# **Samoa SLR paper**

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Abstract:

* SLR is bad,
* Here we use GW modeling combined with SLR scenarios from to produce vulnerability maps of locations where present and future Seal leave may pose problems for hurried or surface infrastructure.

Like many tropical islands across the globe, the U.S. Territory of American Samoa (AS) is disproportionately vulnerable to Sea Level Rise (SLR) due to a high proportion of coastal development and limited land area (Nunn and Mimura, 1997). In the Western Pacific Ocean, regional sea levels have been rising at a rate of 3.2 mm/yr since the 1990s (Hamlington, 2014). However, Tutuila, the cultural and political center of AS currently experiences a particularly high rate of SLR due to the compounding effects of chronic geologic subsidence, viscoelastic relaxation following a disastrous 2009 earthquake, and global SLR, resulting in an effective sea level rise that is five times higher than the global average (Han et al., 2019). While the most noticeable effects of SLR typically manifest through surface flooding during acute compounding events such as king tide or heavy wave events (Keener et al., 2021), a more insidious and chronic impact of SLR lies below and sometimes breaches the ground surface. Groundwater Inundation (GWI) has been identified around the world as an often overlooked consequence of SLR (Rotzoll and Fletcher, 2013; Kane et al., Habel et al., 2017; Masterson et al., 2017; Maliva, 2021). This phenomenon can not only cause inland flooding in areas disconnected from the sea, but can also raise the groundwater table, inundating buried infrastructure and changing the salinity and redox chemistry of the subsurface. Although there are few published case studies of GWI effects, consequences, and projections, those that exist suggest it is likely to cause significant disruption to our coastal communities in the future. For example, in the area of Waikiki on the Hawaiian Island of Oahu Habel et al. (2017) determined that GWI is likely to put over $5 billion worth of real estate at risk of flooding with a SLR of 1 m. Knott et al., (2007) determined that GWI reduced the service life of coastal roadway pavement in New Hampshire by 50% to 92%, and White et al., (2007) found that GWI is the primary risk for the sustainability of drinking water supplies on small atols such as Tarawa, Kiribati.

The water table in island aquifers typically manifests as a basal lens, with the top surface, or groundwater table, lying above mean sea level, and rising inland along a gradient towards higher terrain and typically higher recharge areas (Izuka et al., 2018). In high-recharge, volcanic-island aquifers the position and thickness of the freshwater lens is typically maintained in short-term equilibrium and primarily controlled by seaward flux. The magnitude of this flux, and thus the elevation of the lens, is ultimately driven by the interplay between the heterogeneous fabrics of formation permeability and groundwater recharge (Maliva, 2021). Thus, as sea level rises in a flux controled system, the entire basal lens will rise an equivalent amount controlled by hydrostatic buoyancy (Werner and Simmons, 2009; Bjerklie et al., 2012). In inland areas where the water table is already close to the ground surface this can manifest as flooding of basements and buried infrastructure, and in some cases, breakthrough surface flooding where groundwater seeps out and pools in low-lying areas. This ‘nusance’ flooding often occurs in areas disconnected from the sea by higher seaward terrain. These effects are compounded not only by chronic sea level perturbations but also by alluvial events during heavy rains, where the unsaturated zone becomes so shallow that it can not absorb rainfall resulting in overland flow and widespread nuisance flooding (Habel et al., 2017). Therefore, it is critical that natural resources managers not only consider the effects of bathtub-type surface flooding from SLR, but also recognize the additional challenges posed by GWI. Another major consequence to buried assets and subsurface inundation from inundation with seawater is the associated change in pore water salinity and/or redox conditions. These effects can drive increased corrosion or other unwanted chemical reactions that reduce the lifespan of certain materials, as well as the possibility of contaminant mobilization from legacy contamination locked up in soils (Suthersan, 2001; Lu et al., 2018; Almheiri and Meguid, 2019).

