Modelling of a vanishing Hawaiian stream with DHSVM

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Abstract
Several Hawaiian streams show downward trends in stream flow. In this study Makaha Stream is investigated as an example. Three possible reasons are commonly mentioned for the discharge reduction: groundwater pumping, decreasing rainfall, and changes in vegetation. The effect of these factors on stream flow is evaluated with the model DHSVM. It appears that groundwater pumping is the most likely reason for stream flow reduction in Makaha Valley. To improve the model results more information about the complex volcanic underground is required.

Introduction
Hawaiian watersheds are relatively small, have steep terrains and are subject to heavy rainfall intensities which make them very sensitive to natural changes and anthropogenic influences. Fresh water resources for domestic, agricultural and industrial uses are very finite on small islands such as Hawaii. Therefore, it is extremely important to understand the hydrology of these small watersheds and the impact of any changes on them for their optimum water management. In recent years, stream flow of several Hawaiian streams has decreased. In this study Makaha Stream, located on the island Oahu (see Fig. 1), is taken as an example of a vanishing stream. Since 1990 the number of days Makaha Stream carries no water has increased from a few days to more than 100 days per year. To investigate the water balance of the Makaha watershed, the upper part of the watershed was modelled with the physically based Distributed Hydrology Soil Vegetation Model (DHSVM). Using this model, the impact of groundwater pumping, decreasing rainfall and changes in vegetation on stream flow was examined. These factors are considered possible causes for the decreasing discharge in Makaha Stream (Mair et al., 2007).

DHSVM
The Distributed Hydrology Soil Vegetation Model (DHSVM) was originally developed by Wigmosta et al. (1994, 2002) and simulates, at high spatial resolution, the dynamics in the land-related components of the hydrological cycle. DHSVM is typically used for water balance studies of small mountainous watersheds like Makaha Valley. For this study version 2.0 was used including a deep groundwater component (DHSVM, 2008). The available data of the upper part of Makaha Watershed (5.5 km^2) on topography, soil, vegetation, and meteorology were implemented in DHSVM using a 30 x 30 m grid and hourly time step.

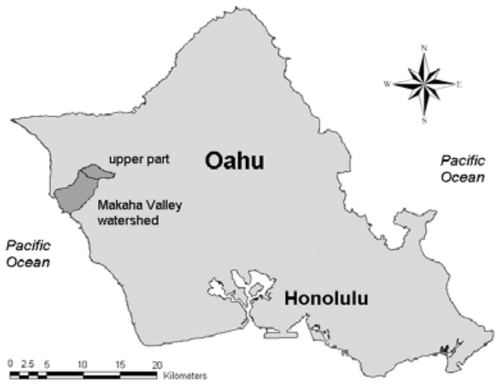

Figure 1. Location of Makaha Valley watershed on the Hawaiian island Oahu.

Calibration and validation
A complex model like DHSVM has many parameters that can be used for calibration. First, a sensitivity analysis was performed to identify the most useful parameters for calibration. Based on this sensitivity analysis the following parameters were selected for calibration: soil depth, base layer conductivity (for loss to deep groundwater), lateral conductivity of the soil, exponent for change of lateral conductivity with depth, and maximum infiltration rate. The model was calibrated for the period November 2005 through May 2006 by changing these parameters, in the order given above, from their default value until the best match was found between simulated and measured stream flow data. Because lateral conductivity and the exponent describing the change of this parameter with depth are likely to be interdependent, several combinations of these two parameters have been tried to find the best fit. The final calibration result is shown in Fig. 2. The fit is reasonable although the peaks are somewhat underestimated and the decline of the hydrograph after a peak is slightly too fast. The validation was done for the same period a year later. Unfortunately the model performance for the validation period was not as good as for the calibration period.

Table 1. Water balance (in mm) of reference situation (calibrated) and scenarios over the period November 2005-May 2006.

