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TRW Environmental Safety Systems Inc.

PERMANENT

Numerical Modeling of Groundwater Flow in the Death Valley Hydrographic Region: Basins 225-230

Civilian Radioactive Waste Management System

Management & Operating Contractor

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CIVILIAN RADIOACTIVE WASTE MANAGEMENT SYSTEM
MANAGEMENT OPERATING CONTRACTOR

Numerical Modeling of Groundwater Flow in the Death Valley Hydrographic Region: Basins 225-230

February 2000

Prepared for:

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1. EXECUTIVE SUMMARY

This report presents the findings of Thiel Engineering Consultants' (TEC's) hydrogeologic investigation of the Yucca Mountain and adjacent area. The study area includes Hydrographic Basins 225 (Mercury Valley), 226 (Rock Valley), 227A (Jackass Flats), 227B (Buckboard Mesa), 228 (Oasis Valley), 229 (Crater Flat) and 230 (Amargosa Desert), and a portion of Hydrographic Basin 243 (Death Valley).

The hydrogeology of the study area is very complex. Groundwater flow in the region can be considered as being dominated by regional flow. The regional aquifer system consists primarily of two aquifer components: the shallow and localized aquifers and the deep regional aquifers.

Groundwater flow in the study area originates as recharge from precipitation predominantly in the highlands and subsurface inflow mainly from the northern and eastern boundaries. After entering the flow domain, groundwater moves generally toward the south and the southwest through the aquifer system. Groundwater discharges in the forms of spring flow and evapotranspiration (ET) in Oasis Valley, Amargosa Desert, Alkali Flat, Furnace Creek Ranch, and Ash Meadows and in the form of groundwater pumpage from wells. A portion of spring discharge and groundwater pumpage becomes secondary recharge. Subsurface outflow may ultimately discharge at Death Valley as ET.

A three-dimensional finite difference model grid consisting of 151 rows and 129 columns in 3 layers was constructed to simulate steady state and transient flow for the study area. A total of two steady-state calibration models (low flux and high flux), four historical verification transient simulation runs and sixteen predictive simulation runs were performed for this study. The computer code used to simulate the regional groundwater flow is MODFLOW (McDonald and Harbaugh, 1988) as implemented by Groundwater Vistas (a groundwater model design environment with pre-processing and post-processing tools developed by Environmental Simulations, Inc.). The blocks are oriented to the north and are of a uniform size of 0.5 mile × 0.5 mile. The bottom of the top model layer is approximately 1,640 ft (500 meters) below the estimated potentiometric surface of the shallow aquifer and the thicknesses of the central and bottom layers are 820 ft (250 meters) and 4,922 ft (1,500 meters), respectively.

The two steady-state models were calibrated by:

- simulating the system fluxes as close as possible to the estimated quantities,
- matching simulated heads with measured heads at 22 selected monitoring locations, and
- general matching a simulated potentiometric surface with an estimated potentiometric surface by D'Agnese and others, 1997.

Then, the two calibrated steady-state models were extended to four transient models with two sets of storage parameters (low and high) for historical verification. The four transient models are:

- low flux with low storage set (Model L1),
- low flux with high storage set (Model L2),
- high flux with low storage set (Model H1), and
- high flux with high storage set (Model H2).

The models were verified against historical monitoring data for the 22 selected sites. The model verification results provide that all the models can be considered as adequate for predictive simulations involving small stress changes to the flow system to evaluate possible impacts over a large distance.

Four transient scenarios were run by using each of the four transient models for an impact evaluation of the proposed pumping at the Yucca Mountain area under two water use contexts. Scenario 1 simulated a possible change of the flow conditions with the current water use to provide an impact evaluation context. Scenario 2 simulated a possible change of the groundwater flow conditions with the current water use and the proposed maximum pumping. Scenario 3 simulated a possible change of the groundwater flow conditions with the full use of all the senior water rights to provide another impact evaluation context. Scenario 4 simulated a possible change of the flow condition with the full use of all of the senior water rights as well as the proposed maximum pumping in Jackass Flats. The differences of the two scenarios under each context would be the net impact caused by the proposed pumping within the corresponding water use context.

Transient simulation results indicate that the proposed pumping does produce a drawdown distribution. The simulated drawdown as a result of the proposed pumping for 100 years at monitoring site AD-2 (near the town of Amargosa Valley) would be less than 1.2 ft. The subsurface flux from Basin 227A (Jackass Flats) to Basin 230 (Amargosa Desert) after 100 years will change from 6,812 to 6,686 Acre-Feet per Annum (AFA) with a net reduction of about 126 AFA (Model L1, between Scenarios 1 and 2). The simulated impact of the proposed pumping on water levels in the Ash Meadows area and on subsurface flux to the Ash Meadow area is negligible. Simulated drawdown due to the proposed pumping for 100 years at the monitoring site AM-4 (Devil's Hole) would be less than 0.1 ft. Total simulated subsurface flux from Basins 225 (Mercury Valley), 226 (Rock Valley, and 227A (Jackass Flats) to Basin 230 (Amargosa Desert) would merely be reduced by approximately 61 to 126 AFA.

2. INTRODUCTION

This report presents the findings of Thiel Engineering Consultants' (TEC's) hydrogeologic investigation of the Yucca Mountain and adjacent area (Figure 1). The study area includes Hydrographic Basins 225 (Mercury Valley), 226 (Rock Valley), 227A (Jackass Flats), 227B (Buckboard Mesa), 228 (Oasis Valley), 229 (Crater Flat) and 230 (Amargosa Desert), and a portion of Hydrographic Basin 243 (Death Valley). Most of the basin boundary lines are drawn along topographic ridges. These basins and Basins 231 (Grapevine Canyon) and 232 (Oriental Wash) comprise the Death Valley Hydrographic Region (Region 14, Rush, 1968). Yucca Mountain, located approximately in the center of the study area, is approximately 90 miles northwest of Las Vegas, Nevada.

Yucca Mountain, situated both on and adjacent to the Nevada Test Site (NTS), is being studied by the U.S. Department of Energy (DOE) for potential use as a high-level radioactive nuclear waste repository. The study activities, as well as the potential construction and operation activities of the repository, require the use of water, which is currently being provided from wells located in Jackass Flats (Basin 227A) and Crater Flat (Basin 229), located east and west of Yucca Mountain, respectively.

Nevada water law states that water above and below the ground belongs to the public. It further requires that any entity wishing to appropriate these public waters must first apply to the State Engineer for a permit to do so (Nevada Revised Statutes 533.325).

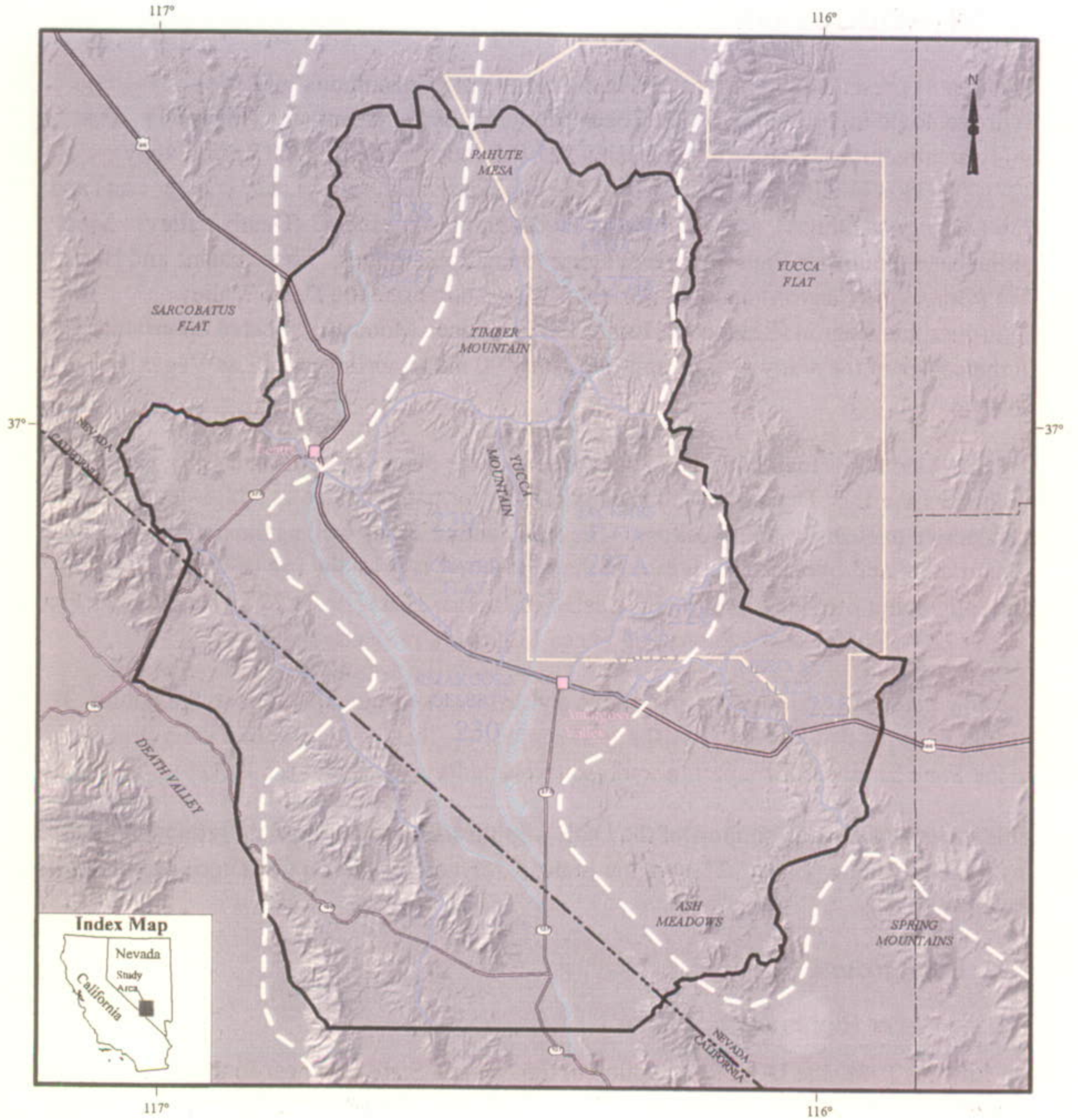
This investigation is in support of the DOE's applications to appropriate groundwater from Jackass Flats (Basin 227A) in the State of Nevada for use on the Yucca Mountain Project (YMP).

2.1. Background

2.1.1. Water Rights Applications

On July 22, 1988, the DOE first applied to the Nevada State Engineer to appropriate groundwater in Jackass Flats (Basin 227 A) and Crater Flat (Basin 229) for industrial uses on the YMP. The State Engineer later issued seven permits (Nos. 57373, 57374, 57375, 57376, 58827, 58828, 58829) to appropriate up to 430 acre-feet per year of water for use during the site characterization stage of the YMP. These permits, with the exception of Permit 57375 located in Crafter Flat (Basin 229), were issued for a finite length of time and will expire in the years 2000 and 2002.

On July 22, 1997, the DOE filed five additional applications (No. 63263, 63264, 63265, 63266, and 63267). The purpose of these filings was twofold: to replace the existing temporary permits and for permanent uses should the site of the repository gain approval from the State of Nevada, Congress and the President of the United States.



Groundwater subbasin boundary based on Laczniak and others (1996, pl. 1)
Shaded relief base from 1:250,000-scale Digital Elevation Model.

0 5 10 15 20 Miles

EXPLANATION

- Model Boundary
- Hydrographic Basin Boundary
- Groundwater Subbasin Boundary
- State/County Boundary
- Prominent Streams
- Nevada Test Site Boundary

Figure 1. Location of the study area

The Nevada Agency for Nuclear Projects, Amargosa Water Committee, Citizen's Alert and the Southern Nye County Conservation District have each filed protests against approval of these applications.

2.1.2. Previous Studies (Models)

There have been numerous geologic and hydrogeologic studies performed in the NTS and Amargosa Desert areas. Appendix D contains a bibliography of the available published and unpublished works in this area.

A large amount of information exists for the study area primarily because the DOE has been conducting on-going studies at the NTS and is currently studying Yucca Mountain for a potential high-level radioactive nuclear waste repository. Many of these studies have been on the aquifer systems in the Death Valley region including the NTS and Yucca Mountain area.

Numerous groundwater flow models have been developed for the Death Valley region in attempts to ascertain regional and local hydrogeologic conditions. These models used two-dimensional finite difference, two-dimensional finite element, and three-dimensional finite difference techniques and their approaches include steady state and transient conditions. The actual model domains vary from portions of to the entire Death Valley region.

The following chronicles the previous models performed in the Death Valley region:

- Waddell (1982) built a two-dimensional finite element model of the Nevada Test Site and vicinity.
- Czarnecki and Waddell (1984) constructed a two-dimensional finite element sub-regional model of Yucca Mountain and vicinity.
- Rice (1984) developed a preliminary two-dimensional regional model of Nevada Test Site and Vicinity to determine flux.
- Czarnecki (1985) applied a subregional two-dimensional model to estimate the effects of increased recharge.
- Sinton (1987) constructed a quasi-three-dimensional steady state model for the Nevada Test Site.
- Czarnecki (1991) applied the finite-element flow model (Czarnecki, 1985) to evaluate the effects of possible pumping scenarios at Wells J-12 and J-13 in Jackass Flats.
- D'Agnese and others (1997) developed a three-dimensional finite difference model of the Death Valley region with three model layers to simulate the present-day steady state flow.
- IT Corporation (U.S. DOE, 1997) developed a three-dimensional steady state predevelopment finite difference model for the region with twenty model layers.

Groundwater models have been getting more complex with time as a result of the increased understanding of the regional hydrogeologic conditions and the development of modeling techniques. However, as of the date of this report, there are no known reports of three-dimensional transient modeling with model verification using historical monitoring data. It was, therefore, necessary to build new models with an emphasis on evaluating the possible effect of the proposed pumping. Nevertheless, the previous modeling work (by others) provides valuable information and basic understanding of the groundwater flow system in the Yucca Mountain area.

2.2. Purpose and Scope

The purpose of this study was to evaluate the hydrogeologic conditions in the Jackass Flats and central Amargosa Desert areas, and the effect of long term pumping from wells in Jackass Flats.

The scope of work for this study consisted of:

(1). Compilation and review/analysis:

a. Available geologic and hydrogeologic references
b. Driller's logs, pumping test and water-level data for wells in Jackass Flats and Amargosa Desert
c. Pumpage data for wells in Jackass Flats and Amargosa Desert

(2). Building and documenting predictive groundwater flow models:

a. to simulate the response of the aquifers in the study area to applied stresses
b. to evaluate the possible hydrologic and hydraulic impacts of the proposed groundwater withdrawal

2.3. Report Organization

This report is organized in a manner to enable the reader to obtain an overview of the geologic/hydrogeologic conditions as well as a summary of the current water rights and historical groundwater withdrawals in Jackass Flats (Basin 227A), Amargosa Desert (Basin 230) and adjacent hydrographic basins (Mercury Valley, Rock Valley, Buckboard Mesa, Oasis Valley and Crater Flat). The information contained herein provides an understanding for the groundwater modeling rationale and results, which is presented in detail.

Groundwater modeling is also presented in a logical format, beginning with a brief discussion of the major existing models for the region followed by a section describing conceptualizations of the aquifer system in the study area. The methodology, assumptions, constraints, configurations, and inputs of the models, as well as the model calibrations, are discussed in the subsequent sections. The verification and predictive simulations follow. All figures showing simulation results are presented in Appendix C.

Conclusions and recommendations for further study are presented at the end of the report, followed by references and appendices.

3. SUMMARY OF REGIONAL GEOLOGY AND HYDROGEOLOGY

3.1. Geology

The study area is located in the southern part of the Great Basin, a large structural and physiographic section of the Basin and Range province, which is generally characterized by linear, fault-bounded ranges separated by intervening deep structural basins. The majority of the study area, however, does not have well-developed typical basin-range features. Most of the area also lies within the Walker Lane Belt, an area with diverse structural style, trends and topography (Carr, 1984, 1988).

The Walker Lane Belt is a northwest trending, strike-slip shear zone separating the northwest/southeast structural-physiographic trends in the southwestern Great Basin from the predominantly north-south trending basin and range structures. The belt has long been recognized as an area with active faulting which contains anomalous patterns of faults with respect to the typical fault patterns in the Great Basin (Reheis and Noller, 1991).

This area is geologically complex and has experienced intermittent marine and non-marine sedimentation, plutonism, volcanism, and extensional/compressive deformation (Stewart, 1980). Following long periods of sediment deposition and numerous tectonic episodes, two major periods of deformation occurred in the area. The first occurred in late Mesozoic and perhaps in early Tertiary time and resulted in folding and thrust faulting of the Precambrian and Paleozoic rocks. During the middle to late Cenozoic the area experienced normal block faulting with the resultant Basin and Range topography (Winograd and Thordarson, 1975).

The area has experienced a long, complex tectonic evolution as described by Grose and Smith (1989), who summarized the geologic history of the region. Deformation has occurred throughout the area and some parts have been nearly continuously tectonically active. Combinations of faulting, folding and volcano tectonic activities have resulted in a complex distribution of stratigraphic units (Figure 2) with an even more complex distribution of hydraulic properties.

The stratigraphic units in the study area include Precambian and Cambrian clastic and crystalline rocks; Paleozoic clastic and carbonate rocks; clastic and intrusive rocks of Mesozoic age; Tertiary volcanic rocks; Tertiary-Quaternary lava flows and basin fill; and Quaternary lake bed deposits (Waddell, 1982; D'Agnese and others, 1997). A summary of the major stratigraphic units in the study area is listed in Table 3.1.

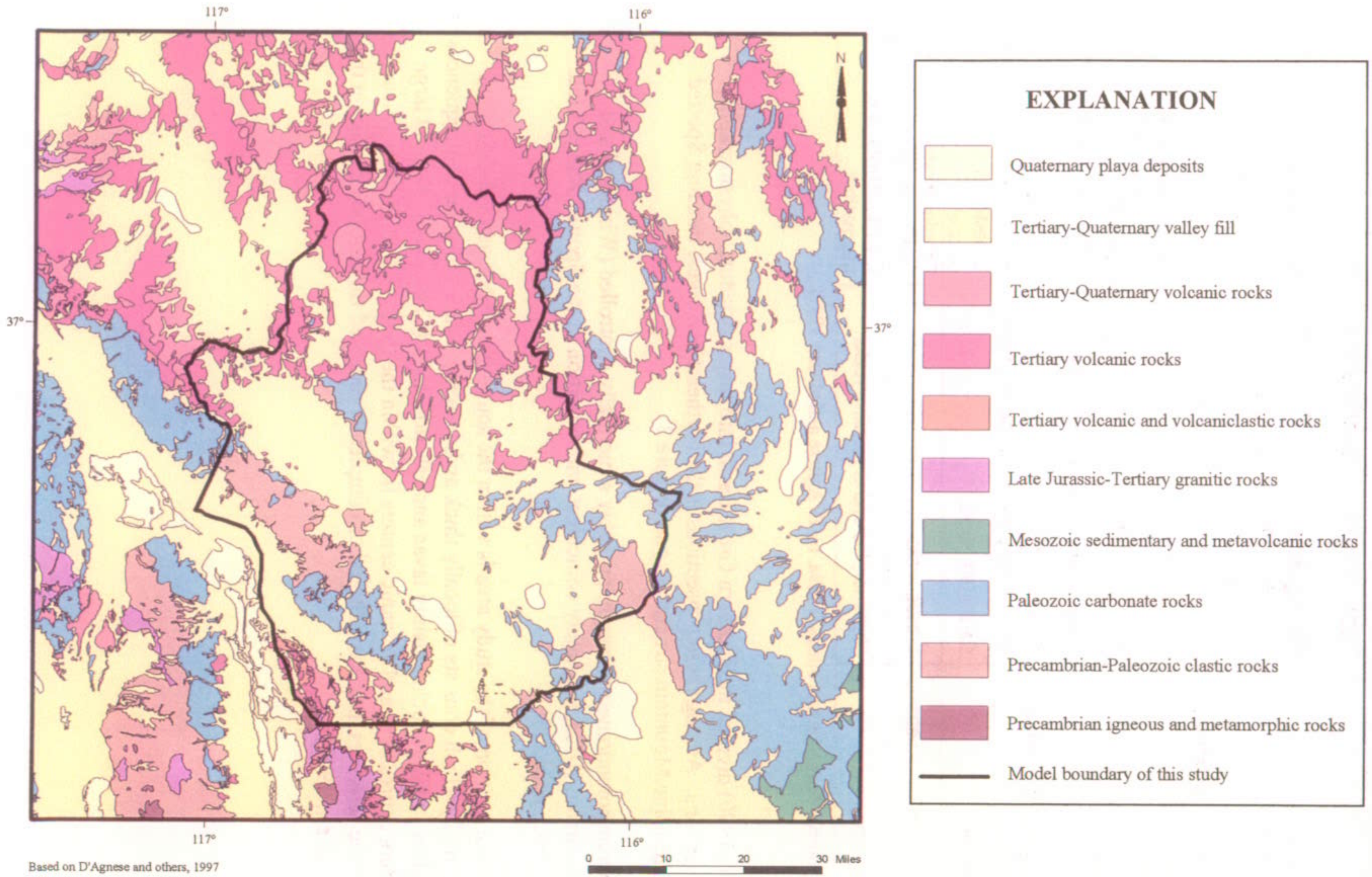


Figure 2. Distribution of stratigraphic units in the study area

Table 3.1 Major Stratigraphic Units

Period	Stratigraphic Unit	Description
Quaternary	Lake bed deposits	Silt and clay
Tertiary – Quaternary	Basin fill	Alluvial and colluvial deposits
	Lava flows	Rhyolitic, andesitic, and basaltic lava flows
Tertiary	Volcanic rocks	Dominantly rhyolitic ash flow tuffs
	Volcanic and volcaniclastic rocks	Tuffs and tuffaceous clastic rocks
Late Jurassic – Tertiary	Granitic rocks	Intrusive granites
Mesozoic	Sedimentary and metavolcanic rocks	Predominantly sandstones
Paleozoic	Carbonate rocks	Limestones, dolomites, and calcareous shales
Precambrian – Paleozoic	Clastic rocks	Conglomerates, argillites and quartzites
Precambrian	Metamorphic and crystalline rocks	Gneiss, schists, and migmatites

[Source: Bedinnger and others (1989a, b), D'Agnese and others, 1997]

Carr (1990) divided the southern Great Basin into major structural-physiographic subsections. Among these subsections is the northeast/southwest trending Spotted Range-Mine Mountain structural zone (Figure 3).

A major potentiometric trough, probably structurally controlled (Winograd and Thordarson, 1975), is roughly coincident with a portion of the Spotted Range-Mine Mountain zone.

A major portion of the study area is within the southwestern Nevada volcanic field (Figure 3) which consists of locally thick and, in some areas, highly faulted sequences of Tertiary volcanic rocks, mainly lavas and ash-flow tuffs (Carr, 1988). Several large caldera depressions and volcanic centers lie within the field. These Tertiary volcano-tectonic activities may have altered or completely removed the carbonate rocks in the area (Carr, 1990).

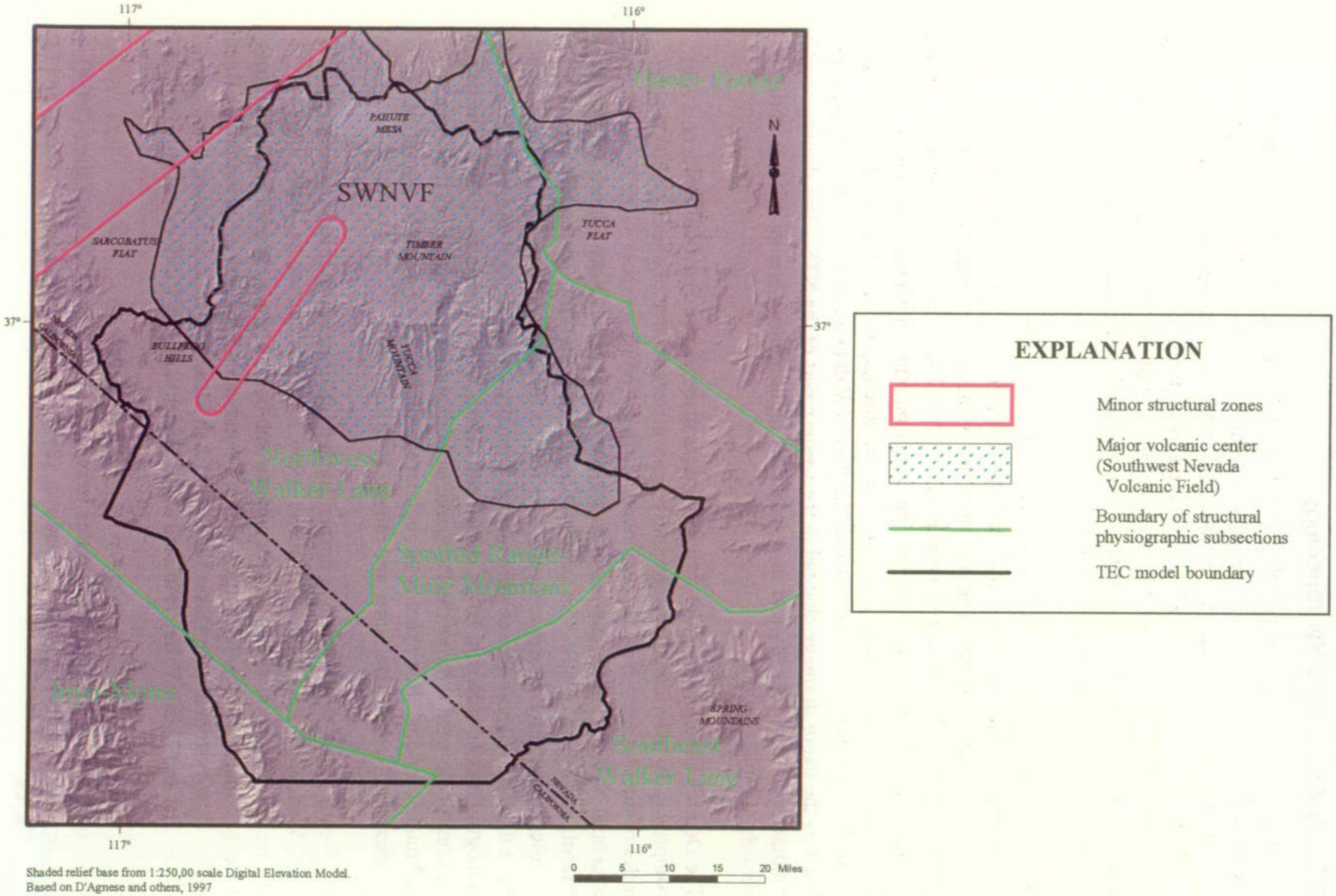


Figure 3. Major structural zones of the study area

3.2. Hydrology and Hydrogeology

The study area is located within the central Death Valley sub-region, a portion of the Death Valley regional groundwater flow system as described by D'Agnese and others (1997). The annual average temperature at Ash Meadows in Basin 230 is approximately 65° F (Dudley and Larson, 1976). Average annual precipitation in the valley areas ranges from 3 to 6 inches and is less than 10 inches in most of the mountain areas (Winograd and Thordarson, 1975). Pan evaporation in the Ash Meadows area is about 100 inches. annually (Dudley and Larson, 1976).

No perennial streams exist in the study area. However, there are numerous ephemeral drainages, with the Amargosa River and one of its tributaries, Fortymile Wash, being the major prominent channels. The Amargosa River may be intermittent in the vicinity of Beatty, Nevada (Winograd and Thordarson, 1975). The river also has stream flow at the southern end of Amargosa Desert during winter months when evapotranspiration is at its lowest level, where it is largely fed from spring discharge in the Ash Meadows area and groundwater in the vicinity of Alkalai Flat Playa (Walker and Eakin, 1963). Fortymile Wash is the major drainage channel in the western part of the NTS. This drainage and its tributaries are normally dry and flow only after high-intensity precipitation or during periods of rapid snowmelt.

The Death Valley groundwater flow system (as discussed by Harrill and others, 1988), comprising 30 individual hydrographic basins, covers an area of about 15,800 square miles of the southern Great Basin between its major recharge areas in the high mountains of central Nevada and its southernmost areas of discharge in Death Valley, California (Harrill and others, 1988). The Death Valley groundwater flow system consists primarily of volcanic rock in the west and carbonate rock in the east and is estimated to transmit more than 70,000 acre-feet of groundwater annually (Blankennagel and Weir, 1973; Winograd and Thordarson, 1975; Harrill and others, 1988; Dettinger, 1989). The largest portion is conveyed through the Paleozoic carbonate rock, referred to as the "central carbonate corridor", that extends throughout the subsurface of much of central and southeastern Nevada (Dettinger and others, 1995).

The Death Valley flow system is further divided into groundwater sub-basins (Rush, 1970, Waddell, 1982, Luckey and others, 1996, Laczniak and others, 1996, and D'Agnese and others, 1997). A groundwater sub-basin defines the area that contributes water to a major surface discharge. Major groundwater discharge areas within the Death Valley flow system are the Oasis Valley and Ash Meadows areas in Nevada, and the Alkali Flat and Death Valley (Furnace Creek Ranch) areas in California (Laczniak and others, 1996).

Three principal groundwater sub-basins were identified by Waddell and others (1984). The three sub-basins are (1) Ash Meadows, (2) Alkali Flat-Furnace Creek Ranch and (3) Oasis Valley.

Within the study area of this report, groundwater occurs in the valley fill and the underlying volcanic and Paleozoic carbonate rocks. Recharge to the groundwater system is supplied by precipitation and subsurface inflow mainly from the northern and eastern study area boundaries. The principal source of the subsurface underflow may be from the higher parts of the Spring Mountains and from the area to the north and northeast of the study area (Thomas, 1988). Infiltration of runoff in Amargosa River and Fortymile Wash probably contributes recharge to the groundwater flow system (Osterkamp and others, 1994; Claassen, 1985; Savard, 1994, 1998). Secondary recharge may occur from spring flow and water uses. Groundwater is naturally discharged is in the forms of springs and evapotranspiration. Groundwater is also pumped for agricultural (primarily irrigation), mining, commercial, and other uses.

Principal hydrogeologic units in the study area are: the valley-fill deposits, volcanic rocks, the lower carbonate aquifer and the lower clastic aquitard. For a description and the distribution of major stratigraphic units, see Table 3.1 and Figure 2, respectively. The valley-fill deposits comprise the principal aquifer in the Amargosa Desert but are generally above the saturated zone in the area north of the Amargosa Desert.

The water table occurs within the volcanic rocks throughout the upper and central parts of the Oasis Valley and Alkali Flat-Furnace Creek Ranch sub-basins, which include Yucca Mountain and the proposed diversion points (Well J-12, Well J-13 and the C-Wells) in Jackass Flats in Applications 63263, 63234, 63265, 63266 and 63267. The lower carbonate aquifer is the dominant aquifer in the Ash Meadows sub-basin and may underlie the entire Yucca Mountain area as indicated by the lithologic log of a well (Well UE-25 p#1) in the northwest portion of Jackass Flats. The existence of a lower clastic aquitard limits the depth of active groundwater flow and impedes lateral movement where it occurs at a shallow depth.

3.2.1. Groundwater Inflow

Groundwater inflow includes recharge from precipitation, subsurface inflow, recharge from surface waters and secondary recharge from water uses. Due to lack of surface water bodies in the study area recharge from surface waters is less significant than other groundwater inflow components.

3.2.1.1. Groundwater Recharge from Precipitation

Direct measurement of recharge from precipitation is almost impossible for a realistic groundwater system in an arid environment such as that in the Death Valley region where precipitation events are typically brief and localized. Because of this, recharge from precipitation has to be estimated by indirect methods, which inherently has uncertainties. Methods used to estimate recharge to the groundwater system underlying the area of this study include empirical, mass balance of certain solute, and geomorphic/distributed-parameters.

The widely applied empirical precipitation-recharge relation for basins in eastern and southern Nevada was developed by Maxey and Eakin (1949). The Maxey and Eakin method correlates recharge from precipitation as a percentage of precipitation with altitude. The Maxey and Eakin method assumes that areas with higher altitude have a greater percentage of precipitation becoming groundwater recharge and below certain altitudes or precipitation levels no recharge occurs. A single percentage rate of precipitation is assigned for a range of altitude in the Maxey and Eakin method. The method ignores factors such as lithology, soils, climate, vegetation, and other topographic features, which may have a direct role in the recharging process.

Osterkamp and others (1994) estimated recharge from precipitation for the Amargosa River Basin based on channel-geometry and analyses with a precipitation/runoff simulator. Campana and Byer (1996) estimated recharge from precipitation for an area which covers a portion of the area of this study by using a mixing cell approach based on the corrected Carbon 14 groundwater ages. D'Agnese and others (1997) compared estimates of recharge from precipitation for the Death Valley region by using the Maxey and Eakin method and a modified Maxey and Eakin method which considers slope-aspect, relative rock and soil permeability and vegetation in addition to altitude.

3.2.1.2. Subsurface Inflow

The only estimate of the subsurface inflow to the study area was made by the Nevada State Engineer (1971). However, estimates of the subsurface inflow can be inferred from recharge estimates for the outside contributing areas and subsurface inflow to the contributing area from some existing studies, such as the estimates made by D'Agnese and others (1997).

3.2.1.3. Secondary Recharge

Water from existing water uses and spring discharge may return to the groundwater system as secondary recharge. Estimates of secondary recharge are not readily available and rates are dependent on the actual quantity of water applied, manner of water use, and return path characteristics. However, it can be implicitly inferred that water use for flood irrigation may have a higher secondary recharge rate than that for pivot irrigation. Dewatering for mining purposes may have an even higher secondary recharge rate if pumped water is purposely put into recharge basins.

Secondary recharge from spring flow in the Ash Meadows area has been interpreted at about 6,500 acre-feet annually (Nichols and others, 1997). Secondary recharge from irrigation water uses in Amargosa Desert has been estimated at approximately 20 percent of the amount of water placed into use (Nevada State Engineer's Ruling #3666, 1996).

3.2.2. Groundwater Outflow

Groundwater outflow consists of evapotranspiration, springs, wells and subsurface outflow.

3.2.2.1. Evapotranspiration

Accurate estimates of evapotranspiration rates are difficult to make because these rates have not been precisely determined for plant communities and bare soils for most areas in the region (D'Agnese and others, 1997). Annual rates of evapotranspiration by native phreatophytes for other areas have been used to estimate evapotranspirative consumption for the study area by investigators (Walker and Eakin, 1963, D'Agnese and others, 1997). These investigators estimated the evapotranspiration by the following steps:

- Evapotranpiration rates were first assigned on the basis of vegetative types, density, and depth to water table.
- Evapotranspiration rates were then multiplied by the corresponding area to estimate total volumetric rate of discharge through native evapotranspiration processes.

Existing estimates for Oasis Valley ranged from 2,000 to 4,300 acre-feet per year and for Amargosa Desert from 24,000 to 43,400 acre-feet per year. For the larger estimates, more discharge areas were identified (D'Agnese and others, 1997). It should be mentioned that these estimates of consumption of water through evapotranspiration in the study area include native consumption of spring discharge. Therefore, the evapotranspiration by native phreatophytes may be considered as all natural discharge from the groundwater system of the study area if human use of spring flow for other purposes (not consumed through evapotranspiration in the areas by native phreatophytes) can be considered negligible.

Care should be exercised for the accounting of the portion of evapotranspiration from spring flow. If spring flow is considered as direct discharge from the groundwater system, then evapotranspiration of spring flow should not be considered as direct discharge again.

3.2.2.2. Springs

Major springs in the study area are located in the Oasis Valley and Ash Meadows area. Reported spring flow rates for Oasis Valley are approximately 920 acre-feet per year (D'Agnese and others, 1997). Estimated spring flow in the Ash Meadows area ranged from 17,000 acre-feet per year (Walker and Eakin, 1963) to about 29,700 acre-feet per year (D'Agnese and others, 1997).

3.2.2.3. Wells

Groundwater withdrawal for most of the study area began in the 1950's with the major withdrawal occurring in Amargosa Desert and Oasis Valley. The major groundwater uses are agricultural (irrigation), mining, municipal and industrial.

3.2.2.4. Subsurface Outflow

The subsurface outflow discharges at the Death Valley saltpan. The total discharge from the Death Valley ranges from about 13,000 acre-feet per year to about 142,000 acre-feet per year (Pal Consultants, 1995, p. 49). D'Agnese and others (1997, p. 46, Table 2) estimated that the total discharge at the main saltpan is about 29,600 acre-feet per year (100,000 m^3/d).

3.2.2.5. Natural Discharge and Human Consumption

Natural discharge is predominantly through evapotranspiration by native plants and springs. Human consumption is through groundwater withdrawal from wells. Water typically originates from groundwater storage at the earlier stages of human groundwater development. With the increasing cones of depression from pumping and the lowering of groundwater level at natural discharge locations, natural discharge tends to decline, as has been reported by Dudley and Larson (1976).

4. WATER RIGHTS AND GROUNDWATER WITHDRAWAL

4.1. Water Rights

Nevada Revised Statutes (NRS 533.025) states that "The water of all sources of water supply within the boundaries of the state whether above or beneath the surface of the ground, belongs to the public." Any person, corporation, private or governmental entity who wishes to appropriate any of the public waters, or to change the point of diversion, manner of use or place of use of water already appropriated, must first file an application with the State Engineer for a permit to do so prior to using that water. The amount of water issued by the State Engineer under permits (to be perfected with proof of beneficial uses) or certificates (perfected with proof of beneficial uses) is defined in this report as the committed water resources within a hydrographic basin.

Water appropriated for the mission of the Nevada Test Site (NTS) is allocated under Federal Reserved Water Rights (reserved rights), which is not administered by the Nevada State Engineer. However, the limits and extents of Federal Reserved Water Rights in the study area have not yet been determined. There is no requirement for appropriation of water under Nevada Revised Statutes for uses determined to be within the scope of the facility's mission. Those uses and activities considered to be outside of the mission of the NTS would require appropriation of water pursuant to Nevada Revised Statutes. The determinations of the relative water rights remain as they are until such time as the groundwater rights are adjudicated, as provided in NRS 534.

4.1.1. Regional Water Rights Summaries

Abstracts of the groundwater rights within Basins 225-230 were obtained from the State Engineer's office. At present, only five of the seven basins have water rights appropriated through the State Engineer's office. Although there are wells operated under the auspices of the NTS, U.S. Air Force, and other federal agencies, those rights are not included in the database maintained by the Nevada State Engineer since they fall under the definition of reserved rights. Because it is not possible to quantify the exact amounts of water used under these reserved rights, figures in this water rights summary do not include the pumpage from these wells.

Water right summaries for each basin based on status and manner of use can be generated with the State Engineer's database. However, supplemental water rights (multiple rights for the same uses with a total combined limit) and duties (the maximum volume of water that can be diverted legally per annum or season under a water right) associated with applications to change may be included in these summaries. This creates a situation where over-counting or "double-dipping" of water rights within a particular basin can occur.

To avoid such a situation, those water rights that are supplemental (i.e. multiple water rights serving the same purpose or place of use under a total combined duty) were determined by reviewing the records on file in the State Engineer's office. The duties associated with those supplemental rights that do not have their own stand-alone duty were not counted as part of the basin totals.

Duties of certain water rights within Basin 230 (Amargosa Desert) that were declared forfeited by the State Engineer were also examined. Current duties as specified by State Engineer's rulings or Court orders as of February 2, 1998 were used in the following summaries. Tables 4.1, 4.2, 4.3, 4.4 and 4.5 list current water rights summaries for Basins 227A (Jackass Flats), 227B (Buckboard Mesa), 228 (Oasis Valley), 229 (Crater Flat), and 230 (Amargosa Desert), respectively. As of February 2, 1998 there were no groundwater rights appropriated through the State Engineer's office for Basins 225 (Mercury Valley) and 226 (Rock Valley). The differences between the quantities used in this summary and those listed in the printout from the database maintained by the State Engineer's office as of this date are listed in Table 4.6. Pending applications to change all or portions of existing water rights are not included in the summaries because they do not appropriate additional amounts of water. However, it should be noted that they may have certain effects on the quantity of water associated with secondary recharge through water uses.

Table 4.1 Basin 227A (Jackass Flats) Water Rights Summary

(Acre-Feet per Annum)

Manner of Use	A Certificate[1]	B Permit[2]	A+B Total Committed	Pending[3]
Commercial	24.98	13.69	38.67	0.00
Domestic	16.14	0.00	16.14	0.00
Industrial	0.00	430.19	430.19	430.00
Irrigation	0.00	0.00	0.00	0.00
Mining & Milling / Dewatering	0.00	0.00	0.00	0.00
Municipal	0.00	0.00	0.00	0.00
Quasi-Municipal	0.00	0.00	0.00	0.00
Recreation	0.00	0.00	0.00	0.00
Stock Water	17.22	0.00	17.22	0.00
Wild Life	0.00	0.00	0.00	0.00
Other	0.00	(Supplemental)	0.00	0.00
Total	58.34	443.88	502.22	0.00[3]

Based on data from Nevada State Engineer's office as of February 2, 1998.
Summary from the State Engineer's Office shows that appropriation by permits is 459.88 acre-feet annually.
Research of the records at the State Engineer's Office could not find where the additional 16 acre-feet annual duty in the summary from the State Engineer's Office originated.

[1] A certificated water rights is perfected with proof of beneficial use.

[2] A water right permit is issued for use of water until the water right is perfected with proof of beneficial use.

[3] Pending applications are water rights in their application stage not yet determined. During this stage, water use is not allowed. Only additional duties requested by pending applications are included.

Table 4.2 Basin 227B (Buckboard Mesa) Water Rights Summary

(Acre-Feet per Annum)

Manner of Use	A Certificate	B Permit	A+B Total Committed	Pending
Commercial	0.00	0.00	0.00	0.00
Domestic	0.00	0.00	0.00	0.00
Industrial	0.00	0.00	0.00	7.24*
Irrigation	0.00	0.00	0.00	0.00
Mining & Milling/ Dewatering	0.00	0.00	0.00	0.00
Municipal	0.00	0.00	0.00	0.00
Quasi-Municipal	0.00	0.00	0.00	0.00
Recreation	0.00	0.00	0.00	0.00
Stock Water	0.00	0.00	0.00	0.00
Wild Life	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00
Total	0.00	0.00	0.00	7.24

Based on data from Nevada State Engineer's Office as of February 2, 1998.

*Calculated from diversion rate of 0.01 cubic feet per second.

Table 4.3 Basin 228 (Oasis Valley) Water Rights Summary

(Acre-Feet per Annum)

Manner of Use	A Certificate	B Permit	A+B Total Committed	Pending
Commercial	3.62	7.00	10.62	0.00
Domestic	0.00	0.00	0.00	0.00
Industrial	0.00	0.00	0.00	0.00
Irrigation	74.60	400.00	474.60	400.00
Mining & Milling/ Dewatering	0.86	0.00	0.86	0.00
Municipal	850.78	312.07	1162.85	0.00
Quasi-Municipal	0.00	0.00	0.00	0.00
Recreation	0.00	50.01 (S)	0.00	0.00
Stock Water	2.20	0.00	2.20	0.00
Wild Life	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00
Total	932.06	719.07	1651.13	400.00

Based on data from Nevada State Engineer's Office as of February 2, 1998.

S = supplemental

This evaluation agrees with the summary from the State Engineer's Office.

Table 4.4 Basin 229 (Crater Flat) Water Rights Summary

(Acre-Feet per Annum)

Manner of Use	A	B	A+B	Pending
	Certificate	Permit	Total Committed	
Commercial	0.00	0.00	0.00	0.00
Domestic	0.00	0.00	0.00	0.00
Industrial	0.00	61.38 (S)	0.00	0.00
Irrigation	0.00	0.00	0.00	0.00
Mining & Milling/ Dewatering	144.33	1094.46	1238.79	0.00
Municipal	0.00	0.00	0.00	0.00
Quasi-Municipal	0.00	0.00	0.00	0.00
Recreation	0.00	0.00	0.00	0.00
Stock Water	0.00	0.00	0.00	0.00
Wild Life	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00
Total	144.33	1094.46	1238.79	0.00

Based on data from Nevada State Engineer's Office as of February 2, 1998.
S = supplemental
This evaluation agrees with the summary from the State Engineer's Office.

Table 4.5 Basin 230 (Amargosa Desert) Water Rights Summary

(Acre-Feet per Annum)

Manner of Use	A	B	A+B	Pending*
	Certificate	Permit	Total Committed	
Commercial	0.71	150.43	151.13	8.00
Domestic	3.22	0.00	3.22	0.00
Irrigation	19749.40	827.26	20576.66	1600.00
Mining & Milling / Dewatering	799.60	3813.80	4613.40	1240.72
Municipal	0.00	613.80 (S)	0.00	0.00
Quasi-Municipal	54.55	987.15	1041.70	2848.36
Recreation	0.00	0.00	0.00	0.00
Stock Water	0.00	0.00	0.00	0.00
Wild Life	0.00	296.76	296.76	0.86
Other	0.00	0.00	0.00	0.00
Total	20607.47	6075.40	26682.87	5697.94

Based on data from Nevada State Engineer's Office as of February 2, 1998.
* Only additional duties requested by pending applications are included.
S = supplemental
Summary from the State Engineer's Office shows that appropriation by certificates is 22,246.51 acre-feet annually, and that appropriation by permits is 6073.23 acre-feet annually. The discrepancy is mainly due to the different treatments to forfeited rights and supplemental rights. The different amounts used by this evaluation and the State Engineer's Office for rights associated with forfeiture are listed in Table 7.
The values used for this evaluation are based on research of the ruling records at the State Engineer's Office.

Table 4.6 Difference in Duties Listed by TEC and NDWR in Water Rights Summary for Basin 230 (Amargosa Desert)

(Acre-Feet per Annum)

Application No.	Duty		Difference
	TEC	NDWR	NDWR-TEC
14078	157.6	315.2	157.6
16178	20	400	380
17137	50	100	50
18772	263.22	213.22	-50
19034	500	515	15
19197	74.62	920.96	846.34
20411	129.2	125.1	-4.1
21584	500 (S)	929.73 (S)	-
22141	106	272.5	166.5
Total	1300.64	2861.98	1561.34

S = supplemental

4.1.2. Yucca Mountain Project Water Rights

A summary of DOE's YMP water rights is listed in Table 4.7. At present, the total combined duty of these water right permits is 430.19 acre-feet per year. These permits, except the temporary change permits, were issued for industrial use which is further described as consisting of water for road construction, dust control, tunnel and pad construction, testing, culinary and domestic uses. The existing filings were approved for the site characterization and the recent filings provide for the anticipated needs of the DOE for the construction, operations and maintenance of any facilities serving the needs of the DOE. As such one must consider the new filings as "replacement" requests for the existing permits.

A brief summary of the new DOE Applications 63263-63267 is provided in Table 4.8. The total combined duty of the new DOE applications and Permit 57375 will be limited to 430 acre-feet per year. No additional duty is sought by these new applications.

Table 4.7 Summary of DOE Yucca Mountain Project Water Rights

As of January, 1999

Permit	Source	Div. (cfs)	Duty (AFA)	Use	Proof Of Completion	Proof Of Beneficial Use	Changes
57373	J-12	0.000	0.00	IND	Filed 12/7/92	Expires 4/9/2002	
57374	J-13	0.800	430.19	IND	Filed 12/7/92	Expires 4/9/2002	
57375	VH-1	1.000	61.38	IND	Filed 12/7/92	4/9/98	45984
57376	J-13	0.200	94.83	IND	Filed 12/7/92	Expires 4/9/2002	52338
58827	UE-25c#1 (C-WELLS)	0.900	430.19	IND	Eot Filed 1/20/99	Expires 12/31/2000	
58828	UE-25c#3 (C-WELLS)	0.900	430.19	IND	Filed 3/8/96	Expires 12/31/2000	
58829	UE-25c#2 (C-WELLS)	0.900	430.19	IND	Filed 3/13/98	Expires 12/31/2000	
63383T	T13S, R49E	0.333	3.00	OTH	--	Expired 12/15/98	57373
63384T	T12S, R49E	0.333	19.00	OTH	--		57373
63385T	T13S, R49E	0.333	3.00	OTH	--		57373

Div. = Diversion Rate. Eot. = Extension of time. IND = Industrial. OTH = Other.

cfs = cubic feet per second. AFA = Acre-Feet per Annum.

Notes: 1. Total combined duty under all these permits shall not exceed 430.19 acre-feet annually.

2. Point of diversion for permit no. 57375 is in Crater Flat (Basin 229) and points of diversion for the rest are in Jackass Flats (Basin 227a).

Table 4.8 DOE Water Applications Summary

New Appl.	POD	Old Appl.	Div. (cfs)	Duty (AFA)
63263	J-13	*57374	1.0	430
	J-13	*57376		
63264	J-12	*57373	1.0	430
63265	C-1	*58827	0.9	430
63626	C-2	*58829	0.9	430
63267	C-3	*58828	0.9	430

*Temporary nature. For expiration date, see Table 8.

Appl. = Application. POD = Point of Diversion. Div. = Diversion Rate.

The annual duty of 430 acre-feet is the total combined duty which includes that applied for by the five new applications and the duty under Permit 57375.

4.1.3. State of Nevada Water Rights in the Region

In Basin 227A (Jackass Flats), there is only one certificate appropriating 16.14 acre-feet annually for domestic use by the Nevada Department of Transportation. The point of diversion is within SW¼ SW¼, Section 18, T. 15 S., R. 50 E., which is about 9 miles from Well J-12, 11 miles from Well J-13, and 12 miles from the C-Wells.

In Basin 230 (Amargosa Desert), the Nevada State Wildlife Division owns 5 certificates appropriating a total of 719.29 acre-feet per year of water for wildlife, irrigation, recreation and other purposes from spring sources within Section 35, T. 17 S., R. 50 E. and Section 18, T. 18 S., R. 51 E., in the Ash Meadows subbasin. This is more than 20 miles from Well J-12, Well J-13 and the C-Wells.

Table 4.9 shows the water rights owned by the State of Nevada in Basins 227A (Jackass Flats) and 230 (Amargosa Desert).

Table 4.9 State of Nevada Water Rights in Basins 227A and 230

Appl. No.	Status	Filing Date	¼	¼	Sec	T. (S)	R. (E)	Use	Div. (cfs)	Duty (AFA)	Nevada State Agency (Source)
Basin 227a											
21593	CER	10/31/63	SW	SW	18	15	50	DOM	0.022	16.14	Transportation Department (Underground)
Basin 230											
11169	CER	9/16/44	SE	NW	18	18	51	IRR	1.500	350.00	Wildlife Division (Spring)
25703	CER	7/7/70	SE	SE	35	17	50	WLD	0.024	17.37	
40428	CER	1/29/80	SW	SE	35	17	50	OTH	0.200	144.86	
40429	CER	1/29/80	NW	SE	35	17	50	REC	0.112	81.08	
40430	CER	1/29/80	SW	SE	35	17	50	REC	0.174	125.98	
Basin 230 Total Duty										719.29	

Appl. = Application. Sec = Section. T. = Township. S = South. R. = Range. E = East.
Div. = Diversion Rate. CER = Certificate. DOM. = Domestic. IRR = Irrigation. WLD = Wildlife.
OTH = Other. REC = Recreation.

4.2. Groundwater Withdrawal

The estimated annual groundwater pumpage in Basins 225 (Mercury Valley), 227A (Jackass Flats), 227B (Buckboard Mesa), 229 (Crater Flat) and 230 (Amargosa Desert) is listed in Table 4.10. From the maximum annual pumpage for each basin listed in Table 4.10, it can be seen that the total actual annual groundwater pumpage in Basins 225 (Mercury Valley), 227A (Jackass Flats), 227B (Buckboard Mesa) and 229 (Crater Flat), and 230 (Amargosa Desert) was less than 16,680 acre-feet. These totals include some reserved pumping other than the reported NTS pumpage. Table 4.11 shows a pumpage summary for Jackass Flats for the years 1993 to 1997. Groundwater pumpage for Basin 230 (Amargosa Desert) is further broken down by manner of use in Table 4.12 and illustrated in Figure 4.

Table 4.10 Groundwater Withdrawal

(Acre-feet per Annum)

Year	225 (Mercury Valley)	227A (Jackass Flats)	227B (Buckboard Mesa)	229 (Crater Flat)	230 (Amargosa Desert)	230 (Ash Meadows*)
1961	-	92	-	-	-	-
1962	13	187	-	-	-	-
1963	8	(560)	16	-	-	-
1964	94	(560)	343	-	-	-
1965	78	(560)	99	-	-	-
1966	145	(560)	111	-	4,203	-
1967	172	(560)	176	-	9,282	-
1968	162	-	-	-	9,043	-
1969	240	-	-	-	-	2,000
1970	213	-	-	-	-	6,900
1971	295	-	-	-	-	6,900
1972	-	-	-	-	-	6,100
1973	-	-	-	-	7,124	4,400
1974	-	-	-	-	-	4,100
1975	-	-	-	-	-	3,800
1976	-	-	-	-	-	3,700
1977	-	-	-	-	-	1,900
1978	-	-	-	-	-	40
1979	-	-	-	-	-	260
1980	-	-	-	-	-	30
1981	-	114	-	-	-	80
1982	-	57	-	-	-	1
1983	174	217	181	-	-	-
1984	252	202	188	-	-	-
1985	128	164	313	-	9,682	-
1986	107	141	350	-	7,248	-
1987	106	162	421	-	5,761	-
1988	163	141	524	-	4,110	-
1989	351	155	510	39	3,921	-
1990	387	159	417	133	7,807	-
1991	337	157	271	43	6,122	-
1992	428	119	428	29	8,114	-
1993	338	205	182	15	11,300	-
1994	236	277	92	45	12,595	-
1995	74	278	64	31	15,035	-
1996	54	432	54	-	13,613	-
1997	35	344	38	-	13,902	-

Data from USGS OFR-94-54, OFR-96-205, OFR-96-533 and OFR-97-821.
Data in parentheses are from Young, 1972 (annual average).
Pumpage data on Well J-12 and J-13 for 1996 and 1997 was provided by Bright of USGS, Las Vegas.
Pumpage data on C-Wells for 1996 and 1997 are as reported to Nevada State Engineer's Office.
1996 and 1997 pumpage data for Amargosa Desert is from Nevada State Engineer's Office
*The part of Amargosa Desert within Ash Meadows Sub-basin only.
- = no data available

Table 4.11 Basin 227A (Jackass Flats) Pumpage Summary (1993-1997)

(Acre-Feet per Annum)

Year	J-12 & J-13	C-Wells	Total	YMP Pumpage	Other NTS Pumpage
1993	205	0	205	80	125
1994	277	0	277	76*	202
1995	259	19	278	113	165
1996	248	184	432	251	181
1997	151	193	344	256	88
Average	228	79	307	155	152

*Includes 0.63 ac-ft from VH-1 in Crater Flat

Notes: 1993 pumpage for J-12 & J-13 is from USGS OFR 95-158 (Hale and Westenburg, 1995).
1994-1997 pumpage data for J-12 & J-13 is provided by Bright of USGS, Las Vegas.
C-Wells pumpage and YMP pumpage are data reported to Nevada State Engineer's Office.
Other NTS pumpage = Total pumpage minus YMP pumpage.
YMP = Yucca Mountain Site Characterization Project.
NTS = Nevada Test Site

Table 4.12 Groundwater Pumpage Inventory (Amargosa Desert, Basin 230)

(Figures in acre-feet)

Year	Irrigation Under Water Rights	Irrigation (No Permits or Certificates)	Industrial	Commercial**	Quasi- Municipal And Domestic**	Industrial-Mineral Ventures	American Borate	Barrick* Bullfrog	Total	Remarks
85	5,807	2,665	950	20	230	---	---	---	9,672	
86	5,552.9	1,000	---	10	125	284	266	---	7,237.9	
87	4,500	1,200	---	10	125	298	10	---	6,137	
88	2,666	312	---	10	125	569	427	---	4,109	
89	1,266	300	---	10	125	525	888	807	3,921	AB 662 CA
90	4,603	350	---	10	125	383.6	503.09	1,832.6	7,807.39	AB 662 CA
91	4,542	225	---	10	100	335	115	620	5,947	AB 94 CA
92	5,711	50	---	10	100	347.5	306	1,639	8,163.5	AB 207 CA
93	8,558.8	150	---	10	100	495	512	1,474	11,300	AB 314 CA
94	8,892	1,085	---	10	100	340	377	1,791	12,595	AB 267CA
95	10,839	1,515	---	10	100	349	431	1,791	15,035	AB 192 CA
96	9,263	1,780	---	285***		272	747	1,266	13,613	AB 539 CA
97	9,349	1,105	---	942***		251	666	1,589	13,902	AB 539 CA

Maximum annual pumpage (1985-1996): 15,035	Average annual irrigation pumpage (1985-1997, including irrigation without permit): 7,175.9
Minimum annual pumpage (1985-1996): 3,921	Average annual pumpage (1985-1997): 9,187.7
20% of average annual irrigation pumpage (1985-1996): 1,435.2	Average pumpage without permits (1985-1996): 902.9

* Formerly operated by St. Joe's Minerals ** Pumpage is estimated ***Includes other pumpage such as domestic

AB = American Borate CA---Pumpage from California side included in the totals

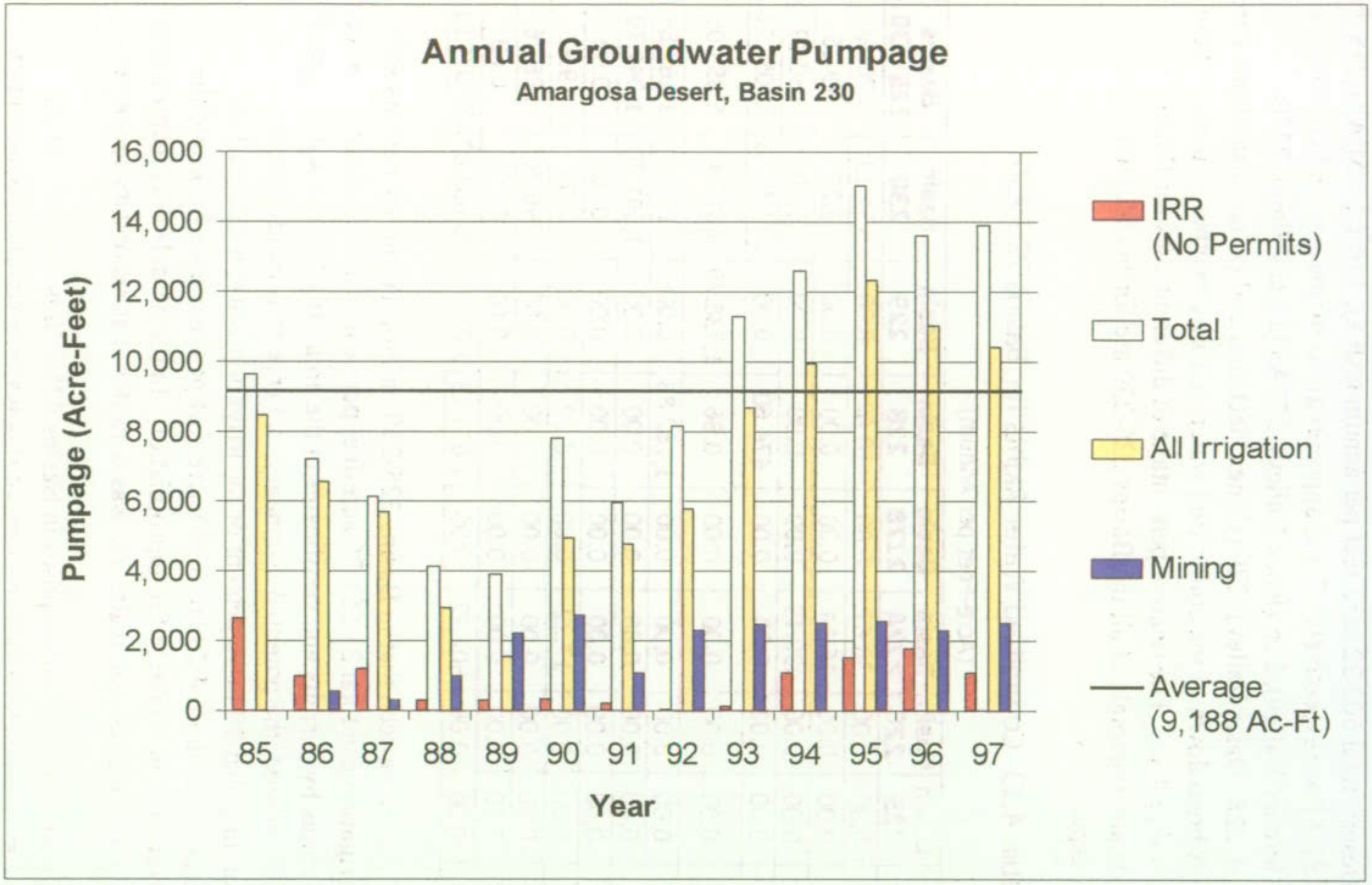


Figure 4. Comparison of groundwater uses in Amargosa Desert
(Pumpage for mining use is the sum of the pumpages by Industrial Mineral Ventures, American Borate and Barrick Bullfrog.)

4.3 Analyses of Water Rights and Groundwater Withdrawal

As of February 2, 1998 committed groundwater resources by water permits and certificates for Basins 227A (Jackass Flats), 228 (Oasis Valley), 229 (Crater Flat), and 230 (Amargosa Desert) total 502.22 acre-feet per annum (AFA), 1,651.13 AFA, 1,238.79 AFA and 26,682.87 AFA, respectively. Total appropriations by permits and certificates for Basins 225 (Mercury Valley), 226 (Rock Valley), 227A (Jackass Flats), 227B (Buckboard Mesa), 228 (Oasis Valley), 229 (Crater Flat), and 230 (Amargosa Desert) are 30,075.01 AFA. A breakdown of the committed water rights by manner of use for these basins is listed in Table 4.13. The relative percentage of different uses for Basin 230 (Amargosa Desert) and the totals of all the Basins 225-230 are further illustrated in Figures 5 and 6, respectively.

Table 4.13 Committed Water Rights for Basins 225-230

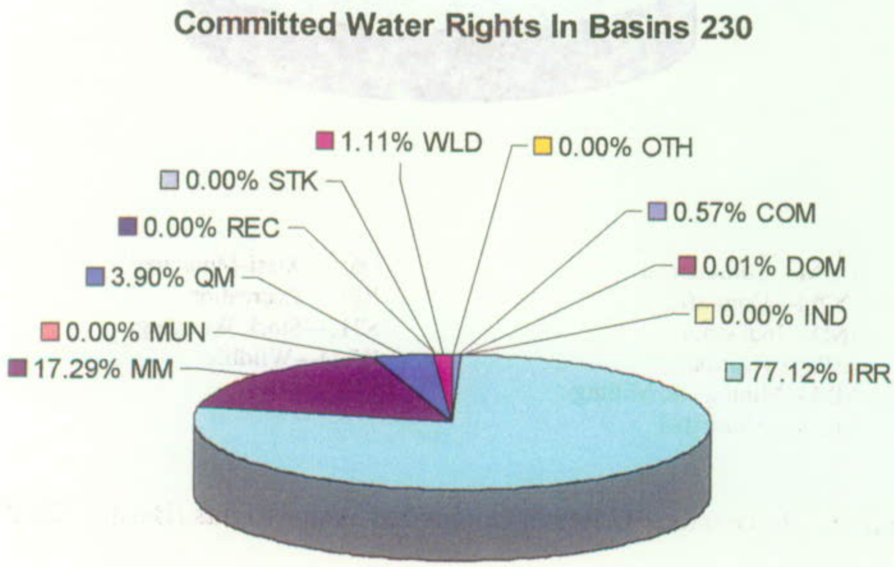
(Acre-Feet per Annum)

Manner of Use	Basin 225	Basin 226	Basin 227A	Basin 227B	Basin 228	Basin 229	Basin 230	Basins 225-230
Commercial	0.00	0.00	38.67	0.00	10.62	0.00	151.13	200.42
Domestic	0.00	0.00	16.14	0.00	0.00	0.00	3.22	19.36
Industrial	0.00	0.00	430.19	0.00	0.00	0.00	0.00	430.19
Irrigation	0.00	0.00	0.00	0.00	474.60	0.00	20,576.66	21,051.26
Mining & Milling / Dewatering	0.00	0.00	0.00	0.00	0.86	1,238.79	4,613.40	5,853.05
Municipal	0.00	0.00	0.00	0.00	1,162.85	0.00	0.00	1,162.85
Quasi-Municipal	0.00	0.00	0.00	0.00	0.00	0.00	1,041.70	1,041.70
Recreation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stock Water	0.00	0.00	17.22	0.00	2.20	0.00	0.00	19.42
Wild Life	0.00	0.00	0.00	0.00	0.00	0.00	296.76	296.76
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.00	502.22	0.00	1,651.13	1,238.79	26,682.87	30,075.01

From Table 4.13, it can be seen that in Basins 225-230, appropriations by permits and certificates for irrigation use total 21,051.26 acre-feet per year, which is about 70 percent of total appropriations by permits and certificates in the area. If all of the water rights for irrigation are fully utilized, the potential secondary recharge to groundwater is significant. Assuming that 20 to 30 percent of the irrigation water is returned as secondary recharge, then about 4,200 to 6,300 acre-feet per year goes back into the groundwater system and is available for appropriation. In the models documented later in this report, 20 percent of irrigation water use was considered as secondary recharge.

