

Thesis Proposal:
A Reevaluation of the Groundwater Flow Model
for
Indian Wells Valley, California

Statement of Problem

Indian Wells Valley is an enclosed basin located in the southwest corner of the Basin and Range physiographic province in the California desert. It supports a population in excess of 20,000 as well as light agriculture, a Naval base, and a neighboring mining industry. It has historically occupied a unique position in California's water management plan, as water is neither imported into, or exported from the region.

As the local community relies solely upon groundwater found beneath the valley for its industrial, agricultural and municipal needs, the hydrogeology has received close scrutiny. Lee (1913) first studied the hydrology of Indian Wells Valley by estimating recharge based upon the orographic effect of precipitation in the watersheds which supply runoff to the valley. Since that time, with the growth of the local population and increased demands upon the groundwater reserves, concern has arisen as to the sustainability and the preservation of the quality of these reserves.

Numerous studies have since been made (Lee, 1913, Kunkel and Chase, 1969, Bloyd and Robson, 1971, Berenbrock and Martin, 1991, U.S. Bureau of Reclamation, 1993, Ostdick, 1997, Thyne and Gillespie, 1997) to characterize the aquifer in Indian Wells Valley with the aim of developing an effective groundwater management plan that would preserve the quality of the groundwater for sustainable use as demand and pumping increased. As a result of these studies, two aquifers have been identified within the valley, and estimations of aquifer parameters such as recharge, evapotranspiration, transmissivity, and storativity of the aquifers have been evaluated, revised and tested by various groundwater models that have been developed for the purposes of making recommendations for a responsible groundwater management plan.

The development of a responsible groundwater management plan has led to ongoing efforts to obtain and refine data on aquifer parameters and characteristics. As such, much new data has been collected since Berenbrock and Martin (1991) modeled groundwater flow in the Indian Wells Valley. With improved understanding of both aquifer parameters and subsurface geology in the Indian Wells

Valley as well as improved modeling techniques this proposal calls for a reevaluation of the groundwater flow models applied to the Indian Wells Valley.

Previously developed models (Bloyd and Robson, 1971, Berenbrock and Martin, 1991) have operated on the assumption that the Indian Wells Valley is a closed hydrogeologic basin where, under steady-state conditions, recharge has equaled discharge through evapotranspiration which has largely taken place upon the playa at China Lake. As such, estimations of recharge have been based largely upon estimations of evapotranspiration, and models have been calibrated under this assumption. Additionally, the southwest portion of the valley has been defined as a distant no-flow boundary that offers no recharge to the groundwater being modeled due to lack of data from this portion of the valley.

The U.S. Bureau of Reclamation has recently drilled numerous multi-component observation wells in the southwest and western portions of the valley (U.S. Bureau of Reclamation, 1993). Both slug tests in the USBR piezometers and recent well tests performed by the Indian Wells Valley Water District in the southwest portion of the valley indicate transmissivities as high as 40,000 ft²/day (Krieger, 1997). These transmissivity values are much higher than suggested by previous models in the southwest portion of the valley. Transmissivities in the west-central portion of Indian Wells Valley on the other hand may be significantly lower than calibrated by earlier models (Berenbrock and Martin, 1991) based upon recent well logs indicating clay lenses in excess of 1000 feet thick in the vicinity of Neal Ranch.

Groundwater gradients obtained from recently drilled piezometers and wells, constrained by gravity surveys (Zbur, 1963; Ostdick, 1997) allow for estimations of groundwater flux in the southwest portion of Indian Wells Valley through the application of Darcy's Law. A calculated flux of 33,500 acre feet/year has been suggested by Ostdick (1997), and Thyne et al., (in press).

Geochemical data from the southwest portion of the Valley (Whelen et al., 1989; Houghton, 1994; Berenbrock and Schroeder, 1994; Ostdick, 1997) and the calculated groundwater flux suggests that the majority of the valley's groundwater may enter through the southwest portion of Indian Wells Valley. This flux has not been included in previous groundwater flow models.

Given the recent acquisition of geochemical and hydrological data in the southwestern portion of Indian Wells Valley, well log data in the central portion of the valley, and well log and hydrological data from within the Naval Weapons Center at China Lake, a reevaluation of the groundwater flow models is warranted.

