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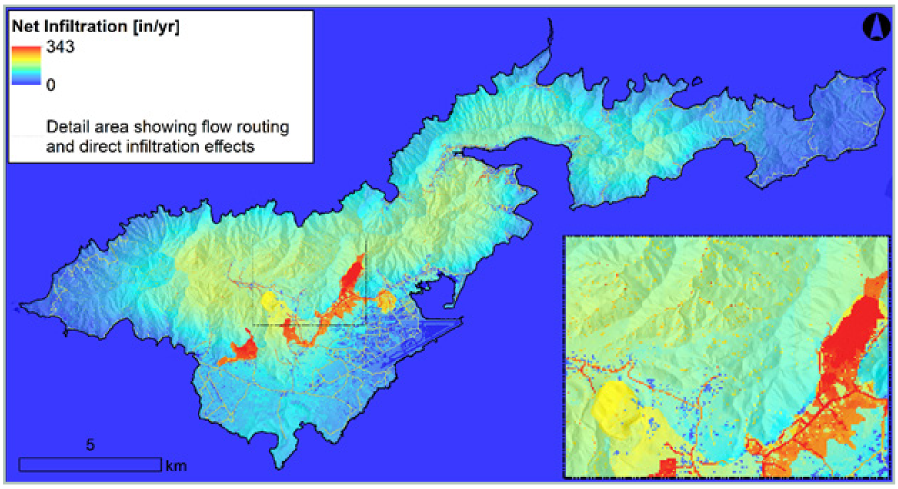
Management Summary for

Groundwater Recharge for Tutuila, American Samoa Under Current and Projected Climate Estimated with a Soil Water Balance Model



WRRC Project Report (2018)
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EPA Region 9

Summary

The primary goal for this study was to apply the Soil Water Balance 2 (SWB2) Model to create high-resolution estimates of water balance components on Tutuila with a particular emphasis on groundwater recharge.

The importance of knowing groundwater recharge

Developing a robust understanding of water resources is critical as water sustainability in Pacific Islands becomes threatened by human land-use practices and climate change. Groundwater is the primary water source on the Island Tutuila in American Samoa, and accurate quantification of groundwater availability is essential for well informed management of this limited resource. In island settings, precipitation rates are the biggest factor controlling water availability. However, it is the partitioning of rainfall into different reservoirs, such as groundwater or surface water, that determines the amount of water accessible for human use.

Accurate assessment of groundwater availability is often limited by uncertainty in the magnitude of recharge, because many critical processes influencing recharge are difficult if not impossible to directly measure. Mass-balance based water budget models that estimate recharge and other water budget components on regional or island wide scales are generally accepted to be the most valuable tools available for understanding groundwater recharge. On Tutuila Island, only three previously documented recharge estimates exist, and of these, only one is available in a published format. Each of the previous estimates were also limited in different aspects such as spatial resolution, coverage area, or reliability (Fig. 1).

WATER-BUDGET MODELS ARE VALUABLE TOOLS AND ARE APPLIED TO MANY WATER RESOURCE-MANAGEMENT QUESTIONS INCLUDING:

- Estimating surface water availability
- Estimating Submarine Groundwater Discharge rates
- Assessing water quality and contaminant transport
- Integrated management of surface and groundwater resources
- Building groundwater models, to calculate groundwater availability

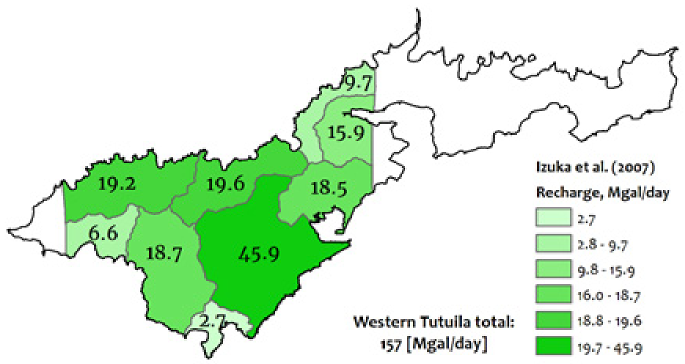

Figure 1: One of Tutuila's existing recharge estimates, covering only Western Tutuila, and converted to a region-standardized format for comparison with other low-resolution estimates.