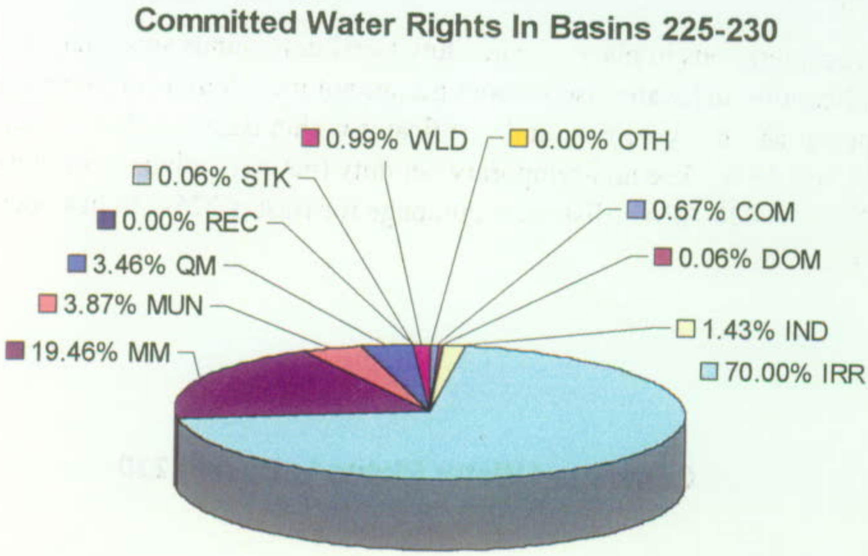
The total appropriation for mining purposes in Basins 225-230 is 5,853.05 AFA. Similarly, if it is assumed that 10 to 20 percent of this water is returned as secondary recharge, then about 580 to 1,170 AFA may be considered not to be consumed by mining uses. Furthermore it is the State Engineer's policy that mining uses are considered temporary. This means that the duties currently under these permits and certificates for mining purposes will cease to exist at some point in the future and may also be available for appropriation.

With these considerations in place, the net duty (total duty minus secondary recharge, pending applications and water use without permit not included) as of February 2, 1998, of all the appropriations by permits and certificates within Basins 225-230, ranges from 22,600 to 25,300 AFA. The non-temporary net duty (net duty minus temporary duty) is about 17,920 to 20,020 AFA. Historical pumpage for Basins 225-230 has been less than 16,700 AFA.



COM—Commercial
DOM—Domestic
IND—Industrial
IRR—Irrigation
MM—Mining and Milling
MUN—Municipal
QM—Quasi-Municipal
REC—Recreation
STK—Stock Watering
WLD—Wildlife
OTH—Other

Figure 5. Percentage of uses in committed water rights (Basin 230)



COM—Commercial
DOM—Domestic
IND—Industrial
IRR—Irrigation
MM—Mining and Milling
MUN—Municipal
QM—Quasi-Municipal
REC—Recreation
STK—Stock Watering
WLD—Wildlife
OTH—Other

Figure 6. Percentage of Uses in Committed Water Rights (Basins 225-230)

From 1989 to 1997 the amount of groundwater withdrawal in Jackass Flats (Basin 227A) and Amargosa Desert (Basin 230) ranged from 119 to 432 AFA and from 3,921 to 15,035 AFA, respectively. Pumpage in Jackass Flats (Basin 227A) increased about 263 percent with a net increment of 313 AFA from 1989 to 1997. The pumpage increase in Amargosa Desert (Basin 230) was 283.5 percent with a net increment of 11,114 AFA from 1989 to 1995. However, groundwater pumpage in the Amargosa Desert (Basin 230) decreased from 15,035 acre-feet in 1995 to 13,902 acre-feet in 1997.

Groundwater withdrawal within Mercury Valley (Basin 225) and Crater Flat (Basin 229) ranged from 35 to 428 AFA and from 31 to 133 AFA, respectively from 1989 to 1997.

5. DISCUSSION OF EXISTING MODELS

Groundwater flow models have been constructed to represent the groundwater flow in the Death Valley region. Representations have evolved from two-dimensional models to three-dimensional models. Currently, there are two major regional groundwater flow models: the U.S. Geological Survey regional model developed for the Yucca Mountain Project (YMP) (D'Agnese and others, 1997) and the regional model developed for the Environmental Restoration Project (ERP) by IT Corporation (U.S. DOE, 1997).

5.1. Purposes of Major Existing models

The YMP model was developed by using MODFLOWP (Hill, 1992) and the ERP model was developed by using MODFLOW (McDonald and Harbaugh, 1988). The mathematical description of the groundwater movement is the same. Numerical approximation techniques used to solve the mathematical problem are also the same with the MODFLOWP having additional nonlinear regression parameter estimation capability. However, the nonlinear regression parameter estimation technique does not guarantee optimal parameter estimation and is limited by model structures and modeling contexts.

The purpose of the YMP model, as described by D'Agnese and others (1997, p. 2), was to assist in:

(1) Definition of boundaries of the subregional and local flow systems,

(2) Characterization of regional 3D groundwater flow paths,

(3) Definition of locations of regional groundwater recharge and discharge,

(4) Estimation of magnitudes and rates of regional subsurface flux,

(5) Assessment of potential effects of a pluvial climate on the regional flow system,

(6) Evaluation of potential and existing anthropogenic effects on groundwater flow,

(7) Characterization of potential impacts of the regional carbonate aquifer on subregional and local flow components, and

(8) Determination of potential effects of regional geologic structure on the flow system.

The ERP model was developed to (U.S. DOE, 1997, p. 7-2):

(1) Provide an integrated tool with which to understand the groundwater flow system in the vicinity of the NTS,

(2) Identify flowpaths from weapons testing areas and calculate flow rates within and down gradient from these areas for use in the evaluation of regional groundwater contaminant transport,

(3) Provide a mechanism for determining the importance of regional-scale hydraulic parameters on estimates of contaminant transport, and

(4) Provide a three-dimensional framework on which to base more detailed models of the weapons testing areas, so that near-field models can be consistent with the regional water budget.

5.2. Similarities in the YMP Model and the ERP Model

Both models are three-dimensional steady-state models based upon the same basic hydrogeologic data set with different interpretations in detail.

Both models were calibrated by variations of both system flux and hydraulic conductivity values. The model calibrations were evaluated against the range of heads in the models to show that the overall residuals are about 3 percent of the total range in measured heads. The simulated gradients by the YMP model are within 60 percent of the gradients evident from the measured heads (D'Agnese and others, 1997, p. 94).

Both the YMP model and the ERP model are based on detailed geologic models. Hydraulic property zoning in both models is based on interpretations of geological features. The actual hydraulic property value in each property zone was determined during the calibration processes. The simplification of the zoning of the hydraulic properties based on geological features helps the model calibration by reducing the number of calibration parameters. However, it also limits model calibration by restricting the reduction of head residuals.

Both models (not intended to be predictive) have a relatively limited capability to predict the impacts of groundwater withdrawals because of their steady-state regional nature and relatively large head residuals on the orders of 10 to 100 meters (which may be appropriate for their intended purposes).

5.3. Differences in the YMP Models and the ERP Model

The configurations of the two models are different. The YMP model has 3 layers with a total simulated thickness of approximately 9,023 ft (2,750 meters) and uniform horizontal cell size of 4,922 ft by 4,922 ft (1,500 meters. by 1,500 meters). The 3 layers represent aquifer materials at 0 – 1,641 ft (0–500 meters), 1,641–4,101 ft (500–1,250 meters), and 4,101– 9,023 ft (1,250–2,750 meters) below an interpreted water table (D'Agnese and others, 1997, p. 75).

The ERP model has 20 layers with a simulated aquifer domain spanning from the top elevation of 6,562 ft (2,000 meters) to the bottom elevation of –13,124 ft (–4,000 meters) with reference to the mean sea level and variable horizontal grid space ranging from 4,922 to 32,810 ft (1,500 to 10,000 meters). The layer thickness of the ERP model varies from 328 ft (100 meters) to 3,281 ft (1,000 meters) (U.S. DOE, 1997, Table 7-1).

Flux components in the YMP model and the ERP model are also different. Generally, The YMP model has a higher system flux while the ERP model has a lower system flux. The YMP model has a consideration of wells while the ERP model has no simulation of pumpage.

6. CONCEPTUAL MODEL

The conceptual model developed for this study is based on the known geologic, hydrogeologic and groundwater withdrawal data for the study area, as discussed in previous sections. The following sections describe the components of this model.

6.1 Conceptualization

Recharge of the groundwater in the study area originates primarily from precipitation in the higher elevations and from subsurface inflow from adjoining basins, primarily along the northern and eastern boundaries. After entering the flow domain, groundwater generally moves toward the south and southwest through the aquifer system.

Groundwater discharges in the forms of springflow and evapotranspiration in Oasis Valley, Amargosa Desert, Alkali Flat, Furnace Creek Ranch, and Ash Meadows and in the form of groundwater withdrawal from wells. A portion of spring discharge and groundwater withdrawal becomes secondary recharge. Subsurface outflow ultimately discharges in Death Valley as evapotranspiration.

The groundwater flow domain can be broadly conceptualized as a three-layer system. The top layer represents the shallow unconfined aquifers (alluvial and tuff) or water table aquifers, which receive recharge from precipitation, surface water runoff, spring discharge and human water uses. Although these aquifers may be locally confined by confining units of limited areal and vertical extent, they are considered to be water table aquifers for this model.

The central layer has different roles in different areas. In the northern and southern parts of the study area, this layer acts as communication windows between the overlying water table aquifers and the lower, regionally confined aquifers. In the central area around Yucca Mountain, this layer has low permeability and thus may act as a barrier to vertical flow between the overlying unconfined and the lower confined layers. The aquifers within this central model layer can be treated as confined aquifers because water level for the central layer is expected to be higher than the upper surface of the model layer.

The bottom layer represents the deep regionally confined aquifers, through which most inter-basin flow occurs.

As noted above, data pertaining to the distribution of hydraulic properties is very limited. It is known that the hydraulic conductivity in the flow domain varies between stratigraphic units as well as within a single stratigraphic unit itself. Additionally, the hydraulic conductivity within faults and fault zones are basically unknown. Because of this, designating hydraulic conductivity in a model on the basis of the distribution of stratigraphic units may not be appropriate and may limit the refinement of model calibration, since both aquifers and aquitards may exist within one stratigraphic unit.

Using a single value of hydraulic conductivity for a specific stratigraphic unit would oversimplify and not accurately represent the actual hydrogeologic conditions. Therefore, conceptually, the zoning of hydraulic conductivity in this study has been based on the principle that any known distributions (data points) of hydraulic conductivity obtained from large-scale field pumping tests should be used for areas where data is available.

In areas without pumping test data, the hydraulic conductivity has been determined by model calibration. In using this method, the distribution of hydraulic conductivity should not be interpreted literally but should be interpreted within the calibration context. It should be pointed out that the calibrated distribution of hydraulic conductivity is not for parameter estimation but for simulations of the system behavior on the basis of limited data to predict possible impact due to proposed groundwater withdrawal.

Compared with the distribution of hydraulic conductivity and the range of its values, the distribution of storage parameters may be relatively simple. This is primarily due to the fact that the range of values for a single storage parameter within a stratigraphic unit, or aquifer system, with similar deformational history may be considered to be relatively small. Additionally, the storage property may be considered to be relatively uniform.

Unfortunately, data on aquifer storage properties in the study area is sparse, especially for the deeper aquifers. Because of this lack of data and the relatively small range of specific yield values for a given unit or aquifer, two zones were assumed for the top layer in the model and one uniform storage zone was assumed for the two deeper layers. The specific yield zones given for the top layer are: one zone primarily for the valley-fill aquifers and the other primarily for volcanic aquifers.

6.2 Flux Components

Flux components include both inflow and outflow components. Major inflow components in the study area are recharge from precipitation, subsurface inflow and secondary recharge from water uses. Major outflow components are evapotranspiration, springs, pumpage from wells and subsurface outflow. The flux configurations for a numerical model include locations where flux components enter into or exit the aquifer system, at what quantities and how the flux components respond to aquifer stresses.

Different system flux configurations can be shown to result in different conceptual models. Because of the relative uncertainties connected with estimating the system flux components and for the purpose of this study, two system flux configurations were developed and modeled. These two system flux configurations are designated as high flux and low flux according to their relative amount of the total system flux. The low flux and high flux designations do not necessarily mean that the estimates of flux components in the low and high flux configurations are low and high, respectively. Rather, both configurations are possible representations of the physical aquifer system.

The two sets of system flux have the same locations but at different quantities based on existing estimates. The high and low flux sets have high and low quantities for boundary flux, recharge from precipitation, and evapotranspiration, respectively. Both sets have the same spring discharges and groundwater withdrawals. The following paragraphs discuss the various flux components used in this study.

The groundwater flux components for the Amargosa Desert and adjacent basins have been estimated in many studies (Malmberg & Eakin, 1962; Walker & Eakin, 1963; Rush, 1970; Nevada State Engineer's Office, 1971; Harrill and others, 1988; D'Agnese, 1994; Osterkamp and others, 1994; Pal Consultants, 1995; D'Agnese and others, 1997; Campana and Byer, 1996). However, there is a wide variation on the flux components for the aquifer system in the study area, despite the considerable amount of study on this issue. The major known estimates of the flux components for most of the study area are summarized Tables 6.1, 6.2, 6.3 and 6.4. Estimates of flux components for the Death Valley portion were not listed due to unavailability.

Subsurface outflow to Death Valley from Amargosa Desert as listed in Table 6.4 is simply based on mass balance and estimates of other flux components. For an estimate of evapotranspiration for the Furnace Creek Ranch area, see Section 7.5.3 of this report. Subsurface flow from Basins 161 (Indian Springs Valley), 162 (Pahrump Valley) and 146 (Sarcobatus Flat) may exist and estimates are not available. In the models documented in this report, the boundary fluxes at these locations were considered. The quantities, which are relatively small as compared to total system flux, were assigned with unknown uncertainty. However, it is believed that the accuracy of these boundary fluxes would not significantly affect the overall model behavior.

From Tables 6.1, 6.2, 6.3 and 6.4, it can be seen that groundwater budgeting is imprecise and approximate in nature. Although other estimates are not substantially different from those of the Nevada State Engineer's Office (1971), it does not mean there is absolute certainty in those values. One example of this is that the potentiometric surface map prepared by Kilroy (1991) clearly shows that there is subsurface flow between the Oasis Valley and the Amargosa Desert.

The following is an estimation of boundary flux for the model area in this study which is based on estimates of flux components of basins upgradient of the modeled area in this study. Figure 7 shows the modeled area and adjacent hydrographic basins within the Death Valley Regional Flow System as defined by D'Agnese and others, 1997. This boundary flux estimation was later used as targets for the "high flux" steady state model.

From the estimated potentiometric surface (D'Agnese and others, 1997, p. 60, Figure 27), it can be seen that there is subsurface boundary flux entering the eastern/northeastern

Table 6.1 Estimates of Recharge From Precipitation

(Acre-Feet per Annum)

<table>
<tr><th>Basin No.</th><th>Basin Name</th><th>1*</th><th>2*</th><th>3*</th><th>4*</th><th>5*</th><th>6*</th><th>7*</th><th>8*</th><th>9*</th><th>10*</th></tr>
<tr><td>225</td><td>Mercury V.</td><td>-</td><td>-</td><td>250</td><td>250</td><td>200</td><td>340</td><td>81</td><td>340</td><td>350</td><td>-</td></tr>
<tr><td>226</td><td>Rock V.</td><td>-</td><td>-</td><td>30</td><td>30</td><td>100</td><td>40</td><td>49</td><td>40</td><td>50</td><td>200</td></tr>
<tr><td>227A</td><td>Jackass Flats</td><td>-</td><td>-</td><td>880</td><td>900</td><td rowspan="2">2,300</td><td rowspan="2">6,600</td><td>795</td><td rowspan="2">6,600</td><td rowspan="2">700</td><td>4,420</td></tr>
<tr><td>227B</td><td>Buckboard Mesa</td><td>-</td><td>-</td><td>1,400</td><td>1,400</td><td>2,628</td><td>-</td></tr>
<tr><td>228</td><td>Oasis V.</td><td>250</td><td>-</td><td>1,000</td><td>1,000</td><td>1,000</td><td>3,100</td><td>3,536</td><td>3,100</td><td>3,100</td><td>3,800</td></tr>
<tr><td>229</td><td>Crater Flat</td><td>-</td><td>-</td><td>220</td><td>220</td><td>200</td><td>110</td><td>97</td><td>110</td><td>100</td><td>500</td></tr>
<tr><td>230</td><td>Amargosa Desert</td><td>-</td><td>1,200**</td><td>-</td><td>600</td><td>500</td><td>410</td><td>8,005</td><td>410</td><td>400</td><td>400</td></tr>
<tr><td colspan="2">Total</td><td>-</td><td>-</td><td>-</td><td>4,400</td><td>4,300</td><td>10,600</td><td>15,191</td><td>10,600</td><td>4,700</td><td>-</td></tr>
</table>

* Authors:
1. Malmberg and Eakin, 1962
2. Walker and Eakin, 1963
3. Rush, 1970
4. Nevada State Engineer Office, 1971
5. Harrill and others, 1988
6. D'Agnese, 1994
7. Osterkamp and others, 1993.
8. Pal Consultants, 1995
9. D'Agnese and others, 1997
10. Campana and Byer, 1996

** Includes recharge from Basin 227.

Table 6.2 Estimates of Evapotranspiration

(Acre-Feet per Annum)

<table>
<tr><th>Basin No.</th><th>Basin Name</th><th>1*</th><th>2*</th><th>3*</th><th>4*</th><th>5*</th><th>6*</th><th>7*</th><th>8*</th></tr>
<tr><td>225</td><td>Mercury V.</td><td>-</td><td>-</td><td>0</td><td>0</td><td>-</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>226</td><td>Rock V.</td><td>-</td><td>-</td><td>0</td><td>0</td><td>-</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>227A</td><td>Jackass Flats</td><td>-</td><td>-</td><td>0</td><td>0</td><td rowspan="2">-</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">0</td></tr>
<tr><td>227B</td><td>Buckboard Mesa</td><td>-</td><td>-</td><td>0</td><td>0</td></tr>
<tr><td>228</td><td>Oasis V.</td><td>2,000</td><td>-</td><td>2,000</td><td>2,000</td><td>-</td><td>4,300</td><td>4,300</td><td>4,300</td></tr>
<tr><td>229</td><td>Crater Flat</td><td>-</td><td>-</td><td>0</td><td>0</td><td>-</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>230</td><td>Amargosa Desert</td><td>-</td><td>24,000</td><td>-</td><td>24,000</td><td>-</td><td>43,000</td><td>24,000</td><td>43,400</td></tr>
<tr><td colspan="2">Total</td><td>-</td><td>-</td><td>-</td><td>26,000</td><td>-</td><td>47,300</td><td>27,300</td><td>47,700</td></tr>
</table>

* Authors:
1. Malmberg and Eakin, 1962
2. Walker and Eakin, 1963
3. Rush, 1970
4. Nevada State Engineer Office, 1971
5. Harrill and others, 1988
6. D'Agnese, 1994
7. Pal Consultants, 1995
8. D'Agnese and others, 1997

Table 6.3 Estimates of Subsurface Inflow

(Acre-Feet per Annum)

Basin No.	Basin Name	Nevada State Engineer (1971)	From	Remarks
225	Mercury Valley	16,000	Basin 160 (Frenchman Flat)	
226	Rock Valley	17,000	Basin 160 (Frenchman Flat)	
227A	Jackass Flats	7,200	Basin 227B (Buckboard Mesa)	Internal*
227B	Buckboard Mesa	5,800	Basin 147 (Gold Flat) and Basin 157 (Kawich Valley)	
228	Oasis Valley	2,500	Basin 147 (Gold Flat)	
229	Crater Flat	1,500	Basin 228 (Oasis Valley)	Internal
230	Amargosa Desert	44,000	Basins 225, 226, 227A, 229	Internal
Total		41,300	Basins 147, 157, 160	Exclude internal flow

*Internal is the subsurface flow between basins within the study area.

Table 6.4 Estimates of Subsurface Outflow

(Acre-Feet per Annum)

Basin No.	Basin Name	Nevada State Engineer (1971)	To	Remarks
225	Mercury Valley	17,000	Basin 230 (Amargosa Desert)	Internal*
226	Rock Valley	17,000	Basin 230 (Amargosa Desert)	Internal
227A	Jackass Flats	8,100	Basin 230 (Amargosa Desert)	Internal
227B	Buckboard Mesa	7,200	Basin 227A (Jackass Flats)	Internal
228	Oasis Valley	1,500	Basin 229 (Crater Flat)	Internal
229	Crater Flat	1,700	Basin 230 (Amargosa Desert)	Internal
230	Amargosa Desert	19,000	Basin 243 (Death Valley)	
Total		19,000	Basin 243 (Death Valley)	Exclude internal flow

*Internal is the subsurface flow between basins within the study area.

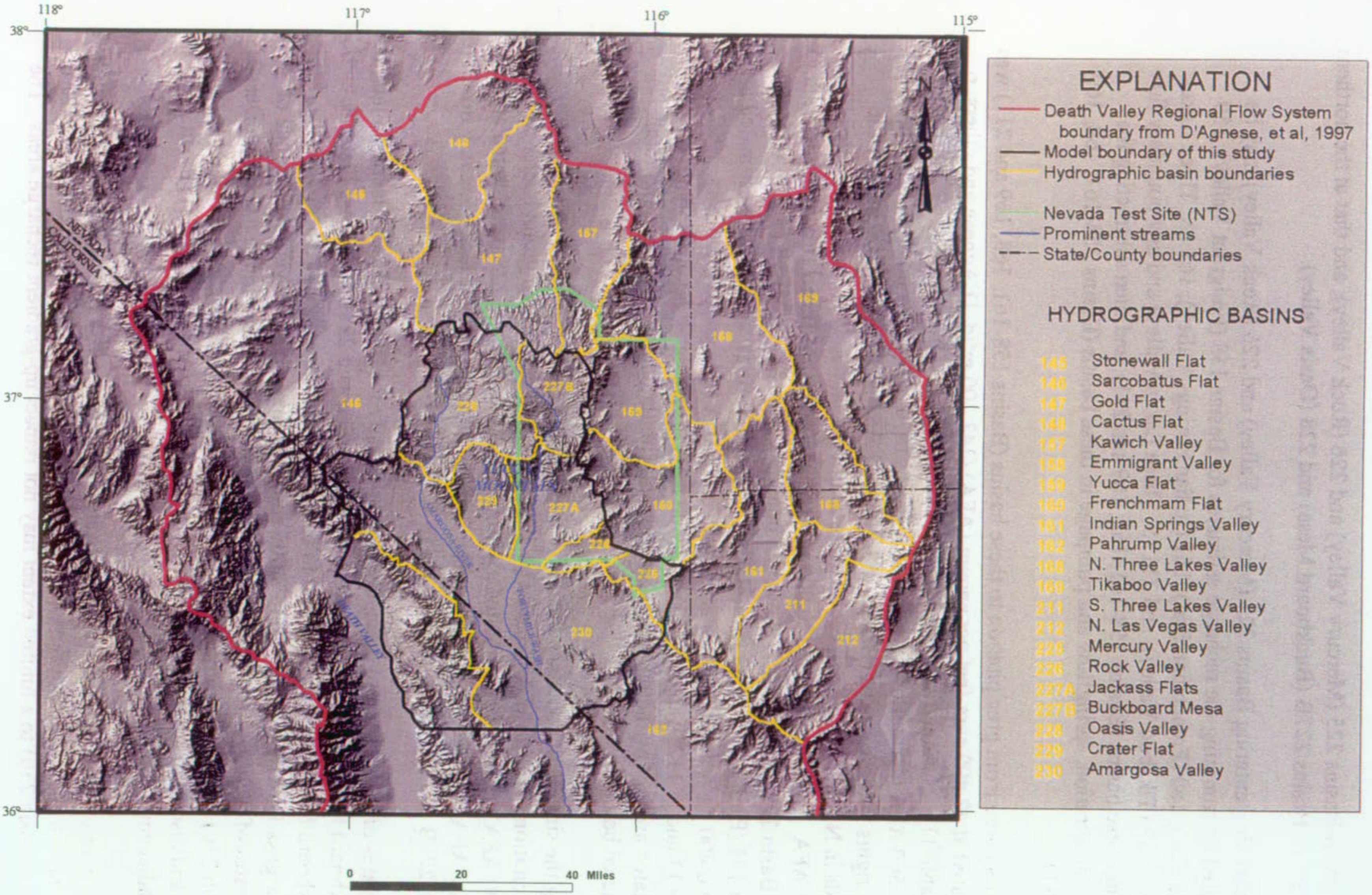


Figure 7. Modeled area of this study and adjacent hydrographic basins

boundary of Basins 225 (Mercury Valley) and 226 (Rock Valley); and that at the northern boundary of Basins 227B (Buckboard Mesa) and 228 (Oasis Valley).

Boundary flux entering Basins 225 (Mercury Valley) and 226 (Rock Valley) may be estimated by summing the recharge estimates for Basins 158 (Emigrant Valley), 159 (Yucca Flat), 160 (Frenchman Flat), 161 (Indian Springs Valley), 168 (N. Three Lakes Valley), 169 (Tikaboo Valley), and 211 (S. Three Lakes Valley) and any boundary flux entering these basins (Basins 158-161, 168, 169 and 211); and then subtracting the evapotranspiration, springflow and pumpage in these basins (Basins 158-161, 168, 169 and 211).

Total recharge from precipitation to these basins (Basins 158-161, 168, 169 and 211) was estimated at 42,400 acre-feet per annum (AFA) (143,100 m^3/d, D'Agnese and others, p. 56, Table 11). Natural discharge in these basins (Basins 158-161, 168, 169 and 211) is about 500 AFA (springflow in Basin 161, Rush, 1970, p. 17). Committed underground water rights in these basins (Basins 158-161, 168, 169 and 211), as indicated by the records in Nevada State Engineer's Office as of February 2, 1998, are approximately 2,900 AFA. Boundary influx (20,000 m^3/d or 5900 AFA) to Basin 169 (Tikaboo Valley) from Basin 209 (Pahranagat Valley) and boundary influx (1,700 m^3/d or 500 AFA) to Basin 158 (Emigrant Valley) from Basin 170 (Sand Springs Valley) were estimated at about 6,400 AFA and simulated at about 13,800 AFA (D'Agnese and others, 1997, p. 71 Table 13 and p. 112, Table 17). The 13,800 AFA is calculated by multiplying the estimated amount by the ratio between the total simulated boundary flux and total estimated boundary flux.

Using the simulated boundary flux (13,800 AFA) and the estimates for recharge from precipitation (42,400 AFA,), discharge (500 AFA) and committed groundwater rights (2,900 AFA), the subsurface boundary influx to Basins 225 and 226 is estimated at about 52,800 AFA (= 13,800 + 42,400 – 500 – 2,900). Similarly, subsurface boundary influx to Basin 227B and 228 is estimated at about 20,800 AFA.

Estimates of recharge from precipitation vary greatly for Basins 227 (A: Jackass Flats; B: Buckboard Mesa) and 230 (Amargosa Desert), with Basin 227 (A: Jackass Flats; B: Buckboard Mesa) ranging from 700 to 6,600 acre-feet annually and Basin 230 (Amargosa Desert) ranging 410 to 8,005 acre-feet annually. The very large range of estimates of recharge from precipitation and evapotranspiration in the Amargosa Desert (Basin 230) has crucial significance to the understanding of the source of water in this area and also to the determination of perennial yield for Amargosa Desert (Basin 230) and adjacent basins.

The lower estimates imply that groundwater in the Amargosa Desert (Basin 230) mainly originates from subsurface flow and lowering the groundwater level in the Amargosa Desert (Basin 230) to a limited extent may not impact up-gradient recharge areas. The higher estimates suggest that the groundwater in the Amargosa Desert (Basin 230) has a significant local source (recharge from the Amargosa River) and lowering of the groundwater level may induce additional recharge. Generally speaking, the more recent estimates of recharge from precipitation, which appear to be based on more extensive studies, tend to be larger than the earlier ones.

Estimates on spring discharge are all relatively close. This flux component has the least amount of uncertainty among all of the flux components.

Groundwater pumpage in the Amargosa Desert (Basin 230) are estimates and their accuracy has not been evaluated. The pumpage inventories by Nevada State Engineer are based primarily on the total acreage irrigated rather than a direct measurement of the water pumped. However, these pumpage inventories are the best information available for the groundwater withdrawal in the Amargosa Desert (Basin 230). Recent groundwater withdrawal data for Jackass Flats (Basin 227A) are the most accurate because they are direct flowmeter measurements of water pumped.

7. CONSTRUCTION OF NUMERICAL MODELS

7.1. Methodology

7.1.1. Transient Continuum Approach

For the purpose of this study, the groundwater flow domain can be treated as porous media. As such, the mathematical description of flow in porous media is applicable. The groundwater flow is assumed to have:

(1). Potential flow, Darcy's Law is applicable,
(2). Inertial force is negligible,
(3). Water density is constant, and
(4). Modeling quantities are only meaningful at the scale at which the flow in porous media can be treated as an average continuum.

Because the main purpose of this modeling effort was to evaluate the impact of small additional groundwater withdrawal, the above assumed continuum approach can be considered as adequate. For more detailed study, dual permeability or porosity models may be more appropriate. However, currently available data may not be sufficient and uncertainty in additional model parameters is high. Because of this, actual implementations of dual porosity models may be impractical.

The U.S. Geological Survey block-centered finite difference groundwater flow model MODFLOW (McDonald and Harbaugh, 1988) as implemented by Groundwater Vistas developed by Environmental Simulations Inc. was used to simulate the groundwater flow of the study area. Groundwater Vistas is a groundwater model design environment with pre-processing and post-processing tools.

7.1.2. Model Configuration and Simulation Scenarios

A total of two steady-state calibration models (low flux and low flux), four historical verification transient simulation runs and sixteen predictive simulation runs were performed for this study.

First, two sets of system flux (low flux and high flux) were simulated using the same flow domain with the same discretization (division of flow domain into model cells or grids). The two steady-state models were calibrated by matching simulated heads with measured heads at selected monitoring locations and by general matching of the simulated potentiometric surface with the estimated potentiometric surface.

Once these calibration runs were completed, transient runs with two sets of storage parameters (low and high) were made on the models for historical verification, resulting in four transient models. The four transient models are low flux with low storage set (Model L1), low flux with high storage set (Model L2), high flux with low storage set

(Model H1) and high flux with high storage set (Model H2). The designations of storage as high and low is for convenience of reference and do not necessarily mean those values are actually high or low. For the values of the two storage parameter sets, see Section 7.5.7 below.

Four scenarios were simulated by using each of the four transient models to evaluate the impact of the DOE proposed pumping under two different contexts: current water use and potential maximum pumping under senior water rights. Under each context, runs were made with and without the proposed pumping. The four scenarios are current water use context without the proposed pumping (Scenario 1), current water use context with the proposed pumping (Scenario 2), potential maximum pumping under senior water rights without the proposed pumping (Scenario 3) and potential maximum pumping under senior water rights with the proposed pumping (Scenario 4).

7.2. Assumptions

7.2.1. Aquifer Thicknesses

The upper boundary of the saturated flow domain can be considered at the water table of the unconfined aquifers; however, the lower boundary of the saturated flow domain is unknown. Groundwater flow may actually be negligible at great depths. For this study, it is assumed that at depths greater than approximately 7382 ft (2250 meters) below the water table, groundwater flow is negligible. This assumption is based on the well data at UE25 p#1 and the maximum depth modeled by D'Agnese and others (1997).

UE-25 p#1 was drilled to a total depth of 1805 meters (5922 ft). The relation between the hydraulic head and depth at UE-25 p#1 as reported by Craig and Robison (1984, p. 9, Figure 4) shows that: (1) groundwater level at depths from 400 meters (1,312 ft) to approximately 900 meters (2,953 ft) is approximately 730 meters (2,395 ft); (2) groundwater level at depths from approximately 900 meters (2,953 ft) to approximately 1,150 meters (3,773 ft) rises from approximately 732 meters (2,402 ft) to 752 meters (2,467 ft); and (3) groundwater level at depths greater than approximately 1,150 meters (3,773 ft) to the bottom of the well is approximately 752 meters (2,467 ft).

Total modeled thickness of this study is approximately 1,640 ft (500 meters) less than that of the D'Agnese and others' (1997) model. This difference of modeled thickness is in the central model layer. As noted above, well data at UE-25 p#1 indicates the thickness of 820 ft (250 meters) used in this study for the central model layer is more consistent with the conceptualizations adopted for this study.

It should be noted that the modeled aquifer thickness does not necessarily represent the actual aquifer thickness. Rather, in the numerical calculations, the thickness is used in connection with hydraulic conductivity. For flow in the horizontal directions, it is the transmissivity (product of aquifer thickness and hydraulic conductivity) that participates in the actual calculation. Any over-representation of the thickness would be compensated with under-representation of the horizontal hydraulic conductivity and vice versa. However, for vertical flow, any over-representation of thickness would mean over-representation of vertical hydraulic conductivity and vice versa

7.2.2. Boundary Conditions

Three types of boundaries were used in the models. The first type is a constant head boundary. This type of boundary applies to those areas where the head will not change with time and is independent of the system flux. In the Death Valley area, the line of constant head is assumed to represent the ultimate discharge at the Death Valley saltpan as evapotranspiration. This is consistent with the treatment of D'Agnese and others (1997).

The second type of boundary is no flow boundary where the flow crossing the boundary is negligible. The third type of boundary is the head dependent boundary. This type of boundary applies to those portions of the flow domain boundary where water levels outside of the flow domain can be considered independent of the water level changes inside the modeled flow domain.

7.2.3. Aquifer Parameters

Distribution of recharge from precipitation is based on land surface elevation intervals following the empirical Maxey-Eakin method (1949). For transient simulation, recharge from precipitation does not change from one stress period to the next.

Distribution of evapotranspiration (ET) areas coincides with the discharge areas indicated by Laczniak and others (1996, Plate 1). In the steady state models, it is assumed the ET surface is approximately at the water table with an extinction depth of 30 ft. The ET surface assumption is primarily based on the fact that no substantial reduction of ET and/or groundwater level decline have been reported for the respective ET areas. The maximum ET rate is determined by uniform distribution of estimated annual ET quantities over the corresponding ET areas. In transient simulations, ET depends on the variation of water table in these areas because the ET surface is the initial water table.

As previously discussed, data on the hydraulic properties of the stratigraphic units in the study area is limited. Much of the available data are small-scale field measurements of hydraulic conductivity, which may not be representative of values suitable for regional scale modeling, especially where the aquifer units have experienced various degrees of deformation and fracturing. Geldon (1996) noted that calculated hydrologic properties are dependent on the volume of aquifer being tested. Geldon (1996) further points out that cross-hole tests indicate site-scale hydrologic properties, whereas single-well tests indicate hydrogeologic properties within a small radius of the testing well.

There is almost no available data on the hydraulic properties of faults and fault zones in the study area. It is assumed that the three principal directions of the hydraulic conductivity tensor coincide with the model grid directions, that horizontal hydraulic conductivity does not change with horizontal directions, and that the vertical hydraulic conductivity is at ten percent of horizontal hydraulic conductivity values. Because of this, the distribution of hydraulic conductivity was almost totally determined by model calibration.

The simple relation between vertical hydraulic conductivity and horizontal conductivity was assumed for simplicity and convenience. Walton (1985, p23) reported that commonly the ratios of vertical to horizontal hydraulic conductivity ranged from 1:2 to 1:100. Because the purpose of the models is to evaluate hydraulic effect resulting from increased pumping, a relatively large ratio (1:10) is assumed to avoid underestimation of hydraulic impact between different layers of the aquifer system. This assumption may affect the simulation of substantial vertical flow, if it is not sufficiently close to actual conditions. For most of the modeled area, vertical flow between modeled layers may not be significant. If the actual ratio is larger than the assumed value, vertical hydraulic effect would be underestimated and vice versa.

The distribution of specific yield for the water table aquifers is based on the location and thickness of stratigraphic units at the depths where changes of water level may occur (interpreted from Figure 2). For this study, two different sets of values of storage coefficients were assigned with historical verification simulations.

The system flux can not be determined by model calibration because of the lack of data on hydraulic parameters. Because of this, system flux components and their distribution were based on existing estimates and current understanding and interpretations of the hydrogeology in the area. The high and low flux models illustrate different representations of the flow system. These multiple representations indicate the uncertainties involved in the modeling of an aquifer system with limited data.

7.2.4. Pumpage and Groundwater Levels

Groundwater pumping wells were simulated as fully penetrated ideal sinks in the top model layer. The historical average pumpage was incorporated in the steady-state models and the annual average pumpage was included in each of the transient simulations. Pumpage variations within any given year were ignored.

The best data for the aquifer system in the study area are groundwater level measurements rather than pumpage data for the individual wells. The reason, as previously discussed, is that unless actual meter readings are taken, most pumping data are estimates based on the acreage irrigated with the pumped groundwater.

A limitation of the groundwater level measurements is that the timing relationship between the measurements and pumping activities is not specifically known. As such, there is an inherent uncertainty about the measurements, especially if operating wells are nearby. It is known that the static water levels have been lowered since groundwater pumping began in the 1950's. But, for this study, it was assumed that the water level in the mid-1980's approximates steady-state conditions with groundwater withdrawal at average historical level. This mid-1980's steady state assumption is based on one of the calibration targets adopted for this study, which is the estimated potentiometric surface constructed by D'Agnese and others (1997). This estimated potentiometric surface is considered as representing the mid-1980's condition (D'Agnese and others, 1997, p.43; D'Agnese, oral comm., 1998). Another reason for the mid-1980's assumption is that the average historical groundwater withdrawal (average pre-1985, see Appendix A) is relatively small as compared with the overall system flux. In addition, water levels at or near pumping wells were affected by groundwater withdrawals. Therefore, it is necessary to take groundwater withdrawals into account. It is also noted that, generally, no steady state exists. However, a set of conditions had to be selected to approximate steady state conditions.

7.3. Modeling Constraints

All numerical models are inherently limited by the quantity and quality of available data, as well as by all the assumptions and simplifications involved. The data used in the models are from reports by the U.S. Geological Survey, and from the Nevada Division of Water Resources. Detailed data sources are included in Appendix B.

Determination of system flux components without sufficient data on hydraulic parameters is beyond the capability of numerical simulations. Numerical simulations, however, may help to evaluate different flux configurations and define flux components for smaller flow domains with accurately calibrated models

7.4. Model Grid

The model grid, as shown in Figure 8, consists of 151 rows and 129 columns in 3 layers. The horizontal grid size is 0.5 mile × 0.5 mile. Distribution of active cells (within the modeled domain) and non-active cells (outside of the modeled domain) are the same in all three layers. The three layers are treated as:

- Top layer: unconfined aquifer, assumed thickness of approximately 1,640 ft (500 meters)
- Central layer: confined aquifer, assumed thickness of 820 ft (250 meters)
- Bottom layer: confined aquifer, assumed thickness of 4,922 ft (1,500 meters)

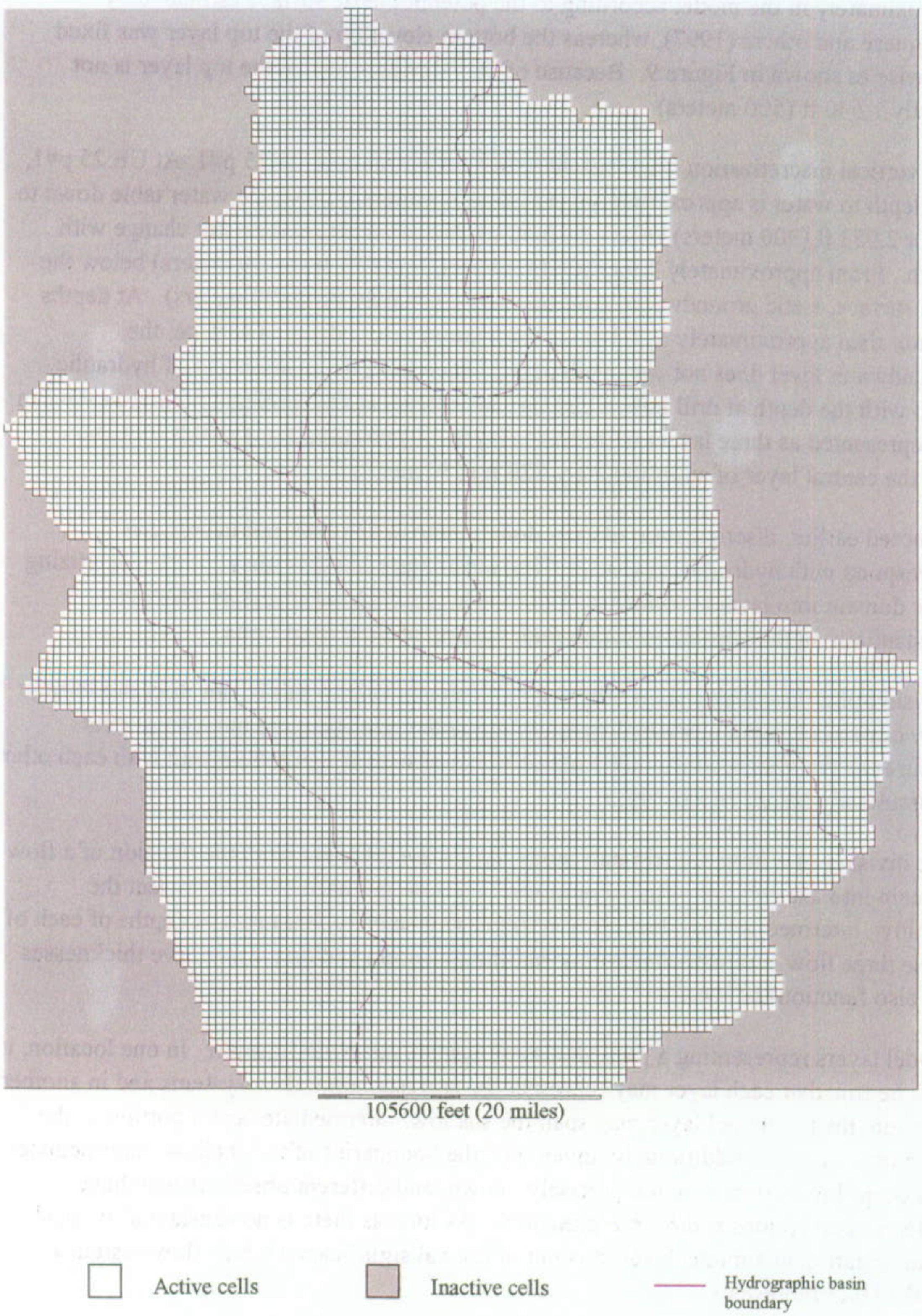


Figure 8. Model grid

It should be pointed out that the elevation of the bottom of the top layer was assigned approximately in the model according to the potentiometric surface estimated by D'Agnese and others (1997), whereas the bottom elevation of the top layer was fixed stepwise as shown in Figure 9. Because of this, the thickness of the top layer is not exactly 1,640 ft (500 meters).

The vertical discretization is consistent with data at drill hole UE25 p#1. At UE 25 p#1, the depth to water is approximately 1,312 ft (400 meters). From the water table down to about 2,953 ft (900 meters) below the land surface, water level does not change with depth. From approximately 2,953 ft (900 meters) to 3,773 ft (1,150 meters) below the land surface, static groundwater level rose approximately 66 ft (20 meters). At depths greater than approximately 3,773 ft (1,150 meters) below the land surface, the groundwater level does not vary with depth. Therefore, the relationship of hydraulic head with the depth at drill hole UE25 p#1 indicates that the aquifers at this location can be represented as three layers with the top layer of approximately 1,640 ft (500 meters) and the central layer of approximately 820 ft (250 meters).

As noted earlier, discretization of flow domain into layers does not necessarily correspond with hydrogeologic units. The most important consideration of discretizing flow domain into layers is whether or not the hydraulic head in a layer changes substantially in the vertical direction under expected flow conditions.

Division of a flow system into different aquifers and/or into sub-basins does not change flow conditions but is a convenient way for one to understand the most prominent features of the system itself. All parts of a flow system still communicate with each other hydraulically but at various rates.

The division of a flow domain into model layers are different from the division of a flow domain into subsystems. The three model layers do not necessarily represent the shallow, intermediate and deep flow systems, respectively, because the depths of each of these three flow systems vary from location to location and their respective thicknesses are also functions of location.

Model layers representing a particular flow system vary with location. In one location, it may be true that each layer may represent the corresponding flow systems and in another location, the top model layer may span the shallow, intermediate, and a portion of the deep flow system. Additionally, given this, the boundaries of the shallow, intermediate, and deep flow systems are not precisely known, and different observers may have different perceptions and/or interpretations. As long as there is no substantial vertical head variation in a model layer, it is not of critical significance which flow system a model layer represents.

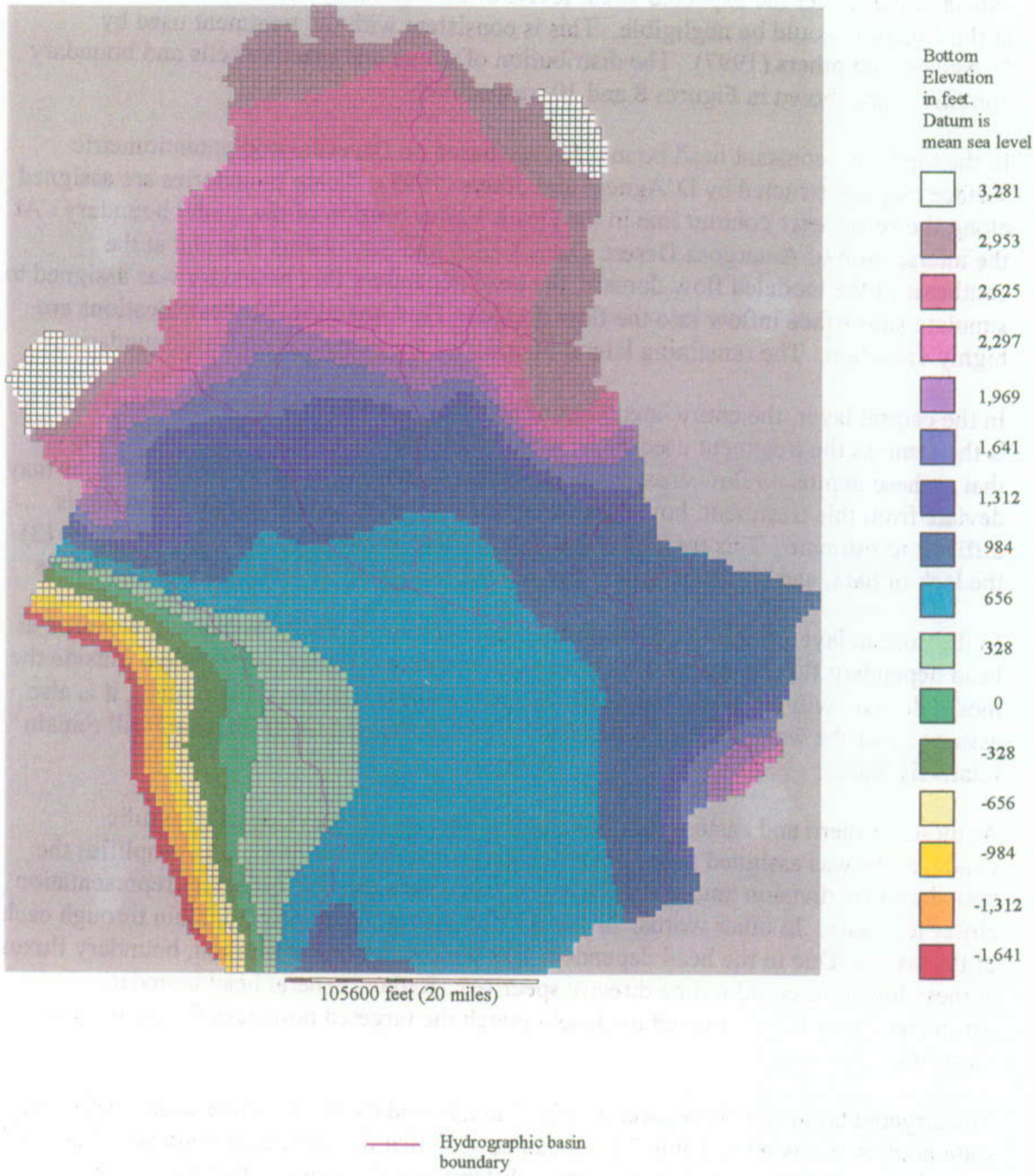


Figure 9. Bottom elevation zones of the top layer in the models

7.5. Model Inputs

7.5.1. Boundary Conditions

The model boundary extends to Death Valley, where a line of constant head is assumed to represent the ultimate discharge at the Death Valley saltpan as evapotranspiration. It is expected that under the expected stress levels of the aquifer system, water level changes at this location would be negligible. This is consistent with the treatment used by D'Agnese and others (1997). The distribution of active and inactive cells and boundary conditions are shown in Figures 8 and 10, respectively.

In the top layer, constant head boundaries are based on the estimated potentiometric surface map constructed by D'Agnese and others (1997). These boundaries are assigned along the zero-meter contour line in the Death Valley portion of the model boundary. At the intersection of Amargosa Desert, Oasis Valley and Sarcobatus Flat and at the southeast of the modeled flow domain, the head dependent flux boundary was assigned to simulate subsurface inflow into the flow domain. Flux quantities at these locations are highly uncertain. The remaining lateral boundaries are treated as no flow boundaries.

In the central layer, the entire lateral boundary is assigned to a no flow boundary, which is the same as the treatment used by D'Agnese and others (1997), because it is believed that at these depths no flow crosses the lateral boundary. The actual flow conditions may deviate from this treatment; however, the actual flow crossing the lateral boundary is difficult to estimate. This treatment was selected due to three factors: (1) simplicity, (2) the lack of data, and (3) the relative insignificance of the boundary flux at these depths.

In the bottom layer, portions of the northern and eastern lateral boundaries are treated as head dependent flux boundaries with the assumption that the inter-basin flow outside the model domain will enter into the model domain at these locations. In addition, it is also assumed that the water level outside of the model domain at these locations will remain relatively stable.

At these northern and eastern flux boundary locations, a high value of hydraulic conductivity was assigned to the boundary cells in all three layers. This simplifies the boundary flux division among all the layers and makes the flux boundary representation closer to reality. In other words, boundary flux enters the modeled domain through each of the layers. Due to the head dependent flux boundary implementation, boundary fluxes at these locations could not be directly specified. Rather, general head boundary parameters have to be adjusted to closely match the targeted boundary fluxes at these locations.

The targeted boundary fluxes and the simulated boundary fluxes in the calibrated steady-state models are listed in Table 7.1. It can be seen that the simulated boundary fluxes are very close to the estimated targets, with a difference of less than 2 percent. Total simulated boundary flux approaches total targeted boundary flux with a difference of less than 0.3 percent.

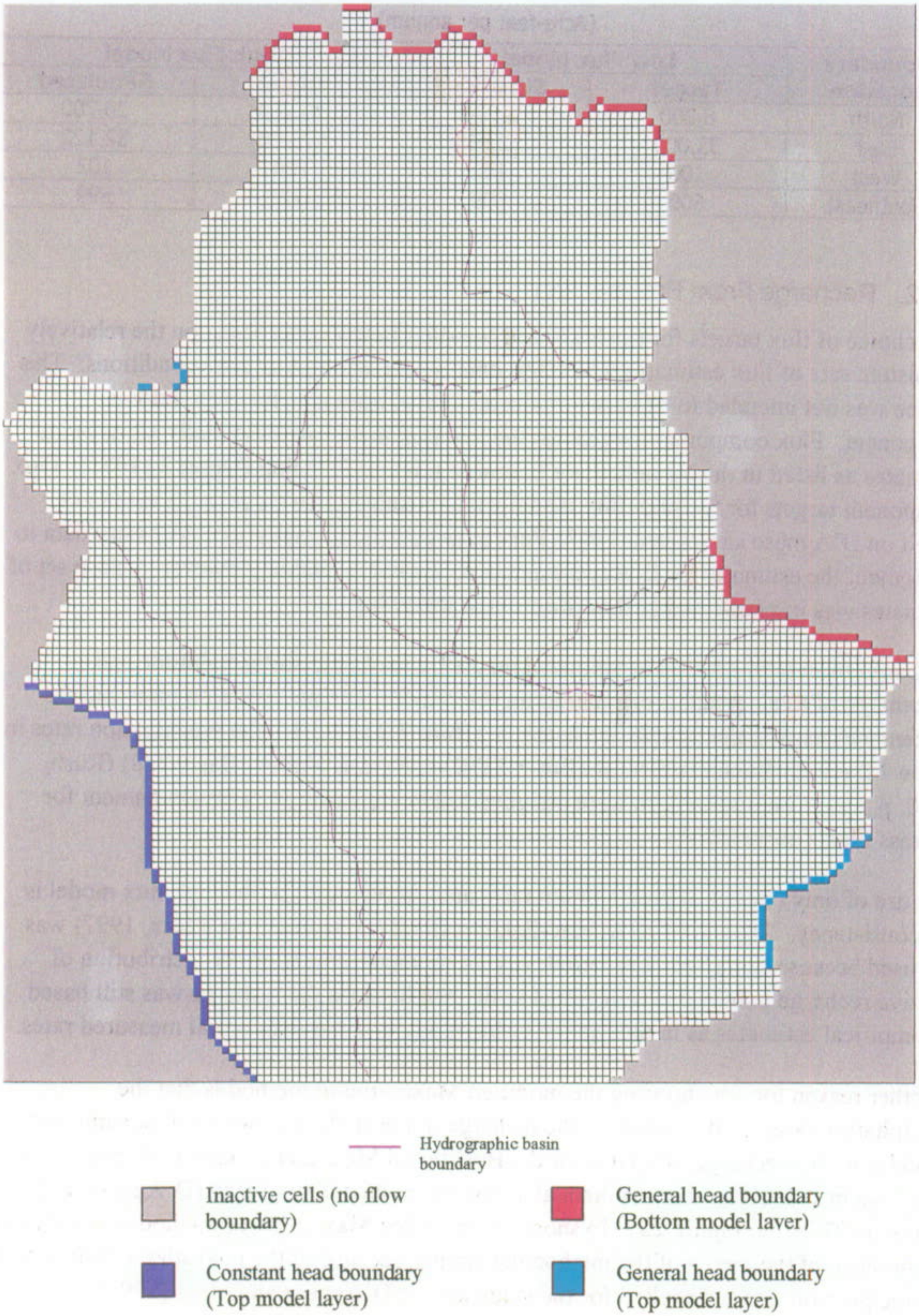


Figure 10. Model boundary conditions

Table 7.1 Boundary Flux Values

(Acre-feet per annum)

Boundary Location	Low Flux Model		High Flux Model	
	Target	**Simulated**	**Target**	**Simulated**
North	8,200	8,226	20,700	20,700
East	33,000	32,868	52,200	52,122
West	100	101	100	102
Southeast	600	599	600	599

7.5.2. Recharge From Precipitation

The choice of flux targets for the high- and low-flux models was based on the relatively consistent sets of flux estimates which reasonably represent the aquifer conditions. This choice was not intended to be based on the bounds of estimates for each individual flux component. Flux component targets for the low flux model are essentially close to the estimates as listed in the Nevada State Engineer's Water Planning Report 3 (1971). Flux component targets for the high flux model were intended to be close to the estimates based on D'Agnese and others, 1997. For recharge from precipitation, necessary data to implement the estimates by D'Agnese and others is not available; however, a close set of estimates was implemented as described in the following.

Recharge from precipitation is estimated on the basis of land surface altitude and percentage of total annual precipitation for the region. The precipitation rates and the percentages used in the models are listed in Tables 7.2 and 7.3. The precipitation rates in Table 7.2 are for Buckboard Mesa (Basin 227B) and Oasis Valley (Basin 228) (Rush, 1970, p. 15). The percentages were assigned following Rush's (1970) assignment for Jackass Flats (Basin 227A).

The use of only one set of precipitation rates and percentages for the high flux model is for consistency. The modified Maxey-Eakin method (D'Agnese and others, 1997) was not used because it may be considered only as an improvement on the distribution of relative recharge potential on a regional scale, and because the recharge was still based on empirical estimates as in the Maxey-Eakin method rather than actual measured rates.

Another reason for not choosing the modified Maxey-Eakin method is that the precipitation rates used to estimate the recharge in the study area were not documented. In addition, the recharge estimates for the Buckboard Mesa and Jackass Flats areas seem inconsistent with the recharge potential as shown in the potential map (D'Agnese and others, 1997, p. 54, Figure 25). In short, the modified Maxey-Eakin method was not used not because of the merits of the method but simply because of the unavailable distribution of precipitation rates as applied for the study area in D'Agnese and other (1997).

Table 7.2 Recharge Zone Data in the High Flux Model

Zone	Annual Precip. (ft)	Percentage	Recharge Rate (ft/day)	Elevation (ft)
1	0.5	0	0	<5,000
2	0.5	3	4.10959E-5	5,000-6,000
3	0.8	7	1.53425E-4	6,000-7,000
4	1.1	15	4.52055E-4	>7,000ft

Data from Rush, 1970

Table 7.3 Recharge Zone Data in the Low Flux Model

Zone	Annual Precip.(ft)	Percentage	Recharge Rate (ft/day)	Elevation (ft)
For Jackass Flats And Amargosa Desert				
1	-	0	0	<5,000 ft
2	0.5	3	4.10959E-5	>5,000 ft
3	0.8	7	1.53425E-4	>6,000 ft
4	1.1	15	4.52055E-4	>7,000ft
For Buckboard Mesa and Oasis Valley				
1	-	0	0	<6,000 ft
5	0.8	3	6.57534E-5	>6,000 ft
6	1.1	7	2.10959E-4	>7,000 ft

Data from Rush, 1970.

Rush's (1970) data for recharge rates were used for the low flux model. The resulting annual recharge for the hydrographic basins are listed in Table 7.4. The recharge estimates for the high flux model, as shown in Table 7.4 are close to those of D'Agnese (1994). Recharge distribution and rates are not changed during model calibration and simulations because to do so would result in different modeling results for the same set of calibration criteria. Figures 11 (a) and (b) show the distribution of the recharge zones.

The recharge in the southern border of the modeled area is arbitrarily assigned to simulate the groundwater mound known to occur in that area. The total recharge rate for that area in both the models is about 106 AFA.

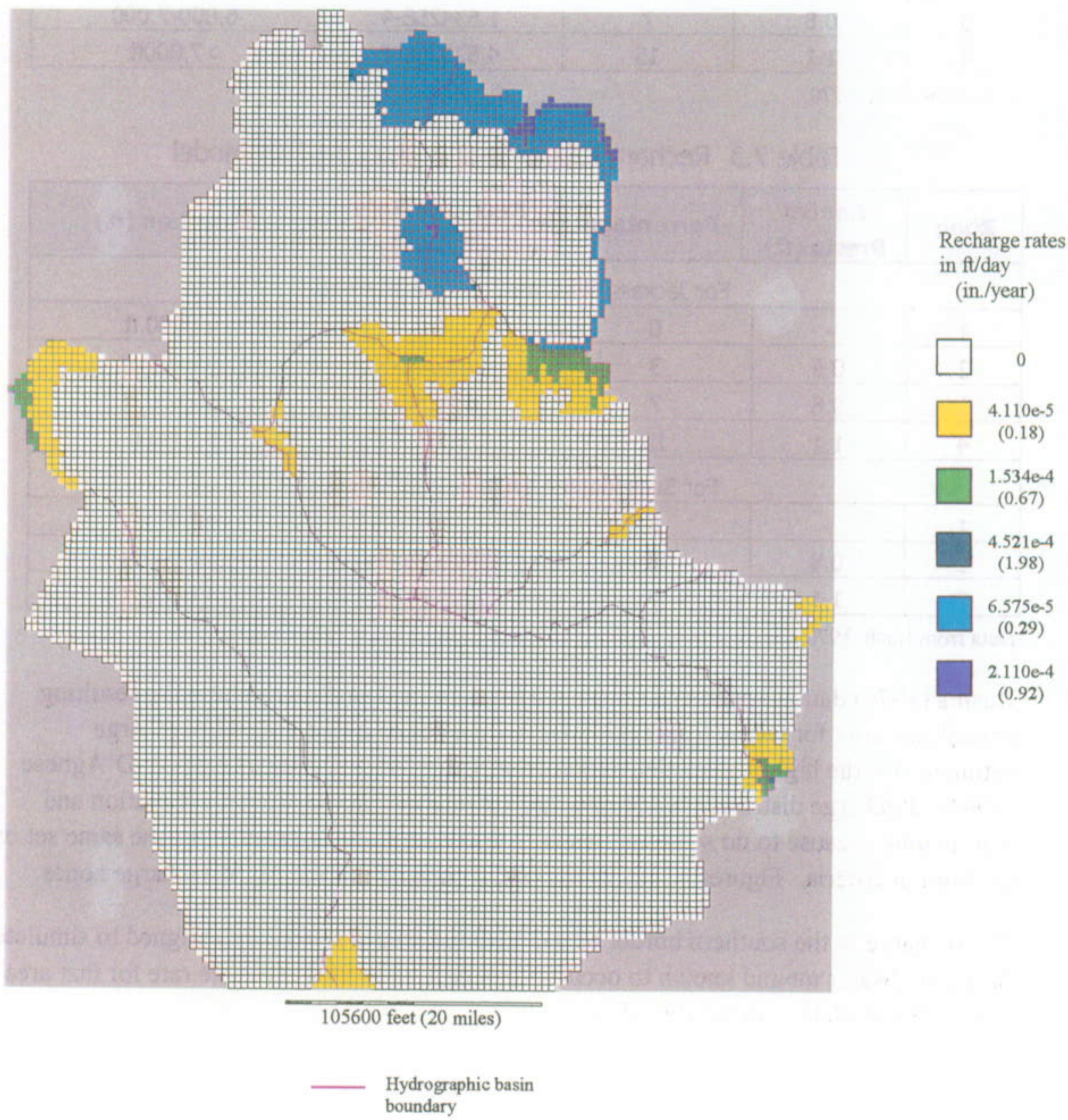


Figure 11 (a). Recharge zones in the low flux models (Top model layer)

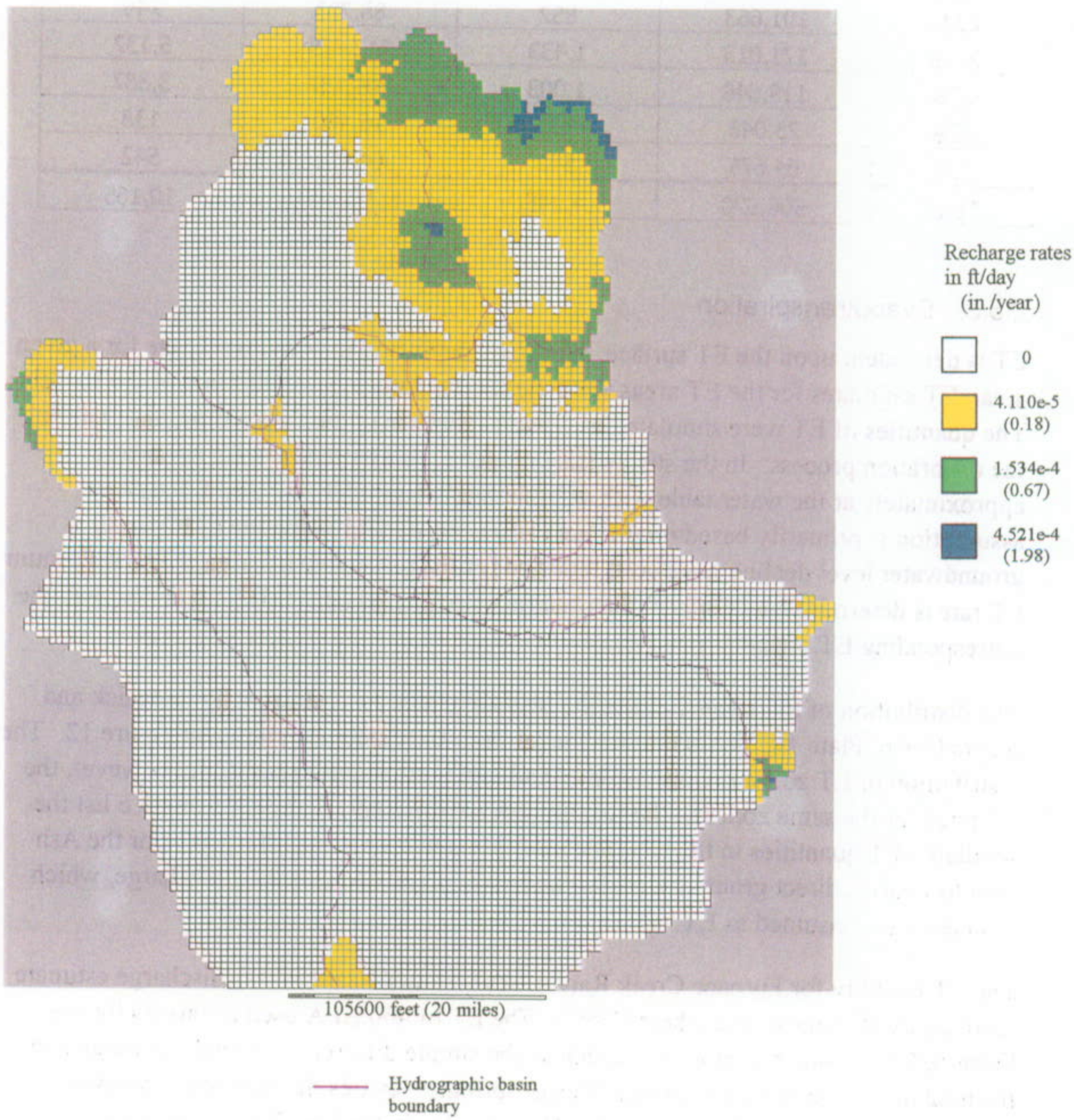


Figure 11 (b). Recharge zones in the high flux models (Top layer)

Table 7.4 Summary of Recharge From Precipitation Simulated in the Models

Basin	Low Flux Model		High Flux Model	
	Ft³/day	AFA	ft³/day	AFA
225	24,232	203	24,232	203
226	2,291	19	2,291	19
227a	101,663	852	88,793	744
227b	171,013	1,433	612,475	5,132
228	119,648	1,003	404,187	3,387
229	23,048	193	16,460	138
230	64,675	542	64,675	542
Total	506,570	4,245	1,213,113	10,165

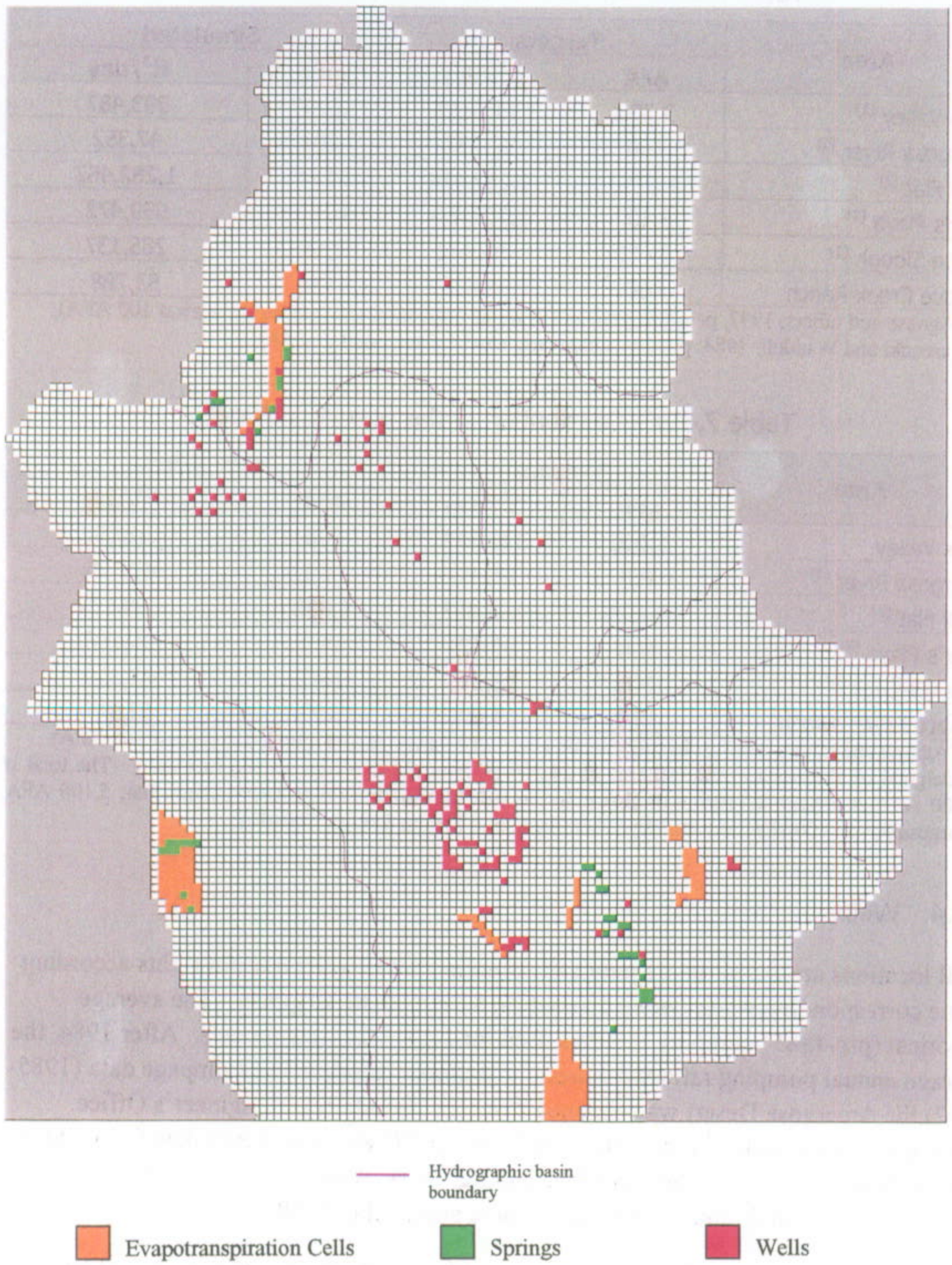
7.5.3. Evapotranspiration

ET is dependent upon the ET surface, extinction depth and maximum ET rate for a given area. ET estimates for the ET areas were the targets during the calibration of the models. The quantities of ET were simulated as close as possible to the targeted estimates during the calibration process. In the steady state models, it is assumed the ET surface is approximately at the water table with an extinction depth of 30 ft. The ET surface assumption is primarily based on the fact that no substantial reduction of ET and/or groundwater level decline have been reported for the respective ET areas. The maximum ET rate is determined by uniform distribution of estimated annual ET quantities over the corresponding ET areas.