Geography

Indian Wells Valley is located approximately 120 miles north of Los Angeles and contains the towns of Ridgecrest, and Inyokern, as well as the China Lake Naval Air Weapons Station. It lies within Kern, Inyo and San Bernardino counties comprising an area of approximately 480 square miles (Figure 1).

Indian Wells Valley is located within the southwestern most corner of the Great Basin of the Basin and Range physiographic province.

Indian Wells Valley lies north of the Garlock Fault and east of the Sierra Nevada Frontal Fault. It is bounded by the Sierra Nevada Mountains on the west, the Coso Mountains on the north, the southern Argus Mountains to the east, and the El Paso Mountains and Rademacher Hills to the south. Surrounding mountains can reach elevations of nearly 9,000 feet above sea level in the Sierra Nevada, while the valley's elevation ranges from 2,175 feet to 2,400 feet above sea level, with the lowest elevation of 2,150 feet on the playa of China Lake in the east-central part of the valley (St. Amand, 1986).

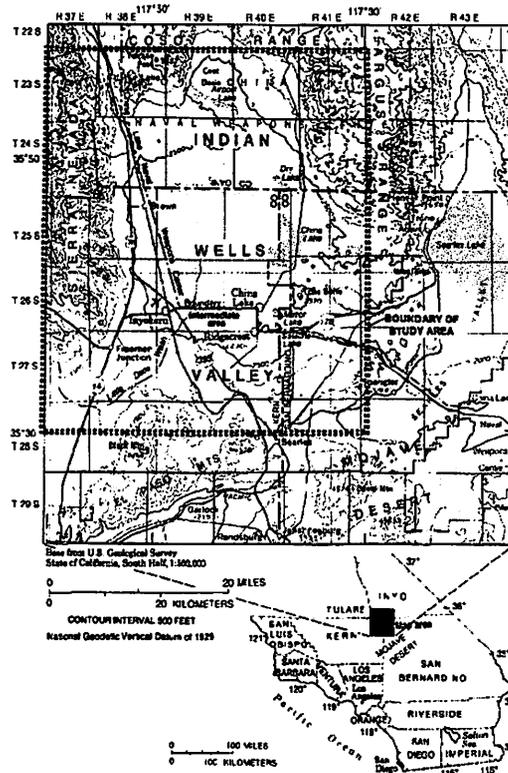


Figure 1. Location of study area. (Berenbrock and Martin, 1991)

The climate in Indian Wells Valley is arid, with an annual precipitation of 2-4 inches on the valley floor. Evaporation rates are estimated to be 80 inches/year from ponded water (Berenbrock and Martin, 1991) and approximately 3 inches per year are lost through evapotranspiration (Kunkel and Chase, 1969). There are no perennial streams located in Indian Wells Valley (Berenbrock & Martin, 1991) and all water used for agriculture, municipal and industrial purposes come from local groundwater sources.

Geology

Indian Wells Valley has been described as a structural depression characteristic of the style of the Basin and Range physiographic province (Ostdick, 1997; Zbur, 1963). Combined seismic-refraction, gravity, aeromagnetic, and geologic studies define a large, structurally depressed block of pre-Tertiary rock which has been folded and warped, and is bounded by steeply dipping faults (Zbur, 1963) (Figure 2).

The valley itself contains alluvium washed down from surrounding mountains in alluvial fans (Austin, 1988), interbedded with lacustrine deposits, eolian sands, playa silts and clays, and possibly a thick section of estuarine and marine sediments at depth. (Whelen, et al., 1989). These unconsolidated Cenozoic deposits are estimated to have a maximum thickness of 2000 feet in the west-central portion of the valley (Zbur, 1963; Dutcher and Moyle, 1973), and fill a basin estimated to have a total thickness of approximately 5,000-6,000 feet at its deepest point which thins laterally to several hundred to a thousand feet thick at its boundaries (Zbur, 1963).

