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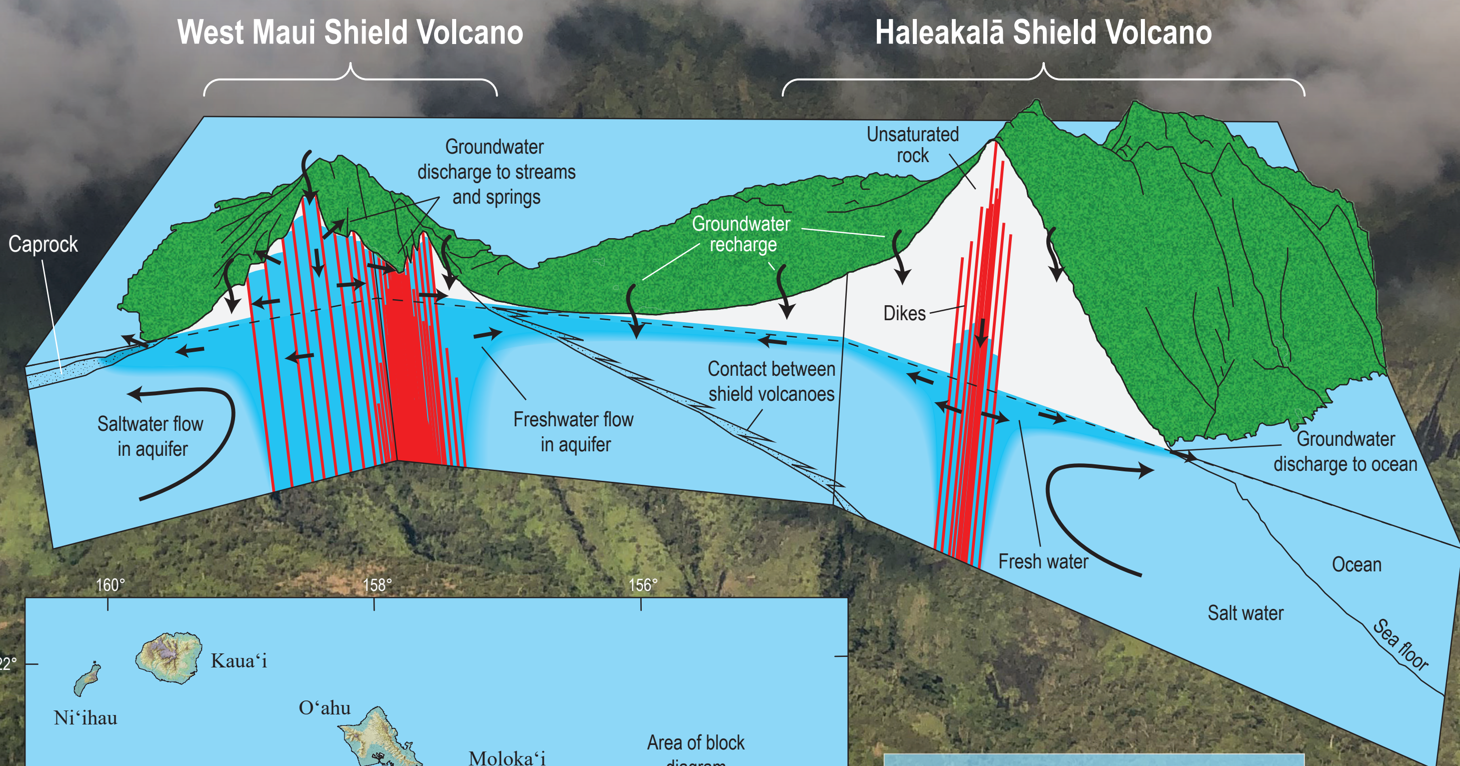
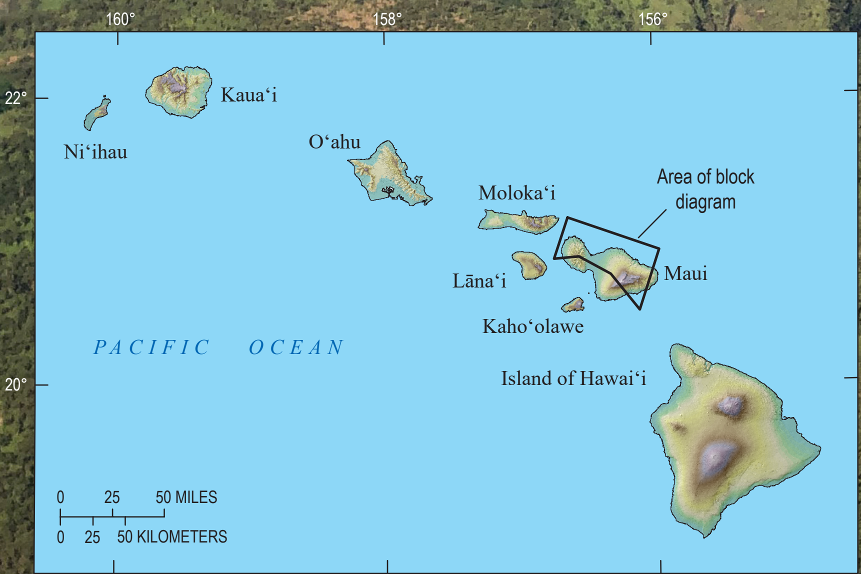
Availability of Groundwater from the Volcanic Aquifers of the Hawaiian Islands

