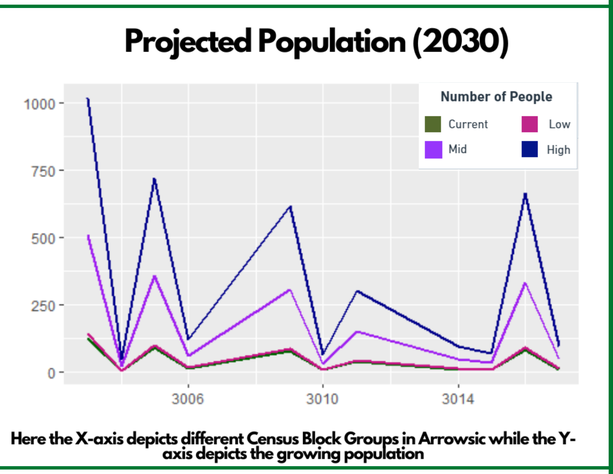


Aquifer Recharge Rate in Arrowsic, ME

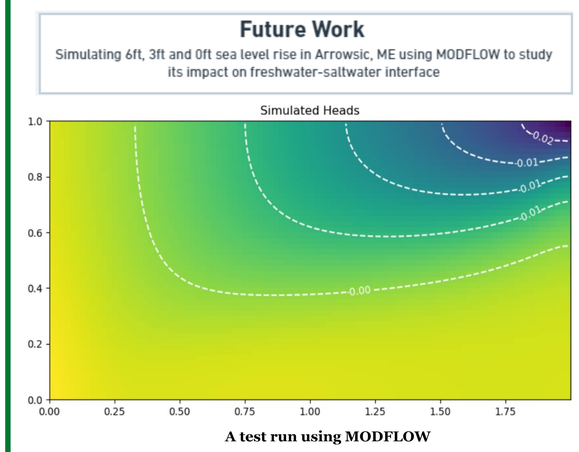
$$Re = 0.25^{*}(P-400)$$

Re = Recharge; P= Precipitation

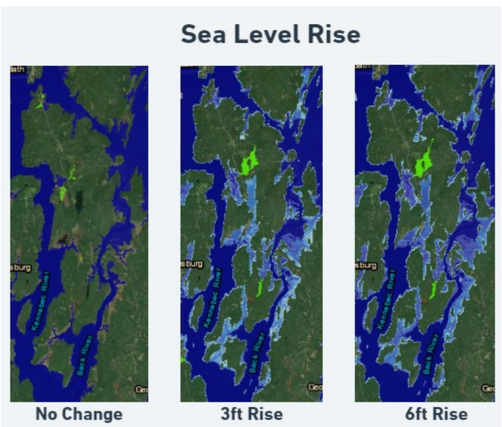




Here the X-axis depicts different Census Block Groups in Arrowsic while the Y-axis depicts the growing population



A test run using MODFLOW



Conclusion

Climate data projections used for this study indicate increased temperature and annual precipitation but in the form of sudden large extreme events for Arrowsic Island. Accompanied by a projected increase in population with the potential affordable housing unit development on the island, therefore an increase in well pumping rates and demand, this change is very likely to put stress on the bedrock aquifers on the island. We defined three population scenarios and the required well yield for each of those scenarios for the year 2030:

Current Population	Low Scenario	Mid Scenario	High Scenario	Total Wells	People per well (Current)	People per well (Low)	People per well (Mid)	People per well (High)
477	535	1908	3816	183	2	3	10	20

Current well yield for all the houses in Arrowsic: **1,379,908.8 gallons per day**
Water required by the current population(100 gbd for two people): **23850 gallons per day**
Well yield required to support the low scenario: **26750 gallons per day**
Well yield required to support the mid scenario: **95400 gallons per day**
Well yield required to support the high scenario: **190800 gallons per day**

Recharge rates(mm/year) over the past twenty years have been decreasing. If this rate of decrease continues into the future, aquifer recharge will not be able to keep up with water demand. Further, we are currently working on simulating sea level rise in Arrowsic at three different levels - no change, 3ft, and 6ft using MODFLOW, a groundwater modeling software. This simulation will help us assess the impact of sea level rise on the depth of the freshwater-seawater interface, therefore affecting the quality of the water in the aquifers by placing briny water in the pump inlets.