The Water Budget Model

The SWB2 Water Budget Model integrates long-term climate data with geospatial maps to effectively model hydrologic processes in steep tropical islands with high-spatial and temporal variability.

In this study we used a water budget approach by applying the SWB2 model, a soil water-balance model developed by the US Geological Survey (USGS) to the Island of Tutuila in American Samoa, under average present-day climate conditions. The model was used to create a high-resolution groundwater recharge coverage for the whole island, as well as estimating other components such as evapotranspiration (ET), canopy interception, surface runoff, and mountain front recharge in gridded formats (Fig. 2). Additionally, the potential effects of future climate change on water resources availability were simulated by integrating dynamically downscaled climate predictions for 2080 to 2099 derived from externally supplied global climate model results. Notable improvements in this model over previously developed water budget models for Tutuila include flow-routing based on land topography, inclusion of the mountain front recharge process, and consideration of direct net infiltration from anthropogenic sources such as on-site wastewater units and leaking water delivery lines.

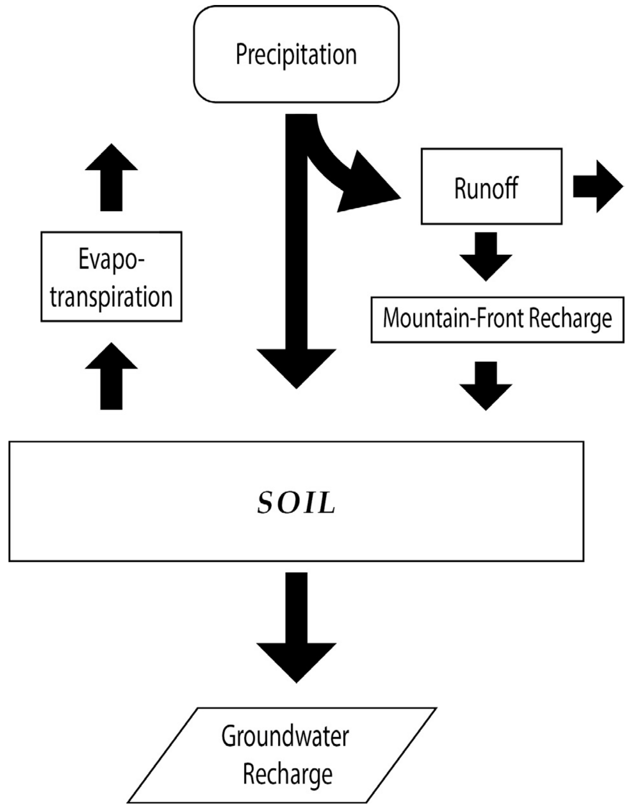

Figure 2: Diagram illustrating factors used to calculate water balance for Tutuila.

Because groundwater recharge is typically the most difficult water budget component to directly measure, it is often calculated as a residual term after other significant components are subtracted from a metered amount of precipitation. In a simplified form, this approach was formulated by Thornthwaite and Mather (1955) as:

$$RECHARGE = RAINFALL - RUNOFF - ACTUAL\ EVAPOTRANSPIRATION$$

Input Datasets

INPUT DATA FOR THE MODEL WERE COMPILED FROM A COMBINATION OF PUBLISHED DATA AND DATA FROM OUR HYDROLOGIC MONITORING NETWORK ON TUTUILA, INCLUDING RAINFALL AND STREAMFLOW DATA COLLECTED SPECIFICALLY FOR THIS PROJECT.

