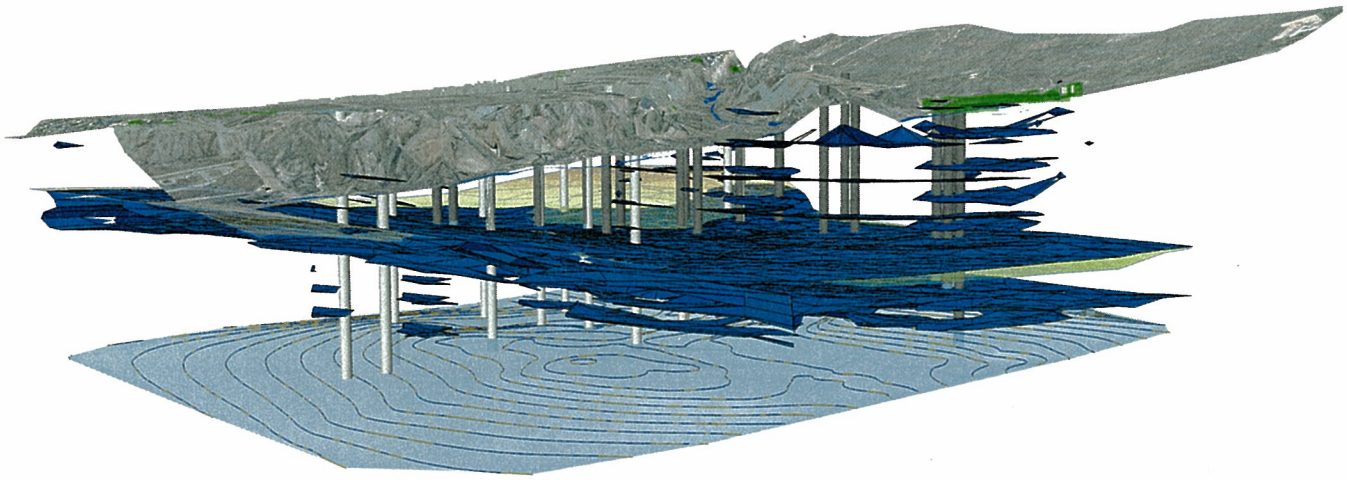
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MODEL OF A PERCHED ZONE OF SATURATION AT SANDIA NATIONAL LABORATORIES, NEW MEXICO



SEPTEMBER 2002

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MODEL OF A PERCHED ZONE OF SATURATION AT SANDIA NATIONAL LABORATORIES, NEW MEXICO

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MODEL OF A PERCHED ZONE OF SATURATION AT SANDIA NATIONAL LABORATORIES, NEW MEXICO

SUMMARY

Sandia National Laboratories found perched water in a zone of saturation beneath Technical Areas I and II near and north of Tijeras Arroyo in southeastern Albuquerque, New Mexico. A conceptual understanding of the perched water is based on: (1) geologic interpretations of geophysical logs and drill cores, (2) distributed sources of recharge to the perched zone, (3) observed water levels and water-level changes in the perched zone, (4) water-quality data, and (5) the relationship to the regional water table. A three-dimensional, variably-saturated numerical model derived from these concepts was prepared in a 2001 phase of modeling. That model was not calibrated. This report describes structural improvements to the previous model grid, and the calibrated match to observed perched-zone hydrographs.

Sources of water in the model include Tijeras Arroyo and Arroyo del Coyote, seepage from currently unused sewage lagoons, leaky water mains, turf irrigation (including lawns, the Tijeras Arroyo Golf Course and parade grounds), a golf course pond that formerly held sewage lagoon water, three Sandia National Laboratories' waste disposal sites, and the site of a City of Albuquerque sewer-line break.

Tijeras Arroyo is simulated as the source of 120 acre feet per year in the modeled reach. A leakage rate of 120 acre feet per year from water-supply lines is simulated. A recharge rate of 268 acre feet per year from the Tijeras Arroyo Golf Course and the original golf course pond, and a sewage lagoon recharge rate of 550 acre feet per year

are simulated. A spill is simulated in year 1994 of about 300 acre feet from a ruptured sewerage pipe. Simulated sewage infiltration is applied over a 24-day period.

Field observations suggest that the currently unused sewage lagoons were a primary source of the perched water. Records of perched-water heads are consistent with a temporary disturbance that is dissipating.

A fraction of the perched water consists of original moisture from natural recharge beneath Tijeras Arroyo emplaced before water-management activities began on the site. Managed water sources such as the sewage lagoons add to and mix with existing soil water. The perched zone of saturation includes fractions of water from unmanaged natural and managed anthropogenic sources.

The model is implemented through FEMWATER (Hsin-Chi and others, 1997, Version 3.0, dated May 23, 2001), a variably saturated, finite-element numerical flow and transport code. The model is calibrated to hydraulic heads at model nodes near perched-aquifer well screens.

The conceptual and the numerical modeling support the interpretation that the perched zone of saturation is a result of the past and ongoing water-management operations superimposed on a system primed for saturation by natural water sources. The perched zone of saturation is expected to expand or to contract depending on future management of water operations.

INTRODUCTION

Sandia National Laboratories, New Mexico (SNL/NM), through Organization 6133, authorized Balleau Groundwater, Inc. in March 2001 to develop and calibrate a model for a perched-water zone at SNL/NM. The tasks include: (1) Examine data, (2) Prepare an appropriate modeling grid, (3) Coordinate input data with staff of Organization 6133, (4) Perform modeling runs including calibration, (5) Perform model sensitivity analysis for hydraulic conductivity and inflow rates, and (6) Prepare a written report, PowerPoint presentation, and laminated poster.

SNL/NM examined groundwater conditions as part of the Technical Area II (TA-II) site investigation in 1992 -1993 (SNL, 2000). An overview of the area of interest is given on Plate 1. Perched water was identified at a depth of about 320 feet during well drilling at TA-II. Low levels of contaminants were discovered in the perched water in October, 1994 (SNL, 2000). Additional wells have been installed to determine the nature and extent of the perched water. Twenty-two monitoring wells are completed in what is believed to be perched water. The well details are give in Table 1.

A conceptual model of the perched flow system was developed in an earlier report (BGW, 2001). Objectives of the present study include evaluation of field data, development of a numerical model with the characteristics of the conceptual model, and calibration of the model to the extent that it reproduces the general water-level trends observed in the field. The model is compatible with geological inferences that can be drawn from referenced reports, well logs, water chemistry, estimated recharge rates, and well hydrographs. One specific objective is that the numerical model simulate rising heads and falling heads in the vicinity of areas where observed perched heads are rising and falling.

The model was conceptualized and digital data files were developed for a finite-element model from June 2001 through June 2002. Mr. W. Peter Balleau and Dr. Ross Wolford reviewed data and conceptualized the model; Mr. Steven Silver used geographic information systems (GIS) for model development tools and data displays. Dr. Wolford assembled the digital model input files. Dr. Wolford, Mr. Dave Romero and Mr. Mike Kernodle ran the model.

This report documents the three-dimensional numerical, variably-saturated flow model of the SNL/NM perched zone of saturation.

SETTING

SNL/NM is located in the southeastern area of the City of Albuquerque (COA), New Mexico on a portion of Kirtland Air Force Base (KAFB) (Plate 1). The KAFB was established during World War II. SNL/NM began operation in 1949. Combined total employment on KAFB and SNL/NM has averaged 29,000 employees.

The site is on a plain adjacent to the Sandia and Manzanita Mountains to the east. The mountain-front faults generally have the downthrown block to the west. East of the West Sandia Fault near Four Hills (Plate 1), the thickness of weathered, unconsolidated materials ranges from zero to a few hundred feet. Near the east end of the Albuquerque International Airport runways (Plate 1) unconsolidated materials are believed to be more than 1000-feet thick. Basin-fill sediments are thousands of feet thick further west near the axis of the Rio Grande Valley. Permeable materials deposited by the ancestral Rio Grande are mapped within 230 feet of the land surface near the KAFB sewage lagoons.

The relatively flat hydraulic gradient in the regional aquifer near Technical Area I (TA-I) (Figure 1) indicates that ancestral Rio Grande or hydraulically similar materials extend to this area.

Precipitation averages about 8.5 inches per year (Gabin and Lesperance, 1977) and areal recharge in upland areas is believed to be essentially nil (SNL, 1998). Two arroyos, Tijeras Arroyo and Arroyo del Coyote join about 4000 feet southwest of SNL/NM's TA-II (Plate 1). Tijeras Arroyo drains an area of about 82 square miles before joining with Arroyo del Coyote, which adds another 39 square miles of watershed area to the drainage. U.S. Geological Survey (USGS) streamflow gaging records (USGS, 1988 – 1996) show that these arroyos flow onto the study area during up to about 20 events per year. Most of these runoff events last a fraction of a day. Runoff averages 432 acre feet per year (AFY) at the USGS gage (Station No. 08330600) below Interstate Highway 25 (Thorn and others, 1993).

Potential contamination sources are waste outfalls, the sewage lagoons, the sewer-line break, the original golf course pond, and landfills. Landfills have not been incorporated into the digital model.

DATA

Well data for the perched zone of saturation are given in Table 1. The perched-zone aquifer was pump tested at Well TJA-2 (Storms, 1998; Plate 1). Results indicated hydraulic conductivity was between 50 feet per day (ft/d) and 17 ft/d. These values are indicative of perched zone horizontal conductivity. One laboratory measurement of vertical hydraulic conductivity (0.0006 ft/d) was obtained from a section of core from Well TA2-NW1-595 (Wolford, 1997). This section of core was selected from what was

believed to be the least permeable zone from depths near but below known perched-water elevations. This measurement may not characterize the large-scale aquifer because a core does not include fractures and other large-scale features. Core measurements can show hydraulic conductivity values orders of magnitude different from field-scale aquifer properties.

The elevation of the regional water table was obtained from a compilation completed by Mr. Franz Lauffer of SNL/NM (Figure 1, Plate 2). The regional water table slopes westward from mountainous areas to the east, and flows toward the north near TA-I and TA-II in response to COA and KAFB pumping.

Water-level data in the perched-aquifer zone were obtained from Mr. Joe Fritts of GRAM, Inc. (personal communication to Dr. Ross Wolford, Balleau Groundwater, Inc., (BGW) October 2, 2000) (Figure 1, Table 1) and from Mr. Mark Holmes of KAFB Environmental Operations (personal communication to Dr. Ross Wolford, BGW, December 5, 2000). Initial water levels of 5160 feet encountered during drilling near the KAFB sewage lagoons (Johnson and others, 2000) were used in compiling perched-aquifer heads. Current water levels in existing wells near the KAFB lagoons are lower than 5160 feet. Water levels in the perched-aquifer wells located north and west of Tijeras Arroyo are falling, while water levels in the perched-aquifer wells to the east of Tijeras Arroyo are rising (Plate 3).

A relationship between recent water use and recent levels of employment at SNL/NM and KAFB was used by SNL/NM to estimate total water used in earlier years (personal communication, Mike Sanders, SNL/NM Department 6135/CDM to Dr. Ross Wolford, BGW, October 2, 2000). From this relationship, average water use between 1949 and 1999 was 4206 AFY with a standard deviation of approximately 20 percent.

Distribution leakage from the water system is estimated at 120 AFY or 2.8 percent of the average distribution of 4206 AFY on KAFB. This value is twice the 1.4 percent leakage of total distribution described in the COA's Comprehensive Water Audit Report for 1999 (personal communication to Dr. Ross Wolford, BGW, from Doug Dailey, COA, March 26, 2002). Leaks were simulated to be concentrated in a few cells covering a simulated 53.39-acre area. One simulated leak was located in TA-I, a second in TA-II, and three in housing areas including one near Four Hills.

Sewage operations for SNL/NM and KAFB have varied over the years. In 1966, two unlined sewage lagoons were constructed about 4000 feet southeast of the east end of the ABQ runways (Plate 1).[1] Between 40 and 100 percent of sewage generated on KAFB was routed to sewage lagoons during the months of April through October for the years 1966 through 1987, with an annual volume estimated at 1000 AFY (Johnson and others, 2000). A portion of the sewage from the lagoons was reconveyed to a pond at the Tijeras Arroyo Golf Course (TAGC), where it was mixed with well water and occasional surface runoff and used to irrigate 91 acres of golf course turf. Additional wastewater was surface-discharged or disposed of in septic systems.

Sewage lagoon and golf course pond infiltration rates were estimated to be a fraction of input to the lagoons (Montgomery Watson, 2000). The combined 17 acres of free-water surface (14 acres of lagoons and 3 acres for the pond) evaporate 99 AFY at 70 inches/year (USDA, 1972) and precipitation adds 12 AFY to free-water surface (8.5 inches on 17 acres). Irrigated turf at TAGC requires 50.13 gal/year/ft^2 (Wilson, 1996), or 610 AFY. Water remaining in the lagoons and pond is 1000 - 99 + 12 - 610 = 303 AFY. That water would seep at a rate of 17.8 ft/year = 303 AFY/17 acres, which is 0.0488 ft/d or 249.5 AFY at the lagoons and 53.5 AFY at the pond. The model rate in ft/d is adjusted for the difference between the modeled surface areas and actual surface areas.

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[1] The construction date differs from earlier reports (e.g. Johnson and others, 2000), but is verified on aerial photographs (Aerial Photo 3-30-1966 1:12,000, Roll 12, Frame 2, Koogle and Pouls Engineering, Albuquerque).

During calibration, the modeled rate of infiltration from the sewage lagoons and golf course pond was doubled from 0.0488 to 0.1 ft/d, to be 666 AFY over the combined 18.24 acres of simulated lagoon and pond area. Based on the previously described computations, 666 AFY of lagoon and pond seepage requires a total input to the lagoons of about 1360 AFY. The increased infiltration rate was indicated by calibration requirements and remains in the reasonable range of earlier estimates.

Some deep percolation is required where turf is maintained. GIS methods were used to estimate that 512 acres of KAFB (Plate 1) are occupied by housing areas, including associated streets, driveways and roofs. About 40 percent of this gross area is estimated to be lawn area. Based on previous work (Wolford, 1997), about 60 percent of lawns on KAFB are well-watered. Well-watered lawn area is estimated at 123 acres. Average seepage under the entire housing acreage area was modeled using 30.75 AFY, or approximately 0.25 ft/year over the 123-acre green-lawn area.

TAGC turf requires about 50.13 gal/year/ft^2 (Wilson, 1996). Salt management in the root zone of the golf course requires 25 percent or more of applied water, or 1.675 ft/year as deep percolation. This equals 0.004587 ft/d on 91 acres, or 0.00485 ft/d to obtain the same volume from the model's descretized 86.07 acres of simulated golf course. The total deep percolation is 152.5 AFY.

Observations by the authors suggest the KAFB parade grounds (Plate 1) were excessively watered in past years. Seepage as deep percolation from these areas was modeled as 28 AFY (two ft/year over 14 acres).

Other man-made discharges are incorporated in the model. The acid-waste outfall (Solid Waste Management Unit (SWMU) 46, Plate 1) had a capacity of 145 AFY (130,000 gallons per day (gpd)) and discharged between 1951 and 1973 (personal communication, John Copland, SNL/NM Organization 6133/SAIC to Dr. Ross

Wolford, BGW, September 14, 2000). The simulated discharge rate for the acid-waste outfall is set to 25 percent of its 130,000-gpd capacity and assumed to operate 50 weeks/year at 40 hours/week, or 8.3 AFY. Another water source is discharge of 0.83 AFY from the combined SWMU's 227 and 229 based on ten percent of the discharge from SWMU 46 (Plate 1). The TA-II shower leachfield (SWMU 165) near Well TA2-SW1-320 has an unknown recharge rate that is assumed to be 1.1 AFY based on 30 workers taking showers seven days a week using 33.33 gallons/shower.

The New Mexico Environment Department (1999) reported that 84 to 89 million gallons (257.8 to 273.1 acre feet) infiltrated or evaporated from a ruptured sewer line in 1994. The spill lasted 24 days and was assumed to be preceded by a five gallons per minute leak lasting one year.

Estimates of aquifer recharge due to flow in Tijeras Arroyo and Arroyo del Coyote on KAFB are available (SNL, 1998). Reported recharge from Tijeras Arroyo was 50.5 AFY and from Arroyo del Coyote was 9.2 AFY. Simulated arroyo recharge was increased from that estimate to 120 AFY during calibration. This recharge value is smaller than the 1790 AFY described by Anderholm (2000) because much of the recharge in Anderholm's estimate occurs further upstream than the model. Hundreds of AFY may infiltrate between Four Hills Road and the KAFB boundary. That water is simulated in the regional aquifer of this model.

Previous work showed that natural areal recharge in non-ponding, mesa areas is not a significant source of water to either the regional or perched zone of saturation (SNL, 1998). The estimated and simulated recharge rates and volumes are summarized in Table 2.

Fritts and Van Hart (1997) reviewed geophysical and drill-core data as a part of an evaluation of the perched-aquifer area. They mapped the extent of a fine-facies zone

located at depths extending from slightly above the perched zone of saturation to below it. That work was revised (Van Hart, 2001) with identification of ancestral Rio Grande facies. Van Hart's structure contours are incorporated into the model grid (fine facies structure data, Dirk Van Hart, SNL to Dr. Ross Wolford, BGW, June 2001). The model grid includes a window through the fine facies in the vicinity of the junction of Arroyo Del Coyote and Tijeras Arroyo (Figure 2). This window to ancestral Rio Grande sediments is larger with depth in the digital model as suggested by contours of field data. The fine facies are present elsewhere throughout the model. The fine facies extend into the regional water table near the TAGC, where perched and regional water tables appear to coincide (Figure 1, Plate 2).