The valley is largely bounded by pre-Tertiary crystalline basement rock and continental deposits of Paleocene age which most likely correlate to the Goler and Ricardo Formations (St. Amand, 1986). Sierran crystalline rocks consist of 80-100 million year old granitic to gabbroic igneous rocks often capped by meta-sedimentary roof pendants. This crystalline rock is presumed to underlie the Indian Wells

Valley at depth, as similar lithologies make up the Argus Range to the east, as well as the Coso and El Paso mountains to the north and south. The Coso Range has been penetrated by basaltic and rhyolitic volcanic rocks of Tertiary to recent age. The El Paso Mountains also contain Tertiary basalts, as well as continental and marine sediments of the Goler (Paleocene) and Ricardo (Miocene) Formations (Diblee and Gay, 1952). It is likely that these continental and marine formations overlie the granitic crystalline basement on the basin floor, forming a relatively impervious unit beneath the late Cenozoic alluvial deposits.

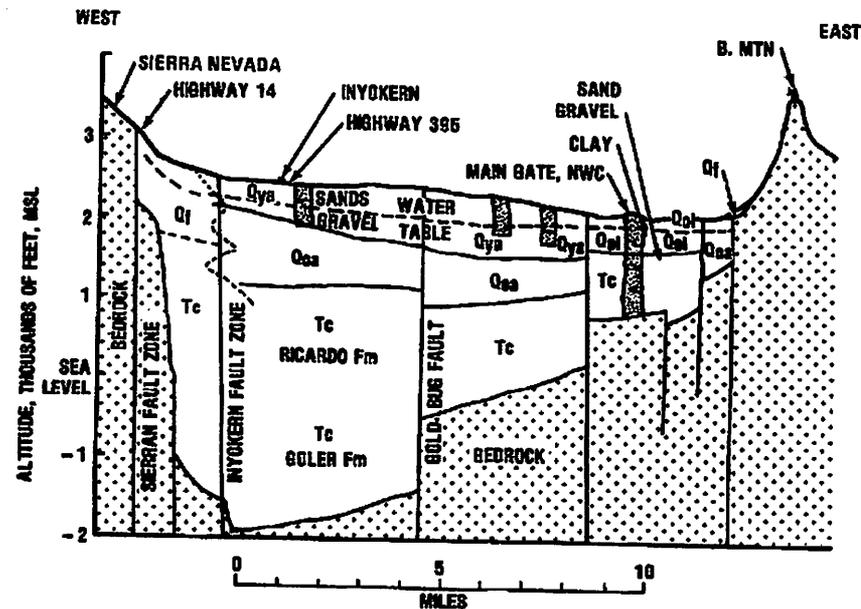


Figure 2. Schematic cross section of Indian Wells Valley along Inyokern-Ridgecrest Road. (St. Amand, 1986)

During the Pleistocene, Indian Wells Valley was the site of China Lake, part of a chain of pluvial lakes connected by the ancestral Owens River, which drained Owens Lake and flowed south through the gap near Little Lake in Rose Valley. As Indian Wells Valley filled with water, China Lake formed in the east-central part of the valley and the excess water spilled over the southeast margin of the valley into Searles Valley, forming the ancestral Searles Lake. Searles Lake, in turn, drained into Panamint Valley and subsequently Death Valley, forming Lake Manly. Silts and sandy silts of similar lithologies at similar elevations in Searles Valley and Salt Wells in the south-eastern portion of Indian Wells Valley suggests that one extensive lake occupied Indian Wells and Searles Valley during some parts of the Pleistocene (von Huene, 1960).

The configuration of the Indian Wells Valley at the end of the last pluvial period, when surface waters ceased emptying into Searles Valley, was essentially as it is today, as evidenced by relic shorelines still preserved on some slopes around its margin. It is believed the pluvial lake in the basin was probably not more than 100 feet deep, though broad in expanse (Zbur, 1963).

Today surface drainage to the valley is entirely internal. Recharge to the valley has been assumed to be entirely from small streams in the canyons of the Sierra Nevada, Coso and Argus Mountains, and the El Paso Mountains (Bloyd and Robson, 1971; Zbur, 1963). Total drainage area for the Indian Wells Valley has been estimated to be about 900 square miles (Kunkel et al., 1954).

Previous Work

The hydrogeology of Indian Wells Valley was first studied by Lee (1913). Lee used orographic effects on precipitation to estimate recharge to the valley to be 27,000 acre feet/year from runoff, and evapotranspiration was estimated to be 31,630 acre-feet/year. Thompson (1929) subsequently revised the estimated recharge to nearly 50,000 acre-feet/year by including runoff from Rose Valley and the Coso Range as additional sources of recharge.

