MODELING HYDROGEOLOGY AND GEOTHERMAL ENERGY IN THE KILAUEA EAST RIFT ZONE, HAWAII

A Preproposal

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INTRODUCTION

Models are useful tools in the advancement of a systematic approach for the development of conventional groundwater systems as well as geothermal energy resources. They can help in the characterization of the nature, distribution, and availability of a specific groundwater or geothermal resource. Based on availability of information about the site, models of different degrees of complexity can be designed. In their simplest form, models can be used to identify some basic information regarding the geothermal reservoir, such as its approximate depth and areal extent. As more information becomes available, sophisticated models can be developed to design, evaluate, and optimize energy utilization schemes. Such models can describe in much greater detail fluid and heat conditions in the field. Employed in such an analysis is the mathematical description of various physical and chemical processes in the reservoir. This class of models employs spatially distributed parameters and uses numerical techniques, such as the finite element, finite difference, and integrated finite difference techniques. Complicated procedures are necessary due to the highly nonlinear nature of the equations and because of phase change.

HYDROGEOLOGY OF THE KILAUEA EAST RIFT ZONE

The hydrology and geology of the Kilauea East Rift Zone (ERZ) can be found in Macdonald, Abbott, and Peterson (1983), Kroopnick et al. (1978), Imada (1984), Thomas (1987), and Jackson and Kauahikaua (1987), among others. The ERZ extends from the summit caldera toward the east for approximately 50 km, where it enters the ocean and continues as a submarine ridge for another 50-60 km. The rift is composed of a very large number (may be in the thousands) of near-vertical thin tabular dikes interspersed with highly fractured country rock (Macdonald, Abbott, and Peterson, 1983). The ERZ is characterized by high recharge rates as the rainfall exceeds 2.5 m/yr.

Two distinct groundwater bodies are known to occur in the ERZ; the deep geothermal reservoir containing hot thermal waters, and overlying this a shallow low-temperature aquifer containing potable groundwater. The degree of inter-connection, if any, between the two aquifers is not well understood.

The characteristics of the shallow potable groundwater body are fairly well understood. Outside the ERZ the groundwater behaves as a normal basal lens of fresh water overlying and displacing seawater. Within the ERZ the shallow groundwater is somewhat elevated because it is confined by the dikes. There is rapid groundwater flow within the shallow aquifer due to the very high permeability of the surface volcanic rocks, and groundwater residence-time is typically less than 10-20 yrs (Kroopnick et al., 1978). Discharge of basal fresh water in coastal springs is known to be in the order 88-131 m^3/s (Stearns and Mcdonald, 1946; Davis and Yamanaga, 1968; and Macdonald, Abbott, and Peterson, 1983).

The characteristics of the deep geothermal reservoir are less well-known. It is quite clear, however, that permeabilities are considerably reduced, that groundwater occurrence is predominately compartmentalized, and that flow is strongly fracture controlled. Recharge to the geothermal reservoir is thought to come from underlying saltwater as well as from surface recharge via the overlying shallow fresh groundwater body. The amounts and rates are not well understood.

OBJECTIVES

Successful exploration, development, and operation of the geothermal resource in Kilauea's ERZ requires a basic understanding of the hydrogeology and hydraulics of both the deep geothermal reservoir and the shallow fresh water aquifer, and their interaction with each other. In particular the areal extent, the nature of external and internal boundaries, fluid flow and transport mechanisms, the amount and source of fluid recharge, and the magnitude and extent of heat source are all critical in defining how and where the resource will be developed and operated. The impact of re-injection of waste fluids on the reservoir must be understood, as well as the impact of geothermal development operations on the shallow fresh water aquifer because this aquifer serves as the potable water source for a sizable population in the region. Finally, in response to recent well blowout problems, it has been stipulated that every geothermal well drilled in the ERZ must have a source of water available adequate to control a possible well blowout. This water almost certainly must come from the shallow groundwater body, which makes it even more critical that the distribution and size of this aquifer be well delineated.

In order to assist in providing the above-described information on the Kilauea ERZ hydrogeology, this proposal includes the following objectives:

1. To evaluate the overall hydrologic and hydraulic nature of the geothermal reservoir system, including:
   (a) Nature and distribution of the fluid flow system; is is dominated by continuum, fracture, or combination continuum-fracture flow?
   (b) Nature and extent of system boundaries including external and internal boundaries
   (c) Recharge sources and amounts
   (d) Reservoir parameters such as hydraulic conductivity, porosity, storativity, etc.
2. To evaluate the impact of re-injection of fluids on the geothermal reservoir and on the shallow fresh groundwater aquifer.
3. To evaluate the overall hydrologic nature and extent of the shallow fresh water aquifer and its interaction with the underlying geothermal reservoir.

APPROACH AND METHODOLOGY

The project will have three main tasks: (1) compilation of all available hydrogeologic data for ERZ and formulation of conceptual models of the geothermal reservoir system and the shallow fresh groundwater systems, (2) computer modeling of the geothermal reservoir system, and (3) computer modeling of the shallow fresh water aquifer system.

