Optimal Management of Freshwater Lens for Extreme Droughts in Tongatapu Island

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ABSTRACT

Groundwater is the only perennial source of freshwater in the Tongatapu Island, the largest island of Kingdom of Tonga. Rainfall harvesting allows additional but intermittent freshwater. Groundwater exists in the form of a thin lens on top of subsurface seawater; the thickness reaches up to 15 m. In the first phase of the project a steady state sharp interface numerical model was developed to assess the status of the freshwater lens in the island. The model result was calibrated against observed freshwater thickness values at 16 monitoring wells. The numerical model estimated the total volume of fresh groundwater residing in the 259 km^2 island to be approximately 2 Gm^3. However, more than half of the volume exists in the thinner part of the lens with the thickness less than 10 m where groundwater development is susceptible to saltwater up coning. More than 250 pumping wells are known to exist and withdraw roughly 27,250 m^3/d. Fifty of them are public wells and are clustered in the small well field. Other wells are village wells and are dispersed throughout the island. Locations of more than half of village wells are not known. The steady state model was used to assess impacts of various hypothetical conditions. In the second phase of the project an unsteady state model was developed to investigate impacts of future droughts. Selected GCM prediction was used to identify periods with the worst drought indices: the longest drought period reached to 77 months. Impacts of the drought were significant. When public wells continued to operate at the same pumping rate, saltwater would start to intrude a well after 23 months into the drought and contaminated up to 23 public wells during the drought. The total freshwater production was reduced to 83.1 % of that of the normal condition. The minimum daily freshwater production would be as low as 50% of that of the normal condition. An optimization model was developed to identify the optimal pumping schedule to investigate if more groundwater can be extracted without saltwater intrusion during the period. Fifty public wells were divided into four groups depending on the maximum saltwater intrusion ratios. The drought period was divided into 13 blocks of six months. Pumping wells in each group were to operate at the same pumping rate during a six-month block. The target of the optimization was to identify 52 (=4*13) pumping rates to maximize the total volume of freshwater production during the drought. The simulation-optimization model identified a pumping schedule which would produce 91.2 % of the total volume under the normal condition. The minimum daily production was 75 % of that of the normal condition. Although droughts are never known in advance, the simulation-optimization model offers a useful tool in managing groundwater resources in islands.

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