Kunkel and Chase (1969) studied the geology and characterized the valley's hydrogeology between 1925 and 1955 and their work has been used as a source of reference for all subsequent groundwater flow models. They collected data and catalogued information on water wells, test wells, well logs, water levels, and geochemistry. This led to the identification of a deep aquifer throughout most of Indian Wells Valley overlain by a shallow aquifer in the eastern and central portion of the valley in the region occupied by the pluvial China Lake. They revised Lee's estimation of plant cover and reevaluated the amount of discharge by evapotranspiration in 1912 to be 11,325 acre-feet. Based upon the assumption of a closed basin in which, under steady state conditions, recharge would be assumed to be equal to discharge by evapotranspiration from the China Lake playa, they estimated perennial yield for the valley to be between 10,000-14,000 acre-feet/year.

Subsequent to the completion of the work by Kunkel and Chase in 1954, the U.S. Geological Survey has continuously maintained data collection programs in the valley in collaboration with the Naval Weapons Center. As a result of this monitoring, when the combined groundwater pumpage and evapotranspiration of 20,000 acre-feet exceeded the average annual recharge of approximately 10,000 acre-feet in 1966 (Dutcher and Moyle, 1973; Lipinski and Knochenmus, 1981), local agencies sought to develop plans to manage the groundwater basin.

The need for groundwater management plans has necessitated the development of mathematical models to simulate groundwater flow, test aquifer parameters that characterize the ability of the aquifer to transmit and store water, and predict the response of the aquifer to groundwater pumping. Bloyd and Robson (1971) developed the first groundwater flow model utilizing a 2-dimensional alternating-direction implicit methodology specifying parameters within a 60 by 40 nodal network with nodes spaced on one-half mile centers. Model boundaries approximated that of the groundwater basin as described by Kunkel and Chase (1969). The model was calibrated to steady

state conditions which were assumed to have existed in 1920-21 by distributing recharge until model-computed water levels matched measured water levels. Steady-state recharge and discharge were deemed to be equal, and estimated at 9,850 acre-feet/year. Aquifer parameters were estimated on the basis of specific capacity tests and drillers logs compiled by Dutcher and Moyle (1973). Transmissivity of the deep aquifer was estimated to range between 33,400 ft²/day to 2,940 ft²/day and from 3,340 ft²/day to 670 ft²/day for the shallow aquifer. The storage coefficient for the deep aquifer was estimated to range from 1×10^{-4} to 0.20. Bloyd and Robson recognized the inherent limitations of a 2-dimensional model in modeling flow in the third dimension between the deep and shallow aquifers. They recommended the development of a more sophisticated mathematical model and further data collection to improve the accuracy of the model.

In 1980 the U.S. Geological Survey, in cooperation with the China Lake Naval Weapons Center and the Indian Wells Valley Water District, developed a 10-year plan to study the aquifer system of Indian Wells Valley. This study was initiated in part by concern that water from the shallow aquifer, containing water of poor quality, might be entering the deep aquifer and degrading the quality of the water being pumped for municipal use. Recognizing that Bloyd and Robson's model did not adequately represent the three-dimensional flow system of the deep and shallow aquifer, they collected data which could be used to gain an understanding of the vertical component of groundwater flow, as well as to update and evaluate the hydrologic data base previously compiled.

Berenbrock and Martin (1991) used these data to develop a 3-dimensional finite difference model of groundwater flow in Indian Wells Valley using the U.S. Geological Survey groundwater flow code MODFLOW (McDonald and Harbough, 1988). Berenbrock and Martin's model was used to characterize the aquifer's ability to transmit and store water, understand the 3-dimensional aspect of groundwater flow between the shallow and deep aquifers, and predict the behavior of the aquifer to various pumping scenarios that might be utilized in a variety of groundwater management plans. Model construction followed boundary conditions previously utilized by Bloyd and Robson (1971) based upon the geological and hydrologic conditions postulated by Kunkel and Chase (1969). The groundwater system in the valley was simulated as two layers: Layer 1, the upper layer, represents the shallow aquifer found on the east side of the valley. Based upon geologic and electric logs of several wells that fully penetrate Layer 1, bottom elevation of the shallow aquifer was estimated to range from about 1,850 feet above sea level near China Lake to about 1,950 feet along the western boundary of Layer 1. Layer 2, the lower layer, represents the deep aquifer which is modeled as confined below Layer 1, and unconfined elsewhere in the valley.

