4-2023

The Role of Aquifer Storage and Recovery (ASR) in Water Resource Management

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SUST 495

Spring 2023

Introduction

Water is vital for life, but businesses, agriculture, industry, and households also depend on a reliable supply of water every day. With growing issues of climate-driven water scarcity, it is becoming increasingly important to find ways to preserve water resources. It was once thought that water was an everlasting resource, but having fresh, clean, drinkable water is not a reality for at least 33 percent of the global population (WHO, 2019). Drivers of this scarcity are climate change and extreme demand for this resource in concentrated areas. Extreme weather events are making water more scarce, unpredictable, and polluted (UN, 2022). Floods and sea level rise are contaminating freshwater on land as these extreme weather events continue to increase. Glaciers, ice caps, and snow fields are melting at a rapid rate. The melted glacier and ice cap water are important to feeding large river systems, but as they begin to disappear, we will see a lower supply of freshwater. Even as global population growth begins to slow, the demand for water continues to increase. Global water use is expected to increase up to 50 percent above current levels by 2050 (DNI, 2021). All of this water use requires "energy-intensive water pumping, transportation, and treatment" (UN, 2022). This high energy use will only exacerbate the issue of climate change, indirectly making water resources even more scarce. With our global water resources declining and the demand for water skyrocketing, sustainable water management techniques are needed in order to ensure the longevity of freshwater resources for generations to come. This report will analyze the use of the sustainable water management technique, Aquifer Storage and Recovery (ASR), in Georgetown County, South Carolina as well as three other locations that use ASR to improve their own water supply. In using this water management technique, the communities discussed in this report contribute to Sustainable Development Goal 6: Clean Water and Sanitation.

Aquifer Storage and Recovery

Aquifer Storage and Recovery (ASR) is a water management technique that can contribute to alleviating the stressors of water scarcity as well as bring other benefits like preventing saltwater intrusion and land subsidence. The process of ASR involves the storage of "water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed" (Pyne, 1995, 6). The concept of storing water underground for later use is not a new idea. Modern ASR facilities have been used throughout the United States since the 1960s, when the first ASR facility was constructed in Wildwood, New Jersey. As of 2015, over 200 sites in 27 different states currently have operational ASRs or have plans to implement an ASR facility (AWWA, 2015). Projects are increasing in numbers, especially in areas that experience water shortages (EPA, 2022). This is due to the many benefits that ASRs can provide in terms of water resource conservation, economic benefit, and more that will be discussed in a later section.

Figure 1 shows a basic diagram of how the process of Aquifer Storage and Recovery works. In most cases, treated surface water is sent from the treatment plant to the ASR well to be injected. This is shown on the left side of the diagram. The treated surface water is injected down into the aquifer through the recharge pipe where a "bubble" is created as it displaces the water that is already in the aquifer. Surrounding this bubble is a buffer zone where there is some mixing between the naturally occurring aquifer water and treated surface water. When water is in higher demand, the water from that bubble and buffer zone is pumped back out of the aquifer through the withdrawal pipe. The withdrawal process is represented on the right side of the diagram. Not shown in the diagram are the air release valves at the top of each of the recharge and withdrawal pipes. When the ASR is undergoing withdrawal, more air is above the water column. When the recharge process begins again, there is less room for that air, so it needs an outlet to escape the well. Georgetown County Water and Sewer District (GCWSD) uses ASR systems to improve and supplement their water supply. This system is represented in Figure 1.