Water, power and wastewater utilities are faced with even more significant challenges as they often manage a significant proportion of subsurface assets. The American Samoa Power Authority (ASPA) is the sole provider of all three of the aforementioned services in AS and thus faces the unique challenges of managing a huge number of critical assets in an isolated location that is especially vulnerable to climate change impacts (Kumar and Taylor, 2015). While ASPA manages utilities across multiple islands in the territory, the economically and politically important Pago Pago Harbor area is one of the most vulnerable areas to GWI. The land fronting the harbor holds a large concentration of infrastructure assets built on coastal plains that lie just above sea level. These assets include approximately 91 km of subsurface water lines, 42 km of below ground wastewater lines, x km of buried power lines, and 76 km of roads. In addition, there are eight sewer system lift stations, five water main booster stations, 2,400 individual mapped buildings, and 1,330 water meters located in the inner harbor area as well. ASPA has already reported instances of inundated sewer lines and corroded manholes, thought to be a consequence of currently rising sea levels (Hua-Hsien, personal communication Dec. 2021). There are also many other subsurface assets in AS that are vulnerable to negative effects of GWI for which no data currently exists such as On-Site Disposal Systems and underground fuel storage tanks. In order for policy makers and utility providers to plan for resilience and to adapt to SLR, decision makers need accurate information regarding projected impacts of SLR. While surface flooding from bathtub-type models are simple to produce and very informative, they miss a key component of the total flooding threat. A better understanding of how the built environment interacts with the compounded threats from climate change can help to mitigate risk to property and amount to significant cost savings in the long-term.

**Study Location:**

Tutuila is the main population center of the Territory of American Samoa and is home to nearly 56,000 permanent residents. Located near 14° S and 170° W and within the South Pacific Convergence Zone, the climate is hot, humid, and has prevalent year-round rainfall, up to 6000 mm/year along the mountain tops. The rainier season lasts from October to May, with the rest of the year experiencing less but still significant rainfall (NWS, 2000). The 142 km2 island is composed of the remnant core of a group of eroded basaltic shield volcanoes (Stearns, 1944) and due to the heavy and prevalent rainfall, the landscape has been eroded into very steep ridges and valleys. This has concentrated human development on thin coastal plains formed by aluvium and marine deposits during recent sea level high stands (Stearns, 1944; Grossman et al., 1998; Blanchon et al., 2009). The Pago Pago Harbor area lies within an ancient collapsed caldera and is documented as one of the best natural harborages in all of the South Pacific. The Harbor is home to a number of villages including the Village of Fagatogo, which is the seat of American Samoa’s territorial government, and Atuu Village the home of the island’s only industry and largest private employer, the StarKist Tuna Cannery. Overall, the extremely steep terrain and the concentration of government and industrial facilities has resulted in a large part of the territory’s built assets being concentrated on the low-lying coastal plains inside of the harbor, which are highly vulnerable to impacts of SLR. Additionally, some villages in the harbor area are said to be underlain by fill composed of bulky waste from the era of US Navy occupation. Contaminants have already been found in coastal sediments offshore of some of these villages (Whitall and Rice, 2015) and GWI only produces additional risk that, if present, contaminants may be mobilized from these land-filled areas.

**METHODS**

In order to assess risk of subsurface flooding to infrastructure, we developed a MODFLOW based groundwater model for Tutuila’s Pago Harbor Region and used the best available projections of local sea level rise from NOAA’s national SLR viewer to modify the base ocean elevation and the coastline position for multiple future scenarios. We considered the range of possible SLR levels predicted by NOAA in the year 2090, some of which also correspond to extremes at more contemporary timescales, which ultimately are often more useful projections for present day managers. Because climate drivers are also projected to be different in the future, the scenarios also incorporated a dynamically downscaled groundwater recharge coverage of an RCP4.5 emissions pathway developed previously by Wang (citation) and Shuler et al (2021) for the period 2080-2100. Modeled water table elevations for present and future scenarios were then used to assess where subsurface and surface based infrastructure would be permanently submerged below the water table, or affected by nuisance flooding, respectively.