Observations indicate perched water is absent a short distance to the west of the sewage lagoons. Well KAFB-507 (Plate 1) was installed about 850 feet to the west of the north end of the KAFB sewage lagoons and did not encounter perched water. Well TJA-3, drilled near the acid-waste outfall site south of TA-II (Plate 1), was found to be dry in the perched-water zone, although during drilling at depths of 245 and 292 feet the borehole was thought to be making water (SNL, 2000, TJA-3 drilling log, August 17 and 18, 1998). Fine facies begin at a depth of about 260 feet in this area. The digital model has fewer layers with fine facies in the region of KAFB-828-1, which is between the sewage lagoons and the parade grounds.

Ancestral Rio Grande sands are recorded in well logs at an elevation of about 5132 feet (230 feet below ground surface) near the KAFB sewage lagoons, where they contain the second of three perched-water layers (Johnson and others, 2000).

Water-quality data for perched and regional wells were examined. Data presented by Rust Geotech (1995) show regional groundwater with chloride concentrations of six to 23 parts per million (ppm) beneath most of the perched-aquifer area. With the exception of Wells TA2-SW1-320 and TJA-5, water from most wells in

the perched zone of saturation are higher in chloride than from regional-aquifer wells (Figure 3). Rust Geotech's (1995) data and an electronic communication (Tommy Tharp, SNL to Ross Wolford, BGW, September 26, 2000) show the highest chloride levels in the northerly perched wells (e.g., Wells TA1-W-07 and TA1-W-03). This suggests a different water source in northern portions of the perched-aquifer zone. One explanation of higher local concentrations is evaporative concentration during irrigation and associated leaching of caliche from soils by percolating water, which could include leaky water lines as well as lawn irrigation. Another possibility is that the perched water in this area came from early KAFB lagoon operations before leachable salts beneath the lagoons were depleted. The Eubank landfill (Plate 1) may have provided recharge by concentrating rainfall-runoff in a small area. The wells are located upgradient from the Eubank landfill under current conditions. Chloride concentrations also are high near Landfill 08.

CONCEPTUAL MODEL

Flow System

The conceptual model is as described in BGW (2001). Flow includes horizontal and vertical components. Horizontal flow is indicated by the distribution of contaminants in the perched zone. Vertical flow is indicated by water reaching the perching zone, by multiple perched zones encountered during well drilling and by the absence of a clear geologic barrier to vertical flow. Where water loading sufficient to cause recharge is present, water is assumed to move primarily in a vertical direction through shallow-surface materials down to the saturated layers represented by the fine-textured geologic facies above the regional water table. Surface materials above the fine

facies range in thickness from 370 feet near the West Sandia Fault to the east, to as little as ten feet along Tijeras Arroyo at the west end of the study area.

Recharge moves near vertically through the surficial materials to the perching layers. Saturation of the perching layers is associated with positive pressure heads. Positive heads, in conjunction with higher horizontal conductivities, cause saturated flow toward areas with lower heads. Flow velocity is in the resolved direction of hydraulic gradients and hydraulic conductivities. The south to southeasterly slope of the fine-facies synclinal axis tends to transmit water toward the axis (Figure 2), where it accumulates until percolation to the regional aquifer matches the inflow rate. Recharge from the TAGC and its former sewage pond moves from the surface to the perching zone, accelerating the rate of rise in perched-aquifer heads near the TAGC. Unsaturated soil properties cause some seepage to continue to reach the perched zone of saturation for a period of time after the surface discharges end.

Vertical flow through the layers beneath the perched water is conveyed to the regional water-table surface, where it flows downgradient and exits at a simulated constant-head boundary. Water moves through the regional aquifer toward KAFB and COA production wells located outside the model grid.

Brady and Domski (2001) showed perched water generally to be chemically more similar to Tijeras Arroyo water than to the regional water-table water. The regional water-table water is the source of all domestic and industrial water on KAFB. The natural soil water may have been retained in the soil at tensions permitting the soil materials to remain near saturation. With water under slight tension, a relatively small increase in recharge rate could create a zone of perched water larger than from anthropogenic water sources alone. Accounting for this pre-condition permits small water additions to create large perched zones, while the perched water maintains a chemical signature indicative of natural arroyo recharge.

Geology and Water Table

The fine facies (perching zone) is highly anisotropic, i.e, horizontal conductivity is much larger than vertical conductivity. The presence of perched water indicates low vertical conductance. Fine-textured materials extend westward to a few hundred feet beyond the KAFB sewage lagoons. In that area, the strata of low-vertical permeability fine-textured materials are replaced by materials with properties similar to regional aquifer properties. This reduces the tendency to perch water near the west edge of the model. The east to southeastern structural slope of the surface of the fine facies, coupled with high horizontal conductivity, causes water to flow eastward from the lagoon area. The reduced thickness of perching materials west of the lagoon produces a relatively fast pathway between the sewage lagoons and the regional aquifer.

The fine facies is present near the surface below recent alluvium at the west edge of the model near Tijeras Arroyo, where it provides a potential water body within reach of the root zone of local vegetation if perched water reaches that location. That location has been observed to be vegetated.

The transition from highly conductive surficial deposits to fine facies is gradual. Transition zones of intermediate permeability are specified for numerical modeling purposes. The first zone of fine facies is specified with a conductance intermediate between surficial materials and the less permeable, primary fine-facies zone. This provides a zone with potentially higher horizontal flow rates above the lowest-permeability zone. A similar transition occurs between the bottom of the least-permeable fine facies and the lower layers in the model.

The materials between the fine-facies perching zone and the water table at lower elevation are materials of an intermediate conductivity. These materials will remain

moist but unsaturated because flow rate is limited by the lower conductivity perching zone above them. At the east area of the model there is no distinction between perched water levels and the regional water table. At the extreme eastern area of the model, the fine facies of the perching zone rises to the water-table elevation.

Water Sources

Evaporation is incorporated in the conceptual model by reduction of infiltration rates at recharge sites. Evaporation is subtracted from recharge before recharge is added to the model. With the exception of recharge from periodic flows in the arroyos, no natural recharge through surface soils is expected.

Recharge water is estimated to enter surface materials beneath Tijeras Arroyo and Arroyo del Coyote at annual rates of 120 AFY in the model reach. This is the natural background source of water in the conceptual model and it is assumed to be uniformly distributed along the simulated channels of each arroyo. Recharge is about twice the reported rate (SNL, 1998) in deference to hydrochemical studies (Brady and Domski, 2001) that found arroyo recharge water to be characteristic of the perching zone.

Managed water sources include the KAFB sewage lagoons (14 acres, 550.8 AFY while operating) and the original TAGC pond (three acres, 115.5 AFY while operating) (Plate 1). Managed open channel and septic-water sources include the acid-waste outfall (SWMU 46, 8.3 AFY), the waste outfall at SWMU's 227 and 229 (0.83 AFY) and the TA-II shower leachfield (SWMU 165) located adjacent to the site of Well TA-2-SW1-320 (1.1 AFY) (Plate 1). Water-system leakage (120 AFY) is distributed in five cells including three in housing areas and two in Technical Areas I and II. Irrigation seepage to groundwater includes 30.75 AFY from lawns at housing, 28 AFY from the parade grounds (Plate 1) and 152.5 AFY from the golf course. These values are distributed in

time as shown on Table 2. Peak recharge rate during the 1950 through 2000 modeling period was 1133 AFY between 1967 and 1973. After 1987, recharge remains a constant 456 AFY, of which 392 AFY is provided by the golf course, leaky water lines, and arroyos (Table 2).

NUMERICAL MODEL

A three-dimensional, variably saturated finite-element FEMWATER (Hsin-Chi and others, 1997, Version 3.0, dated May 23, 2001) numerical code is applied to solve equations of saturated and unsaturated flows. In this code, a set of variably spaced x, y and z nodes is linked to form a mesh of triangular solid elements. Each element has three sides and a top and bottom face, each in contact with one face of an adjacent element or a portion of the model's exterior boundary. Lower-elevation nodes are located vertically beneath the topmost node at each x-y location. The SNL application has 13,285 nodes comprising the apexes of a total of 23,746 elements. Elements above the land surface are removed, as are elements that would extend more than about 90 to 120 feet into the regional aquifer. The top and bottom surfaces of the model are irregular, with the top of the model following topography to the nearest 30 feet of elevation. The top and bottom of the model have discontinuous layers. The grid and specifications are displayed on Plate 2.

The elements in the model are distributed among 30 layers of uniform thickness. Layers are not homogenous (i.e. material types vary by location within some layers). Layers 1 through 8 are 30-feet thick, Layer 9 is 20-feet thick, Layers 10 through 18 are 15-feet thick, Layer 19 is 20-feet thick, and the thickness of all lower layers is 30 feet.

Thirty-one material types are specified in developing the model grid. Hydraulic characteristics of several of these material types are identical (Table 3). Figure 4 shows the structure of the model grid composed of four materials: ancestral Rio Grande, transitional, fine and coarse materials. The availability of multiple material types provided the capability to change the model characteristics in different layers and provided clearer visualization of the model grid. Layer 12, near the center of the 15-foot thick layers, is the transitional material (Material 15 in Table 3). The structure of this layer top parallels the top of the fine-facies contours mapped by Van Hart (2001). Elevations of other layers in the model follow the structure contour of the top of the fine facies. There are up to 12 layers above the perched-water zone (Layers 1 through 12, Materials 4 through 15) and up to 18 fine-facies layers that include the perched-water zone (Layers 13 through 30, Materials 16 though 33). Model Layer 12 (Material 15) has a conductivity that is intermediate between the permeable upper layers and the lower perching layers, and also occurs in vertical columns between fine and coarse facies (Table 3). The intermediate hydraulic properties of Material 15 were selected for numerical reasons. Vertical hydraulic conductivity is intermediate between Material 14 and 16 to prevent conductivity between layers from varying by more than three orders of magnitude (Hsin-Chi and others, 1997). Layers 13 through 30 are composed of materials (Materials 16 through 33) with a low conductivity. Model materials are anisotropic (Table 3).

Ancestral Rio Grande material is specified in the grid along the western edge of the model. The top of the ancestral Rio Grande material intersects the top of the fine-facies materials (Van Hart, 2001), which are absent in the vicinity of the junction of Tijeras Arroyo and Arroyo del Coyote (Figure 2). The area without fine facies is compatible with drilling records at recently drilled well TJA-6, which failed to find perched water. The ancestral Rio Grande was simulated as having a vertical hydraulic conductivity of 10 ft/d to allow water to drain rapidly from the overlying fine- and

medium-grained perching zone. The ancestral Rio Grande horizontal hydraulic conductivity is specified as a unit value which is not further calibrated.

The conceptual model has no perching zone west of the sewage lagoons. In the numerical model, a single layer of fine material type 16 is simulated west of the lagoons to support calibration. The extent of ancestral Rio Grande grows with depth near the sewage lagoons.

Unsaturated hydraulic properties (moisture content and relative conductivity) are entered into FEMWATER as matrices of tension head and parameter values derived by Van Genuchten (1980). FEMWATER was found to be sensitive to these data, with steeper curves requiring smaller time steps. Some unsaturated parameter specifications were adjusted to facilitate model convergence while maintaining reasonable results. Figure 5 illustrates relative hydraulic conductivity curves with head for two textbook soils, and the relative hydraulic conductivity curve used for all materials in the model. The curve used is an exponential function of the form:

$$K_r = 0.865\, e^{-3.9942H}$$

Where:

K_r is hydraulic conductivity, relative to tension head,

H is tension head in feet.

The curve represents a slope less steep than Van Genuchten sandy loam over a tension head range of zero to one foot (Figure 5). Soil moisture retention curves were adjusted from reference values to reduce the range of possible water contents. For example, the porosity given by Yates and Others (1992) for a Touchet silt-loam soil (Figure 5) is reasonable for a surface soil, but is thought to be inappropriate for silt loam underlying several hundred feet of geologic materials for thousands of years. A narrow range of water contents reduces effective porosity, so that water travels further at a

given rate of flow. This modification also makes the curves less steep, which aids model convergence.

Recharge boundaries apply water at rates in ft/d across the face of elements. Lagoon and pond seepage, water main leaks, and turf irrigation are applied as recharge across the face of elements overlying those areas (Figure 6). At locations such as the TAGC pond where element faces and surface features have different map areas, unit rates are adjusted to provide an equivalent volumetric recharge rate. Recharge from Tijeras Arroyo and Arroyo del Coyote is divided uniformly between the 241.0 acres of element faces along each arroyo. Recharge from the acid-waste outfall (SWMU 46), the TA-II shower leachfield (SWMU 165), and SWMU's 227 and 229 were input as flow across an element face near the source (Plate 1).

The regional water table is simulated by constant heads at each node at and below the water table around the circumference of the model. The constant pressure heads were set equal to the depth of the node below the contoured regional aquifer (electronic communication, Sue Collins, SNL to Dr. Ross Wolford, BGW, April 20, 2001) at each location. The lower three to four layers of the model, which consist of both ancestral Rio Grande deposits and finer piedmont sediments derived from the Sandia and Manzanita Mountains, serve as a boundary that receives the vertical flow from perched zones, but the layers represent a thin upper interval of the saturated regional flow system. Water reaching the regional water table from any source in the model is transported through the upper interval of the regional aquifer.

Field conditions show that soils are relatively moist at depth. Initial conditions for the model are established by running the model for a period of about 1000 years starting from relatively wet conditions with arroyo recharge as the only surficial input source. One thousand years of drainage from wetter pluvial conditions provides a year 1947 starting soil moisture for historical simulations.

Rates of recharge, locations of recharge sites, land surface elevation and elevation of fine-facies perching layers are placed to represent a mathematical version of the physically-based conceptual model.

SENSITIVITY

Sensitivity was examined in the process of model calibration. Sensitivity tests include eight model runs that use various parameters, stresses, and model grids.

Parameters used in Runs 1 through 6, listed on Table 4, produced perched water at relatively low positive heads. Little to no perching occurred from runs made to establish initial conditions for year 1947. The perched zone of saturation at the golf course and lagoons remained separated or joined within the last years before the lagoons ceased operation after 1988. Perched water northwest of Tijeras Arroyo disappeared in the model before the first physical observations of perched water occurred in August 1993. Investigation showed that the bulk of the water was dissipating into unsaturated storage in the perched zone and into coarse materials overlying that zone.

Initial estimates of sewage lagoon recharge used the residual when all other sources of water loss are subtracted from the estimated 1000 AFY input. The inputs to the sewage lagoon are not known within 25 percent. Because recharge is computed as a residual, any error in the estimate of input to the lagoons becomes an equal addition or subtraction from lagoon recharge. Recharge at the sewage lagoons and golf course pond was increased to a continuous 0.1 ft/d over the simulated lagoon area, and

provided the water necessary to produce the simulated perching zones described in the final model.

Calibration runs included reducing available porosity for storage (Runs 2 through 8, Table 4), removing the hole in the fine layers that existed in the original grid just to the southeast of the sewage lagoons (Runs 4 through 8, Table 4), lowering vertical hydraulic conductivity of the fine layers, increasing recharge rate from the sewage lagoons (Runs 6 and 8, Table 4), and modifying the shape of the unsaturated hydraulic conductivity curve. The latter two modifications produced a perched zone similar to that observed. Run 8 produced an extensive perched zone that includes most areas where perched water has been observed. Perched water west of Tijeras Arroyo largely is dissipated by year 2002 while heads near the golf course are constant to rising. The final Run 9 produced acceptable results shown in Figures 7 through 11 and Plate 3. Final parameters are given in Table 4. The model is reasonably robust with perched saturation seen to some extent with most of the alternative specifications.

HISTORY MATCH

The model was operated in two steps of simulated time. The model reached a stable condition through an arbitrary 1060-year run with Tijeras Arroyo recharge only (pre-development run). Arroyo recharge was set to 120 AFY as the source term in the pre-development run and remained at that rate in subsequent historical-period (1947 through year 2002) simulations.

After 1060 simulated pre-development years, arroyo seepage increases the moisture content to near-saturated conditions along the arroyos. Year 1947 contours of the regional water table and perched zone are shown in Figure 7.

The second step of simulated time starts in 1947. Simulated seepage from the area's water system (120 AFY), lawns (30.75 AFY), parade grounds (28 AFY), the acid-waste outfall (8.3 AFY), leaky sewer lines (5.1 AFY), the TA-II shower leachfield (1.1 AFY), and SWMU 227/229 (0.83 AFY) are added to arroyo recharge creating a total recharge rate of 314.08 AFY. Some of these new recharge sources do not affect the perched zone by 1967.

The simulated water balance shows that the water stored in the whole model increased by an average of 197 AFY during this period in agreement with the change in recharge. The discharge from the acid-waste outfall is relatively large (8.3 AFY) in comparison to the element area where it is applied (0.5 acres) and reaches the perched zone before 1967. Other man-caused recharge sources, including the parade grounds, leaky pipes and sewers, lawn irrigation seepage, and irrigation returns from the parade grounds, do not appear to affect the perched zone by 1967. These water sources are small and the simulated areas over which they are applied are large, so through 1967 these sources primarily contribute to simulated unsaturated storage above perched-water zones.

During the period from 1947 to 1967, perched water is simulated below the arroyos. With arroyo recharge specified constant at 120 AFY, the modeled effect of arroyo recharge is a numerically unsteady cycle of perched head. The simulated perched water head oscillates five to ten feet while the unsaturated model nodes change moisture content enough to drain the perched water down to the regional water table. Contours of perched water in January 1947 and 1967 are shown on Figures 7 and 8. This cycle of simulated head buildup and decline is a numerical feature, not a feature expected to be observed in the field. The anthropogenic source water applied after 1967 combined with arroyo recharge creates a volume of perched water maintained and

continually draining until the end of the simulated history (2002), without any further evidence of the numerical oscillation.