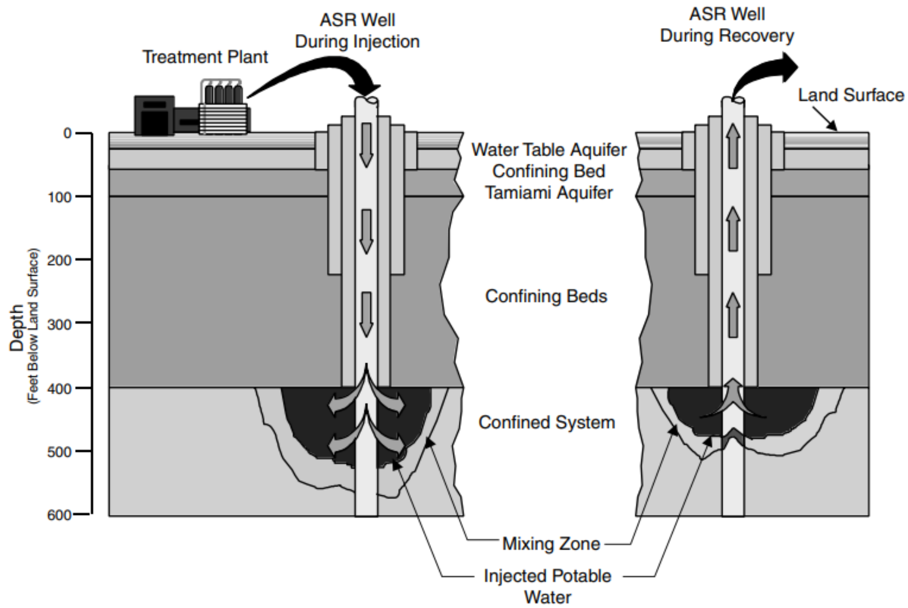

Figure 1: Aquifer storage and recovery conceptual diagram for brackish water aquifers where freshwater bubble creates mixing transition zone that increases with time (from AWWA M21 Groundwater Manual 2014)

2.1 ASR systems in Georgetown County, SC

Georgetown County Water and Sewer District (GCWSD) has a total of five ASR wells, four of which are presently online and operational. Another well in Georgetown County will be converted to ASR next year (2024). These six locations are shown in the GIS map below in Figure 2. According to Water Department Supervisor, Paul Muzycyzn, the primary reason for the implementation of these ASRs was to combat an issue with composition of the existing groundwater. The groundwater has high levels of fluoride. “Weathering and leaching of fluoride-bearing minerals from rocks and sediments” is the main cause of high fluoride levels in groundwater (Jha 2013, 52). Many factors including temperature, pH, and solubility of fluoride-bearing minerals, anion-exchange capacity of aquifer materials, the nature of geological formations drained by water, and the contact time of water with the source minerals influence the time and capacity at which fluoride is released into the water (Jha 2013, 53). The legal limit for fluoride levels in drinking water is 4 mg/L, which is a level specified by the U.S Environmental Protection Agency. To minimize the potential for fluorosis, or staining of the teeth, the secondary maximum contaminant level goal has been set to 2mg/L (SC DHEC n.d., 1). To summarize, the EPA recommends that there be no more than 2 mg/L of fluoride, but it is illegal to exceed 4mg/L. Although high levels of fluoride produce adverse effects to humans, it is important that the fluoride levels are not too low either.

Figure 2: GIS map showing the extent of the Waccamaw Neck region in Georgetown County. Within this region there are five ASR wells (shown in blue) and one planned ASR well (shown in yellow).

At the water plant, one of the additives for raw water (untreated water taken from the river) is fluoride. Although it is not mandated in some states, is beneficial for human health to have some levels of fluoride in the water. Water with no fluoride poses risks "including dental caries, lack of formation of dental enamel, and deficiency of mineralization of bones, especially in children" (Jha 2013, 52). To avoid deficiencies, the lower limit for levels of this element is 0.7 mg/L. According to South Carolina's Department of Health, "the most benefit to oral health is achieved when waters are fluoridated to 0.8 mg/L” (SC DHEC n.d., 1). The naturally occurring groundwater in Georgetown County’s aquifer does not fall within the specified range of fluoride levels. With the implementation of ASRs, GCWSD is able to dilute the groundwater with surface water. Water sourced from the river that has undergone the treatment process is injected into the four operational ASR wells as needed. This injected water mixes with the high fluoride water and dilutes it. In doing so, GCWSD is able to meet drinking water standards. Figure 3 below shows the legal limits and recommended limits of fluoride drinking water.