We also found multiple data gaps throughout the course of this project, which include:

- Incomplete count and characterization of wells
- The precise number of people per residential lot is unknown
- Changes in annual well yield unknown
- Annual measurement of well salinity not available

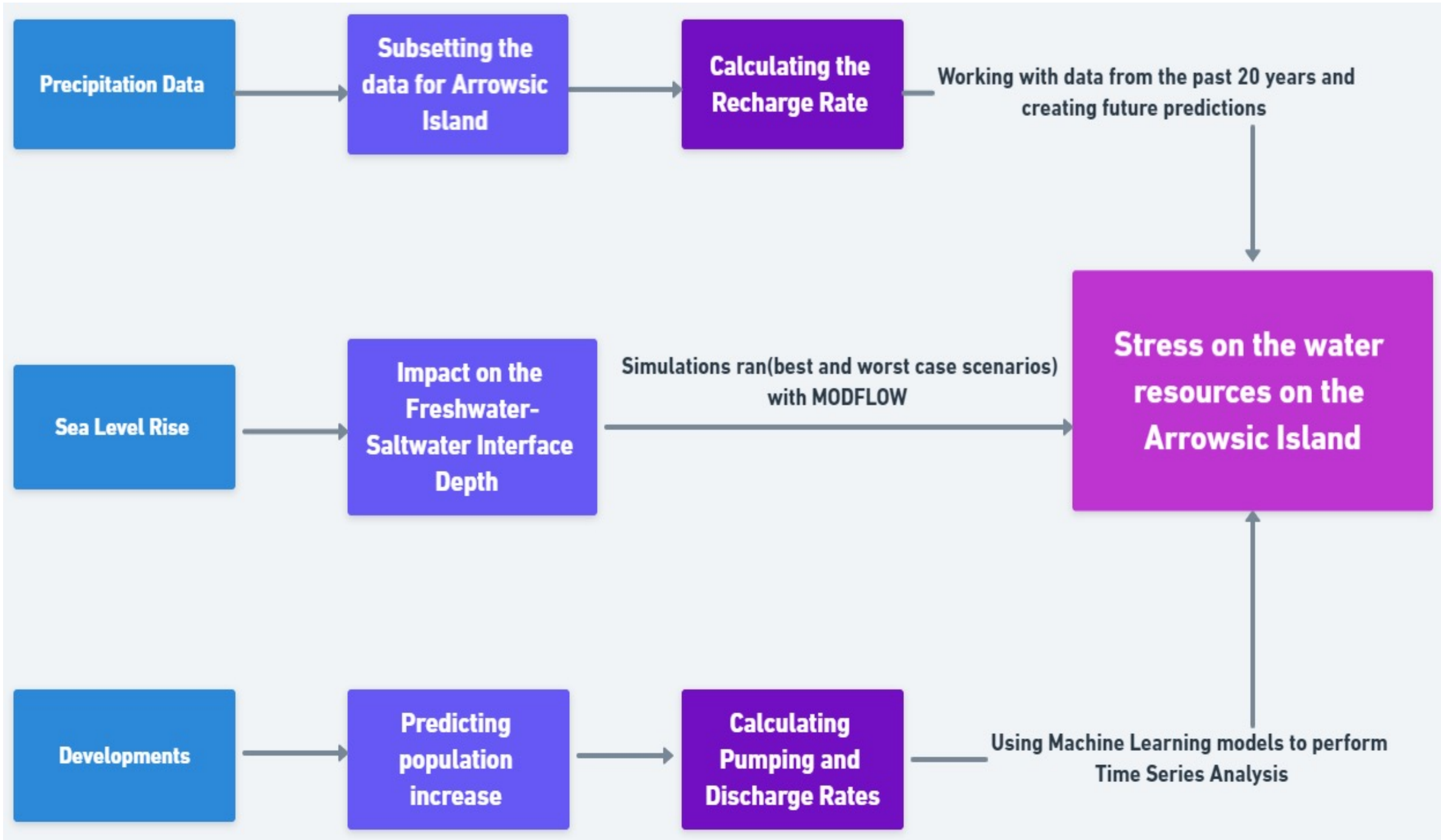
References

- [1] S. Lee, J. Peng, A. Williams, D. Shin, ASCENDS: Advanced data science toolkit for non-data scientists, Journal of Open Source Software, 5 (2020) 1656. https://doi.org/10.21105/joss.01656.
  [2] J. Peng, S. Lee, A. Williams, J.A. Haynes, D. Shin, Advanced data science toolkit for non-data scientists – A user guide, CALPHAD, 68 (2020) 101733. https://doi.org/10.1016/j.calphad.2019.101733.
