1. INTRODUCTION

The Lake Tahoe Basin lies near the crest of the Sierra Nevada Mountains along the California-Nevada border about 150 miles northeast of San Francisco. Lake Tahoe has a surface area of approx. 191 square miles. The total land area of the Tahoe Basin's watershed is approx. 300 square miles, 70% of which is publicly owned. The volume of inflow and outflow from the lake is very small relative to lake volume. This results in a fragile ecosystem in which the actions of man and nature are tightly linked.

Over the past 40 years, a sharp increase in development has occurred around the lake, especially in the southern basin. During this period, lake water quality decreased dramatically. Increased nutrient and sediment discharge caused increased algae growth in lake water. In Lake Tahoe, algae productivity has been found to accelerate with the addition of phosphorous and nitrogen. Numerous studies have been conducted and remediation measures have been implemented to reduce the discharge of nutrients to the lake. Studies indicate that groundwater may play a significant role in this discharge. Water exchange between the lake and the adjacent groundwater at South Lake Tahoe is not well understood. Groundwater flow provides a mechanism for the transport of nutrients to the lake. The delineation of potential subsurface transport pathways will help aid future remediation efforts.

In July 2002, the U.S. Army Corps of Engineers-Hydrologic Engineering Center (HEC) was contacted by the Sacramento District of the U.S. Army Corps of Engineers to provide technical assistance with an on-going environmental study at the southern Lake Tahoe Basin in California. Specifically, HEC was requested to develop a groundwater flow model to better understand lake-groundwater interaction.

A numerical model was developed to estimate the volume, rate, and distribution of groundwater flux to the lake along its southern shore. Model results will be used to guide future nutrient remediation efforts. The model consisted of 6 layers with cells 200 ft square. Model layers generally varied from 10-50 ft thick. The model was calibrated to water levels and stream flows measured in fall 1996 and spring 2002.

2. SITE DESCRIPTION

2.1 Overview

The study area encompasses about 6 miles by 6 miles (Figure 1). General site boundaries include: Lake Tahoe to the north, the South Lake Tahoe airport to the south, and the mountain front recharge zones to the east and west. The eastern end of the study area extends to the California-Nevada border. The study area includes the city of South Lake Tahoe, the most populous city (pop. 23,609; 2000 census) in the Tahoe Basin.

2.2 Geology

Lake Tahoe is a prime example of a graben lake due to the dominant influence of crustal sinking in its formation. The lake occupies the depression between two up faulted mountain systems: the Carson Range to the east, and the Sierra Nevada to the west. The floor of this depression is 4700 ft MSL, the same as the Carson Valley to the east. There are four main groups of rocks in the Tahoe Basin: Pre-Cretaceous metamorphic rocks, Cretaceous granitic intrusions, Cenozoic volcanic rocks, and Quaternary glacio-fluvial deposits. Glaciation was prevalent along the western, southern, and northern sides of the basin. Huge valley glaciers as much as 1000 ft thick crept down canyons scouring away loose rock and building up great piles of morainal debris. Glaciers extending into the lower Truckee River, the lake's only outlet, formed an ice dam that raised the lake 600 ft above its present level. As the glaciers receded, the melted runoff water washed silt and sand into the lake and built thick deltas, the largest of which underlies the city of South Lake Tahoe.

The geology of the study area can be characterized by glacial, lacustrine, and alluvial deposits at the lower altitudes, flatlands, and low lying hills; and by granitic rocks that make up the steep mountain slopes. The major landforms attributed to glaciation in the study area are deep basin-fill deposits, steep mountain slopes adjacent to the upper reaches of Trout Creek, and large lateral moraines that divide the Upper Truckee River from Trout Creek and the Upper Truckee River watershed from Fallen Leaf Lake (TRPA and USFS, 1971). The unconsolidated deposits are heterogeneous at the project scale and generally consist of sand deposits with layers of clay and silt. The deposition of fine-grained lacustrine strata between coarser grained depositional events resulted in anisotropic conditions that restrict flow in the vertical direction.

2.3 Hydrology

The Tahoe Basin is located in what is classified as a humid continental climatic zone. The major characteristics of this type of climate are a cold winter with moderate to heavy precipitation, and a warmer, drier summer. Most of the precipitation in winter months is snow, though heavy winter rains can occur and often cause flooding. Intense summer thunderstorms have also caused localized flooding. The mean monthly temperature at South Lake Tahoe ranges from 28 degrees in January to 59 degrees in July. Average annual precipitation at the South Lake Tahoe airport is 34 inches.

Elevation has a major impact on precipitation. Annual snowfall in the Tahoe Basin can range from 100 in. at lake level to over 500 in. at higher elevations. The snow pack in the Tahoe Basin is usually developed in November and continues to increase through winter and early spring to such a depth that it often persists into June. The maximum water equivalent of snow pack depletion will occur at a rate of about 0.75 inches of water per day as measured in late April (Miller, 1955).

The Upper Truckee River and Trout Creek are the two largest surface inflows into Lake Tahoe. The 1996-2002 average flow of the Upper Truckee River at the I-50 crossing was 90 ft^3/sec. The 1996-2002 average flow of Trout Creek at Martin Avenue was 36 ft^3/sec.

3. PRIOR GROUNDWATER MODELING STUDIES

3.1 Woodling (1987) Model

Woodling (1987) developed a two-dimensional, steady-state groundwater flow model of the South Lake Tahoe area. The U.S. Geological Survey (USGS) groundwater flow model MODFLOW (McDonald and Harbaugh, 1988) was used to simulate the net water exchange between groundwater and Lake Tahoe. The model grid consisted of 25 rows (north-south) and 17 columns (east-west). Row spacing varied from 2,000 ft at the southern boundary to 1,000 ft at the lakeshore. Column spacing was a constant 2,000 ft. The model consisted of 1 layer with a total of 193 active cells.

Transmissivity values were derived from analysis of pumping tests. The distribution of transmissivity values correlated with sediment thickness, increasing gradually from the mountain fronts to the Tahoe Keys. Sediment depths ranged from zero at the mountain fronts to greater than 800 ft towards the Tahoe Keys area. Hydraulic conductivity of the sediments was assumed to be 10-15 ft/day. The specification of transmissivity in the model assumed that drawdown at wells was insignificant compared to aquifer thickness. This is a reasonable assumption.

Lake Tahoe was simulated using a constant head boundary specified as 6226 ft MSL. The southern model boundary near the airport was simulated using a constant head boundary. Outcrops on the east and west sides of the site were simulated using a specified flux boundary.

Simulated results indicated a net discharge to the lake of 1.9 ft^3/sec (164,000 ft^3/day). Over half of this discharge occurred in the Tahoe Keys area. The model simulated total flux to the lake, rather than net flux i.e. outflows – inflows. Significant inflows from the lake likely occurred due to pumping at the Al Tahoe and Paloma wells. The model did not simulate streams. Additionally, the new Valhalla pumping well near the western shoreline of the study area was not in operation at the time of model development.

3.2 AGRA (1999) Model

AGRA (1999) developed a three-dimensional groundwater flow (MODFLOW) model of the study area. The focus of the study was groundwater resource evaluation of the Al Tahoe and Paloma well fields. The model grid consisted of 46 rows (north-south) and 39 columns (east-west). Row and column spacing varied from 1,000 ft at the mountain fronts, and 500 ft at the well fields. The model consisted of 4 layers with a total of 4,073 active cells. Layer bottom elevations (MSL) were specified as: 6200 ft, 6100 ft, 5900 ft, and bedrock (5850 ft-5400 ft).