Seepage from the sewage lagoons (550.8 AFY), the TAGC (152.5 AFY) and the TAGC pond (115.5 AFY) begins in 1967 with the conditions shown in Figure 8. The influx of relatively large volumes of water from the lagoons and the TAGC results in the rapid spread of perched water from the vicinity of the sewage lagoons toward the TAGC at the eastern edge of the model. By January 1972 a substantial saturated zone is present beneath the sewage lagoons and the separate saturated water body near the TAGC has merged with the main perched-water body (Figure 9). Saturation is less extensive near the TAGC because of the larger application of water per unit area over the TAGC.

Simulated recharge at the sewage lagoons and TAGC pond ends in 1988. The TA-II shower leachfield's (SWMU 165) 1.1 AFY source ceases operating after 1992, as does the 0.83 AFY from SWMU 227 and 229.

Figure 10 shows the extent of the simulated perched water body in January 2002 at the end of the historical period. Figures 8 through 10 show a progressive enlargement and northward movement of the extent of the perched-water zone. The area of perched water begins beneath Tijeras and Coyote Arroyos in 1947, where natural recharge occurs. The area enlarges over time to include areas beneath all of the anthropogenic sources of recharge.

Figure 11 shows measured versus simulated heads for observation-well locations in both the regional and perched zones. Range bars of 45 feet are shown to bracket the thickness of model layers that apply to the simulated pressure head. A trend line (red) is comparable to the line of equality (black) between measured and observed heads.

Simulated total heads (pressure plus elevation heads) are compared to observed hydraulic heads in 15 perched-zone wells on Plate 3. The seven additional wells listed in Table 1 do not have repeated water-level measurements for plotting. Model node heads at three depths are displayed with each well hydrograph to show how head varies within the vertical node spacing. The layer thickness used in generating the model grid controls the 15 to 30-foot range between model nodes displayed on the hydrograph plots. Heads near the well-screen depth often display the observed trend, although the observed head trend may be more nearly simulated in the next upper or lower node. In some cases, simulated hydraulic head trends from model zones deeper or shallower than the screens of existing wells match observations better than the zones nearest the well screen. Well screen length is comparable to the layer thickness between nodes. Either node in a layer may be considered representative of the well screen. The general match of observed and simulated head trends based on four material classes (coarse surficial materials, ancestral Rio Grande materials, fines, and transitional materials) suggests that the major stresses causally linked to the observed response, are reasonably-well identified.

Figures 12 and 13 show the recharge and the simulated response to recharge during the period of historical water operations. Table 5 displays the simulated water balance in the period of historical water operations. The simulation prior to 1947 displays a numerical tendency to cycle up to ten AFY between water in storage and water leaving the model domain via the regional aquifer. This cyclical behavior continues into the historical (1947 through year 2002) period with superimposed anthropogenic stresses and responses, thereby explaining the dip in domain outflow in the 1960's (Figure 13).

Table 6 lists model boundary flows in terms of the difference from year 1947 conditions, thereby quantifying the effect of water operations after 1947. Figure 13 and Table 6 show that for the period 1947 to the late 1970's, all recharge went to increased

aquifer or soil storage. Beginning in the late 1970's net outflow through the regional flow system began to increase above the initial condition, eventually to show a gain of 70 AFY for net outflow of 199.7 AFY. Table 6 shows by the end of the simulation 98 percent of the cumulative anthropogenic recharge (29,286 AF) is retained in saturated and unsaturated soil storage.

Figure 14 is a set of stereograms of the flow line vectors and water content change at year 2002. Each stereo pair is viewable as a three-dimensional object by overlapping the images with a pocket stereoscope or by controlling the viewer's focus point without a stereoscope. The flow lines indicate the direction and distance that water would move in 100 and 1000 years under the conditions prevailing in year 2002. The water content change is that caused by water operations and by background fluxes in the period 1947 to 2002.

CONCLUSIONS

1. The digital FEMWATER model explains the processes, fluxes and heads observed under historic conditions. Generalized geology is used as the basis for the model grid which is specified in homogenous anisotropic blocks based on four material types. Dipping geologic structure is an important feature of the model.

2. Recharge to the perched layer at Sandia National Laboratories, New Mexico includes natural arroyo recharge, seepage from former sewage lagoons, golf-course irrigation, a former sewage pond at the golf course, irrigation at the parade grounds, and the acid-waste outfall. Leaky water mains, turf irrigation at homes, and two smaller waste disposal sites are of lesser significance as recharge. The former sewage lagoons account for much of the perched water in the western portions of the model.

3. By the year 2002, anthropogenic source water has added a cumulative volume of 29,286 acre feet to the flow system. In terms of mass accounting, a net of 98 percent of this volume has accumulated in system storage and the remaining two percent is accounted for by a net discharge from the modeled space via the regional flow system.

4. Water in the perched layer is a mixture of native water and anthropogenic water incidental to managed water operations. The perched water present near the sewage lagoons and Tijeras Arroyo Golf Course results from managed-water sources combined with original soil moisture. The perched water body is contracting in the west due to the elimination of the sewage lagoons as a water source, and is expanding in the east in response to ongoing water operations.

The saturated perched water body will expand or contract as sources are added or removed.

5. Model calibration provides a reasonable match of simulated to observed hydrographs over the model's area. The match between simulated and historic data suggests the model has predictive value.

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TABLES

TABLE 1. PROPERTIES OF WELLS IN THE PERCHED ZONE OF SATURATION

Well Name	State Plane Coordinate 1983 X (ft)	State Plane Coordinate 1983 Y (ft)	Surface Elevation (ft msl)	Total Depth (ft)	Top of Screen (ft)	Bottom of Screen (ft)	Elevation of Screen Center (ft msl)	Water Depth Below Top of Casing (ft)	Casing Stickup (ft)	Water Elevation (ft)	Date of Water Measure-ment	Head Trend (ft/yr)	Comment	Development (gal/min)
KAFB-0310	1557213	1466839	5410.5	455.0	400.0	445.0	4988.0	353.0	3.31	5060.8	9/1/2000	1.86		
KAFB-0313	1556617	1467169	5416.3	370.0	348.0	368.0	5058.3		2.04	5065.5	9/1/2000			
KAFB-0314	1558641	1468584	5453.1	451.0	428.0	448.0	5015.1		2.04	5032.9	9/1/2000			
KAFB-0506	1547161	1468730	5360.6	221.6	200.1	220.0	5150.5			5167.0	1999		Drilling water level observation	
KAFB-0602	1556835	1463638	5362.8	466.0	437.0	457.0	4915.8			5050.3	6/21/1905			
KAFB-0608	1556558	1463981	5358.5	332.0	307.0	327.0	5041.5			5058.9	9/1/2000			
KAFB-0609	1556896	1463908	5363.2	355.0	316.0	336.0	5037.2			5061.3	1999			
KAFB-0610	1556431	1463591	5356.8	363.0	333.0	353.0	5013.8			5059.3	9/1/2000			
KAFB-3391	1549958	1471852	5393.9	282.5	262.5	282.5	5121.4			5127.0	9/1/2000			
TA1-W-03	1555304	1473270	5452.7	363.0	337.0	357.0	5105.7	337.7	1.7	5116.6	3/4/1998	-0.45	Sand 326'-362'	276 g/197 min
TA1-W-06	1552577	1471982	5414.7	330.0	300.0	320.0	5104.7	299.7	-0.28	5114.7	9/1/1998	-0.37	Sand 291'-330'	228 g/85 min
TA1-W-07	1550692	1472486	5399.9	290.0	268.6	288.6	5121.3	274.0	2.33	5128.3	1/15/1999	-0.83	Sand 258'-290' very low yield	12 g/330 min, 5 g/4 min
TA2-NW1-325	1553085	1470843	5417.3	330.3	295.0	325.0	5107.3	311.3	1.28	5107.3	8/31/2000	-0.43		
TA2-SW1-320	1552796	1469733	5407.4	324.6	299.6	319.6	5097.8	312.4	1.82	5096.8	8/31/2000	-0.21		
TA2-W-01	1553478	1470182	5414.7	332.0	312.0	332.0	5092.7	321.3	2.61	5096.0	9/13/2000	-0.22		
TA2-W-19	1554409	1468690	5346.3	285.9	265.9	285.9	5070.4	266.9	2.28	5081.6	8/31/2000	0.18		
TA2-W-26	1555511	1470552	5371.5	305.0	276.0	296.0	5085.5	280.1	1.63	5093.1	9/1/1998	0.10	Sand 261.5'-305'	259 g/123 min
TA2-W-27	1554760	1469680	5358.4	306.5	275.0	295.0	5073.4	275.0	1.81	5085.2	9/1/1998	0.12	Sand 264.5'-306.5'	316 g/226 min
TJA-2	1555580	1468674	5348.6	310.0	275.0	295.0	5063.6	273.4	1.95	5077.1	8/31/2000	0.26		
TJA-4	1555381	1467217	5335.6	399.0	360.0	380.0	4965.6	314.9	2.86	5023.6	1/15/1999	1.86	Sand 350'-399'	801 g/503 min
TJA-5	1555375	1467200	5335.6	298.0	267.0	287.0	5058.6	267.8	3.07	5070.9	1/15/1999	0.72	Sand 254'-298'	251 g/64 min
WYO-2	1550206	1470090	5387.7	295.0	265.0	285.0	5112.7	275.1	2.11	5114.7	8/31/2000	-0.71		

TABLE 2. SIMULATED RECHARGE RATES IN SANDIA NORTH MODEL

Source	Simulated Surface Area (acres)	Field Surface Area (acres)	Model Rate			Start	End	Total Volume 1947 - 2002 (AF)[2]
			(ft/d)[1]	(AFY)	(gpd)			
Leaky Water Lines	53.39	unknown	0.00615	120.00	107,056	1947	2002	6,720
Tijeras Arroyo and Arroyo del Coyote	241.00	unknown	0.00136	120.00	107,056	Year 0	2002	6,720
Tijeras Arroyo Golf Course	86.07	91 green	0.00485	152.47	136,021	1967	2002	5,489
Sewage Lagoons - (Initial Estimate)	15.08	14	0.04530	249.50	222,587	1967	1987	5,240
Sewage Lagoons - (Final Calibration)	15.08	14	0.10000	550.80	491,383	1967	1987	11,567
Housing Lawns	123.11	123 green	0.00068	30.75	27,433	1947	2002	1,722
Parade Grounds	15.12	14	0.00507	28.00	24,980	1947	2002	1,568
Abandoned TAGC Pond - (Initial Estimate)	3.16	3	0.04632	53.50	47,729	1967	1987	1,124
Abandoned TAGC Pond - (Final Calibration)	3.16	3	0.10000	115.50	103,038	1967	1987	2,425
Leaky Sewer Lines	53.39	unknown	0.00026	5.08	4,530	1947	2002	284
Sewer Line Break Ponding area	11.11	unknown	0.97017	3,937.09	3,512,398	9/14/1994	10/7/1994	259
Acid Waste Outfall (SWMU 46)	.50	line source	0.04549	8.31	7,415	1947	1973	224
TA-II Shower Leachfield (SWMU 165)	.51	1.16	0.00604	1.12	1,000	1947	1992	52
Combined SWMU 227 and 229	.24	unknown	0.00943	.83	742	1947	1992	38
Sewer Line Break Site	1.06	Point Source	0.02083	8.07	7,200	9/14/1993	9/13/1994	8
Total	603.74			5,078	4,530,250			37,076

[1]Rate is adjusted to reflect the simulated area

TABLE 3. SIMULATED MATERIAL PROPERTIES IN SANDIA NORTH MODEL

Material	Description	Thickness (ft)	Saturated Water Content (%)	Residual Water Content (%)	Kx, Ky (ft/d)	Kz (ft/d)
4	Coarse	30	0.2	0.11	50	0.2
5	Coarse	30	0.2	0.11	50	0.2
6	Coarse	30	0.2	0.11	50	0.2
7	Coarse	30	0.2	0.11	50	0.2
8	Coarse	30	0.2	0.11	50	0.2
9	Coarse	30	0.2	0.11	50	0.2
10	Coarse	30	0.2	0.11	50	0.2
11	Coarse	30	0.2	0.11	50	0.2
12	Coarse	20	0.2	0.11	50	0.2
13	Coarse	15	0.2	0.11	50	0.2
14	Coarse	15	0.2	0.11	50	0.2
15	Transitional	15 to 30	0.2	0.11	40	0.002
16	Fine	15	0.29	0.183	20	0.0001
17	Fine	15	0.29	0.183	20	0.0001
18	Fine	15	0.29	0.183	20	0.0001
19	Fine	15	0.29	0.183	20	0.0001
20	Fine	15	0.29	0.183	20	0.0001
21	Fine	15	0.29	0.183	20	0.0001
22	Fine	20	0.29	0.183	20	0.0001
23	Fine	30	0.29	0.183	20	0.0001
24	Fine	30	0.29	0.183	20	0.0001
25	Fine	30	0.29	0.183	20	0.0001
26	Fine	30	0.29	0.183	20	0.0001
27	Fine	30	0.29	0.183	20	0.0001
28	Fine	30	0.29	0.183	20	0.0001
29	Fine	30	0.29	0.183	20	0.0001
30	Fine	30	0.29	0.183	20	0.0001
31	Fine	30	0.29	0.183	20	0.0001
32	Fine	30	0.29	0.183	20	0.0001
33	Fine	30	0.29	0.183	20	0.0001
38	Ancestral R.G.	15 to 30	0.2	0.11	1	10

TABLE 4. PARAMETER VALUES IN MODEL RUNS

Run #	Fine Materials				Coarse Materials				Kr Curve[1]	Grid[2]	Lagoon Recharge (AFY)	Arroyo Recharge (AFY)
	Kv (ft/d)	Kh (ft/d)	Porosity	Residual Water Content	Kv (ft/d)	Kh (ft/d)	Porosity	Residual Water Content				
1	0.000600	10	0.498	0.183	1.0	100	0.30	0.057	VG	Geologic	249.5	120
2	0.000300	10	0.34	0.183	1.0	100	0.25	0.11	VG	Geologic	249.5	120
3	0.000075	30	0.34	0.183	1.0	30	0.25	0.11	VG	Geologic	249.5	120
4	0.000075	30	0.34	0.183	1.0	30	0.25	0.11	VG	No Hole	249.5	120
5	0.000300	30	0.29	0.183	0.2	50	0.20	0.11	VG	No Hole	249.5	120
6	0.000300	30	0.29	0.183	0.2	50	0.20	0.11	VG	No Hole	499.0	120
7	0.000300	30	0.29	0.183	0.2	50	0.20	0.11	EXP	No Hole	249.5	240
8	0.000300	30	0.29	0.183	0.2	50	0.20	0.11	EXP	No Hole	499.0	120
Final	0.000100	20	0.29	0.183	0.2	50	0.20	0.11	EXP	Geologic	550.8	120

[1] Relative hydraulic conductivity curve labeled VG is the van Genuchten curve for Touchet silt loam, while EXP is the exponential curve described in the text.

[2] The geologic grid is based on contoured data from Van Hart's (2001) report, while that labeled No Hole has at least 60 feet of fines everywhere.