The model was calibrated to simulate the steady-state conditions as approximated by 1920-1921 water levels and transient conditions for 1920-1985. Initial recharge values used in the model were calibrated recharge values generated by Bloyd and Robson. Total recharge values of 9,850 acre-feet/year were adopted on the assumption that recharge equaled evapotranspiration from the China Lake playa in a hydrologically enclosed basin. Distribution along surface-drainage areas contributing recharge were not modified during calibration as in Bloyd and Robson's model, nor were low values of transmissivity used to simulate groundwater flow barriers or faults. Calibration of the 3-dimensional model was accomplished by adjusting the transmissivities of Layer 2, the hydraulic conductivity of Layer 1, and the leakance factor between Layer 1 and Layer 2.

Transmissivities assigned to the deep aquifer ranged from 36,800 ft²/day in the west-central portion of the valley to less than 1,400 ft²/day in the shallow aquifer. The hydraulic conductivity of the shallow aquifer ranged in value from 8 ft/day to 0.1 ft/day. Leakage between layers occurs whenever there is a difference in hydraulic head between those layers, and is required as input data into the model. Leakage values were varied as a result of calibration changes in the horizontal hydraulic conductivity of Layer 1.

A transient simulation was modeled for the period between 1920 and 1985 using 66 yearly stress periods. The transient simulation was calibrated by modifying storage coefficients for the shallow and deep aquifers, and adjusting leakage between the two layers. The transient simulation indicated that 86% of the 548,900 acre-feet of groundwater removed from the deep aquifer between 1920 and 1985 came from storage, about 10% was derived from reduction of evapotranspiration from Layer 1, and about 4% was derived from artificial recharge of waste-water and shrubbery-irrigation water. Historically, the deep aquifer was responsible for recharge to the shallow aquifer. Since 1920 pumping has induced about 28,870 acre-feet of groundwater to flow from the shallow aquifer to the deep aquifer, causing a degradation of water quality in the deep area in the vicinity of this reversed flow. Model simulations suggested that increased groundwater pumping in the southwest with a concomitant reduction in pumping in the "intermediate zone" between China Lake and Inyokern could serve to reduce groundwater flow from the shallow to deep aquifer.

In 1990, the United States Bureau of Reclamation (USBR), in cooperation with the Indian Wells Valley Water District, the Naval Air Weapons Station (NAWS), and the North American Chemical Company drilled ten multiple piezometer observation wells in the southwest and western regions of Indian Wells Valley. The study, known as the Indian Wells Valley Groundwater project (US Bureau of Reclamation, 1993) was in response to a need for better information on deep aquifer characteristics in this part of the valley so that groundwater management plan alternatives could be responsibly assessed. The study concluded that a greater quantity of water is in storage at depth in the intermediate and southwest areas than that indicated by earlier works which implied low recharge rates. The study also indicated that much of the west and northwest parts of the valley have relatively poor water at depth associated with a very thick and extensive clay layer.

Ostdick (1997) first quantified much of the data that had previously been used in groundwater flow models on the basis of estimations. Over a two year period, by gauging stream flow in the Sierran surface waters, and measuring precipitation at 500 foot elevation intervals in the Sierras, Ostdick quantified the amount of annual recharge made available to the southwest aquifer from precipitation in the conventional surface drainage area as 2,525 acre-feet/year for the two year study period. This compared favorably with previous estimates.

Geochemical data derived from recently drilled piezometers and wells indicates that water in the deep aquifer of the southwest portion of Indian Wells Valley may be derived from a different source than the conventional eastern Sierran watershed which has been historically assumed to provide the bulk of the valley's recharge from the west. The geochemical analysis of the deep, southwest groundwater indicates a fresher (total dissolve solids (TDS) < 300 mg/L) Na-HCO₃ type water in contrast to the more saline (TDS @ 300-600 mg/L)

Ca-SO₄ type water which issues from the Sierran surface streams (Ostdick, 1997). These data, combined with geochemical data identifying water types gathered by Houghton (1994), Whelen et al. (1989), Berenbrock and Schroeder (1994), do not account for the quantity or quality of water to be found in the southwest region.