**Groundwater Modeling Methods**

The modeling framework used for this project followed from the collaborative modeling framework developed by Shuler and Mariner (2020). Stakeholder involvement was a key element in the modeling, and many of the critical input data were provided directly by ASPA including water level observations, well extraction rates, and infrastructure locations. The modeling framework was produced in a reproducible open-source manner by employing the Python package FloPy to manage model development and to document all code-based model scripts via Jupiter Notebooks (citation) in an open-source repository on GitHub (citation). MODFLOW has been previously proven to be an effective model for simulation of coastal GWI in high-island settings (Habel et al., 2017; Masterson et al., 2017), and a recent study by Habel et al., (2019) suggests that using more computationally or time intensive density dependent models such as SEAWAT is not necessary to accurately simulate local groundwater gradients for successful GWI simulation.

For this study, a 7.5 x 7.5 km region surrounding Pago Pago Harbor was delineated as the single layer model domain, and it was divided into 2.25 million model cells to achieve a 5 m cell resolution. Top elevations were assigned from a 3 m resolution DEM (Citation??\_\_\_) and the bottom elevation was held constant at a depth of 500 m below MSL. The shoreline was assigned a specified head boundary at 0 MSL for the base scenario, and terrestrial boundaries were assigned a specified head equivalent to the head level taken from the island-wide model detailed in Shuler and Mariner, (2020). Shoreline position, based on NOAA SLR scenarios (citation), and sea level specified heads were modified accordingly for each of the three SLR scenarios. Oceanic areas outside of the coastal specified head boundaries were assigned an inactive status. Streams were simulated as drains and major channels were obtained from the National Hydraulic Dataset (USGS, 2018). Pumprates for active wells in the model domain were obtained from ASPA and were set at their average extraction rates calculated between 2005-2017, the period of available data. A total of 27 water level observations at wells detailed in Shuler and Mariner, (2020) were used for model calibration. Recharge for both present-day and future climate RCP4.5 scenarios were clipped from the island-wide high-resolution recharge coverages of Tutuila produced by Shuler et al., (2021). Spatially distributed horizontal hydraulic conductivity (K) values were assigned using a zone based approach based on the eleven geologic units within the Pago Harbor area as defined by Stearns (1944). Note that since the model was a 1-layer model it does not take vertical hydraulic conductivity or anisotropy into account.

The FloPy model was run using MODFLOW 2005 and the resulting water table surface was used to assess the depth to groundwater by geospatially subtracting the land-surface height at each cell. This allowed us to obtain a spatially distributed estimate of the depth to groundwater throughout the entire model domain.

**Subsurface and and Surface-based Infrastructure Data**:

Two-dimensional AsBuilt drawings of water, sewer and buried electrical infrastructure (items 1-6 below) were obtained directly from ASPA as CAD or GIS-shapefiles. Shapefiles of roads and buildings were obtained from the American Samoa Department of Commerce GIS-Portal (ASDOC, 2015). Infrastructure considered in this assessment included:

1. Transmission and Distribution water mains
2. Sewer lines
3. Water system booster stations
4. Sewer system lift stations
5. Customer water meters.
6. Electrical lines
7. Roadways
8. Buildings

Since the depth of buried assets is variable and none of the available data files contained vertical dimensionality, the average depth for all subsurface infrastructure was assumed to be 1 m. This estimate is considered to be conservative as many buried pipes are located even deeper, especially when placed under roads or other areas with vehicle traffic. Subsurface infrastructure included water, sewer, and buried electrical lines as well as sewer lift stations as most of the station components except for the electrical portion are located below grade. Surface-based infrastructure included water boosters, roads, buildings, and customer water meters. Roads and buildings shapefiles circa 2009, were obtained from the Am Samoa GIS users group. All shape files and Asbuilts were clipped to their extent within the inner harbor area shown on FIG X. While the model boundary does include some outer villages on the north and south shores, infrastructure in these areas were not included due to boundary condition effects. To determine where infrastructure was flooded, all cells within the depth to water coverage(s) with a value less than 1 m for subsurface infrastructure and less than 0m for surface infrastructure were aggregated into a ‘flooded area’ shapefile, and geospatial locations of infrastructure were intersected with the flooded areas. This method was reproduced for each SLR and climate change scenario to calculate the total length or number of each infrastructure asset type modeled as flooded for each scenario.