Model input datasets included:

- Gridded monthly precipitation
- Temporal rainfall distributions
- Land use data
- Impervious surface ratios
- Canopy coverage ratios
- Soil type data
- Direct infiltration data
- Runoff-to-rainfall ratios
- Potential evapotranspiration
- Canopy evaporation data
- Gridded temperature data
- Mountain front recharge

The SWB2 model requires all spatially distributed input files to be in the ESRI ascii grid format, and for consistency, all input grids were pre-processed to have consistent boundaries and a 20 m cell-size (Fig. 3). However, the model can be set up to run at any cell size resolution.

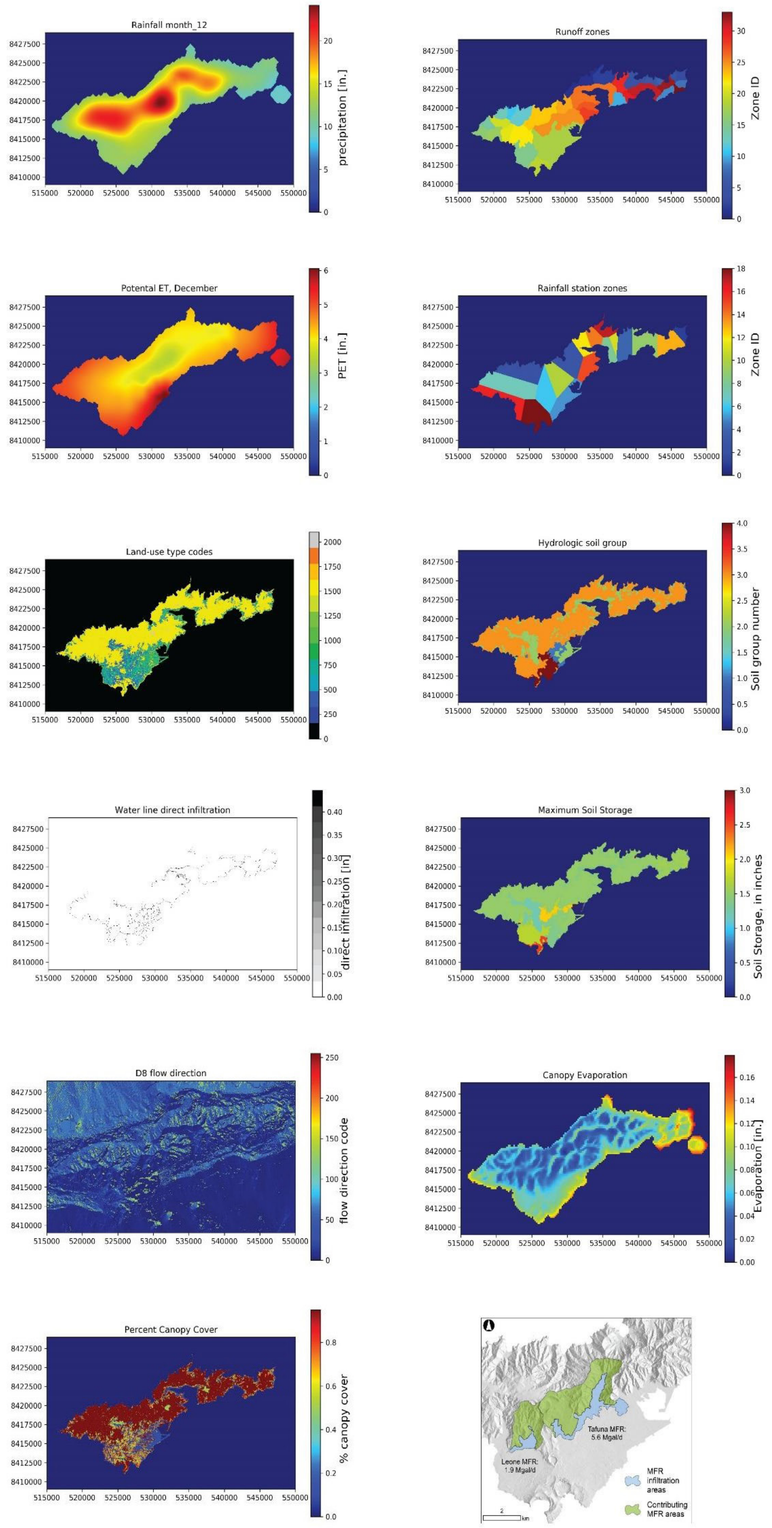

Figure 3: Grid / map views of different spatial input datasets used to build the SWB2 model, represented here at the 20 m cell size.