MODEL

TABLE 5. SIMULATED AVERAGE ANNUAL FLOWS AT MODEL BOUNDARIES

Year	Cumulative Total			Annual Rate			Annual Flow Balance (AFY)
	Recharge Volume (AF)	Volume Into Storage (AF)	Volume Out Of Model Domain (AF)	Recharge (AFY)	Flow Into Aquifer Storage (AFY)	Flow Out Of Model Domain (AFY)	
1947	305	176	130	305.3	175.7	129.7	-0.1
1948	619	360	259	313.6	184.0	129.5	0.0
1949	932	544	388	313.5	184.4	129.2	-0.1
1950	1,246	729	517	313.5	184.7	128.9	0.0
1951	1,559	914	646	313.5	185.1	128.4	0.0
1952	1,873	1,099	774	313.5	185.6	127.9	0.0
1953	2,186	1,286	901	313.5	186.2	127.4	-0.1
1954	2,500	1,472	1,028	313.5	186.6	126.9	0.0
1955	2,813	1,660	1,154	313.5	187.3	126.3	-0.1
1956	3,127	1,847	1,280	313.5	188.0	125.7	-0.2
1957	3,440	2,036	1,405	313.5	188.4	125.2	-0.1
1958	3,754	2,225	1,530	313.5	188.9	124.7	0.0
1959	4,068	2,415	1,654	313.5	189.9	124.1	-0.5
1960	4,381	2,606	1,778	313.5	191.0	124.2	-1.7
1961	4,695	2,795	1,902	313.5	189.6	124.0	0.0
1962	5,008	2,985	2,026	313.5	189.9	123.6	0.0
1963	5,322	3,174	2,149	313.5	189.2	123.2	1.2
1964	5,635	3,365	2,272	313.5	191.1	122.8	-0.3
1965	5,949	3,557	2,394	313.5	191.8	122.3	-0.6
1966	6,262	3,744	2,516	313.5	187.1	122.3	4.0
1967	7,395	4,754	2,639	1,132.8	1,009.7	123.1	0.1
1968	8,527	5,762	2,764	1,132.4	1,008.3	124.6	-0.5
1969	9,660	6,769	2,890	1,132.5	1,006.1	126.3	0.0
1970	10,792	7,774	3,018	1,132.5	1,005.5	127.2	-0.2
1971	11,925	8,779	3,145	1,132.4	1,005.2	127.3	0.0
1972	13,057	9,785	3,272	1,132.4	1,005.3	127.2	0.0
1973	14,181	10,785	3,399	1,124.1	1,000.3	127.5	-3.6
1974	15,306	11,781	3,528	1,124.1	996.1	128.1	0.0
1975	16,430	12,777	3,656	1,124.1	996.0	128.3	-0.2
1976	17,554	13,772	3,785	1,124.1	995.5	128.8	-0.2
1977	18,678	14,767	3,914	1,124.1	994.3	129.8	0.0
1978	19,802	15,759	4,046	1,124.2	992.4	131.8	-0.1
1979	20,926	16,750	4,180	1,124.1	990.7	133.6	-0.1
1980	22,050	17,738	4,316	1,124.1	988.3	135.9	0.0
1981	23,174	18,724	4,454	1,124.1	985.5	138.7	-0.1
1982	24,299	19,707	4,596	1,124.1	983.1	141.3	-0.3
1983	25,423	20,689	4,739	1,124.1	982.1	143.7	-1.7
1984	26,547	21,667	4,886	1,124.1	978.2	146.2	-0.3
1985	27,671	22,643	5,034	1,124.1	975.6	148.8	-0.3
1986	28,795	23,616	5,186	1,124.1	973.1	151.3	-0.3
1987	29,253	23,920	5,339	457.6	304.1	153.8	-0.3

MODEL

TABLE 5. SIMULATED AVERAGE ANNUAL FLOWS AT MODEL BOUNDARIES

Year	Cumulative Total			Annual Rate			Annual Flow Balance (AFY)
	Recharge Volume (AF)	Volume Into Storage (AF)	Volume Out Of Model Domain (AF)	Recharge (AFY)	Flow Into Aquifer Storage (AFY)	Flow Out Of Model Domain (AFY)	
1988	29,710	24,222	5,496	457.7	301.7	156.6	-0.6
1989	30,168	24,520	5,656	457.7	298.1	159.9	-0.3
1990	30,626	24,815	5,819	457.7	294.9	163.0	-0.2
1991	31,084	25,107	5,985	457.7	291.8	166.1	-0.3
1992	31,539	25,395	6,154	455.7	288.5	169.2	-1.9
1993	31,997	25,684	6,327	458.1	288.8	172.6	-3.2
1994	32,691	26,201	6,503	693.8	517.5	175.8	0.4
1995	33,147	26,478	6,682	455.7	276.6	179.3	-0.1
1996	33,603	26,751	6,865	455.7	273.1	182.8	-0.2
1997	34,058	27,021	7,051	455.7	269.8	186.5	-0.5
1998	34,514	27,287	7,241	455.7	266.3	189.9	-0.4
1999	34,970	27,550	7,434	455.7	262.8	193.1	-0.1
2000	35,426	27,809	7,630	455.7	259.6	196.4	-0.2
2001	35,881	28,066	7,830	455.7	256.1	199.7	-0.1

MODEL

TABLE 6. SIMULATED DIFFERENCE FROM YEAR 1947 FLOWS AT MODEL BOUNDARIES

Year	Cumulative Total			Annual Rate			Annual Flow Balance (AFY)
	Recharge Volume (AF)	Volume Into Storage (AF)	Volume Out Of Model Domain (AF)	Recharge (AFY)	Flow Into Aquifer Storage (AFY)	Flow Out Of Model Domain (AFY)	
1947	186	186	- 0.1	185.6	185.7	- 0.1	0.0
1948	379	380	- 0.3	193.9	194.1	- 0.3	0.0
1949	573	574	- 0.9	193.8	194.5	- 0.5	-0.1
1950	767	769	- 1.7	193.9	194.7	- 0.9	0.0
1951	961	964	- 3.1	193.8	195.1	- 1.3	0.0
1952	1,155	1,160	- 5.0	193.8	195.7	- 1.9	0.1
1953	1,349	1,356	- 7.3	193.8	196.2	- 2.4	0.0
1954	1,543	1,553	- 10.2	193.9	196.7	- 2.9	0.0
1955	1,736	1,750	- 13.7	193.8	197.4	- 3.5	-0.1
1956	1,930	1,948	- 17.7	193.9	198.0	- 4.1	-0.1
1957	2,124	2,147	- 22.3	193.8	198.5	- 4.6	-0.1
1958	2,318	2,346	- 27.4	193.8	199.0	- 5.1	0.0
1959	2,512	2,546	- 33.1	193.8	199.9	- 5.7	-0.4
1960	2,706	2,747	- 38.7	193.9	200.9	- 5.6	-1.5
1961	2,899	2,946	- 44.5	193.8	199.6	- 5.8	0.0
1962	3,093	3,146	- 50.7	193.9	200.0	- 6.2	0.0
1963	3,287	3,345	- 57.3	193.8	199.3	- 6.6	1.1
1964	3,481	3,547	- 64.3	193.8	201.1	- 7.0	-0.3
1965	3,675	3,748	- 71.8	193.9	201.9	- 7.5	-0.6
1966	3,869	3,946	- 79.2	193.8	197.4	- 7.4	3.8
1967	4,882	4,966	- 85.9	1,013.2	1,019.7	- 6.7	0.1
1968	5,895	5,984	- 90.9	1,012.8	1,018.3	- 5.1	-0.5
1969	6,907	7,000	- 94.3	1,012.8	1,016.1	- 3.4	0.0
1970	7,920	8,016	- 96.9	1,012.8	1,015.5	- 2.6	-0.1
1971	8,933	9,031	- 99.4	1,012.8	1,015.3	- 2.5	0.0
1972	9,946	10,046	-102.0	1,012.8	1,015.3	- 2.6	0.0
1973	10,950	11,056	-104.2	1,004.5	1,010.1	- 2.3	-3.4
1974	11,955	12,062	-105.9	1,004.5	1,006.2	- 1.7	0.0
1975	12,959	13,068	-107.4	1,004.5	1,006.1	- 1.4	-0.2
1976	13,964	14,074	-108.4	1,004.5	1,005.6	- 1.0	-0.1
1977	14,968	15,078	-108.2	1,004.5	1,004.3	0.1	0.0
1978	15,973	16,081	-106.2	1,004.5	1,002.4	2.1	0.0
1979	16,977	17,081	-102.2	1,004.5	1,000.7	3.9	-0.1
1980	17,981	18,080	- 96.1	1,004.5	998.3	6.2	0.0
1981	18,986	19,075	- 87.1	1,004.4	995.5	9.0	0.0
1982	19,990	20,068	- 75.5	1,004.5	993.1	11.6	-0.2
1983	20,995	21,060	- 61.5	1,004.5	992.0	14.0	-1.6
1984	21,999	22,049	- 45.0	1,004.5	988.2	16.5	-0.2
1985	23,004	23,034	- 25.9	1,004.5	985.6	19.1	-0.2
1986	24,008	24,017	- 4.3	1,004.5	983.1	21.6	-0.3
1987	24,346	24,331	19.8	338.0	314.1	24.1	-0.3

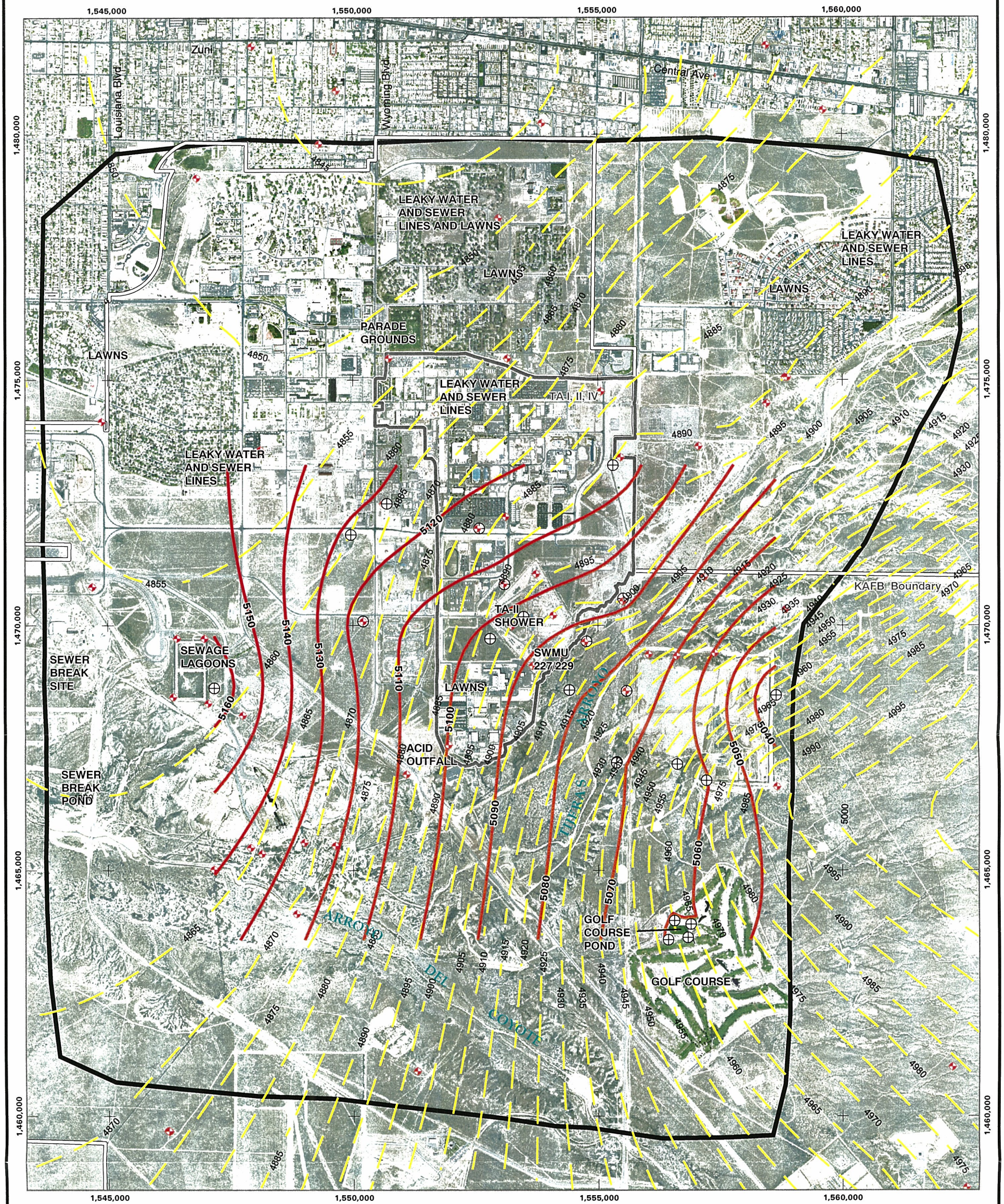
MODEL

TABLE 6. SIMULATED DIFFERENCE FROM YEAR 1947 FLOWS AT MODEL BOUNDARIES

Year	Cumulative Total			Annual Rate			Annual Flow Balance (AFY)
	Recharge Volume (AF)	Volume Into Storage (AF)	Volume Out Of Model Domain (AF)	Recharge (AFY)	Flow Into Aquifer Storage (AFY)	Flow Out Of Model Domain (AFY)	
1988	24,684	24,643	46.7	338.0	311.7	26.9	-0.6
1989	25,022	24,951	76.9	338.0	308.1	30.2	-0.2
1990	25,360	25,256	110.2	338.0	304.9	33.3	-0.2
1991	25,698	25,558	146.6	338.0	301.8	36.4	-0.2
1992	26,034	25,856	186.1	336.1	298.4	39.5	-1.8
1993	26,373	26,155	229.0	338.8	298.9	42.9	-3.0
1994	26,934	26,669	275.2	560.9	514.3	46.2	0.4
1995	27,270	26,956	324.8	336.1	286.5	49.6	-0.1
1996	27,606	27,239	377.9	336.1	283.1	53.1	-0.1
1997	27,942	27,519	434.6	336.0	279.7	56.8	-0.5
1998	28,278	27,795	494.8	336.1	276.2	60.2	-0.4
1999	28,614	28,068	558.3	336.1	272.7	63.4	-0.1
2000	28,950	28,337	625.0	336.1	269.5	66.8	-0.2
2001	29,286	28,603	695.0	336.1	266.1	70.0	0.0

[1]Negative indicates flow into domain.

FIGURES



0 1,000 2,000 3,000 4,000 5,000 Feet

1:24,339

PROJECTION AND 5000 FOOT GRID ARE NEW MEXICO CENTRAL ZONE, NAD83, FEET.

IMAGERY SOURCE: 1999 BERNALILLO COUNTY DIGITAL ORTHOPHOTOS.

N W E S

Legend

- OBSERVED PERCHED ZONE HEADS (FEET)
- OBSERVED REGIONAL WATER-TABLE HEADS (FEET)

WELL DATA (SEE PLATE 1 FOR WELL NAMES)

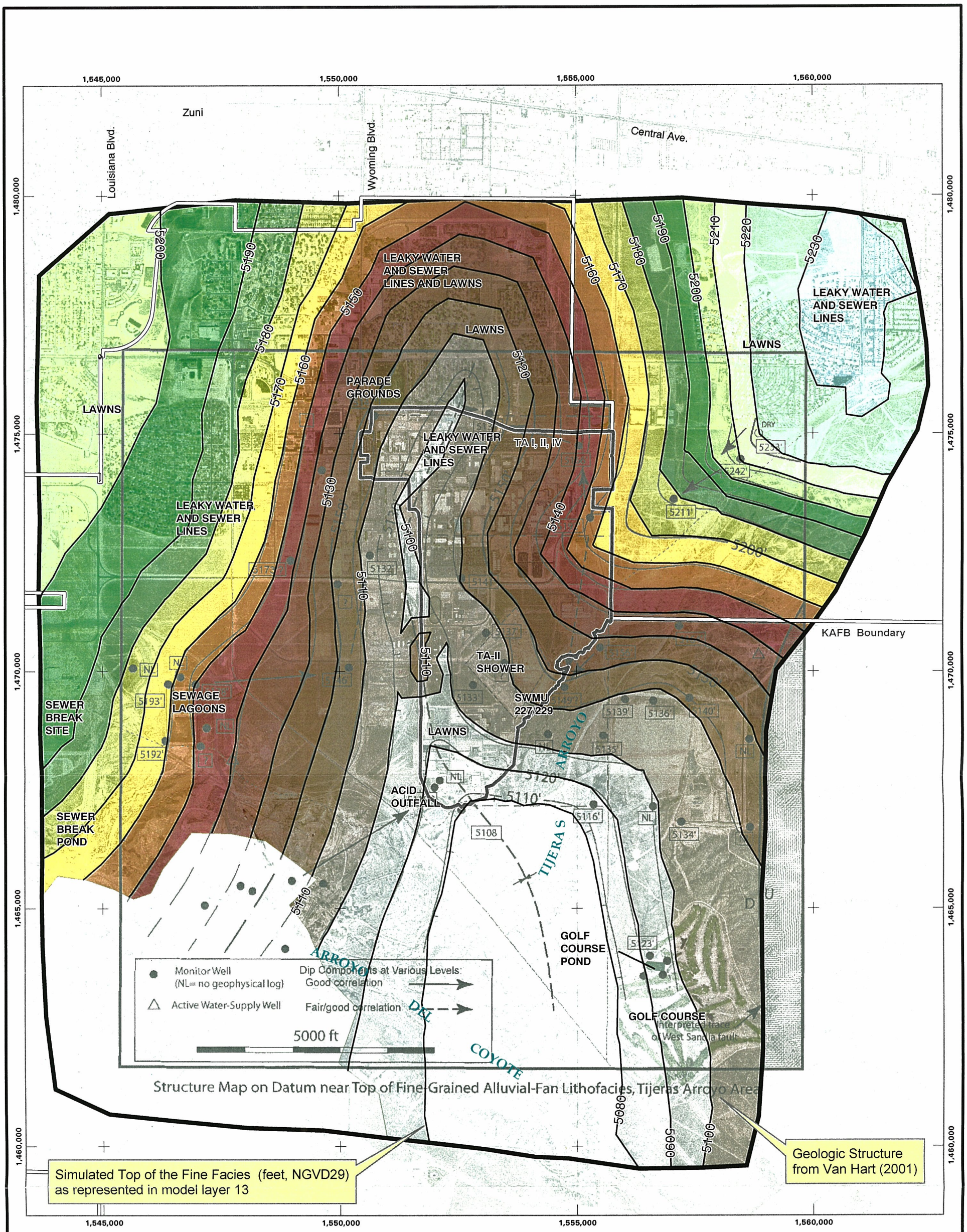
- REGIONAL AQUIFER WELL
- PERCHED ZONE WELL

SANDIA NATIONAL LABORATORIES/ MODEL

OBSERVED HEAD IN PERCHED AND REGIONAL ZONES OF SATURATION

DATE: 6/25/2002	**FIGURE 1**
PRODUCED BY: SES	
CHECKED BY: WPB	
FILE NAME: FIGURE1.MXD	

BALLEAU GROUNDWATER, INC.



Structure Map on Datum near Top of Fine-Grained Alluvial-Fan Lithofacies, Tijeras Arroyo Area

0 1,000 2,000 3,000 4,000 5,000 Feet

1:24,191

PROJECTION AND 5000 FOOT GRID ARE NEW MEXICO CENTRAL ZONE, NAD83, FEET.

IMAGERY SOURCE: 1999 BERNALILLO COUNTY DIGITAL ORTHOPHOTOS.