**SLR Scenarios**

Three different levels of SLR were selected for use in the model based on projections provided by the NOAA Sea level Viewer: 2ft, 5ft, and 8ft. These sea levels are representative of different possible SLR projections at different times. Climate projections are often produced at the end of century resolution and managers must often plan for these long term timelines, thus the year 2090 was selected as a key point in our assessment. Specifically in the year 2090, 8ft is considered to be the ”extreme” scenario, 5ft is the ”intermediate high” scenario, and 2ft is the ” “intermediate low” scenario (NOAA citation). These projected sea levels also correspond to other potentially useful points of reference, specifically 5ft is the “extreme” scenario in the year 2070, and 2ft is the ”extreme“ scenario in the year 2040. The year 2040 is currently well within the engineering lifespan of most surface and subsurface infrastructure components, making this point of reference highly useful for informing present day equipment procurement decisions. The year 2090 is also likely to have a different climate and this different groundwater recharge distribution than the present day. TO account for this we applied the only available future downscaled recharge coverage (Shuler et al., 2021), which was derived from the only available AS downscaled climate model (wang and zeng citation), based on the RCP 4.5 emissions projection for the period 2080 to 2100.

**Model Calibration and Sensitivity Testing**

By using the FloPy package, the MODFLOW executable and all processing of model inputs were run directly from a single Python interface. This allows the model to be easily wrapped into a loop function and parameters to be varied to assess performance under different controlled parameterizations for both calibration and sensitivity testing. Model calibration was performed for the most uncertain model parameter, hydraulic conductivity (K). Spatially distributed K values were varied using a zone based approach with a unique K parameter for each of the eleven geologic units in the model. The model cost function was defined as the root-mean square error (RMSE) between the set of computed and observed water levels at the 27 observation points. The Python Package (insert scipy details here) was used iterativly to optimize the cost function and determine the best fitting K values. Ultimately calibration resulted in an RMSE of [best fit value here] which was deemed to be acceptable once subsequent calibration iterations yielded no significant improvement in RMSE.

The model wrapper function was also applied in a sensitivity test of the model response to independent perturbations of each of the K values and other key parameters including stream conductance, well pumping rates, and recharge rates. The final objective value, represented by the total length of flooded subsurface water and sewer lines, was calculated for each sensitivity test case and the resulting percent difference in this value between each test case and the base case scenario (no perturbations) was recorded. While it is not possible to directly quantify model uncertainty due to the iterative and non-linear nature of the Results and discussion of sensitivity tests are presented in Table x

**Results**

For the present-day calibrated base case scenario, the model indicated that less than 1% of surface infrastructure, and less than 4% of subsurface infrastructure is currently affected by GWI. This is reasonable according to ASPA operations staff, and helps to validate the model’s accuracy (See section x below). For the different SLR scenarios, GWI effects grade towards the most extreme case, where in the 8ft SLR scenario, which includes the 2090 RCP4.5 climate regime, the model calculates that 30%-50% of subsurface infrastructure, and 10-30% of surface infrastructure may be affected by GWI or surface flooding. In this worst-case scenario, the model calculated the total lengths of flooded roads in the model domain at 21.4 km, flooded sewer lines at 13 km, 7 of the 8 sewer lift stations flooded at their bases, and 37.6 km of inundated water lines. For context, replacing 37.6 km of water lines would require approximately 6,200 individual 20 foot-long pipes, which if assuming each had a 12 inch diameter, would require 85 semi-truck loads to transport. In all scenarios, the majority of impacted infrastructure features are primarily located in those areas of heavy development built upon the relatively low-elevation coastal plains at the valley mouths. These areas include: Fogotogo Village, Utulei Village, Pago Village, and Aua Village. As an example Figure x display’s flooded subsurface infrastructure at the 5 ft level. The model assessed GWI impacts on eight individual infrastructure types, across a large region. While the exact locations of GWI impacts on each of these assets can be seen by plotting the associated shapefiles in the project repository (github repo), a higher level synthesis is useful for managers and policy makers. This is shown in Table x which shows the percentage of the total number of point assets or the total length of linear assets affected by GWI for each scenario.