The islands of Hawai‘i were built by basaltic shield volcanoes in the Pacific Ocean. These volcanoes formed aquifers that supply hundreds of millions of gallons of fresh water per day to the islands' residents and diverse industries. Groundwater discharge from the volcanic aquifers to streams and the coast also supports traditional practices and ecosystems. The aquifers' capacity to yield fresh groundwater is limited, however, by limitations placed on the consequences of groundwater withdrawal, such as water-table depression, rise of saltwater, and reduction of groundwater to streams, springs, and the ocean. The magnitude of these consequences will change if groundwater recharge changes as a result of climate and land-use changes.

This fact sheet summarizes groundwater availability and its relation to the consequences of groundwater withdrawals in the volcanic aquifers of Hawai‘i. This topic was addressed in detail in the Hawai‘i Volcanic Aquifer Study (HVAS) (https://doi.org/10.3133/pp1876).





Shaded-relief map modified from U.S. Geological Survey 10-meter digital elevation model
Universal Transverse Mercator projection zone 4 north, North American Datum of 1983

Groundwater occurrence and movement are illustrated in a box diagram of the volcanic aquifers of Maui, one of the basaltic shield-volcano islands of Hawai‘i. Area of block diagram is shown in a map of the Hawaiian Islands.

Background photograph of Mount Wai‘ale‘ale and stream-eroded valleys on the island of Kaua‘i, Hawai‘i. Photograph by Chui Ling Cheng, U.S. Geological Survey.

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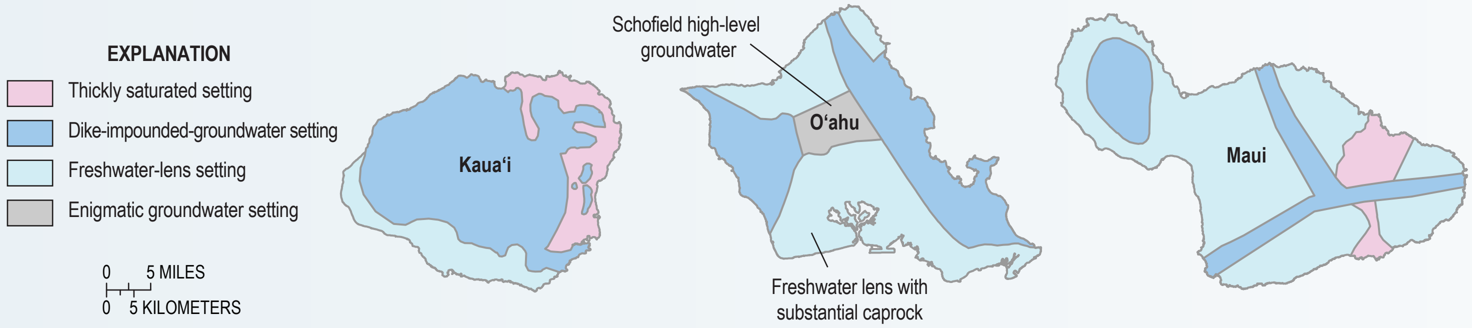
Principal Groundwater Settings in Hawai‘i's Volcanic Aquifers