The distribution of ET zones follows the discharge areas as indicated by Laczniak and others (1996, Plate 1). The actual ET locations in the model are shown in Figure 12. The distribution of ET zones in both the high and low flux models is the same; however, the ET rates for the same zones in the two models are different. Tables 7.5 and 7.6 list the simulated ET quantities in the high and low flux models and their targets. For the Ash Meadows area, direct groundwater discharge was simulated as spring discharge, which ultimately is consumed as ET.

The ET quantity for Furnace Creek Ranch was assigned based on the discharge estimate reported by D'Agnese and others (1997). The ET of 460 AFA used as targets for the Furnace Creek Ranch area in the models is the simple difference of total discharge and the total discharge of major springs (Texas Springs, Nevares Springs and Travertine Springs). The targeted ET estimate for Oasis Valley in the low flux model is the difference between the total natural discharge and the spring discharge for Oasis Valley.

The targeted ET estimates for the high flux model are the most recent and correspond to the higher estimates of system flux. Conversely, the choices of the targeted ET estimates for the low flux model are consistent with the earlier estimates.



Note: In the Ash Meadows area, the spring discharges were considered as mainly consumed by ET. To avoid double counting, the groundwater discharges in this area were simulated as springs. Springs were simulated as drains

Figure 12. Evapotranspiration cells, springs, and wells in the models (Top model layer)

Table 7.5 ET Distribution in the High Flux Model

Area	Targets		Simulated	
	AFA	ft^3/day	AFA	ft^3/day
Oasis Valley (1)	3,300	393,830	3,297	393,487
Amargosa River (1)	400	47,737	397	47,352
Alkali Flat (2)	10,746	1,282,454	10,746	1,282,462
Peter's Playa (1)	8,400	1,002,477	8,375	999,472
Carson Slough (1)	2,400	286,422	2,489	285,137
Furnace Creek Ranch	460	54,898	451	53,788

(1) D'Agnese and others, 1997, p.46 (original unit is m^3/d. Converted and rounded to nearest 100 AFA).
(2) Czarnecki and Waddell, 1984, p. 20 (original unit is m^3/d. Converted to AFA).

Table 7.6 ET Distribution in the Low Flux Model

Area	Targets		Simulated	
	AFA	ft^3/day	AFA	ft^3/day
Oasis Valley	1,000	119,343	990	118,097
Amargosa River (1)	400	47,737	400	47,676
Alkali Flat (1)	5,100	608,647	5,098	608,426
Peter's Playa (2)	800	95,474	797	95,150
Carson Slough (2)	700	83,540	698	83,330
Furnace Creek Ranch	460	54,898	449	53,547

(1) D'Agnese and others, 1997, p.46 (original unit is m^3/d. Converted and rounded to nearest 100 AFA).
(2) Assigned on the basis of the estimate of 24,000 AFA total ET in the Amargosa Desert. The total of 24,000 AFA is divided as: spring discharge in the Ash Meadows: 17,000 AFA; Alkali Flat: 5,100 AFA; Amargosa River: 400AFA; Peter's Playa: 800 AFA; and Carson Slough: 700AFA.

7.5.4. Wells

Well locations are based on the points of diversion for all known water rights according to the corresponding water permits issued by Nevada State Engineer. The average historical (pre-1985) pumping rate was used for the steady state models. After 1984, the average annual pumping rates were used for transient simulations. Pumpage data (1985-1997) for Amargosa Desert was obtained from the Nevada State Engineer's Office. Pumpage data for Jackass Flats, Mercury Valley and Crater Flat were taken from USGS Open-File Reports (La Camera and Westenburg, 1994; Westenburg and La Camera, 1996; La Camera and others, 1996; La Camera and Locke, 1998).

Historical pumpage (pre-1985) in Basins 225 (Mercury Valley), 227A (Jackass Flats), 228 (Oasis Valley) and 230 (Amargosa Desert) was incorporated in the steady state models. Pumpage simulated in the steady state models for Basins 225 (Mercury Valley) and 227A (Jackass Flats) is the average historical pumpage between 1961-1984. The average pumpage for Basin 227A (Jackass Flat) used in the models is 145 AFA. This average pumpage is calculated from the number of years for which data is available (See Table 4.10, the estimated annual pumpage by Young, 1972, for 1964-1967 was not included in the calculation of the average.). Average historical pumpage between the years 1961-1984 in Basin 230 was simulated in the steady state models assuming 20 percent secondary recharge, which was achieved by simulating 80 percent of the average pumpage. The pumpage was assigned to wells according to the relative percentage of the 1985 pumpage distribution for Basin 230 (Amargosa Desert). The 1985 pumpage distribution is based on Nevada State Engineer's pumpage inventory which listed estimated pumpage under each water right and estimated pumpage without water rights. In the Ash Meadows Area, no pumpage was simulated in the steady state models because of the decline to near ceasing of historical pumping in the area.

The total pumpage simulated in the steady state models for Basin 228 (Oasis Valley) is 524.29 AFA. Since pumpage data in Basin 228 (Oasis Valley) was not readily available, historical municipal pumpage in Basin 228 (Oasis Valley) was assumed to be at the 1995 quantity of 393 AFA (Buqo, 1996). This pumpage was distributed evenly among the water right permits for municipal uses, whereas, historical pumpage for other uses in the basin was assumed to be the annual duty of certificated water rights. No secondary recharge for Basin 228 (Oasis Valley) was considered.

Annual withdrawals in Basins 225 (Mercury Valley), 227A (Jackass Flats), 229 (Crater Flat), and 230 (Amargosa Desert) for 1985-1997 were simulated in the transient models for model verification. As in the steady-state models, pumpage for Basin 230 (Amargosa Desert) was simulated with an assumption of 20 percent secondary recharge in all transient models.

Wells and simulated withdrawals in both the high flux model and the low flux model are the same. All of the simulated well locations and withdrawal rates are presented in Appendix A. Figure 12 shows the simulated well locations.

7.5.5. Springs

Springs were simulated as drains in each of the models. Spring parameters were determined by reference to measured and estimated spring discharge data. Spring discharge rates were simulated as close as possible to the targeted quantities.

The springs were assigned to the top model layer even though the ultimate source of the springs may be from the deeper aquifers. This assignment is simply due to the fact that springs have to appear at the land surface.

The spring discharge data for major springs in the Ash Meadows area used as targets in the models are from Dudley and Larson (1976). The spring flow data (about 29,700 AFA) in D'Agnese and others (1997) for the Ash Meadows area was not used as targets because the total amount of the spring discharge is significantly larger than historically reported (Walker and Eakin, 1963; Rush, 1970 and Dudley and Larson, 1976). An examination of the phreatophyte areas in the Ash Meadows area indicates that the total area with phreatophytic consumption is less than 2,500 acres. This suggests that the spring flow estimates by D'Agnese and others (1997) for the Ash Meadows area may be too high.

The spring discharge for Oasis Valley (Basin 228) is based on D'Agnese and others (1997, p 46: 3,100 m^3/d). The estimated quantity was rounded to 1,000 AFA and redistributed evenly among the ten springs simulated for Oasis Valley (see Table 7.7). The discharge estimates for springs in Death Valley is also from D'Agnese and others (1997, p. 47, Table 3). The total discharge estimate of 1,908 m^3/d for the Nevares Springs was redistributed evenly among eight springs simulated for the group (see Table 7.7).

Since most of the ET in the Ash Meadows area may be considered as originating from spring flow, the natural discharge for the aquifer system in the Ash Meadows area was simulated as spring flow only. In this sense, ET from spring flow is not a direct discharge from the aquifer but a consumption of spring flow. This distinction of direct discharge and indirect discharge was made for the purpose of avoiding double counting the natural discharge from the aquifer system in the models.

The simulated springs are listed in Table 7.7 and the drain conductance values for the springs are listed in Table 7.8. Simulated spring locations are also shown in Figure 12. The total simulated spring discharges for the Ash Meadow area, Oasis Valley and Furnace Creek Ranch are 17,413 AFA, 1,006 AFA, and 2,814 AFA in the high flux model and 17,367 AFA, 997 AFA and 2,822 AFA in the low flux model, respectively.

Table 7.7 Simulated Springs

Spring No	Row	Col.	Spring Name Simulated	Simulated		Targets	
				Low Flux	High Flux	ft^3/day	Remarks
1	139	84	Grapevine Springs	-	-	-	
2	135	88	Last Chance Spring	194.4	188.5	192.5	
3	135	89	Last Chance Spring East	-	-	0	
4	134	88	Bole Spring	2,460	2,286	2,310.3	
5	134	89	Bole Spring East	-	-	0	
6	132	88	Big Spring	195,940	198,776	200,229.1	
7	129	85	Point of Rocks West-1	240,053	239,794	240,660	
8	129	86	Point of Rocks West-2	133,298	134,616	133,807	Davis springs
9	129	87	Point of Rocks With East springs	81,115	80,596	80,861.8	
10	130	88	Jack Rabbit Springs	114,379	115,858	115,516.8	
11	126	83	Crystal Pool	572,650	577,242	577,584	
12	125	85	Devil's Hole West	8,149	8,160	8,086.2	School Springs
13	125	86	Devil's Hole East	-	-	0	
14	124	84	Northwest Devil's Hole	83,453	82,238	82,787.0	
15	124	83	West of NW Devil's Hole	-	-	0	
16	120	83	Longstreet Spring East	-	-	0	
17	120	82	Longstreet Spring West	202,028	206,492	207,930.2	
18	117	80	Fairbanks spring	312,097	302,767	304,194.2	
19	117	81	Soda Spring	15,766	15,558	15,209.7	
20	118	82	Rogers Spring	110,981	113,639	113,591.5	
21	121	25	Texas Spring	42,617	41,146	40,451.1	
22	123	26	Travertine Springs (all 11)	227,021	227,605	229,140.5	
23	114	27	Nevares Springs	7,983	8,750	8,425.8	1,908 m^3/d Distributed evenly Among 8 cells
24	114	26	Nevares Springs West-1	8,678	7,944	8,425.8	
25	114	25	Nevares Springs West-2	8,312	8,732	8,425.8	
26	114	24	Nevares Springs West-3	8,383	8,476	8,425.8	
27	114	23	Nevares Springs West-4	8,398	7,794	8,425.8	
28	115	24	Nevares Springs SW-1	8,515	8,494	8,425.8	
29	115	23	Nevares Springs SW-2	8,504	8,325	8,425.8	
30	115	22	Nevares Springs SW-3	8,310	8,540	8,425.8	
31	85	16	Monach Spring	-	-	0	
32	48	34	Crystal Springs (all 3)	11,863	11,972	11,934.3	1,000 AFA Distributed evenly Among 10 cells
33	47	39	Goss Springs (all 5)	11,948	11,977	11,934.3	
34	48	39	Goss Springs South	11,751	11,834	11,934.3	
35	50	38	Hot Springs	-	-	0	
36	51	38	Hot Springs South-1	12,229	12,112	11,934.3	
37	52	38	Hot Springs South-2	11,910	12,093	11,934.3	
38	54	30	Indian Springs	11,887	11,955	11,934.3	
39	54	29	Indian Springs West	11,883	11,979	11,934.3	
40	53	29	Indian Springs North West	-	-	0	
41	56	27	Indian Springs SW+2	11,681	11,908	11,934.3	
42	55	37	Unknown-1	11,990	12,098	11,934.3	
43	58	35	Unknown-2	11,882	12,089	11,934.3	

Table 7.8 Drain Conductance Values

Spring No	Row	Col.	Spring Name Simulated	Conductance	
				ft²/day	m²/day
1	139	84	Grapevine Springs	-	-
2	135	88	Last Chance Spring	6.42	0.60
3	135	89	Last Chance Spring East	-	-
4	134	88	Bole Spring	77.01	7.15
5	134	89	Bole Spring East	-	-
6	132	88	Big Spring	6,674.30	620.06
7	129	85	Point of Rocks West-1	8,022.00	745.27
8	129	86	Point of Rocks West-2	4,460.23	414.37
9	129	87	Point of Rocks With East springs	2,695.39	250.41
10	130	88	Jack Rabbit Springs	3,850.56	357.73
11	126	83	Crystal Pool	19,252.80	1,788.64
12	125	85	Devil's Hole West	269.54	25.04
13	125	86	Devil's Hole East	-	-
14	124	84	Northwest Devil's Hole	2,759.57	256.37
15	124	83	West of NW Devil's Hole	-	-
16	120	83	Longstreet Spring East	-	-
17	120	82	Longstreet Spring West	6,931.01	643.91
18	117	80	Fairbanks spring	10,139.81	942.02
19	117	81	Soda Spring	506.99	47.10
20	118	82	Rogers Spring	3,786.38	351.77
21	121	25	Texas Spring	1,348.37	125.27
22	123	26	Travertine Springs (all 11)	7,638.02	709.59
23	114	27	Nevares Springs	280.86	26.09
24	114	26	Nevares Springs West-1	280.86	26.09
25	114	25	Nevares Springs West-2	280.86	26.09
26	114	24	Nevares Springs West-3	280.86	26.09
27	114	23	Nevares Springs West-4	280.86	26.09
28	115	24	Nevares Springs SW-1	280.86	26.09
29	115	23	Nevares Springs SW-2	280.86	26.09
30	115	22	Nevares Springs SW-3	280.86	26.09
31	85	16	Monach Spring	-	-
32	48	34	Crystal Springs (all 3)	397.81	36.96
33	47	39	Goss Springs (all 5)	397.81	36.96
34	48	39	Goss Springs South	397.81	36.96
35	50	38	Hot Springs	-	-
36	51	38	Hot Springs South-1	397.81	36.96
37	52	38	Hot Springs South-2	397.81	36.96
38	54	30	Indian Springs	397.81	36.96
39	54	29	Indian Springs West	397.81	36.96
40	53	29	Indian Springs North West	-	-
41	56	27	Indian Springs SW+2	397.81	36.96
42	55	37	Unknown-1	397.81	36.96
43	58	35	Unknown-2	397.81	36.96

7.5.6. Hydraulic Conductivity

The hydraulic conductivity values in the region show a wide range of variability. Within the study area, the generally expected ranges of reasonable hydraulic conductivity (K) values (D'Agnese and others, 1997) are:

- high range, 0.1~100 meters/day
- medium range, 0.0001~0.1 meters/day
- low range, $2\times10^{-7}\sim1\times10^{-4}$ meters/day

Using this range of values, a set of twenty zones with values spanning over the entire expected range was established. Vertical hydraulic conductivity values were assigned values of one tenth of the corresponding horizontal hydraulic conductivity values. The twenty zones of hydraulic conductivity were chosen to cover the expected ranges of hydraulic conductivity values with small enough incremental changes between the adjacent zone levels. For the rationale for the vertical conductivity assignment, see Section 7.2.3. The hydraulic conductivity zone values are listed in Table 7.9.

Originally, hydraulic conductivity was assigned to the grid in large zones based on the general conceptualization of the flow system, which in turn was based on understanding of the geology and hydrogeology in the area. Areas with high hydraulic gradient and low flux have low transmissivity and vice versa. During the calibration process, the zones were refined to improve calibration.

The calibration was performed by varying the hydraulic conductivity zone areas instead of zone values with the fixed distribution of zone areas. The rationale for using this method is that fixed zoning restricts the calibration refinement and imposes an average value for each zone. This method obviously oversimplifies its representation for zones covering a large area with a wide range of hydraulic conductivity values. Conversely, variation of hydraulic conductivity zones tends to be too specific with the current knowledge of the hydraulic conductivity distribution. This "over-representation" requires that the distribution of the hydraulic conductivity in the calibrated models be interpreted within the modeling context including the flux configuration and the set-up of all the hydraulic conductivity zones.

The final distribution of the hydraulic conductivity zones was obtained by matching the simulated water level distribution with the estimated water level distribution and with the measured heads at selected monitoring locations. The selection of the monitoring sites was dictated by the available data as shown in Figure 21 (a). Water levels in the central and the bottom layers may be different and water level data for these deep layers is sparse. Well UE 25 p#1 is the only available data point for the bottom layer in the Yucca Mountain area. Because of this, matching the groundwater level in the top layer with measured heads was the focus of the calibration efforts, whereas the calibration of the central and bottom layers is more general (less zones).

The hydraulic conductivity distribution in the C-Wells area was calibrated as close as possible to the estimates from pumping tests by Geldon and others (1998). Geldon and others (1998) reported that analyses of drawdown and recovery indicate that the Miocene tuffaceous rocks in the vicinity of the C-Wells have transmissivity values of 17,200-34,400 ft^2/day (1,600-3,200 m^2/day) and horizontal hydraulic conductivity values of 21-42 ft/day (6.5-13 m/day). The actual hydraulic conductivity distributions for the two calibrated steady-state models are shown in Figures 13 (a), (b), (c) and 14 (a), (b) (c). Section 8.2.1 presents an evaluation of the hydraulic conductivity distributions.

Table 7.9 Hydraulic Conductivity Values in the Models

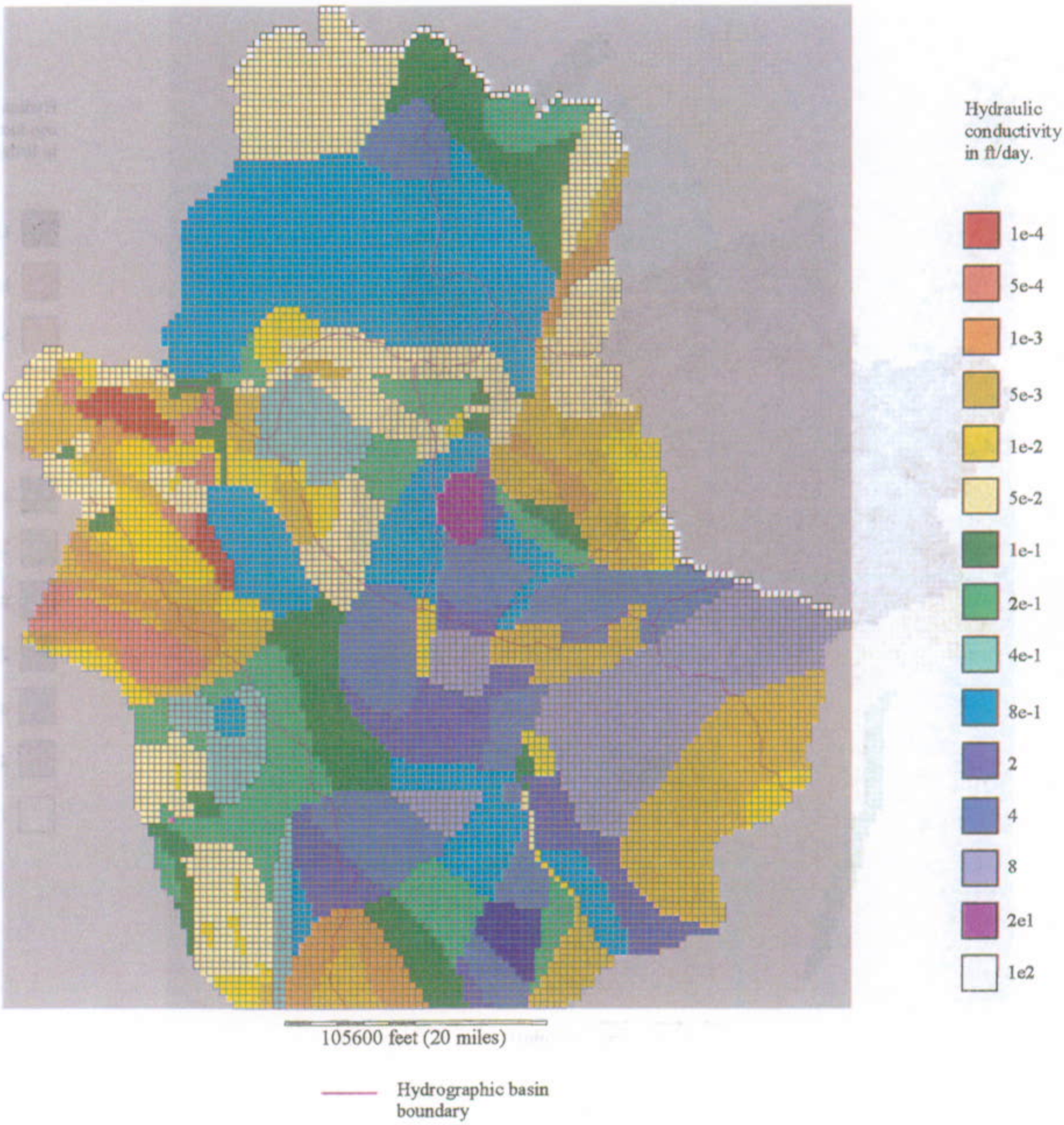
Hydraulic Conductivity (K) Zone	Kx and Ky (ft/day)	Kz (ft/day)
1	1×10^{-5}	1×10^{-6}
2	5×10^{-5}	5×10^{-6}
3	1×10^{-4}	1×10^{-5}
4	5×10^{-4}	5×10^{-5}
5	1×10^{-3}	1×10^{-4}
6	5×10^{-3}	5×10^{-4}
7	1×10^{-2}	1×10^{-3}
8	5×10^{-2}	5×10^{-3}
9	0.1	1×10^{-2}
10	0.2	2×10^{-2}
11	0.4	4×10^{-2}
12	0.8	8×10^{-2}
13	1.7	0.17
14	2	0.2
15	4	0.4
16	8	0.8
17	$1 \times 10^{+1}$	1
18	$2 \times 10^{+1}$	2
19	$4 \times 10^{+1}$	4
20	$1 \times 10^{+2}$	$1 \times 10^{+1}$

Kx, Ky, and Kz are the principal components of the hydraulic conductivity tensor in the principal horizontal directions (K_x, K_y) and in the vertical direction (K_z).

7.5.7. Storage Parameters

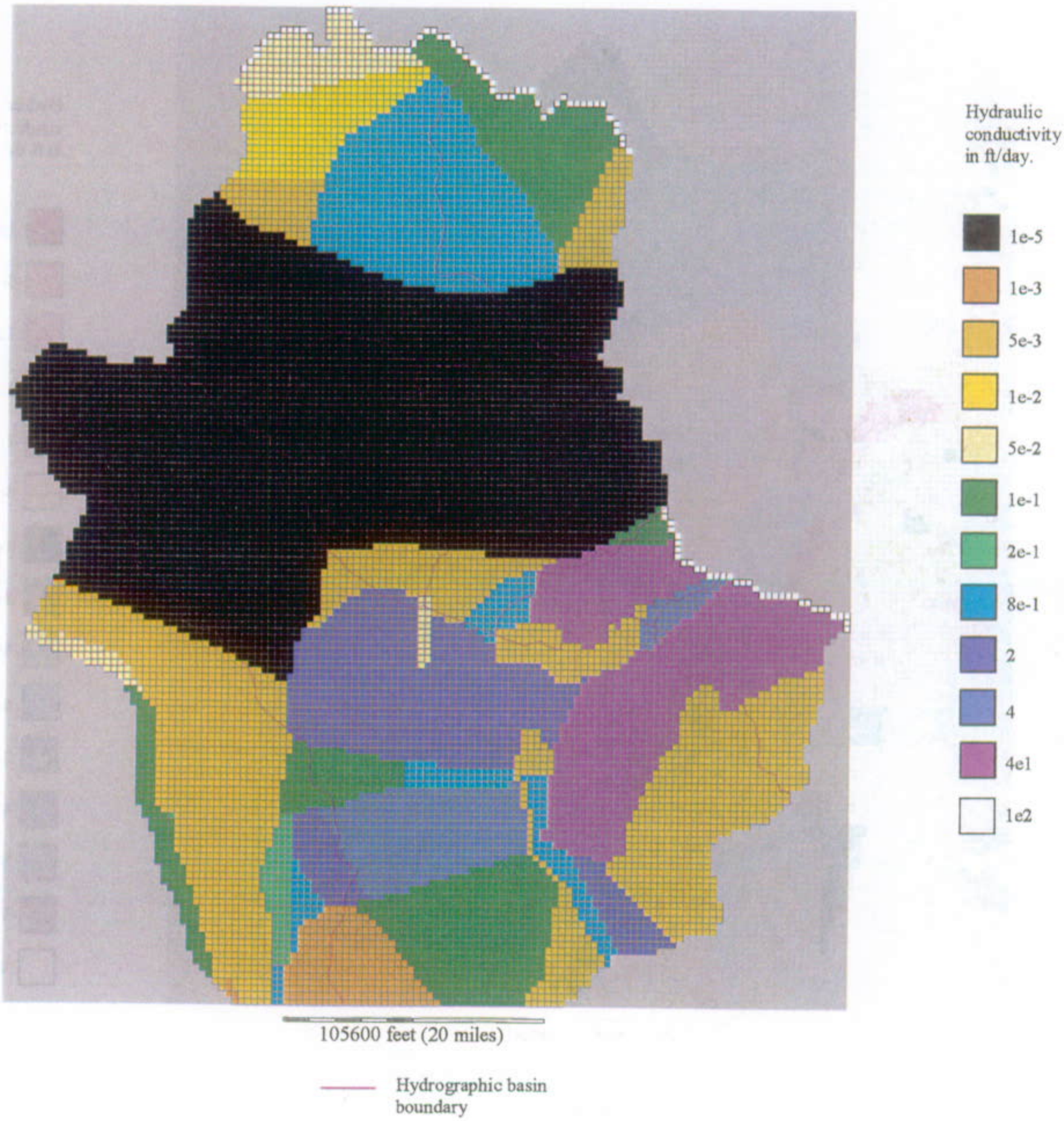
As previously discussed, storage data for the study area is scarce. The most recent storativity values from tests in volcanic rocks at the C-Wells ranged from 0.001 to 0.003, and specific yield ranged from 0.01 to 0.2 (Geldon and others, 1998).

Because the purpose of this modeling study was to estimate potential impact due to the proposed groundwater withdrawal, a more refined determination of storage properties was beyond the scope of this study. Therefore, conservative values of storage parameters were selected.



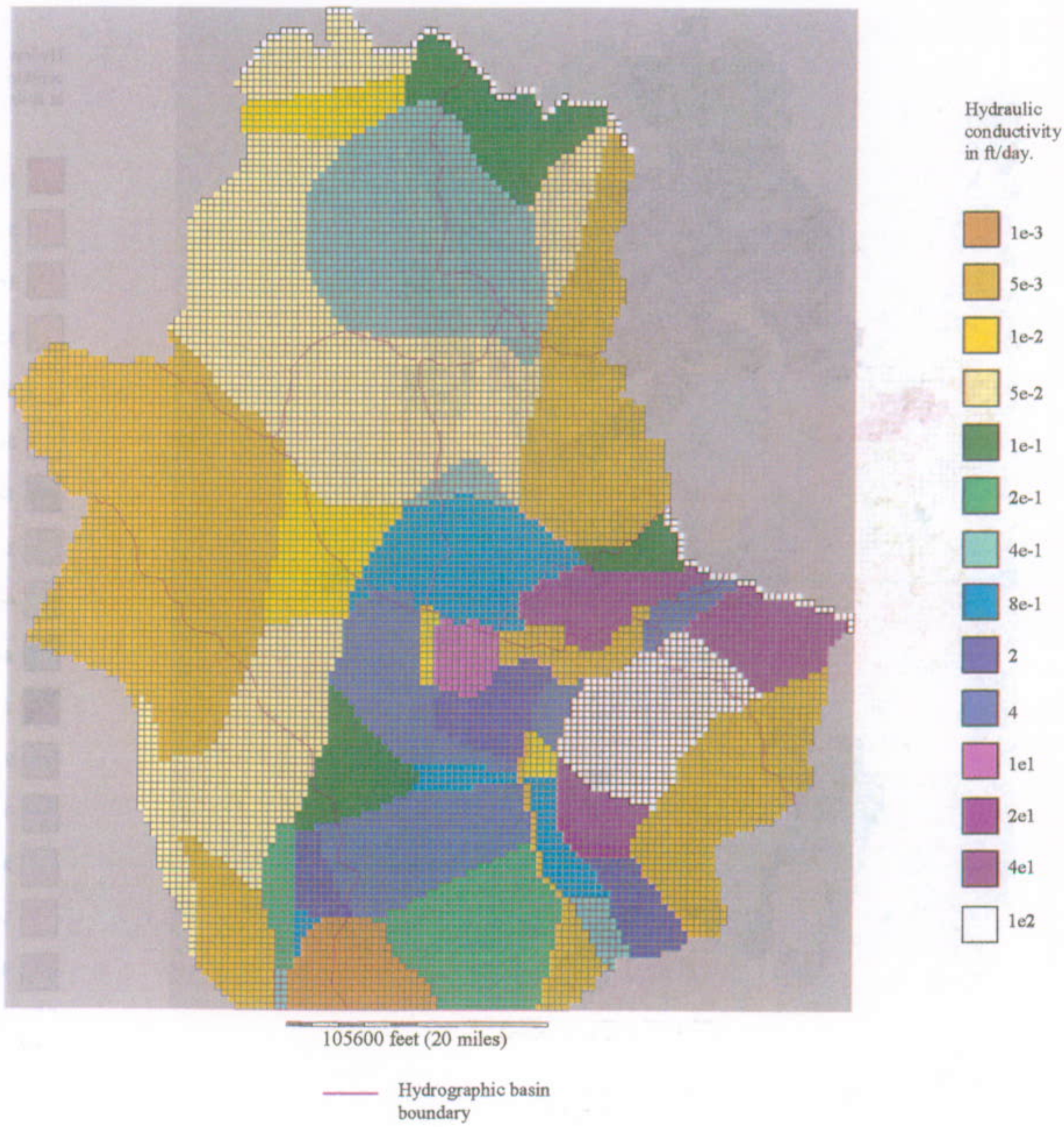
Note: Listed values of hydraulic conductivity are for horizontal components.
Values of vertical components are assumed to be one tenth of those for the corresponding horizontal components .

Figure 13 (a). Hydraulic conductivity zones in the low flux models (Top model layer)



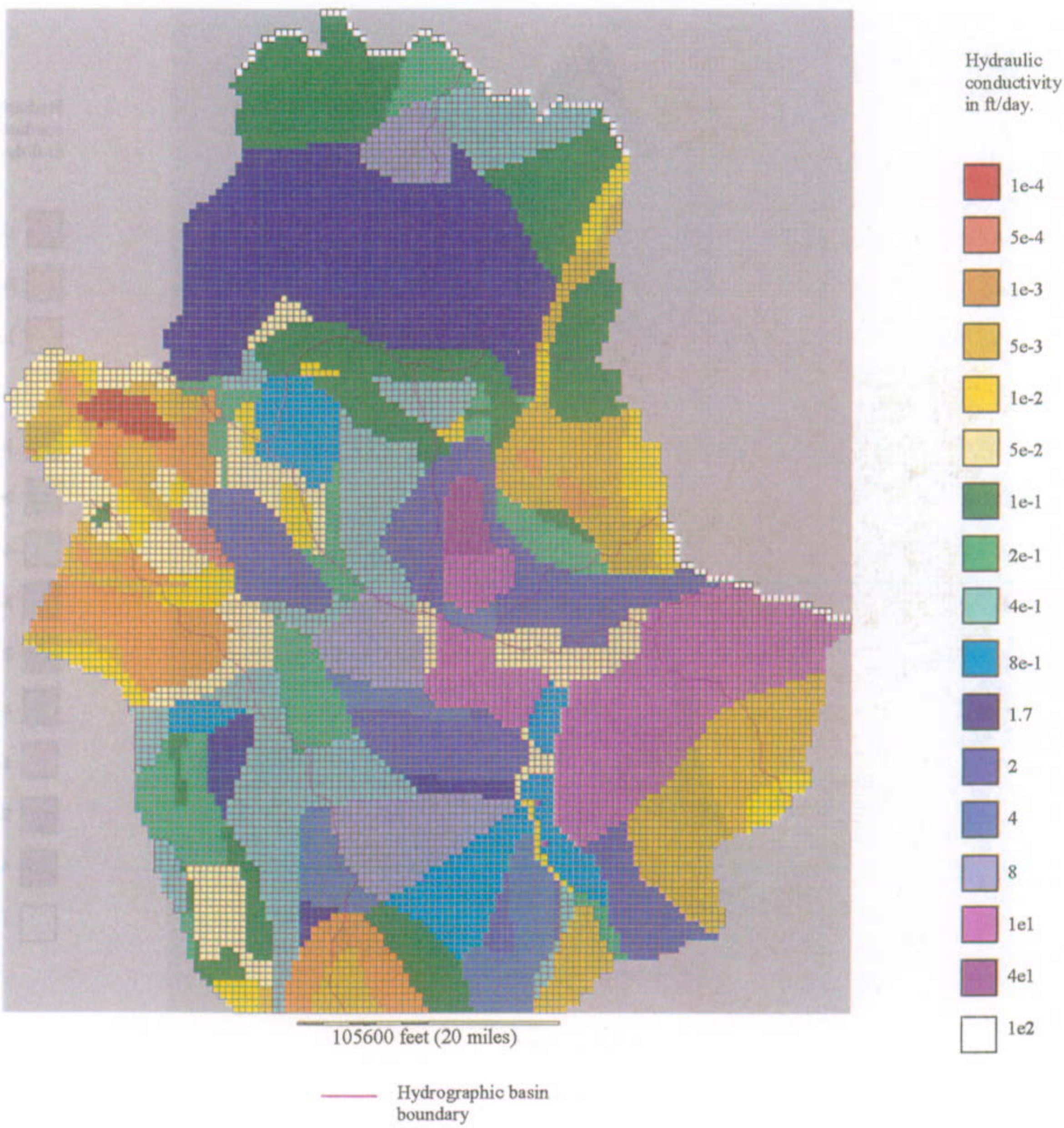
Note: Listed values of hydraulic conductivity are for horizontal components.
Values of vertical components are assumed to be one tenth of those for the corresponding horizontal components .

Figure 13 (b). Hydraulic conductivity zones in the low flux models (Central model layer)



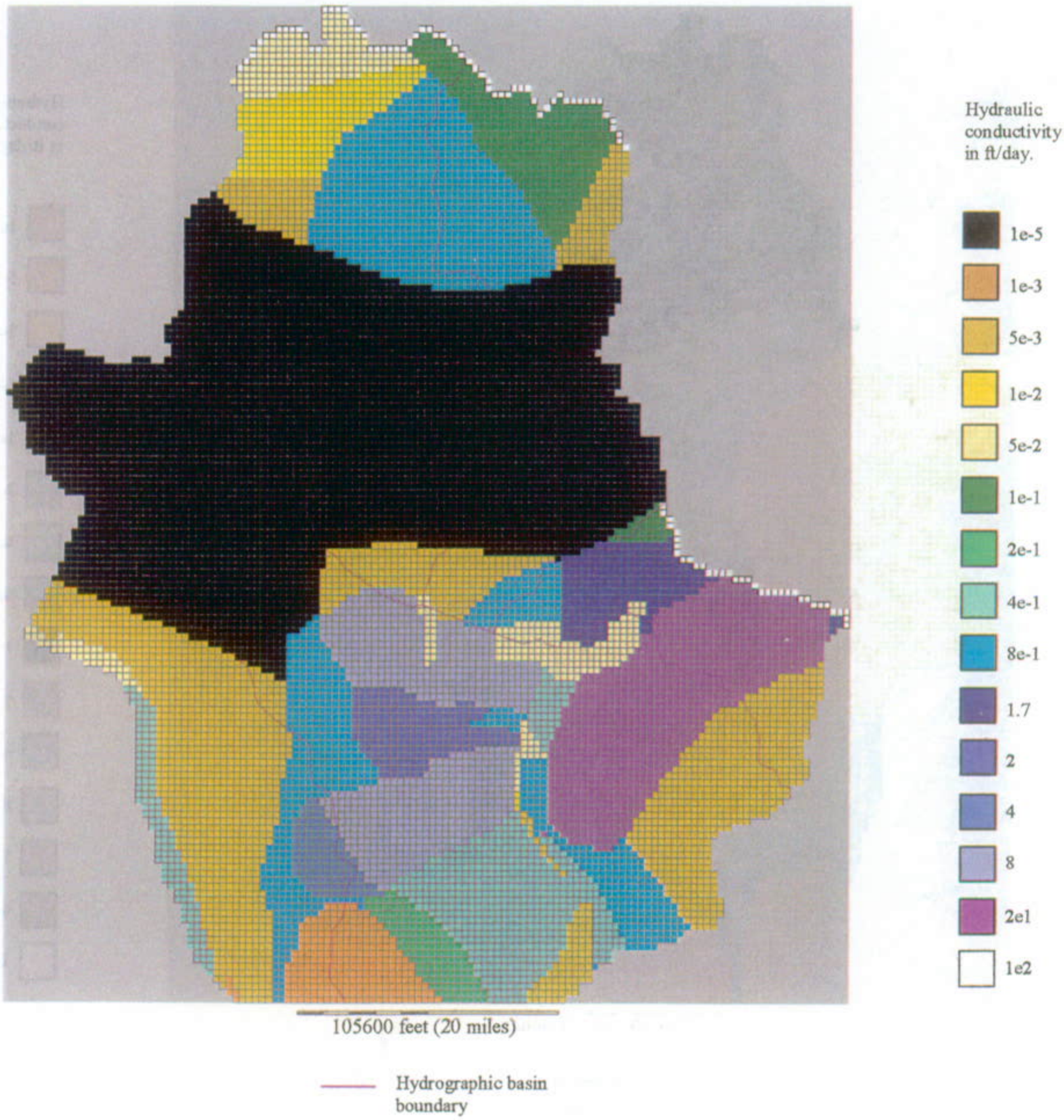
Note: Listed values of hydraulic conductivity are for horizontal components.
Values of vertical components are assumed to be one tenth of those for the corresponding horizontal components .

Figure 13 (c). Hydraulic conductivity zones in the low flux models (Bottom model layer)



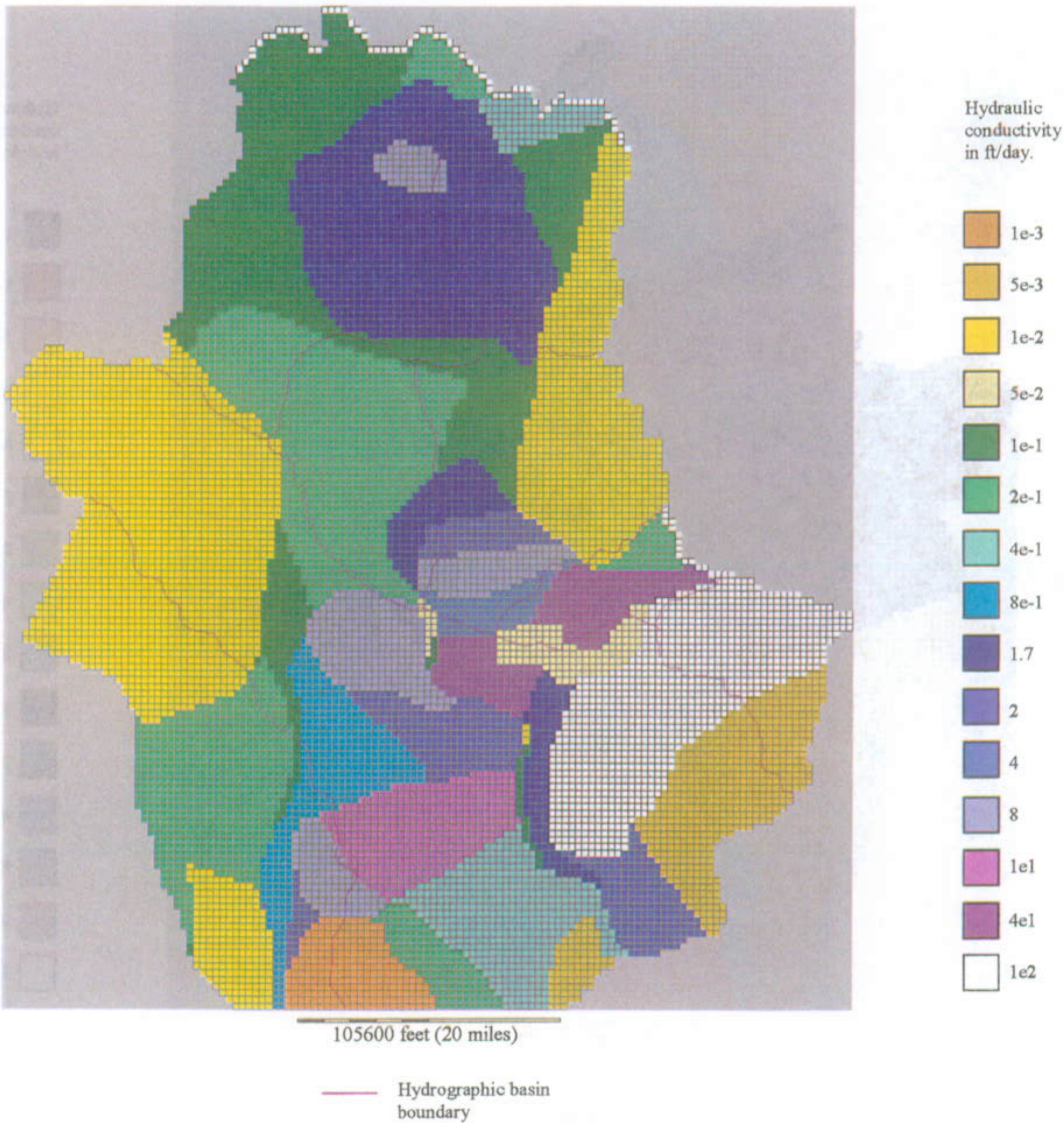
Note: Listed values of hydraulic conductivity are for horizontal components.
Values of vertical components are assumed to be one tenth of those for the corresponding horizontal components .

Figure 14 (a). Hydraulic conductivity zones in the high flux models (Top model layer)



Note: Listed values of hydraulic conductivity are for horizontal components.
Values of vertical components are assumed to be one tenth of those for the corresponding horizontal components .

Figure 14 (b). Hydraulic conductivity zones in the high flux models (Central model layer)



Note: Listed values of hydraulic conductivity are for horizontal components.
Values of vertical components are assumed to be one tenth of those for the corresponding horizontal components .

Figure 14 (c). Hydraulic conductivity zones in the high flux models (Bottom model layer)

Storativity is related to aquifer thickness, where, for the same specific storage, the thicker the aquifer, the larger the storativity. Specific yield values are related to the capacity of an aquifer in the interval with water table variations over time rather than the aquifer thickness. For simplicity, the conservative distribution of specific yield for the water table aquifers is based on the distribution of hydrogeologic units at the depth where changes of water level may occur.

Due to the relatively small range of variation of storage values and the lack of available data, two zones were assumed for the top model layer and one uniform storage zone was assumed for the two deeper model layers. The two zones for the top model layer are: one zone primarily for the valley-fill aquifers and the other primarily for the volcanic aquifers. Two different sets of values of specific yield were assigned with historical verification simulations.

The two sets of specific yield values chosen for the top layer of the model grid are: (1) 0.10 for primarily valley-fill aquifers and 0.01 for other aquifers (low storage set); and (2) 0.15 for primarily valley-fill aquifers and 0.05 for other aquifers (high storage set). The distribution of specific yield zones for the top layer is shown in Figure 15. In Figure 15, the specific yield zone for non-valley-fill aquifers was assigned for Jackass Flats (Basin 227A) and Crater Flat (Basin 229) because major aquifers in Basin 227A (Jackass Flats) and Basin 229 (Crater Flat) are not valley fill aquifers. In addition, most valley fill material in these two basins is above water table.

The storativity value of 0.001 was assigned to both the central layer and the bottom layer of the model grid in each of the models.

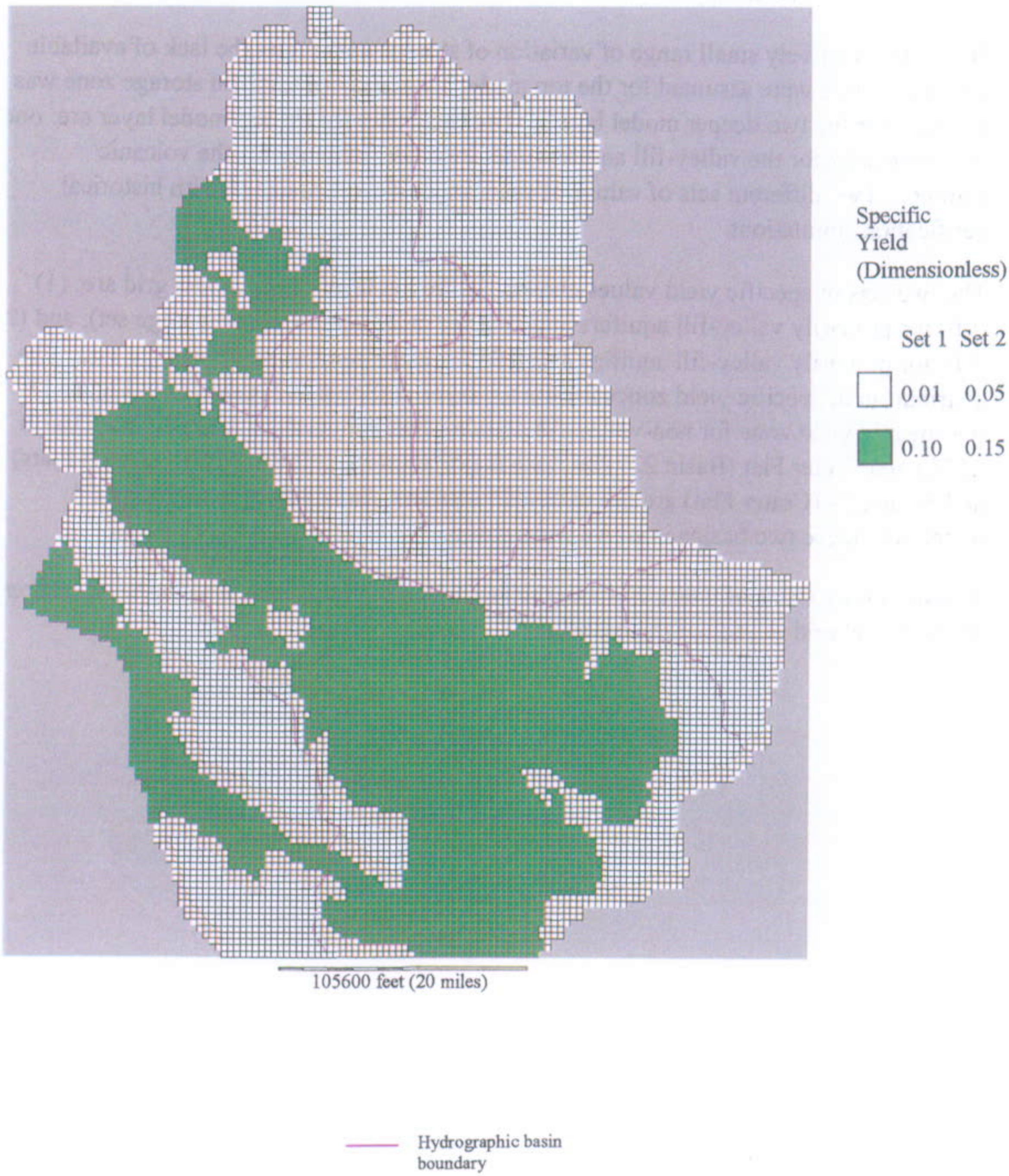


Figure 15. Specific yield zones in the models (Top model layer)

8. CALIBRATION OF NUMERICAL MODELS

8.1. Calibration Approach

Calibration was performed by matching: (1) simulated major flux components with existing estimates, (2) simulated hydraulic heads with measured heads at selected locations, and (3) simulated potentiometric surface with an estimated potentiometric surface. These are commonly used targets for calibration (Leake, 1999, p. 50). The matching was achieved by varying hydraulic conductivity zones with small incremental changes in values of adjacent zone levels rather than varying the values of hydraulic conductivity zones with fixed distribution. Hydraulic conductivity values for each zone remained fixed and were assigned based on the expected ranges of hydraulic conductivity values (see Section7.5.5). Varying zone distribution provided the mechanism for refining the matching of heads and fluxes.

Zonation itself is a way to simplify modeling for modeler's convenience rather than being a goal or standard. Zonation of hydraulic conductivity does not necessarily follow hydrogeologic units. However, for a relatively uniform hydrogeologic units, or any known areas with uniform hydraulic conductivity values, a fixed zonation should be followed. The most extreme case of zonation is to designate every model cell as a unique zone. Similarly, the most extreme case of calibration is to vary or adjust the value of hydraulic conductivity for each and every model cell.

The calibration approach adopted in this study adjusts the hydraulic conductivity values in steps for each cell group rather than continuously. The primary reason for this approach is that hydraulic conductivity values for a cell or cell group will represent an average of the aquifer(s) in that cell or group and estimates of average hydraulic conductivity values can often vary orders of magnitude for the same aquifer material. As long as the steps are small enough the calibrated distribution of the hydraulic conductivity zones is capable of representing actual aquifer conditions in an average sense. Varying zones of hydraulic conductivity values in small steps is in fact the same as varying both values of hydraulic zones and zonation. The approach adopted in this study can easily incorporate any known zones of hydraulic conductivity values by directly assigning the known values to the cells comprising the zones and any known fixed zonations by varying zone steps for the fixed zonation. Due to the limited information of hydraulic conductivity distribution in the modeled area, no fixed zonations are known and hydraulic conductivity values are also basically unknown. Therefore, during calibration of the models in this study, both rezonation and zone step change were allowed to achieve refinement of calibration.

Due to no known fixed zonation, the calibrated distribution of hydraulic conductivity zones for the high flux model and the low flux model are different with different zone steps. The very nature of these differences indicate the uncertainty in the zonation of hydraulic conductivity.

It is noted that the distribution of hydraulic properties should be controlled by geology and structures. However, the knowledge of geology and structures in the modeled area is not yet enough that the distribution of hydraulic properties can be defined with certainty.

Distribution of head measurements in the area is not uniform, rather, most head measurements are concentrated in localized areas. This available water level data dictates the calibration approach used in this study. It is recognized that an estimated construction of the potentiometric surface contains interpretations for interpolating and extrapolating water levels over large distances. As such, different interpretations may result in different constructions of the potentiometric surface.

Many potentiometric surface maps have been constructed for portions or all of the study area (Winograd and Thordarson, 1975; Claassen, 1985; Kilroy, 1991; D'Agnese and others, 1997). The estimated potentiometric surface used for the model calibrations was taken from D'Agnese and others (1997). The choice of using the construction of the D'Agnese and others (1997) is fourfold: (1) it is considered to be more representative of the groundwater flow on a regional scale; (2) it was constructed by using present-day (mid-1980's) water level data; (3) it was constructed on the basis of the most updated understanding of the regional hydrogeology; and (4) only previously published and quality-assured data with field checks was used to prepare the potentiometric surface (D'Agnese and others, 1998, p. 5).

With the continued advancement of the understanding of the regional geology and hydrogeology, and accumulation of more quality data, future constructions will certainly supercede the construction of the potentiometric surface constructed by D'Agnese and others (1997).

8.2. Calibration Results

8.2.1. Distribution of Hydraulic Conductivity in the Calibrated Models

The distribution of hydraulic conductivity in both the calibrated models of steady state is shown in Figures 13 (a), 13 (b), 13 (c), 14 (a), 14 (b), and 14 (c). The most permeable zones are areas with the highest flux and lowest gradients, and the least permeable zones are areas with the lowest flux and highest gradients.

Figures 13 (a, b, & c) and 14 (a, b, & c) show that in the calibrated models, the most permeable zone is in the bottom layer in the area upgradient to the Ash Meadow Springs, which is within the Spotted Range-Mine Mountain structural zone where the regional carbonate aquifer occurs. The least permeable zone is in the area around Yucca Mountain in the central layer.

Hydraulic conductivity values of the top model layer show that the valley fill aquifers generally have higher values than the other aquifers. For the bottom model layer, regional carbonate aquifer has the highest hydraulic conductivity values. For areas with consolidated clastic formations such as northwestern Funeral Mountain and southeast of Ash Meadows, the hydraulic conductivity values are in the lowest range. A narrow line of zones with low hydraulic conductivity values just downgradient of the Ash Meadows Springs, may explain why the springs occur.

The value of horizontal hydraulic conductivity for the area around the C-Wells in the low flux model is 20 ft/day (6.1 m/day). This is very close to the low limit of the range of 21 to 43 ft/day (6.5 to 13 m/day) as estimated by Geldon and others (1998) from the C-Wells pumping tests. In the high flux model, the value of horizontal hydraulic conductivity for the area around the C-Wells is 40 ft/day (12.2 m/day), which is slightly less than the high limit (43 ft/day) as estimated by Geldon and others (1998).

Based on this data, it can be said that the distribution of hydraulic conductivity in the calibrated models is consistent with the current understanding of the hydrogeology of the modeled area.

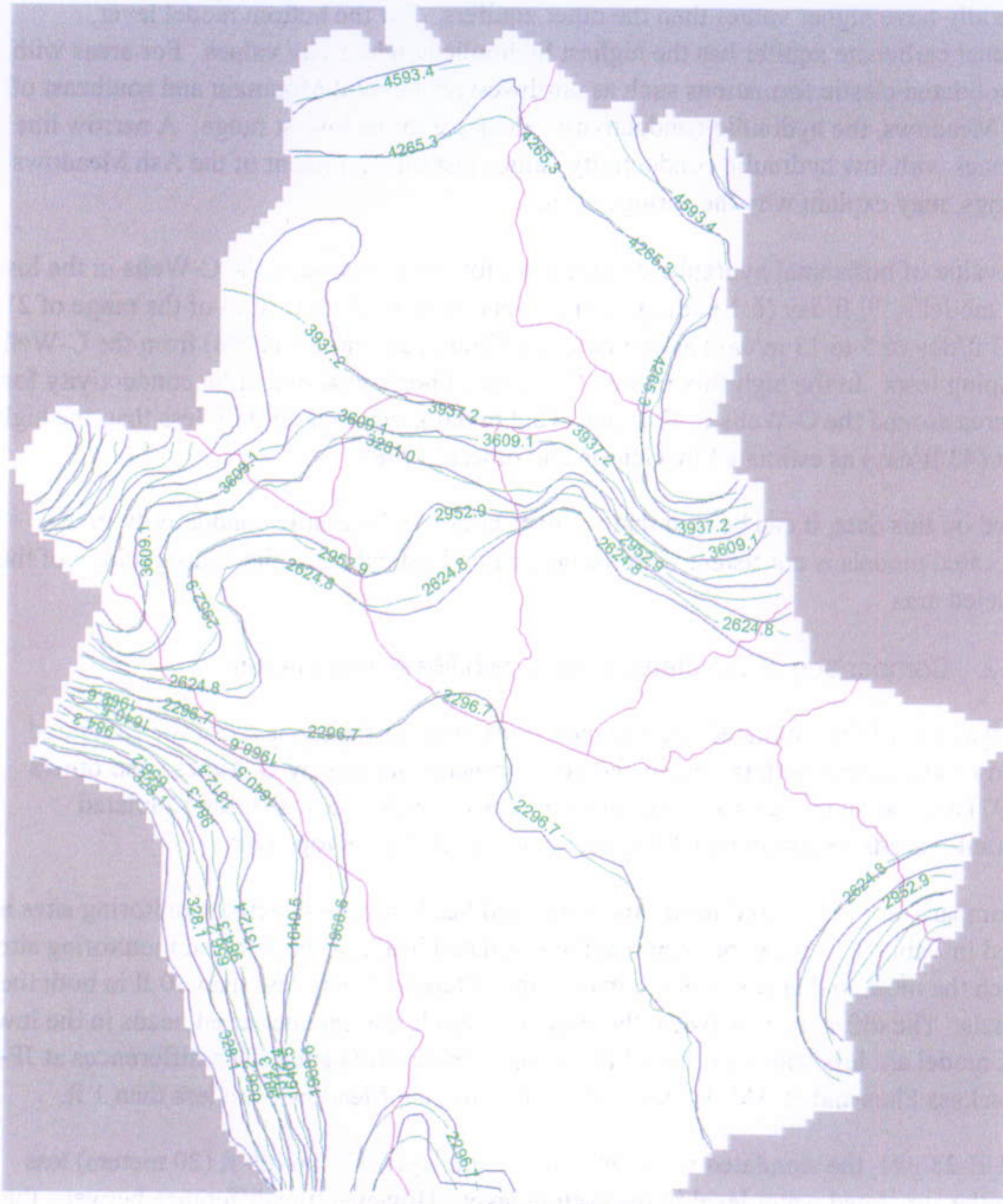
8.2.2. Comparison of Simulated Heads with Measured Heads

Comparison of the simulated potentiometric surfaces for the top layer of the calibrated steady state models with the estimated potentiometric surface by D'Agnese and others (1997) are shown in Figures 16 (a) and (b). These figures show that the simulated hydraulic heads generally match the estimated heads for the top layer.

A comparison of measured heads and simulated heads for the selected monitoring sites is listed in Table 8.1. It can be seen that the simulated heads at the selected monitoring sites match the measured heads with the maximum difference being less than 30 ft in both the models. The differences between the simulated heads and the measured heads in the low flux model are less than 12 ft for all the selected monitoring sites. The differences at JF-3 in Jackass Flats and at AM-4 (Devil's Hole) in the Ash Meadows, are less than 1 ft.

At UE-25 p#1, the simulated water level in the top layer is about 66 ft (20 meters) less than the simulated water level in the bottom layer. However, the difference between the simulated and measured water levels in the bottom layer is less than 2 ft. This head variation in the vertical direction basically reproduces the field observations at UE-25 p#1.

The monitoring site AD-7 had the largest difference among all the selected sites. The reason for this may be a localized effect of permeability and/or an inaccurate representation of wells close to the site.



105600 feet (20 miles)

—2296.7— Simulated contour of water level. Contour interval 328.1 ft (100 m.). Datum is sea level

Estimated contour of water level (From D'Agnese and others, 1997)

Hydrographic basin boundary

Figure 16 (a). Comparison of simulated groundwater level with estimated groundwater level (Top layer in the low flux steady state model)

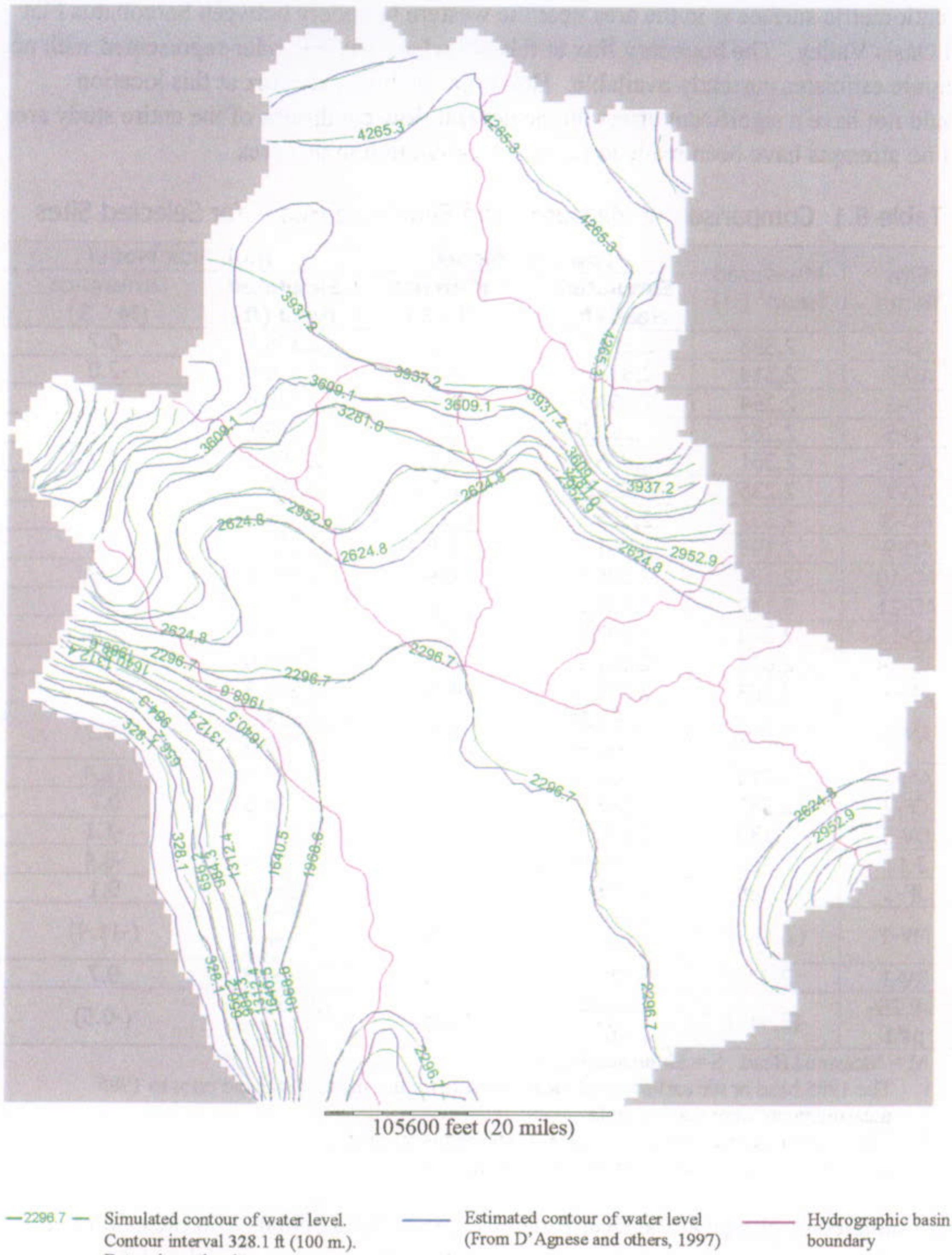


Figure 16 (b). Comparison of simulated groundwater level with estimated groundwater level (Top layer in the high flux steady state model)

The largest difference between the estimated potentiometric surface and the simulated potentiometric surface is in the area near the western boundary between Sarcobatus Flat and Oasis Valley. The boundary flux at this boundary may be under-represented with no accurate estimates currently available. However, the boundary flux at this location should not have a significant effect on the general flow conditions of the entire study area and no attempts have been made to refine the calibration in this area.