Table X: Length or number of flooded infrastructure assets, both surface and subsurface, in the Pago Pago Harbor under different scenarios of sea level rise and future climate. Present day absolute column gives lengths of linear assets in meters (m) and number of flooded point assets. Other columns show the percentage of the total length or number that simulated to be flooded in the given scenario.

|  | Present Day (m or #) | Present day % flooded | 2ft 2090 climate % flooded | 5ft 2090 climate % flooded | 8ft 2090 climate % flooded | 2ft present day climate % flooded |
| --- | --- | --- | --- | --- | --- | --- |
| **Subsurface** |  |  |  |  |  |  |
| Water Lines |  |  |  |  |  |  |
| Sewer Lines |  |  |  |  |  |  |
| Electrical Lines |  |  |  |  |  |  |
| Sewer Lift stations |  |  |  |  |  |  |
| **Surface** |  |  |  |  |  |  |
| Water Meters |  |  |  |  |  |  |
| Water Line Boosters |  |  |  |  |  |  |
| Roads |  |  |  |  |  |  |
| Buildings |  |  |  |  |  |  |

**Present-Day Validation**

In order to get the most direct estimate of the model validity we very carefully examined the calibrated base scenario to assess locations where the model predicted open water and compared those with existing features across the landscape. Overall the model did a fairly good job of limiting the extent of surface exposed standing water to locations where there are existing drainage ditches or canals that typically have standing or flowing water even in dry conditions. (see Figure x)

* overall the different inundation scenarios a large range of different outcomes ranging from x% of infrastructure becoming permanently inundated to x%
* Specifically of the x m of the incintoried water lines in the model area
* The RCP 4.5 scenarios all show a higher recharge and thus water table and Therefore the future climate scenarios all show a greater degree of surface and subsurface flooding

**Sensitivity Test Results:**

The sensitivity of the results to each of the key model input parameters was assessed through a sensitivity analysis

specifically the measure of how much of the linear subsurface infrastructure, consisting of an aggregation of the buried water, sewer, and electrical lines,

oParameters from the groundwater model were

Table X: Sensitivity test results expressed as the percentage difference between the test case and the base case scenarios for perturbations of individual parameters at 25%, 50%, 200% and 400% of the parameter values from the base case scenario. Note that all parameters are scalar values except for well pump rates and recharge, which are a set of point values and a gridded raster, respectively. These were all modified at once by the multiplier value for each test scenario.

| **Parameter** | **25% multiplier** | **50% multiplier** | **200% multiplier** | **400% multiplier** |
| --- | --- | --- | --- | --- |
| K-Aua (m/d) | 8.9% | 4.0% | -2.3% | -4.3% |
| K-Fagaalu (m/d) | 11.6% | 3.9% | -2.5% | -4.9% |
| K-Laulii (m/d) | 0.0% | 0.0% | 0.0% | 0.0% |
| K-Utulei (m/d) | 68.3% | 35.4% | -7.6% | -9.2% |
| K-Vaipito (m/d) | 124.5% | 61.6% | -67.3% | -73.0% |
| K-Vatia (m/d) | 0.1% | 0.0% | -0.2% | -0.4% |
| K-minor (m/d) | 1.7% | 0.4% | -0.7% | -1.1% |
| K-Dikes (m/d) | 2.2% | -0.4% | 0.0% | 0.0% |
| K-Pago-Inner-East (m/d) | -0.8% | -0.1% | -0.3% | -1.1% |
| K-Pago-Inner-West (m/d) | 11.1% | 4.6% | 5.3% | 6.0% |
| K-Pago-Outer (m/d) | 6.0% | 3.3% | -6.6% | -15.3% |
| K-Trachyte (m/d) | -0.3% | 0.0% | 0.0% | -0.2% |
| Stream Conductance | 6.3% | 2.2% | -1.4% | -2.1% |
| Well Pump Rates | 11.1% | 6.7% | -20.1% | -68.7% |
| Recharge | -85.5% | -82.0% | 138.4% | 312.9% |

**Discussion**

Overall this work can be used directly by managers and decision makers at utilities or agencies in American Samoa to make site-specific procurement and planning decisions for the future. The physical building blocks of many island societies have historically been based around a paradigm of static sea levels, and it is clear that planning decisions can no longer be made within that framework. The maps produced by this model are by no means an exact prediction of the future, but they do help to show where Pago Pago’s lowest lying areas are and where there are inland areas with a combination of low elevation and higher groundwater tables that are potentially at risk for additional flooding beyond what simple bathtub modeling would suggest.