Legal Limit	EPA Recommendation of Max Limit	Ideal	Lower Limit
4 mg/L	**2 mg/L**	**0.8 mg/L**	**0.7 mg/L**

Figure 3: Chart showing the legal limit of fluoride and the recommended limits of fluoride in drinking water.

Along with using the ASRs to dilute the groundwater, GCWSD also benefits from the use of ASRs to provide the county with a supplemental water supply. Georgetown is a coastal county that includes high grossing tourist locations within its boundaries like Murrells Inlet, Litchfield, and Pawleys Island. In the year 2021 alone, the county received $2.5 million in state accommodation tax, a tax which “people pay when they check into a vacation rental or hotel”, but in the last ten years the county has only gained 3,500 new residents (Russo 2021). These numbers indicate that there is a significantly higher number of people in Georgetown County throughout the course of the year (specifically in the summer) than the amount of people who actually live there. Because of the influx of tourists in the summer months, the water plant needs to be prepared to keep up with demand. This is where the benefit of having ASRs comes in. Throughout the non-tourist months, GCWSD injects surplus treated water from the plant into the below-ground aquifer through the ASR wells. This creates a large supply of drinking water that is able to be recovered when needed. When demand is higher in the summer, GCWSD is able to take this drinkable water from the well and send it through the distribution pipes to be used by the surrounding area.

1. Global Uses of ASRs

The primary reasons for implementing the use of ASR for water management according to the American Water Works Association is to “store water until such time as it is needed to meet peak needs, long-term growth demands, or emergency conditions, or because of poor water quality” (AWWA, 2015). It has also been found, though, that ASR can be used to tackle environmental issues like land subsidence and sea level rise, as well. Different geographical areas face different issues in terms of climate and water availability, so naturally, water management districts around the world use ASRs for varying reasons. In the following sections, three different cases where a municipality has implemented the use of Aquifer Storage and Recovery will be discussed. Hilton Head, SC, Hampton Roads, VA, and Central Spain have each used ASRs to address a specific environmental or water supply issue they are facing.

3.1 Hilton Head, SC- Preventing Saltwater Intrusion

Not two-hundred miles away from Georgetown County is the town of Hilton Head, SC. Although both areas have similar geographic location, Hilton Head uses their ASR well for different reasons than Georgetown. The primary benefit Hilton Head gets from their ASR operation is to prevent saltwater intrusion.

Residential development in this area began in 1956 and Hilton Head now has a permanent population of 37,000. However, due to its beaches, golf courses, and amenities, Hilton Head is a popular tourist location, so depending on the season, the population can reach 275,000 (Pyne, 2015). The north end of Hilton Head's water is supplied by Hilton Head Public Service District (HHPSD), the south end of the island is serviced by South Island Public Service District (SIPSD), and "a small area in the middle is served by the Broad Creek Public Service District (BCPSD)" (Pyne, 2015). These water districts source their raw water from the Upper Floridian Aquifer (UFA), but Savannah, Georgia, which is only about 30 miles away, has caused a significant decline in groundwater levels due to their high pumping rates of the UFA's water for municipal and industrial use. Consequently, the hydraulic gradient under Hilton Head is reversing, causing saltwater to "intrude at the north end of the island, and also through other springs closer to Broad Creek in the middle of the island" (Pyne 2015). When saltwater intrudes into the regular wells, the water districts are forced to turn them off. About a quarter of the wells that supply the Hilton Head area have already been lost and saltwater intrusion is accelerating at approximately 200 ft/year.

Among other measures implemented to improve the reliability of the water supply, HHPSD initiated a project in 2010 to construct an ASR well in Hilton Head Plantation. Underneath this ASR is the Middle Floridian Aquifer (MFA). Monitor wells and a transmission pipeline were also constructed. During times of low demand, specifically in the winter months, HHSPD outsources its water from a neighboring water district "at a reduced wholesale water rate". This treated Savannah River surface water is sent from the treatment plant to the transmission pipeline (HHPSD, 2019). The pipeline injects up to 7.6Ml/D of drinking water into the MFA below the well on Hilton Head Plantation. (Pyne, 2015). This creates a bubble of fresh drinking water underground because the freshwater displaces the brackish aquifer water. In the summer months, when Hilton Head's population and water demand is higher (and the wholesale water rate is much higher), HHPSD can withdraw and re-treat 2 MGD (million gallons per day) of drinking water (HHSPD, 2019). The implementation of ASR for Hilton Head, South Carolina has minimized the threat of saltwater intrusion into the MFA and provided their citizens with fresh drinking water all while saving money on outsourcing their water.