Table 8.1 Comparison of Measured and Simulated Heads for Selected Sites

Site Name	Measured Head[1] (ft)	Low Flux Model		High Flux Model	
		Simulated Head (ft)	Difference (M – S)	Simulated Head (ft)	Difference (M – S)
AD-1	2,358	2,356.7	1.3	2,358.7	-0.7
AD-2	2,314	2,313.7	0.3	2,316.0	-2.0
AD-3	2,264	2,254.6	9.4	2,259.4	4.6
AD-5	2,262	2,264.0	-2	2,265.1	-3.1
AD-6	2,361	2,365.6	-4.6	2,366.2	-5.2
AD-7	2,236	2,224.27	11.73	2,206.3	29.7
AD-8	2,357	2,368.5	-11.5	2,368.3	-11.3
AD-9	2,198	2,201.6	-3.6	2,202.1	-4.1
AD-10	2,184	2,184.9	-0.9	2,185.9	-1.9
AD-11	2,139	2,131.1	7.9	2,136.0	3.0
AD-12	2,343	2,347.1	-4.1	2,341.4	1.6
AD-14	2,037	2,041.1	-4.1	2,048.6	-11.6
AM-1	2,263	2,272.6	-9.6	2,260.3	2.3
AM-4	(2,358)[2]	(2,358.2)[2] 2,341.4	(-0.2)[2]	(2,358.9)[2] 2,340.5	(-0.9)
AM-7	2,318	2,321.3	-3.3	2,299.6	18.4
CF-2	2,557	2,558.7	-1.7	2,556.3	0.7
DV-3	2,130	2,130.1	-0.1	2,131.1	-1.1
J-11	2,402	2,403.6	-1.6	2,402.4	-0.4
JF-3	2,388	2,388.9	-0.9	2,387.9	0.1
MV-1	(2,368)[2]	(2,375.0)[2] 2,375.0	(-7)	(2,379.4)[2] 2,379.2	(-11.4)
RV-1	2,379	2,380.8	-1.8	2,369.3	9.7
UE 25-p#1	(2,467)	(2,468.6) 2,403.7	(-1.6)	(2,467.5)[2] 2,401.2	(-0.5)

M = Measured Head. S = Simulated Head.

1. The 1985 head or the earliest head measurements for the sites if 1985 and prior to 1985 measurements were not available.
2. The heads in parentheses are for layer 3. The rest is for layer 1.
3. See Figure 21 (a) for locations of the monitoring sites,

The simulated discharge at the Death Valley constant head boundary in the calibrated steady-state models is approximately 9,765 AFA for the low flux model and approximately 30,168 AFA for the high flux model. This simulated discharge at the constant head boundary in the high flux model is close to the estimate (29,600 AFA) of the discharge at the Death Valley main saltpan reported by D'Agnese and others (1997).

The models show that the simulated fluxes fall within the 2 percent of their corresponding targets, if simulated total spring flows of the spring groups are considered. See Section 7.5 for comparisons between the simulated evapotranspiration, spring flow, recharge from precipitation, and head dependent boundary fluxes and the targeted estimates of those flux components.

8.3. Discussion

All available information should be considered in the calibration process despite the inherent uncertainty connected with any data. Determining flux distribution without sufficient knowledge of the hydraulic conductivity distribution is beyond the typical calibration of a flow model. Therefore, there were no attempts to determine flux components in the models of this study. Rather, they were simulated as close as possible to existing estimates chosen as the calibration targets.

Model calibration was achieved by the traditional "trial and error" method rather than a nonlinear regression method for parameter estimation. Although it gives the impression of a substantial method, calibration of a flow model using a nonlinear regression method for one parameter at a time is not a guarantee for optimal results, because the objective functions are not independent of other parameters. The values of all the other parameters provide a context for the regression and the context is primarily based on the judgement of a modeler,. Because of this, there is no theoretical basis for the uniqueness of a single value of the estimated parameter to minimize the objective functions.

No specific sensitivity analysis was performed for this study. The sensitivity of a parameter depends on the formation of the objective function, which consists of the simulated quantities at the selected locations. Parameters sensitive to one objective function may not necessarily be sensitive to a different objective function. Sensitivities calculated for the same parameter under different contexts (different values for other parameters and for itself provide different sensitivity analysis contexts) will be different for a nonlinear flow system. For a steady-state groundwater flow model, parameters affecting flux to and from the selected locations are the most sensitive. Conversely, parameters affecting flux to and from locations which are far away from the selected locations are the least sensitive.

General analyses of sensitivity are of limited value, because all parameters are sensitive to the simulated quantities in the specific area where they control the flux. The relative flux to and from a specific area controlled by a parameter will determine the relative sensitivity of that parameter to the simulated quantities in the said area. In other words, all parameters are sensitive to the simulated quantities they affect.

One primary use of sensitivity analyses is for a modeler to calibrate a model. The results of sensitivity analyses have no effects on simulations of a calibrated model. In addition, sensitivity analyses do not increase or reduce the uncertainties in a calibrated model. Results of sensitivity analyses are often obvious with reference to Darcy's Law.

In addition, performing a sensitivity analysis by slightly varying a parameter value without the corresponding variation of all other parameters changes the calibration at different levels. This is because the matching of targets would be different.

As the above discussion illustrates, it is obvious that any uncertainty in the estimated quantities used as model calibration criteria must be reduced through other means (non-modeling approaches such as direct measurements). However, the effect to the model as a whole from the uncertainty of one parameter may be compensated by the effects from the uncertainties of the other parameters in a calibrated model.

9. RESULTS OF NUMERICAL SIMULATIONS

9.1. Justification and Verification Simulations

Calibrated steady-state models are limited by their very nature for use as a predictive tool. As such, a calibrated steady-state model does not necessarily provide a good representation of the actual groundwater flow conditions it intends to represent because of the many uncertainties in the calibration process. Because of the differences between steady-state scenarios, there are unknown risks to use one calibrated steady-state model to predict the uncalibrated steady-state groundwater flow conditions in another scenario. In addition, a steady-state groundwater flow model does not consider aquifer storage properties whereas observed aquifer responses always have effects due to aquifer storage.

To verify the representation of aquifer properties by the calibrated steady-state models, it is necessary to extend the models to transient conditions using historical observations. Since storage parameters come into play in transient models, transient verifications of the hydrogeologic conditions and hydraulic properties as represented by calibrated steady state models can only be general. Because of this, the verification simulations of the two calibrated steady state models in this study used two different sets of storage parameters for each transient extension. By doing this, the results of verification simulations should be indicative of the predictive capability of the extended transient models (Models L1, L2, H1 and H2).

Model verification was performed by extending the calibrated steady-state models to transient models. This extension was achieved by: (1) maintaining the hydraulic conductivity distribution of the steady-state model; (2) maintaining the boundary conditions; (3) using the steady-state simulated heads as initial conditions; (4) extending the pumping stresses and variable boundary conditions from steady-state to transient, and (5) using transient monitoring data (pumping rates and heads) and a conceptualization of the aquifer storage characteristics.

The historical (1985-1997) monitoring data of pumping rates and groundwater levels for Amargosa Desert (Basin 230), Jackass Flats (Basin 227A), Mercury Valley (Basin 225) and Crater Flat (Basin 229) were used as verification data. The historical pumping rates were simulated as the annual average rates and the annual averages of the head measurements for the selected sites were used as the representative heads. Changes within a given year are beyond the data resolution because of a lack of some monthly pumpage estimates. Figures 17, 18, 19, and 20 included in Appendix C show the transient simulation results compared to the measured heads for the 22 selected monitoring sites. The results as shown in these figures indicate that the model simulates the general trend of water level change at these sites.

The simulated hydrographs by each of the models have similar trends of change and similar amounts of change to those of the measured hydrographs For Sites AD-1, AD-2, AD-6, AD-7, AD-8, AD-11, AD-14, AM-1, AM-4, CF-2, JF-3, J-11, RV-1, and MV-1.

See Figures 17, 18, 19 and 20, the hydrographs simulated by Model L1 have the smallest difference for Sites AD-5 and AD-7. For sites AD-1, AD-2, AD-6, J-11, JF-3 and AM-4, simulated hydrographs of each of the four transient models are similar because of the large distances from these sites to the pumping wells and the corresponding small water level changes.

All of the models simulate the impact of pumping in the Amargosa Desert to the surrounding areas at a relatively large distance very well. These models may, therefore, be used to estimate impacts at a distance similar to that between the pumping centers and the referenced monitoring well sites.

Simulated hydrographs for sites AD-3, AD-5, AD-10, and DV-3 also show trends of change similar to those of the measured hydrographs, although the total amount of simulated change is less.

The simulated hydrograph for site AD-9 indicates a lesser amount of change than the measured hydrograph with the largest difference. The possible reasons for this are: (1) the values of hydraulic parameters (hydraulic conductivity, specific yield) used in the models for the adjacent area around AD-9 may be higher than those in reality, and (2) measurements at AD-9 (and AD-10) may have been influenced by groundwater withdrawals in close proximity at the time the measurements were made. If so, then the simulated pumpage and its distribution in space and time may not accurately reflect the pumping history in the vicinity of AD-9.

Simulated hydrographs for Sites AD-12, AM-7 and UE-25 p#1 show the opposite trends to the measured hydrographs over the verification period. The rising trends in the measured hydrographs for these sites may also be localized effects of local recharge and/or reduction of groundwater withdrawal in adjacent wells.

Generally, the verification results suggest that the models accurately simulate the flow history at a regional scale. The less than actual drawdown in the Site AD-9 area and the reverse trends at Sites AD-12, AM-7 and UE-25 p#1 may be considered to be a localized inaccuracy of the models. With more accurate data of aquifer storage properties and pumpage, further modification of the model may improve the numerical representation of the regional and localized flow conditions.

The similar results from the four models indicate that the uncertainties in the models have minimal effects on the regional scale evaluation of the hydraulic impact of small stress such as the proposed pumping from wells in Jackass Flats. Hence, the models may be considered as adequate for an evaluation of regional scale hydraulic impacts due to small stresses.

9.2. Predictive Simulations

Transient simulations were performed to estimate the effect of the proposed pumping by the DOE. Four transient scenarios were considered. The simulated time period for each of the four scenarios is 100 years after 1997 (1998 to 2097). The four scenarios described below were used to provide a prediction of the impact of the proposed pumping under both the current water use context and under the maximum use of senior water rights context.

Scenario 1

This scenario provided a current water use context. All existing pumping in Amargosa Desert (Basin 230), Crater Flat (Basin 229), and Mercury Valley (Basin 225) continue at the 1997 pumping level and pumping in Jackass Flats (Basin 227 A) and Oasis Valley (Basin 228) is maintained at the average historical level (pre-1985, see Sec. 7.5.4 for the determination of the average). Simulated pumpage for Basin 227A (Jackass Flats) was 145 AFA. Total simulated annual pumpage for 1998-2097 within the study area is 11,856.49 AF (after deduction of secondary recharge in Amargosa Desert).

Scenario 2

This scenario was designed to evaluate the hydraulic effects of the proposed groundwater withdrawal under the current water use context. Pumpage in Jackass Flats (Basin 227 A) was increased by 430 AFA at the proposed points of diversion with all the other pumpages remaining the same as in Scenario 1. The 430 AFA was distributed uniformly in J-12, J-13 and the C-Wells. Total simulated annual pumpage for 1998-2097 within the study area is 12,286.49 AF (430 AF more than that of Scenario 1).

Scenario 3

This scenario provided a maximum water use context under existing senior water rights. After 1997, all senior rights in Basins 225, 226, 227A, 228, 229, and 230 were assumed to be used to their full extent (maximum pumping potential). The senior rights included committed water rights (certificates and permits) and pending applications with filing dates prior to July 27, 1997. Pumping in Basin 230 for irrigation purposes represents 80 percent of the duty of the water rights with the remaining 20 percent considered as secondary recharge. Temporary water rights for mining purposes were not included in the maximum pumping potential because that these rights will probably expire before pumping rates in the basins reach their maximum withdrawal potential.

The total simulated pumping rate for 1998-2097 within the study area is 24,194.52 AFA (after deduction of secondary recharge in Amargosa Desert). Total simulated pumpages for each of the basins are listed in Table 9.1 with a summary of water right allocations.

Table 9.1 Simulated Pumpages with Summary of the Corresponding Water Rights

(Acre-Feet per Annum)

Basin	1*	2*	3*	4*	5*	6*	7*
225	0	0	0	0	0	0	0+35
226	0	0	0	0	0	0	0
227A	502.22	0	0	430.19	0	72.03	72.03+145
227B	0	7.24[1]	0	0	0	7.24	0
228	1,651.13	200	474.60 (200)	0	134.92	1,851.13	1,851.13
229	1,238.79	0	0	1,238.79	0	0	0
230	26,682.87	5,697.94	20,576.66 (1,600)	4,613.4 (1,240.72)	4,435.33	26,526.69	22,091.36[2]

*1. Certificates and Permits;
2. Pending applications with filing date prior to 7/27/1997;
3. Irrigation rights: committed (pending);
4. Temporary permits: committed (pending);
5. Secondary recharge potential (20% of irrigation rights);
6. Maximum pumping potential (*1* + *2* – *4*);
7. Pumpage in the model.
[1] Based on diversion rate.
[2] Equals (*1* + *2* – *4* – *5*) only for Basin 230.

Scenario 4

This scenario was designed to evaluate the hydraulic impact due to the proposed pumping under the maximum use of the senior water rights context. Pumpage in Basin 227A (Jackass Flats) was increased by 430 AFA after 1997 and all the other pumpages are the same as those in Scenario 3. The 430 AFA was distributed uniformly in J-12, J-13 and the C-Wells. Total simulated annual pumpage for 1998-2097 within the study area is 24,624.52 AF.

The difference between the two scenarios under each context would be the net impact of the proposed pumping under the corresponding context. It is very important to determine the difference between the two scenarios under each context. Any impact to the natural discharge areas from Scenario 1 or Scenario 3 is not because of the proposed pumping in Jackass Flats (Basin 227 A).

By determining the difference between the two scenarios under each context, the impact of the proposed withdrawal in Jackass Flats (Basin 227A) is distinguished from that of existing groundwater withdrawals or possible groundwater withdrawals under senior water rights. In this way, the impact of the proposed pumping to existing rights and to the discharge areas can be evaluated appropriately.

All four transient models (Models L1, L2, H1 and H2) were used to simulate the four scenarios. Table 9.2 lists the figures that show the simulated drawdown distributions, hydrographs, and drawdown differences. These results shown on these figures (see

Appendix C) indicate the possible extent of the hydraulic impact due to the proposed groundwater withdrawal.

Table 9.2 Index of Figures Showing Simulation Results

	Drawdown Distribution											
Scenario	**1**			**2**			**3**			**4**		
Layer	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Model L1	21 (a)*	25 (a)	29 (a)	22 (a)	26 (a)	30 (a)	23 (a)	27 (a)	31 (a)	24 (a)	28 (a)	32 (a)
Model L2	21 (b)	25 (b)	29 (b)	22 (b)	26 (b)	30 (b)	23 (b)	27 (b)	31 (b)	24 (b)	28 (b)	32 (b)
Model H1	21 (c)	25 (c)	29 (c)	22 (c)	26 (c)	30 (c)	23 (c)	27 (c)	31 (c)	24 (c)	28 (c)	32 (c)
Model H2	21 (d)	25 (d)	29 (d)	22 (d)	26 (d)	30 (d)	23 (d)	27 (d)	31 (d)	24 (d)	28 (d)	32 (d)

	Hydrographs		Drawdown Difference	
Scenario	**1 & 2**	**3 & 4**	**1 & 2**	**3 & 4**
Layer	-	-	**1**	**1**
Model L1	33	37	41 (a)	42 (a)
Model L2	34	38	41 (b)	42 (b)
Model H1	35	39	41 (c)	42 (c)
Model H2	36	40	41 (d)	42 (d)

*This index is read as Figure 21 (a) showing drawdown distribution of Scenario 1 in the top layer of Model L1. Layers 1, 2, and 3 represent the top layer, central layer and the bottom layer of the model grid, respectively. All figures are included in Appendix C.

The drawdown was calculated with reference to the simulated water levels from the respective steady-state models. Drawdown distributions for the top model layer indicate that in the northwestern Amargosa Desert, if groudwater withdrawal continues at the simulated pumping rates, substantial drawdown (up to hundreds of feet) will occur. In other words, the existing water rights in this area cannot be fully utilized without significantly lowering the water table.

The drawdown distributions also show that the greatest amount of drawdown is in the top model layer and the least amount of drawdown near pumping wells is in the bottom layer. However, areas in the central model layer away from the pumping centers have the smallest amount of drawdown. This is due to the relative transmissivity difference between the layers since in the more transmissive layers, drawdown propagates faster.

One obvious feature in the drawdown distributions for the central model layer (Figures 25, 26, 27, and 28) is that in the northwestern Funeral Mountains area, there is an elongated drawdown pattern. The reasons for this pattern may be: (1) inter-layer flux exchange resulting in net flux losses in the central layer due to the transmissivity differences among the layers; (2) numerical error resulting from the relative small flux in this layer, relatively large flux change (as compared to the small flux) in this layer due to pumping in the top model layer, and contrasting permeability zones; and/or (3) errors caused by automatic contour generation. The consistent pattern in all the distributions from all the models and for all the scenarios suggests that inter-layer flux exchange might be the major cause.

Another feature in the drawdown distribution for the central model layer (Figures 25, 26, 27, and 28) is the steep drawdown slope south of CF-2 and JF-3. This is due to the distribution of the hydraulic conductivity in the central layer. This location of this steep slope follows the boundary between the relatively more permeable area in the south and the relatively less permeable area in the northwest. This feature shows that the existence of less permeable zones effectively limits the propagation of hydraulic effect due to increased pumping in Amargosa Desert.

Comprison of simulated hydrographs for the pair of scenarios (with or without the proposed pumping) under different water use contexts (historical and maximum use of senior water rights) (See Figures 33-40) shows that proposed pumping would produce 5 to 10 ft of additional drawdown at JF-3 but only about 0.5 to 1.0 ft at UE-25 p#1, and less than 0.1 ft at AM-4 (Devil's Hole). This result suggests that the central layer representing the confining unit between the carbonate aquifer and the volcanic aquifer at the central modeled area around Yucca Mountain may serve as an excellent barrier to the propagation of hydraulic effects between the two aquifers.

Figures 41 and 42 show the simulated net drawdown impact to the top model layer as a result of the proposed pumping by DOE. These results indicate that possible impact is primarily confined to Jackass Flats (Basin 227A) and Crater Flat (Basin 229).

9.3 Discussion

All numerical models are limited to a certain degree by the inadequacies of conceptual models and data deficiencies. Another limitation inherent in all steady state models is the non-uniqueness of their solutions if both flux configuration and aquifer parameters are unknown or uncertain. A seemingly acceptable calibration could be obtained using a completely different set of values for model parameters, if constraints on the parameter values are not very strict.

The most important aspect of this modeling effort was to attempt to represent the pumping history in the system more accurately. The use of the historical pumpage data and existing water level monitoring data to verify the predictive capability of the models served to greatly increase the confidence in the predictive results of the models.

During the calibration process on the steady-state models in this study, special attention was paid to ensure that the system fluxes and their general distribution were maintained as close as possible to the estimated quantities. Variation of both system flux and aquifer parameters during calibration was avoided in this study to provide confidence in the calibration. This significantly reduced the range of solutions with stable general flux which permitted more accurate representations of the conceptualization of the flow system.

The general agreement of the simulated heads with the estimated heads for the top model layer (Figures 16 (a), and (b) and Table 8.1) and the simulated higher heads in the UE-25 p#1 area for the bottom layer indicate the models provide good representations of the flow system.

The model verification results demonstrate that the model may be considered as adequate for predictive simulations involving small stress changes to the flow system to evaluate possible impacts over a large distance.

10. CONCLUSIONS

In, 1997, the DOE filed applications with the Nevada State Engineer to appropriate groundwater in Jackass Flats. The applications have been protested by the Nevada Agency for Nuclear Projects, Amargosa Water Committee, Citizen Alert and the Southern Nye County Conservation District. Two three-dimensional steady-state numerical models and four transient models of the aquifer system in the area, which include the points of diversion of the proposed water appropriation and the areas in which the protestants are interested, were built to simulate the possible impact of the proposed pumping to those areas.

The study area is geologically complex and has experienced intermittent marine and non-marine sedimentation, plutonism, volcanism, and extensional/compressive deformation. Combinations of faulting, folding and tectonic activities have resulted in a complex distribution of stratigraphic units. The stratigraphic units occuring in the study area include Precambian and Cambrian clastic and crystalline rocks; Paleozoic clastic and carbonate rocks; clastic and intrusive rocks of Mesozoic age; Tertiary volcanic rocks; Tertiary-Quaternary lava flows and basin fill; and Quaternary lake bed deposits.

Within the study area, groundwater occurs in the valley fill, the volcanic and Paloezoic carbonate rocks. Groundwater flow in the area originates as recharge from precipitation predominantly in the highlands and subsurface inflow mainly from the northern and eastern boundaries. After entering the flow domain, groundwater moves generally toward the south and the southwest through the aquifer system. Groundwater discharges in the forms of spring flows and ET and in the form of groundwater pumpage from wells. A portion of spring discharge and groundwater pumpage becomes secondary recharge. Subsurface outflow ultimately discharges at the Death Valley as ET.

The flow domain can be broadly conceptualized as a three-layer system in the vertical direction. The top layer represents mainly the shallow aquifers with localized flow patterns and generally may be considered as unconfined water table aquifers which receive recharge from precipitation, surface water runoff, spring discharge and human water uses. The central layer has different roles in different areas. In the northern and southern parts of the study area it may act as communication windows between the top water table aquifers and the bottom layer. In the central area around Yucca Mountain it may act as a barrier to flow between the top layer and the bottom layer. The bottom layer represents deep aquifers, which include the regional carbonate aquifer.

A three-dimensional finite difference model grid consisting of 151 rows and 129 columns in 3 layers was constructed to simulate steady state and transient flow for the study area. A total of two steady-state models, four historical verification simulations and sixteen predictive simulations were performed for this study. The computer code used to simulate the regional groundwater flow was MODFLOW (McDonald and Harbaugh, 1988) as implemented by Groundwater Vistas (a groundwater model design environment with pre-processing and post-processing tools developed by Environmental Simulations, Inc.). The blocks are oriented to the north and are of a uniform size of 0.5 mile × 0.5 mile. The bottom of the top layer is approximately 1,640 ft (500 meters) below the estimated potentiometric surface of the shallow aquifer and the thicknesses of the central and bottom layers are 820 ft (250 meters) and 4,922 ft (1,500 meters), respectively.

The two steady-state models were calibrated by:

- simulating the system fluxes as close as possible to the estimated quantities,
- matching simulated heads with measured heads at 22 selected monitoring locations, and
- general matching a simulated potentiometric surface with an estimated potentiometric surface by D'Agnese and others, 1997.

The models were verified against historical monitoring data for the 22 selected sites. The model verification results illustrate that all the models can be considered as adequate for predictive simulations involving small stress changes to the flow system to evaluate possible impacts over a large distance.

Four transient scenarios were run by using each of the four transient models under two water use contexts to evaluate the impact of the proposed pumping at the Yucca Mountain area. Scenario 1 simulated a possible change of the flow conditions with the current water use to provide an impact evaluation context. Scenario 2 simulated a possible change of the groundwater flow conditions with the current water use and the proposed maximum pumping. Scenario 3 simulated a possible change of the groundwater flow conditions with the maximum use of all the senior water rights to provide another impact evaluation context. Scenario 4 simulated a possible change of the flow condition with the maximum use of all of the senior water rights as well as the proposed maximum pumping in Jackass Flats. The differences of the two scenarios under each context would be the net impact caused by the proposed pumping within the corresponding water use context.

Transient simulation results indicate that the proposed pumping does produce a drawdown distribution. The simulated drawdown as a result of the proposed pumping for 100 years at monitoring site AD-2 (near the town of Amargosa Valley) would be less than 1.2 ft. The subsurface flux from Basin 227A (Jackass Flats) to Basin 230 (Amargosa Desert) after 100 years will change from 6,812 to 6,686 AFA with a net reduction of about 126 AFA (Model L1, between Scenarios 1 and 2).

The simulated impact of the proposed pumping on water levels in the Ash Meadows area and on subsurface flux to the Ash Meadow area is negligible. Simulated drawdown due to the proposed pumping for 100 years at the monitoring site AM-4 (Devil's hole) would be less than 0.1 ft. Total simulated subsurface flux from Basins 225 (Mercury Valley), 226 (Rock Valley), and 227A (Jackass Flats) to 230 (Amargosa Desert) would merely be reduced by approximately 61 to 126 AFA.

It should be noted that different flux configurations and conceptualizations of a flow system would result in different numerical approximations. Similarly, concurrent estimation of aquifer parameters and system flux by using the same set of calibration heads would result in non-unique solutions. Uncertainty in the estimates of the system flux components can not be reduced by the modeling efforts when the hydraulic parameters of the aquifer system are basically unknown. This is because estimates of these flux components were used as calibration targets.

For most of the study area, the models in this study were calibrated by a construction of the estimated potentiometric surface consisting of contours with intervals of 100 meters. The potentiometric surface of finer resolution with smaller intervals was not available at the time of this study. Therefore, the model is limited by this calibration resolution for areas without monitoring data points. Fracture flow at localized scale was not simulated. Modeling results should be interpreted under the context of the purpose of this study and under that all the assumptions invoked in the model could be considered as reasonable.

11. RECOMMENDATIONS

The models presented in this report are considered dynamic tools for understanding the complex hydrogeology of the Yucca Mountain area. As such, additional data will help to provide more accurate predictive simulations of groundwater movement and impacts from pumping, if any. Therefore, TEC recommends future generations of the models be prepared using additional data as it becomes available.

12. DISCLAIMER

The results and conclusions of this modeling study are solely for the purposes intended under all the assumptions invoked and should be interpreted strictly under the modeling contexts. Any other uses of the results and findings of this study is at user's own discretion and risks.

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14. APPENDICES

Appendix A-1 Simulated Annual Average Pumpage Data

Wells in Model			Annual Pumpage Rate (cubic-feet/day)													
Well No.	Row	Col.	Steady State	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Wells in Basin 227A, Jackass Flats																
1	70	71		0	0	0	0	0	0	0	0	0	0	2267.5068	21959.014	23033.096
2	73	74	8652.33	9786.08	8413.64	9666.74	8413.64	9249.04	9487.73	9368.38	7100.88	12232.60	13545.37	15454.85	14798.47	9010.36
3	79	75	8652.33	9786.08	8413.64	9666.74	8413.64	9249.04	9487.73	9368.38	7100.88	12232.60	13545.37	15454.85	14798.47	9010.36
Wells in Basin 229, Crater Flat																
4	57	50	0.00	0.00	0.00	0.00	0.00	1163.59	3968.14	1282.93	865.23	447.53	1342.60	924.90	924.90	924.90
5	57	52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	59	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	61	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	63	49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	63	52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	58	52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	59	46	0.00	0.00	0.00	0.00	0.00	1163.59	3968.14	1282.93	865.23	447.53	1342.60	924.90	924.90	924.90
12	73	54	0.00	0.00	0.00	0.00	0.00	1163.59	3968.14	1282.93	865.23	447.53	1342.60	924.90	924.90	924.90
13	75	57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	90	62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	68	53	0.00					1163.59	3968.14	1282.93	865.23	447.53	1342.60	924.90	924.90	924.90
Well in Basin 230, Amargosa Desert																
16	59	26	0.00	4773.70	4773.70	4773.70	4773.70	4773.70	4773.70	4773.70	4773.70	4773.70	4773.70	4773.70	4773.70	34943.47
17	60	27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	67	21	0.00	0.00	0.00	0.00	0.00	9630.94	21870.70	7399.23	19560.23	17591.08	21374.24	21374.24	15108.76	18963.52
19	67	26	0.00	0.00	0.00	0.00	0.00	9630.94	21870.70	7399.23	19560.23	17591.08	21374.24	21374.24	15108.76	18963.52
20	66	27	0.00	0.00	0.00	0.00	0.00	9630.94	21870.70	7399.23	19560.23	17591.08	21374.24	21374.24	15108.76	18963.52
21	67	29	0.00	0.00	0.00	0.00	0.00	9630.94	21870.70	7399.23	19560.23	17591.08	21374.24	21374.24	15108.76	18963.52
22	65	30	0.00	0.00	0.00	0.00	0.00	9630.94	21870.70	7399.23	19560.23	17591.08	21374.24	21374.24	15108.76	18963.52
23	67	31	0.00	0.00	0.00	0.00	0.00	9630.94	21870.70	7399.23	19560.23	17591.08	21374.24	21374.24	15108.76	18963.52
24	67	33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	63	34	0.00	17185.32	7160.55	7160.55	7160.55	7160.55	7160.55	4773.70	4773.70	4773.70	4773.70	4773.70	21481.64	54038.27
26	63	35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	69	27	0.00	0.00	0.00	0.00	0.00	9630.94	21870.70	7399.23	19560.23	17591.08	21374.24	21374.24	15108.76	18963.52
28	69	29	0.00	0.00	0.00	0.00	0.00	9630.94	21870.70	7399.23	19560.23	17591.08	21374.24	21374.24	15108.76	18963.52
29	95	73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	96	73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	95	74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	107	60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16707.95	16707.95	16707.95	16707.95	16707.95

Well No.	Row	Col.	Steady State	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
33	106	58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	108	58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	763.79
35	108	60	68112.64	86728.56	55694.74	55694.74	0.00	0.00	55694.74	76379.18	59671.23	119552.51	115380.30	115380.30	115380.30	111740.83
36	105	56	0.00	0.00	238.68	238.68	238.68	477.37	2625.53	0.00	1766.27	20765.59	1670.79	40337.75	3222.25	4773.70
37	105	53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2864.22	0.00	0.00	0.00	0.00
38	105	54	0.00	0.00	0.00	0.00	477.37	0.00	0.00	0.00	0.00	5155.59	9451.92	9451.92	2291.38	4773.70
39	105	67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	106	67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	109	64	0.00	0.00	0.00	0.00	0.00	23868.49	38189.59	59671.23	59671.23	59671.23	59671.23	59671.23	59671.23	59671.23
42	110	68	15738.49	20039.99	17509.93	17509.93	17509.93	7160.55	7160.55	0.00	17509.93	17509.93	17509.93	17509.93	17509.93	17509.93
43	114	71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	114	72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	115	71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	113	71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	112	71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1932.39	1932.39	1737.63	2501.42	2509.06	2509.06
48	116	70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	116	71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	116	68	0.00	0.00	0.00	19094.79	28642.19	38189.59	75424.44	52510.68	51555.95	125834.70	120535.89	188847.52	188847.52	184073.82
51	115	66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	115	61	7498.09	9547.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53	116	61	99349.67	126503.01	62917.35	64253.98	54324.69	50123.84	36623.82	31983.78	33177.21	47259.62	32461.15	33320.42	25968.92	23963.97
54	116	62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	117	61	0.00	0.00	4296.33	4296.33	4296.33	6205.81	6205.81	6205.81	6205.81	6205.81	6205.81	6205.81	6205.81	6205.81
56	117	62	5623.57	7160.55	0.00	0.00	0.00	11934.25	11934.25	4773.70	4773.70	4773.70	4773.70	4773.70	4773.70	4773.70
57	117	63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	117	66	93726.11	119342.47	59671.23	78766.03	29835.62	47.74	22064.04	0.00	0.00	0.00	0.00	11342.31	0.00	0.00
59	117	67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	117	68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61	119	69	1874.52	2386.85	0.00	1145.69	1145.69	1145.69	1145.69	0.00	1527.58	1527.58	1909.48	2386.85	2386.85	2386.85
62	123	66	0.00	0.00	0.00	0.00	477.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	123	67	0.00	0.00	0.00	0.00	477.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	127	70	0.00	0.00	25396.08	381.90	40767.39	84780.89	48032.96	10979.51	29215.04	48882.67	35993.69	41149.28	71319.06	63585.67
65	128	69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
67	128	70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
68	128	72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
69	127	72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Well No.	Row	Col.	Steady State	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
70	127	71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	126	82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
72	126	85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
73	129	88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
74	122	86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
75	114	61	64820.98	82537.25	82537.25	82107.62	0.00	0.00	2386.85	111656.81	94948.87	111656.81	111656.81	82537.25	76331.44	82537.25
76	114	63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
77	114	64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78	114	65	0.00	0.00	0.00	0.00	0.00	16707.95	30026.56	16707.95	0.00	9547.40	9547.40	0.00	0.00	0.00
79	112	62	0.00	0.00	0.00	0.00	0.00	2386.85	2386.85	0.00	1527.58	18140.05	954.74	4773.70	2386.85	8115.29
80	112	67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
81	110	69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
82	106	72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5251.07	5251.07	0.00	0.00	0.00	0.00
83	108	62	0.00	0.00	0.00	16707.95	16707.95	16707.95	14321.10	16707.95	16707.95	16707.95	19094.79	28642.19	21720.33	10502.14
84	109	70	1702.07	2167.26	0.00	954.74	954.74	1432.11	1432.11	0.00	0.00	4554.11	3341.59	0.00	477.37	477.37
85	110	70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
86	109	69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
87	116	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
88	117	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
89	117	101	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4773.70	4773.70	0.00	0.00	954.74	954.74
90	106	57	0.00	0.00	0.00	0.00	601.49	0.00	954.74	0.00	572.84	286.42	1670.79	1432.11	1193.42	2673.27
91	106	56	31866.88	42485.92	58239.12	10502.14	71070.83	5728.44	39144.33	39144.33	59384.81	29405.98	30613.73	41053.81	17424.00	37783.82
92	107	56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	107	57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	381.90
94	106	53	27660.45	35220.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10502.14	5728.44	0.00	0.00
95	104	54	0.00	0.00	18617.42	0.00	40576.44	0.00	0.00	0.00	0.00	8592.66	7160.55	8592.66	477.37	1861.74
96	104	53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
97	104	52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	104	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3532.54	3532.54	17662.68	17662.68	17662.68	8831.34	8831.34
99	105	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	106	50	22494.27	28642.19	57284.38	0.00	19094.79	0.00	0.00	0.00	0.00	19094.79	45827.51	38189.59	38189.59	23868.49
101	106	51	49209.96	62659.57	76613.09	0.00	4506.37	0.00	0.00	0.00	0.00	36547.44	51632.32	65208.72	62798.01	62798.01
102	104	57	28117.83	35802.74	36757.48	36757.48	36757.48	0.00	0.00	0.00	0.00	0.00	5728.44	28642.19	0.00	0.00
103	108	51	0.00	0.00	0.00	25396.08	0.00	0.00	64683.62	0.00	0.00	63490.19	63490.19	63490.19	63490.19	63490.19
104	108	53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	109	52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1909.48	3818.96	1909.48	954.74	1670.79	1670.79	2267.51
106	112	60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Well No.	Row	Col.	Steady State	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
107	111	61	93726.11	119342.47	0.00	0.00	0.00	0.00	0.00	0.00	59671.23	0.00	59671.23	59671.23	59671.23	0.00
108	110	59	87487.70	111399.03	111399.03	111399.03	0.00	0.00	58086.36	0.00	0.00	23868.49	22277.90	77992.69	77992.69	77972.64
109	109	59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	109	60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59671.23	59671.23	59671.23	59671.23	59671.23	59671.23	59671.23
111	109	62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19094.79	19094.79	0.00	59671.23	88313.42	119342.47	119342.47
112	110	61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
113	110	62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
114	107	62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
115	106	63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
116	107	64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
117	105	65	7498.09	9547.40	11934.25	11934.25	11934.25	16116.01	16116.01	4773.70	16111.23	16116.01	15275.84	23271.78	21548.48	16469.26
118	103	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	95.47	0.00	0.00	0.00
119	104	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1307.99	0.00	0.00	0.00	0.00
120	104	66	0.00	0.00	0.00	0.00	0.00	2386.85	2386.85	0.00	1336.64	1336.64	1432.11	8783.61	3102.90	3102.90
121	105	66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
122	112	72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All in Basin230			706507.40	923472.00	691040.61	549075.59	392331.20	374382.09	723926.62	584443.92	779439.01	1078840.61	1202484.18	1435455.95	1301193.77	1327231.43
Wells in Basin 228																
123	38	31	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28
124	37	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0
125	38	61	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28	131.28
126	50	38	6468.36	6468.36	6468.36	6468.36	6468.36	6468.36	6468.36	6468.36	6468.36	6468.36	6468.36	6468.36	6468.36	6468.36
127	54	38	102.64	102.64	102.64	102.64	102.64	102.64	102.64	102.64	102.64	102.64	102.64	102.64	102.64	102.64
128	55	38	432.02	432.02	432.02	432.02	432.02	432.02	432.02	432.02	432.02	432.02	432.02	432.02	432.02	432.02
129	56	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130	58	34	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93
131	59	34	13785.25	13785.25	13785.25	13785.25	13785.25	13785.25	13785.25	13785.25	13785.25	13785.25	13785.25	13785.25	13785.25	13785.25
132	60	34	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93
133	55	28	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93
134	57	29	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93
135	53	29	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93	7816.93
136	42	34	2434.59	2434.59	2434.59	2434.59	2434.59	2434.59	2434.59	2434.59	2434.59	2434.59	2434.59	2434.59	2434.59	2434.59
Wells in Basin 225																
137	102	114	18378.74	15275.84	12769.64	12650.30	19452.82	41889.21	46185.53	40218.41	51078.58	40337.75	28164.82	8831.34	6444.49	4176.99

Note: Listed pumpage for Basin 230 is 80% of the annual pumpage estimates because 20% of the pumpage is considered as secondary recharge.

Appendix A-2 Simulated Annual Average Pumpage Data for Scenairo 3 After 1997

Well No	Row	Column	Permit No or Well Name Simulated	AFA	cf/day
1	70	71	C-Wells	143.33	17105.75
2	73	74	J-13	215.83	25758.08
3	79	75	J-12	215.83	25758.08
new 1	96	74	18528, 21593, 60705	54.81	6541.16
new 2	60	81	11141	5.65	674.28
new 3	87	75	12729	11.57	1380.79
4	57	50	52847, 60985, 62375	0.00	0.00
5	57	52	60989	0.00	0.00
6	59	50	60986	0.00	0.00
7	61	50	60987	0.00	0.00
8	63	49	60988	0.00	0.00
9	63	52	60911	0.00	0.00
10	58	52	60990	0.00	0.00
11	59	46	51555	0.00	0.00
12	73	54	48436	0.00	0.00
13	75	57	57375	0.00	0.00
14	90	62	59124	0.00	0.00
15	68	53	52347	0.00	0.00
16	59	26	13574	3.22	384.28
17	60	27	63584T, 58857	0.00	0.00
18	67	21	51846	0.00	0.00
19	67	26	51843, 58860	0.00	0.00
20	66	27	58859, 51842	0.00	0.00
21	67	29	51844, 58861, 61412	0.00	0.00
22	65	30	58858, 51841	0.00	0.00
23	67	31	51845, 58862	0.00	0.00
24	67	33	58863	0.00	0.00
25	63	34	51879	431.85	51538.04
26	63	35	51880	0.00	0.00
27	69	27	58864, 61413, 61576, 51847	1447.98	172805.50
28	69	30	51848	0.00	0.00
29	95	73	47528	10.83	1292.48
30	96	73	26673, 40448	234.71	28010.87
31	95	74	62309, 59400	0.00	0.00
32	107	60	15702	140.00	16707.95
33	106	58	14078	126.08	15046.70
34	108	58	60464, 60469	16.00	1909.48
35	108	60	15893, 43873	1076.30	128448.77
36	105	56	59181, 55156, 25744, 25743, 25742,25099, 23797	396.88	47364.64
37	105	53	52616	120.00	14321.10
38	105	54	26152	48.00	5728.44
39	105	67	16047	17.62	2102.34

Well No	Row	Column	Permit No or Well Name Simulated	AFA	cf/day
40	106	67	50385	30.88	3685.30
41	109	64	22746	640.00	76379.18
42	110	68	16545, 49220	146.72	17509.93
43	114	71	44741	0.86	102.63
44	114	72	20355	14.42	1720.44
45	115	71	28777	8.50	1014.41
46	113	71	59180	5.00	596.71
47	112	71	20162, 28828	148.56	17729.52
48	116	70	61080, 62116	50.00	5967.12
49	116	71	45162, 45163	9.76	1164.78
50	116	68	17241, 29649, 43524, 59729, 15929, 62115	1679.20	200399.87
51	115	66	59277	640.00	76379.18
52	115	61	14059, 27813	571.20	68168.42
53	116	61	27812, 35592	9.45	1127.79
54	116	62	52887	0.00	0.00
55	117	61	49885	52.00	6205.81
56	117	62	14054	101.60	12125.19
57	117	63	63565, 63566, 63567, 63568	0.00	0.00
58	117	66	21584, 19034	412.00	49169.10
59	117	67	61131, 61911	0.00	0.00
60	117	68	24729, 60866	200.00	23868.49
61	119	69	17694	76.00	9070.03
62	123	66	29452	0.00	0.00
63	23	67	29451	0.00	0.00
64	127	70	48479, 48483, 48482	0.00	0.00
65	128	69	48481	0.00	0.00
66				0.00	0.00
67	128	70	48480	0.00	0.00
68	128	72	45061	172.63	20602.09
69	127	72	28062, 56781, 48477, 45361	183.60	21911.28
70	127	71	48478, 45360, 53181, 63407, 63408, 53182, 52663	168.00	20049.53
71	126	82	61219	2.24	267.33
72	126	85	44741	0.00	0.00
73	129	88	53596	296.76	35416.07
74	122	86	32279	0.61	72.80
75	114	61	20352	935.60	111656.81
76	114	63	47223	0.00	0.00
77	114	64	47205	36.99	4414.48
78	114	65	61205	111.60	13318.62
79	112	62	22233	152.00	18140.05
80	112	67	63082	0.00	0.00
81	110	69	45740, 62366	3.38	403.38
82	106	72	46218, 17348, 53009, 62637	78.57	9376.98
83	108	62	19916, 22761	640.00	76379.18
84	109	70	62371, 62367, 40954	38.15	4553.15
85	110	70	62368, 62373	0.00	0.00

Well No	Row	Column	Permit No or Well Name Simulated	AFA	cf/day
86	109	69	62370, 19197, 62369	59.70	7124.27
87	116	100	54271	1.23	146.79
88	117	100	22141, 63250	84.80	10120.24
89	117	101	22140	32.00	3818.96
90	106	57	17657A01, 17657A02, 17657A03, 60449, 60440, 60442, 60443, 60473, 60474, 63715, 60439, 60233, 60466, 60462	264.74	31594.25
91	106	56	60437, 60455, 60435, 16562, 63232, 60465, 60470, 60475, 60471, 60450, 60463, 60433, 60434, 53189, 60162, 46748, 36584	617.93	73745.29
92	107	56	60386, 60468, 60431, 60480, 60451, 60479	95.26	11369.04
93	107	57	60472, 60238, 60441	8.00	954.74
94	106	53	17417	183.28	21873.09
95	104	54	18764, 29341	285.60	34084.21
96	104	53	63140, 26442	0.00	0.00
97	104	52	16178	16.00	1909.48
98	104	50	19448	148.01	17663.64
99	105	50	62465	0.00	0.00
100	106	50	26283	640.00	76379.18
101	106	51	24725, 30176	621.96	74226.24
102	104	57	15881, 49947	225.52	26914.11
103	108	51	18222	1074.00	128173.81
104	108	53	62411	0.00	0.00
105	109	52	18772, 60150, 62464, 62412, 62413	210.98	25178.40
106	112	60	17137, 63010	40.00	4773.70
107	111	61	17404	640.00	76379.18
108	110	59	38127, 38363	933.34	111387.57
109	109	59	63153, 63152, 63151, 62918, 62919, 63174	0.00	0.00
110	109	60	30411	604.00	72082.85
111	109	62	19917	640.00	76379.18
112	110	61	57304	0.00	0.00
113	110	62	15410	640.00	76379.18
114	107	62	62529	640.00	76379.18
115	106	63	22941	0.68	81.15
116	107	64	59352	1129.57	134805.67
117	105	65	42171, 24585, 29521, 31727	255.00	30432.33
118	103	65	62322, 25636, 62326T, 62327	83.23	9933.11
119	104	65	31204	18.22	2174.90
120	104	66	24763, 26718, 29069, 63236	99.36	11857.87
121	105	66	20411, 63233, 63234, 63235	103.36	12335.24

Well No	Row	Column	Permit No or Well Name Simulated	AFA	cf/day
122	112	72	49804	0.12	14.32
new 4	111	72	51915	9.70	1157.62
			Total for 230	**22091.34**	**2636434.99**
					0.00
Wells in Basin 228					0.00
					0.00
1	38	31	6725	1.10	131.28
2	37	41	61704	400.00	47736.99
3	38	61	9606	1.10	131.28
4	50	38	12489	54.20	6468.36
5	54	38	44236	0.86	102.63
6	54	39	47342	3.62	432.02
7	56	38	62558	2.00	238.68
8	58	34	20890	123.04	14683.90
9	59	34	54224, 22838	209.93	25053.56
10	60	34	22839, 57257	378.60	45183.06
11	55	28	52044	312.07	37243.20
12	57	29	52045	0.00	0.00
13	53	29	38126	139.21	16613.66
14	42	34	12075, 62264	25.40	3031.30
new 5	55	38	61079	200.00	23868.49
Wells in Basin 225					
1	102	114	Army Well #1	35.00	4176.99

Appendix B Modeling data documentation list

TABLE OF CONTENTS

SOFTWARE

MODFLOW (McDonald and Harbaugh, 1988): A three-dimensional finite difference computer code for groundwater flow.

Groundwater Vistas (Version 1.99b, 1996) developed by Environmental Simulations Inc.

Groundwater Vistas is a groundwater model design environment with pre-processing and post-processing tools.

MODEL BOUNDARY

Location

Eastern, northern, and western boundary follows hydrographic basin boundaries of Basin 225, 226, 227A, 227B, 228, and 230. The southern boundary is approximately the southern boundary of the Alkali Flat-Furnace Creek Ranch sub-basin. The southern boundary is approximately perpendicular to the potentiometric surface (as constructed by D'Agnese and others, 1997). The southwestern boundary is along the 0 meter contour line of the potentiometric surface (as constructed by D'Agnese and others, 1997) A portion of the western boundary (a straight line section in the northeast-southwest direction) is arbitrarily chosen along a direction perpendicular to the potentiometric surface (as constructed by D'Agnese and others, 1997).

Sub-basin boundary

Sub-basin boundary is from Laczniak and others, 1996 (pl. 1) and La Camera and Locke, 1998 (p. 3, Fig. 1).

Hydrographic basin boundary

Based on topographic divide from U.S Geological Survey digital elevation model, 1:250,000 (scale)

DISTRIBUTION OF STRATIGRAPHIC UNITS

Based on D'Agnese and others, 1997 (p.18, Fig. 8)

Aquitard distribution

Based on Laczniak and others, 1996 (pl. 1)

MAJOR STRUCTURAL FEATURES

Based on D'Agnese and others, 1997 (p. 16, Fig. 7)

GENERAL GEOLOGIC HISTORY

Based on Grose and Smith, 1989 and D'Agnese and others, 1997

ESTIMATED POTENTIOMETRIC SURFACE

Based on D'Agnese and others, 1997 (p. 60, Fig. 27)

EXPECTED RANGES OF HYDRAULIC CONDUCTIVITY VALUES

Based on D'Agnese and others, 1997 (p.109, Table 16)

Hydraulic conductivity values at the C-wells

Based on Geldon and others, 1998 (p.29, Tables 4 &5)

RANGE OF STORAGE PARAMETERS

Based on Geldon and others, 1998 (p.29, Tables 4 &5)

WATER USE DATA

Well locations

Based on points of diversion for water rights permits and/or certificates From Nevada State Engineer's office.

Pumpage data

- Early pumpage data (1962-1967) for Jackass Flats is from Young, 1972.
- Pumpage data on Well J-12 and J-13 for 1996 and 1997 was provided by Bright of USGS, Las Vegas.
- Pumpage data on C-Well Complex for 1996 and 1997 are as reported to Nevada State Engineer's Office.
- Pumpage data for Amargosa Desert (Basin 230) is from Nevada State Engineer's Office
- Other pumpage data for Basins 225, 227, 229, and 230 is from USGS OFR-94-54, OFR-96-205, OFR-96-533 and OFR-97-821 (La Camera and Westenburg, 1994;

Westenburg and La Camera, 1996; La Camera and others, 1996; La Camera and Locke, 1998).

- Historical municipal pumpage in Basin 228 is from Buqo, 1996 (p. 22).

SECONDARY RECHARGE

Water from spring flow and water uses may return to the ground water system resulting in secondary recharge. Estimates of secondary recharge are not readily available. Secondary recharge rates depend on the actual quantity of water applied, manner of water use, and return path characteristics. Water use for flood irrigation may have a higher secondary recharge rate than that for pivot irrigation. Mining dewatering may have an even higher secondary recharge rate if pumped water is purposely put into recharge basins. Secondary recharge from spring flow in the Ash Meadows area has been interpreted at about 6,500 acre-feet annually (Nichols and others, 1997) which ultimately may discharge as evapotranspiration. Secondary recharge from irrigation water uses in Amargosa Desert has been estimated at approximately 20 percent of the amount of water placed into use (Nevada State Engineer's Ruling #3666 p. 3).

WATER LEVEL DATA FOR MONITORING SITES

Water level data is from USGS OFR-94-54, OFR-96-205, OFR-96-533 and OFR-97-821 (La Camera and Westenburg, 1994; Westenburg and La Camera, 1996; La Camera and others, 1996; La Camera and Locke, 1998).

Appendix C Figures Showing Simulation Results

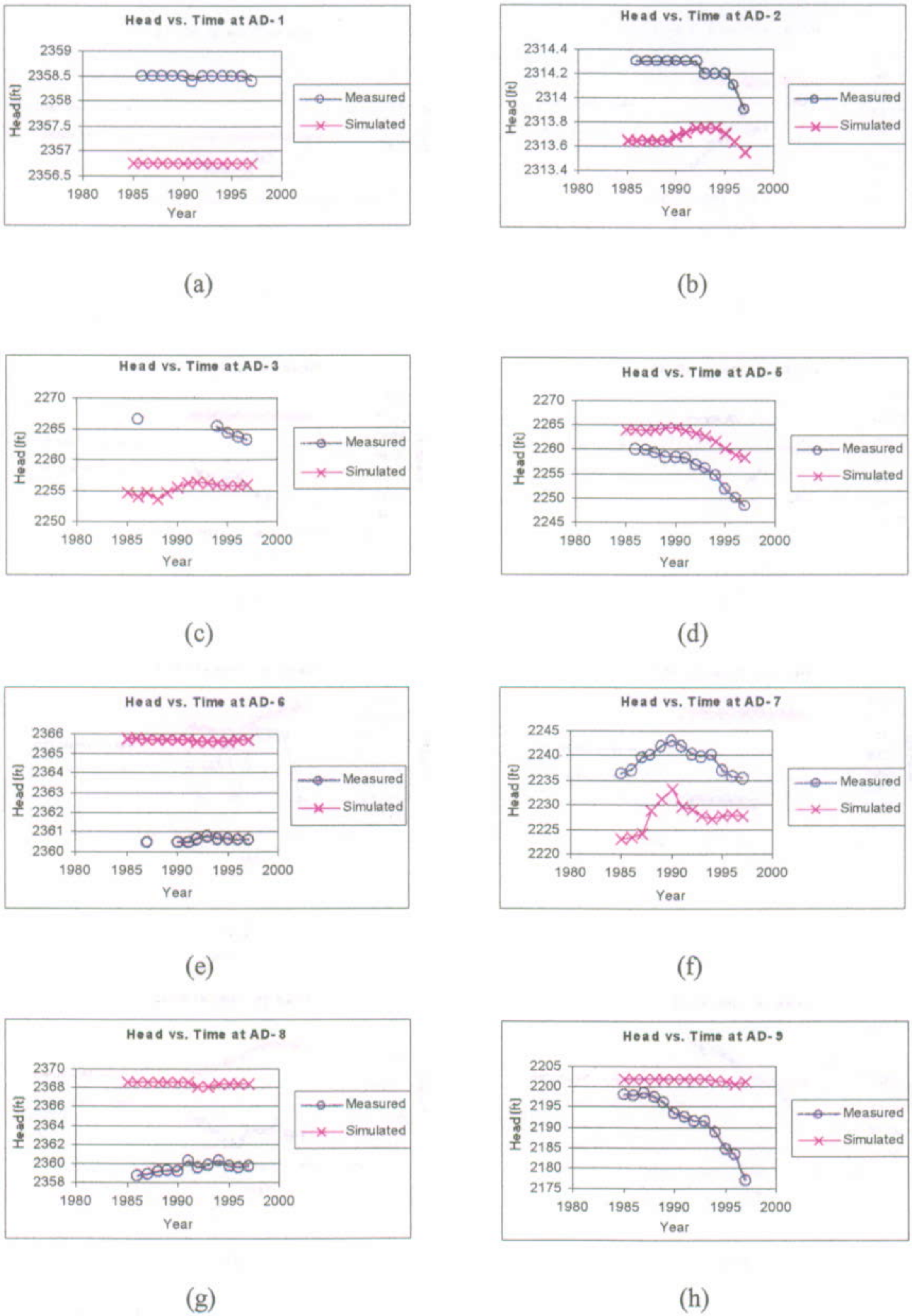
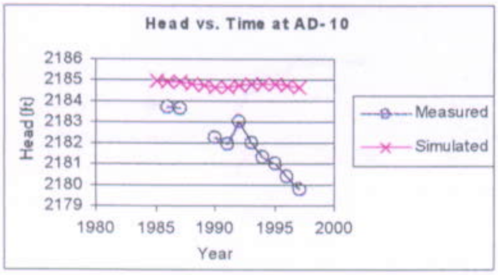


Figure 17. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model L1)



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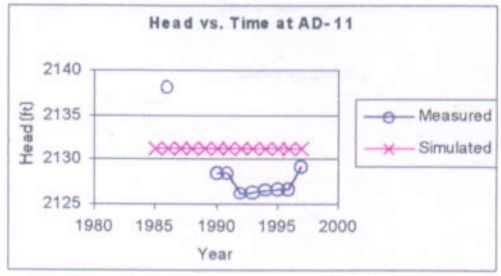

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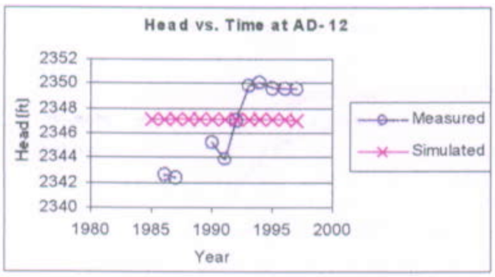

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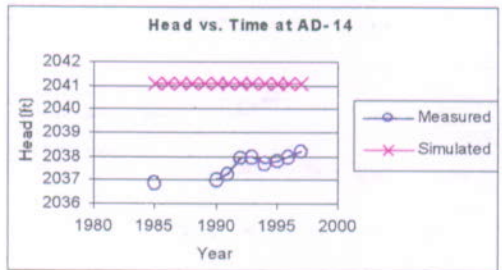

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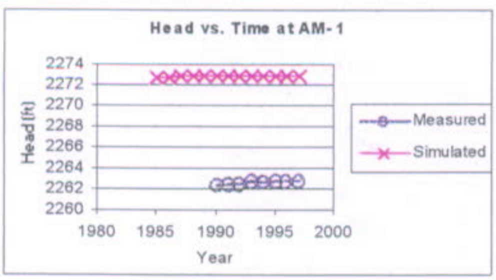

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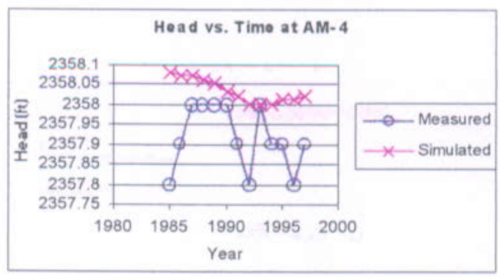

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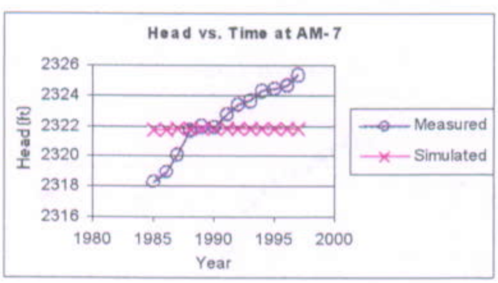

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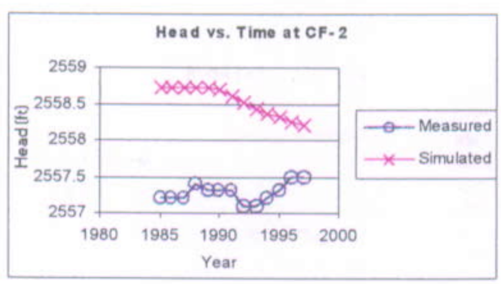
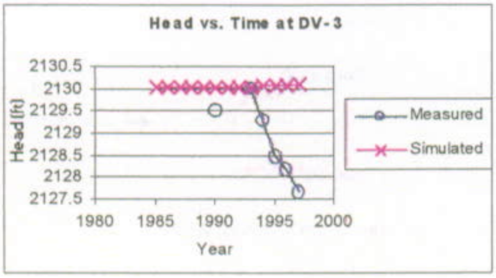
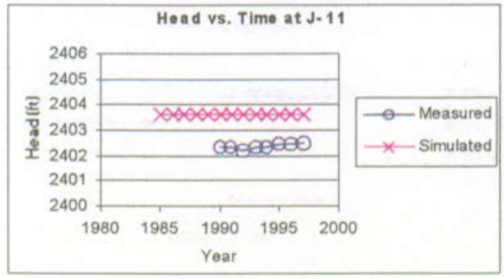


(p)

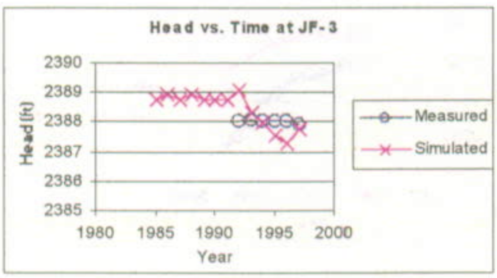
Figure 17 *(Continued)*. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model L1)



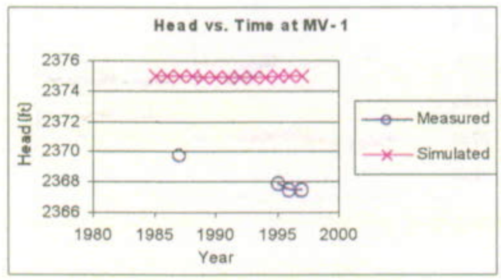
(q)



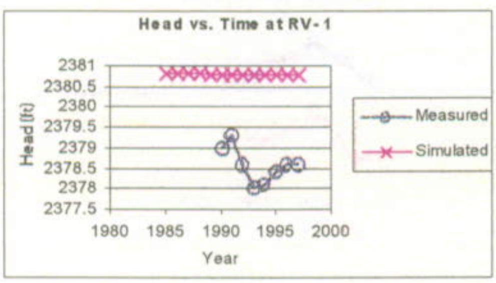
(r)



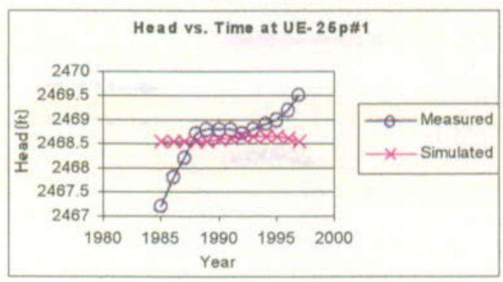
(s)



(t)



(u)



(v)

Figure 17 *(Continued)*. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model L1)

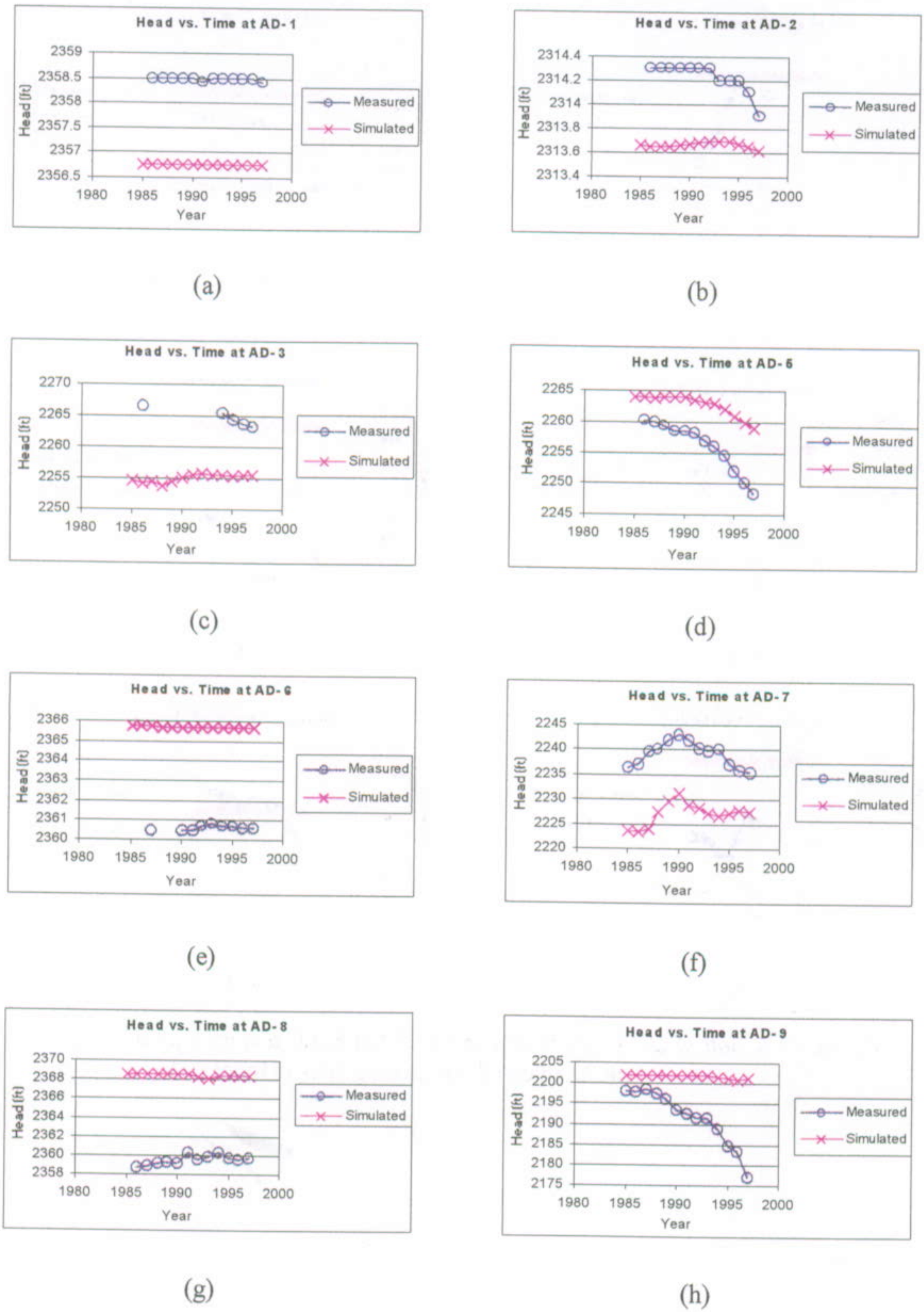
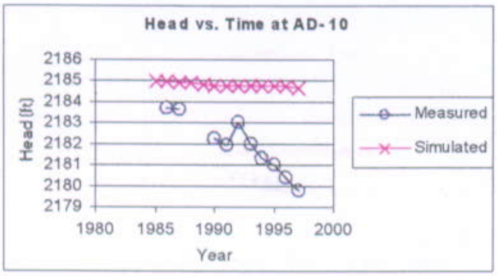
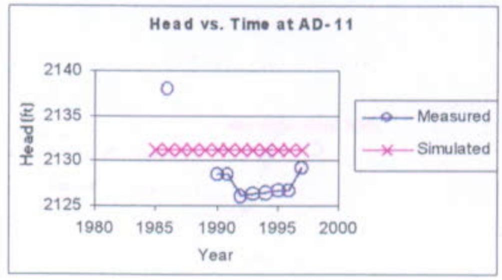


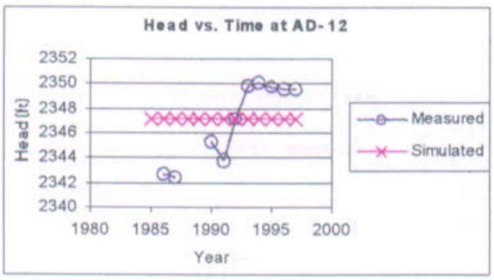
Figure 18. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model L2)



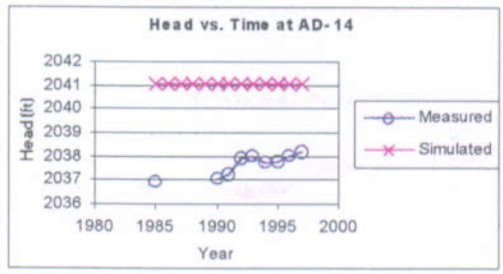
(i)