- Shih-Chieh Kao, Moetasim Ashfaq, Deeksha Rastogi, and Sudershan Gangrade.2022. CMIP6-based Multi-model Hydroclimate Projection over the Conterminous US. HydroSource. Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA. DOI: https://doi.org/10.21951/SWA9505V3/1887469
- Meseret B. Addisie; Groundwater recharge estimation using water table fluctuation and empirical methods. *H2Open Journal* 1 September 2022; 5 (3): 457–468. doi: https://doi.org/10.2166/h2oj.2022.026

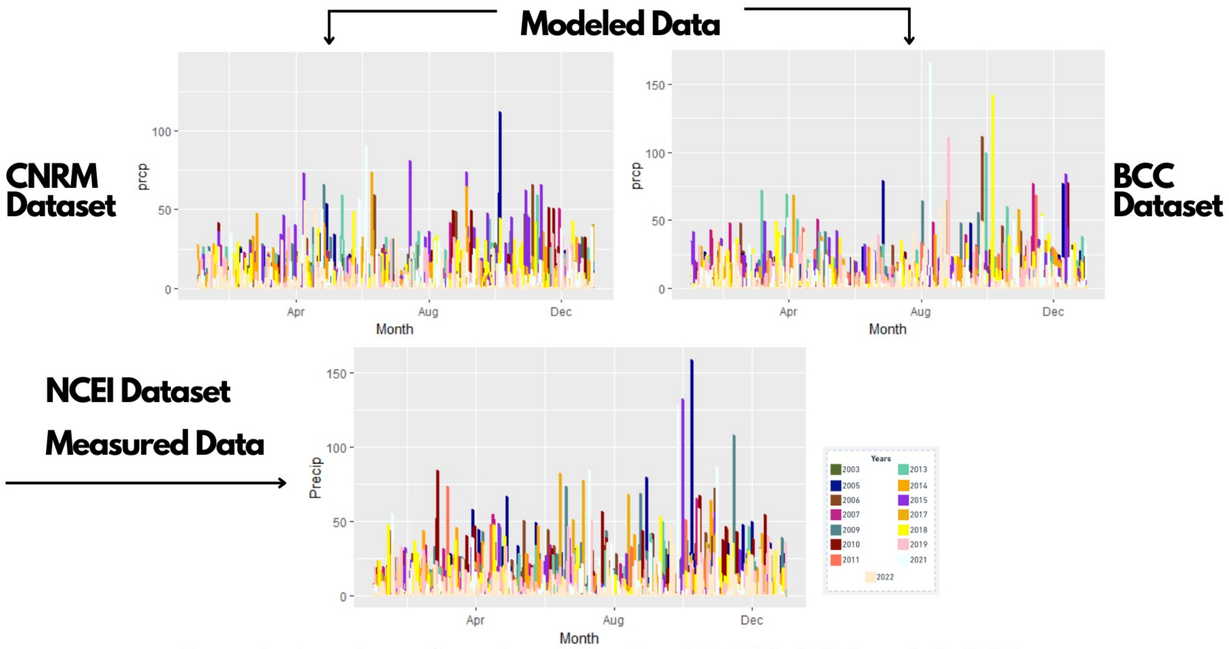
Acknowledgments

- *This research used resources of the Oak Ridge Leadership Computing Facility, which is a DOE Office of Science User Facility supported under Contract DE-AC05-00OR22725.*
- *This research used resources of the Compute and Data Environment for Science (CADES) at the Oak Ridge National Laboratory, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC05-00OR22725*
- *Arrowsic Climate Resilience Committee, Groundwater Work Group*

