DEEP PERCOLATION OF WATER FROM PINEAPPLE FIELDS

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SUBSURFACE WATER QUALITY: PESTICIDES CONTAMINATION

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COOPERATING AGENCIES

Federal

U.S. Department of the Navy
U.S. Geological Survey

State of Hawaii

Department of Health

City and County of Honolulu

Board of Water Supply

PREFACE

This report is part of the "Subsurface Water Quality: Pesticides Contamination" project authorized in Act 285, Section 38F, by the Twelfth Legislature, State of Hawaii, and supported by the Office of Environmental Quality Control with the cooperation of several data collecting agencies. Other project activities currently in progress focus on the following topics: geologic factors, mineralogic parameters, chronology of deep water percolation through pineapple fields, leaching properties of fumigants from soils, temporal and spatial distributions of contaminants in basal groundwaters, well and aquifer rehabilitation, and methods of contaminant removal. Forthcoming reports will present the results of these activities.

ABSTRACT

Efforts are being made to identify the sources, concentrations, spatial extent, movements, and rates of degradation of recently detected groundwater contaminants in Hawai'i. A spatially detailed evaluation of the time series of water percolation is required so that leaching from the top soil, downward transport through the profile, and eventual movement of the pesticides within the basal groundwater may be estimated. Using the water balance method, the 1946 through 1983 sequence of downward percolating water will be estimated for each present and former pineapple growing area of central O'ahu. Thus far, work on this project has focused on land-use identification, parameter evaluation, and data gathering. Results obtained using the same model in a previous study indicate that ET-suppression by pineapple causes percolation to be significantly higher than that experienced under a natural vegetative cover. This may account for the unexpected movement of these chemicals through the great thickness separating the pineapple fields from the basal water table.

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INTRODUCTION

In recent years, various chemical contaminants have been detected in Hawai'i's groundwater supplies. Three compounds, dibromochloropropane (DBCP), ethylene dibromide (EDB), and trichloropropane (TCP), have been of particular concern because of their associated health effects, both known and unknown. It is suspected that DBCP and TCP were transported to the basal groundwater by downward percolating water from pineapple fields. Soil fumigation by DBCP and another fumigant containing TCP has been used by the pineapple growers in Hawai'i for nematode control. EDB has also been used as a pesticide in some pineapple fields. However, since EDB is found in gasoline, it is possible that the contamination originated from one or more fuel pipeline spills that have occurred in the region. Although the use of the compounds as pesticides has been discontinued, the recent discoveries raise questions about their possible continued leaching into the groundwater from contaminated soils and rock of the vadose zone.

Efforts are now being made to identify the sources, concentrations, spatial extent, movements, and rates of degradation of the groundwater contaminants. A spatially detailed evaluation of the time series of water percolation is required so that leaching from the top soil, downward transport through the profile, and eventual movement of the pesticides within the basal groundwater may be estimated. The purpose of this study is to provide an estimate of downward percolating water in high spatial and temporal detail for present and former pineapple growing areas of central O'ahu.

METHODOLOGY

The water balance method is used in this study to estimate the sequence of downward percolating water for each location of interest. The study area includes all areas overlying the principal groundwater bodies of central O'ahu which have been used for pineapple cultivation at any time between 1946 and 1983. The water balance is computed separately for each major pineapple field on a monthly time interval for the entire study period, 1946 through 1983, regardless of whether the area remained in pineapple. Thus, the model should be adaptable for handling various alternative land uses.

Using principles developed by Thornthwaite (1948), and Thornthwaite and Mather (1955), and others, a model of the water balance was devised in which the influences of land use are described by certain variables. Other variables in the model account for the climatic influences and site factors unaffected by land use. With such a model, the appropriate climatic sequence and land use parameters can be used to estimate the water balance for a particular time and place.

Model

The model used in this study is a variant of the Thornthwaite and Mather (1955) bookkeeping procedure. For a given location, the model keeps account of the moisture exchanges that occur within the soil-plant system during each time interval. To do so, the state variable X_i is first computed. (Variables are expressed as the average equivalent water depth over the entire area unless otherwise noted.) X_i is determined as

$$X_i = S_{i-1} + (P_i - RO_i)G^{-1} + I_i + U_i - E_i$$

where S_{i-1} is available soil moisture at beginning of time interval i, (unpaved area only); P_i is precipitation during time interval i; RO_i is surface runoff during time interval i; G is ratio of unpaved area to total area; I_i is agricultural irrigation during time interval i, U_i is urban irrigation during time interval i (applied to a portion of unpaved area depending on degree of urbanization); and E_i is actual evapotranspiration during time interval i. On the basis of X_i, the end-of-interval soil moisture and percolation are determined as

$$S_i = 0 \qquad \text{For } X_i < 0$$
$$Q_i = 0$$
$$E_i = -X_i$$

$$S_i = X_i \qquad \text{For } 0 < X_i < \Phi$$
$$Q_i = 0$$

$$S_i = \Phi \qquad \text{For } X_i > \Phi$$
$$Q_i = G(X_i - \Phi)$$

where S_i is available soil moisture content at the end of time interval (unpaved area only); Q_i is downward percolation beyond the root zone during time interval i; and Φ is soil available moisture capacity (unpaved area only). Note that when X_i is negative, E_i is also adjusted.