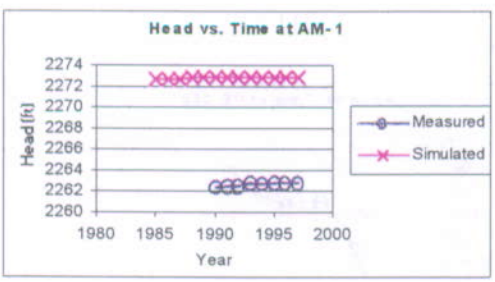
(j)



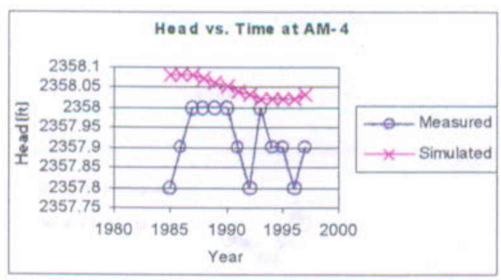
(k)



(l)



(m)



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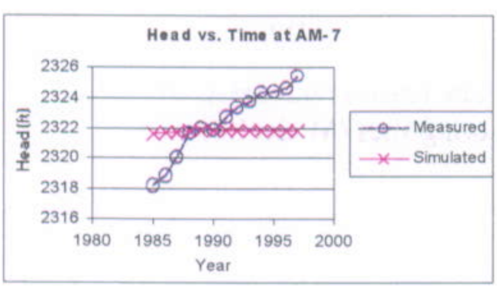
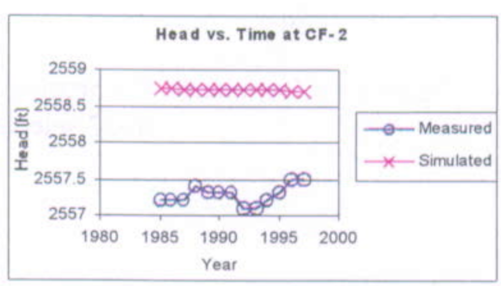
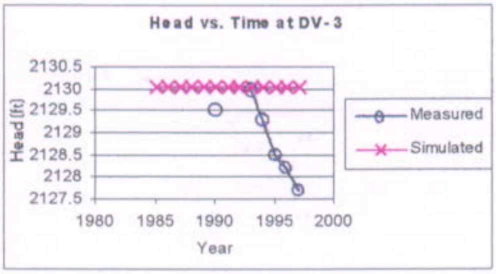


(o)

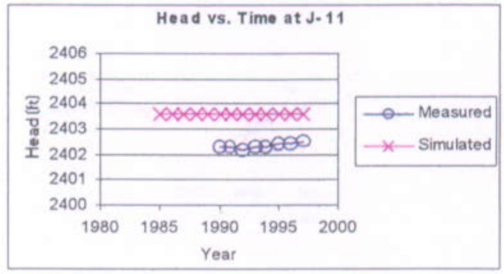


(p)

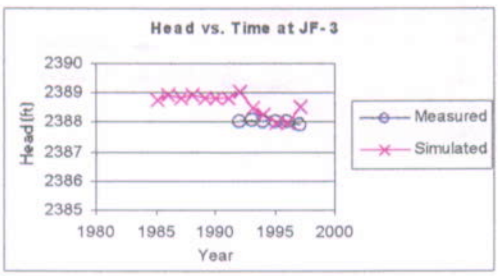
Figure 18 *(Continued)*. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model L2)



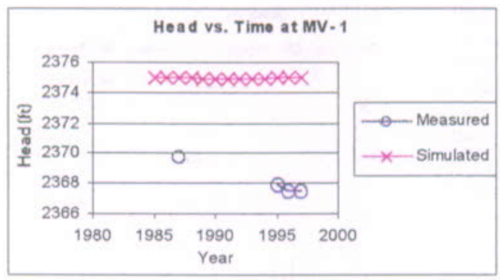
(q)



(r)



(s)



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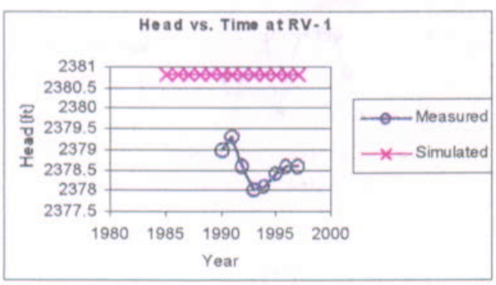
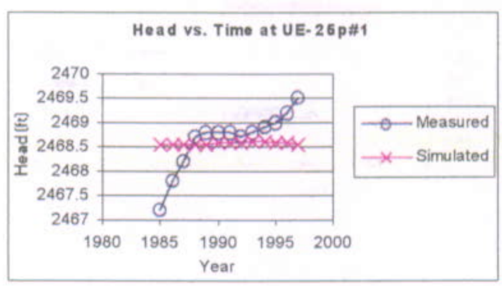


(u)



(v)

Figure 18 *(Continued)*. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model L2)

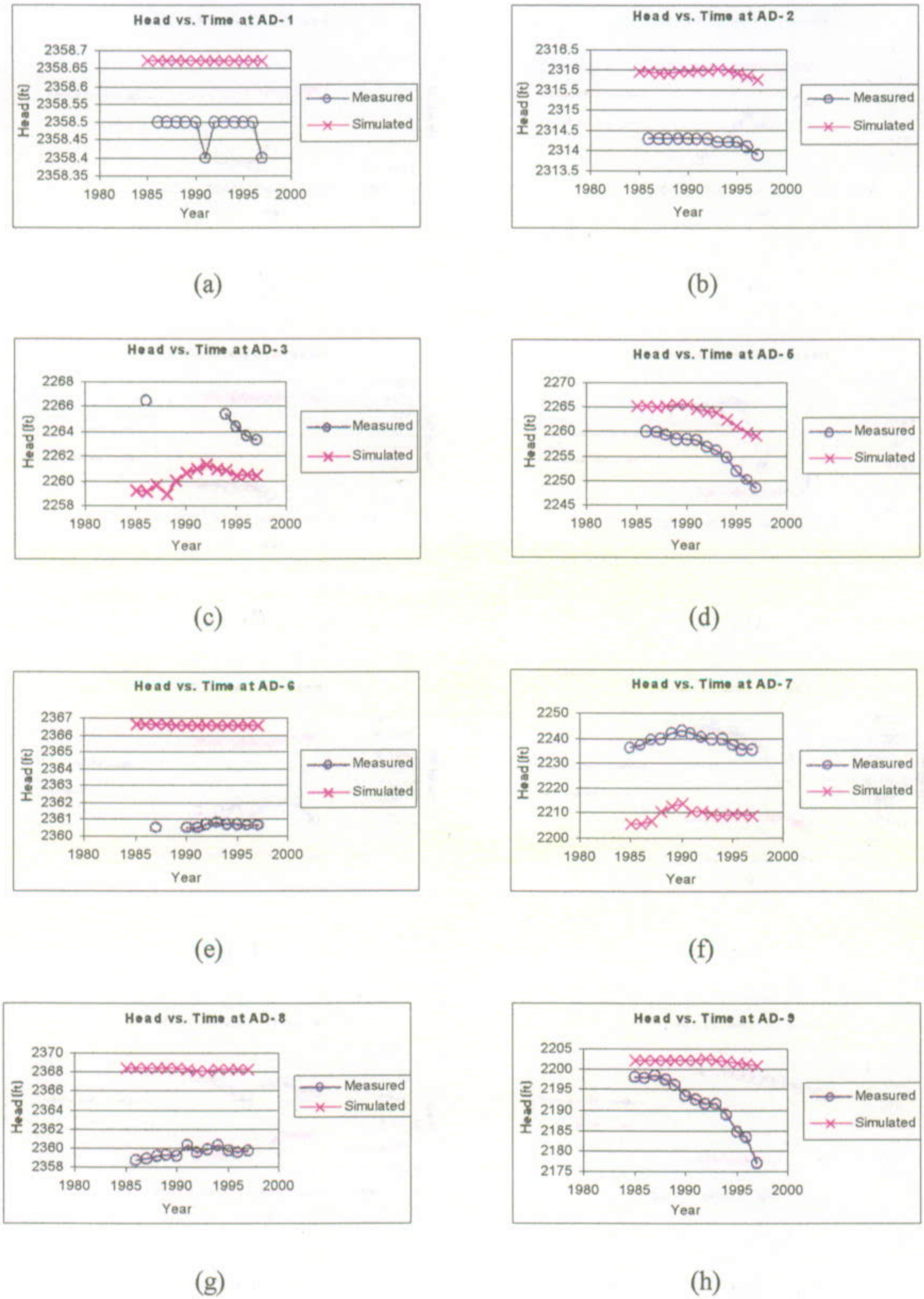
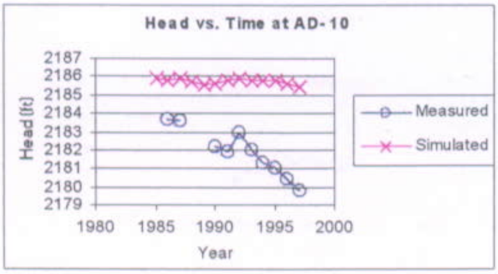
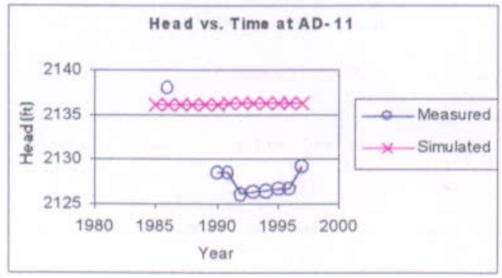


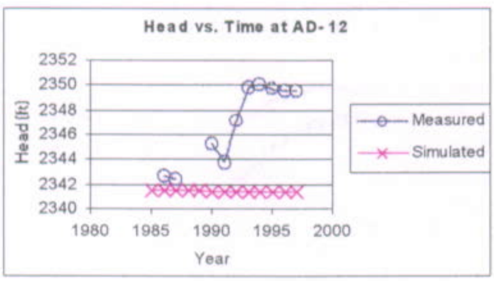
Figure 19. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model H1)



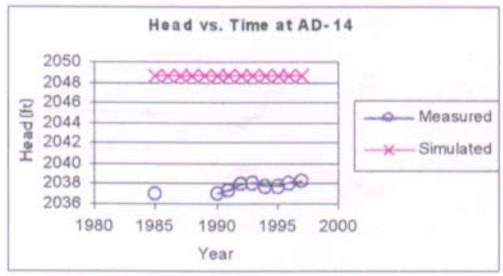
(i)



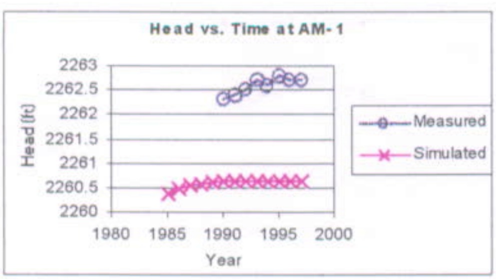
(j)



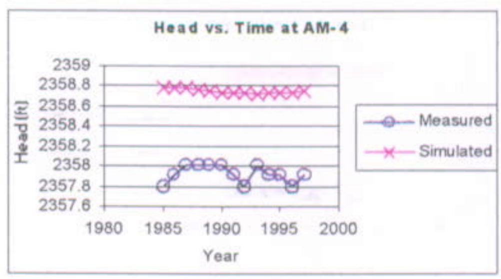
(k)



(l)



(m)



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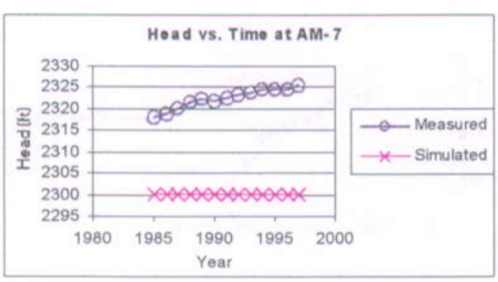
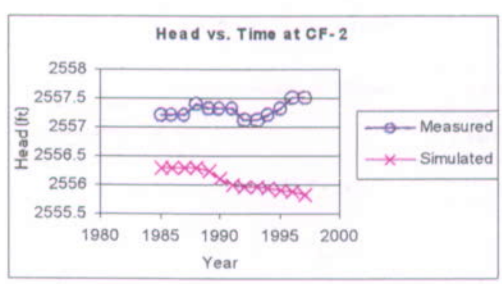
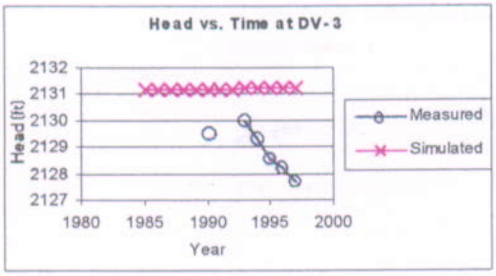


(o)

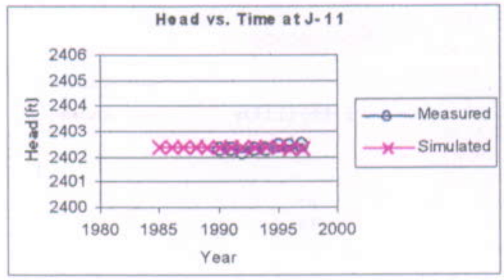


(p)

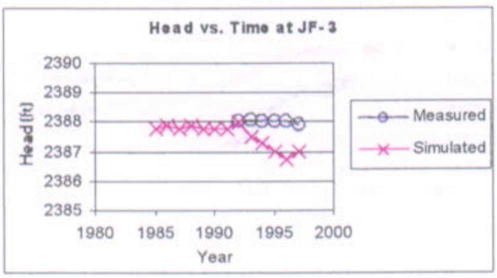
Figure 19 *(Continued)*. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model H1)



(q)



(r)



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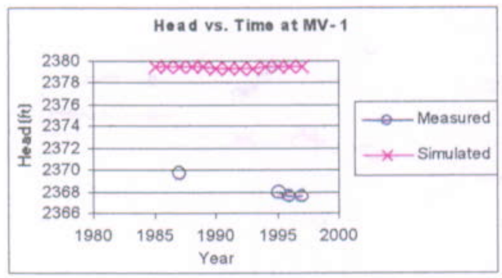
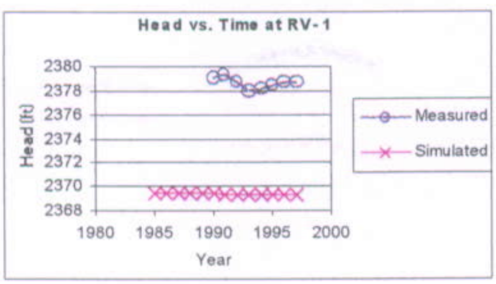
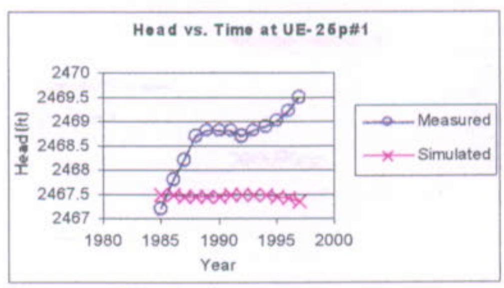


(t)



(u)



(v)

Figure 19 *(Continued)*. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model H1)

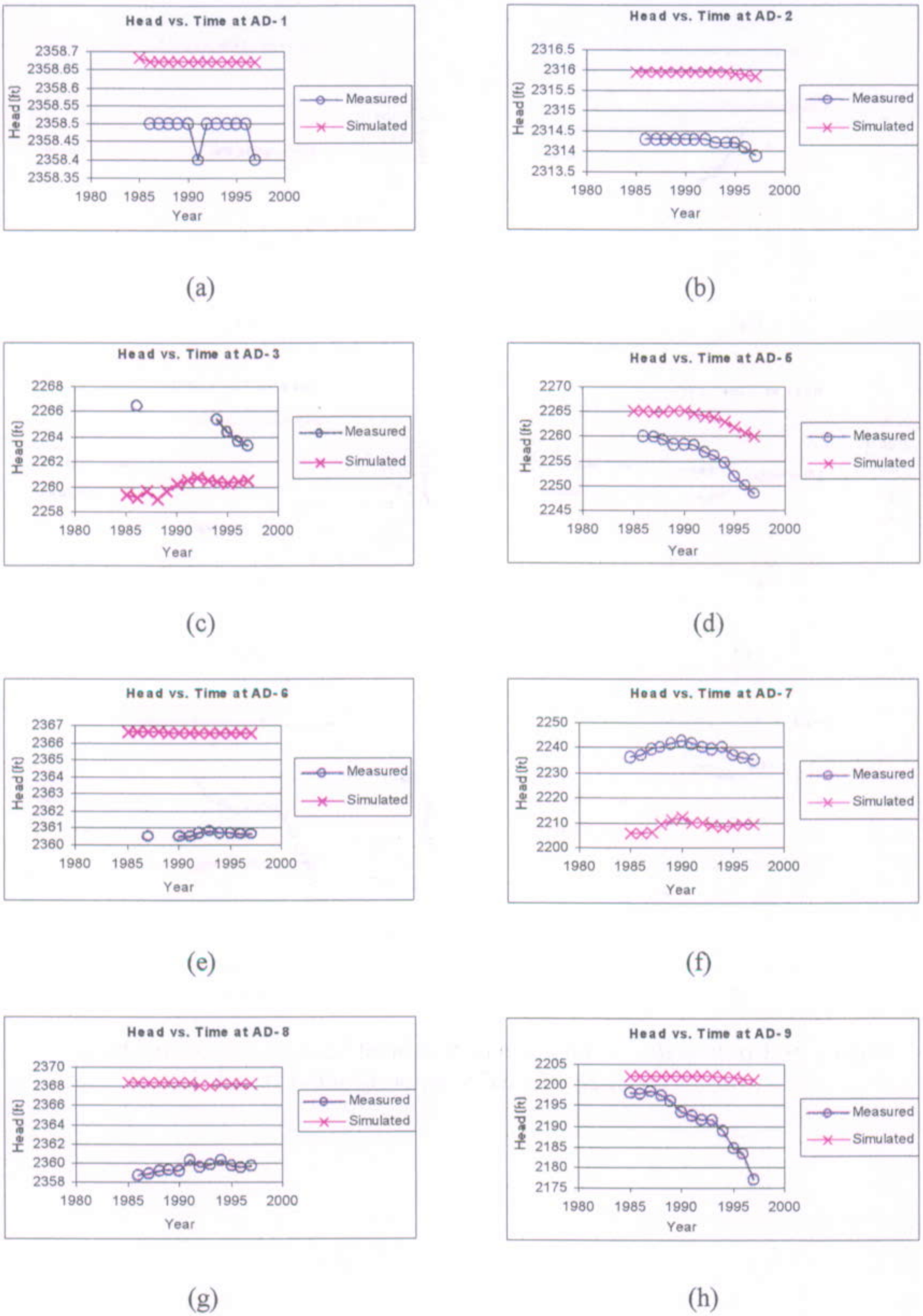
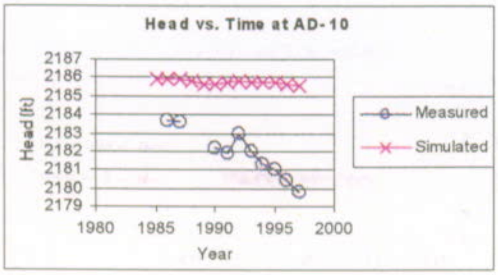
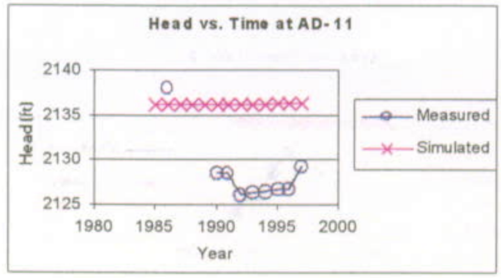


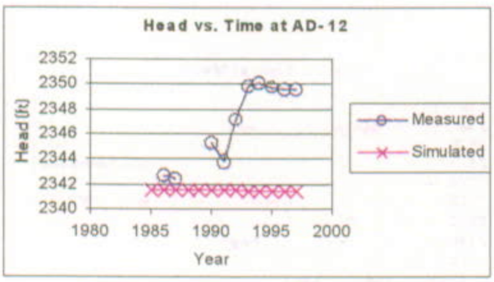
Figure 20. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model H2)



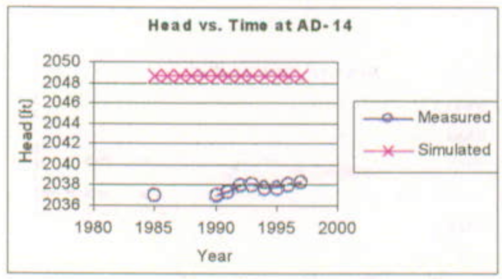
(i)



(j)



(k)



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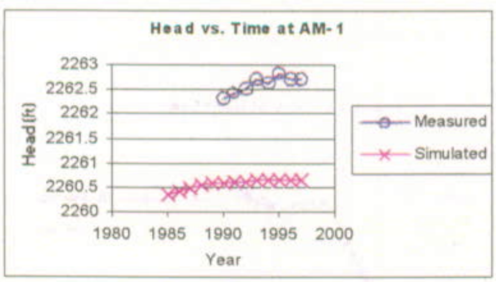
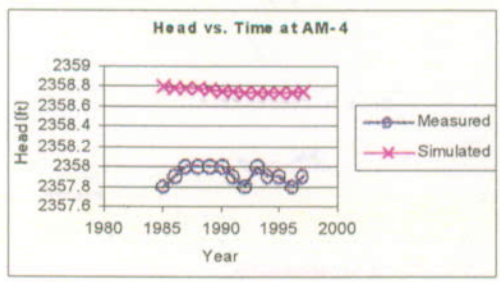
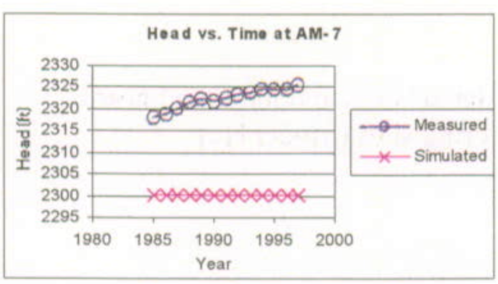


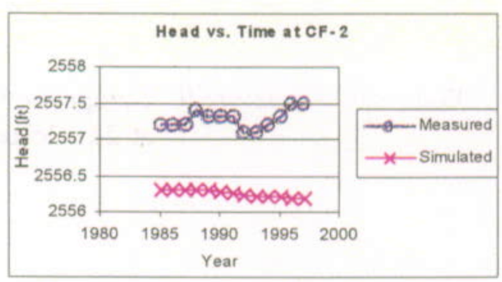
(m)



(n)

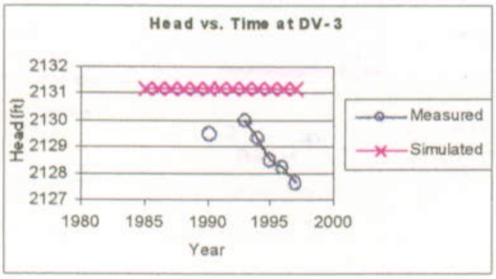


(o)

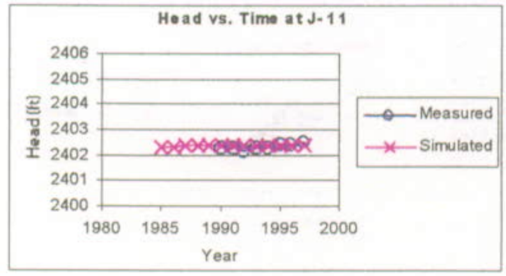


(p)

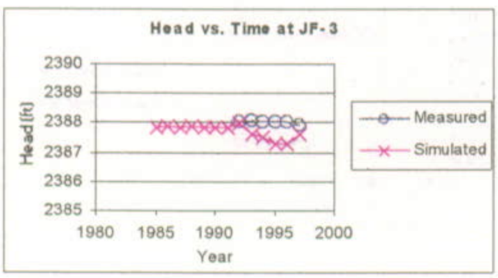
Figure 20 *(Continued)*. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model H2)



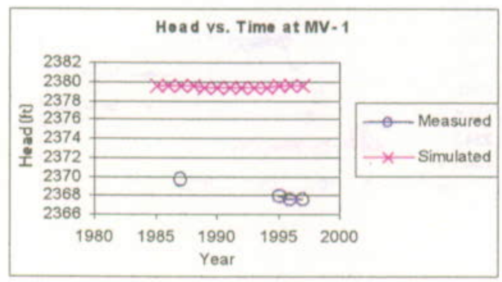
(q)



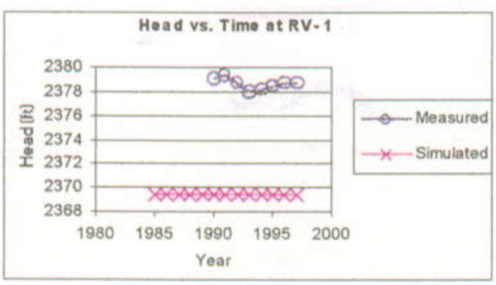
(r)



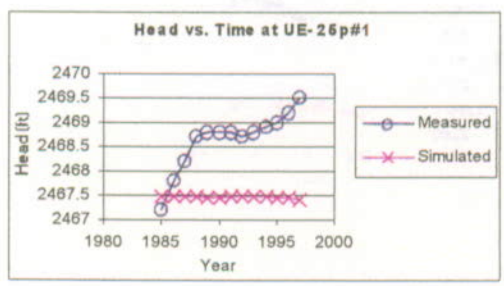
(s)



(t)



(u)



(v)

Figure 20 *(Continued)*. Comparison of simulated heads and measured heads at 22 selected monitoring sites (Model H2)

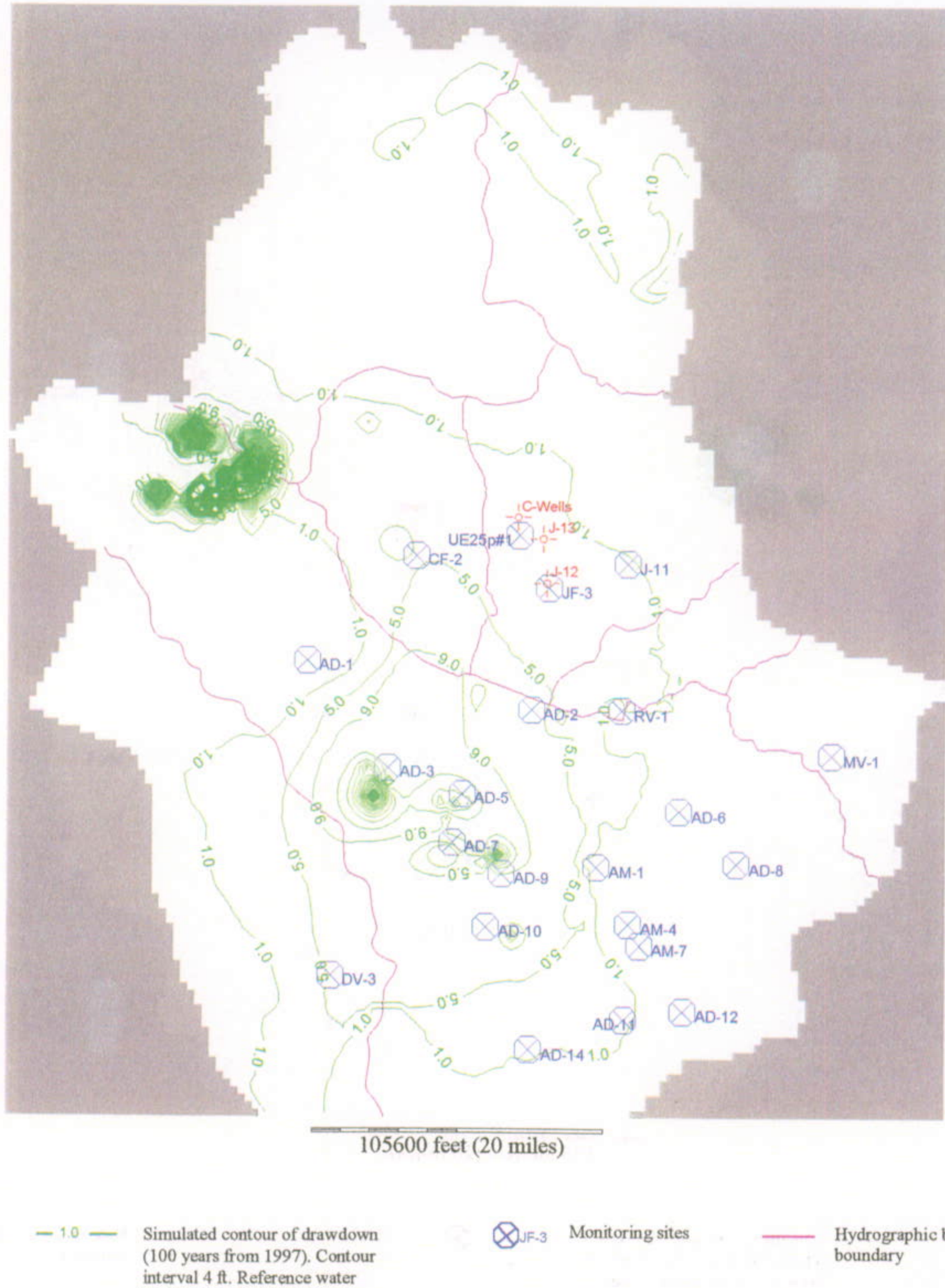
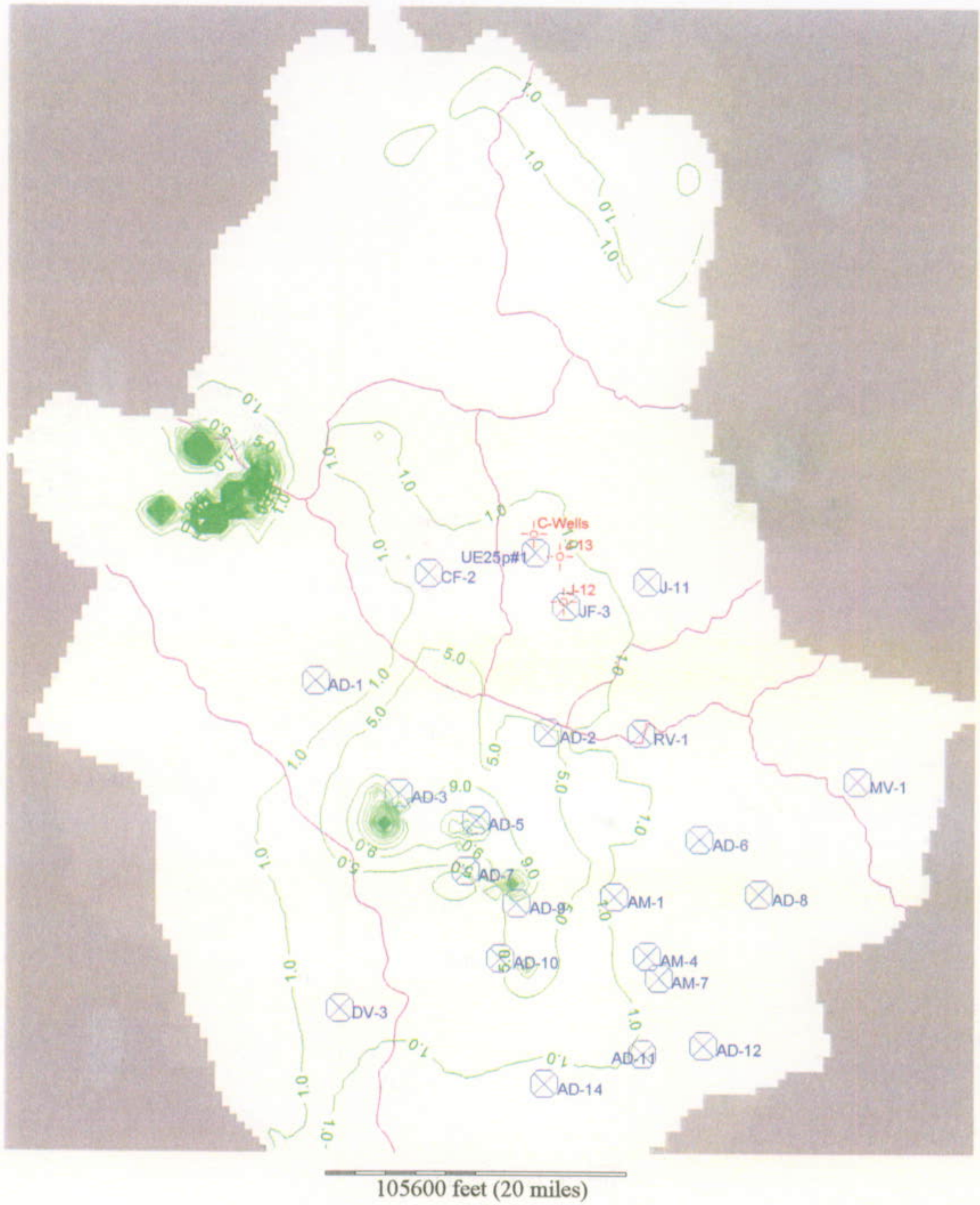


Figure 21 (a). Simulated drawdown of Scenario 1 (Top layer of Model L1)
(Historical water use context without the proposed DOE appropriation)

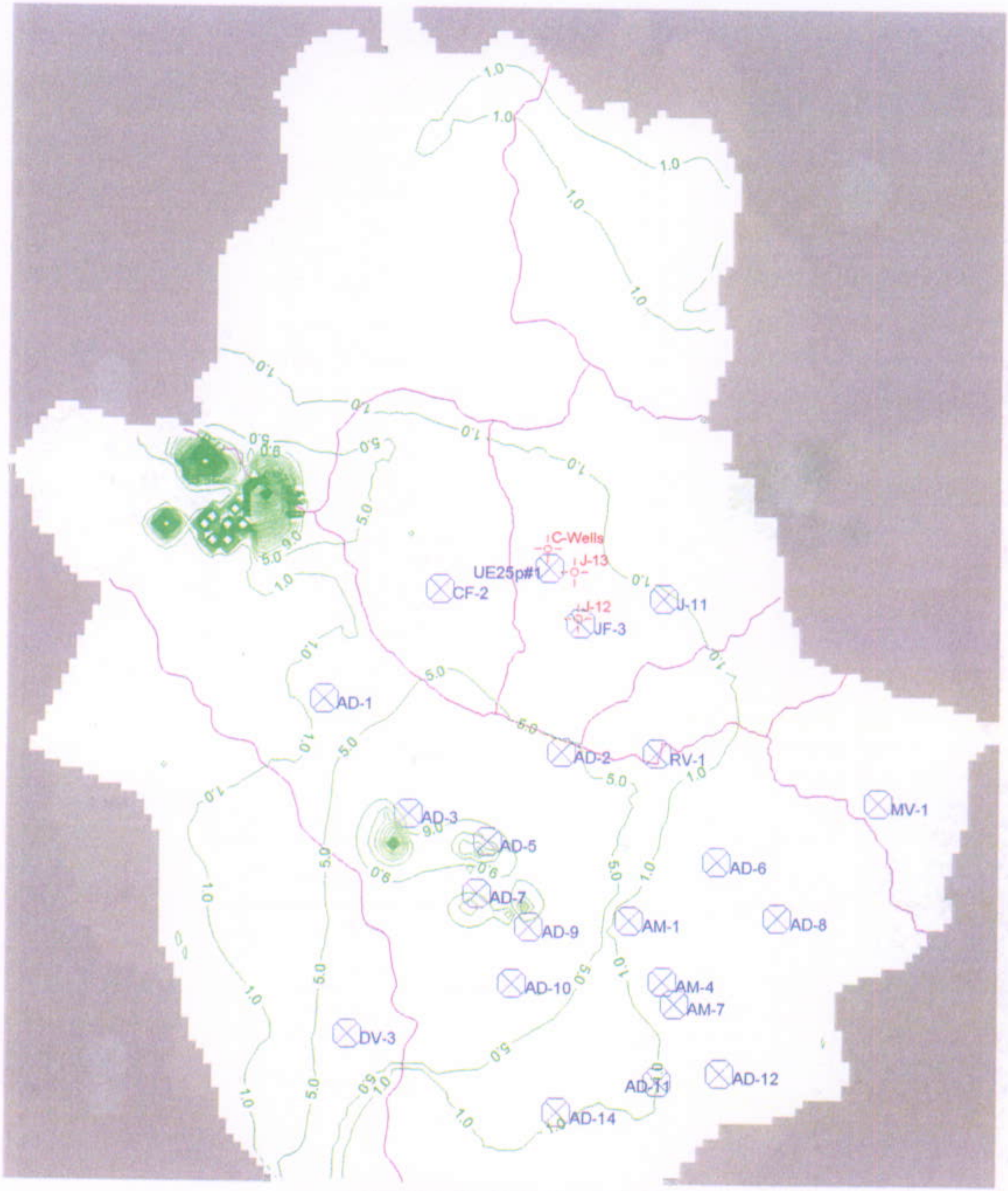


— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 21 (b). Simulated drawdown of Scenario 1 (Top layer of Model L2)
(Historical water use context without the proposed DOE appropriation)



105600 feet (20 miles)

— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

UF-3 Monitoring sites

Hydrographic basin boundary

Figure 21 (c). Simulated drawdown of Scenario 1 (Top layer of Model H1)
(Historical water use context without the proposed DOE appropriation)

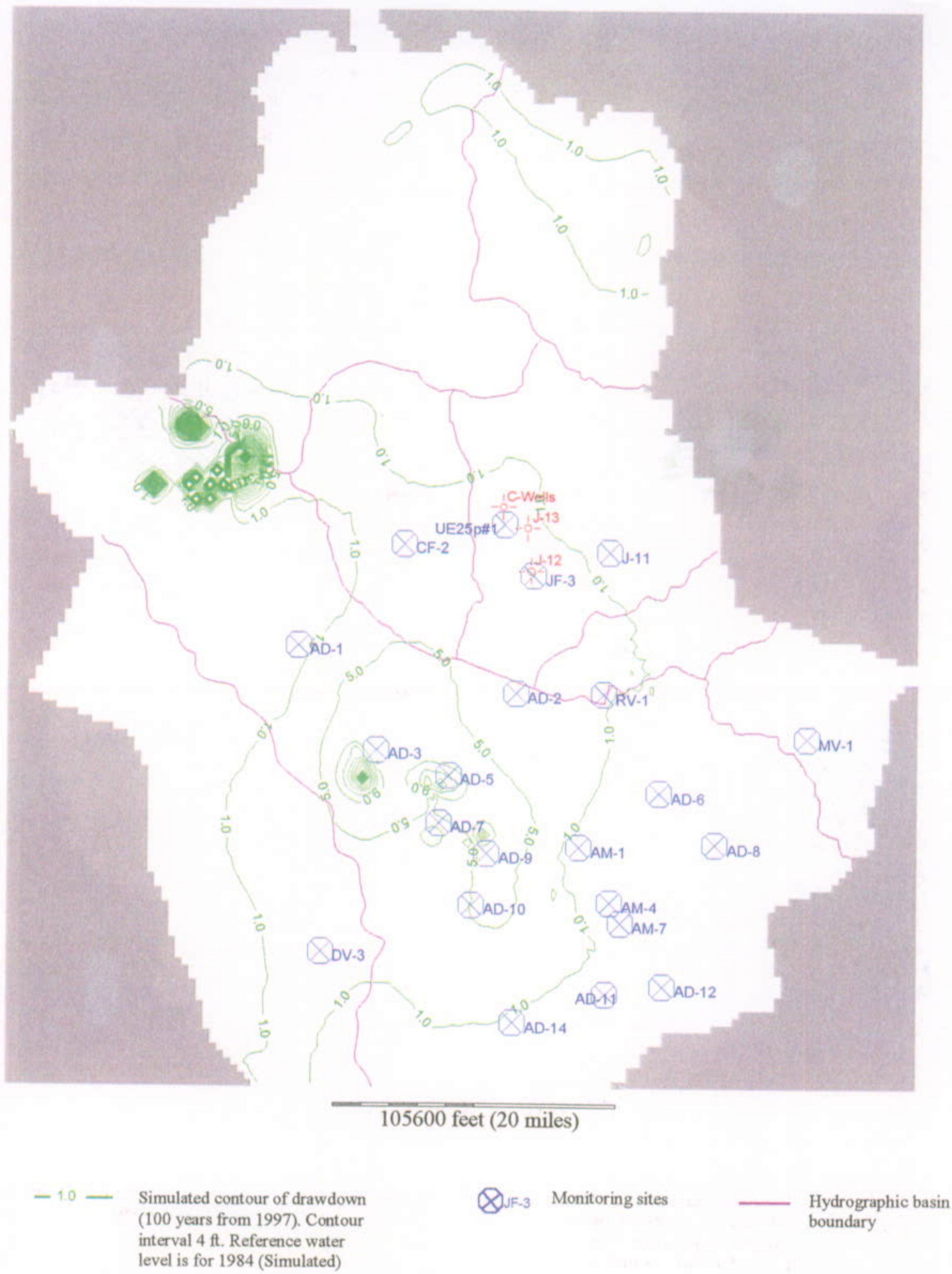
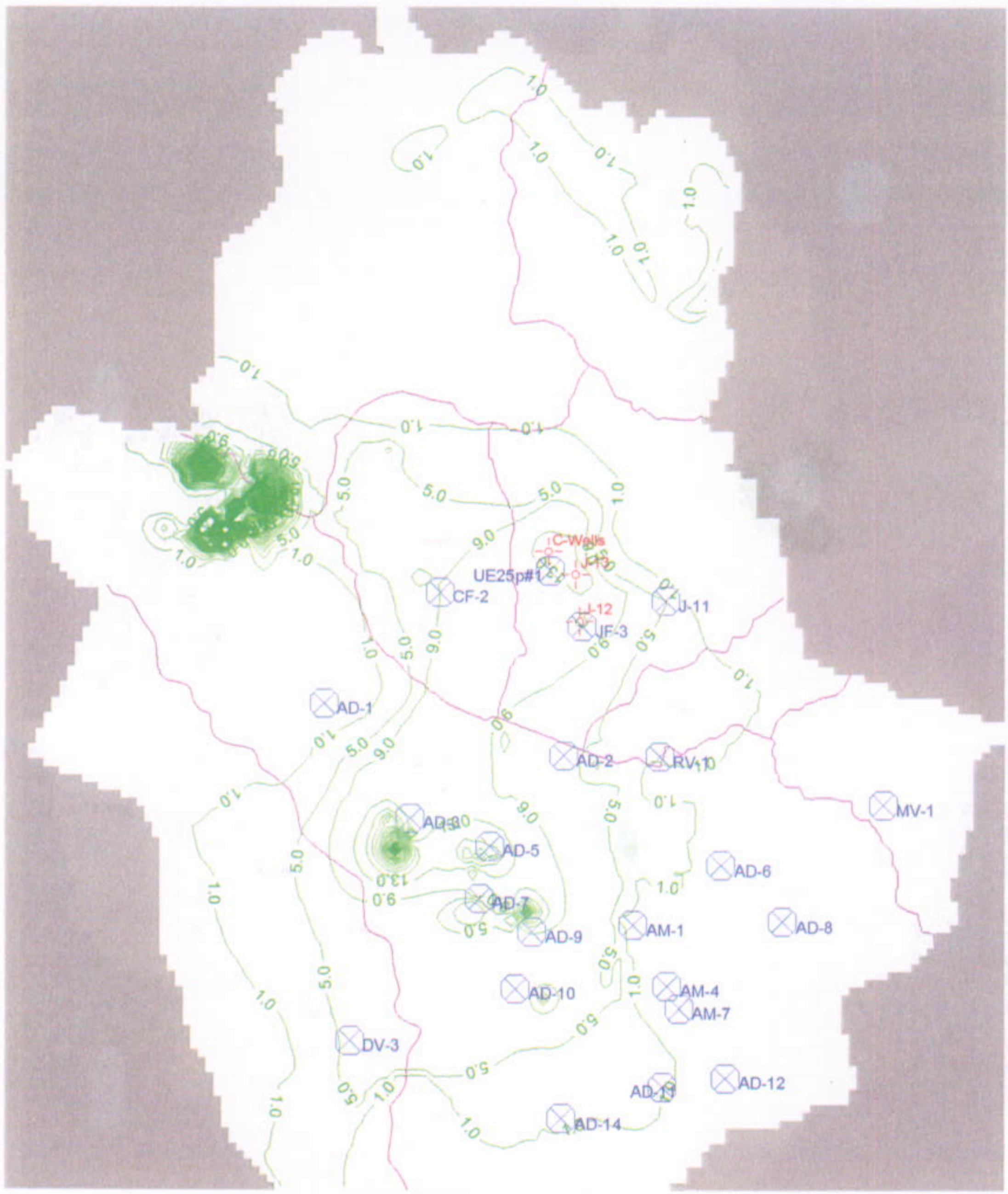


Figure 21 (d). Simulated drawdown of Scenario 1 (Top layer of Model H2)
(Historical water use context without the proposed DOE appropriation)



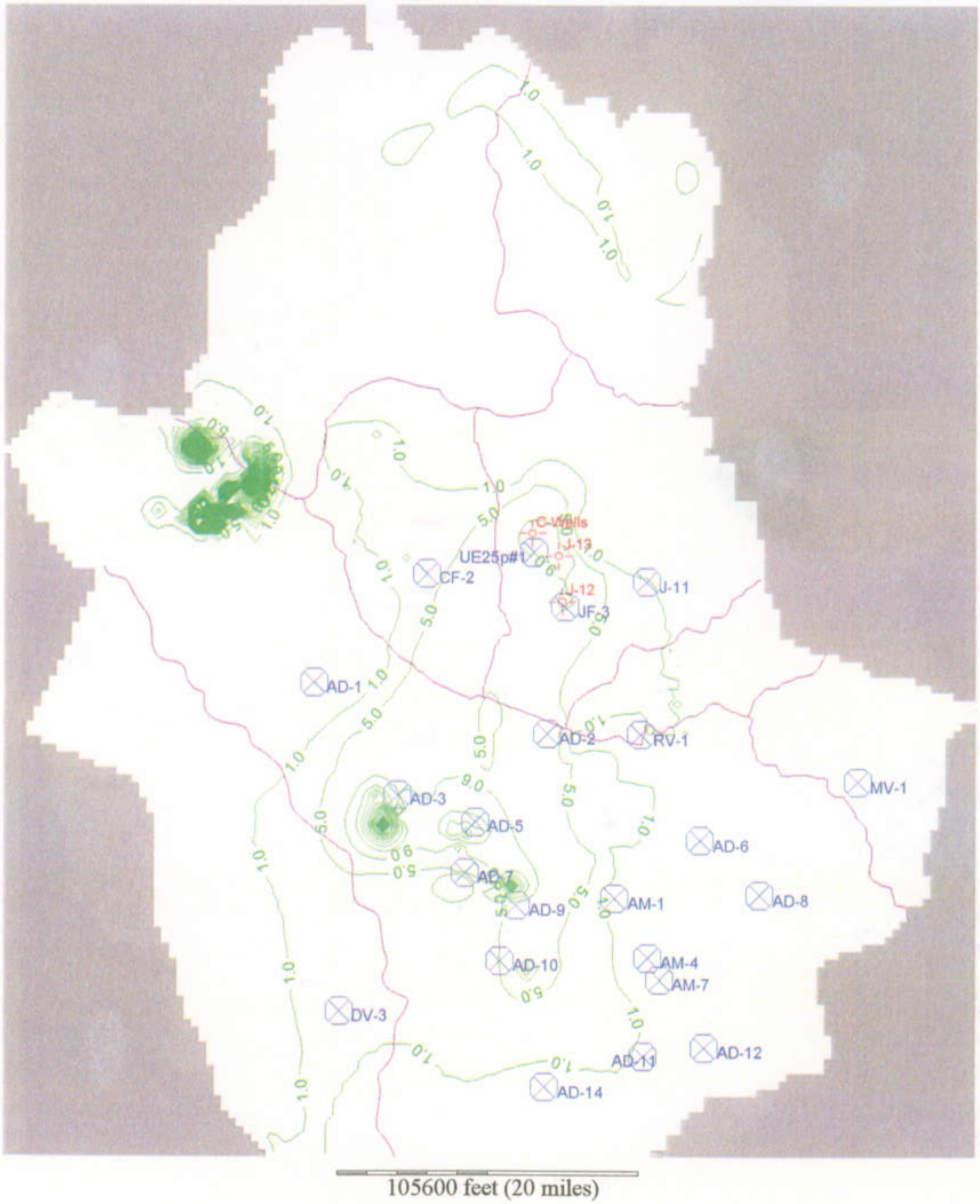
105600 feet (20 miles)

— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 22 (a). Simulated drawdown of Scenario 2 (Top layer of Model L1)
(Historical water use context with the proposed DOE appropriation)

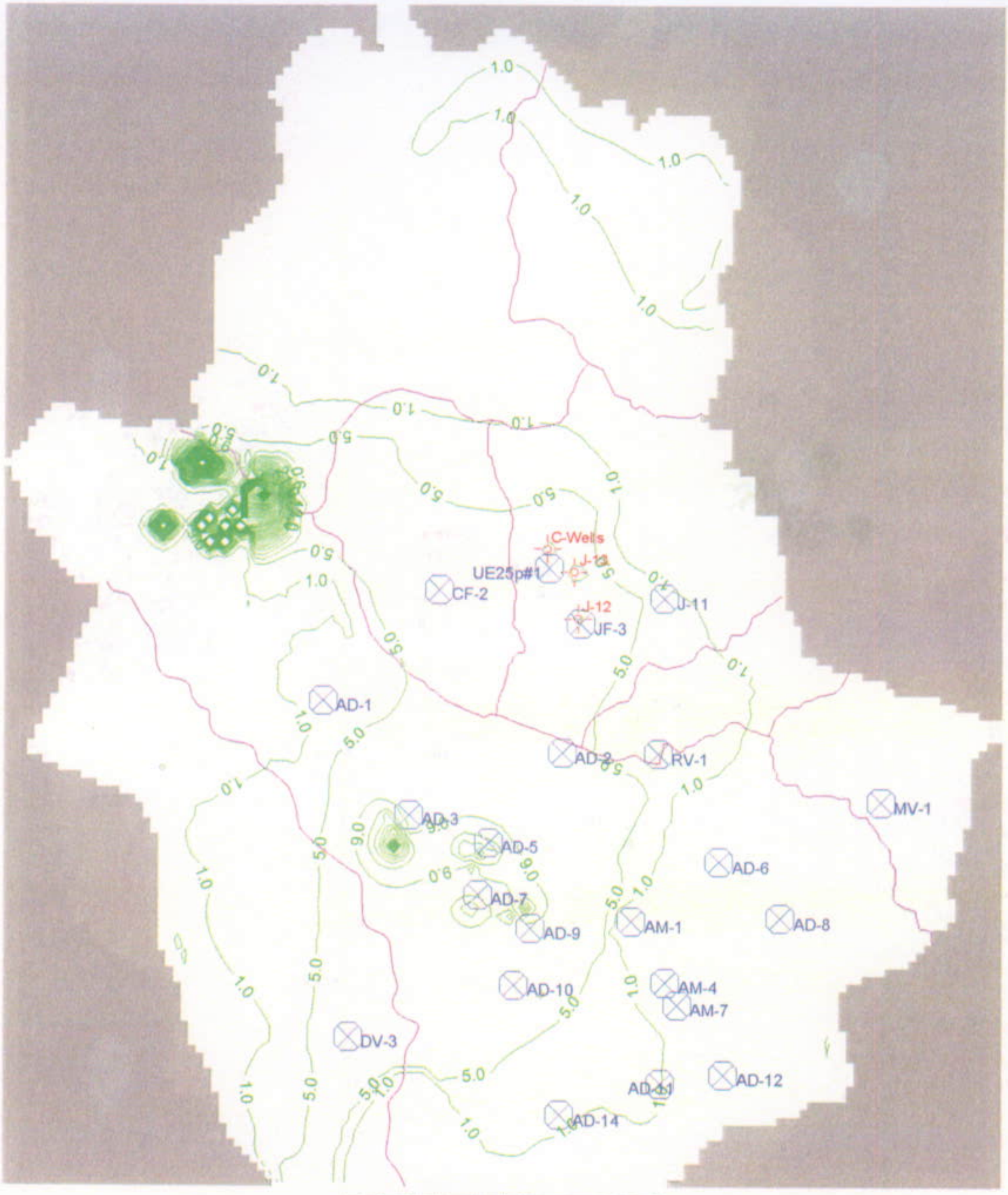


1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 22 (b). Simulated drawdown of Scenario 2 (Top layer of Model L2)
(Historical water use context with the proposed DOE appropriation)

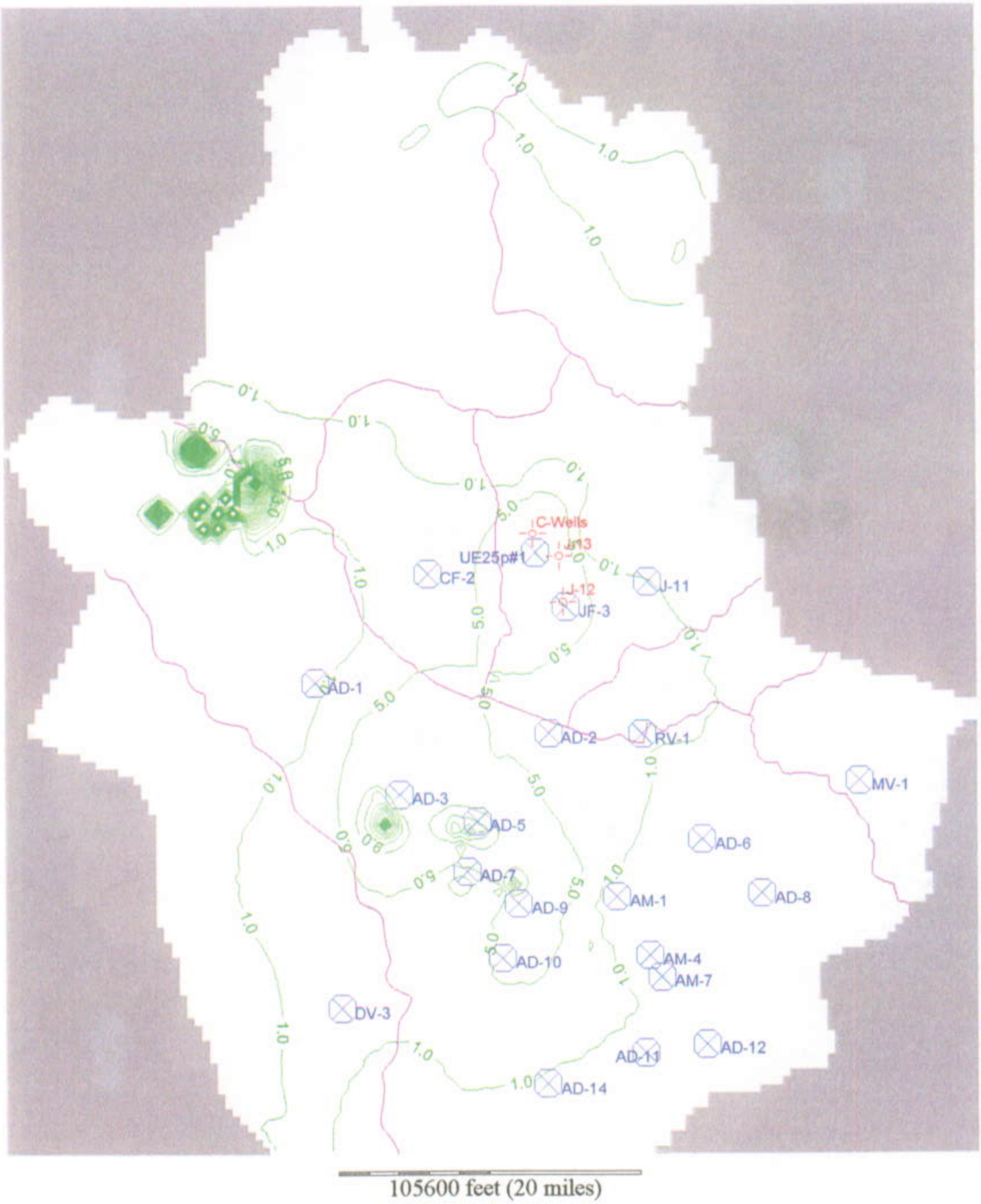


1.0 Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 22 (c). Simulated drawdown of Scenario 2 (Top layer of Model H1)
(Historical water use context with the proposed DOE appropriation)

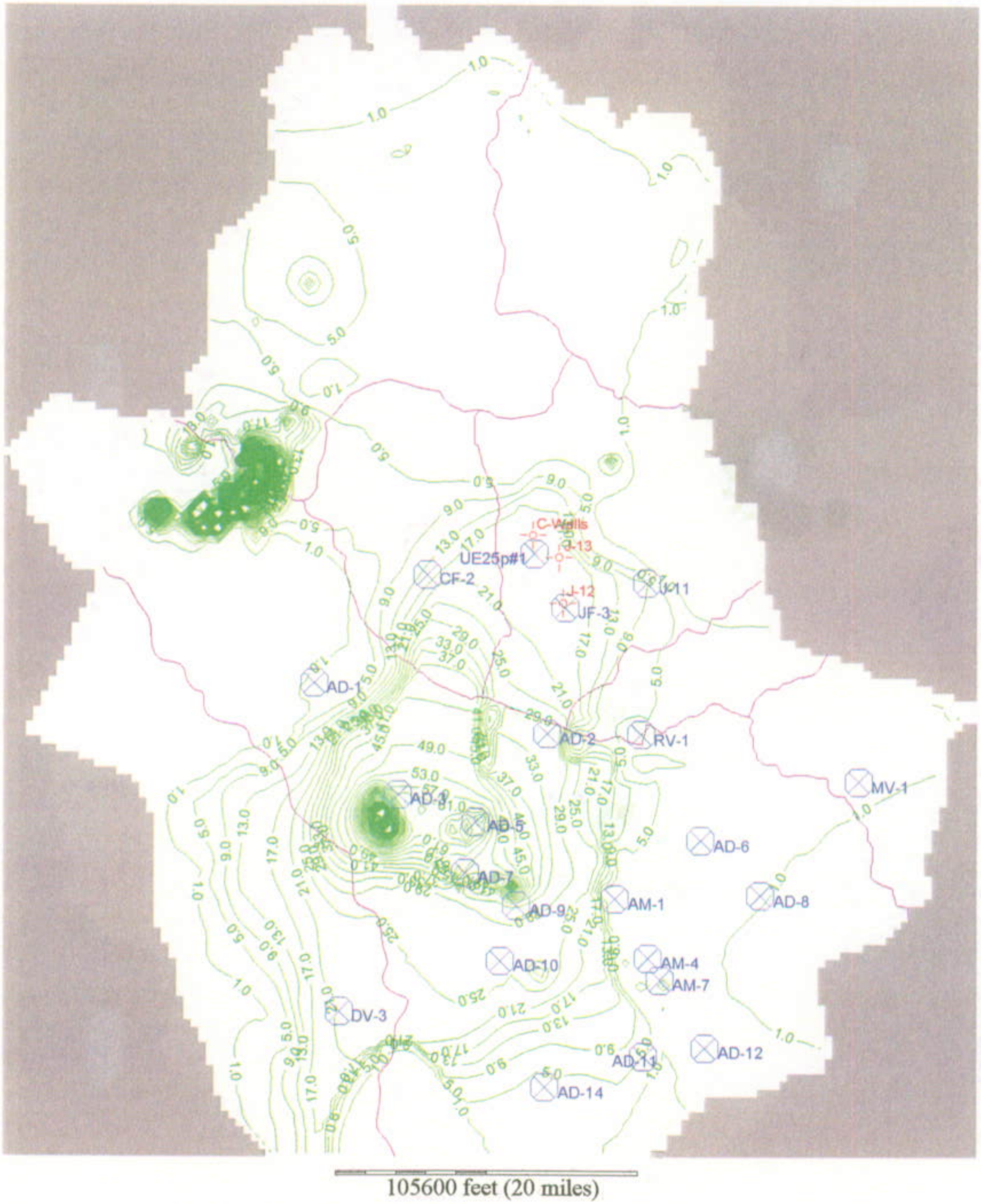


— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 22 (d). Simulated drawdown of Scenario 2 (Top layer of Model H2)
(Historical water use context with the proposed DOE appropriation)

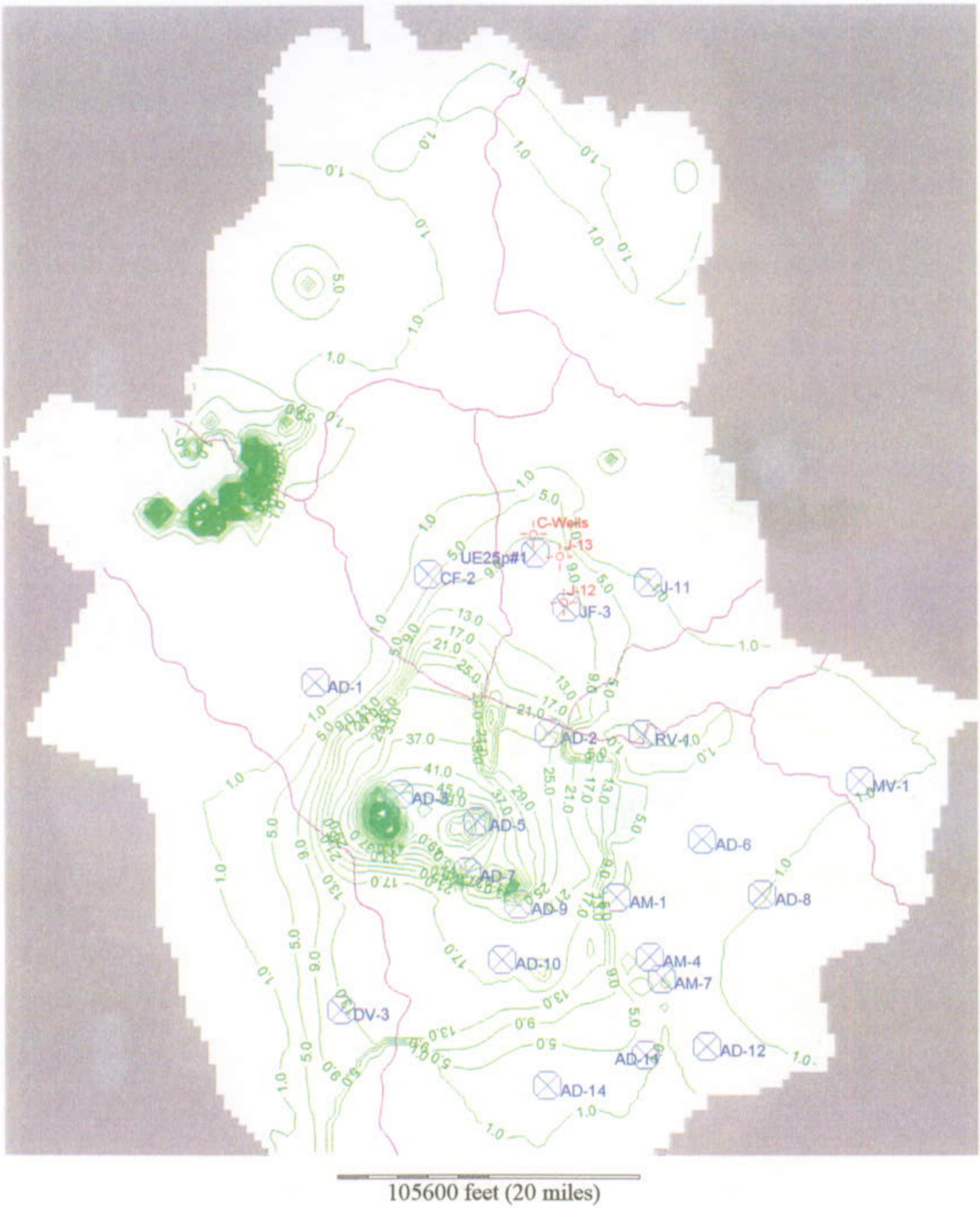


— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 23 (a). Simulated drawdown of Scenario 3 (Top layer of Model L1)
(Maximum use of senior water rights context without the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 23 (b). Simulated drawdown of Scenario 3 (Top layer of Model L2)
(Maximum use of senior water rights context without the proposed DOE appropriation)