Methodology



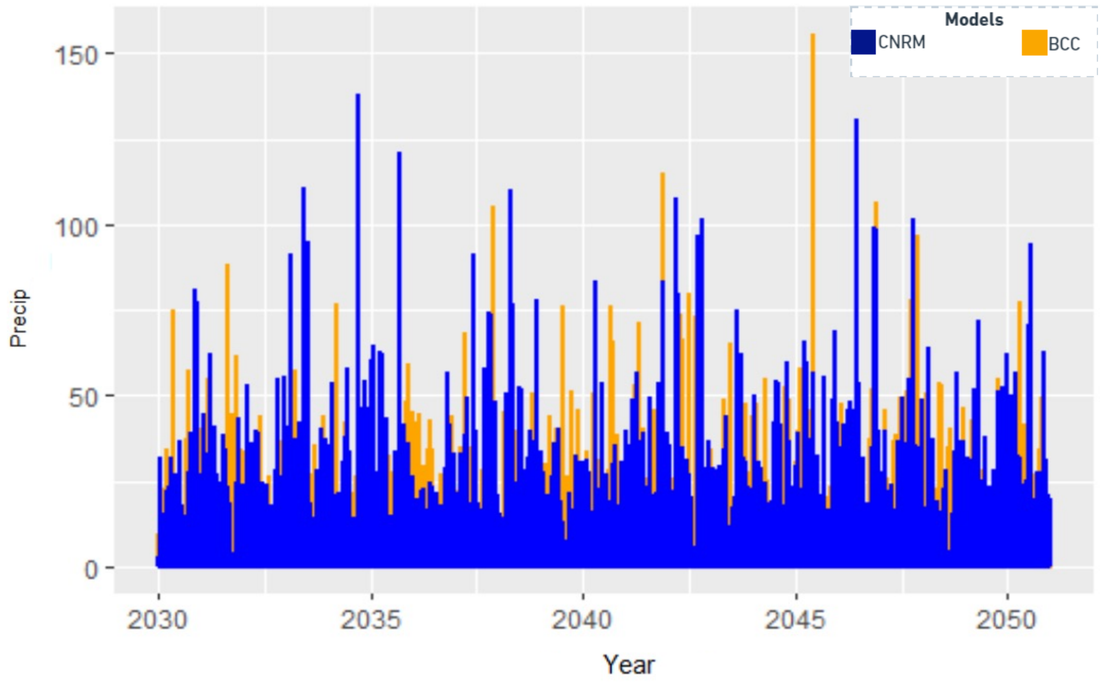
Results and Discussion – Precipitation



Precipitation for Arrowsic, ME (2003 - 2022)

- Modeled Data(historical and projections): **9505 Dataset**
- Measured Data: **NCEI Data**

- Regular and light rain helps replenish and fill up wells
- Our plots indicate that instead of regular and light rain, precipitation is going to be in the form of sudden large extreme events leading to freshwater runoff.



Precipitation for Arrowsic, ME (2030 - 2050)