The task of data compilation will begin immediately and will consist of assembling all available geologic, hydrologic, and hydraulic data for the ERZ area, including information from the current SOH drilling project and all pertinent information from on-going private development. Furthermore, it is anticipated that a new ERZ hydrologic and geochemical data collection program will be undertaken concurrently with this proposed modeling study (D. Thomas, pers. comm.) to further augment the overall hydrogeologic data base for the area. These data will be used to formulate conceptual models of the geothermal and shallow groundwater systems. The conceptual models in turn will serve as the basis for selection of mathematical computer models of the two aquifer systems.

For computer modeling, the project will employ available models and will modify them as necessary to fit ERZ conditions. Treatment of the shallow fresh water aquifer should be fairly straightforward and several well-documented field-validated models are available, including SUTRA (Voss, 1984) for analysis of density dependent flow, and MOC (Konikow and Bredhoeft, 1978) and ASM (Kinzelbach and Rausch, 1990) for assessment of groundwater quality. The choice of a specific model or models will depend on a number of factors, including dimensionality of the problem and the major physical and chemical processes involved.

Modeling of the geothermal system is much more complicated, but several models for this purpose have been developed, including MULKOM (Pruess, 1983, 1988) which solves a system of equations describing conservation of mass and energy for multicomponent fluids under nonisothermal conditions. The fluids include water, noncondensable gases such as CO_2 and dissolved solids such as NaCl or SiO_2. Binary diffusion in the gas phase can be also modeled. Heat flow is assumed to occur by conduction and convection. Models dealing with flow in fractured media include MINC (Pruess and Narasimhan, 1982, 1985). The model employs the double-porosity approach in the simulation of the fractured system. It combines features of both the explicit fracture and effective continuum approaches. The main feature of the model is treating the fracture system is a continuum, which interacts with several matrix continua. The model is also equipped to handle nonequilibrium conditions between matrix and fractures and the transient interporosity flow effects. A recent model that includes the features of both MULKOM and MINC has recently been introducted by Pruess (1991). The model, called TOUGH2, which has been developed by scientists at Lawrence Berkeley Laboratory, is distributed by the National Energy Software Center, Argonne National Laboratory.

It should be emphasized that the objective of our proposed work is not to produce a full-blown reservoir management model, but rather to provide a coupled groundwater flow/geothermal model that will allow evaluation of basic resource concerns such as: (1) what is the nature and distribution of the fluid and heat flow system; is it dominated by continuum, fracture or combination continuum-fracture flow, (2) what is the nature and extent of internal and external system boundaries, (3) what are the recharge sources and amounts, and (4) what are the magnitude and distribution of reservoir parameters such as hydraulic conductivity, porosity, storativity, etc. It is intended that this level of geothermal modeling effort will provide the State of Hawaii with sufficient independent expertise, so that it can competently evaluate the various reservoir development and management proposals, reservoir management modeling outputs, etc. which it is anticipated will be submitted by private developers and operators to the State for consideration and possible action.

Although the first task of this project is to compile all available hydrogeologic data, it is recognized that many of the parameters needed for simulation are not readily available. Thus, an iterative procedure will be generally needed because models are not unique representations of the physical system. The iterative procedure will include making assumptions about the unknown parameters and the use of field-measured hydraulic and thermal responses of the system to validate these assumptions. In the absence of suitable or complete field measurements, a sensitivity or uncertainty analysis can be performed.

RESEARCH TEAM/BUDGET

Aly El-Kadi:	Principal Investigator
Frank Peterson:	Co-Principal Investigator
TBA:	Graduate Assistant (GA)

The project will be completed over a three-year period. The major budget items include:

Salary and Fringe Benefits	Year 1	Year 2	Year 3-
PIs (5% time)	15,000	16,500	18,000
GA	21,500	23,000	24,500
	36,500	39,500	42,500
Computer Software/Hardware	20,000	10,000	
Travel: Island of Hawaii	2,000	2,000	2,000
Lawrence Berkeley Lab	2,000		
Misc. Supplies	2,500	1,500	1,500
Publication		1,000	4,000
TOTAL	63,000	54,000	50,000

TOTAL PROJECT COST = $167,000

QUALIFICATIONS OF PRINCIPAL INVESTIGATORS

The Principal Investigator, Aly El-Kadi has over 14 years of modeling experience in various groundwater/unsaturated quantity- and quality-related problems. He has developed and applied models that adopt both the deterministic and stochastic approach for porous and fractured media. His expertise covers multiphase flow and transport under isothermal conditions (water/gasoline/vapor in the unsaturated zone) and under nonisothermal conditions, including phase change (water/vapor/ice in the unsaturated zone). His expertise has been greatly enhanced by working with state-of-the-art model review at the International Groundwater Modeling Center for seven years, before joining the University of Hawaii. This work included testing and validating a wide variety of models. Although he has not been involved directly in modeling geothermal reservoirs, his experience in multiphase transport under nonisothermal conditions, in transport in fractured media, and in stochastic analysis are all relevant to objectives of the current project.

The Co-Principal Investigator, Frank Peterson has 25 years of geologic and hydrogeologic experience working on a wide variety of insular and volcanic groundwater quantity and quality problems. He has conducted research and published extensively on groundwater occurrence and development problems throughout the Hawaiian Islands, including several studies on the island of Hawaii. He is a co-author (with G. Macdonald and A. Abbott) of the widely-used and acclaimed book Volcanoes in the Sea, Geology of the Hawaiian Islands. During the past several years he has increasingly worked on numerical modeling studies of insular groundwater systems involving both carbonate and basaltic aquifers.