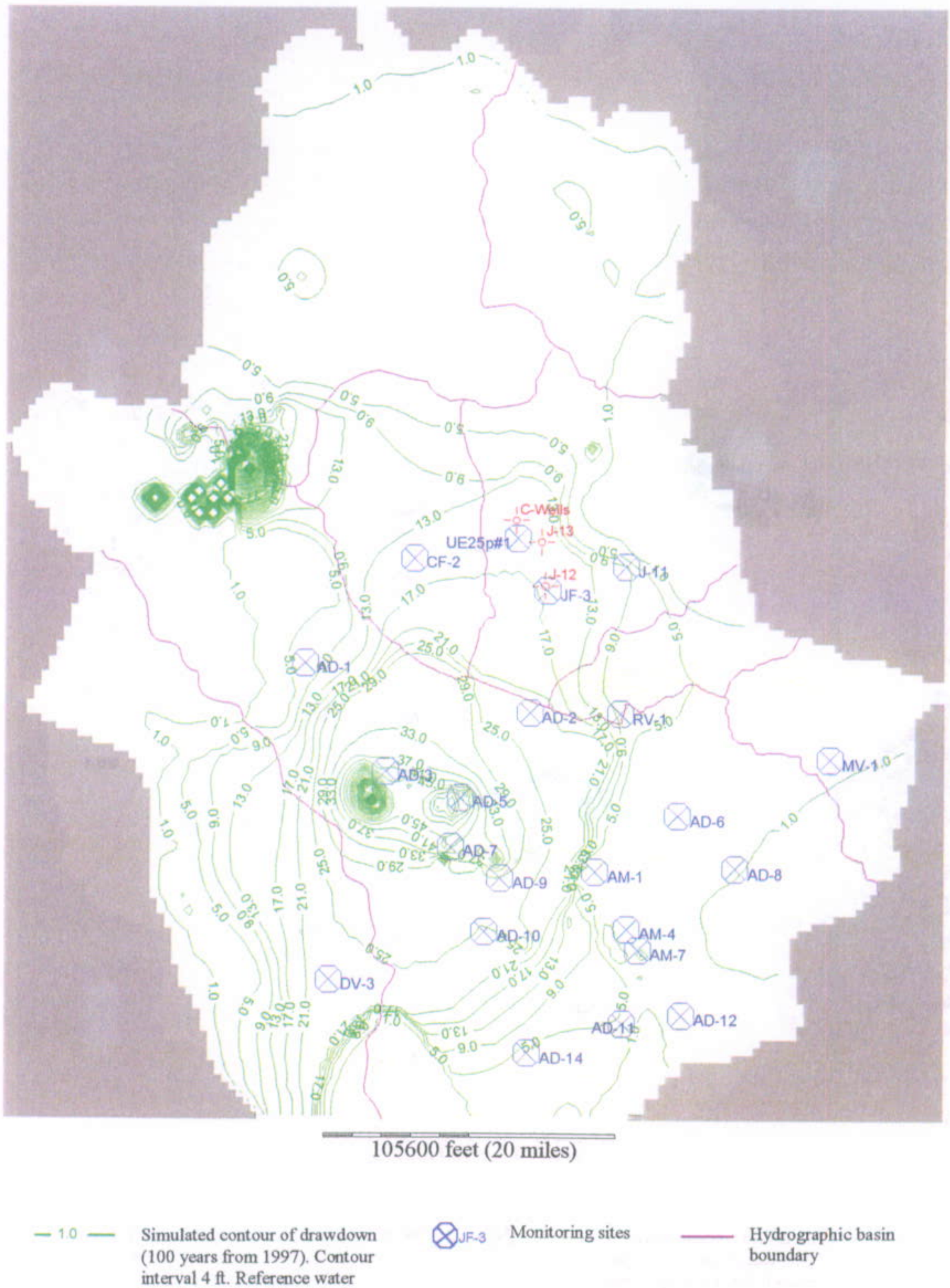
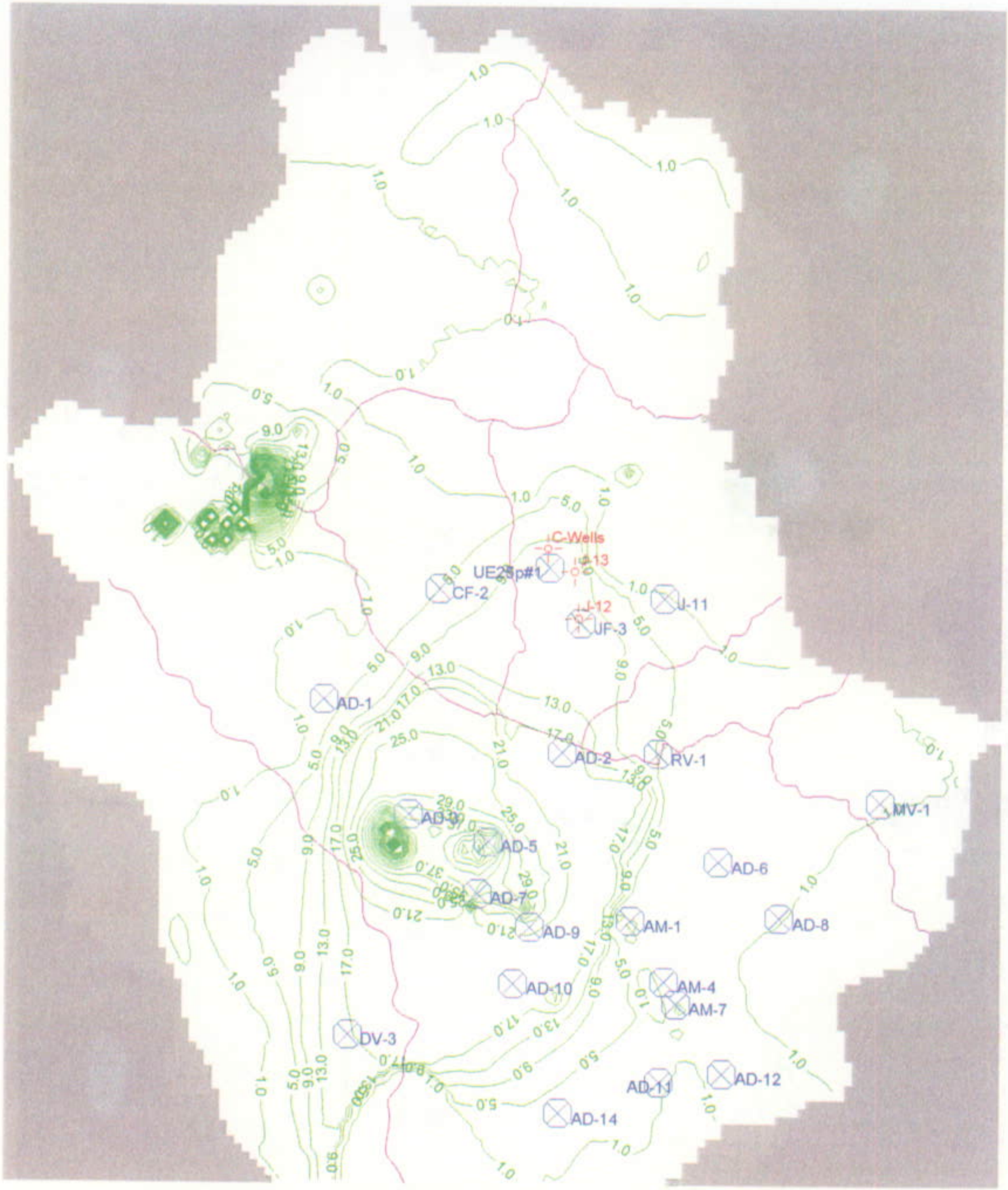


Figure 23 (c). Simulated drawdown of Scenario 3 (Top layer of Model H1)
(Maximum use of senior water rights context without the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

⊗JF-3 Monitoring sites

—— Hydrographic basin boundary

Figure 23 (d). Simulated drawdown of Scenario 3 (Top layer of Model H2)
(Maximum use of senior water rights context without the proposed DOE appropriation)

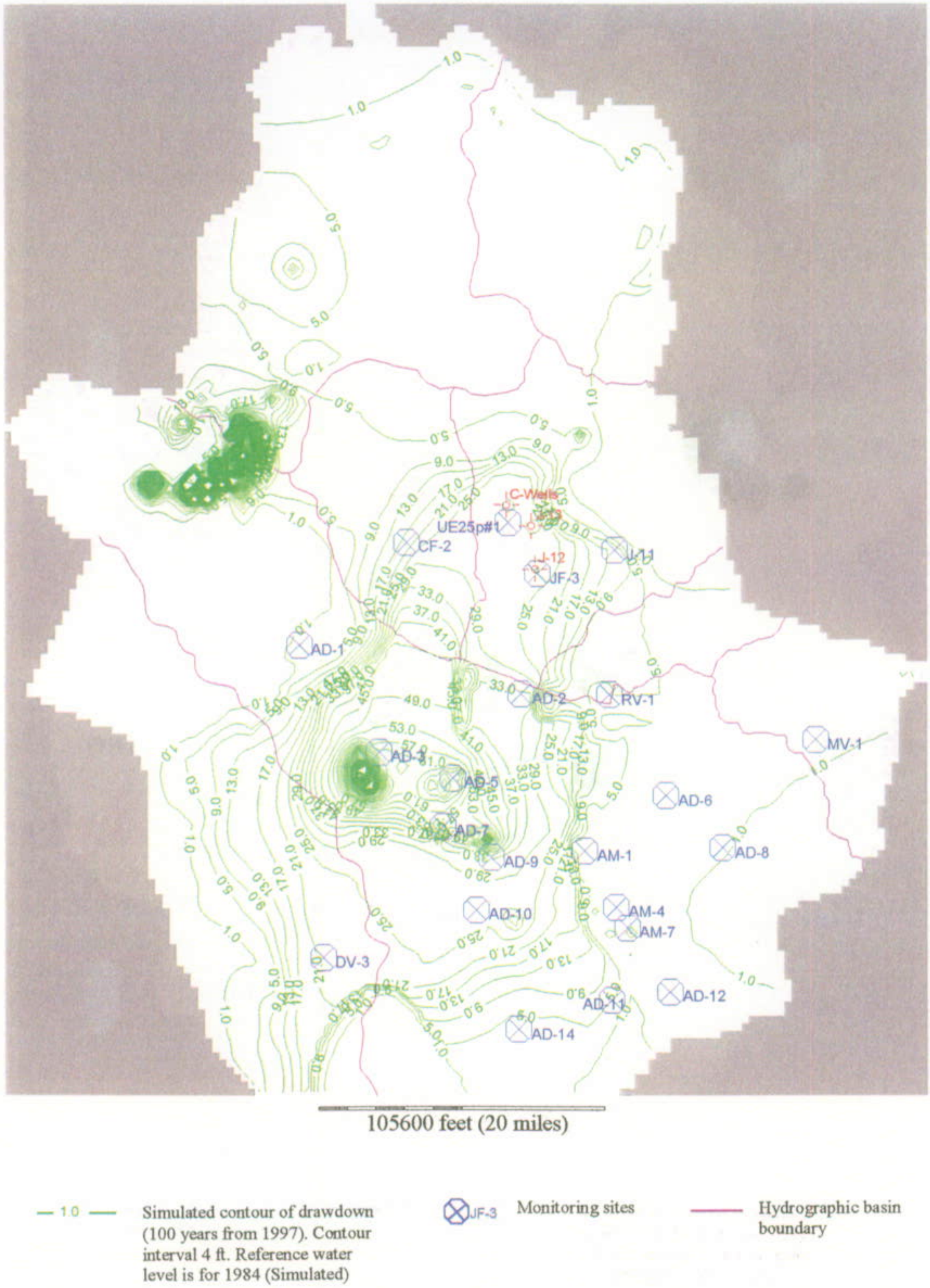
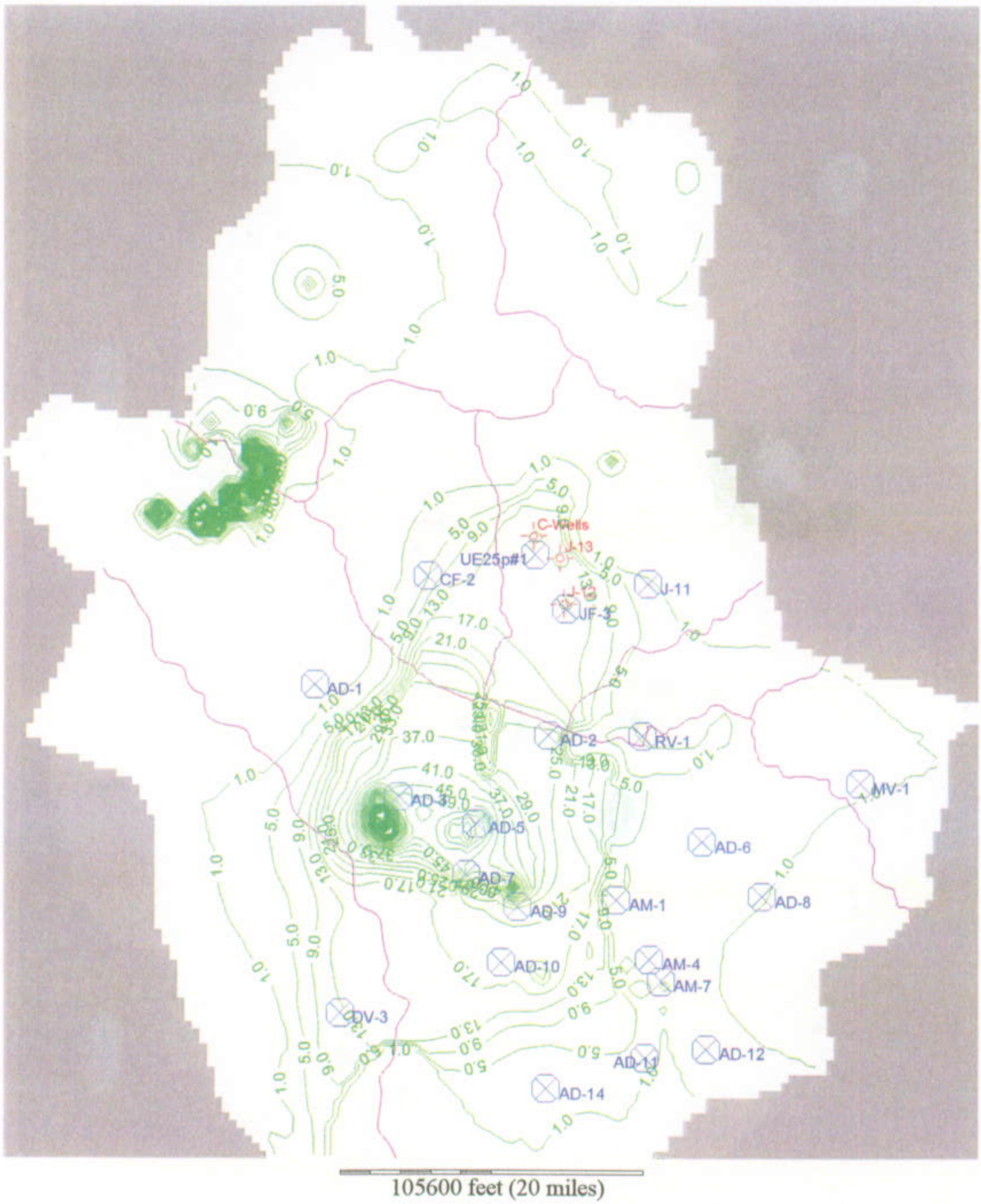


Figure 24 (a). Simulated drawdown of Scenario 4 (Top layer of Model L1)
(Maximum use of senior water rights context with the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 24 (b). Simulated drawdown of Scenario 4 (Top layer of Model L2)
(Maximum use of senior water rights context with the proposed DOE appropriation)

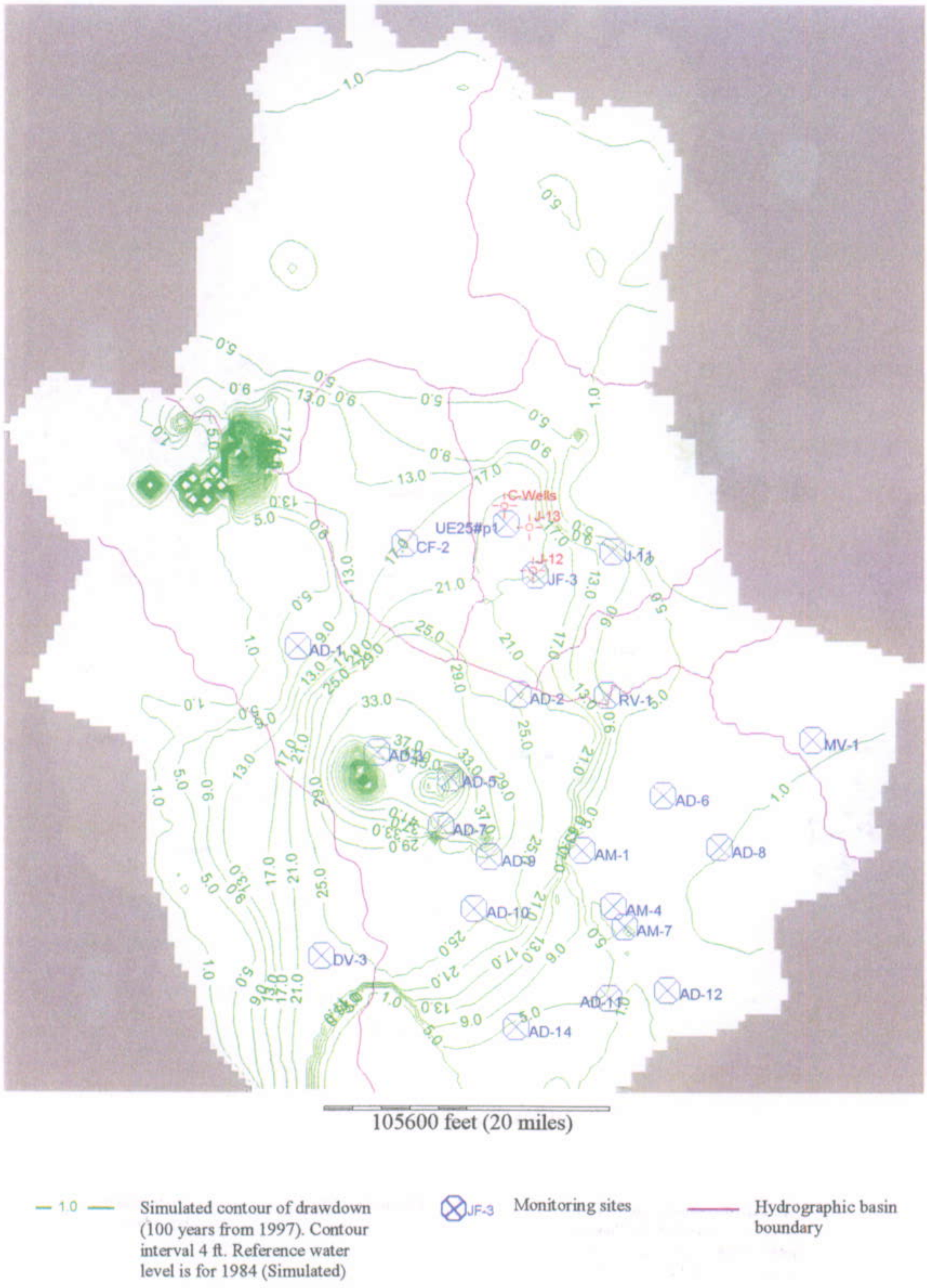
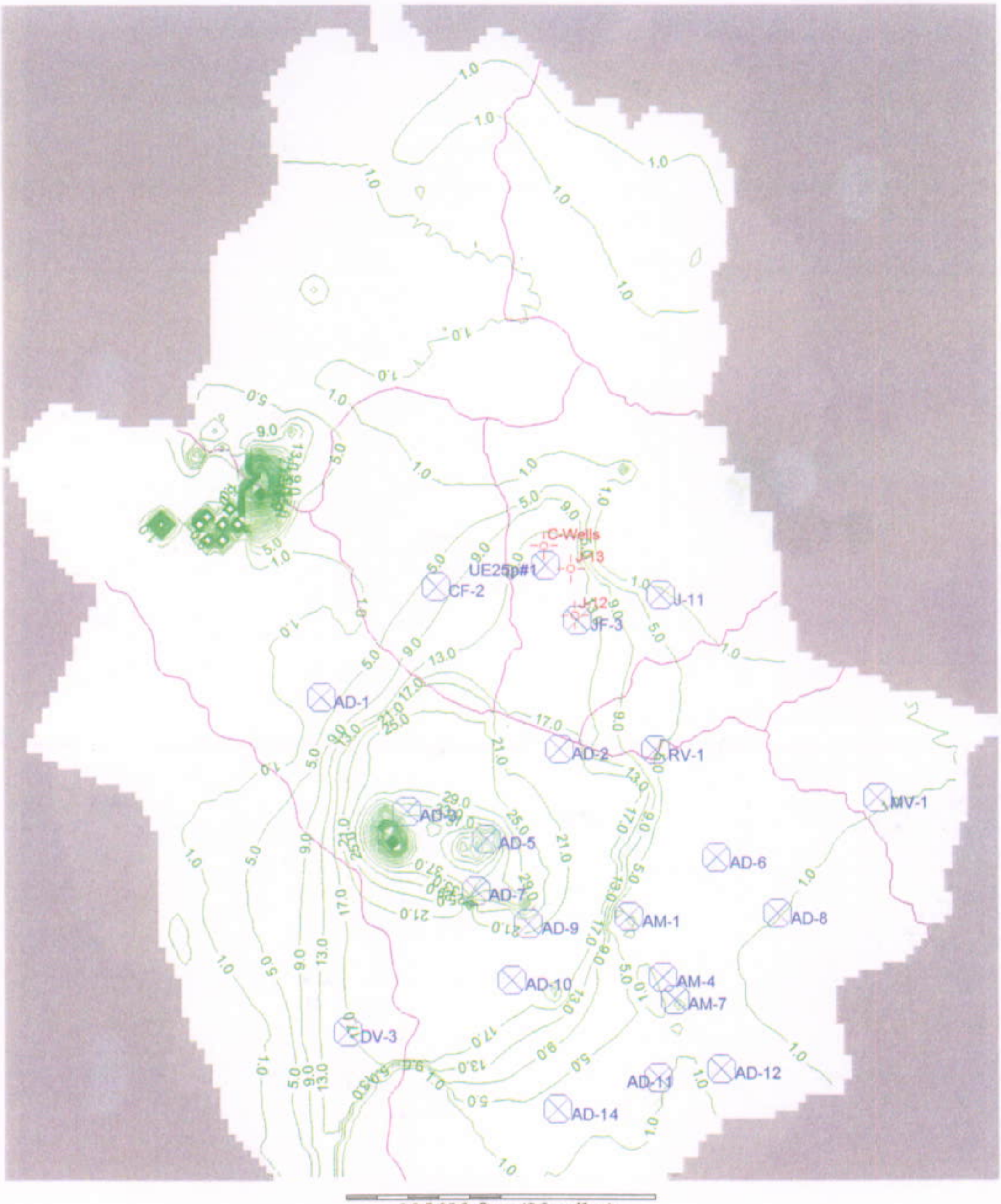


Figure 24 (c). Simulated drawdown of Scenario 4 (Top layer of Model H1)
(Maximum use of senior water rights context with the proposed DOE appropriation)

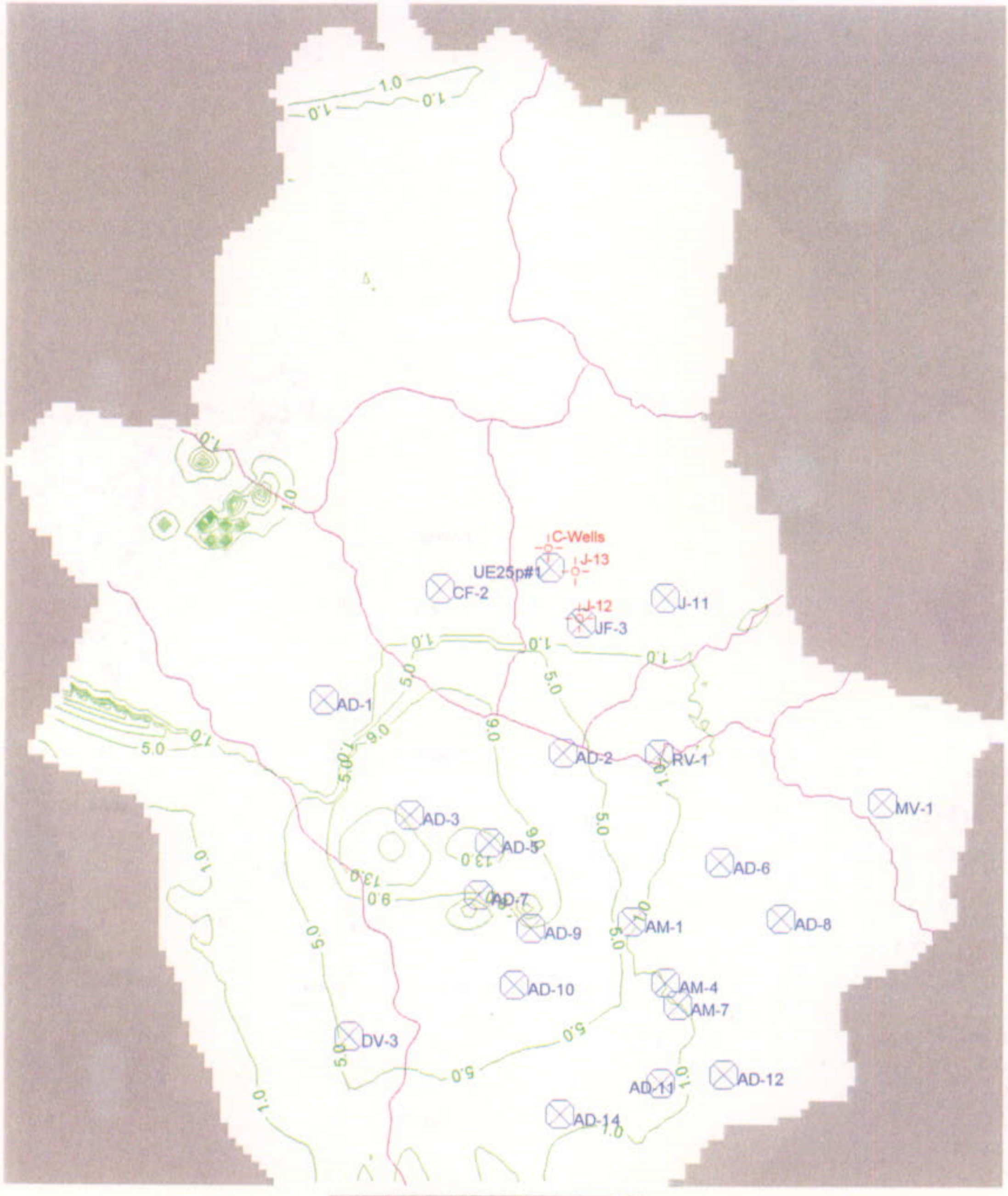


— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 24 (d). Simulated drawdown of Scenario 4 (Top layer of Model H2)
(Maximum use of senior water rights context with the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 25 (a). Simulated drawdown of Scenario 1 (Central layer of Model L1)
(Historical water use context without the proposed DOE appropriation)

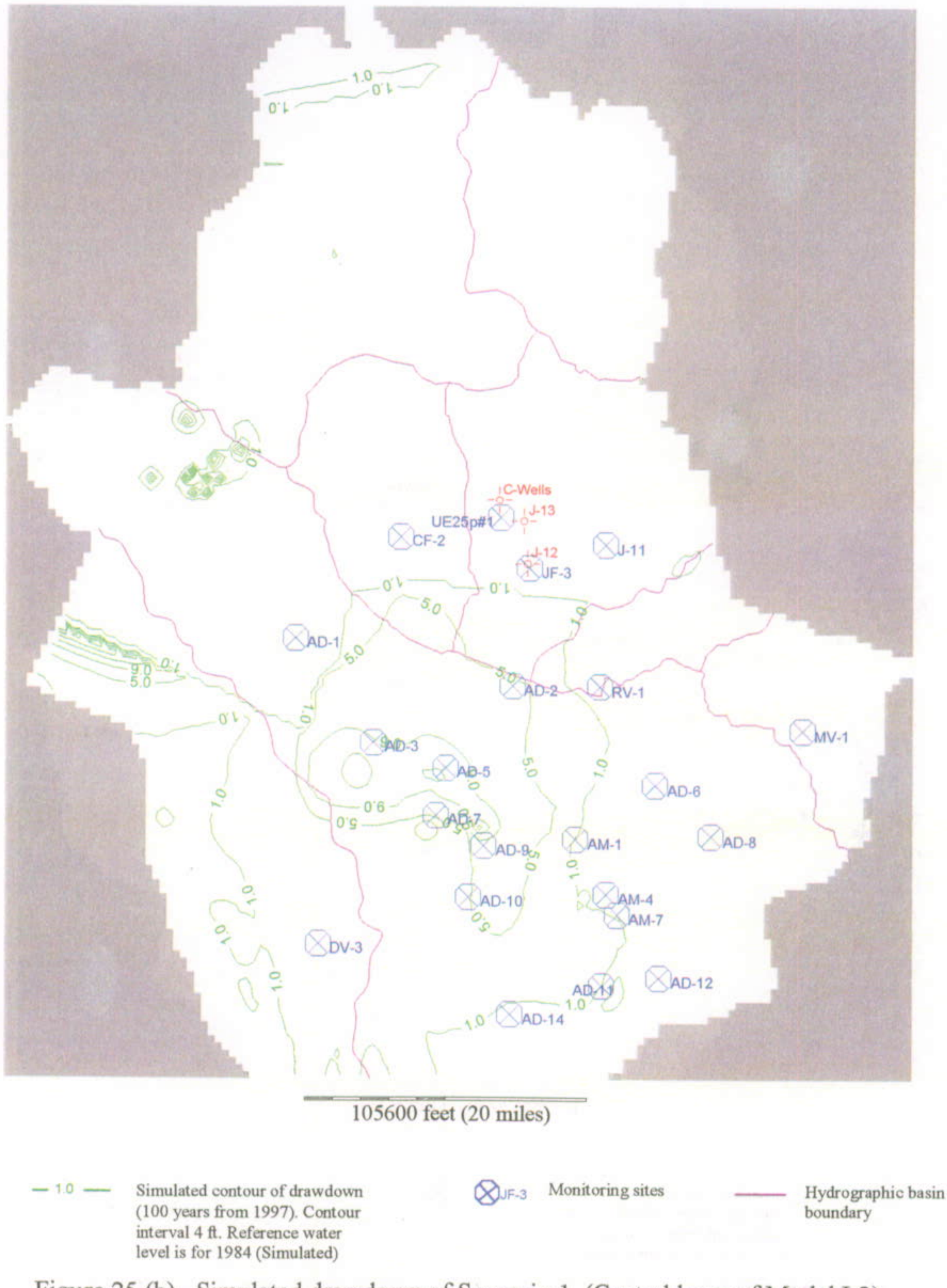
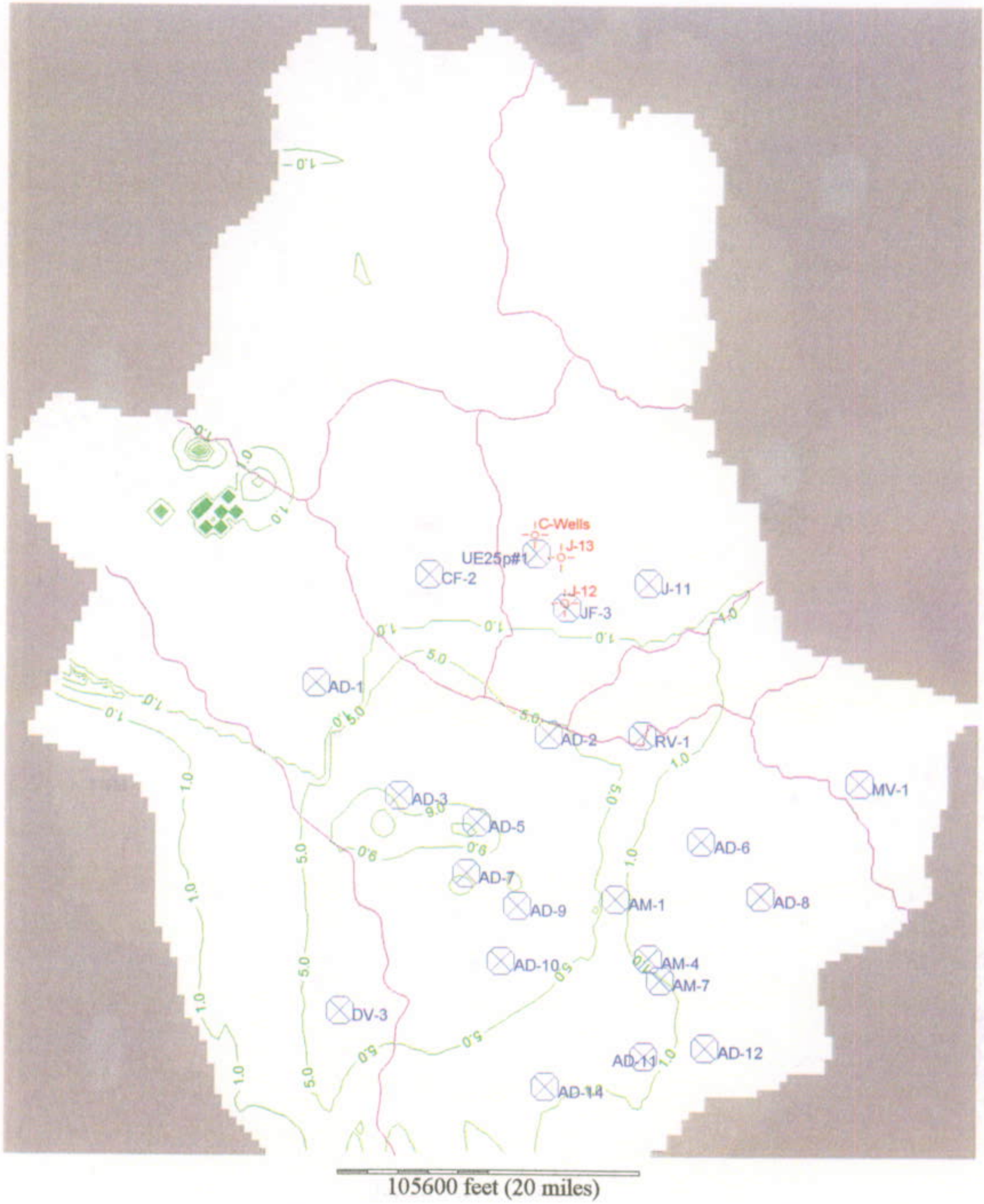


Figure 25 (b). Simulated drawdown of Scenario 1 (Central layer of Model L2)
(Historical water use context without the proposed DOE appropriation)

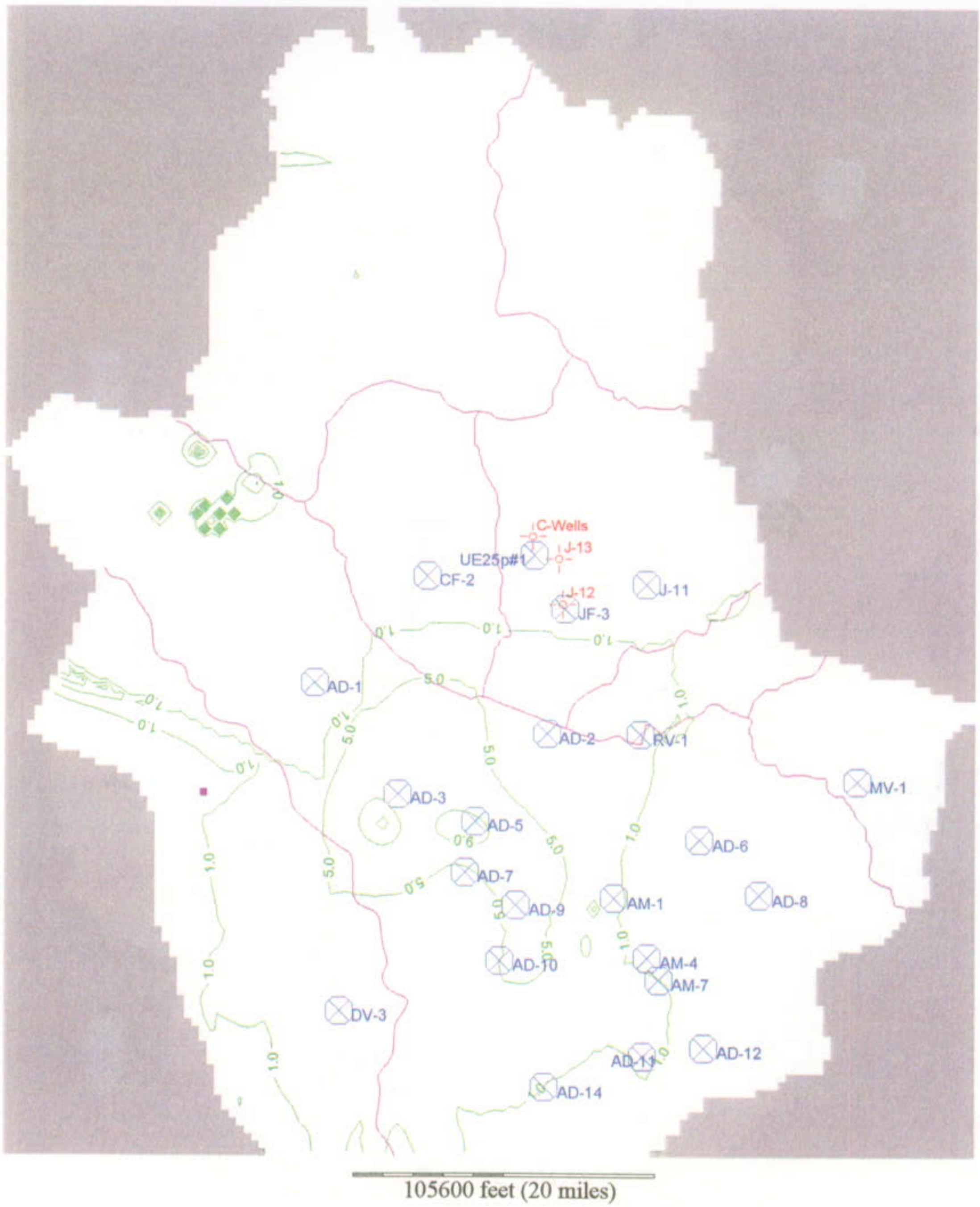


— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

UF-3 Monitoring sites

Hydrographic basin boundary

Figure 25 (c). Simulated drawdown of Scenario 1 (Central layer of Model H1)
(Historical water use context without the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

UF-3 Monitoring sites

Hydrographic basin boundary

Figure 25 (d). Simulated drawdown of Scenario 1 (Central layer of Model H2)
(Historical water use context without the proposed DOE appropriation)

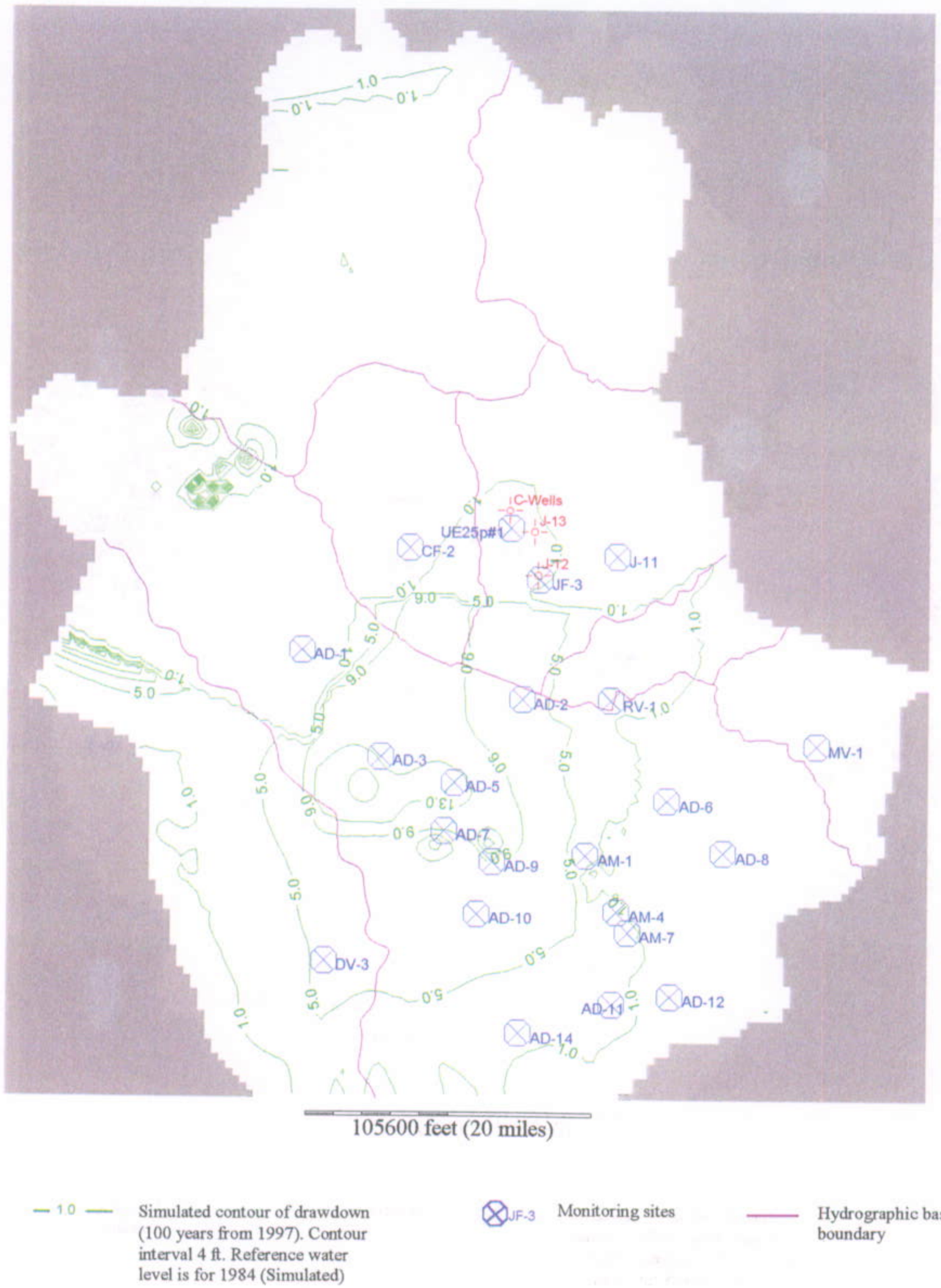


Figure 26 (a). Simulated drawdown of Scenario 2 (Central layer of Model L1)
(Historical water use context with the proposed DOE appropriation)

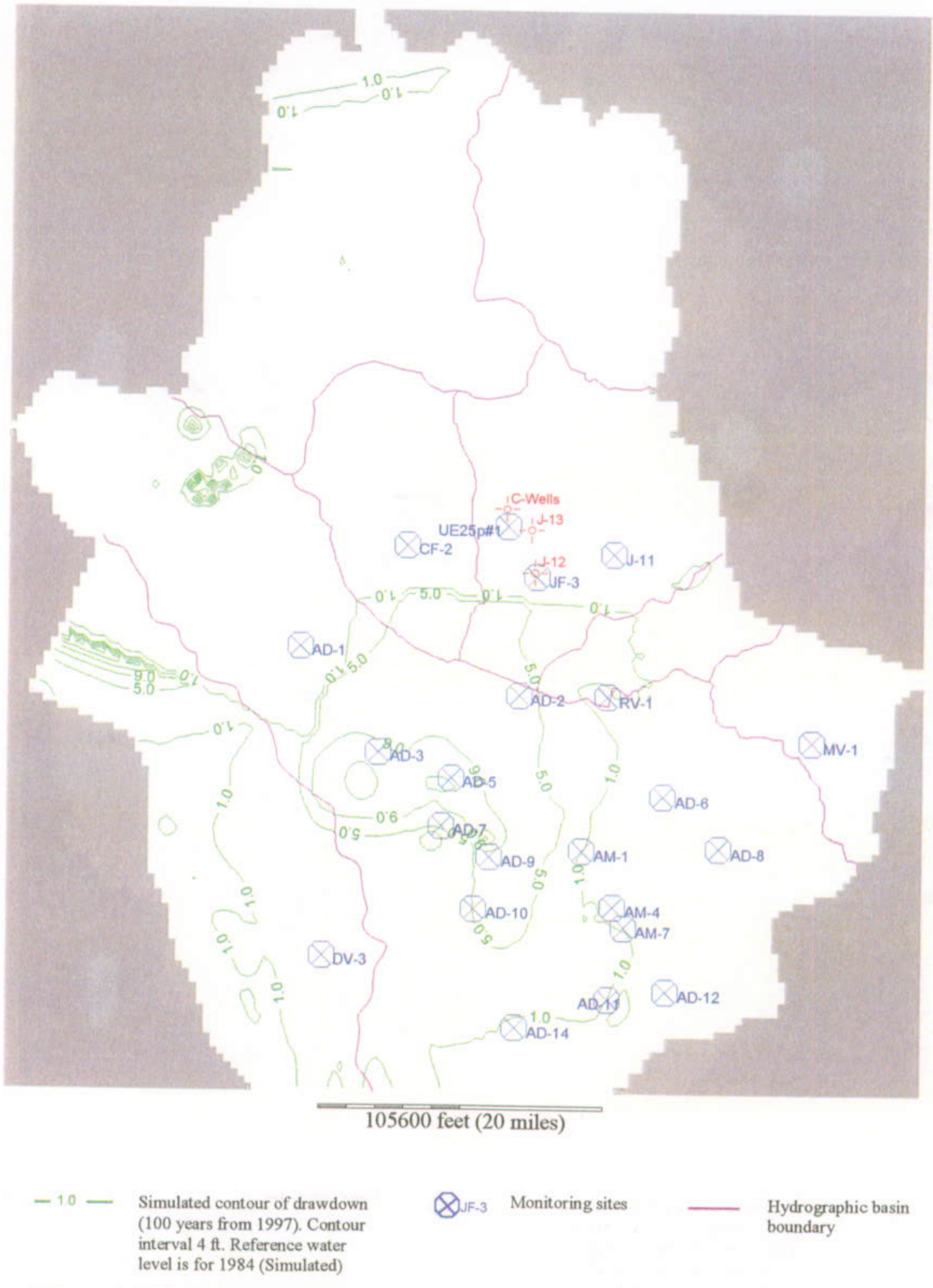
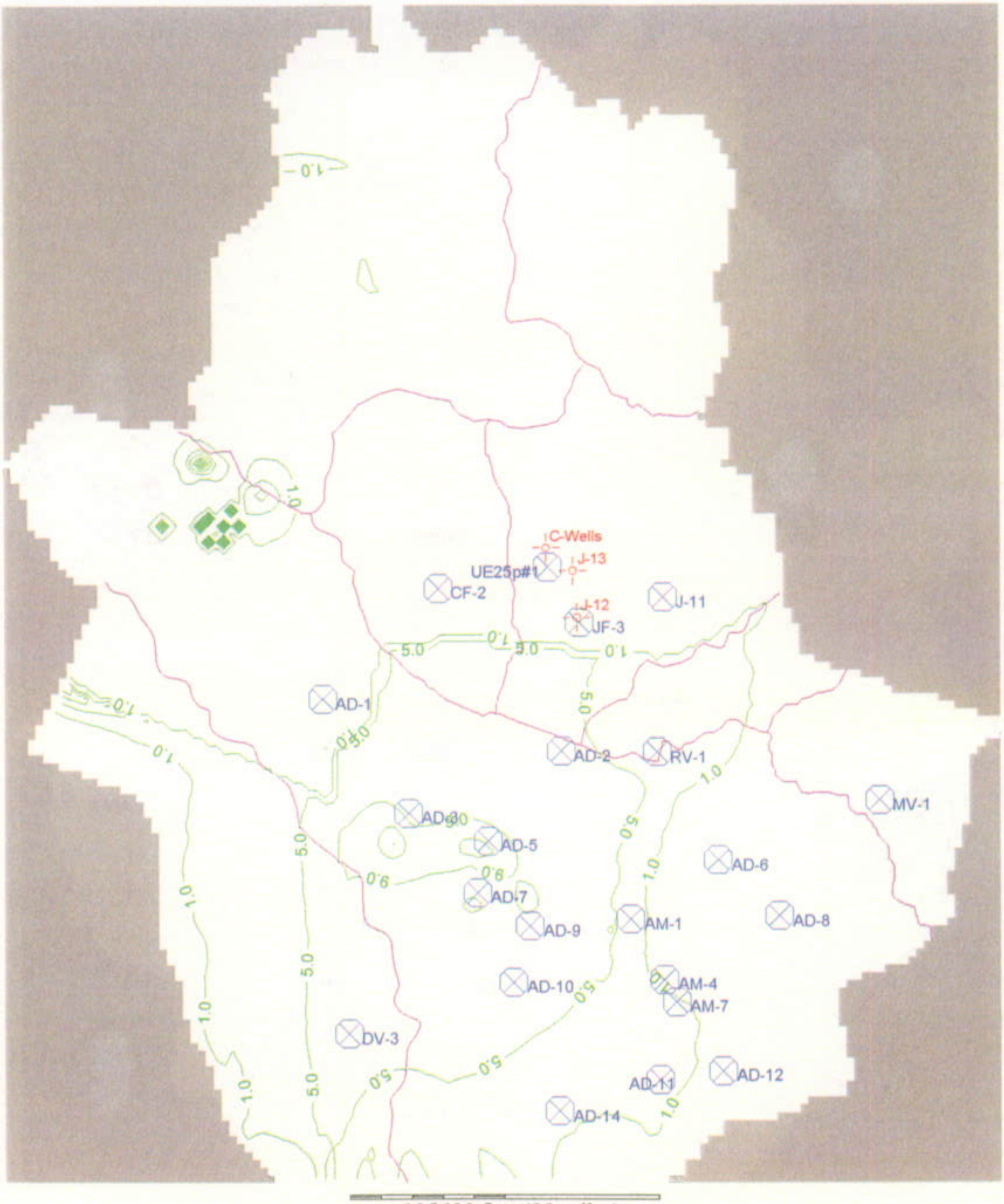


Figure 26 (b). Simulated drawdown of Scenario 2 (Central layer of Model L2)
(Historical water use context with the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 26 (c). Simulated drawdown of Scenario 2 (Central layer of Model H1)
(Historical water use context with the proposed DOE appropriation)

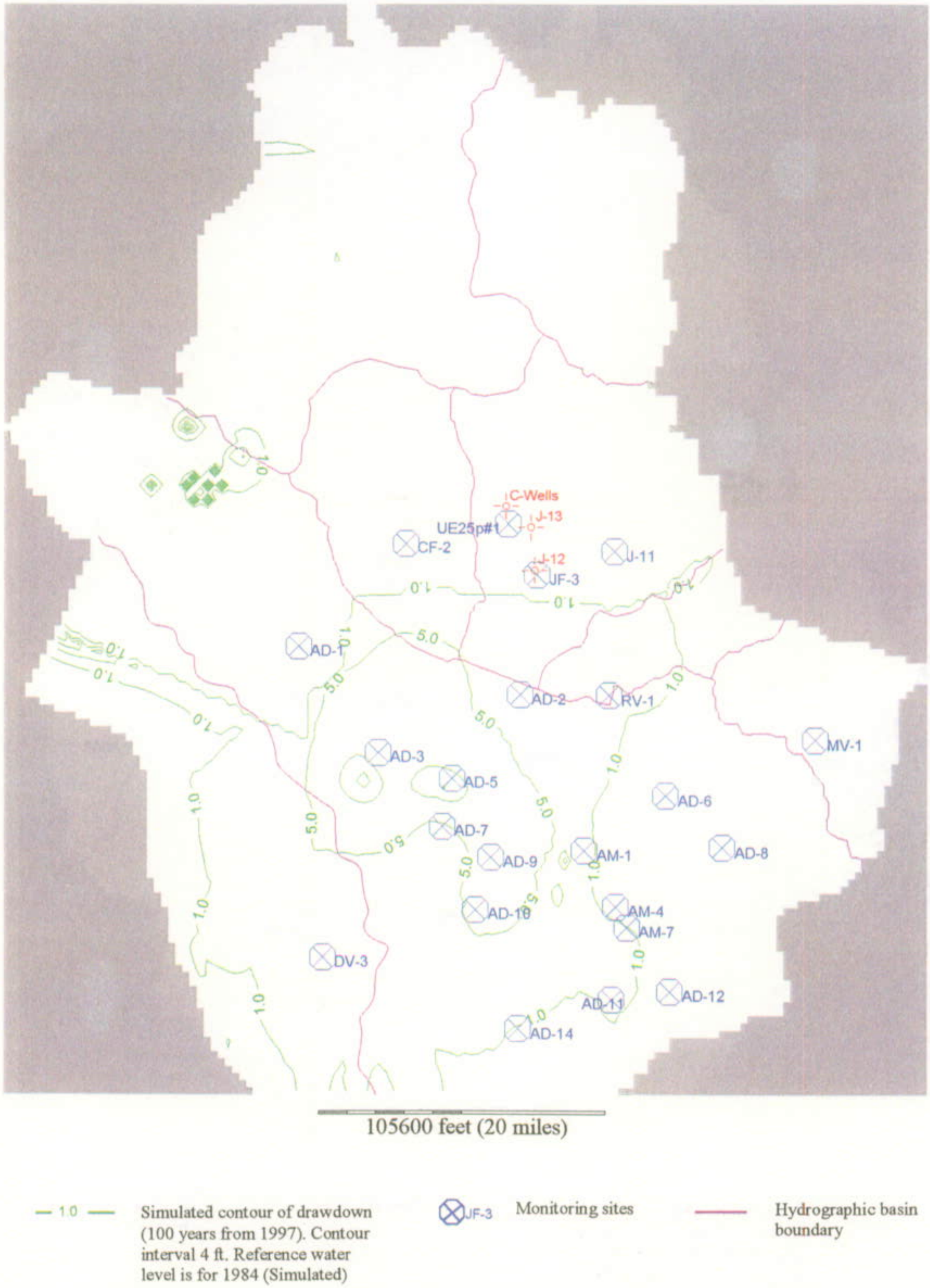
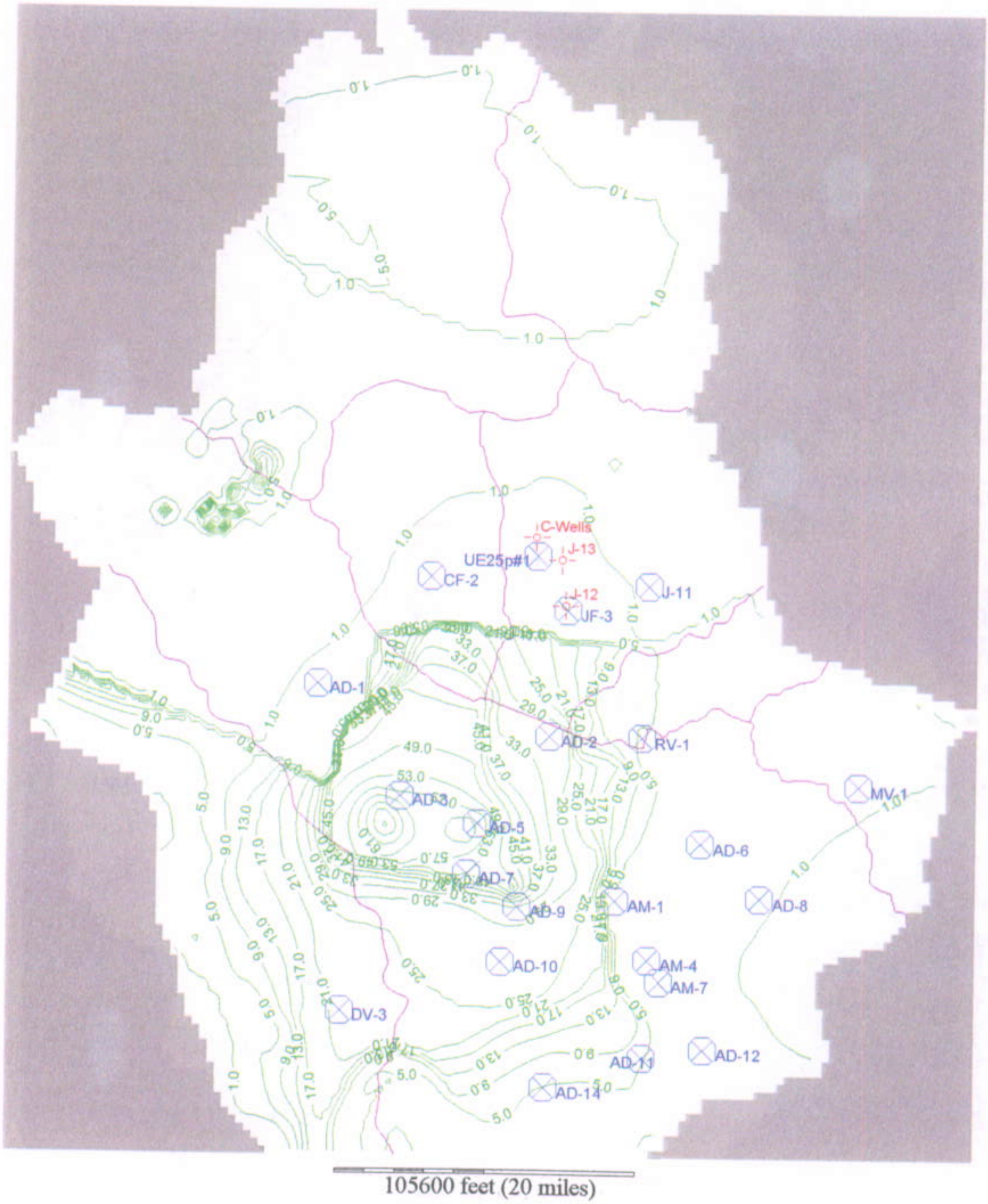


Figure 26 (d). Simulated drawdown of Scenario 2 (Central layer of Model H2)
(Historical water use context with the proposed DOE appropriation)

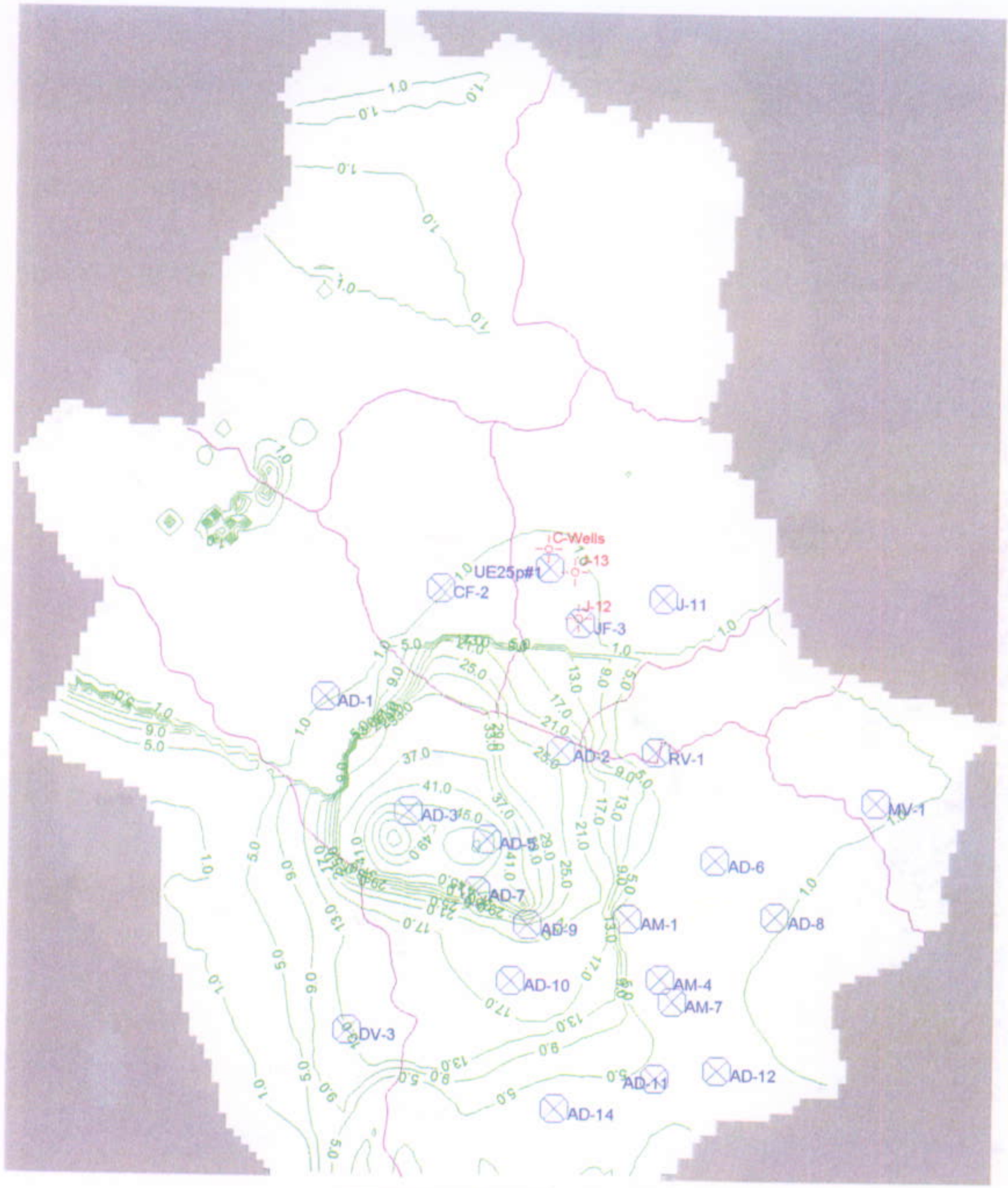


— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 27 (a). Simulated drawdown of Scenario 3 (Central layer of Model L1)
(Maximum use of senior water rights context without the proposed DOE appropriation)



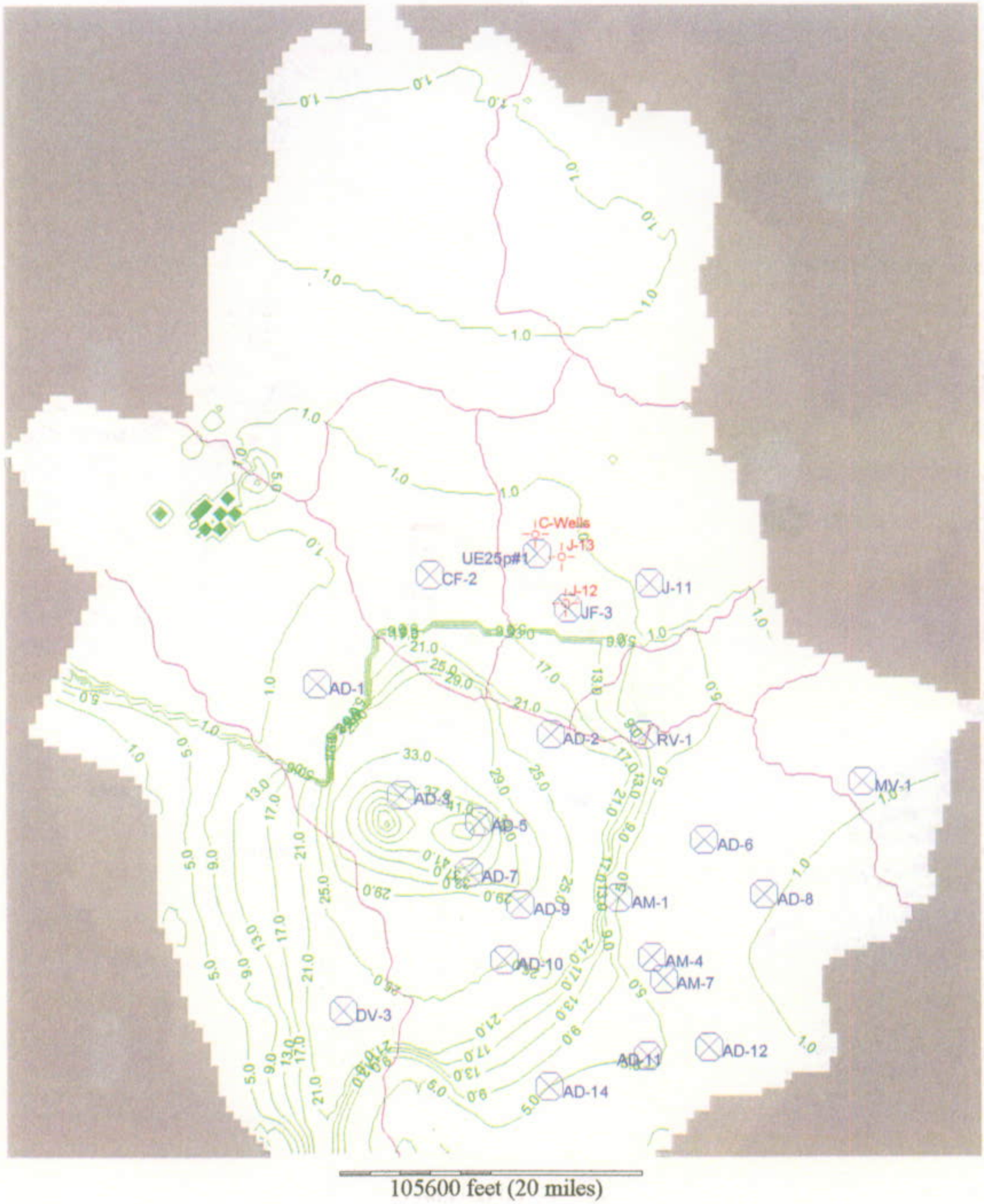
105600 feet (20 miles)

— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 27 (b). Simulated drawdown of Scenario 3 (Central layer of Model L2)
(Maximum use of senior water rights context without the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 27 (c). Simulated drawdown of Scenario 3 (Central layer of Model H1)
(Maximum use of senior water rights context without the proposed DOE appropriation)