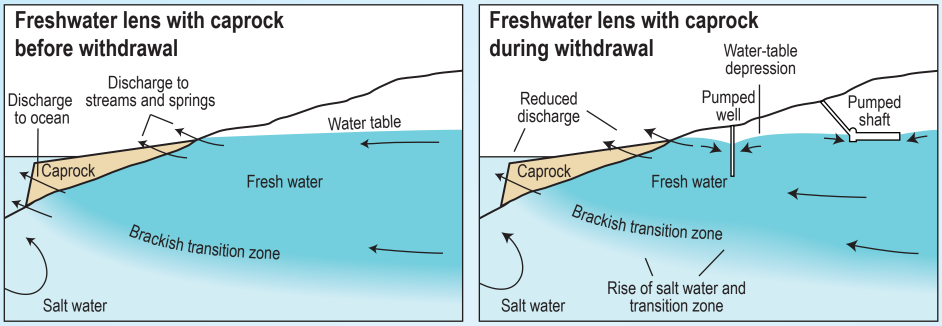
Hawai‘i's volcanoes form aquifers in which fresh water coexists with salt water and naturally discharges to streams and the coast. Most groundwater in Hawai‘i can be categorized into one of three principal groundwater settings described below, each of which responds differently to groundwater withdrawals.

Some groundwater occurrences do not fit into the three principal groundwater settings and their hydrogeologic framework is not fully understood. For example, the Schofield high-level groundwater in central O‘ahu is in a high-permeability aquifer but has water levels that are hundreds of feet higher than those typically associated with freshwater-lens settings.



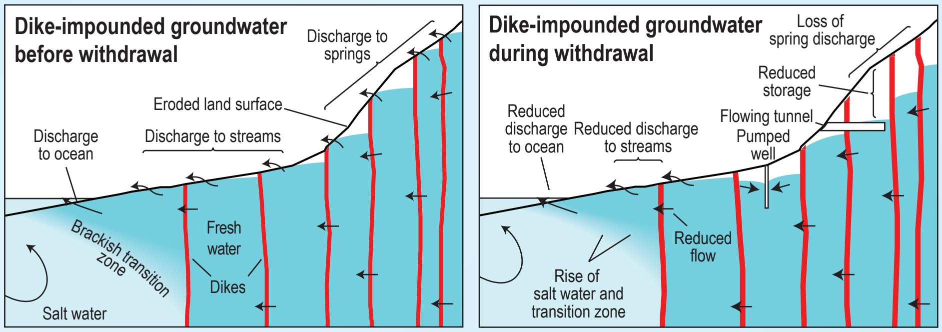
Freshwater-Lens Setting

Stacks of thin lava flows form high-permeability aquifers in which a lens-shaped body of fresh groundwater overlies denser salt water. Groundwater flows from inland areas toward discharge areas near the coast. Where substantial coastal sediments form a low-permeability unit (known as caprock) that resists coastal discharge, the freshwater lens is thicker; some groundwater discharges to springs where the caprock pinches out above sea level, and some groundwater flows through the caprock and discharges above or below sea level.



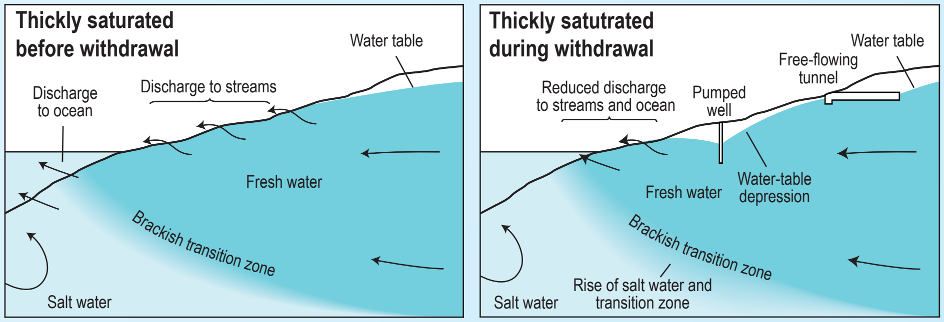
Dike-Impounded Setting

Dikes (near-vertical sheets of low-permeability intrusive volcanic rock) cut through lava-flow aquifers and form a system of compartments in some areas. Groundwater is impounded in the compartments and can accumulate to high altitudes. Groundwater flows from one compartment to another and to adjacent downgradient groundwater settings. Where erosion has breached the dike compartments, much of the groundwater discharges to streams and springs.



Thickly Saturated Setting

In some aquifers, low permeability is characteristic of the whole aquifer, not just intrusive structures like dikes. The low-permeability aquifer resists groundwater flow and becomes thickly saturated with fresh water. Streams drain some of the groundwater to keep the water table below most of the land surface. Most natural groundwater discharge occurs above sea level at these streams; less discharges directly to the ocean. Salt water probably underlies fresh groundwater near the coast, but whether salt water exists farther inland is not known.