3.2 Hampton Roads, VA- Land Subsidence

Hampton Roads is a coastal region in Southeast Virginia on Chesapeake Bay. This area has implemented the use of Aquifer Storage to combat their issues of land subsidence. Land subsidence is the sinking of the land's surface that is often caused by human activities (Spellman 2017, 160). In Hampton Roads' case, land subsidence above the Potomac Aquifer is caused by the unsustainable pumping of its groundwater which has led to a decrease in pressure underneath the land's surface. Land subsidence contributes to more rapid rates of sea-level rise, which also contributes to higher risk of flooding and shoreline retreat (Spellman 2017, 161). The residents of Hampton Roads alone send 150 million gallons of wastewater to the treatment centers every day (HRSD n.d.). In the last century, groundwater withdrawal in the Potomac Aquifer has lowered the land above it by 6 inches and the Chesapeake Bay area has seen one foot of sea level rise in the same time period (Spellman 2017, 160). To combat this growing issue, Hampton Roads Sanitation District (HRSD) has launched its Sustainable Water Initiative for Tomorrow (SWIFT). With the SWIFT project, HRSD plans to inject highly treated wastewater from seven of their plants back into the Potomac Aquifer. This SWIFT water has been treated to match the chemistry of the water naturally occurring in the aquifer. When SWIFT is fully implemented, over 100 million gallons will be injected back into the Potomac Aquifer each day. In turn, the water table of the aquifer will rise and the pressure below ground will increase. Increased pressure along the coast is also expected to prevent saltwater intrusion into the aquifer (HRSD n.d.). The SWIFT project has the potential to stabilize and restore the water resources of the Potomac Aquifer, "provide years of added use of highly valuable developed land impacted by sea-level rise" and protect the wetland environments around it (HRSD n.d.).

3.3 Mediterranean- Water Scarcity

Groundwater is widely used for irrigation. Forty-three percent of irrigation water comes from groundwater. Where water resources are not carefully managed, it is easy for aquifers to become depleted and bring about issues of water scarcity and drought. One place where this has occurred is central Spain, where the Los Arenales aquifer is located. Agriculture is the main economic sector in Spain, so a significant proportion of their water resources goes to watering crops. In the second half of the twentieth century, the Los Arenales aquifer was overexploited and unregulated. Two subdivisions of the aquifer were used in a case study in 2022 to assess how water scarcity is alleviated by aquifer recharge systems. Los Arenales (LA) and Medina del Campo (MC) are these two subdivisions. It was found that the unsustainable pumping of the aquifer led to a 1.14 m/year decrease in the groundwater levels in the LA subdivision and a 0.8 m/year decrease in MC (Casas 2022, p.1). Climate change is also contributing to the less reliable supply of water. Five out of the seven of the most significant drought periods have occurred in the last twenty-three years. Less water availability during this time period has caused "substantial crop damage (e.g., 70% loss of cereal crops in 2016-2018), urban water supply rationing" and water quality issues (Casas 2022, p.3). It is expected that climate change will lead to more frequent drought periods and models show that "by the end of the century, there will be a decrease in monthly, seasonal, and average" discharge from the Douro River, the main river basin in the study site (Casas 2022, p.3). The growing issue of water scarcity prompted farmers in the region to petition for the implementation of a managed aquifer recharge system (MAR). While this case uses a different name, MAR is essentially the same as ASR. Just like aquifer storage and recovery, managed aquifer recharge is described as a process that involves "the intentional recharge of aquifers for later use or environmental purposes" (Casas 2022, p.2). Because of this initiative to implement these systems in Spain, MAR sites were officially established near the LA subdivision in 2002. As a result, groundwater levels in the aquifer have recovered there. They continue to decrease in MC where there are no MAR facilities. Trend analysis and groundwater drought analysis were conducted which confirmed that the LA subdivision which has the MAR systems, is "subject to less frequent hydrological droughts" than the MC subdivision which does not (Casas 2022, p.7). Figure 4 below shows the groundwater level differences in these two areas. This graph provides statistical evidence that the MAR systems have significantly improved the groundwater levels and water supply in the sites that it was implemented.