Ostdick monitored groundwater surface elevation in wells in the southwest valley monthly to ascertain natural changes in the water table. This information was also used to assess the presence of multiple aquifers and the location of possible recharge and discharge areas. The hydraulic gradients within some of the nested piezometers of the USBR observation wells suggest the presence of locally confining or semi-confining layers separating some intervals in the nest.

Utilizing hydraulic gradients, hydraulic conductivity estimations from slug tests performed by the USBR, and gravity surveys, Ostdick (1997) used Darcy's Law to calculate groundwater flux values through the southwest aquifer in excess of 30,000 acre-feet/year. This value is much larger than the amount of measured precipitation recharging this part of the valley. Lineament data collected in the Sierra by Ostdick (1997) and Howard et al. (1997a, 1997b) combined with precipitation and stream flow and geochemical data, suggests the possibility that some of this ground water may enter the Indian Wells Valley from the Kern Plateau via faults and fractures in Sierran crystalline rocks. The excess recharge may discharge via subsurface flow into Searles Valley. Calculations of salt dissolution in the west end of the Searles lake bed by North American Chemical company suggest such a flow boundary may exist (G. Moulton, personal communication). These data suggest that the valley may not be a closed hydrologic basin as all previous groundwater flow models of the valley have assumed.

Project Proposal

The objective of this proposal is to reevaluate and update the 3-dimensional groundwater flow model previously developed by Berenbrock and Martin (1991). The need for such a reevaluation arises for the following reasons:

Much new data has been collected since the development of the model. This data includes:

Well log data from the southwest and western regions of the valley.

Geochemical data identifying water types based upon ionic composition, isotopic signatures, and tritium age inferences.

Aquifer test data providing better estimations of aquifer parameters.

Recent data suggest that recharge estimates may need to be reevaluated.

The Berenbrock and Martin model neglected to include the southwest region as an important factor in the groundwater flow

regime of the valley.

Well logs in the northwest region of the valley indicate a thick, laterally extensive clay layer which suggests that the high transmissivity values used in this area of the model may need to be reevaluated.

To accomplish a reevaluation of the model, the following guidelines suggested by Dutcher and Moyle (1973) will be followed:

Select a grid network for modeling the basin related to the size of the basin, density of data, and need for modeling data.

Re-evaluate the distribution of aquifer storage coefficients and transmissivity.

Re-evaluate geologic control such as basin boundaries, groundwater barriers, depth of basin, vertical separation of aquifers, and relation of aquifers

Determine historic pumping rates and quantities subsequent to Berenbrock and Martin's study.

Determine historic groundwater elevations subsequent to Berenbrock and Martin's study.

Re-evaluate the amount and distribution of recharge and discharge to and from the basin aquifers.

It is anticipated that the grid network used in previous models is adequate and appropriate for the proposed model.

Transmissivities from previous models need to be reevaluated and, as such, I will enter initial values for transmissivity based upon current well information or historical information as catalogued in previous work.

New information on the southwestern part of Indian Wells Valley will be forthcoming as the Navy drills approximately six new wells as part of a Seabee training program under the supervision of Mike Stoner. As these wells are drilled, cuttings will be logged, geophysical-logs will be run, and pump-tests performed. These data will enhance understanding of the subsurface geology, aquifer parameters and hydraulic gradients in this area.

Historic pumping rates and groundwater elevations are largely a matter of record. Recent information needs to be obtained from local agencies, and has been requested.

Upon completion of data compilation, hydrologically closed and open basin models will be simulated. The open basin model will assume traditional areas and rates of recharge and discharge used in the Berenbrock and Martin model in addition to higher flux values suggested by Ostdick (1997). As higher recharge flux is modeled, higher discharge flux will also be modeled. Figures for evapotranspiration previously used by Berenbrock and Martin will be utilized. Additional groundwater discharge may occur as subsurface flow to Searles

Valley through fractures in the crystalline basement rock.

Another simulation, modeling lower flux in the southwest portion of the valley will utilize a flow barrier to account for high hydraulic gradients found there. This will be a closed basin model using recharge and evapotranspiration values used by previous models with modifications of transmissivity to account for recently acquired data.

Models will be calibrated by adjusting figures for recharge, discharge, transmissivity and leakance between layers within reasonable ranges as suggested by historical data and recently acquired aquifer parameters. Calibration will be deemed successful when calculated groundwater elevations are within five feet of measured groundwater elevations.

