Assessment of Hydraulic Properties through Tidal Ground-level Analysis for the State of Hawaii

Basic Information

Title:	Assessment of Hydraulic Properties through Tidal Ground-level Analysis for the State of Hawaii
Project Number:	2013HI438S
USGS Grant Number:	G13AP00074
Sponsoring Agency:	USGS
Start Date:	8/5/2013
End Date:	12/31/2014
Funding Source:	104B
Congressional District:	1
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Models, None
Descriptors:	
Principal Investigators:	Aly I El-Kadi

Publications

1. Rotzoll, K., D.S. Oki, and A.I. El-Kadi, 2014, Development of a hydrogeologic framework from tidal analysis of coastal groundwater levels, Hawaii, 40th American Water Works Association Conference, Honolulu, May 6–9.
2. Rotzoll, K., D.S. Oki, and A.I. El-Kadi, 2013, Development of a hydrogeologic framework using tidally influenced groundwater levels, Hawaii. Abstract H11H–1248, presented at 2013 Fall Meeting, AGU, San Francisco, CA, Dec. 9–13.
3. Rotzoll, K., D.S. Oki, and A.I. El-Kadi, 2014, "Up and Down: How can we assess hydraulic properties from tidal fluctuations in coastal aquifers?", Abstract H53B-0845, presented at 2014 Fall Meeting, AGU, San Francisco, CA, Dec 15–19.

Problem and Research Objectives

The Hawaii aquifers supply water to 1.36 million residents, diverse industries, and a large segment of the U.S. military in the Pacific. With the increase of residential population on the islands, drinking water resources remain limited and are therefore susceptible to impacts from human activity and climate change (Izuka 2013). Decisions related to future infrastructure development and alternate sources of freshwater, including desalinization, depend on the long-term sustainability of the groundwater resources in Hawaii's aquifers.

Numerical groundwater models are becoming standard tools for sustainable development and optimal resource management (e.g., Oki 2005, Gingerich 2008). Identifying relevant components in the hydrogeologic framework and quantifying hydraulic properties for volcanic rock aquifers helps to constrain input parameters for models used in ongoing U.S. Geological Survey (USGS) groundwater-availability and groundwater-resources studies in Hawaii (Izuka 2013). Additionally, evaluating hydraulic properties for coastal sediment aquifers can be beneficial for studies assessing the effects of sea-level rise (e.g., groundwater inundation), including groundwater height in coastal inundation scenarios (Rotzoll and Fletcher 2013).

Ocean-tide signal attenuate through coastal aquifers based on the aquifer's regional hydraulic diffusivity (Jacob 1950, Ferris 1951). Thus, analyzing tidal amplitude decay with distance from the coastline allows estimating regional-scale hydraulic properties and identifying the importance of different hydrologic units (Rotzoll et al. 2013). A few localized studies of tidally influenced groundwater levels in Hawaii exist (e.g., Dale 1974, Gingerich 1995, Oki, 1997, Rotzoll et al. 2008), but a statewide compilation and comparison is lacking.

In this study, aquifer properties were examined in a regional context with respect to the hydrogeologic framework of each island. Hydrologic data exist for some areas in Hawaii, but there has been no effort to synthesize the existing separate efforts into a comprehensive framework for the entire Hawaiian Islands region. The results help to better understand the groundwater flow processes in Hawaii aquifers and facilitate the development of regional numerical groundwater flow and transport models. Water managers and hydrologists benefit from a more detailed characterization of the regional groundwater-flow properties for various purposes (e.g., monitoring, management, and research).

The scope of work covers the large-scale estimation of hydraulic properties of volcanic-rock and coastal-sediment aquifers from tidal attenuation by compiling available data for the state of Hawaii.

Methodology

Tidal attenuation was analyzed by comparing the amplitudes of groundwater level fluctuations occurring on tidal frequencies against the ocean tide amplitudes. This study analyzed existing continuous water-level records, in addition to published tidal-attenuation data from Oahu (Pearl Harbor [Dale 1974], the North Shore [Oki 1997], Honolulu [Rotzoll and Fletcher 2013]), east Maui (Gingerich 1995), and central Maui (Rotzoll et al. 2008). Continuous ocean water level was recorded at several tide gages in Hawaii (National Oceanographic and Atmospheric Administration 2013). Groundwater level records were collected by the USGS and other entities from various wells across the state. Also, unpublished hydrographs from USGS well folders were digitized and compared to historic tides. Although generally short in duration, tidally influenced constant-rate aquifer test data were digitized from state well-permit applications and compared to ocean tide amplitudes.

Filtering methods to separate water-level fluctuations caused by ocean tides and other environmental stresses, such as barometric pressure and long-period ocean level variations, were explored. For short-term records, several approaches to identify tidal components were examined.

The results of the tidal influence were separated by the island, and by the volcanic rock and the coastal sediment aquifers. The goal is to include the areas that were not assessed comprehensively (e.g., Kauai, Molokai, and the Island of Hawaii). Moreover, groundwater records with little or no tidal influence in coastal areas, allowed identifying areas that have limited hydrological connection to the ocean. Finally, tidally derived aquifer parameters were compared statewide.

Principal Findings and Significance

Hawaii aquifers are extremely heterogeneous. However, they can generally be grouped into three simplified hydrogeologic units: (1) dike-intruded volcanic rock, (2) dike-free volcanic rock, and (3) sediments and rejuvenated Volcanics. The tidal response in groundwater levels can also help to identify these hydrogeologic units and aid in estimating regional hydraulic properties. For example, no tidal signal was observed in the hydrogeologic unit of dike-intruded volcanic rock. It was also found that the lower-permeability caprock unit causes a damping effect for the tidal signal at the boundary. This study combined the volcanic-rock aquifer-diffusivity and the hydraulic conductivity of different regions on each island. The subsequent results were related to the general age of the island. It was demonstrated that hydraulic-conductivity estimates generally decrease with the island age because weathering reduces open pore space and flow paths. The results from this study will be used in the regional island-wide numerical models by the USGS Groundwater Resources Program.

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