The presence of these low-lying, inland sink areas makes a case against relying entirely on seawalls, the grey engineered solution of that has historically been the primary response to coastal erosion and rising seas in AS. Even if a seawall or levee can hold back encroaching sea level from the harbor itself, the connectivity of the seawater to the continuously flowing groundwater underlying these built environments is likely to raise up the groundwater to the where problems with continuously saturated soil or even nuisance flooding on the surface are likely to manifest. Therefore special consideration should be given to these types of areas identified by the model, and if shoreline armoring is used other strategies such as fill or pumping may also be needed inland.

One silver lining with the topography in Pago Harbor is that there are not a huge amount of inland sink type of areas compared to some other locations. In places where lithified or unconsolidated aeolian dunes front the shore such as barrier islands or parts of the windward shores of the Hawaiian Islands (citations) surface manifestation of GWI may end up being widespread. In Pago Pago Harbor, the landward portions of the coastal plains typically build upwards fairly quickly due to alluvial deposition from frequent flooding and extensive sediment transport. This means that surface flooding will likely not be too extensive, as the 5 ft and 8 ft modeled scenarios show only x and x amount of surface flooded area, which is disconnected from the sea. However, the extent of subsurface area that will become saturated is much larger, in the 5 ft and 8 ft modeled scenarios a total of x and x amount of area that lies outside of the extent of ocean flooding is sub-surface inundated to at least the 1 m depth. This suggests the problems from GWI in the Pago area will be more difficult to detect and will primarily impact buried infrastructure. It should also be remembered that depending on the design specifications of the buried infrastructure, permanent inundation may have different effects. Some infrastructure like the water line buried 3.5 m under the harbor estuary are intended to be constantly inundated with salt water and experience no problems. While other infrastructure like sewer mains may suffer major problems such as excessive inflow and infiltration. The more insidious effects of constant inundation with high salinity water include corrosion caused by salt or shifts in soil redox conditions driven by poorly oxygenated groundwater.

**Geologic controls on Vulnerability** Tutuila ia an interesting test case for this work because it contains multiple geologic provinces that span a gradient of ages, each with radically different vulnerabilities to SLR And thus GWI. Specifically the older part of the island is million years (citations etc) but. Tafuna is young, Holocene. Because of it’s age the older part of the island has experienced a longer period of subsidence, which depending on the rate, can allow for extensive reef growth which tends to produce extensive shallow nearshore platforms (some general citation on island aging). Whereas in younger terrains (such as taf -Leo) even where the lava flows near sea level, they are often fronted by rapid drop offs and rise fairly quickly at the average slope of a lava flow 3 dg for pahoehoe 10 ddsg for aa (citation). One of the biggest controls on geologic age has on SLR vulnerability may relate back to specific geometry, or the island’s existence, 120 to… k years ago. This period represented the last major global sea level high stand and was associated with ocean levels that were up to 6 m higher that present day (citation). While it is difficult to reconstruct sea level history on pacific islands as they are constantly growing and subsiding, platforms made of coralline limestone standing approximately 2 m above current sea level are commonly found on many islands and create extensive Coastal plains. (multiple citations form islands). Therefore island geometries that favored extensive reef flat development 120k Yago systematically acted to produce many areas that subsequently left these flats as limestone platforms now standing above sea level. The nature of human development, which favors good access to resources, preference for flat easy building sites and proximity to water (cite blue mind book :), has worked to turn these low lying coral platforms into centers of development and some of the highest value real estate in the pacific. Of course this poses a clear and obvious problem in the face of rising seas To grossly generalize the math, a common situation where development is concentrated on 2m tall platforms, with infrastructure buried at 1 m deep then plus 1 m of SLR suggests that GWI is likely to be a widespread and pervasive problem throughout the pacific and affecting some of the most economically important and density populated parts of the islands.