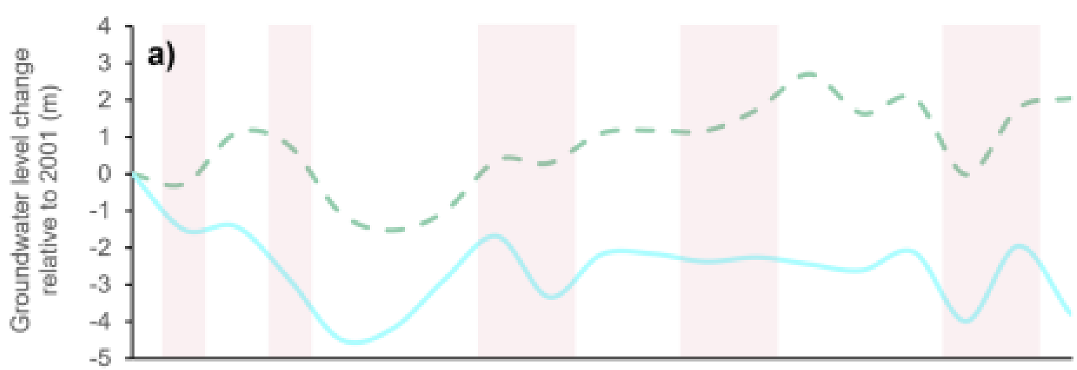

Figure 4: Average groundwater levels, measured in meters, in Los Arenales (LA) and Medina del Campo (MC). This data was collected from groundwater monitoring sites. The green

dashed line represents groundwater levels in LA and the solid blue line represents levels in MC. (Casas 2022, 7)

2. Sustainable Development Goal 6: Clean Water and Sanitation

Sustainable Development Goal (SDG) 6 aims to “ensure the availability and sustainable management of water and sanitation for all by 2030” (UN 2021, p.4). The world is not currently on track to meet this goal. Billions of people are still living without access to safely managed drinking water. The graph in Figure 5 represents where the globe is now in achieving this goal, the projection of where we will be at by 2030, and much progress needs to increase to achieve the goal. According to this data, “universal access to basic and safely managed drinking water by 2030 will require a doubling of current rates” and “a quadrupling of current rates” respectively (UN 2021, p.15).

Figure 5: This graph, sourced from the United Nations Summary Progress Update for 2021 shows global progress on SDG 6. The goal aims to ensure that 100% of the global population has access to safe water. The dotted lines represent projected progress if we continue at this rate and the shaded areas represent how much more we need to improve to achieve the goal.

With the pressures of climate change, as a global community we need to find measures to become more resilient to the consequences. In relation to water management, the consequences of climate change that will make it much more difficult to achieve SDG 6 include the aforementioned- increased drought, water scarcity, and saltwater intrusion. Aquifer Storage and Recovery is one such measure that can assist in resilience at a local level. Hilton, Head, Hampton Roads, and Central Spain are examples of ASRs effectiveness in improving resilience. Georgetown County uses their ASRs to improve the quality of groundwater for safe drinking which contributes to SDG 6 at a local level. In is not unlikely, though, that Georgetown's ASRs may come in handy in the future for improving their own resilience to climate related issues like drought, water scarcity, and saltwater intrusion.