Results

THE PRIMARY WATER BUDGET COMPONENTS CALCULATED BY THE SWB2 MODEL INCLUDE CANOPY INTERCEPTION, ACTUAL EVAPOTRANSPIRATION, SURFACE RUNOFF, AND NET INFILTRATION

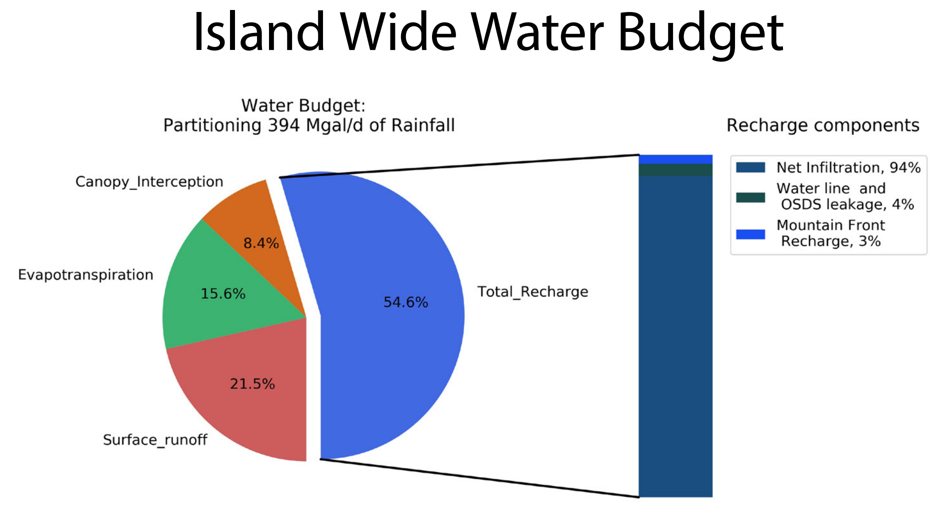

Figure 4: Model results indicated approximately 54% of Tutuila's rainfall infiltrates as groundwater recharge, 8% is lost to canopy evaporation, another 15% is lost to evapotranspiration from soils, and 21% is removed through surface-water features as stormflow-runoff. Of the 54% that infiltrates as recharge, 3% of that is from mountain front recharge in the Tafuna-Leone Plain, 4% is sourced from leaking water lines and discharge from On-Site Disposal Systems (OSDS), with the remainder calculated as the net infiltration from rainfall exceeding the soil moisture capacity.

The SWB2 model produces spatially and temporally-distributed datasets for each output parameter in a NetCDF file format. Output datasets can be summarized spatially by calculating the total volume of water from each component on an island-wide scale (Fig. 4), or within any areas of interest, such as within each watershed on the island. Temporally, outputs can be generated on daily, monthly, or annual bases. Figure 5 shows the annual recharge amount, as a high-resolution gridded raster dataset at 20 m cell resolution.