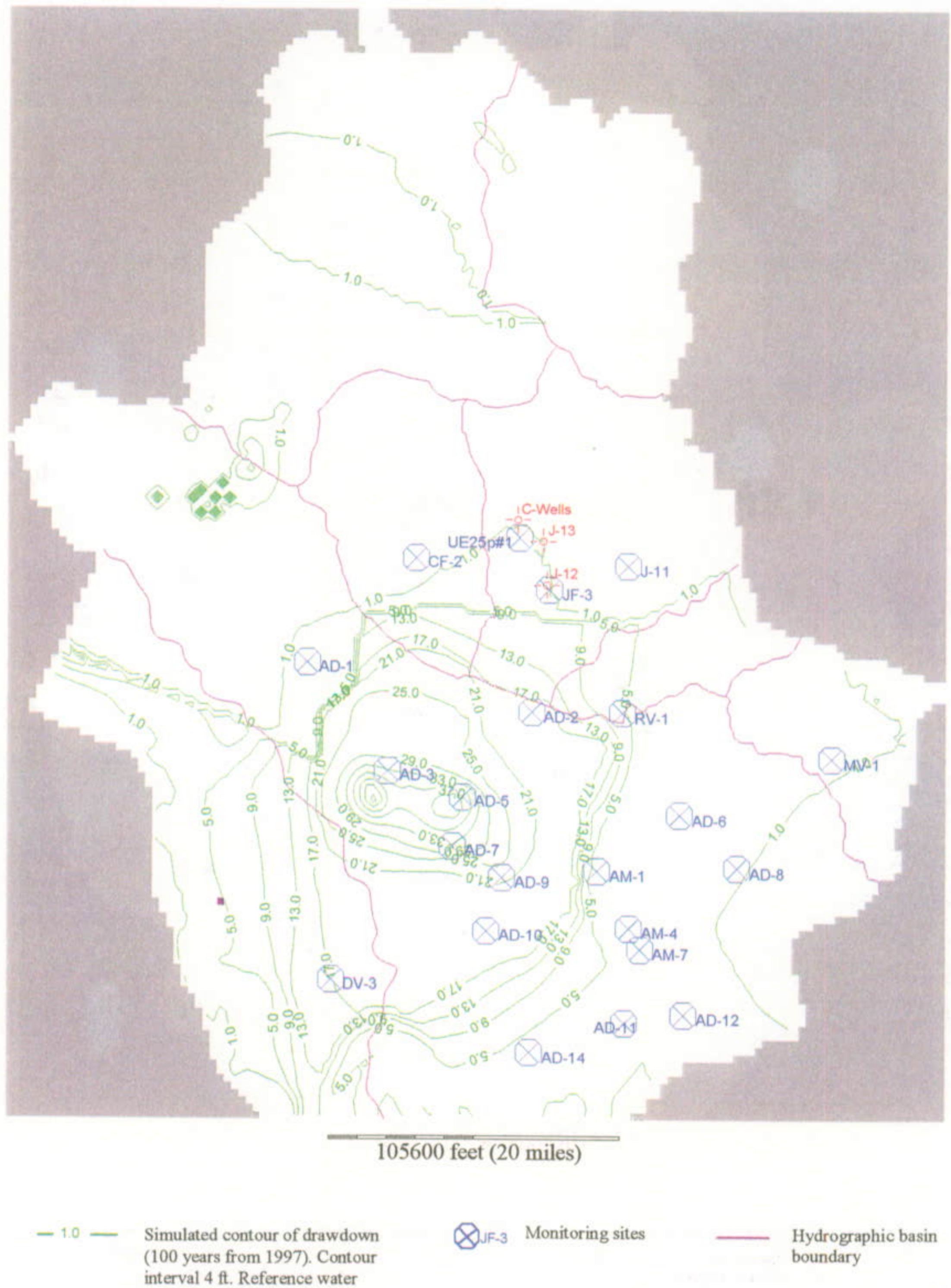


Figure 27 (d). Simulated drawdown of Scenario 3 (Central layer of Model H2)
(Maximum use of senior water rights context without the proposed DOE appropriation)

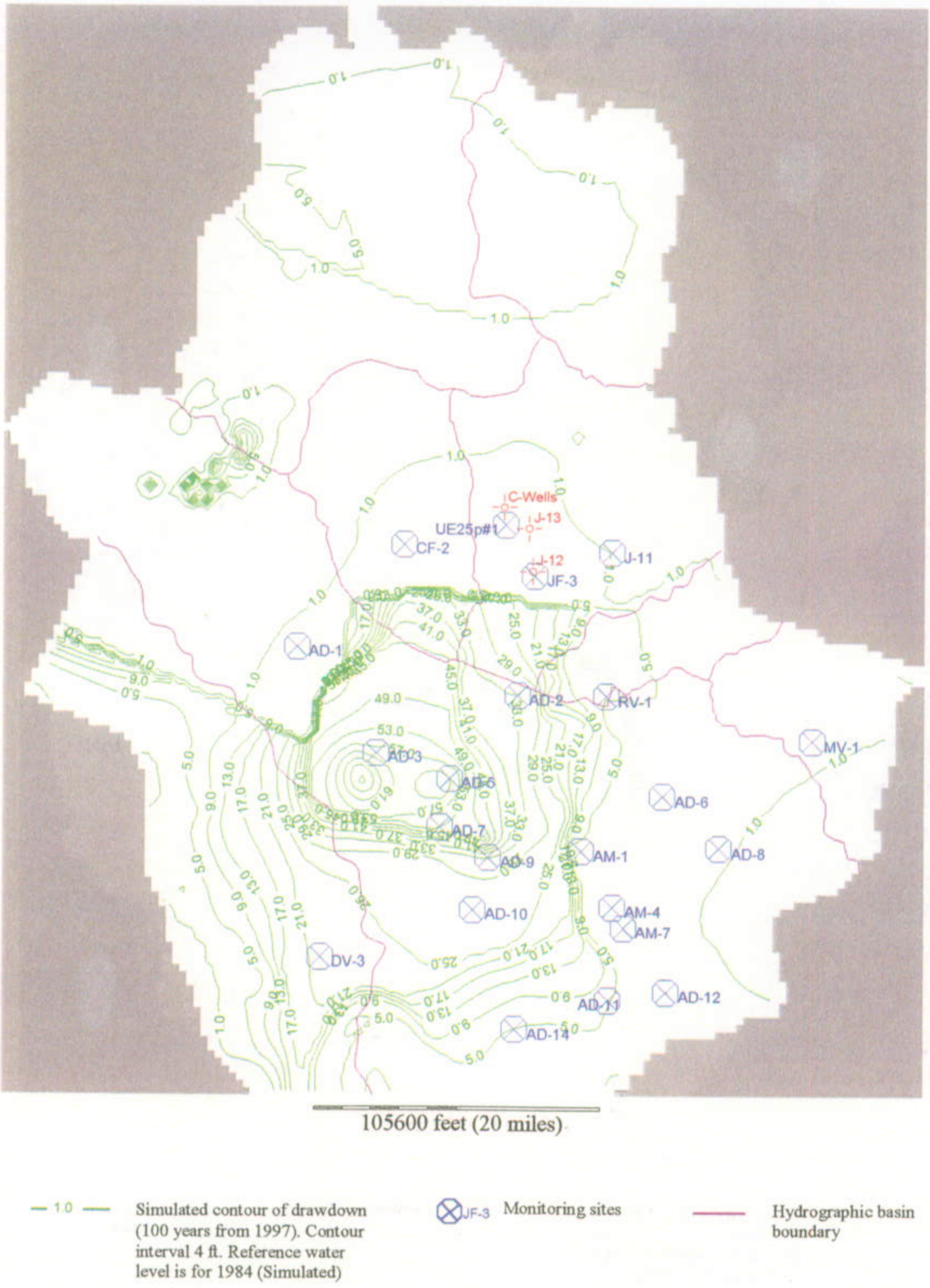
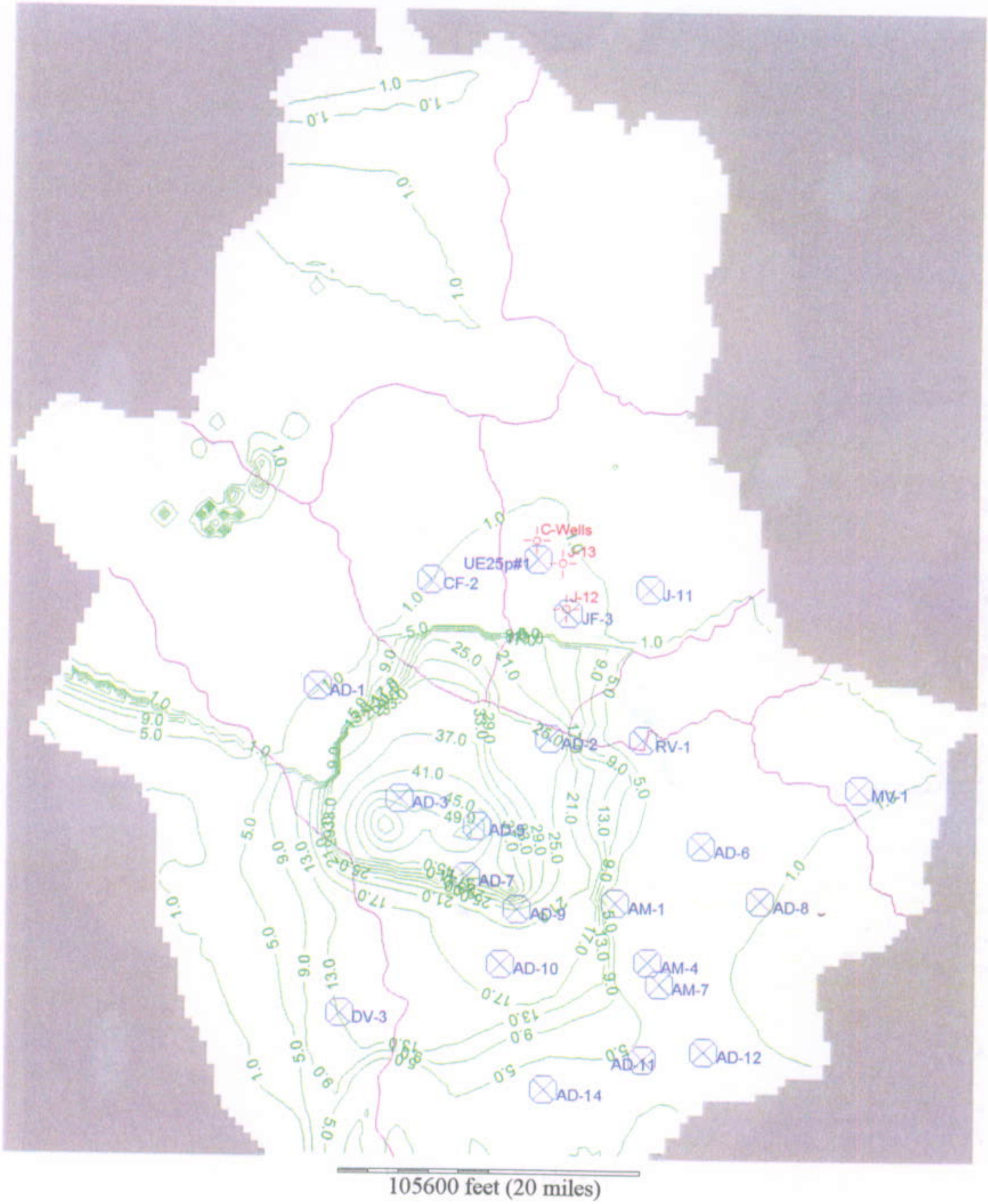


Figure 28 (a). Simulated drawdown of Scenario 4 (Central layer of Model L1)
(Maximum use of senior water rights context with the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 28 (b). Simulated drawdown of Scenario 4 (Central layer of Model L2)
(Maximum use of senior water rights context with the proposed DOE appropriation)

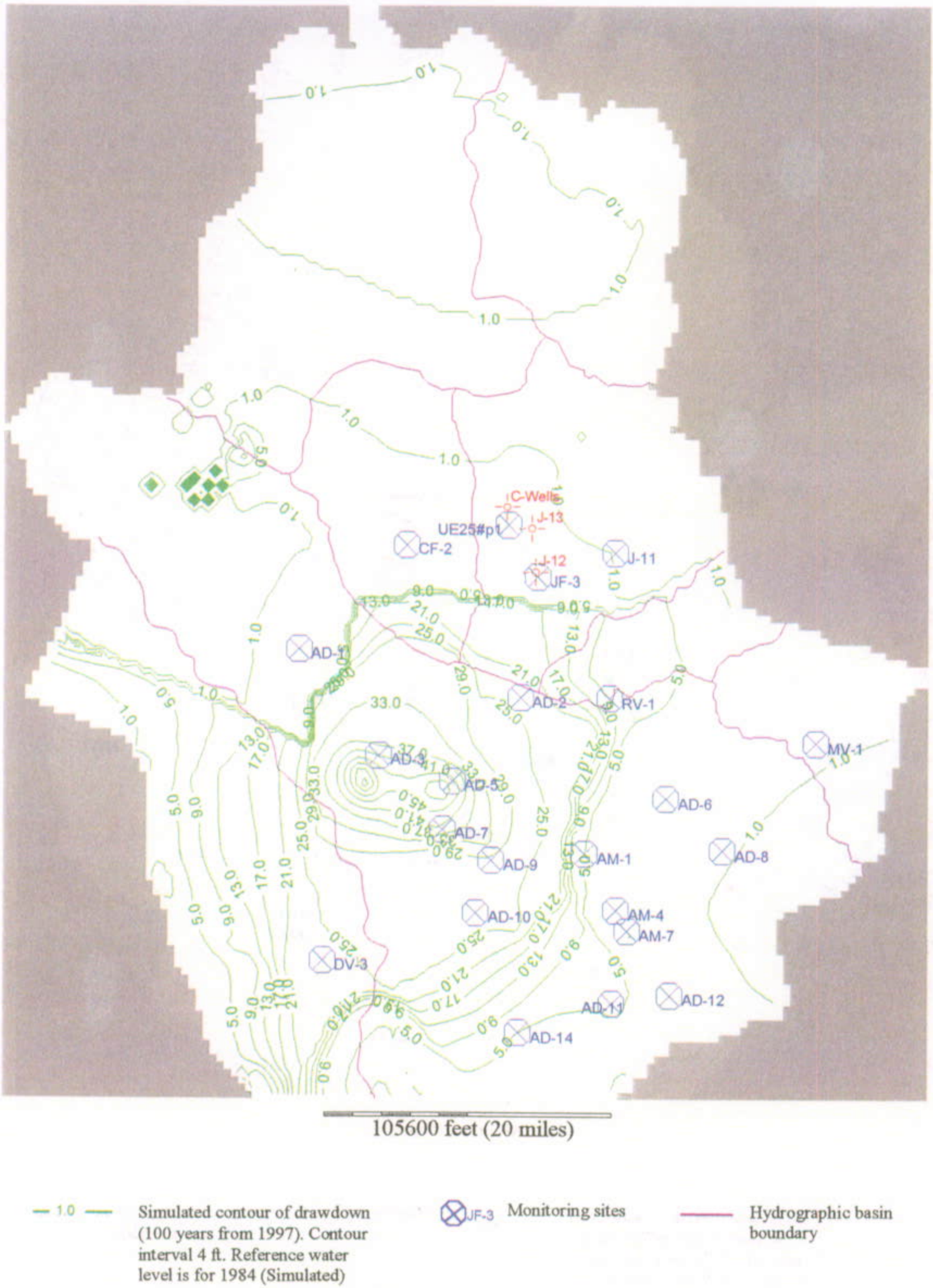
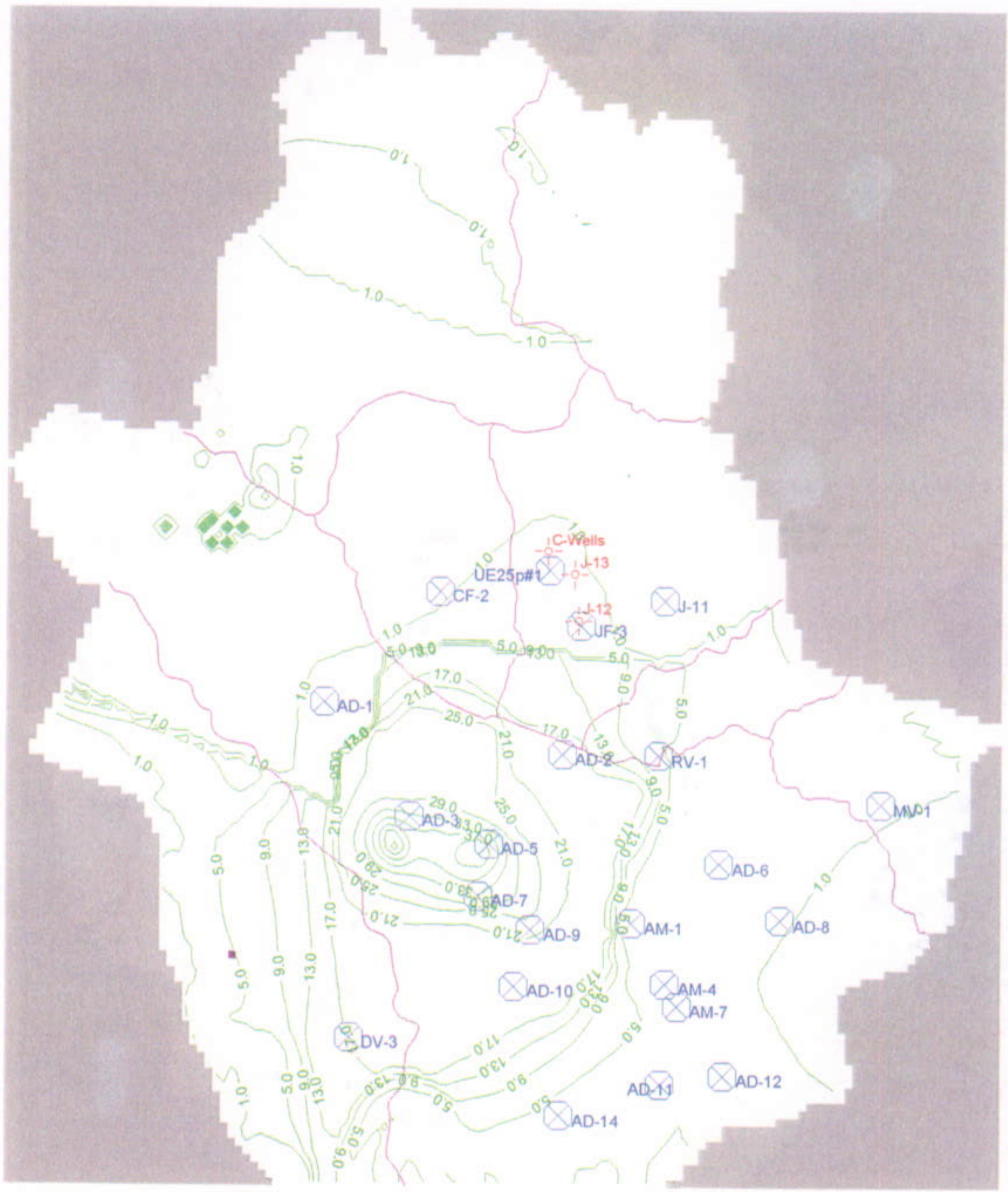


Figure 28 (c). Simulated drawdown of Scenario 4 (Central layer of Model H1)
(Maximum use of senior water rights context with the proposed DOE appropriation)



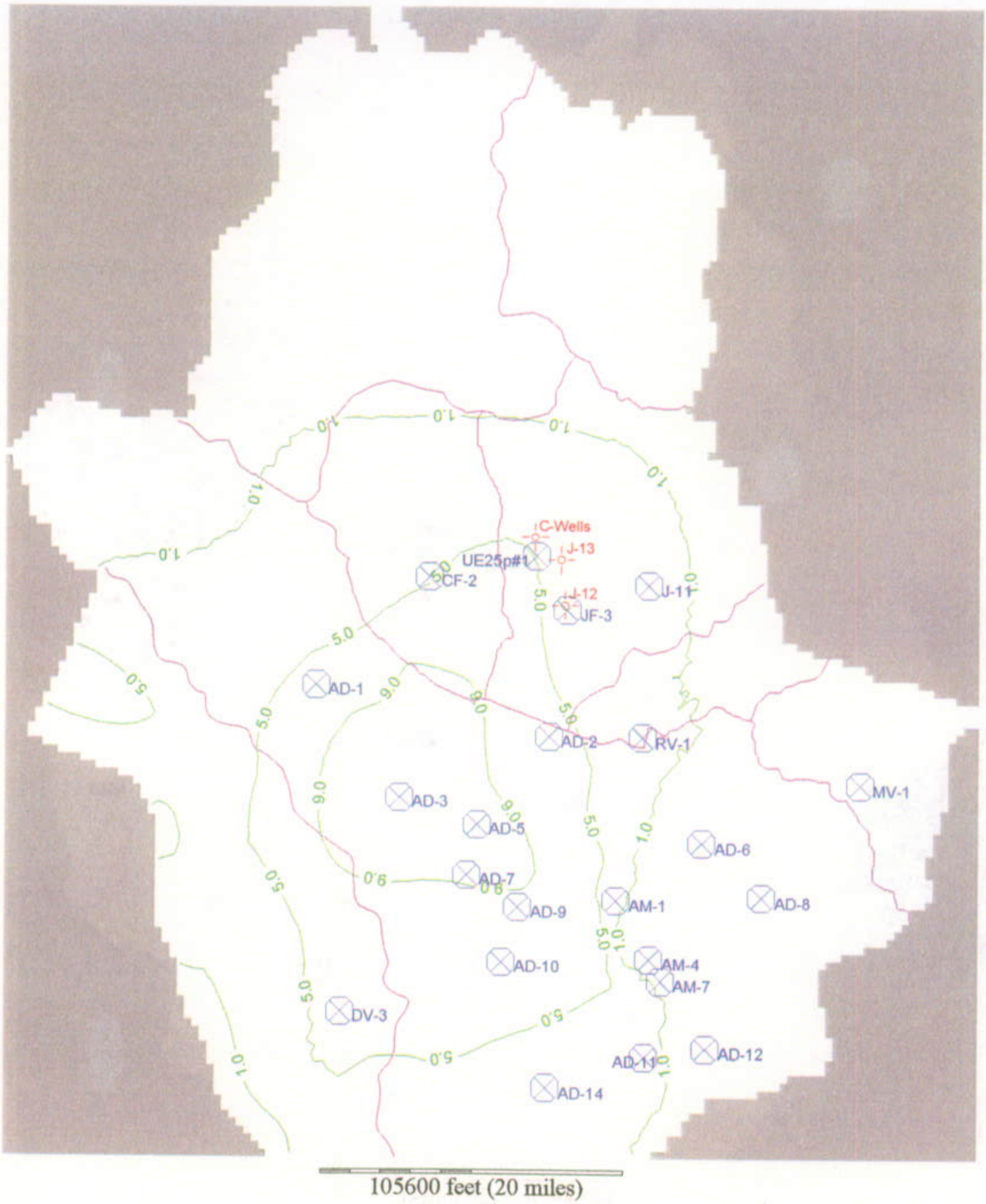
105600 feet (20 miles)

— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

⊗JF-3 Monitoring sites

Hydrographic basin boundary

Figure 28 (d). Simulated drawdown of Scenario 4 (Central layer of Model H2)
(Maximum use of senior water rights context with the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

UF-3 Monitoring sites

Hydrographic basin boundary

Figure 29 (a). Simulated drawdown of Scenario 1 (Bottom layer of Model L1)
(Historical water use context without the proposed DOE appropriation)

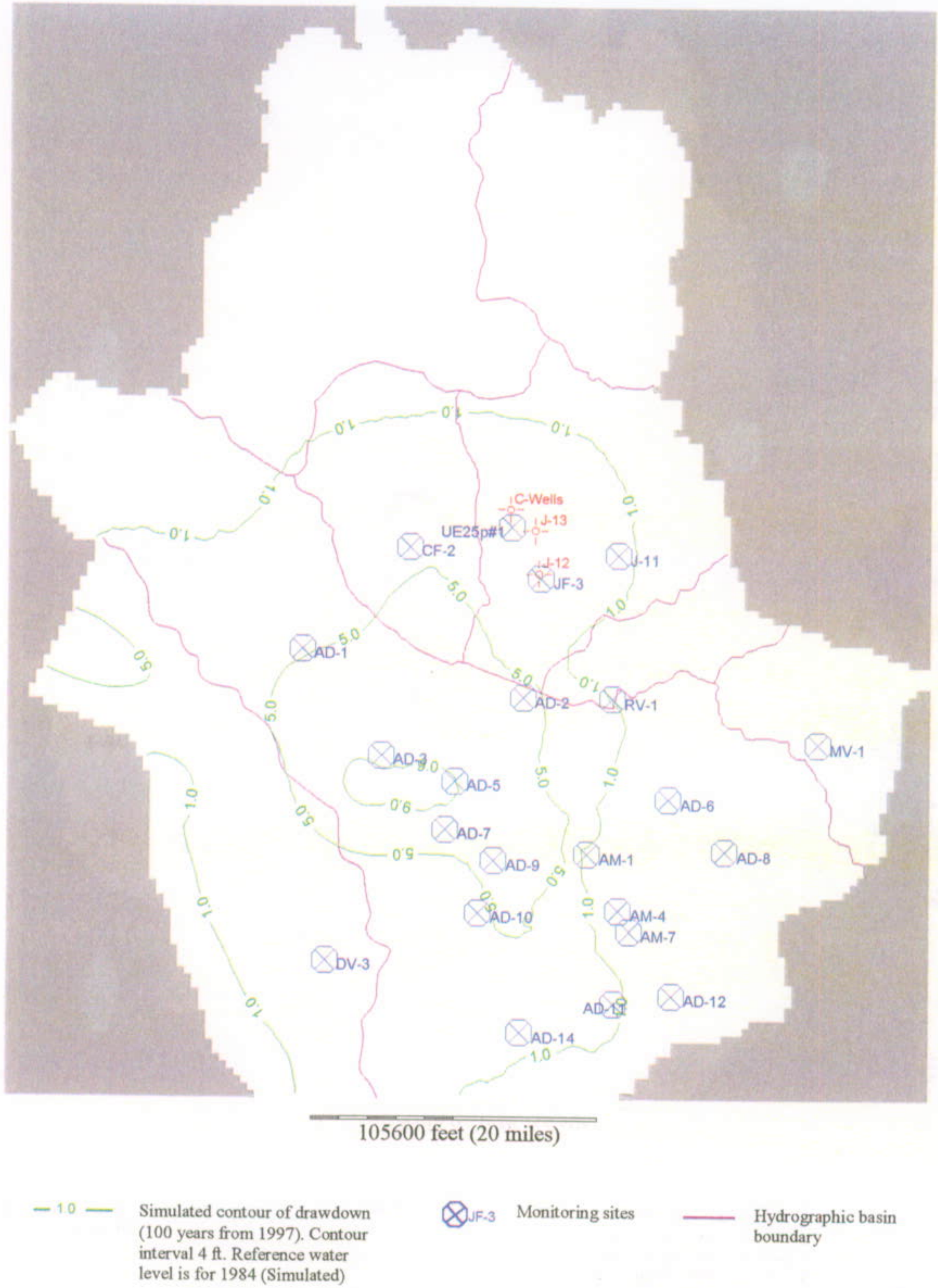


Figure 29 (b). Simulated drawdown of Scenario 1 (Bottom layer of Model L2)
(Historical water use context without the proposed DOE appropriation)

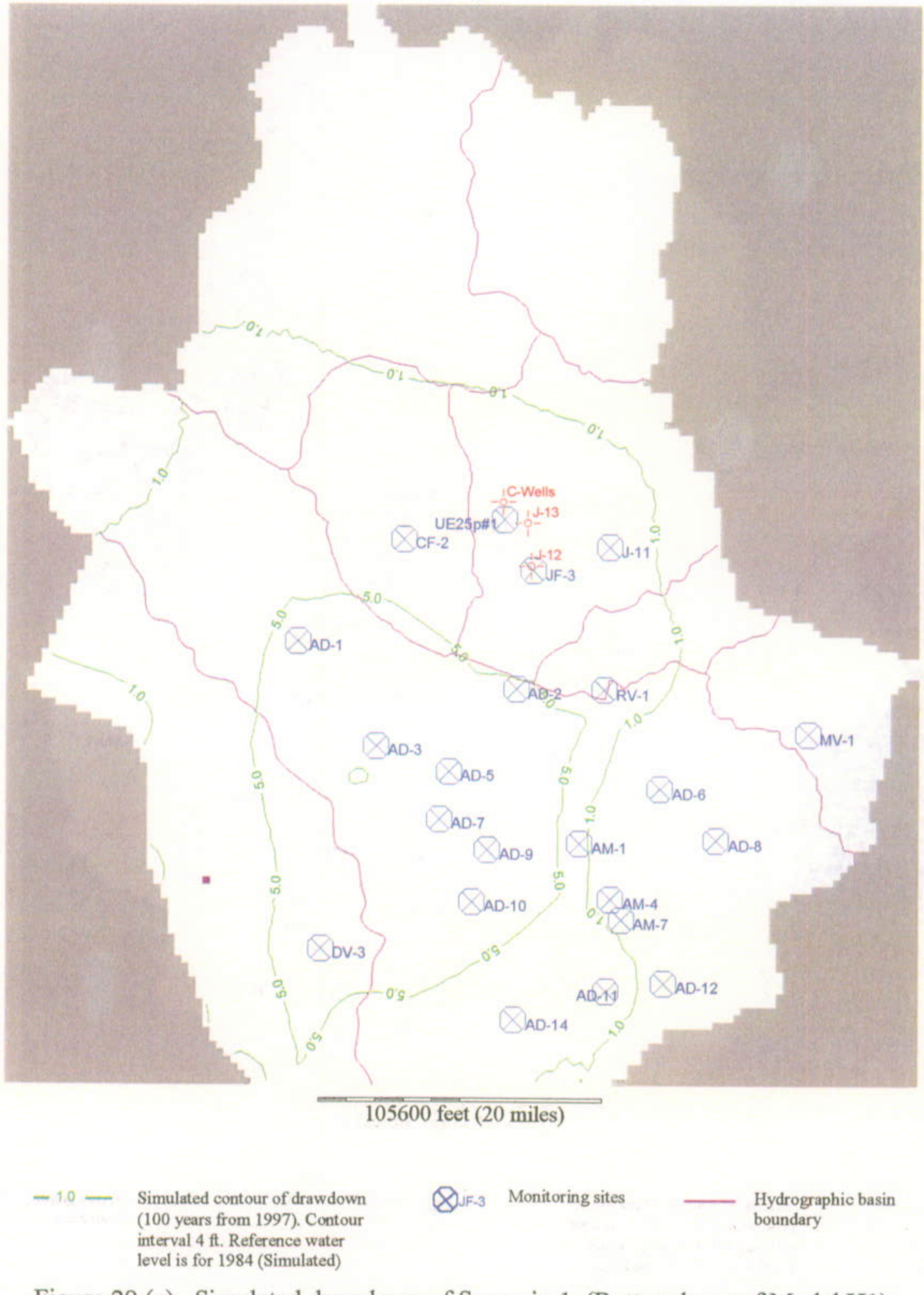
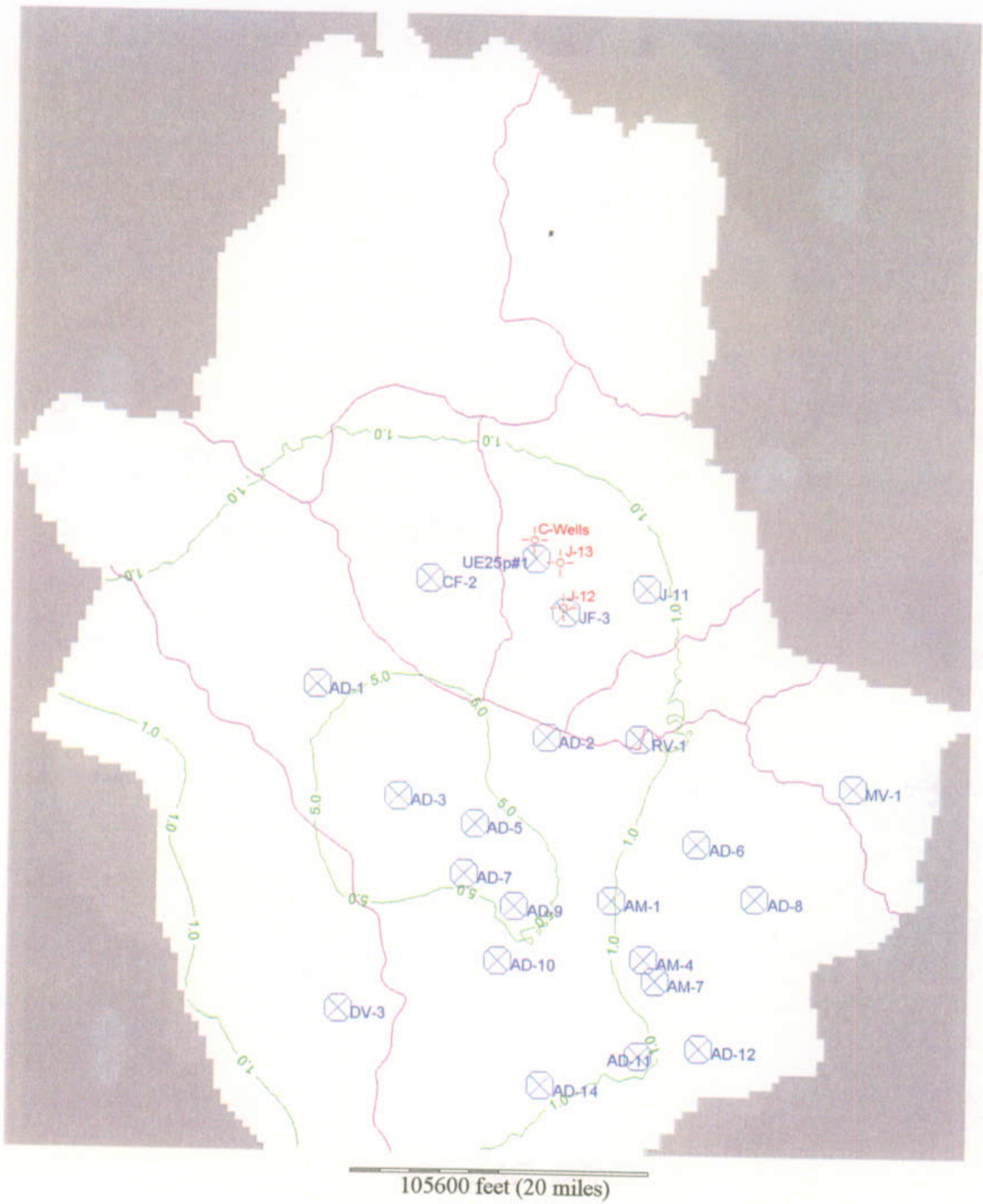


Figure 29 (c). Simulated drawdown of Scenario 1 (Bottom layer of Model H1)
(Historical water use context without the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

UF-3 Monitoring sites

Hydrographic basin boundary

Figure 29 (d). Simulated drawdown of Scenario 1 (Bottom layer of Model H2)
(Historical water use context without the proposed DOE appropriation)

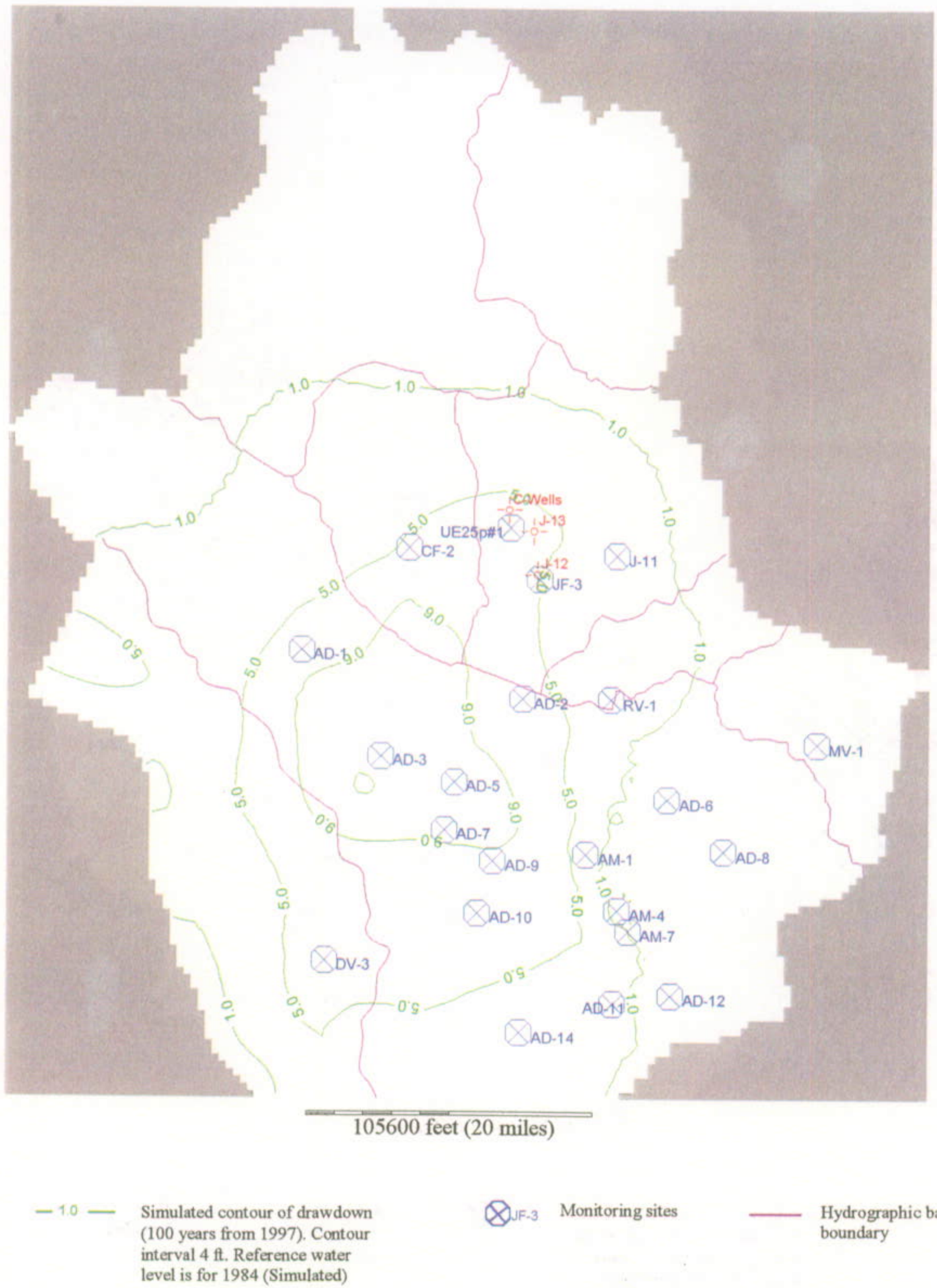


Figure 30 (a). Simulated drawdown of Scenario 2 (Bottom layer of Model L1)
(Historical water use context with the proposed DOE appropriation)

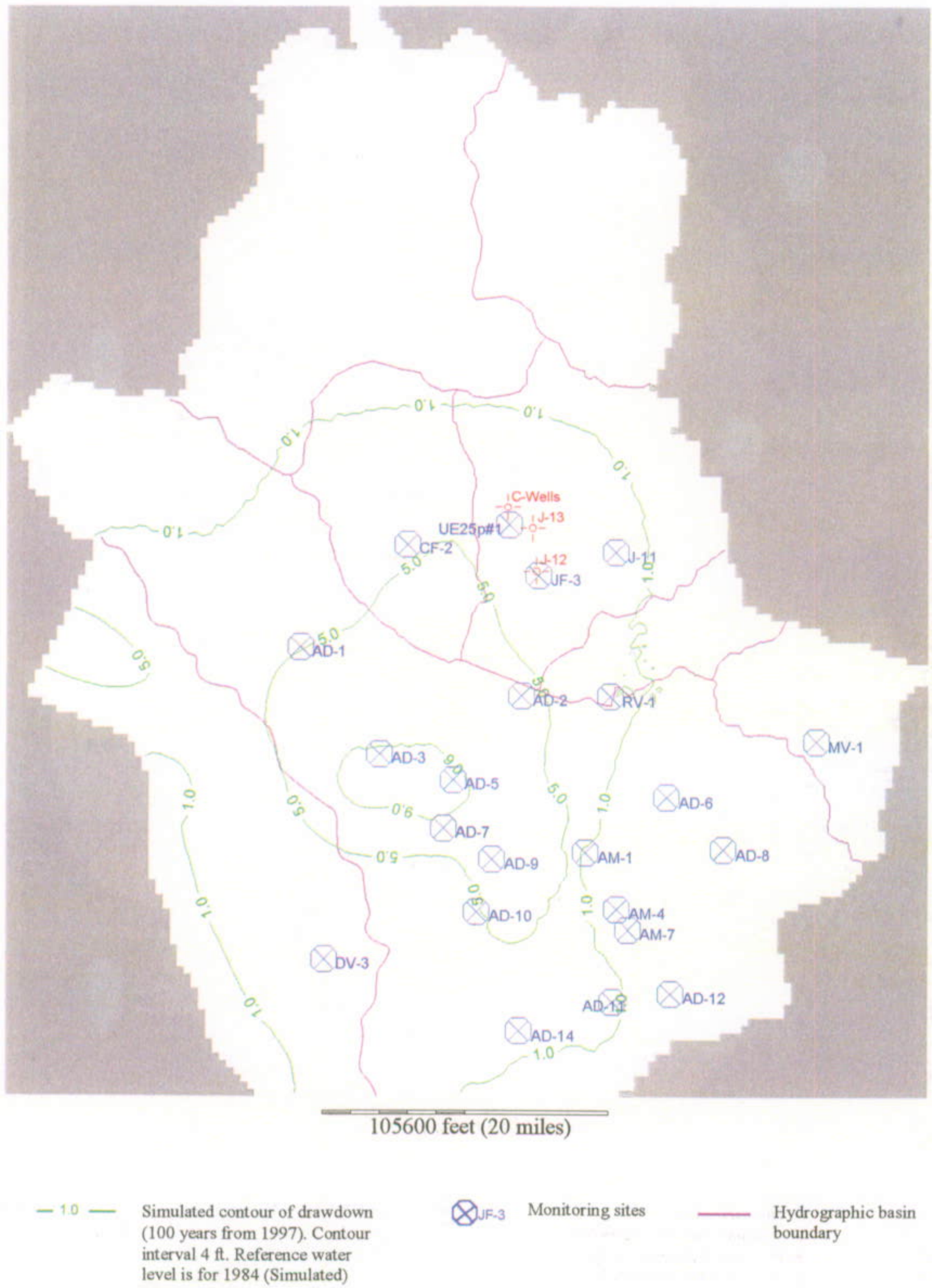


Figure 30 (b). Simulated drawdown of Scenario 2 (Bottom layer of Model L2)
(Historical water use context with the proposed DOE appropriation)

Figure 30 (c). Simulated drawdown of Scenario 2 (Bottom layer of Model H1)
(Historical water use context with the proposed DOE appropriation)

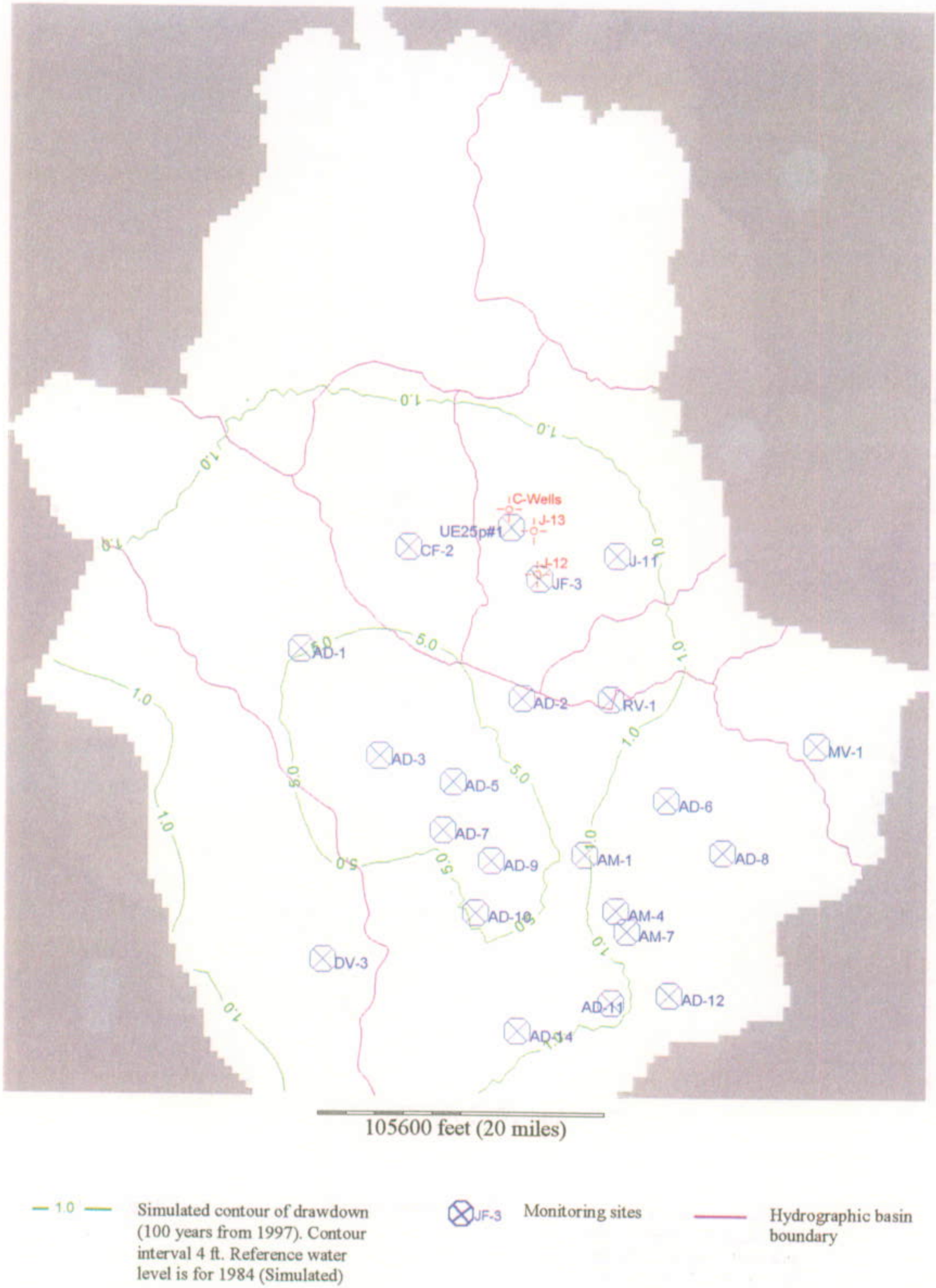
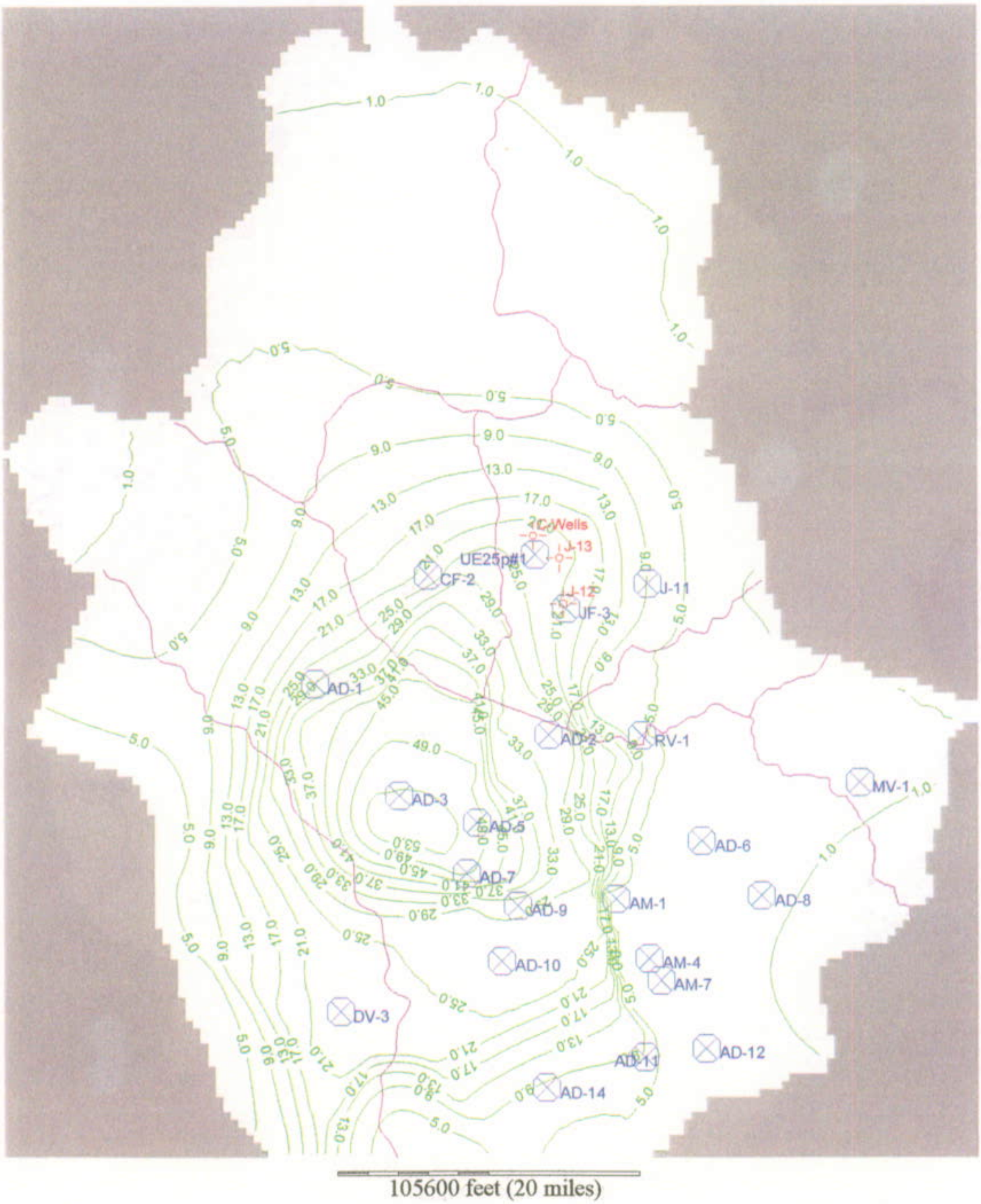


Figure 30 (d). Simulated drawdown of Scenario 2 (Bottom layer of Model H2)
(Historical water use context with the proposed DOE appropriation)

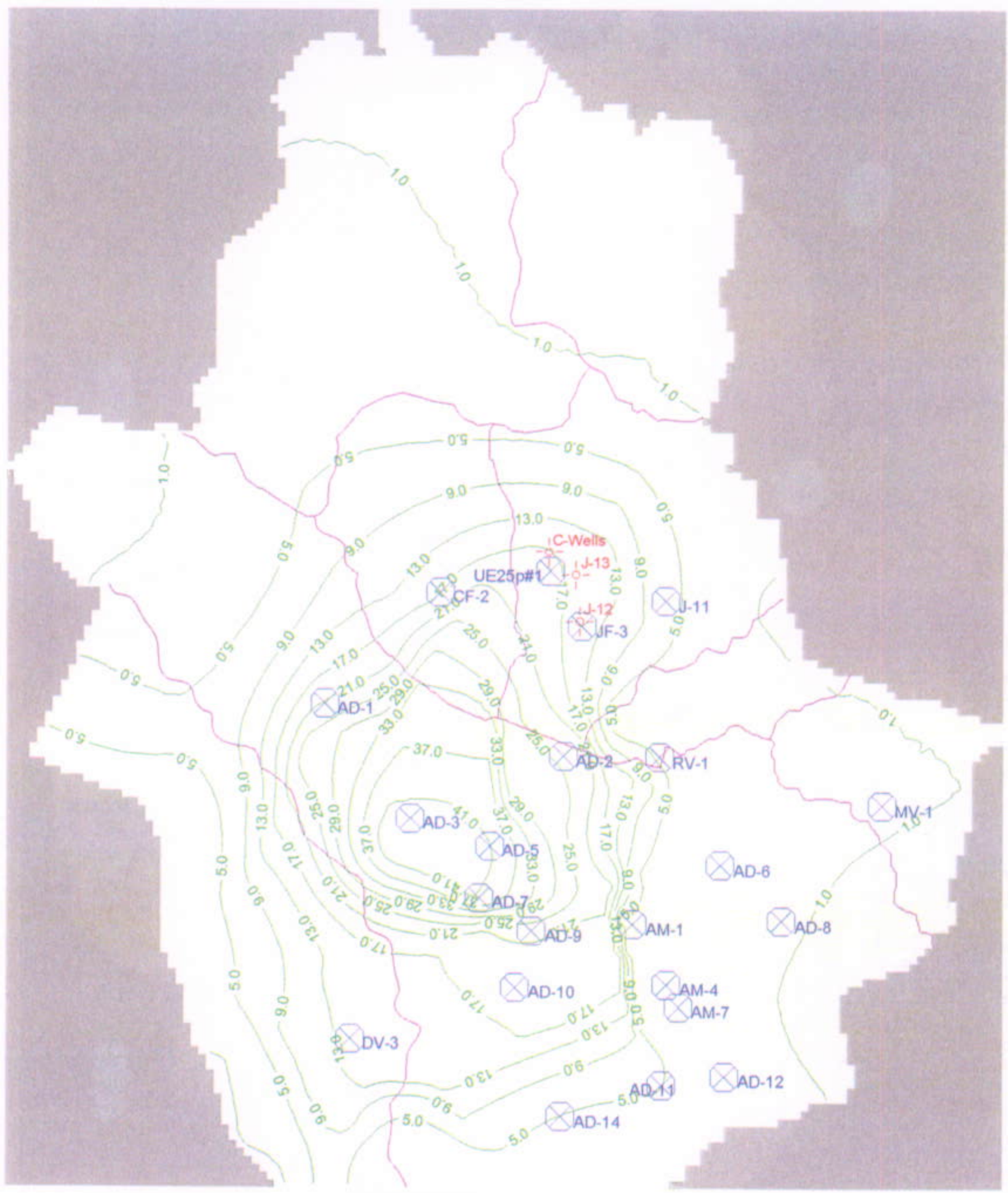


— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 31 (a). Simulated drawdown of Scenario 3 (Bottom layer of Model L1)
(Maximum use of senior water rights context without the proposed DOE appropriation)



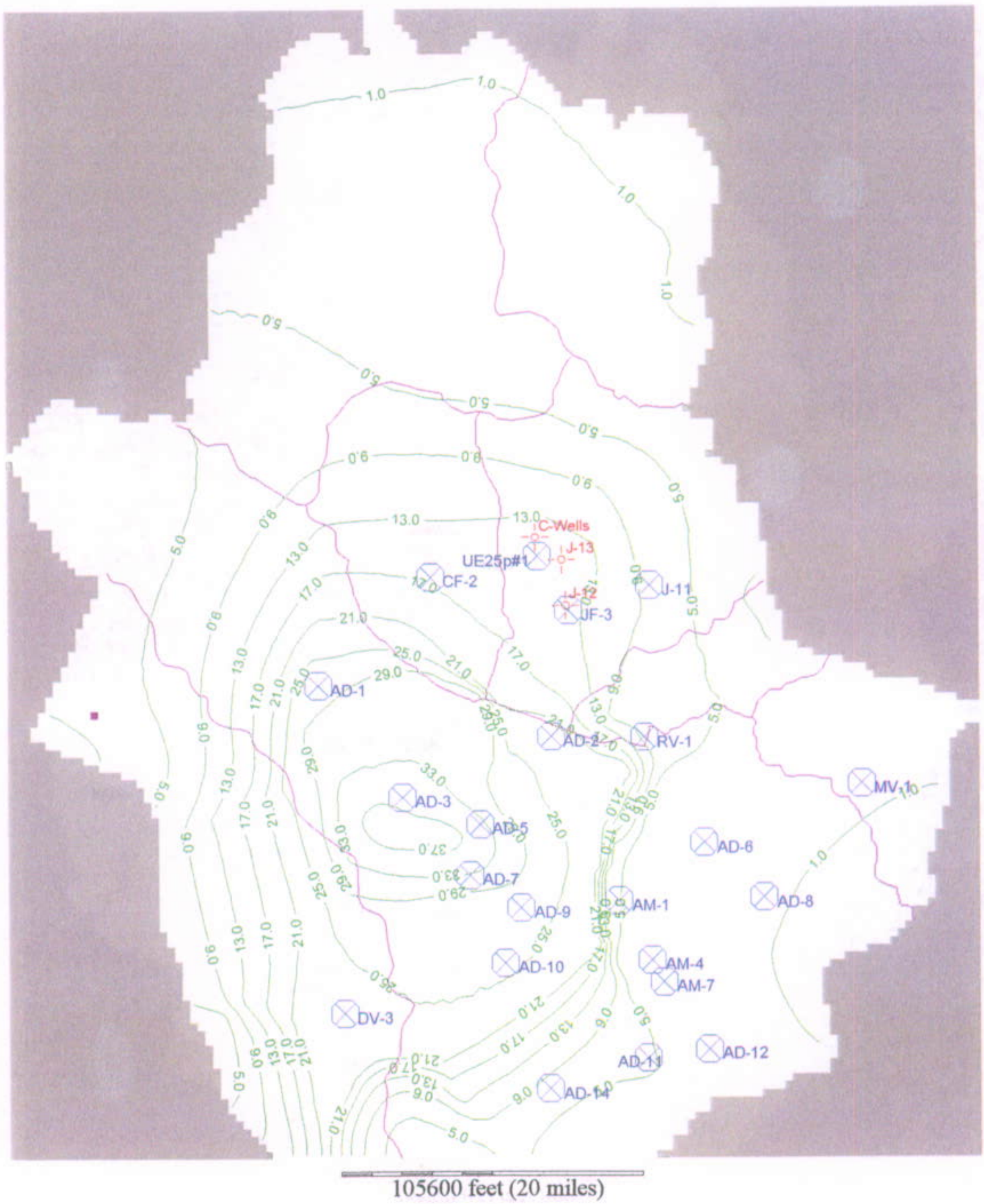
105600 feet (20 miles)

— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 31 (b). Simulated drawdown of Scenario 3 (Bottom layer of Model L2)
(Maximum use of senior water rights context without the proposed DOE appropriation)



— 1.0 —	Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)	JF-3	Monitoring sites	——	Hydrographic basin boundary

Figure 31 (c). Simulated drawdown of Scenario 3 (Bottom layer of Model H1)
(Maximum use of senior water rights context without the proposed DOE appropriation)

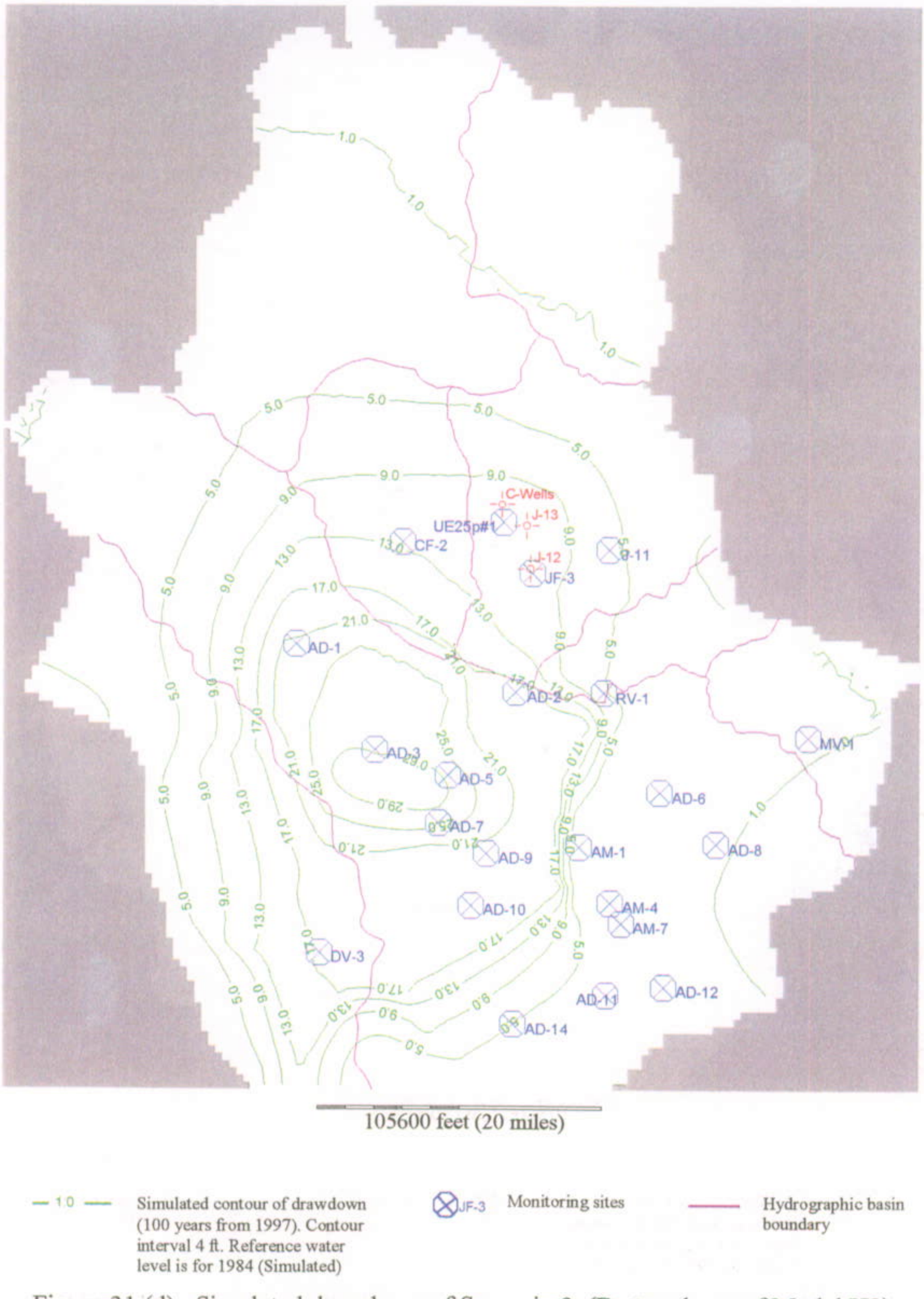
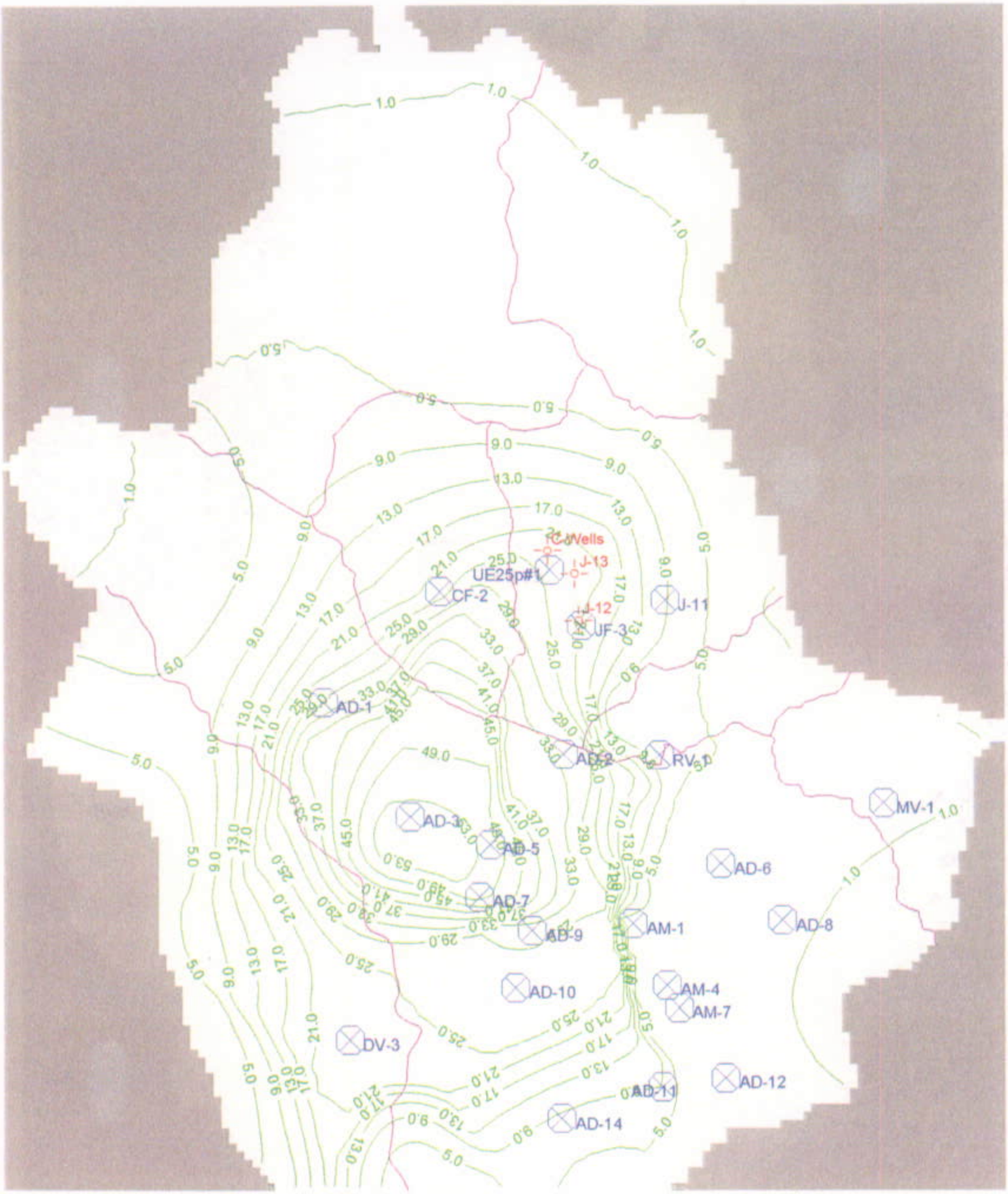


Figure 31 (d). Simulated drawdown of Scenario 3 (Bottom layer of Model H2)
(Maximum use of senior water rights context without the proposed DOE appropriation)