Each input variable in the model is evaluated by direct measurement or by estimation from physical or empirical relationships. The evaluation of input variables is described below.

Precipitation

Monthly precipitation is estimated at each node of a 10 by 10 grid superimposed over the study area by computer interpolation. The monthly precipitation sequence for each pineapple field is assumed equal to that of the nearest node.

Runoff

Runoff in the water balance model is defined to include overland flow, interflow, and high level spring flow. Streamflow data are insufficient for estimating runoff at the spatial resolution required for this study. Runoff curve numbers have been derived experimentally for Hawai'i pineapple and sugarcane fields (Cooley and Lane 1980) for use in the Soil Conservation Service (SCS) (U.S. Department of Agriculture 1972) runoff model. A modified version of the SCS method (Giambelluca 1983) is used to estimate monthly runoff for each pineapple field.

Agricultural Irrigation

Sugarcane irrigation is estimated on the basis of well pumpage, ditch flow, and stream diversion records. Pineapple in Hawai'i is traditionally irrigated only at planting time and during extreme drought. The amounts had a negligible effect on the water balance. In recent years, drip irrigation systems have been installed in some fields, and these now receive a significant amount of irrigation. Pineapple irrigation is estimated from water source records.

Urban Irrigation

Seasonal fluctuation in municipal water consumption on O'ahu has been attributed to variations in outdoor uses, primarily lawn sprinkling (Yamauchi 1981). Assuming that the lowest observed water use represents a period of no lawn sprinkling (an extended rainy period), the volume of water used for urban irrigation was computed for each month of a 10 yr sample period. The area over which this irrigation occurred was estimated and monthly depths of lawn sprinkling determined (Giambelluca 1983, Table 9). Monthly means from the 10 yr sample period are used as input to the water balance model for residential and park land uses.

Evapotranspiration

Evapotranspiration (ET) is evaluated using the concept of potential evapotranspiration (PE) (Thornthwaite 1948). Evaporative demand (PE) is first determined. Actual evapotranspiration (E) is estimated as a fraction of PE according to the prevailing soil moisture content. PE is estimated on the basis of recently prepared annual pan evaporation maps (Ekern and Chang 1985). Average monthly PE is estimated from the annual figure and seasonal patterns at individual pan stations. Adjustments are made for surface type and vegetation density. The relationship between E and soil moisture for Hawai'i developed by Giambelluca (1983) depends on soil type, root depth, and evaporative demand (PE).

INTERIM RESULTS

Thus far, work on this project has focused on land-use identification, parameter evaluation, and gathering of necessary hydrological data. As such, no percolation figures are yet available. However, based on previous studies using the same model (Giambelluca 1983), it appears that ET-suppression by pineapple causes percolation to be significantly higher than that experienced under a natural vegetative cover. This fact has important implications regarding the leaching of pesticides and may account for the unexpected movement of these chemicals through the great thickness separating the pineapple fields from the basal water.

Project tasks and approximate portions completed as of 15 November 1985 are listed below.

1. Land Use. Identification of O'ahu pineapple growing areas and their land use chronologies since 1946. 80% complete.
2. Soils. Identification of type and hydrologic characteristics of soils for each pineapple field. 90% complete.

3. Precipitation. Compilation of monthly precipitation records for all pertinent stations in central O'ahu during the 1946-1983 period; development of methodology to interpolate monthly station rainfall to grid nodes; interpolation of monthly rainfall at grid nodes for each month of study period. 40% complete.
4. Runoff. Development and testing of methodology for estimating monthly runoff from each field under various possible land uses; computation of runoff for each field, each month. 10% complete.
5. Irrigation. Compilation of irrigation records for sugarcane and pineapple; conversion of volumetric data for equivalent depths for each field, each month; estimation of average monthly urban irrigation. 20% complete.
6. Evapotranspiration. Evaluation of PE for each pineapple field based on recent pan evaporation maps. 0% complete.
7. Percolation. Computation of monthly percolation from each pineapple field using water balance model. 0% complete.

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