4.1 Drought

Droughts are a threat to human health, food security, ecosystems, and the economy. In the last century, more than 10 million deaths have occurred due to major drought events, causing hundreds of billions of US dollars in economic losses globally (UN, 2022). There are multiple variables when evaluating drought severity. These variables include precipitation, "atmospheric evaporative demand (AED), evapotranspiration (ET), soil moisture, streamflow, and vegetative conditions" (Vicente-Serrano, 2022). Using "long-term precipitation records and different drought metrics…over the past four decades", a scientific literature review from 2022 concluded that "more severe ecological and agricultural droughts are expected" in most regions of the world

(Vicente-Serrano, 2022). This is because AED is expected to increase globally due to higher temperatures and decrease in humidity. Sometimes described as atmospheric thirst, AED results in more loss of water on the Earth's surface into the atmosphere, making it unavailable for human consumption (Albano et.al., 2022). A visual of how drought is projected to worsen by 2069 using the Palmer Drought Severity Index is shown in Figure 6.

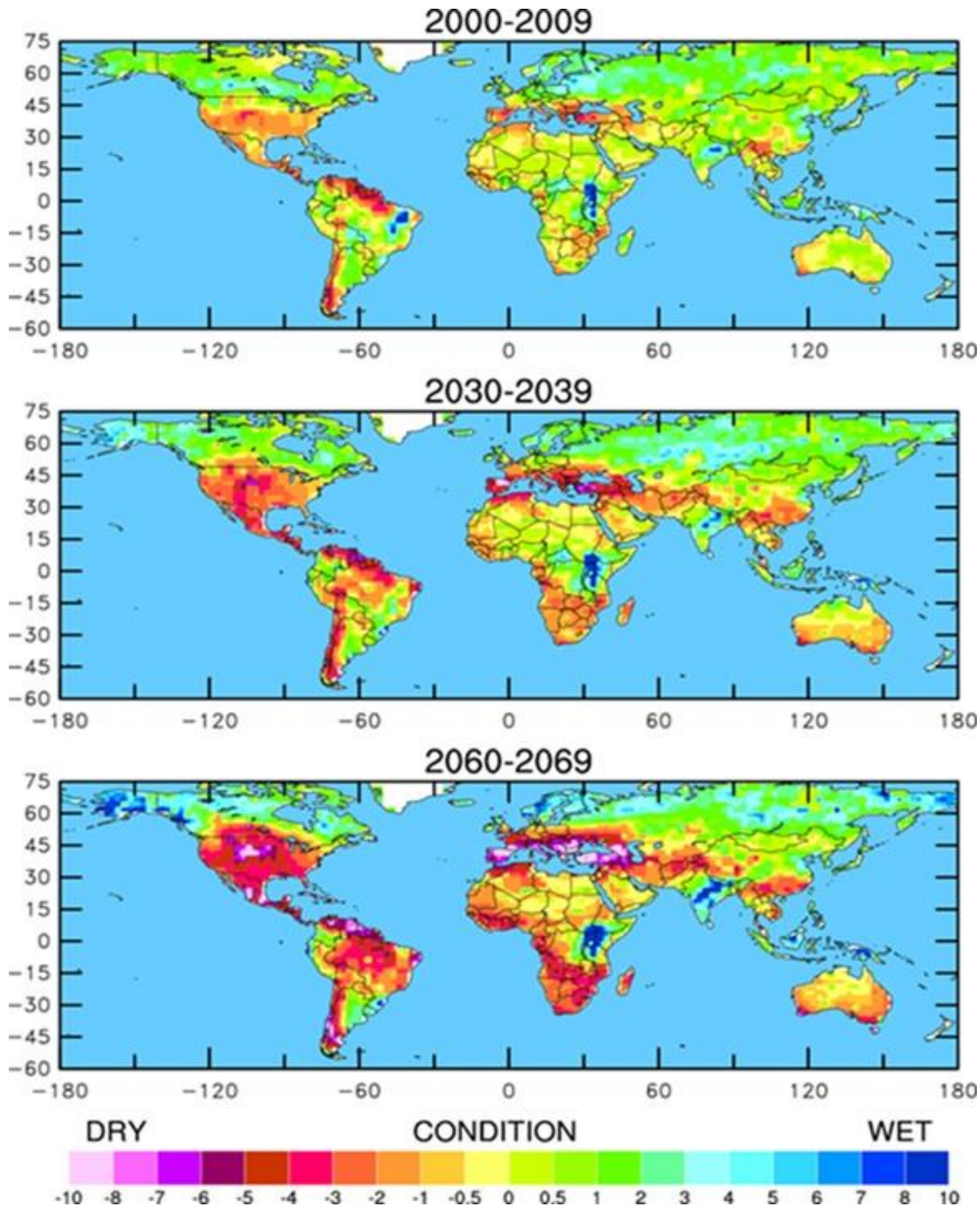

Figure 6: Palmer Drought Severity Index map for three 10-year time periods. From the National Science Foundation. https://www.nsf.gov/news/news_summ.jsp?cntn_id=117866

4.2 Water Scarcity

Global water demand is projected to increase by 50% before 2050 and climate models predict that droughts will become more frequent. This is recipe for water scarcity. Water scarcity is defined by the UN as a condition where water "demand increases and/or as