	Reference	Groundwater pumping	Rainfall (-15%)	Vegetation change
Initial storage	**1368**	**1368**	**1368**	**1368**
Final storage	**2097**	**2049**	**1965**	**2010**
Input (rainfall)	**1260**	**1260**	**1070**	**1260**
Output	**531**	**579**	**473**	**618**
Runoff	142	117	97	120
Evapotranspiration	389	389	367	498
Loss to deep groundwater	0.34	73	0.32	0.34

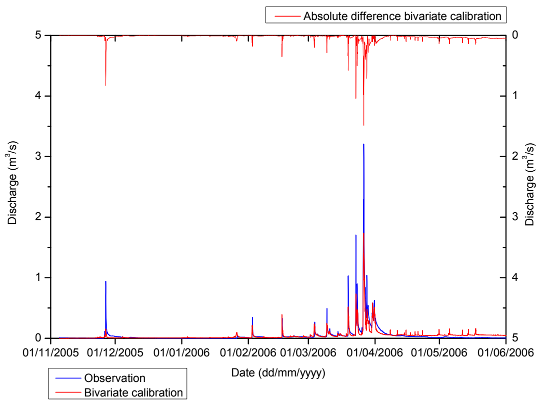

Figure 2. Observed and simulated discharge and absolute difference after calibration.

The calibration and validation could be further improved; however, the results were thought to be sufficient for the scenario analysis.

Scenario analysis

The calibration period was used to evaluate the impact of groundwater pumping, decreasing rainfall, and changes in vegetation on stream flow.

Groundwater pumping was simulated by changing the base layer conductivity such that the loss to deep groundwater increased to a total value of 73 mm over the simulated period, approximating the average amount of groundwater pumping since 1991.

Trends in rainfall in Makaha Valley have been studied by Mair et al. (2007). Between the pre-pumping (1960-1990) and the pumping period (1991-2005), mean annual rainfall at a gage near the outlet of the watershed decreased by 14%. A gage at the highest point in the watershed, however, showed a slight increase in rainfall of 2%. To investigate the effect of less rainfall, the rainfall was decreased with 15% over the entire area.

In Makaha Valley part of the native species has been taken over by invasive species that have different evaporation and interception characteristics. This has been modelled by changing the current vegetation of mainly forest and shrubs to evergreen forest which increased evaporation and decreased through fall.

Table 1 shows the water balance for each scenario. From the table it can be seen that all scenarios reduce the runoff. When looking at the hydrographs (not shown) it appears that lower rainfall mainly reduces the peak flow, while groundwater pumping reduces base flow. Changes in vegetation characteristics have little impact on the overall hydrograph.

Conclusions

Model results showed that base flow was most sensitive to groundwater abstraction, while peak flow was affected most by changes in rainfall. The influence of changes in vegetation characteristics on stream flow was negligible. Since base flow is the most continuous source of water, it is likely that groundwater pumping has a major contribution to the increased number of days that Makaha Stream carries no water.

The high resolution of DHSVM seems to be adequate to model a small mountainous watershed like Makaha Valley. The calibration can probably be improved by more advanced calibration techniques. Modelling the volcanic underground with complex dike systems, however, remains a problem due to lack of data.

References

DHSVM (2008) DHSVM website http://www.hydro.washington.edu/Lettenmaier/Models/DHSVM/index.shtml (last accessed November 2008)

Mair, A., A. Fares, and A. El-Kadi (2007) Effects of rainfall and groundwater pumping on stream flow in Makaha, Oahu, Hawaii. Journal of the American Water Resources Association 43(1):148-159.

Wigmosta, M.S., D.P. Lettenmaier, and L.W. Vail (1994) A distributed hydrology-vegetation model for complex terrain. Water Resources Research 30(6): 1665-1679.

Wigmosta, M.S., B. Nijssen, and P. Storck (2002) The distributed hydrology soil vegetation model. In: V.P. Sing and D. Frevert (eds.) Mathematical models of small watershed hydrology and applications. Water Resources Publications, p. 7-42.