Groundwater Availability is Limited by the Consequences of Withdrawal

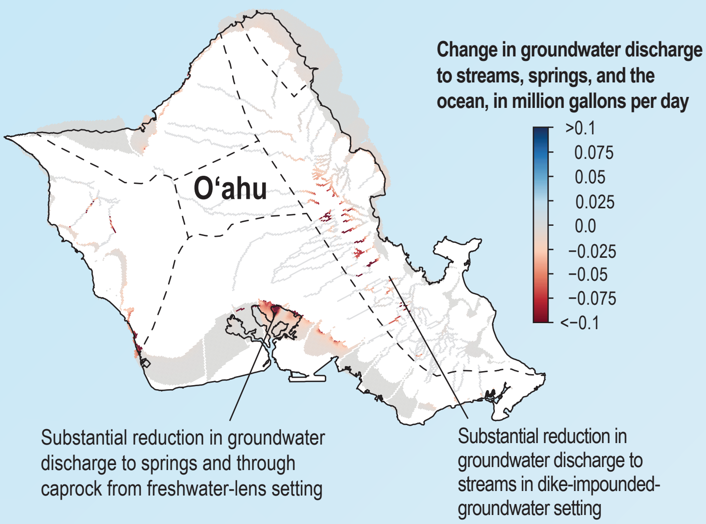
Any amount of fresh groundwater withdrawal by humans has consequences. In Hawai‘i, these consequences include water-table depression, rise of salt water in the aquifer, and reduction of groundwater discharge to streams and the ocean. Restrictions placed on these consequences—such as restrictions on streamflow reductions to protect ecosystems and traditional practices, or restrictions on water-table depression or saltwater rise to protect productivity of existing wells—can limit groundwater availability; thus, knowing the consequences of withdrawal is key to knowing how much groundwater is available for human use.

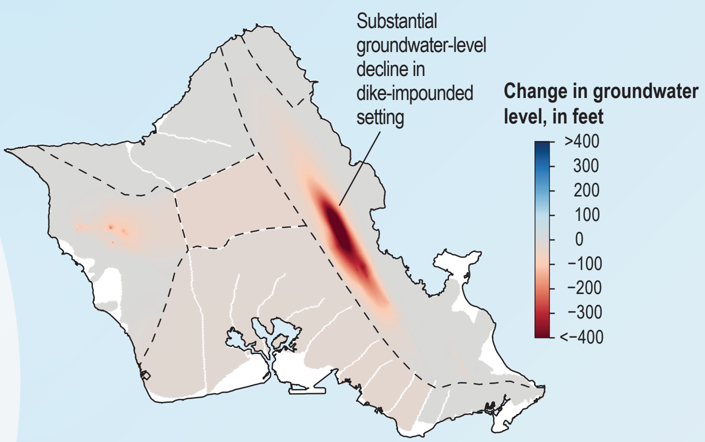
The HVAS used groundwater models of Kaua‘i, O‘ahu, and Maui to quantify the consequences of historical and future groundwater withdrawals. Groundwater models can be used to comprehensively analyze the multiple factors that bear on the consequences that limit groundwater availability. The models of Kaua‘i, O‘ahu, and Maui encompass Hawai‘i's principal groundwater settings, so results from these models can help understand groundwater availability in other islands of the archipelago.

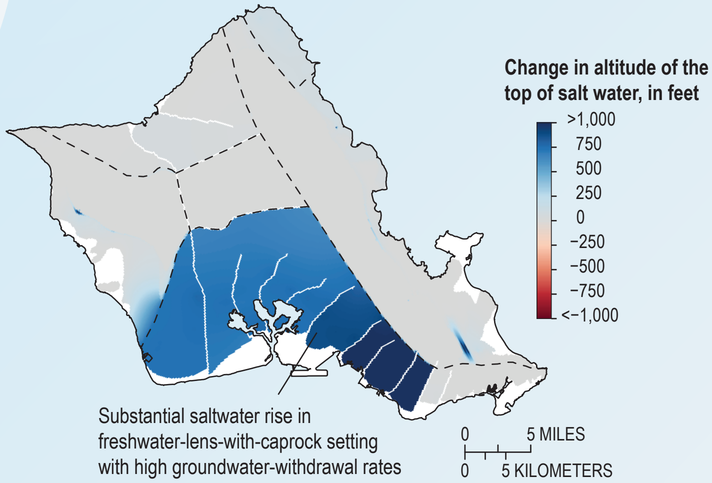
Consequences Differ Among Groundwater Settings