water supply is affected by decreasing quantity or quality" (UN, n.d.). According to UNICEF, "almost two thirds of the world's population experience severe water scarcity for at least one month each year" and at this rate, as early as 2025, half of the world's population could be facing water scarcity (UNICEF, 2020).

4.3 Sea Level Rise

Sea level rise is another threat to clean water and sanitation. The National Oceanic and Atmospheric Administration (NOAA), NASA, and the US Geological Survey predict that sea level could rise as much as fourteen inches on the East Coast of United States before 2050 (NASA, 2022). In the next thirty years, the sea level will rise as much as it has in the last century. Localized to the county of Georgetown, Figure 7 shows what the county would look like with one foot of sea level rise.

> ***Saltwater movement is usually slow but relentless, and the ultimate outcome is predictable (Pyne 2015)***

Five major rivers, the Waccamaw, Little Pee Dee, Great Pee Dee, Black, and Sampit Rivers are all located in Georgetown County, making the county particularly susceptible to sea level rise. As sea levels rise, saltwater will continue to move onto the land and infiltrate the freshwater rivers and aquifers. This process, known as saltwater intrusion, can occur when storm surges and high tides happen in areas of low elevation. River avulsions, the process of rivers changing their course to the sea, forming new paths, are also predicted to occur more frequently with sea level rise (NSF, 2020). Figure 7 is an example of how major flooding events; these can be catastrophic natural hazards to the communities and ecosystems surrounding the rivers.