Sensitivity analyses will be performed to quantify the uncertainty of the calibrated models by systematically adjusting parameters such as recharge, discharge, evapotranspiration, leakance, storage coefficients, and transmissivity within plausible ranges as suggested by the data.

References

Austin, C.F., 1988, Hydrology of Indian Wells Valley. China Lake, Calif., Naval Weapons Center, 10 June 1988 (NWC Reg Memo 2606/103, document UN-CLASSIFIED.)

Berenbrock, C., and Martin, P., 1991, The groundwater flow system in the Indian Wells Valley, Kern, Inyo and San Bernardino Counties, California: USGS Water-Resources Investigation Report 89-4191.

Berenbrock, C. and Schroeder, R., 1994, Groundwater flow and quality, and geochemical processes in Indian Wells Valley, Kern, Inyo, and San Bernardino counties, California: USGS Water-Resources Investigations Report 93-4003.

Bloyd, R.M., and Robson, S., 1971, Mathematical groundwater model of Indian Wells Valley, California: USGS Open File Report.

Diblee T.W., Jr., and Gay, T.E., Jr., 1952, Geology of the Saltdale Quadrangle, California: California Division of Mines Bulletin 160.

Dutcher, L, and Moyle, W., 1973, Geologic and hydrologic features of Indian Wells Valley, California: USGS Water Supply Paper 2007.

Houghton, B.D., 1994, Groundwater geochemistry of the Indian Wells Valley: M.S. thesis, California State University, Bakersfield.

Howard, P.A., Oehlschlager, E.K., Gillick, J., McAlee, J., Sherman,

A.T., Ostdick, J.R., Steward, D.C., Gillespie, J.M. and Thyne, G.D., 1997a, The Kern Plateau: a potential extra-basinal source of groundwater recharge to the Indian Wells Valley: American Assoc. of Pet. Geol., v. 81, p. 688.

Howard, P.A., McAlee, J. and Gillespie, J.M., 1997b, The role of fractures in surface and groundwater flow: a field study of two canyons in the southeastern Sierra Nevada: Abstracts with programs, Geol. Soc. Am. 93rd Ann. Cordilleran Sec. Meeting, Kona, HI.

Krieger, C.A., 1997, Memorandum to Indian Wells Valley Water District.

Kunkel, F., Chase, G., Hiltgen, W., 1954, Geology and ground water of the Inyokern Naval Ordinance Test Station and vicinity: USGS Closed File Report.

Kunkel, F., and Chase, G., 1969, Geology and ground water in Indian Wells Valley, California: USGS Open File Report.

Lee, C., 1913, Ground water resources of Indian Wells Valley, California: California State Conservation Commission Report.

Lipinski, P., and Knochenmus, D., 1981, A 10-year plan to study the aquifer system of Indian Wells Valley, California: USGS Open-File Report 81-404.

McDonald, M., and Harbaugh, A., 1988, A modular three-dimensional finite-difference ground-water flow model: Techniques of Water Resources Investigations 06-A1, USGS.

Ostdick, J., 1997, The hydrogeology of southwest Indian Wells Valley, Kern county, California: Evidence for extrabasinal, fracture-directed groundwater recharge from the adjacent Sierra Nevada Mountains: M.S. thesis, California State University, Bakersfield.

Saint-Amand, P., 1986, Water supply of Indian Wells Valley, California: NWC Technical Publication 6404.

Thompson, D.G., 1929, The Mojave Desert region, California. USGS Water-Supply Paper 578.

Thyne, G., and Gillespie, J., 1997, Indian Wells Valley hydrogeology: Report prepared for NAWS - Geothermal Projects Office.

U.S. Bureau of Reclamation, 1993, Indian Wells Valley Groundwater Project: Technical Report.

Von Huene, R., 1960, Structural geology and gravimetry of Indian Wells Valley, southeastern California: Ph.D. Thesis, University of California, Los Angeles.

Whelen, J., Baskin, R., and Katzenstein, A., 1989, A water geochemistry study of Indian Wells Valley, Inyo and Kern Counties, California: NWC Technical Paper 7019.

Zbur, R., 1963, A geophysical investigation of Indian Wells Valley, California: NOTS Technical Publication 2795.