N W E S

SANDIA NATIONAL LABORATORIES/ MODEL

GEOLOGIC AND SIMULATED STRUCTURE OF FINE FACIES SEDIMENTS

DATE: 6/25/2002	**FIGURE 2**
PRODUCED BY: SES	
CHECKED BY: WPB	
FILE NAME: FIG2.MXD	

BALLEAU GROUNDWATER, INC.

1,545,000 1,550,000 1,555,000 1,560,000

1,480,000 1,475,000 1,470,000 1,465,000 1,460,000

Zuni

Louisiana Blvd.

Wyoming Blvd.

Central Ave.

LEAKY WATER AND SEWER LINES AND LAWNS

LAWNS

LEAKY WATER AND SEWER LINES

LAWNS

LEAKY WATER AND SEWER LINES

TA I, II, IV

TA1-W-03: 261 ppm

TA1-W-07: 95 ppm

KAFB-3391: 86 ppm

TA1-W-06: 95 ppm

TA2-NW1-325: 127 ppm

TA2-W-26: 58 ppm

KAFB Boundary

TA2-W-01: 108 ppm

WYO-2: 116 ppm

TA2-SW1-320: 26 ppm

TA2-W-27: 143 ppm

KAFB-3015: 27 ppm

SWMU 227/229

SEWER BREAK SITE

KAFB-0506: 150 ppm

LAWNS

TJA-2: 73 ppm

TA2-W-19: 68 ppm

KAFB-0314: 180 ppm

TJA-4: 20 ppm

TJA-5: 16 ppm

KAFB-0313: 53 ppm

KAFB-0310: 110 ppm

SEWER BREAK POND

KAFB-0608: 22 ppm

KAFB-0609: 30 ppm

KAFB-0610: 50 ppm

0 1,000 2,000 3,000 4,000 5,000 Feet

1:24,175

PROJECTION AND 5000 FOOT GRID ARE NEW MEXICO CENTRAL ZONE, NAD83, FEET.

IMAGERY SOURCE: 1999 BERNALILLO COUNTY DIGITAL ORTHOPHOTOS.

N W E S

Legend

PERCHED ZONE WELL WITH WATER-QUALITY DATA

CHLORIDE CONCENTRATION (ppm)

- 16 - 50
- 50 - 100
- 100- 150
- 150 - 250
- 250- 262

CHLORIDE CONCENTRATION INDICATED (ppm)

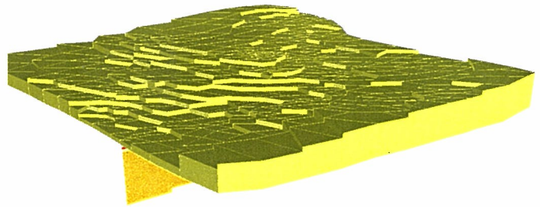
SANDIA NATIONAL LABORATORIES/ MODEL

CHLORIDE CONCENTRATIONS IN PERCHED ZONE OF SATURATION

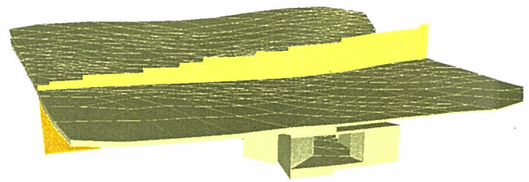
DATE: 6/25/2002	FIGURE 3
PRODUCED BY: SES	
CHECKED BY: WPB	
FILE NAME: FIG3.MXD	

BGW

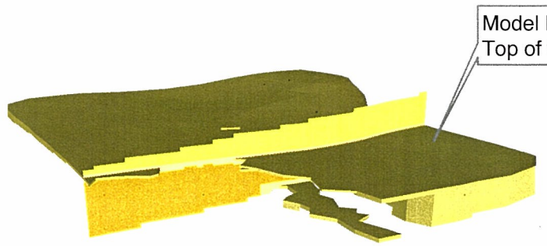
BALLEAU GROUNDWATER, INC.



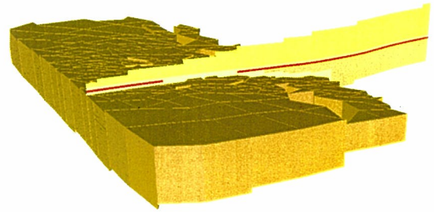
Coarse Material



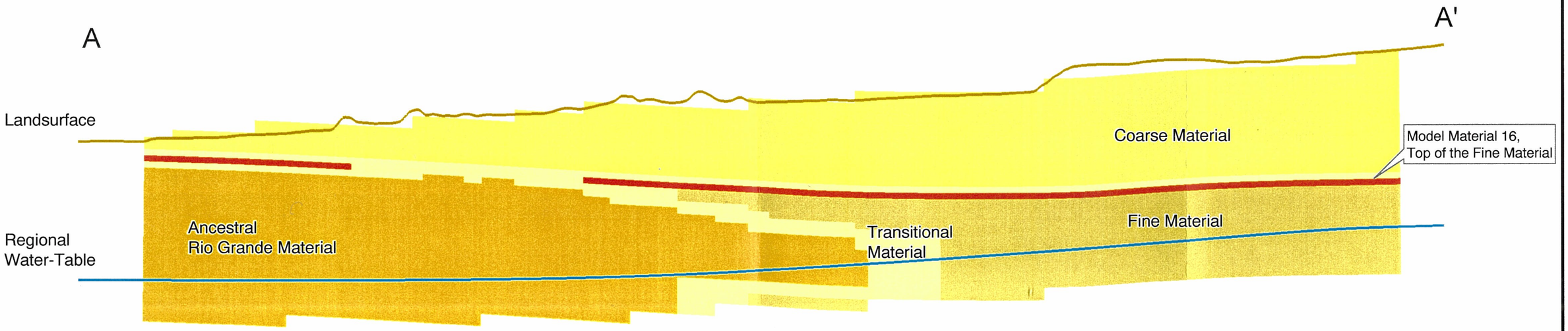
Transitional Material

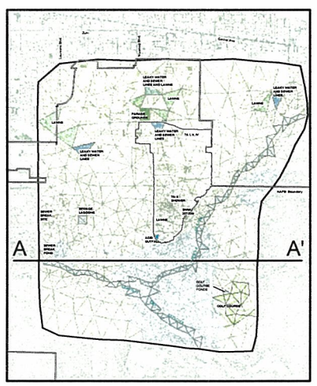


Fine Material



Ancestral
Rio Grande Material





Material	Thickness (ft)	Saturated Water Content (%)	Residual Water Content (%)	Kx, Ky (ft/d)	Kz (ft/d)
Coarse	15 to 30	0.2	0.11	50	0.2
Transitional	15 to 30	0.2	0.11	40	0.002
Fine	15 to 30	0.29	0.183	20	0.0001
Ancestral R.G.	15 to 30	0.2	0.11	1	10

SANDIA NATIONAL LABORATORIES/
MODEL

MODEL STRUCTURE AND MATERIAL TYPES

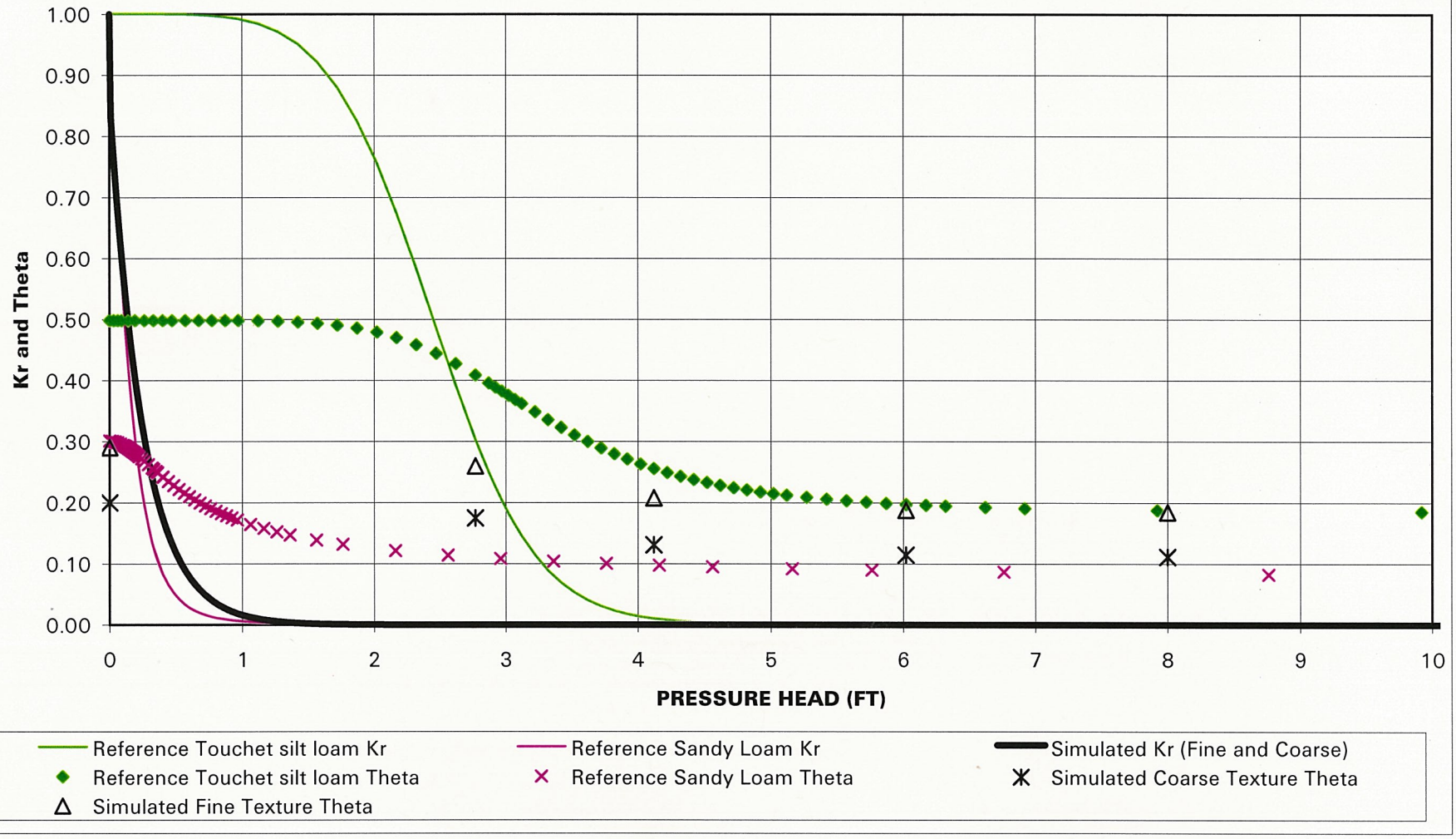
DATE: 6/25/2002
PRODUCED BY: SES
CHECKED BY: WPB
FILE NAME: FIG4.MXD

FIGURE 4

BALLEAU GROUNDWATER, INC.

FIGURE 5
RELATIVE HYDRAULIC CONDUCTIVITY (Kr) AND WATER CONTENT (Theta) VS PRESSURE HEAD

Touchet silt loam from Yates and others (1992). Sandy loam from Hsin-Chi and others (1997).



SoilPropertiesFig.xls
RW
9/20/02

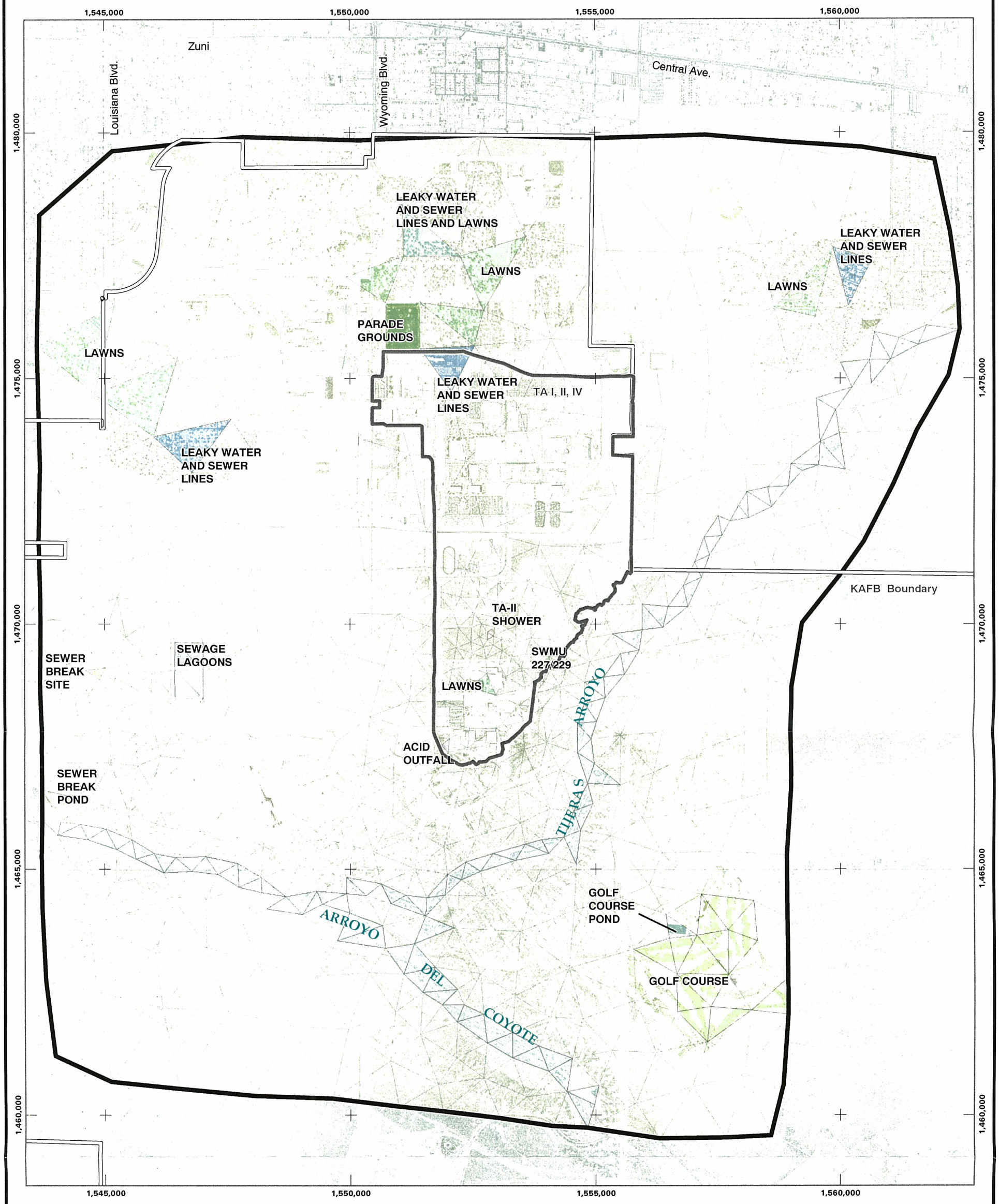


TABLE 2. SIMULATED RECHARGE RATES IN SANDIA NORTH MODEL

Source	Simulated Surface Area (acres)	Field Surface Area (acres)	Model Rate (ft/d)[1]	Model Rate (AFY)	Model Rate (gpd)	Start	End	Total Volume 1947 - 2002 (AF)
Leaky Water Lines	53.39	unknown	0.00615	120.00	107,000	1947	2002	6,717
Tijeras Arroyo and Arroyo del Coyote	241.00	unknown	0.00136	120.00	107,000	Year 0	2002	6,717
Tijeras Arroyo Golf Course	86.07	91 green	0.00485	152.47	136,000	1967	2002	5,488
Sewage Lagoons - (Initial Estimate)	15.98	14	0.04275	249.50	223,000	1967	1987	5,250
Sewage Lagoons - (Final Calibration)	15.08	14	0.10000	550.80	491,000	1967	1987	11,559
Housing Lawns	123.11	123 green	0.00068	30.75	27,400	1947	2002	1,722
Parade Grounds	15.12	14	0.00507	28.00	25,000	1947	2002	1,569
Abandoned TAGC Pond - (Initial Estimate)	3.16	3	0.04632	53.50	47,700	1967	1987	1,123
Abandoned TAGC Pond - (Final Calibration)	3.16	3	0.10000	115.50	103,000	1967	1987	2,425
Leaky Sewer Lines	53.39	unknown	0.00026	5.08	4,530	1947	2002	284
Sewer Line Break Ponding area	11.11	unknown	0.97017	3,937.09	3,510,000	9/14/1994	10/7/1994	259
Acid Waste Outfall (SWMU 46)	.50	line source	0.04549	8.31	7,420	1947	1973	225
TA-II Shower Leachfield (SWMU 165)	.51	1.16	0.00604	1.12	1,000	1947	1992	52
Combined SWMU 227 and 229	.24	unknown	0.00943	.83	742	1947	1992	38
Sewer Line Break Site	1.06	Point Source	0.02084	8.07	7,200	9/14/1993	9/13/1994	8
Total	603.74			5,078	4,530,000			37,062

[1] Rate adjusted to reflect the simulated area

0 1,000 2,000 3,000 4,000 5,000 Feet

1:24,094

PROJECTION AND 5000 FOOT GRID ARE NEW MEXICO CENTRAL ZONE, NAD83, FEET.

IMAGERY SOURCE: 1999 BERNALILLO COUNTY DIGITAL ORTHOPHOTOS.