OAK RIDGE National Laboratory

Results and Discussion – Precipitation

Aquifer Recharge Rate in Arrowsic, ME

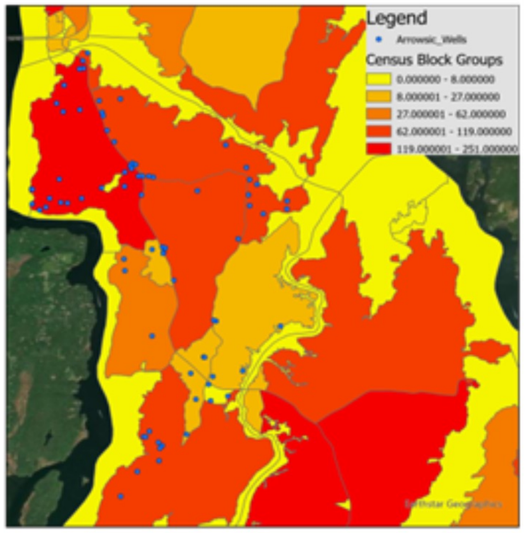
$$Re = 0.25*(P-400)$$

Re = Recharge; P= Precipitation

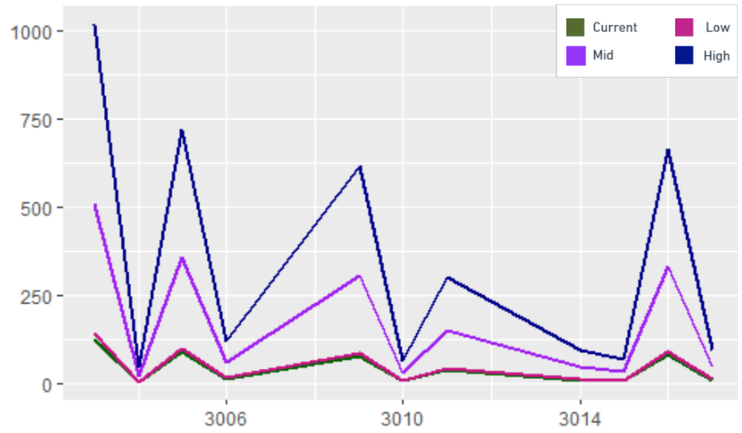
Recharge Rate in the last twenty years shows downward trend, indicating the recharge rate may continue to decline in the future

Results and Discussion – Increase in Population

Census Block Group Population Data Mapped in ArcGIS Pro



Projected Population (2030)



Here the X-axis depicts different Census Block Groups in Arrowsic while the Y-axis depicts the growing population

These plots are based on the incoming Affordable Housing Units and the 12% increase in population(per decade) based on the data Karin sent in.

The current well yield seems sufficient even for the highest population scenario, however we are unsure if all the water being pumped out of the wells would be potable and useful.

Current Population	Low Scenario	Mid Scenario	High Scenario	Total Wells	People per well (Current)	People per well (Low)	People per well (Mid)	People per well (High)
477	535	1908	3816	183	2	3	10	20

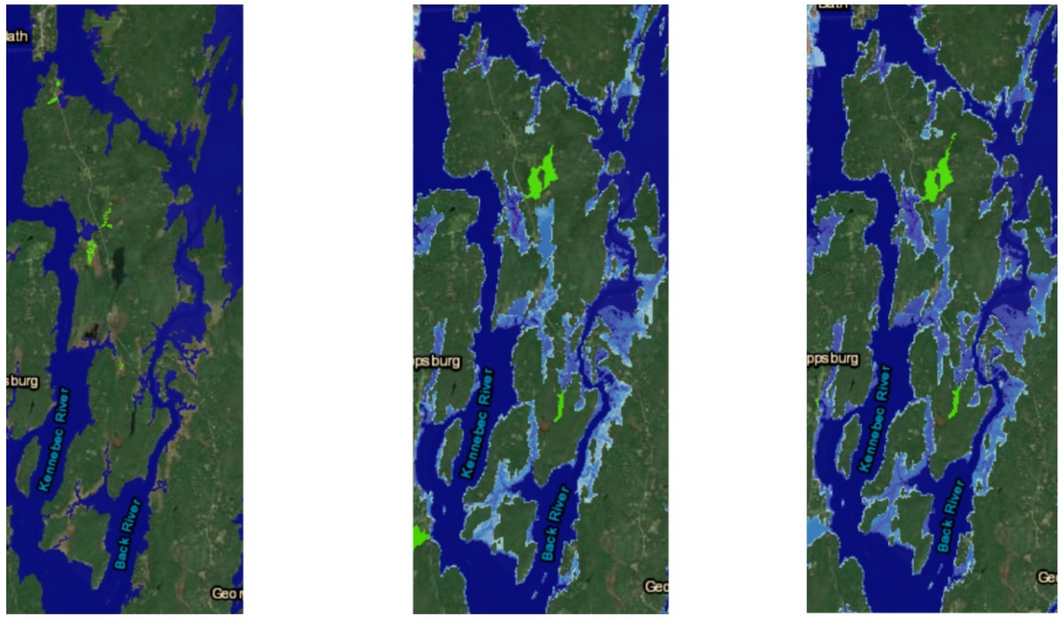
Current well yield for all the houses in Arrowsic: **1,379,908.8 gallons per day**
Water required by the current population(100 gpd for two people): **23850 gallons per day**
Well yield required to support the low scenario: **26750 gallons per day**
Well yield required to support the mid scenario: **95400 gallons per day**
Well yield required to support the high scenario: **190800 gallons per day**