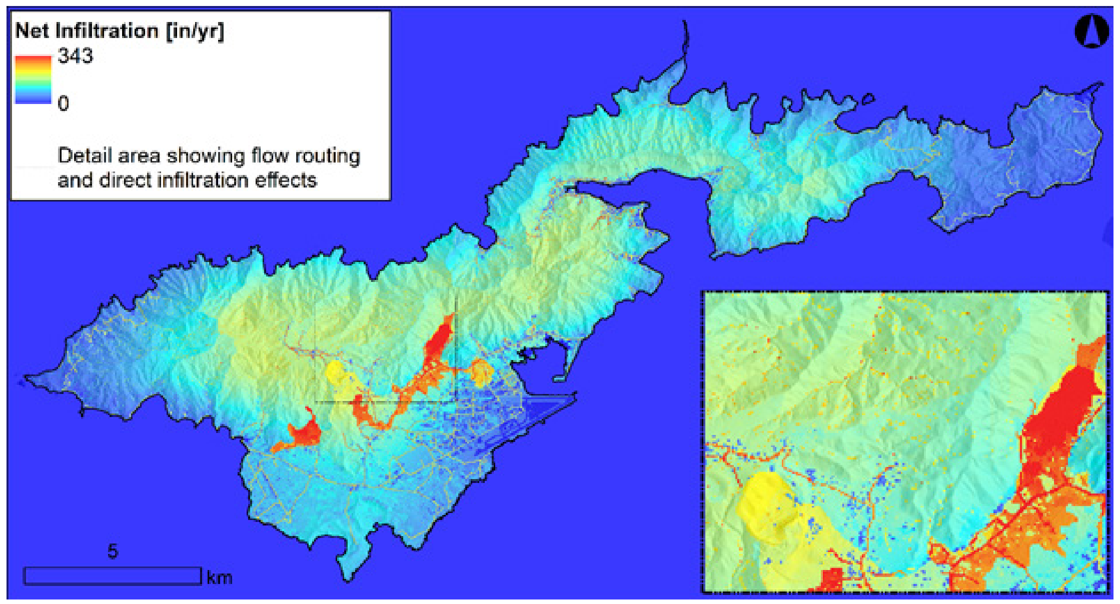

Figure 5: Map of model calculated average-annual net infiltration at 20 m cell-size resolution. Inset map shows detail of 1) flow routing effects, seen as higher recharge squares at the bottom of drainage channels, 2) direct infiltration from leaking water lines, seen as linear zones of higher infiltration, and 3) MFR zones seen as larger patches of high-infiltration.

Climate Scenarios

WANG, Y. AND ZHANG, C. (2016) PRODUCED DYNAMICALLY DOWNSCALED CLIMATE PREDICTIONS FOR 2080 TO 2099 DERIVED FROM A GLOBAL CLIMATE MODEL, FOR THREE SCENARIOS: (1) PRESENT DAY CLIMATE, (2) MODERATE INCREASE IN CO_2 LEVELS (RCP 4.5), AND (3) BUISNESS AS USUAL, OR HIGH INCREASE IN CO_2 LEVELS (RCP 8.5).

The water budget calculations discussed so far use climate data collected in the late 20th and early 21st centuries, and therefore represent estimates of hydrologic conditions during this time. However, the climate of the late 21st century, and likely beyond, will undeniably be significantly different than it has been in the short period of time since the start of the industrial revolution. The availability of water resources will be most affected by changes in amount and distribution of rainfall, as well as an increase in temperature, which is a major driver of ET. To estimate the potential effects of future climate change on water budget components, and thus future water resources availability in American Samoa, the Tutuila SWB2 model was run with modified input files derived from dynamically-downscaled climate projections for American Samoa. These projections were developed by Wang and Zhang (2016) using a physically-based global climate model.