N W E S

SANDIA NATIONAL LABORATORIES/ MODEL

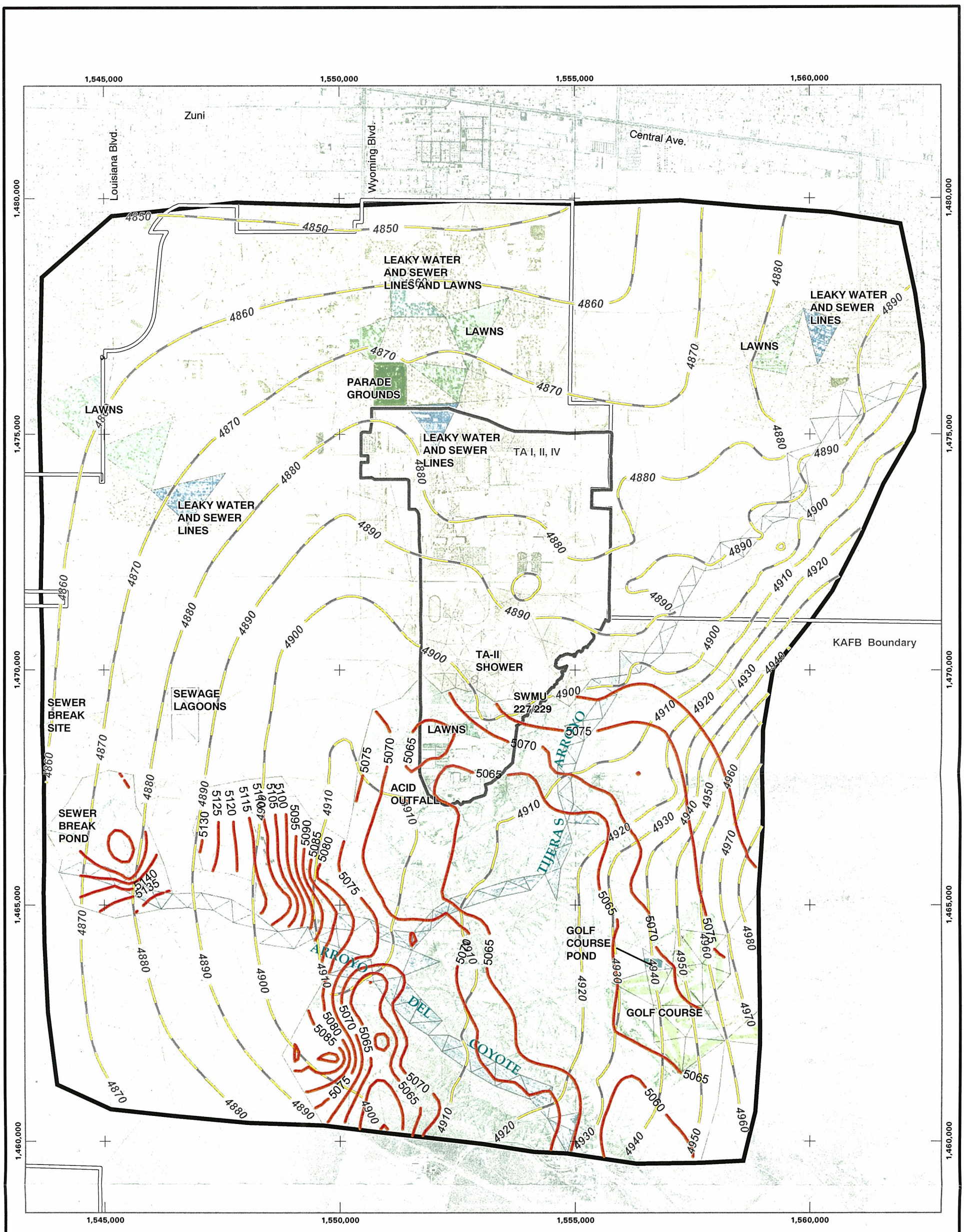
SIMULATED RECHARGE BOUNDARY CONDITIONS FOR YEARS 1947 - 2002

DATE: 6/25/2002
PRODUCED BY: SES
CHECKED BY: WPB
FILE NAME: FIG6.MXD

FIGURE 6

BGW

BALLEAU GROUNDWATER, INC.



Legend

SIMULATED JANUARY 1947 REGIONAL WATER TABLE

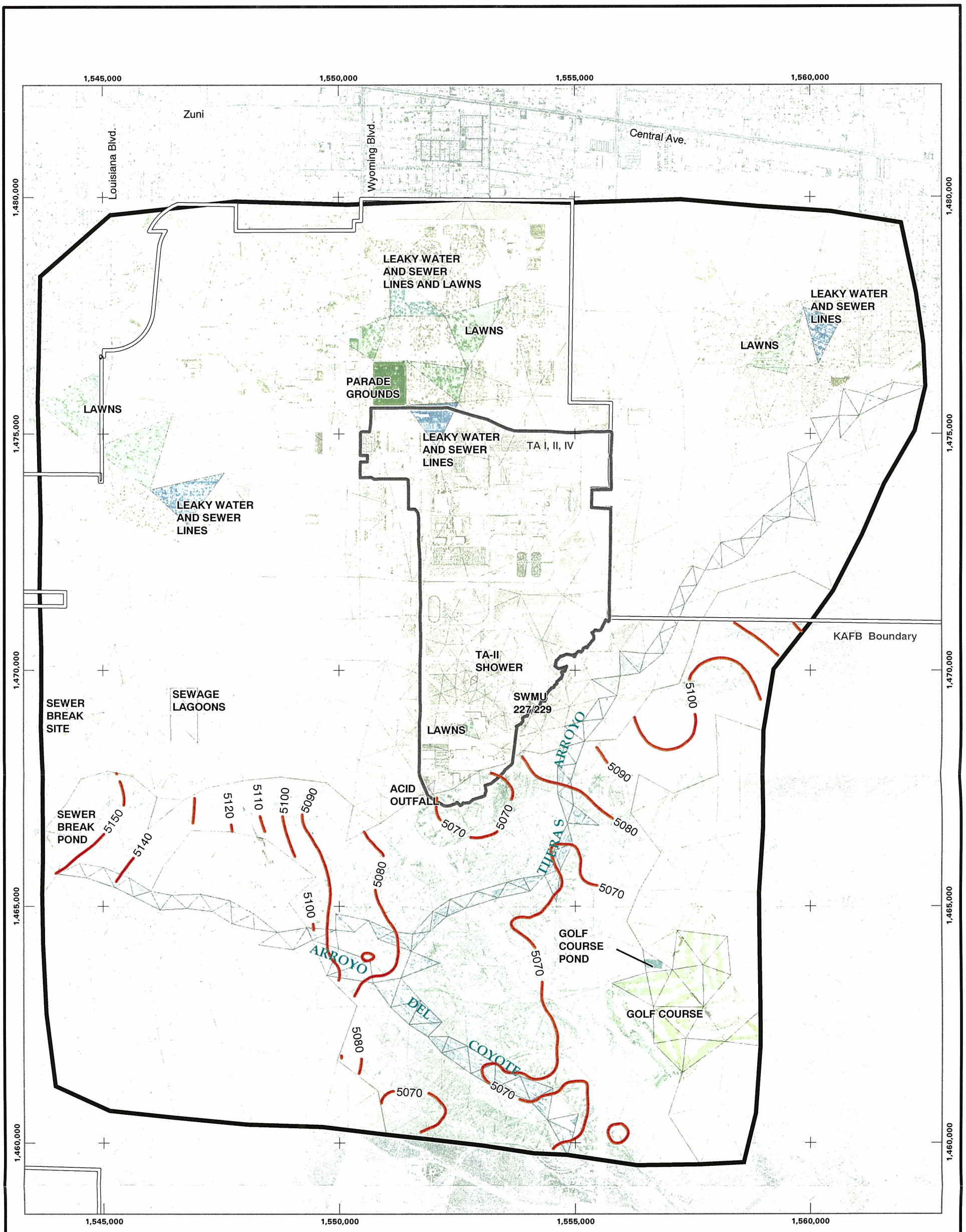
SIMULATED JANUARY 1947 AVERAGE TOTAL HEAD (FEET) IN THE TOP 45 FEET OF THE FINE GRAINED MATERIAL

SANDIA NATIONAL LABORATORIES/ MODEL

SIMULATED 1947 REGIONAL WATER-TABLE AND PERCHED CONDITIONS

DATE: 6/25/2002	**FIGURE 7**
PRODUCED BY: SES	
CHECKED BY: WPB	
FILE NAME: FIG7.MXD	

BALLEAU GROUNDWATER, INC.



0 1,000 2,000 3,000 4,000 5,000 Feet

1:24,298

PROJECTION AND 5000 FOOT GRID ARE NEW MEXICO CENTRAL ZONE, NAD83, FEET.

IMAGERY SOURCE: 1999 BERNALILLO COUNTY DIGITAL ORTHOPHOTOS.

N W E S

Legend

SIMULATED JANUARY 1967 AVERAGE TOTAL HEAD (FEET) IN THE TOP 45 FEET OF THE FINE GRAINED MATERIAL

SANDIA NATIONAL LABORATORIES/ MODEL

SIMULATED 1967 CONTOURS OF PERCHED ZONE OF SATURATION

DATE: 6/25/2002	FIGURE 8
PRODUCED BY: SES	
CHECKED BY: WPB	
FILE NAME: FIG8.MXD	

BGW

BALLEAU GROUNDWATER, INC.

1,545,000 1,550,000 1,555,000 1,560,000

1,480,000 1,475,000 1,470,000 1,465,000 1,460,000

Zuni

Louisiana Blvd.

Wyoming Blvd.

Central Ave.

LEAKY WATER AND SEWER LINES AND LAWNS

LAWNS

LEAKY WATER AND SEWER LINES

LAWNS

PARADE GROUNDS

LAWNS

LEAKY WATER AND SEWER LINES

TA I, II, IV

LEAKY WATER AND SEWER LINES

KAFB Boundary

TA-II SHOWER

SWMU 227/229

SEWAGE LAGOONS

SEWER BREAK SITE

LAWNS

ACID OUTFALL

SEWER BREAK POND

ARROYO

TIJERAS

ARROYO

DEL

COYOTE

GOLF COURSE POND

GOLF COURSE

5170 5160 5150 5140 5130 5120 5110 5100 5090 5080 5070 5060

0 1,000 2,000 3,000 4,000 5,000 Feet

1:24,161

PROJECTION AND 5000 FOOT GRID ARE NEW MEXICO CENTRAL ZONE, NAD83, FEET.

IMAGERY SOURCE: 1999 BERNALILLO COUNTY DIGITAL ORTHOPHOTOS.

N W E S

Legend

SIMULATED JANUARY 1972 AVERAGE TOTAL HEAD (FEET) IN THE TOP 45 FEET OF THE FINE GRAINED MATERIAL

SANDIA NATIONAL LABORATORIES/ MODEL

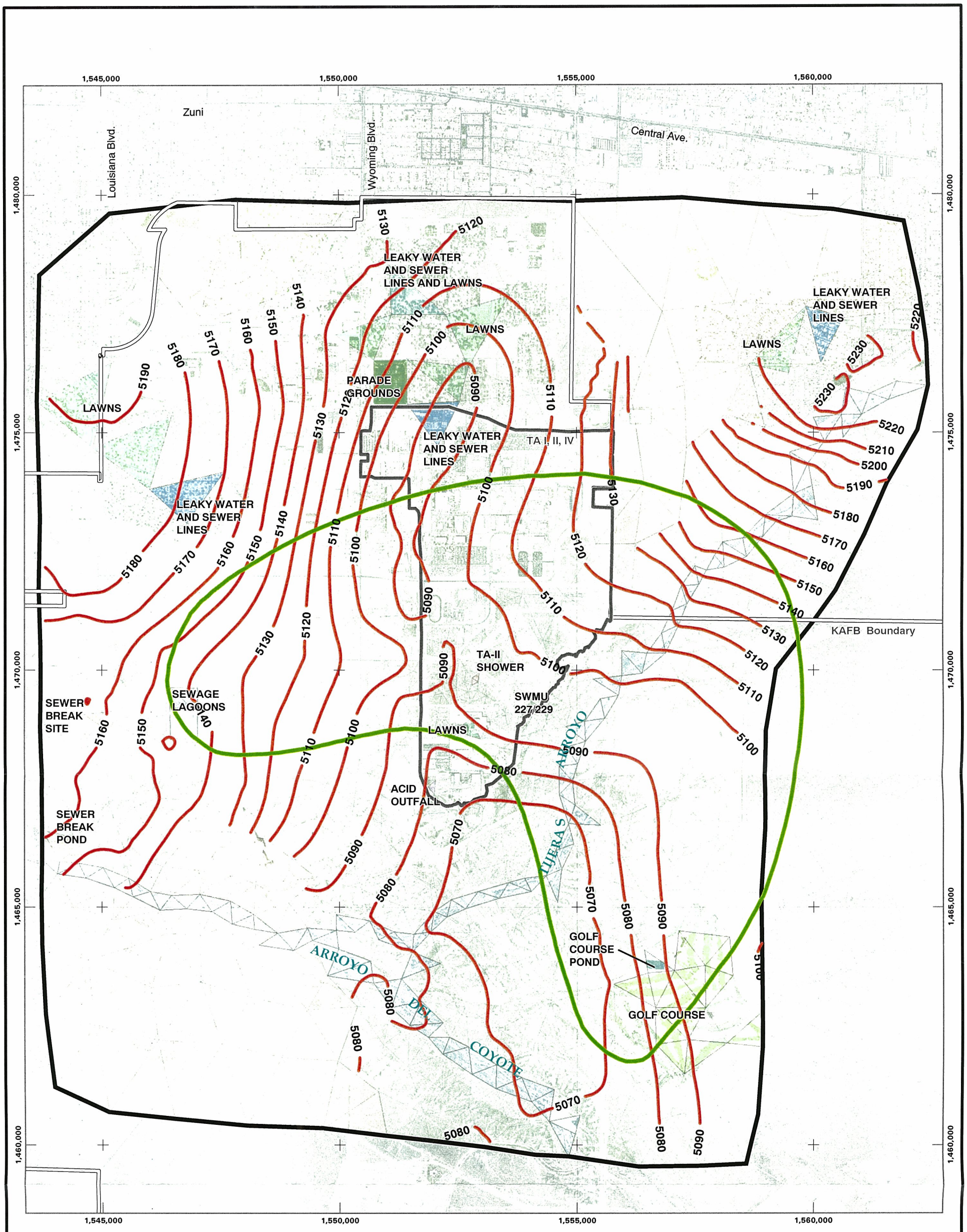
SIMULATED 1972 CONTOURS OF PERCHED ZONE OF SATURATION

DATE:	6/25/2002
PRODUCED BY:	SES
CHECKED BY:	WPB
FILE NAME:	FIG9.MXD

FIGURE 9

BGW

BALLEAU GROUNDWATER, INC.



0 1,000 2,000 3,000 4,000 5,000 Feet

1:24,109

PROJECTION AND 5000 FOOT GRID ARE NEW MEXICO CENTRAL ZONE, NAD83, FEET.

IMAGERY SOURCE: 1999 BERNALILLO COUNTY DIGITAL ORTHOPHOTOS.

N W E S

Legend

SIMULATED JANUARY 2002 AVERAGE TOTAL HEAD (FEET) IN THE TOP 45 FEET OF THE FINE GRAINED MATERIAL

NOVEMBER 2000 EXTENT OF PERCHED AQUIFER (FEET) (Adapted From: SANDIA NATIONAL LABORATORIES MAP "NOVEMBER 2000 EXTENT OF PERCHED AQUIFER")