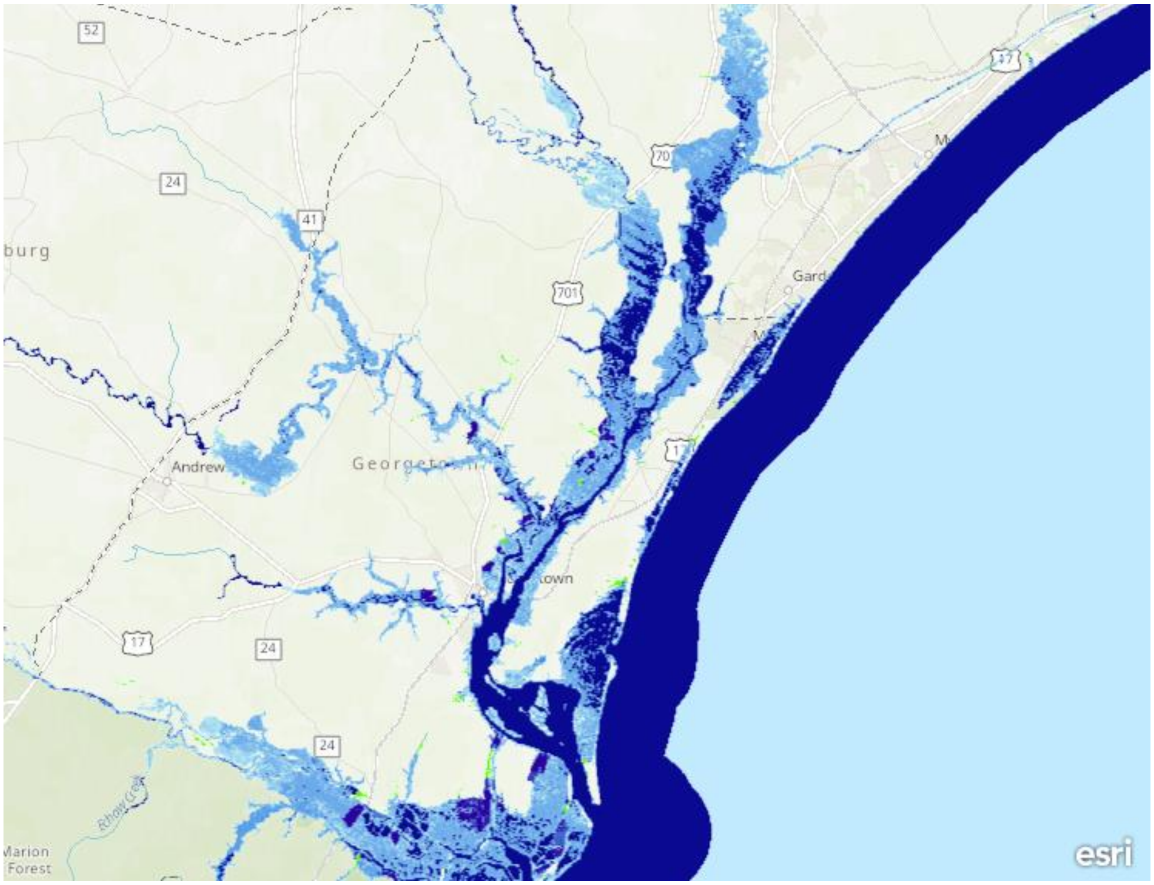

Figure 7: ArcGIS map of Georgetown County that utilizes NOAA's Sea Level Rise Inundation Living Atlas Layer. The dark and light blue shading over the base map represents how much water is predicted to cover the land with only 1 foot of sea-level rise.

4.4 ASRs and SDG 6

While ASRs cannot solve the climate crisis, the implementation of Aquifer Storage and Recovery in vulnerable communities can help to build community resilience and alleviate the impacts of drought, water scarcity, and sea level rise. Aquifer Storage and Recovery does not provide a new water source in times of water scarcity but is a water storage technology that will help to manage existing water resources to increase preparedness. Just like GCWSD stores water in the aquifer during the winter to prepare for high demand in the summer, ASR can be used to store water underground in times of plentiful water in preparation for times of scarcity. With the threat of sea level rise being so high on the coast of Georgetown County, they may also utilize their ASR facilities to slow or prevent saltwater intrusion into the aquifers that exist there. ASR in Georgetown County already serve many purposes in improving their water management, like diluting fluoride in the groundwater and providing supplemental seasonal water supply, but because of these already existing facilities, Georgetown is more resilient to future issues of drought, water scarcity, and saltwater intrusion. At a local level, the four (soon to be five) Aquifer Storage and Recovery wells here are assisting in achieving Goal 6: Clean Water and Sanitation.

Recommendations

It is the responsibility of local governments and municipalities to identify their vulnerability to these threats to their water supply. Areas that are highly susceptible to these threats may benefit from implementing Aquifer Storage and Recovery systems within their water treatment facilities.

Conclusion

Aquifer Storage and Recovery is a viable water management technique for areas that are experiencing water scarcity, saltwater intrusion, and/or land subsidence. Due to climate change, drought, water scarcity, and saltwater intrusion are becoming increasingly important issues that need to be addressed with sustainable solutions. Implementing ASR can add a supplemental water supply and alleviate some of these stressors. This method has proved, through scientific studies done in many regions of the world, including in Georgetown County, SC, that ASR can do so, as well as protect the resources of the aquifer and preserve the land above it in order to ensure the availability of this resource for future use.

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