Because each principal groundwater setting in Hawai‘i responds differently to groundwater withdrawals, the consequences that limit groundwater availability differ among the settings. Consequences of withdrawals also depend on their magnitude and location relative to streams, springs, and the ocean. Since the first well in Hawai‘i was drilled in 1879, total groundwater withdrawals from Kaua‘i, O‘ahu, and Maui have increased to nearly 400 million gallons per day. Because Hawai‘i relies on its aquifers for virtually all of its drinking water, groundwater withdrawals are anticipated to increase with population. Results of the HVAS show that historical withdrawals have caused, and if future increases in withdrawals occur, they will cause,

- **Reductions in groundwater discharge to streams and springs**, especially in the dike-impounded-groundwater and thickly saturated settings, and in the freshwater-lens setting if caprock is present;
- **Reductions in groundwater discharge to the ocean**, especially in the freshwater-lens settings and where production wells are near the coast;
- **Lowering of groundwater levels**, especially in low-permeability aquifers, such as in the dike-impounded-groundwater and thickly saturated settings, or where withdrawals are high;
- **Rise of salt water**, especially in heavily developed freshwater-lens settings; and
- **Changes in subsurface flows between sectors within an island**, where withdrawals from one sector affects groundwater availability in other sectors.



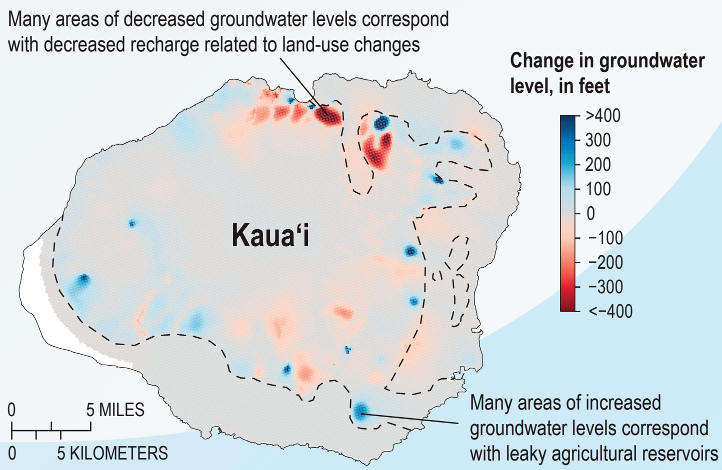


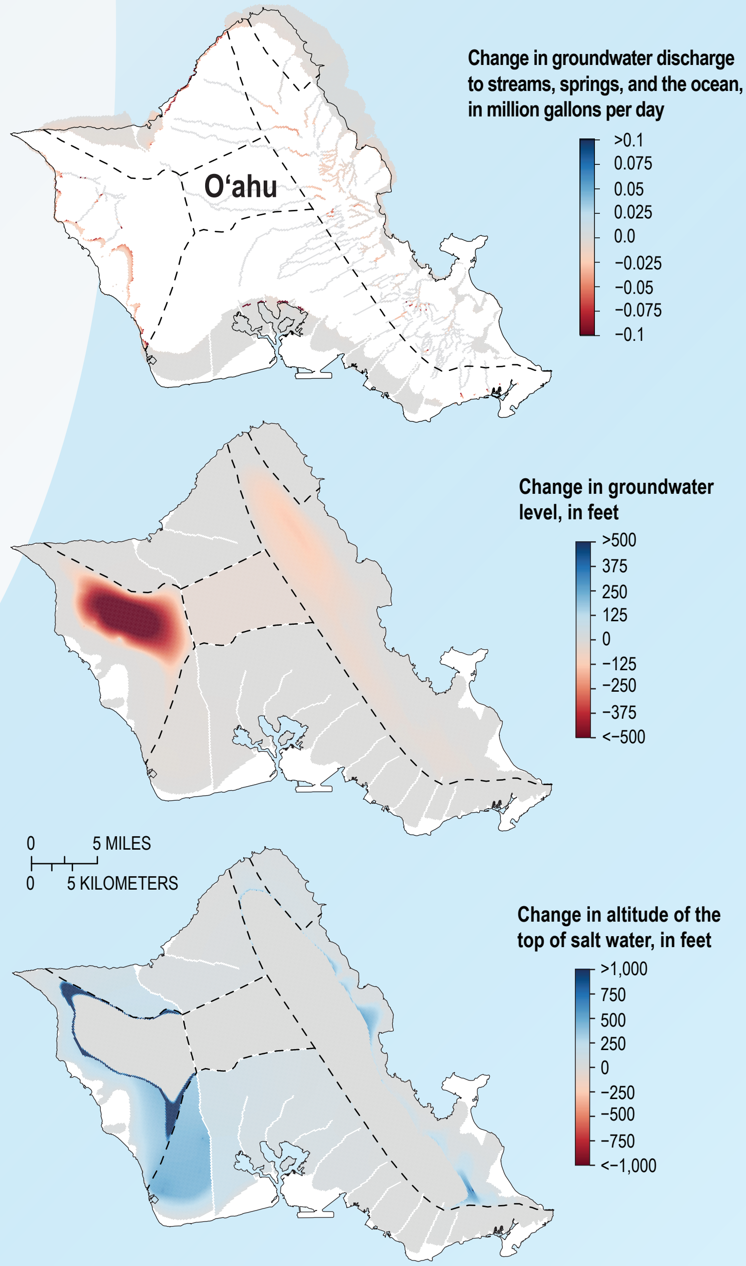


Maps of model results show the effects of groundwater withdrawals on O‘ahu's aquifers from 2001 to 2010. Similar maps for Kaua‘i and Maui can be found at https://doi.org/10.3133/pp1876.

Changes in land use or climate can cause changes in groundwater recharge over time. Results of the HVAS indicate that changes in recharge to Hawaiʻi's aquifers can alleviate or exacerbate the consequences of groundwater withdrawals. The degree to which recharge changes alter the consequences of withdrawal depends on the groundwater setting and the magnitude and location of the recharge changes.

- **Increases in recharge can offset the consequences of groundwater withdrawals**—In Hawaiʻi, increases in recharge have resulted from human activities, such as crop irrigation and construction of surface-water reservoirs.
- **Decreases in recharge can exacerbate the effects of withdrawals**—In Hawaiʻi, decreases in recharge have resulted from land-use changes, such as changes in agriculture and replacement of native forest by nonnative forest. Substantial decreases in future recharge are also indicated by HVAS computations that use projections of future decreases in rainfall by Ellison Timm and others (2015).