(OLD) Although the risks of GWI in the Pago Harbor area of Tutuila are high, this is not to say that the whole territory is at risk. Tutuila benefits from having developable land with a varying array of geologic histories. While a large portion of the population in the geologically older part of the island reside on low lying coastal plains at valley mouths, a large percentage of the islands development is centered on the Tafula-Leone Plain. This plain is a pahoehoe lava delta, recently erupted and for the most part has developable land situated at elevations between 10 and 70 m.

[waimanalo high stand sea level stuff]

3 Comparison of Pago vs Tafuna then compare to other islands

- Wai Manoa stand of sea level left 2m benches across many pacific islands and now these areas where built on are highly vulnerable q

* The scenarios explored in this model represent the full range of SLR possibilities by 2090. However, in the near term, by 2040 only the 2ft scenario, which represented the extreme projection produced measurable

**Assumptions, limitations and uncertainties**

With any modeling study it is important to clearly understand the specific limitations and the conditions required to make reasonable use of results and to avoid overinterpretation. For this work, the key assumption relies on the intersection of the modeled water table elevations, the DEM surface elevations, and the infrastructure locations all being accurate and projected relative to a common sea-level based datum. The 3 m DEM used was compared against a 1 m LIDAR DEM produced by NOAA in 2012??????(citation) and overall the average absolute percentage difference between the 3 m and 1 m DEMs was ± m (RUN ANALYSIS). This suggests that the surface elevations used were fairly robust. Unfortunately, the water table elevations are probably less well constrained than the surface elevations due to the large numbers of difficult to constrain inputs required to generate the water table elevations with the MODFLOW model. The model is limited by its most poorly constrained parameter which, as shown by results of sensitivity testing, was the subsurface K. Although the best available water level data was used to calibrate the model K values, difficulty in constraining this parameter typically contribute the most to model uncertainties. Although this uncertainty can not be propagated through the model (because it is run iteratively) the sensitivity testing revealed that uncertainties in the K values of the most highly sensitive units, specifically Vaipito and [ANY OTHER KEY UNITS] may lead to significant uncertainties in the final model results. Finally, we can qualitatively identify the depth of infrastructure features as the primary contributor of uncertainty in the results. This results from the fact that depth information on any infrastructure data is completely absent, and even the horizontal locations of many of the asBuilts are subject to errors, as the utility companies themselves often have to do time consuming locate exercises to constrain their locations well enough to avoid hitting buried pipes and lines while digging. While a depth of 1 m is the best available assumption to make (Wei Hua-Hsien: ASPA personal communication, Jan, 2017), it is nonetheless a large assumption and overall generalization as it is know that some utilities are located deeper and some are buried closer to the surface.

Some other key assumptions of note are:

* The dual-density effects of seawater were ignored and a basic groundwater flow model (MODFLOW) was used as opposed to more computationally expensive models such as SEAWAT or SUTRA that consider the dual-density effects of seawater. This was considered to be reasonable based due to the success found by Habel et al, [MOST RECENT ONE] with using an even simpler approach. Although seawater recirculation will cause variation in water table elevations very near the coast, these are likely to be negligible at the region wide scale where hydrodynamic lift in the water table will likely make up the bulk of effects of SLR on the aquifer.
* Because there are no dedicated monitoring wells in AS water levels used for calibration were taken from shut off pumping wells as described in Shuler and Mariner (2020). The predominant assumptions in using this approach are that 1) the well recovery tests yielded fully recovered water levels, and 2) the effects of nearby pumping wells did not extend to the measurement point when the recovery tests were taking place. Therefore, the model was calibrated to a hypothetical state with no aquifer pumping. While this could lead to some inconsistencies once extraction wells are added into the model the lack of other observation data precluded the use of a better method.

Notes

Tables:

Table X: Sensitivity test results expressed as the percentage difference between the test case and the base case scenarios for perturbations of individual parameters at 25%, 50%, 200% and 400% of the parameter values from the base case scenario. Note that all parameters are scalar values except for well pump rates and recharge, which are a set of point values and a gridded raster, respectively. These were all modified at once by the multiplier value for each test scenario.

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| Recharge | -85.5% | -82.0% | 138.4% | 312.9% |

**References**

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