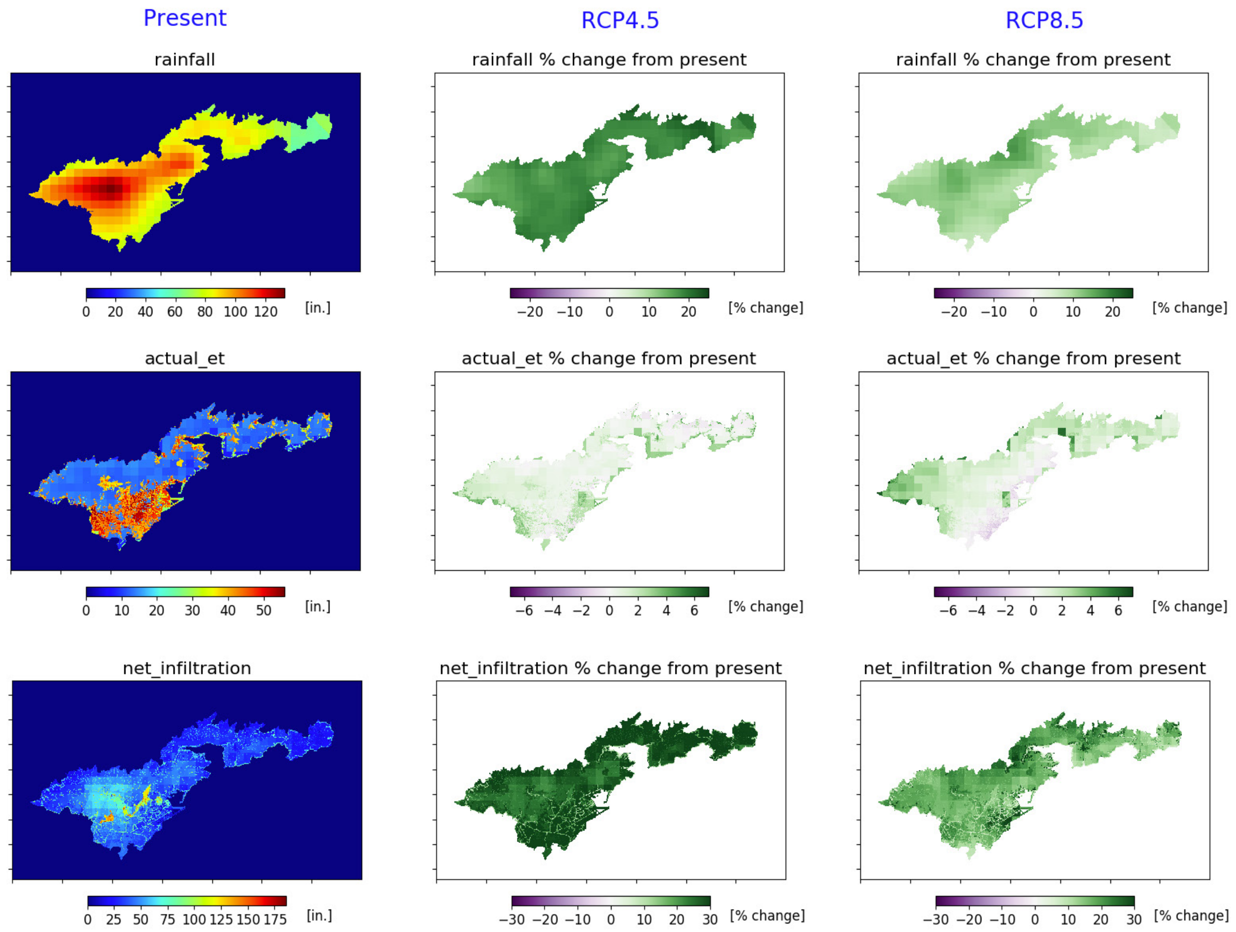

Figure x: Water budget results using downscaled rainfall and temperature predictions (Wang and Zhang, 2016). Present-day predictions are shown as depth of water (left column) whereas future predictions are shown as % change from the present-day scenario for the RCP4.5 (center column) and RCP8.5 (right column) scenarios.

References: -- Wang, Y. and Zhang, C. (2016): 21st Century High-Resolution Climate Projections for Guam and American Samoa. Retrieved from: https://www.science base.gov/catalog/item/583331f6e4b046f05f211ae6 -- Izuka, S.K., J.A. Perreault, and T.K. Presley. (2007). Areas contributing recharge to wells in the Tafuna-Leone Plain, Tutuila, American Samoa. Honolulu, HI: Geological Survey (US). Report no. 2007-5167. https://pubs.er.usgs.gov/publication/sir20075167 -- Thornthwaite, C.W., and J.R. Mather. (1955). The water balance. Publications in Climatology (Laboratory of Climatology) 8(1): 1–86.

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W.R.R.C.

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