Maps of model results show how land-use change from 1870 to 2010 caused changes in groundwater recharge that affected groundwater levels on Kauaʻi, and how changes in future groundwater recharge may affect Oʻahu using the projected climate changes of representative concentration pathway 8.5 for years 2041–2070 in Elison Timm and others (2015). Other maps showing effects of recharge changes can be found at https://doi.org/10.3133/pp1876.

Groundwater Availability Depends on Acceptable Limits to Consequences

The HVAS demonstrates that groundwater withdrawals have consequences that are quantifiable through groundwater models. An essential next step in assessing groundwater availability is to set acceptable limits to these consequences, that is, how much water-table depression, saltwater rise, and reduction of groundwater discharge to streams and the ocean is acceptable. Setting acceptable limits typically involves multiple stakeholders and consideration of diverse factors such as human and environmental health, traditional and customary practices, economic growth, and legal rights and statutes. Once acceptable limits to the consequences are set, additional model simulations can determine how much water can be withdrawn within those limits. Model results can thereby inform management decisions that seek to balance the need to limit the consequences of groundwater withdrawals with the need to develop water for human use.

Reference Cited

Elison Timm, O., Giambelluca, T.W., and Diaz, H.F., 2015, Statistical downscaling of rainfall changes in Hawaiʻi based on the CMIP5 global model projections: Journal of Geophysical Research; Atmospheres, v. 120, p. 92–112, https://doi.org/10.1002/2014JD022059.

Further Reading

Izuka, S.K., Engott, J.A., Rotzoll, K., Bassiouni, M., Johnson, A.G., Miller, L.D., and Mair, A., 2018, Volcanic aquifers of Hawaiʻi—Hydrogeology, water budgets, and conceptual models (ver. 2.0, March 2018): U.S. Geological Survey Scientific Investigations Report 2015-5164, 158 p., https://doi.org/10.3133/sir20155164.

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Izuka, S.K., Rotzoll, K., and Nishikawa, T., 2021, Volcanic aquifers of Hawaiʻi—Construction and calibration of numerical models for assessing groundwater availability on Kauaʻi, Oʻahu, and Maui: U.S. Geological Survey Scientific Investigations Report 2020–5126, 63 p., https://doi.org/10.3133/sir20205126.

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