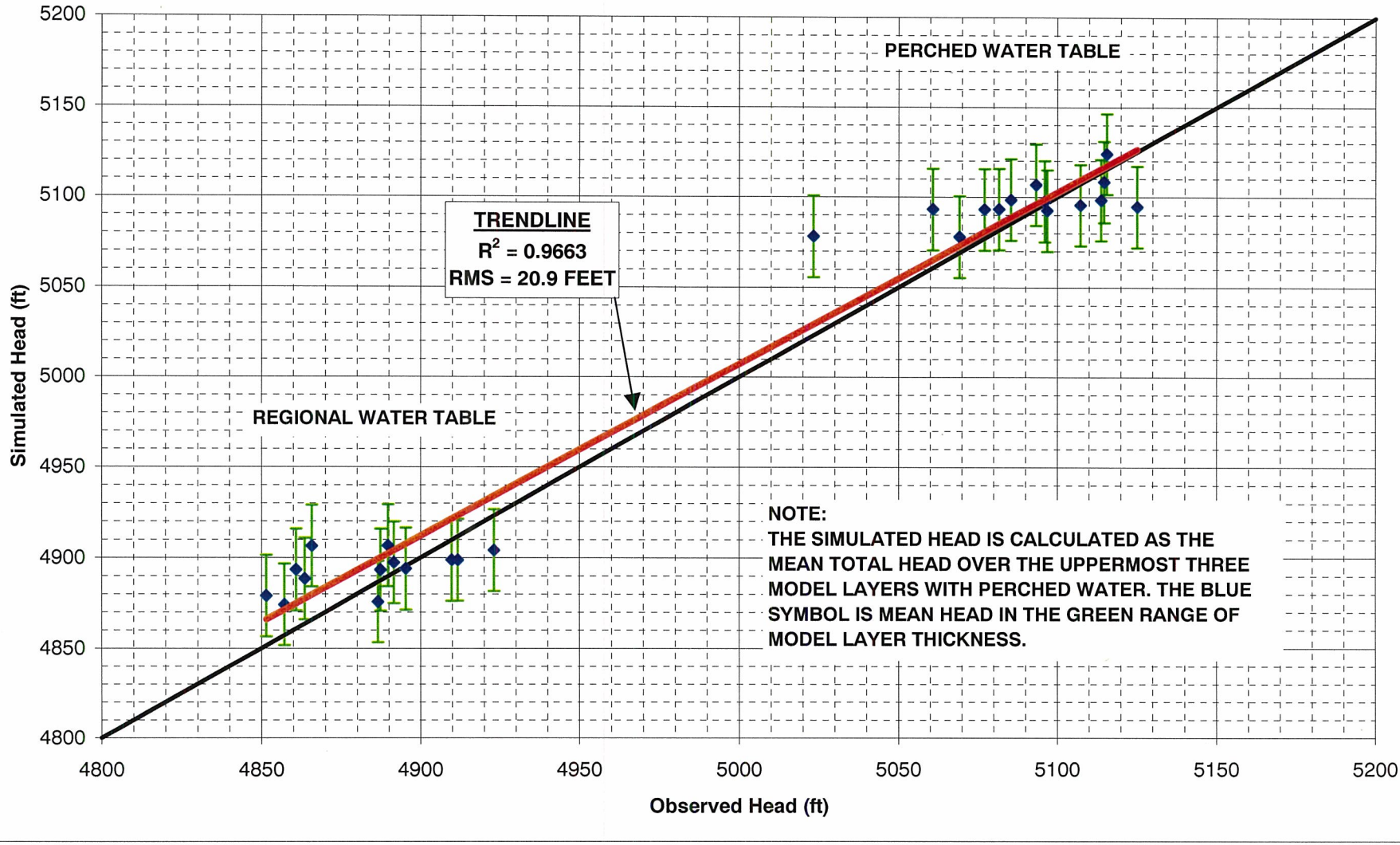
SANDIA NATIONAL LABORATORIES/ MODEL

SIMULATED 2002 CONTOURS OF PERCHED ZONE OF SATURATION

DATE: 6/25/2002	
PRODUCED BY: SES	
CHECKED BY: WPB	FIGURE 10
FILE NAME: FIG10.MXD	

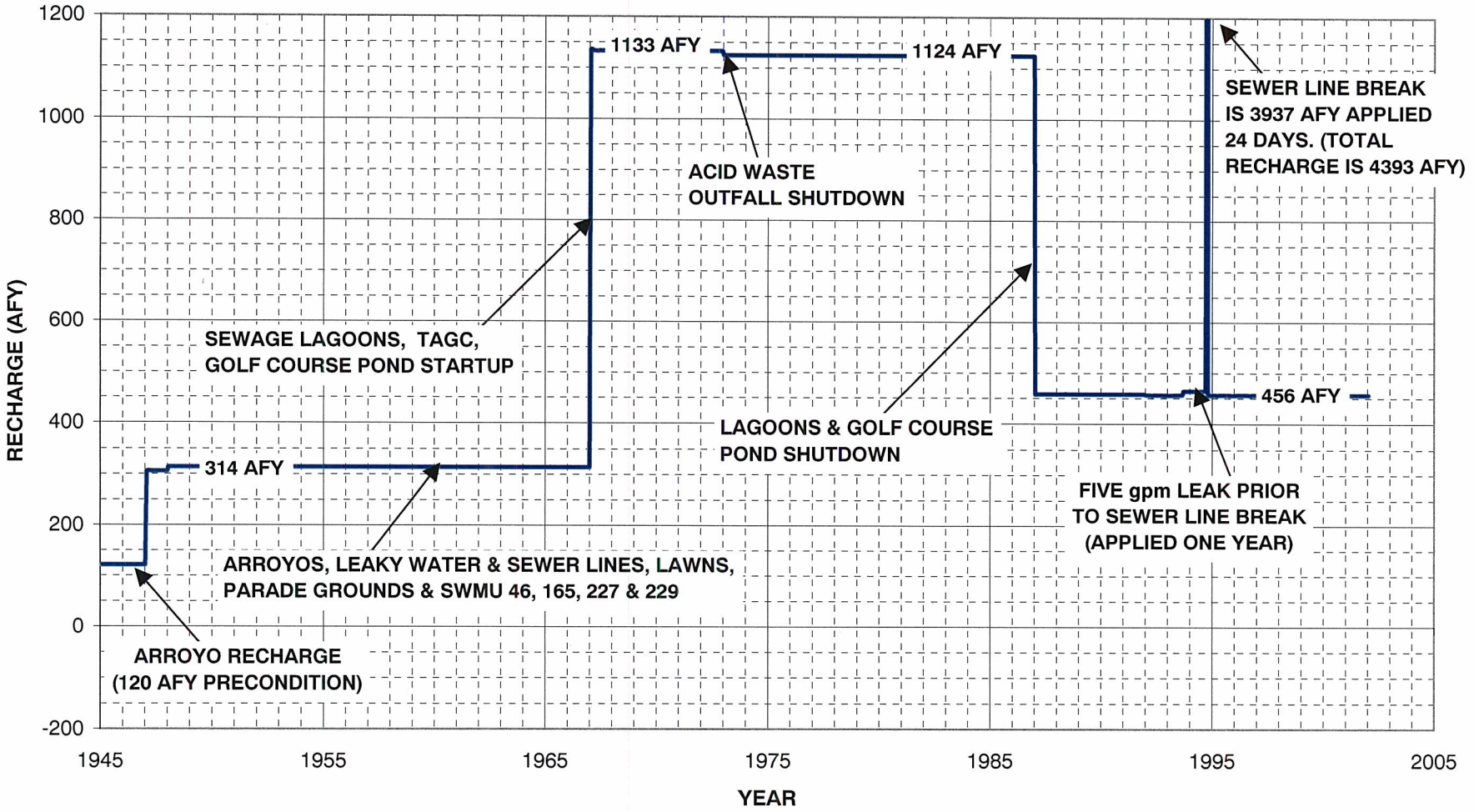
BALLEAU GROUNDWATER, INC.

FIGURE 11
CORRELATION OF OBSERVED AND SIMULATED WATER LEVELS



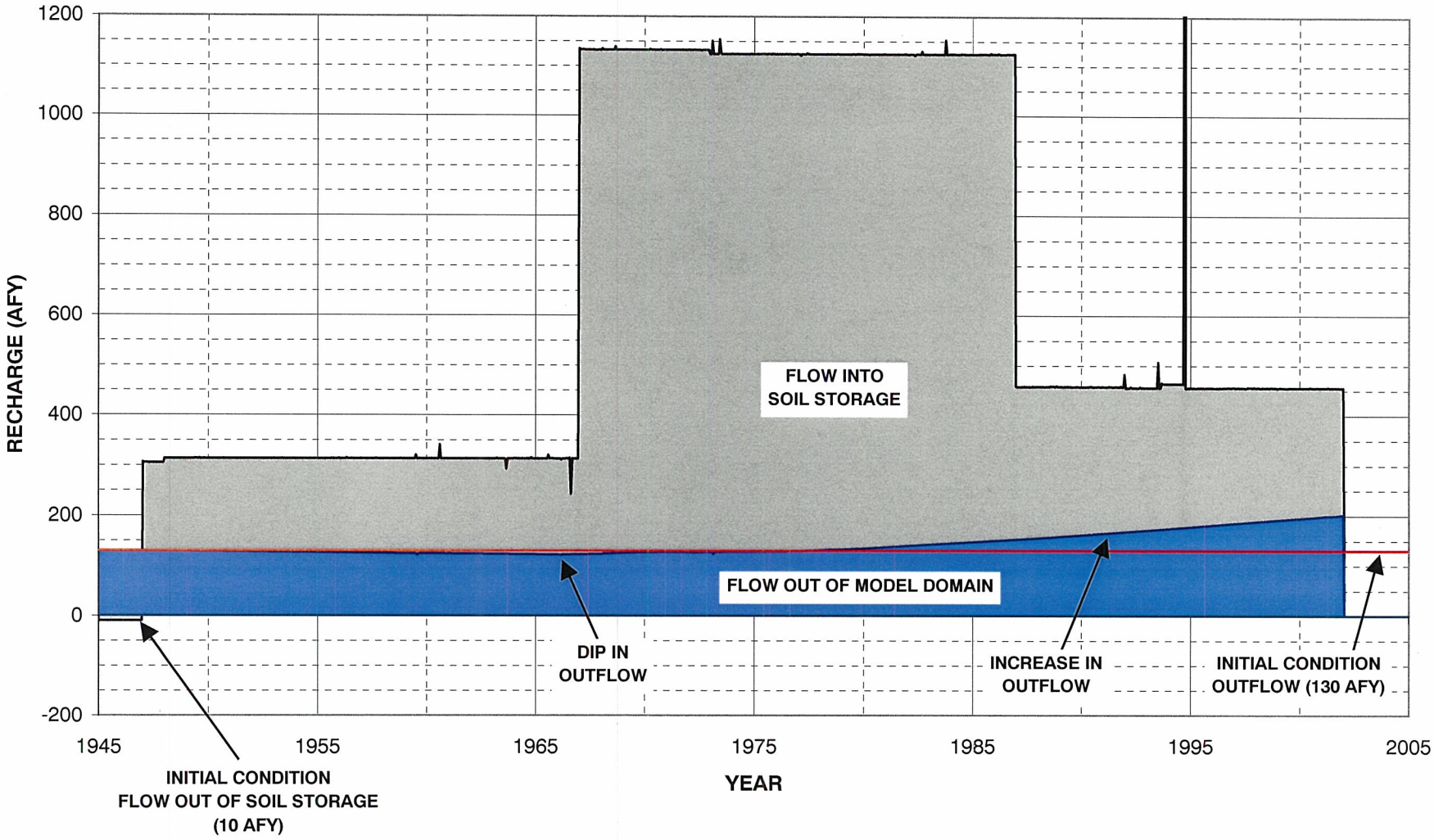
crossplot.xls
SES
8/30/02

FIGURE 12
SIMULATED HISTORICAL RECHARGE RATE

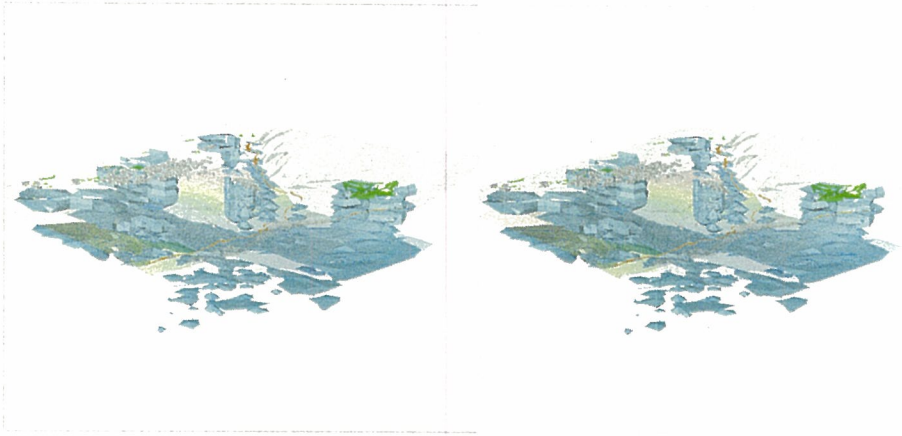


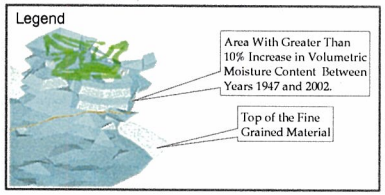
MassBalance.xls
DR
8/30/02

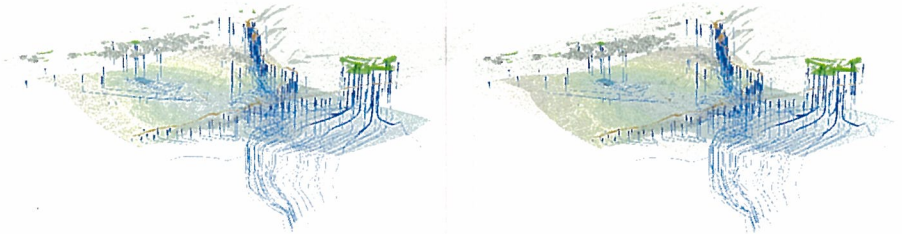
FIGURE 13
SIMULATED RESPONSE TO RECHARGE RATE

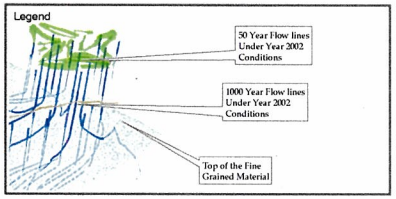


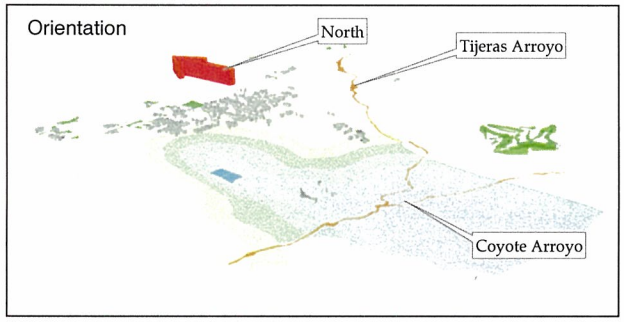
MassBalance.xls
DR
8/30/02











SANDIA NATIONAL LABORATORIES/ MODEL

STEREOGRAMS

DATE: 8/30/2002	
PRODUCED BY: SES	
CHECKED BY: WPB	**FIGURE 14**
FILE NAME: FIGURE14.MXD	

BALLEAU GROUNDWATER, INC.





Legend

- WELL WITH CONFIRMED ABSENCE OF PERCHED AQUIFER
- REGIONAL AQUIFER WELL
- PERCHED ZONE WELL

0 1,000 2,000 3,000 4,000 5,000 Feet

PROJECTION AND 5000 FOOT GRID ARE NEW MEXICO CENTRAL ZONE, NAD83, FEET.
IMAGERY SOURCE: 1999 BERNALILLO COUNTY DIGITAL ORTHOPHOTOS.

N W E S

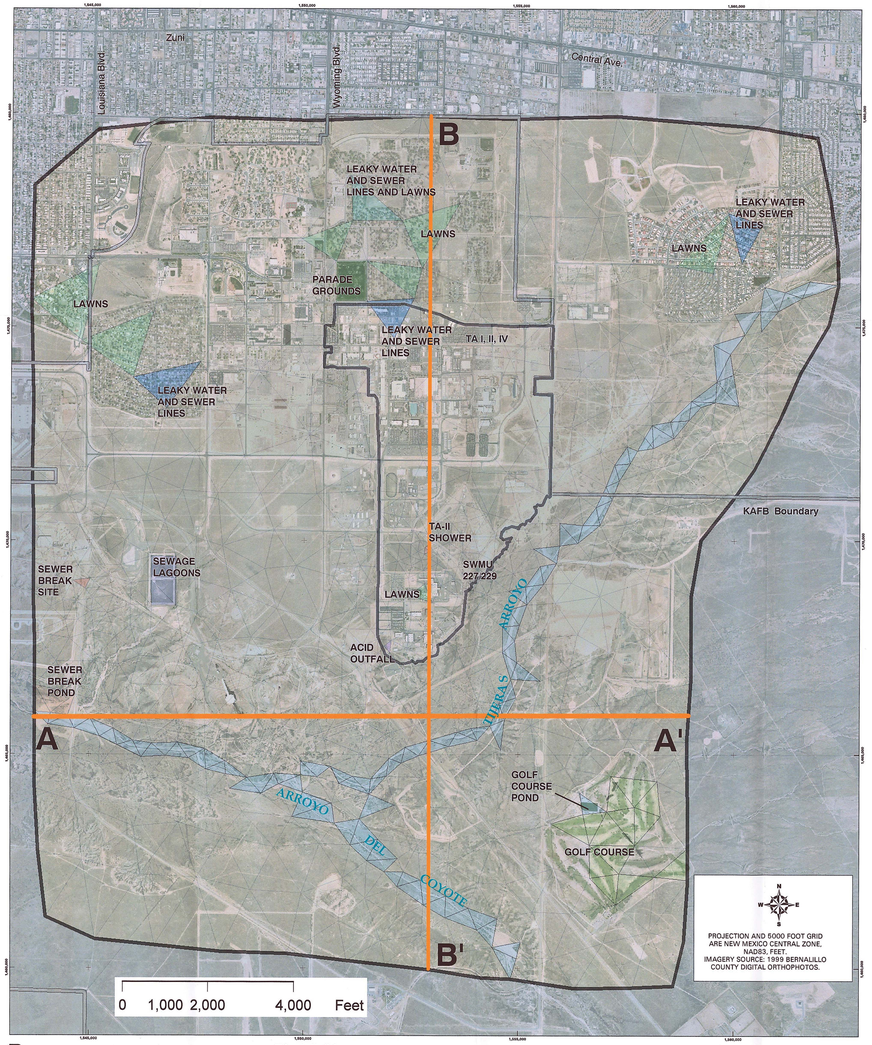
SANDIA NATIONAL LABORATORIES/ MODEL

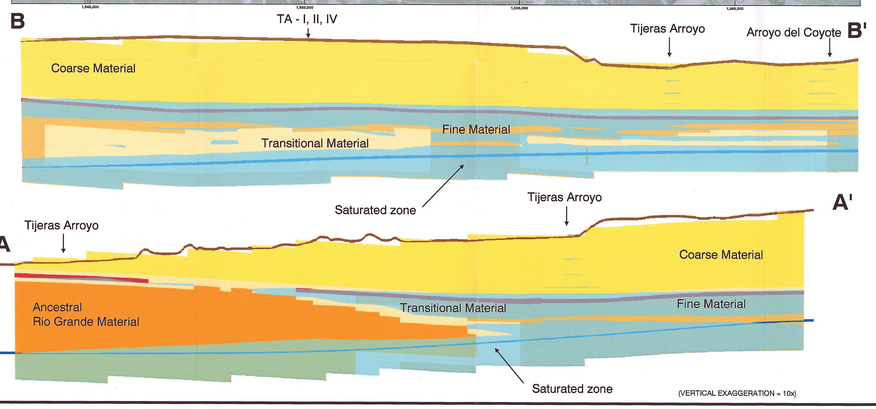
LOCALITY MAP

DATE: 08/14/2003
DRAWN BY:
CHECKED BY:
FILE NAME: PLATE1.MXD

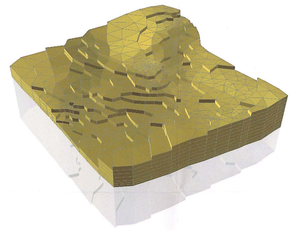
PLATE 1

BALLEAU GROUNDWATER, INC.