OAK RIDGE National Laboratory

Future Work and Data Gaps

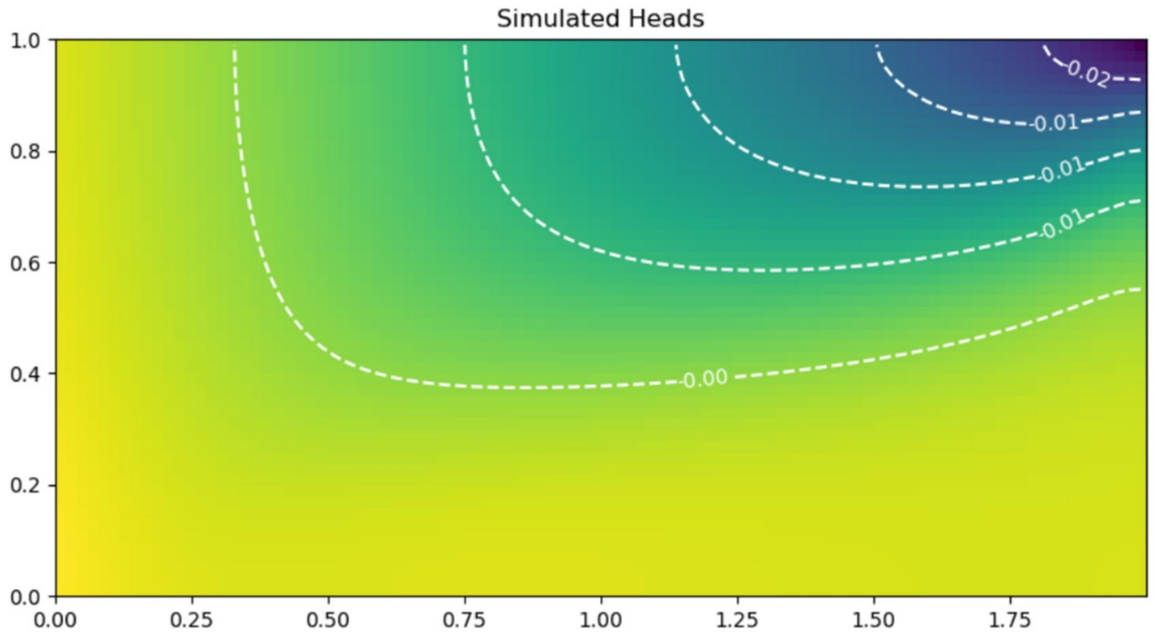
- Currently working towards simulating 6ft, 3ft and 0ft sea level rise in Arrowsic, ME using MODFLOW, a USGS developed water modelling software to study its impact on the increasing salinity in the aquifers.
- We also found multiple data gaps throughout the course of this project, which include:
  - Incomplete count and characterization of wells
  - The precise number of people per residential lot is unknown
  - Changes in annual well yield unknown
  - Annual measurement of well salinity not available

Sea Level Rise



No change **3ft** **6ft**

Test run using MODFLOW and FloPY



OAK RIDGE National Laboratory

Acknowledgements and References

- This research used resources of the Oak Ridge Leadership Computing Facility, which is a DOE Office of Science User Facility supported under Contract DE-AC05-00OR22725.
- This research used resources of the Compute and Data Environment for Science (CADES) at the Oak Ridge National Laboratory, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.
- We also thank the Arrowsic Climate Resilience Committee, Groundwater Work Group.

- [1] S. Lee, J. Peng, A. Williams, D. Shin, ASCENDS: Advanced data science toolkit for non-data scientists, Journal of Open Source Software, 5 (2020) 1656. https://doi.org/10.21105/joss.01656.
- [2] J. Peng, S. Lee, A. Williams, J.A. Haynes, D. Shin, Advanced data science toolkit for non-data scientists – A user guide, CALPHAD, 68 (2020) 101733. https://doi.org/10.1016/j.calphad.2019.101733.
- Shih-Chieh Kao, Moetasim Ashfaq, Deeksha Rastogi, and Sudershan Gangrade.2022. CMIP6-based Multi-model Hydroclimate Projection over the Conterminous US. HydroSource. Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA. DOI: https://doi.org/10.21951/SWA9505V3/1887469
- Meseret B. Addisie; Groundwater recharge estimation using water table fluctuation and empirical methods. *H2Open Journal* 1 September 2022; 5 (3): 457–468. doi: https://doi.org/10.2166/h2oj.2022.026