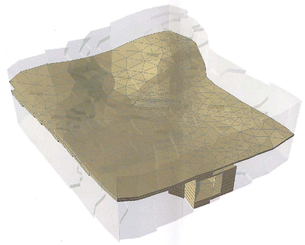




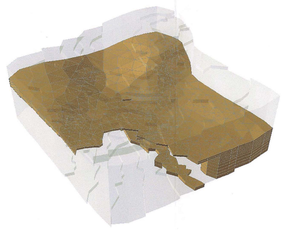
MODEL MATERIALS AND STRUCTURE



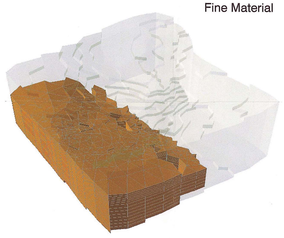
Coarse Material



Transitional Material

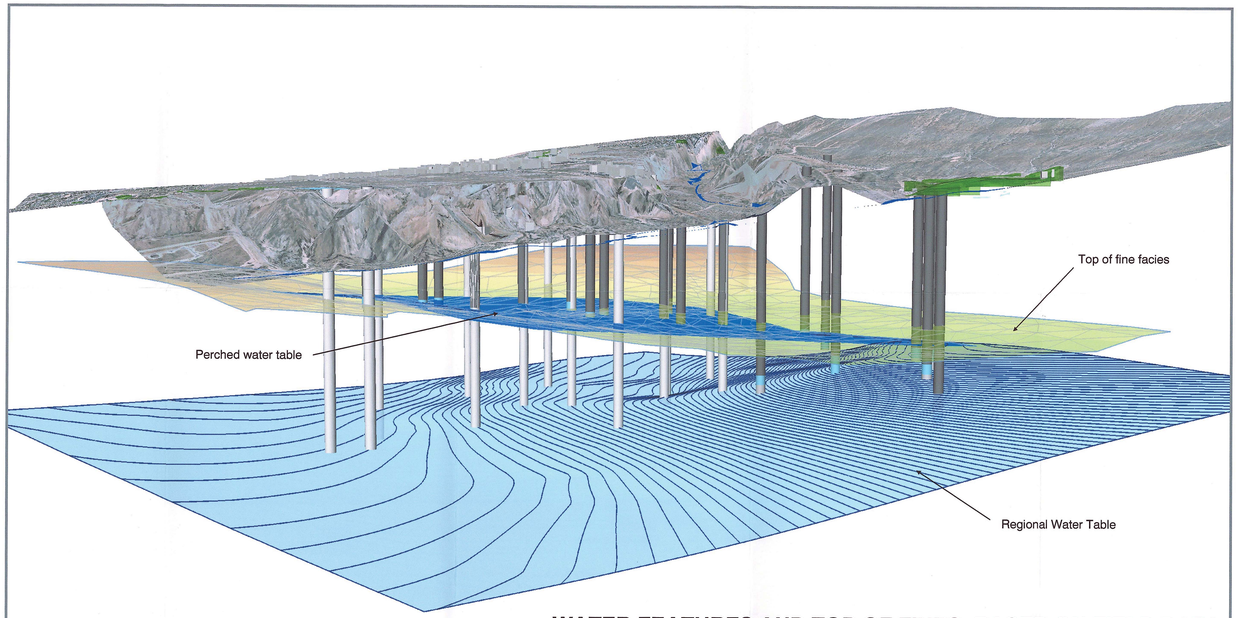


Fine Material



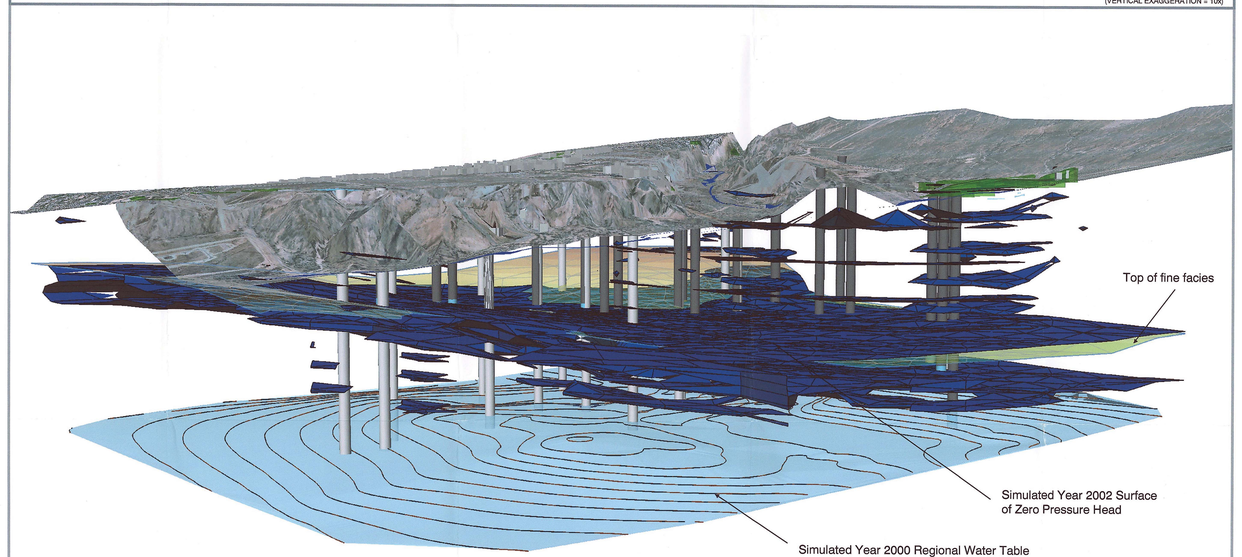
Ancestral
Rio Grande Material

Material	Thickness (ft)	Saturated Water Content (%)	Residual Water Content (%)	Kx, Ky (ft/d)	Kz (ft/d)
Coarse	15 to 30	0.2	0.11	50	0.2
Transitional	15 to 30	0.2	0.11	40	0.002
Fine	15 to 30	0.29	0.183	20	0.0001
Ancestral R.G.	15 to 30	0.2	0.11	1	10



WATER FEATURES AND TOP OF FINES BASED ON FIELD DATA

(VERTICAL EXAGGERATION = 10x)



WATER FEATURES AND TOP OF FINES AS SIMULATED

(VERTICAL EXAGGERATION = 10x)

SANDIA NATIONAL LABORATORIES/ MODEL

MODEL GRID, BOUNDARY CONDITIONS AND CROSS-SECTIONS

PLATE 2

BALLEAU GROUNDWATER, INC.

1,545,000 1,550,000 1,555,000 1,560,000

1,480,000 1,475,000 1,470,000 1,465,000

Zuni

Louisiana Blvd.

Wyoming Blvd.

Central Ave.

LEAKY WATER AND SEWER LINES AND LAWNS

LAWNS

PARADE GROUNDS

LEAKY WATER AND SEWER LINES

TA I, II, IV

LEAKY WATER AND SEWER LINES

TA I

LEAKY WATER AND SEWER LINES

TA II SHOWER

SEWAGE LAGOONS

SWMU 227/229

LAWNS

ACID OUTFALL

ARROYO

TIJERAS ARROYO

ARROYO DEL COYOTE

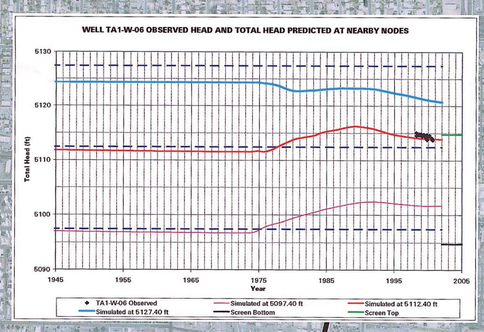
GOLF COURSE PONDS

GOLF COURSE

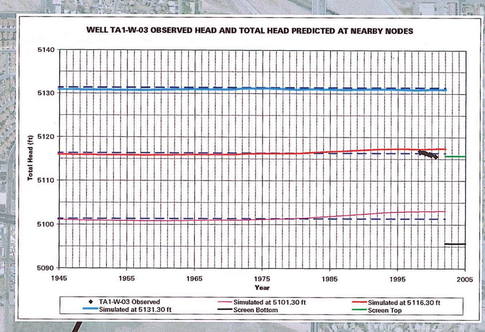
KAFB Boundary

KAFB Boundary

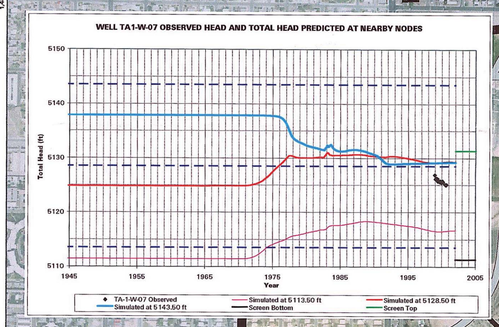
WELL TA1-W-06 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



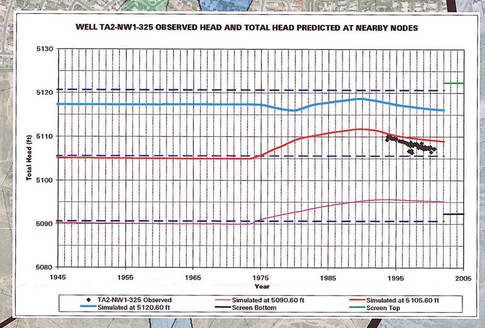
WELL TA1-W-03 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



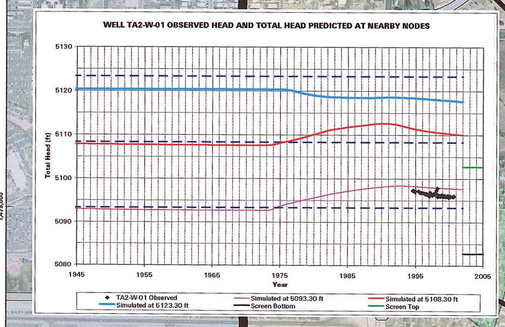
WELL TA1-W-07 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



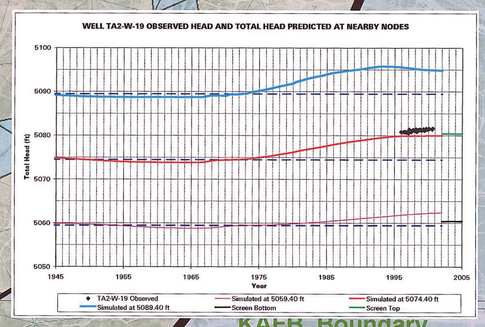
WELL TA2-NW1-325 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



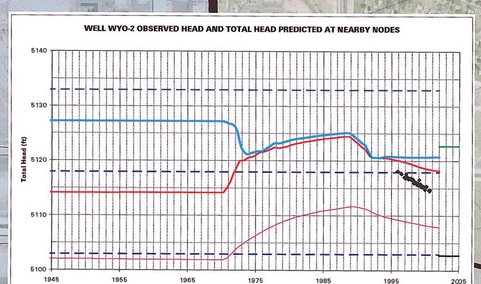
WELL TA2-W-01 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



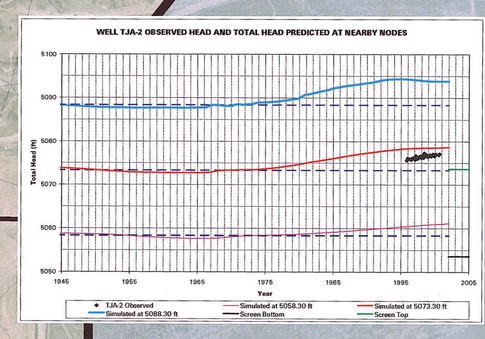
WELL TA2-W-19 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



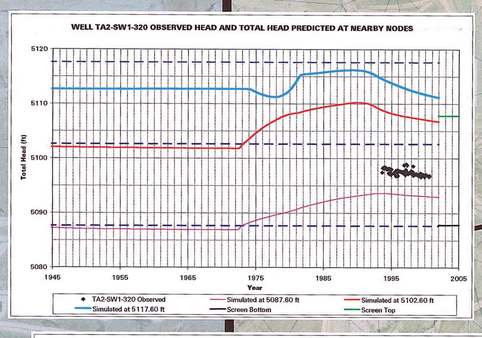
WELL WYO-2 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



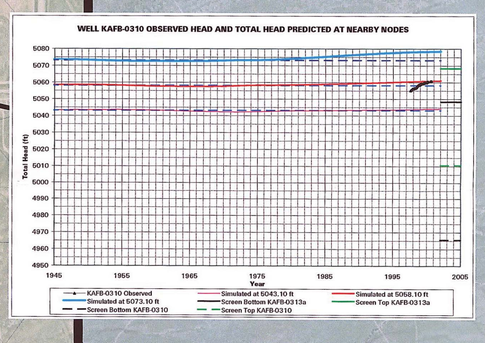
WELL TJA-2 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



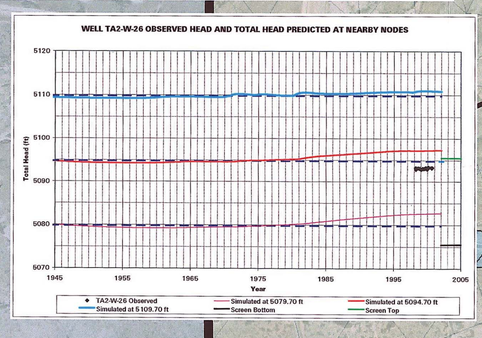
WELL TA2-SW1-320 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



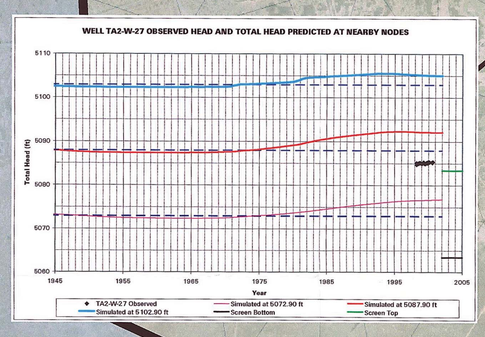
WELL KAFB-0310 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



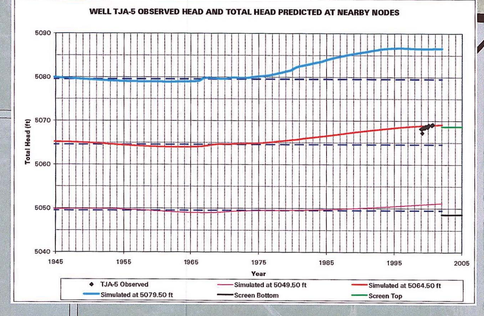
WELL TA2-W-26 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



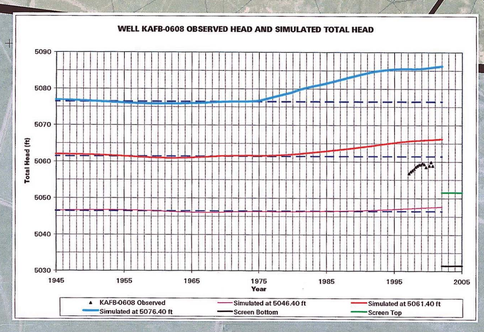
WELL TA2-W-27 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



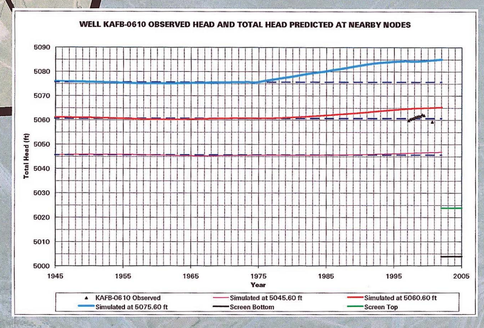
WELL TJA-5 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES



WELL KAFB-0608 OBSERVED HEAD AND SIMULATED TOTAL HEAD



WELL KAFB-0610 OBSERVED HEAD AND TOTAL HEAD PREDICTED AT NEARBY NODES





0 1,000 2,000 3,000 4,000 5,000 Feet

PROJECTION AND 5000 FOOT GRID ARE NEW MEXICO CENTRAL ZONE, NAD83, FEET.
IMAGERY SOURCE: 1996 BERNALILLO COUNTY DIGITAL ORTHOPHOTOS.

N W E S

SANDIA NATIONAL LABORATORIES/ MODEL

OBSERVED AND SIMULATED HYDROGRAPHS

DATE: 07/15/2002
PROJECTED BY:
DRAWN BY:
CHECKED BY: DATE:
FILE NAME: PHOTO.DWG

PLATE 3

BALLEAU GROUNDWATER, INC.