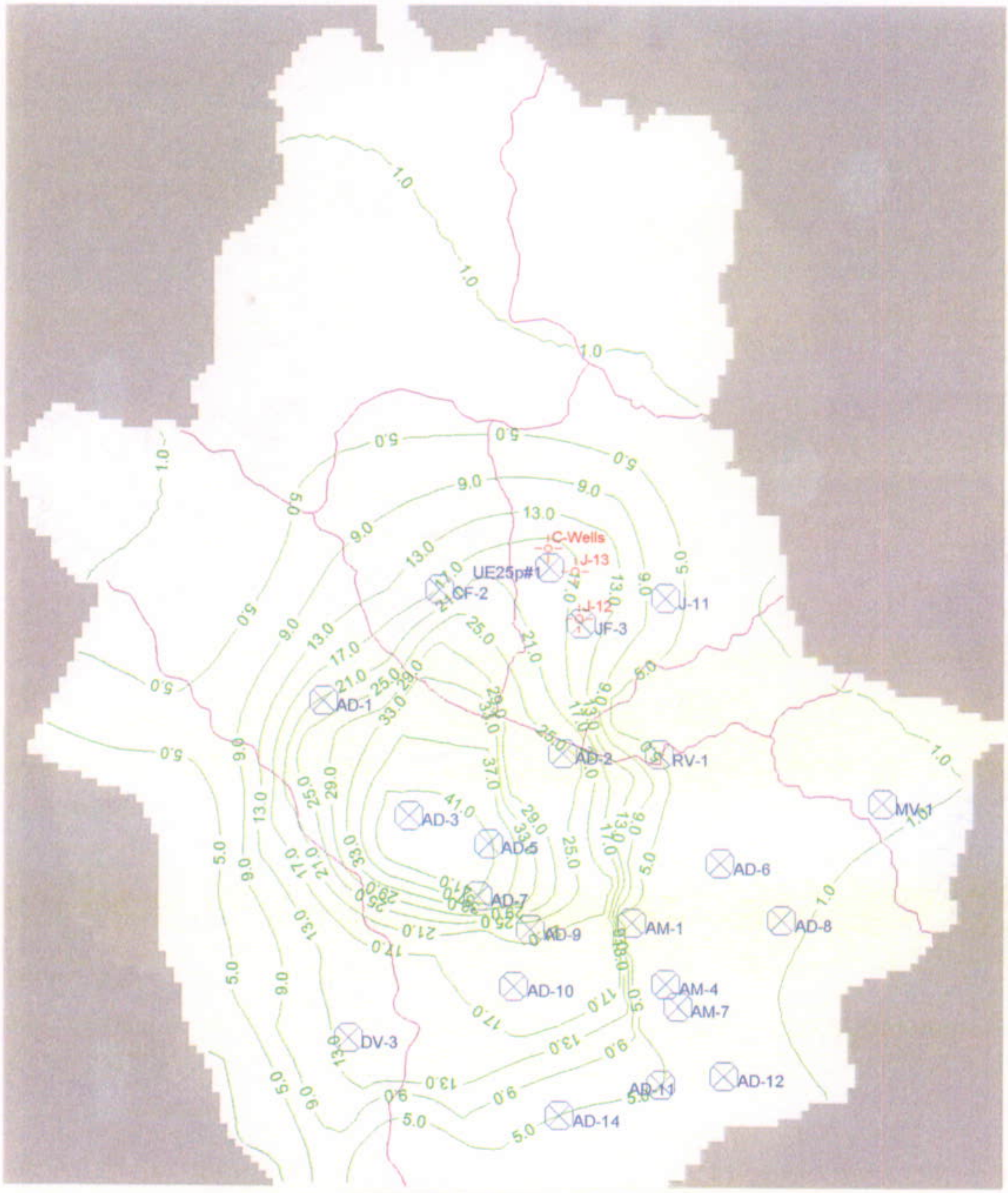
105600 feet (20 miles)

— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

⊗JF-3 Monitoring sites

—— Hydrographic basin boundary

Figure 32 (a). Simulated drawdown of Scenario 4 (Bottom layer of Model L1)
(Maximum use of senior water rights context with the proposed DOE appropriation)



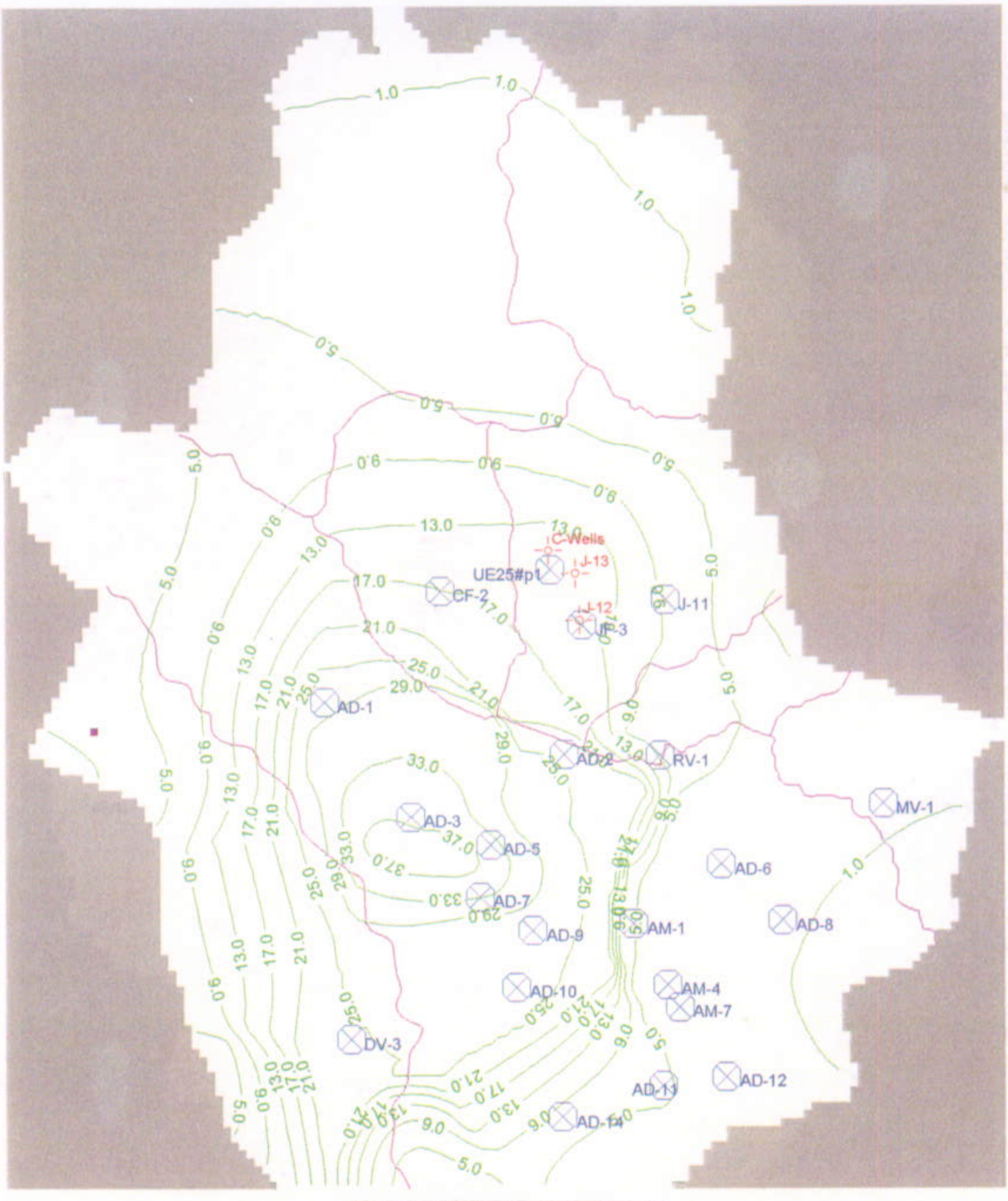
105600 feet (20 miles)

— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 32 (b). Simulated drawdown of Scenario 4 (Bottom layer of Model L2)
(Maximum use of senior water rights context with the proposed DOE appropriation)

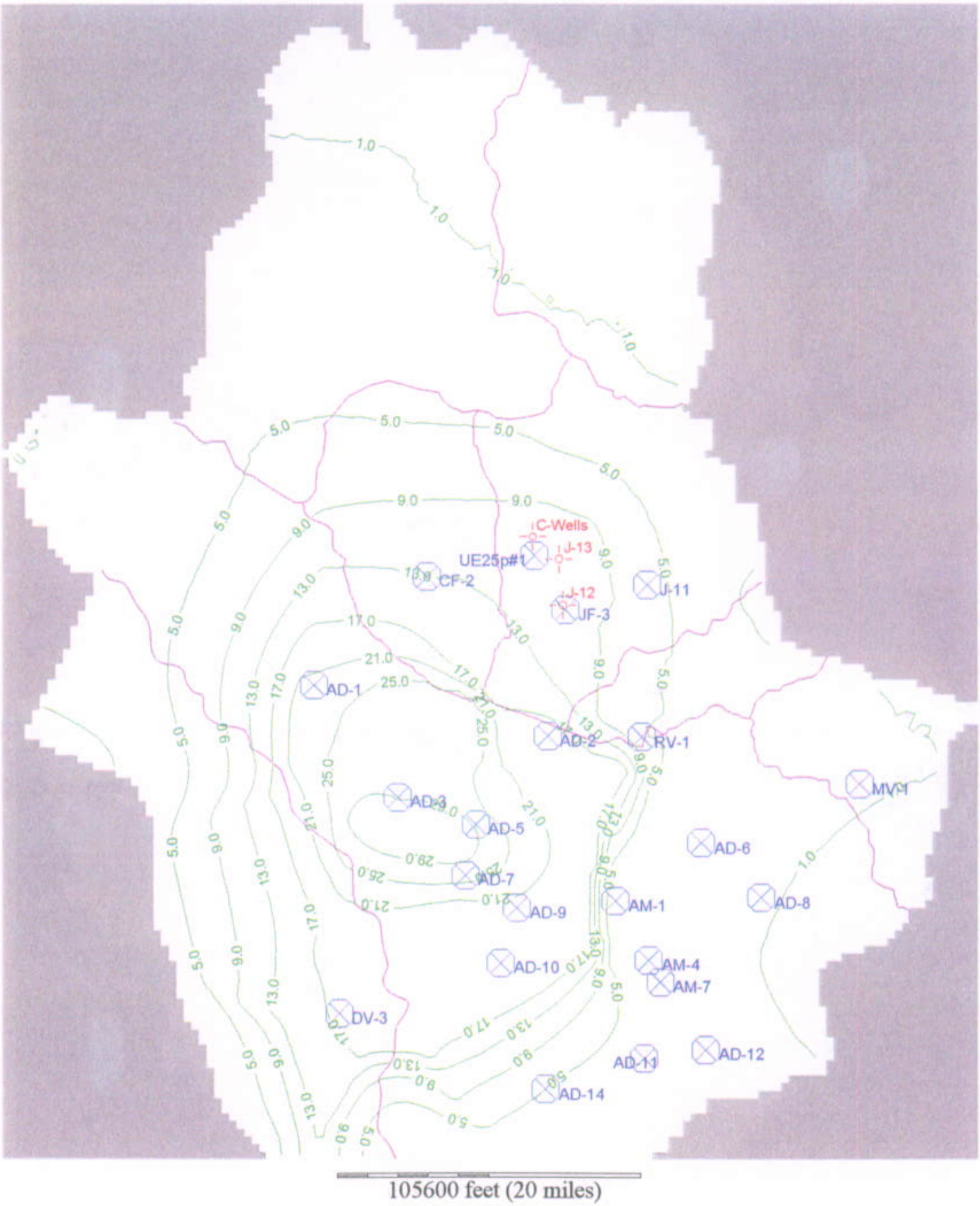


— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

JF-3 Monitoring sites

Hydrographic basin boundary

Figure 32 (c). Simulated drawdown of Scenario 4 (Bottom layer of Model H1)
(Maximum use of senior water rights context with the proposed DOE appropriation)



— 1.0 — Simulated contour of drawdown (100 years from 1997). Contour interval 4 ft. Reference water level is for 1984 (Simulated)

UF-3 Monitoring sites

Hydrographic basin boundary

Figure 32 (d). Simulated drawdown of Scenario 4 (Bottom layer of Model H2)
(Maximum use of senior water rights context with the proposed DOE appropriation)

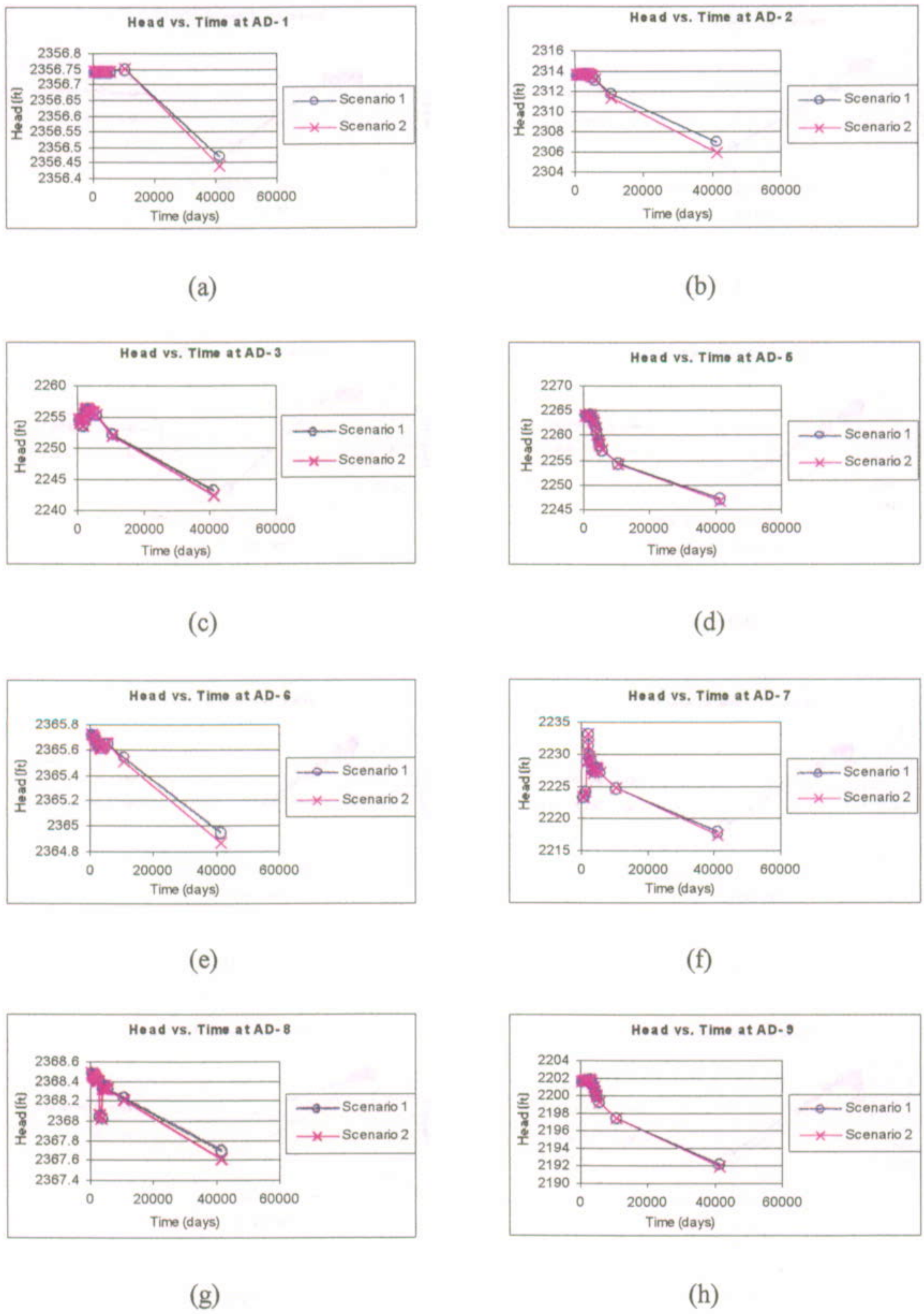


Figure 33. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model L1)

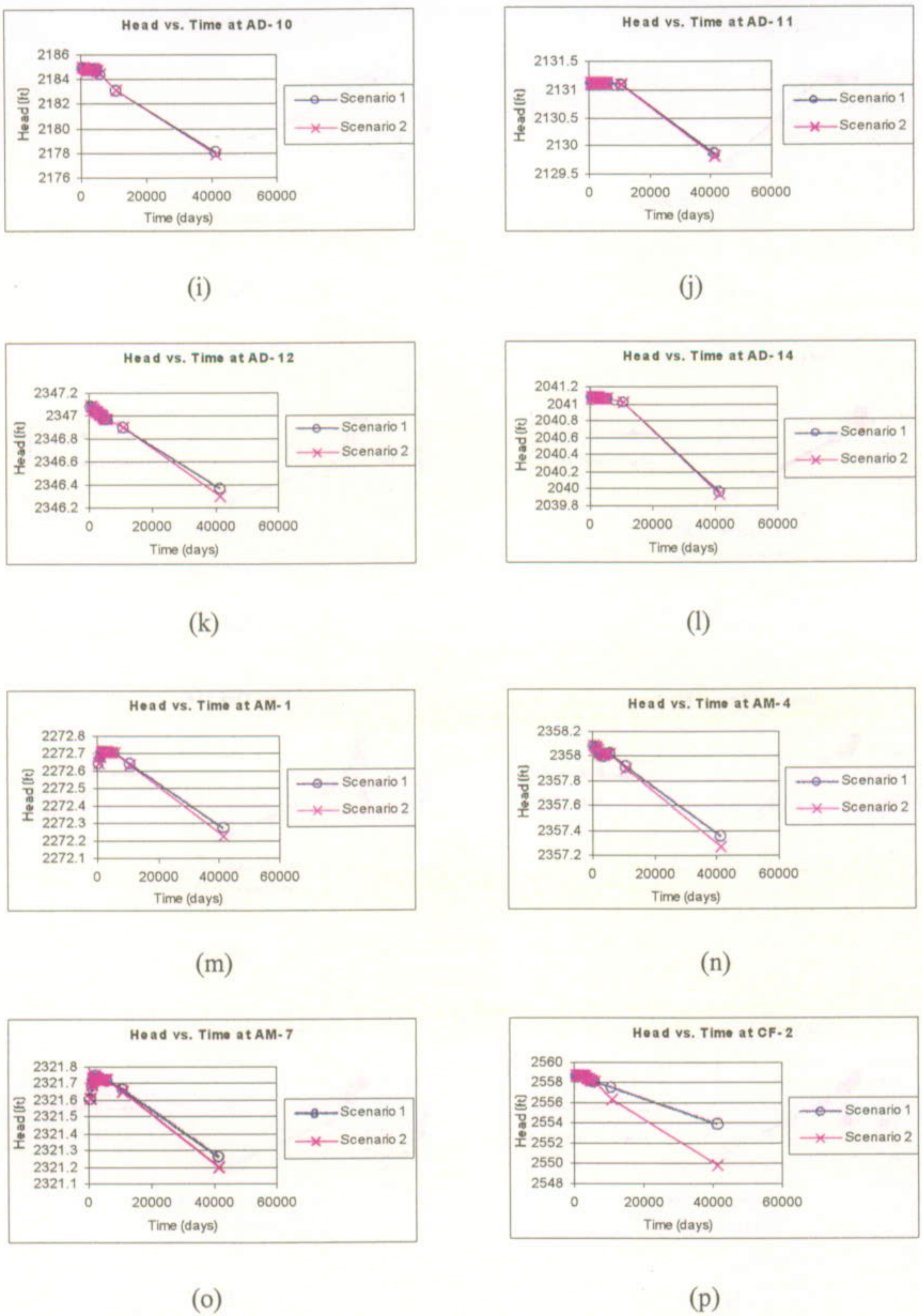
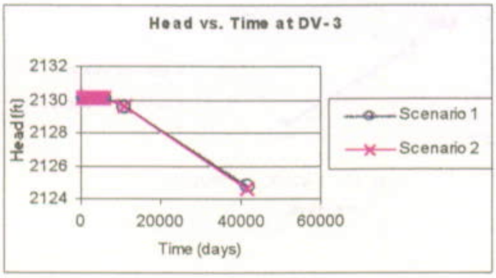
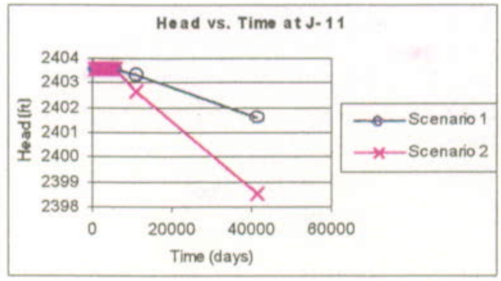


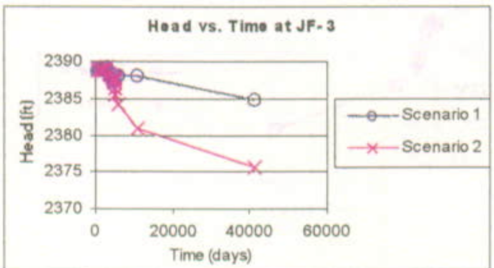
Figure 33 *(Continued)*. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model L1)



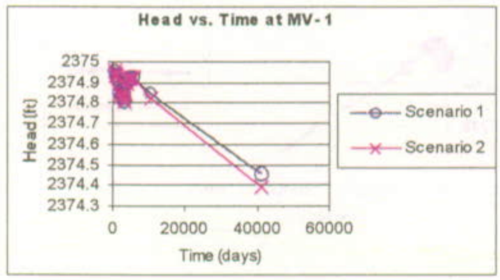
(q)



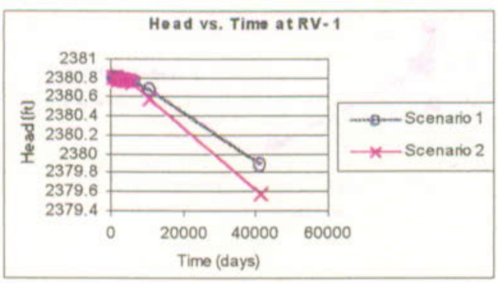
(r)



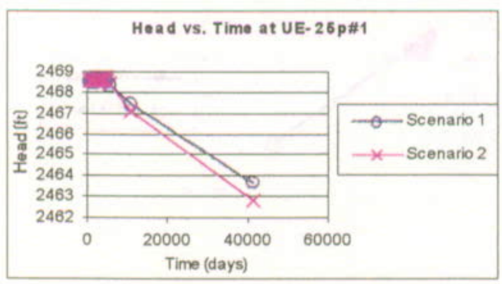
(s)



(t)

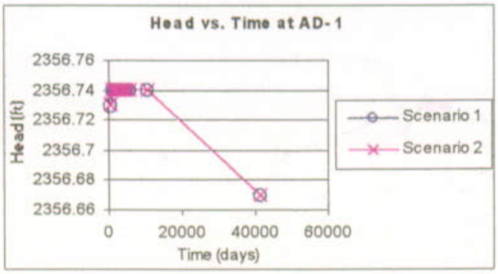


(u)

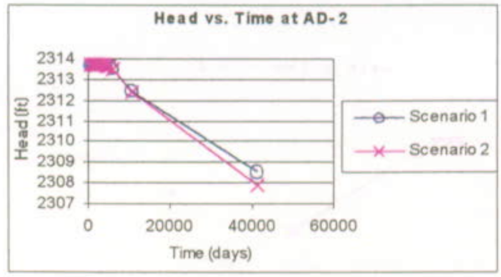


(v)

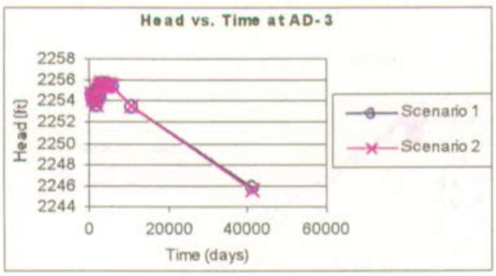
Figure 33 *(Continued)*. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model L1)



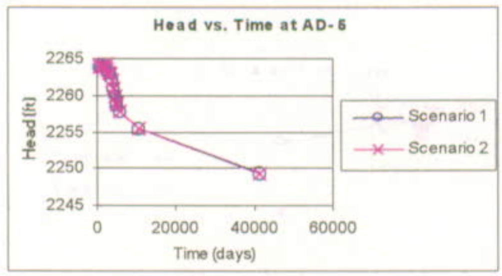
(a)



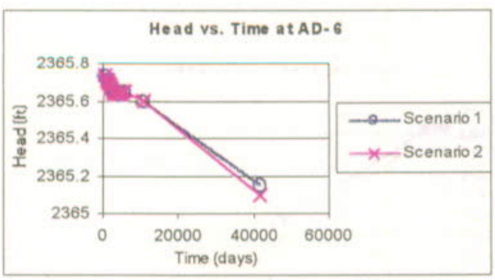
(b)



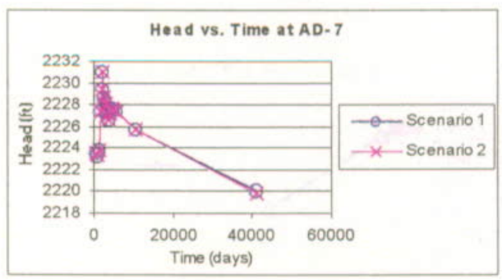
(c)



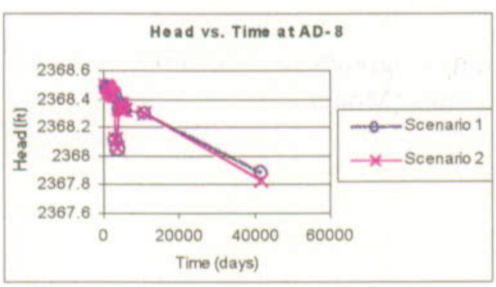
(d)



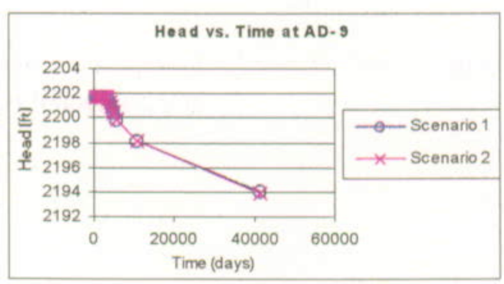
(e)



(f)



(g)



(h)

Figure 34. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model L2)

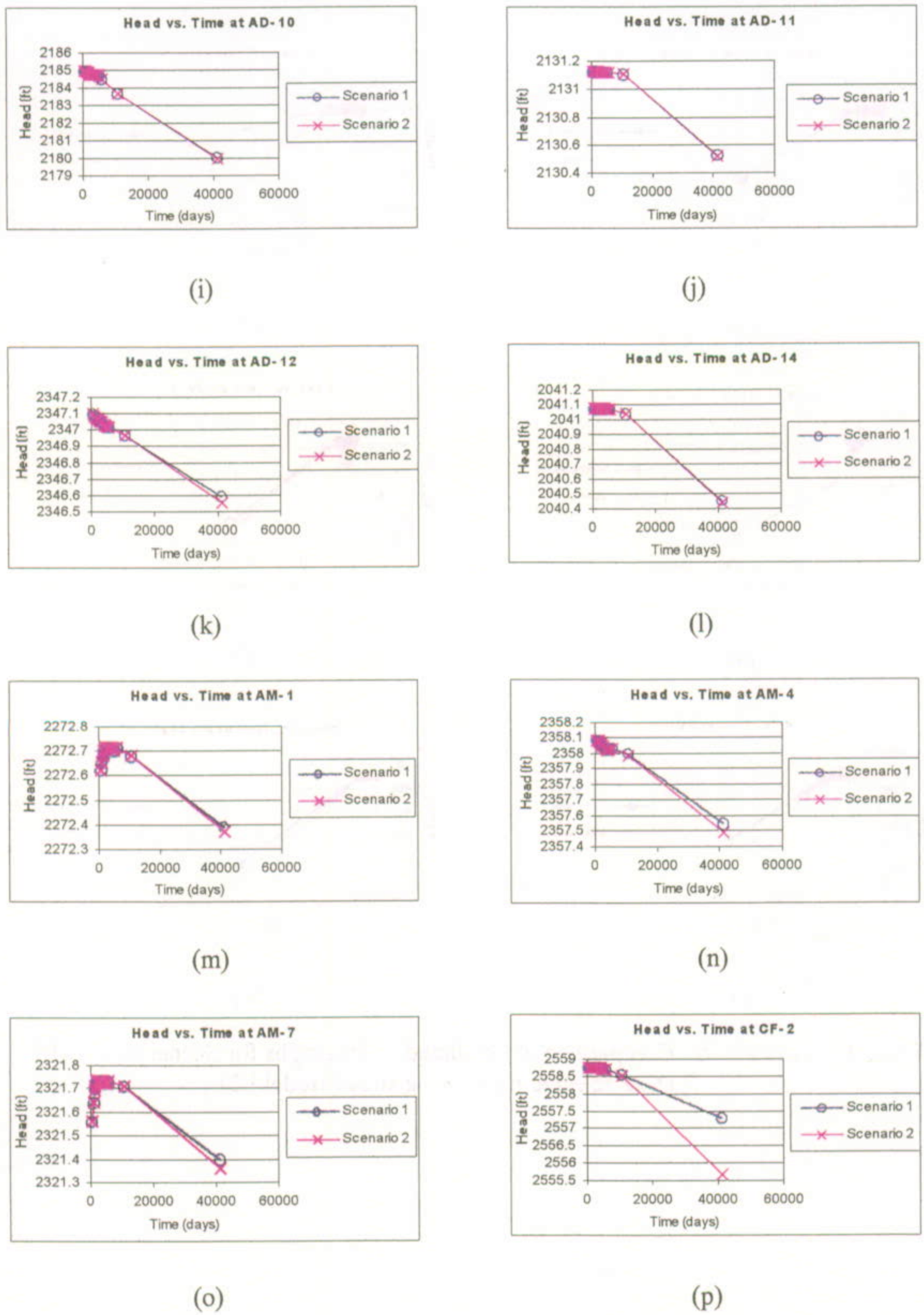
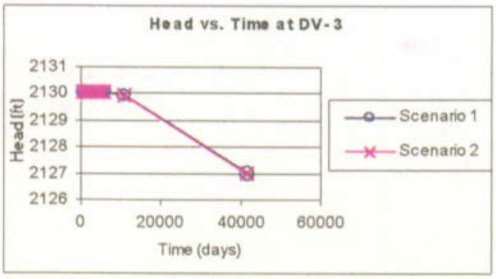
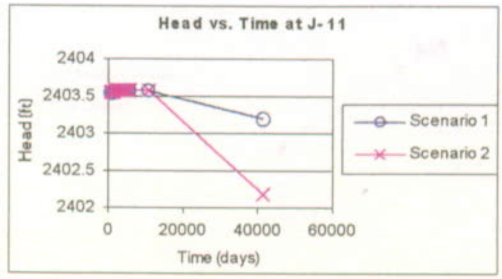


Figure 34 *(Continued)*. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model L2)



(q)



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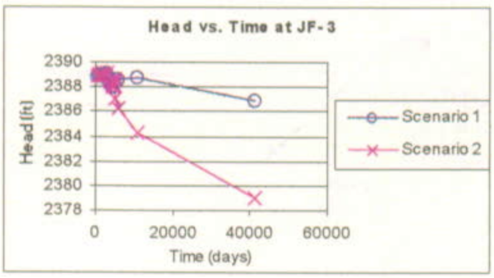

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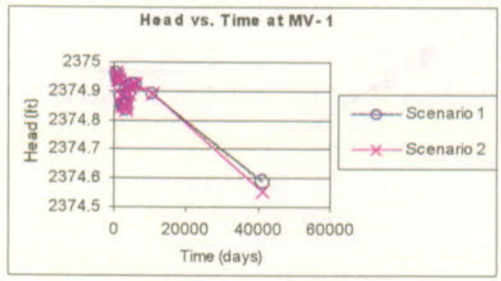

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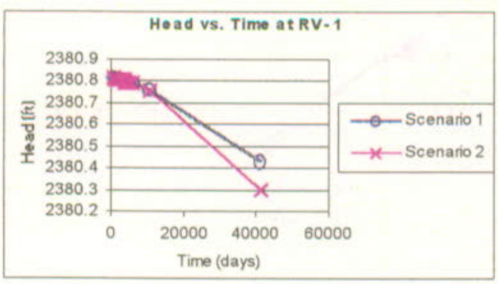

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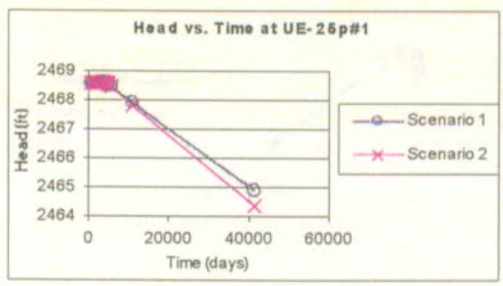


(v)

Figure 34 *(Continued)*. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model L2)

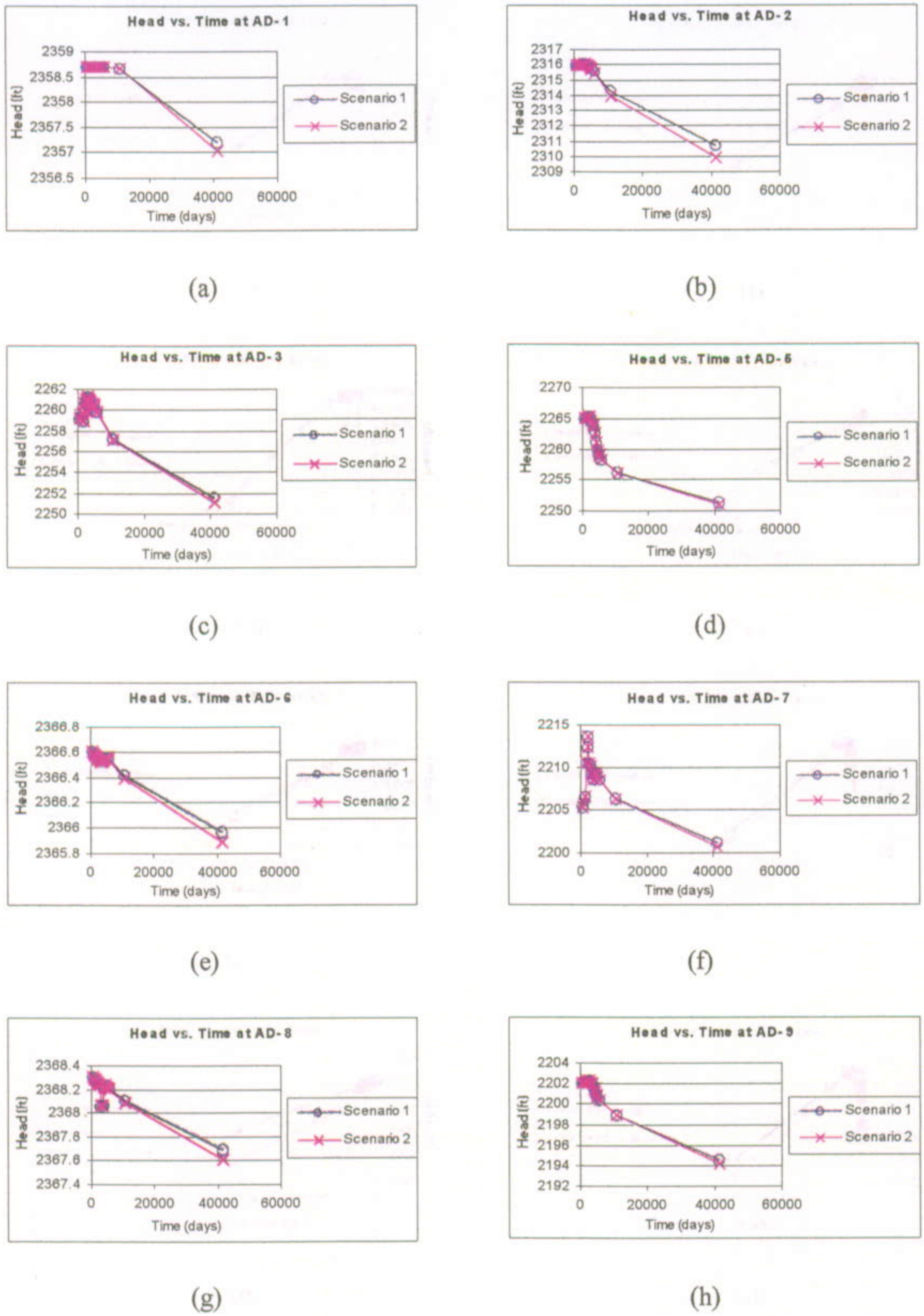
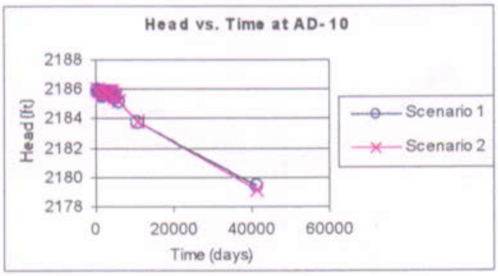


Figure 35. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model H1)



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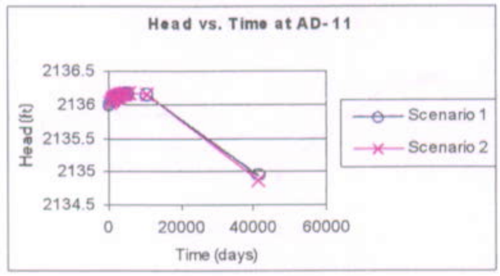

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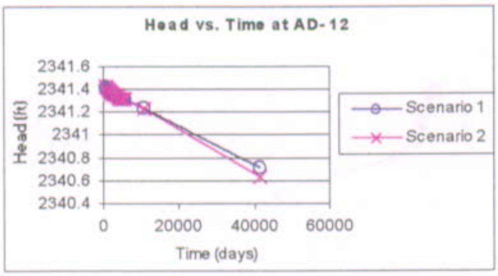

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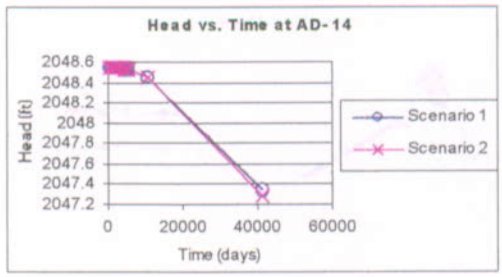

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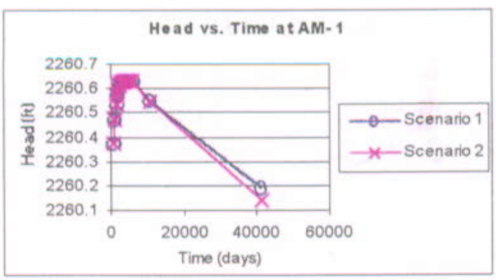

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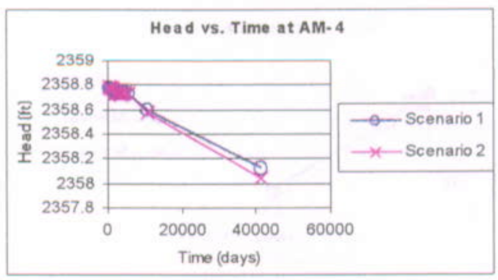

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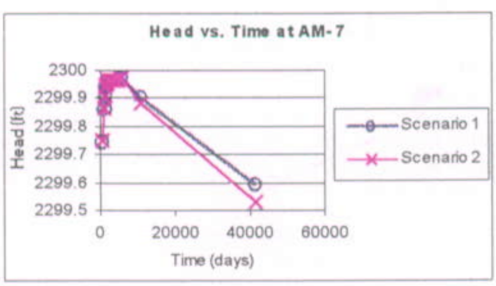

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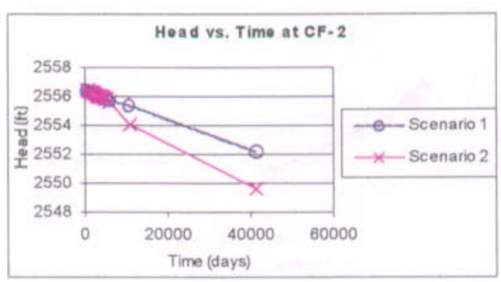

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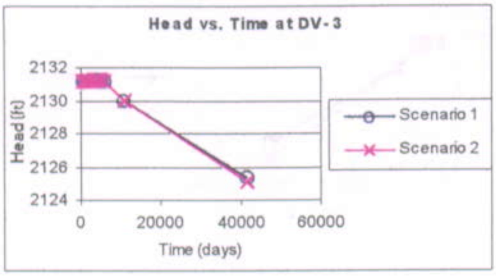
Figure 35 *(Continued)*. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model H1)



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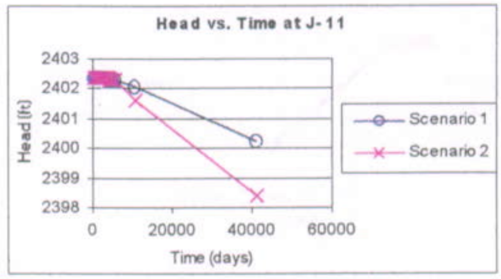

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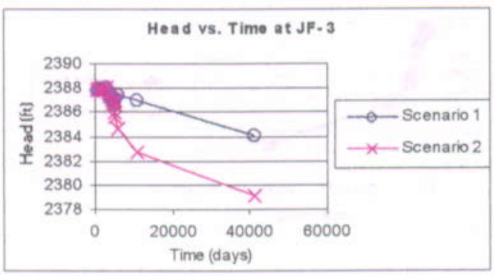

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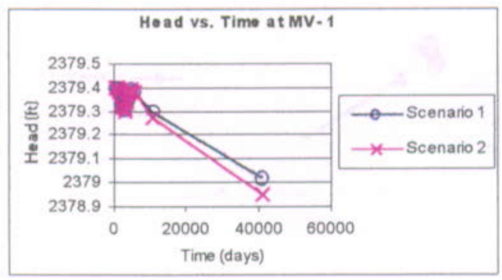

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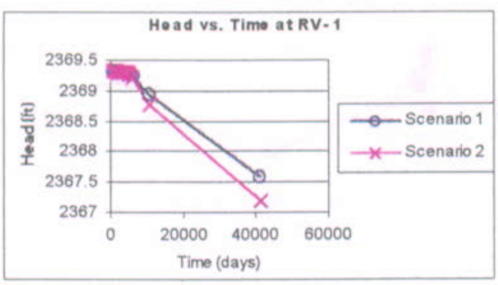

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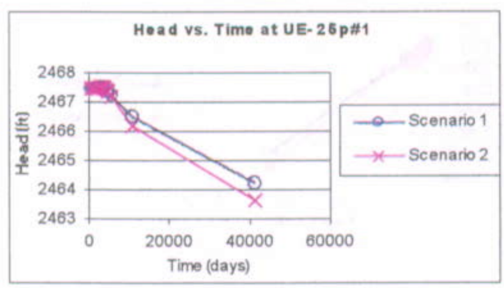


(v)

Figure 35 *(Continued)*. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model H1)

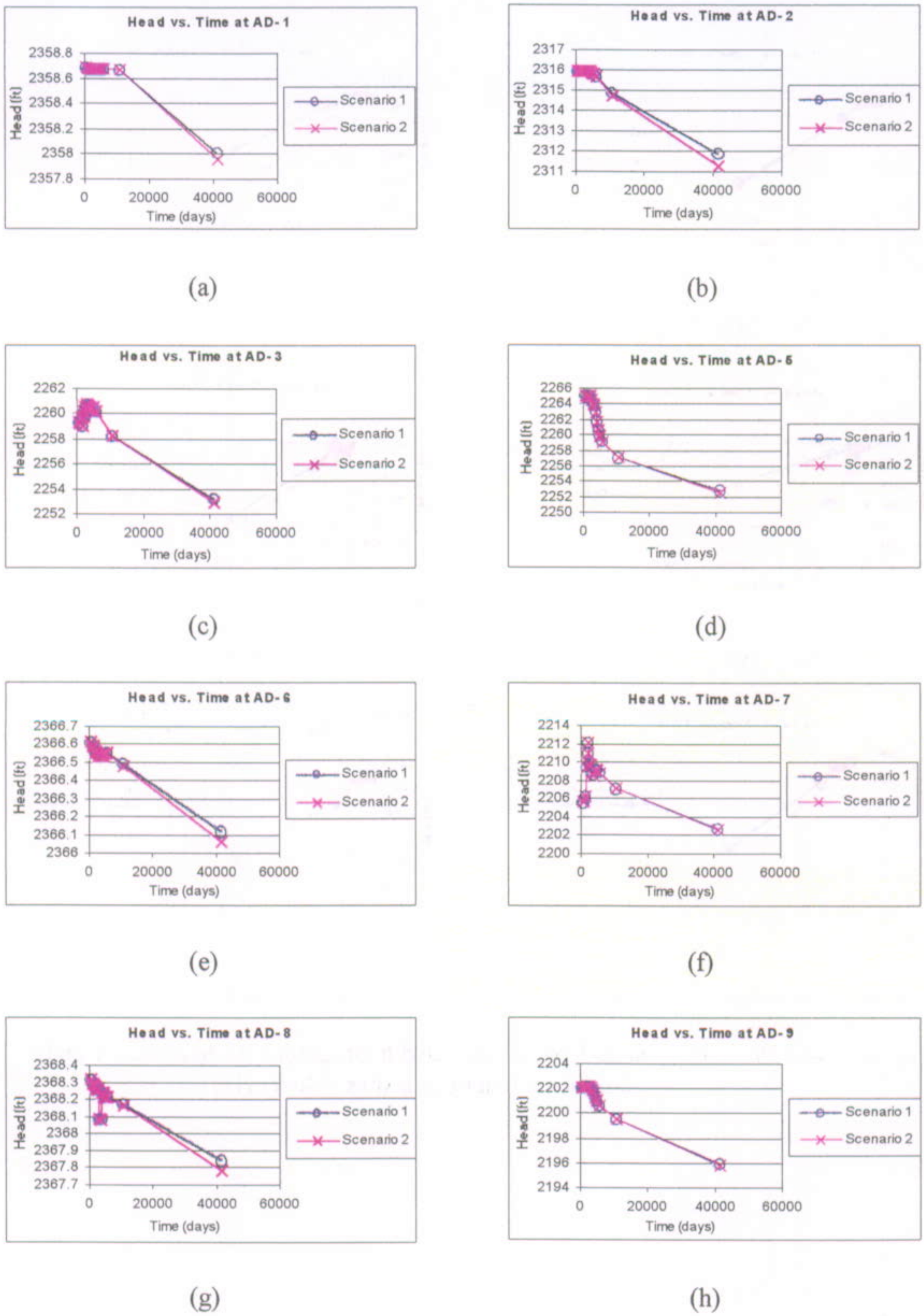
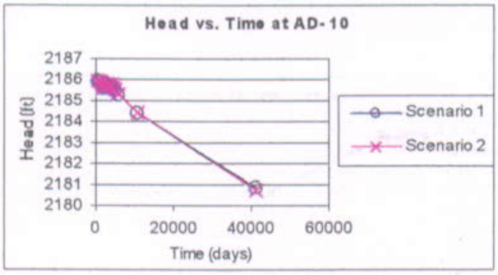


Figure 36. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model H2)



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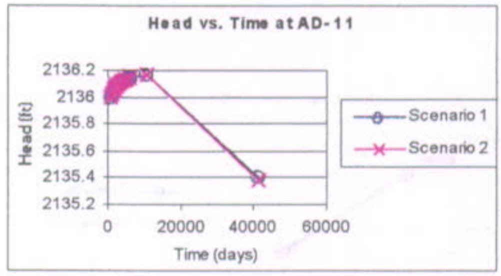

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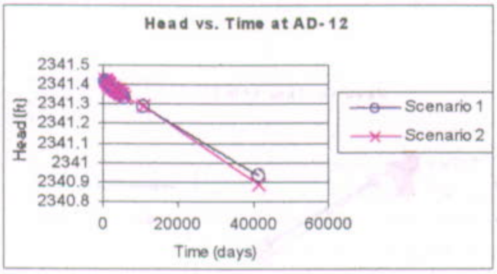

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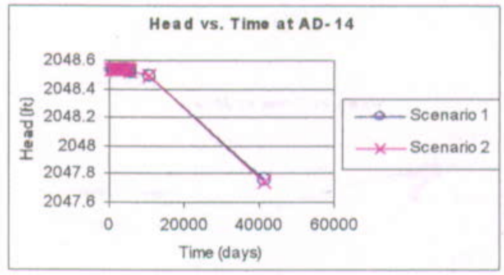

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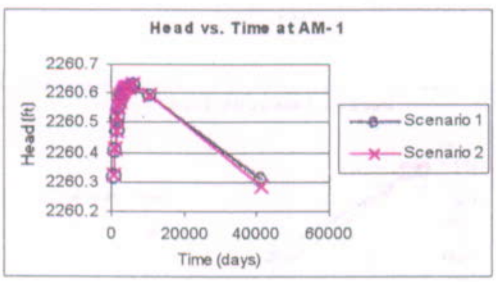

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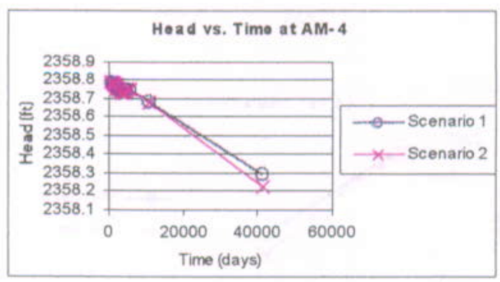

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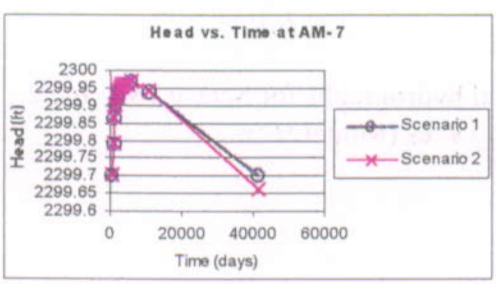

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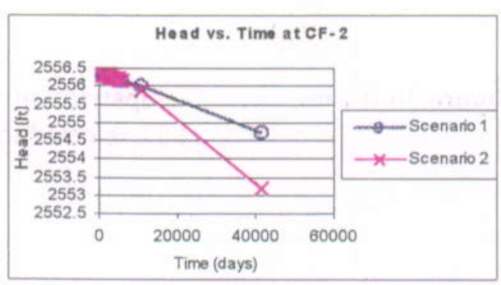

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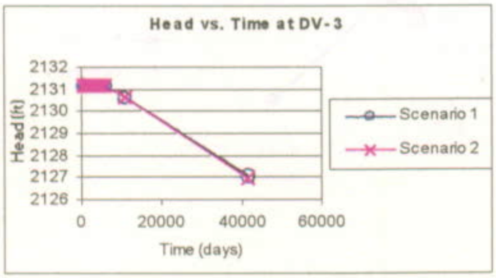
Figure 36 *(Continued)*. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model H2)



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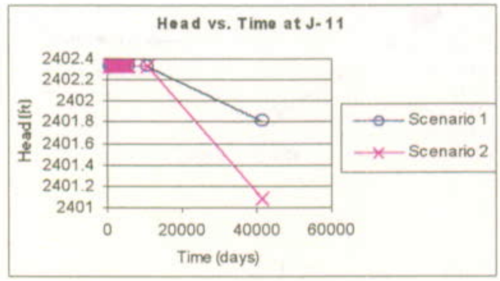

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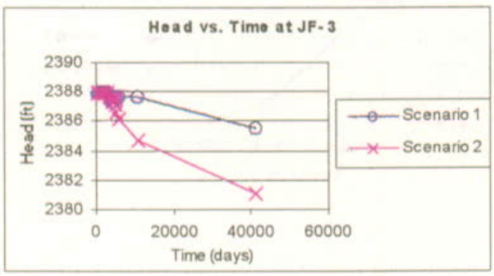

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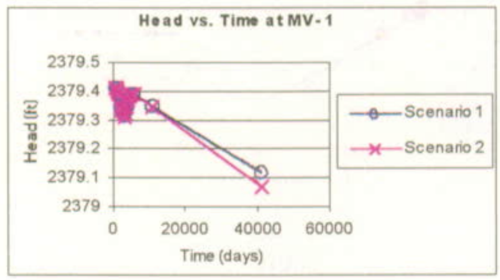

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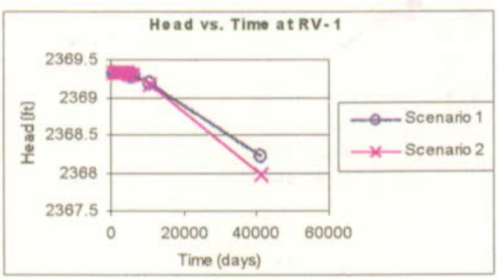

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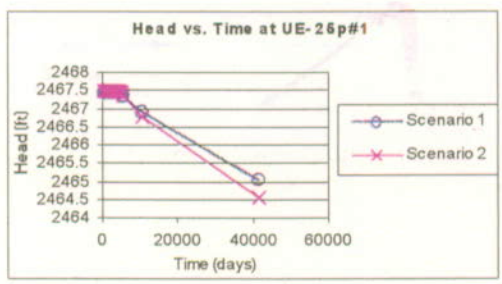
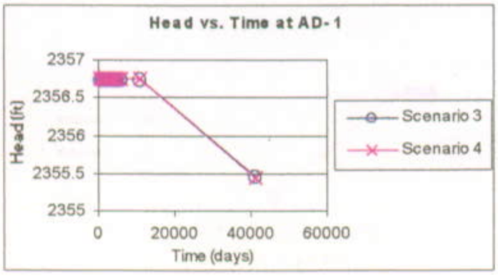
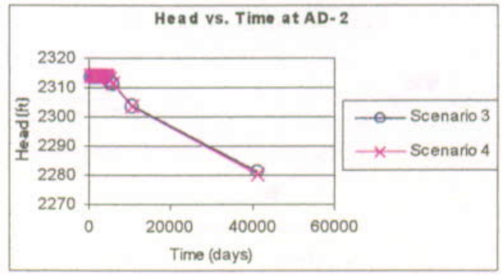


(v)

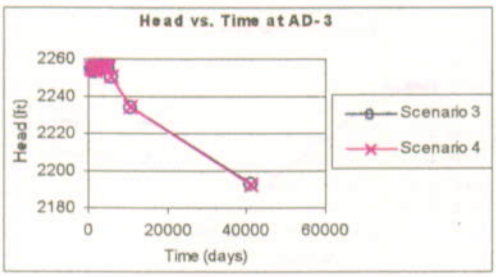
Figure 36 *(Continued)*. Comparison of simulated hydrographs for Scenarios 1 and 2 at 22 selected monitoring sites (Model H2)



(a)



(b)



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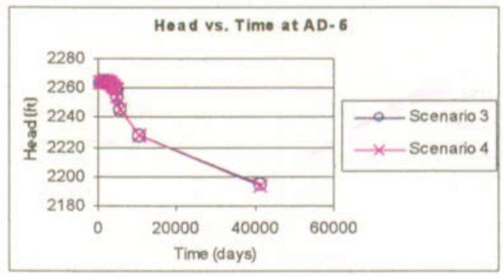

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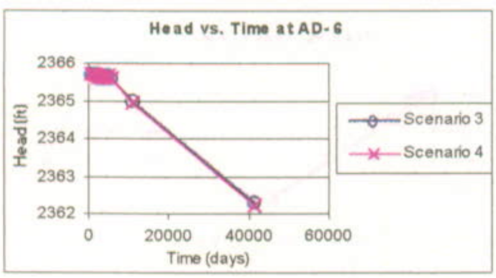

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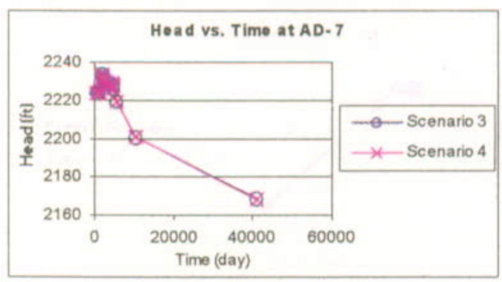

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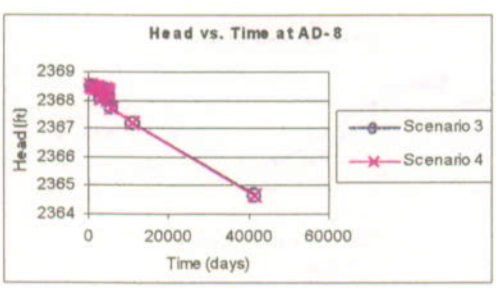
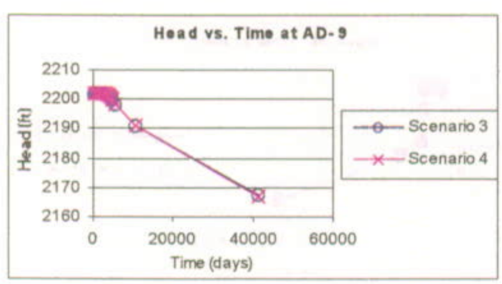


(g)



(h)

Figure 37. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model L1)

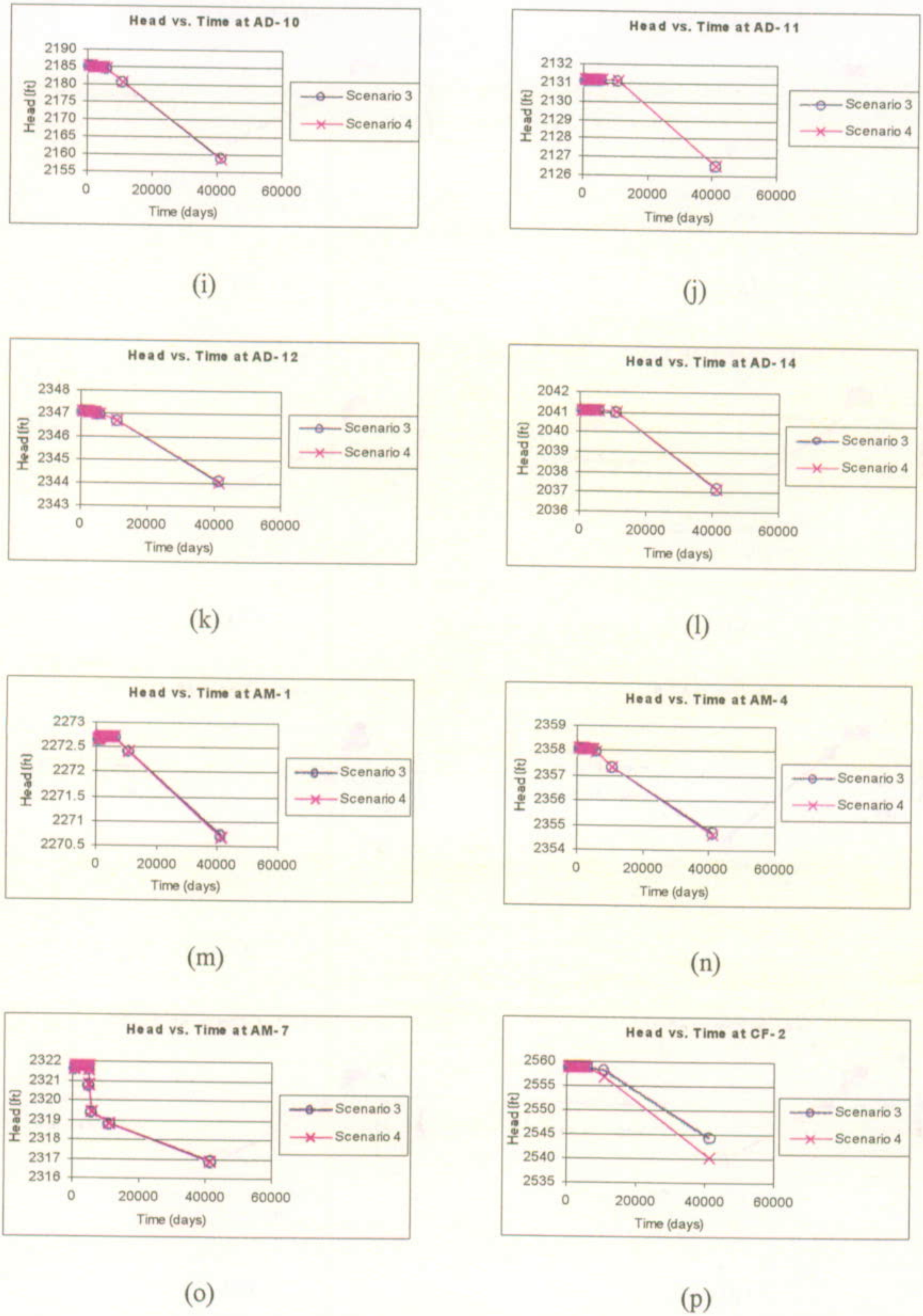
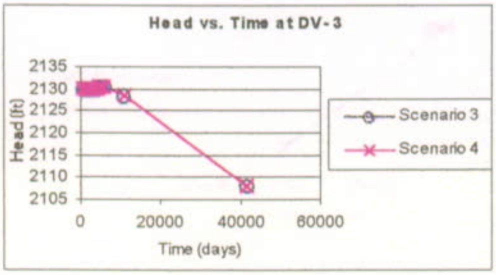


Figure 37 *(Continued)*. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model L1)



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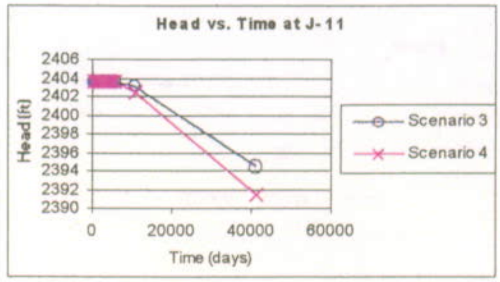

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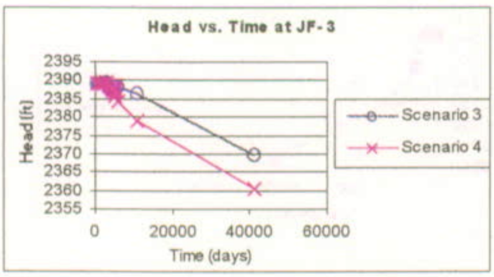

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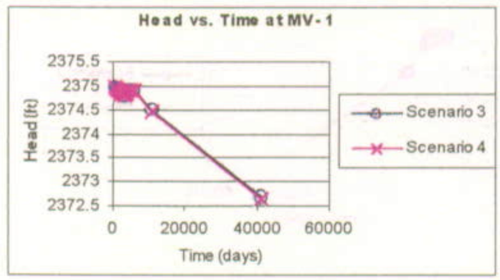

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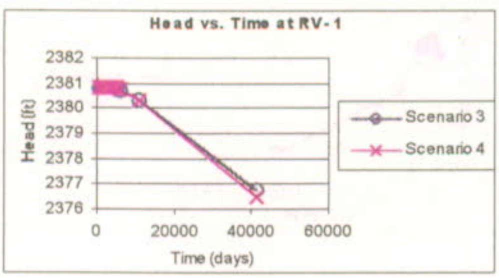

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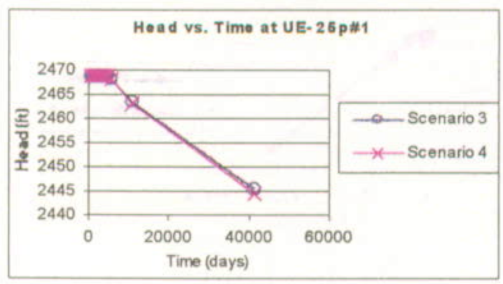
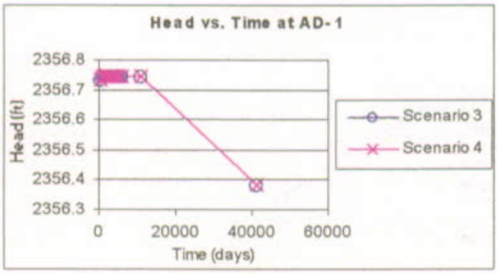


(v)

Figure 37 *(Continued)*. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model L1)



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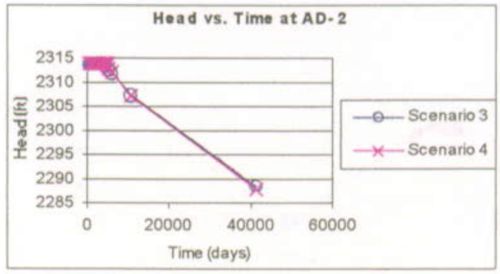

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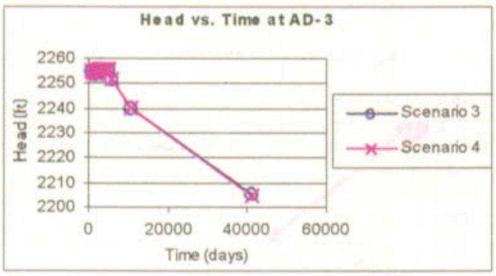

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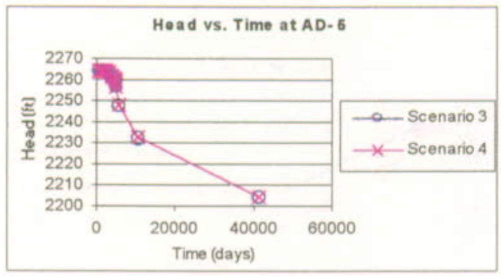

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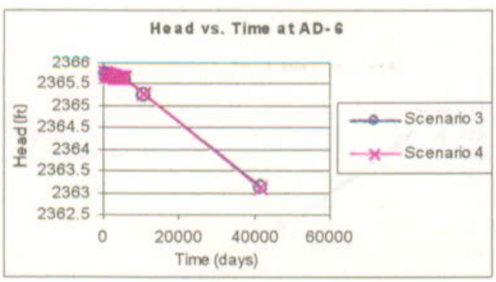

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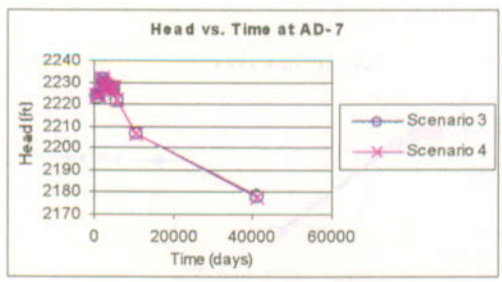

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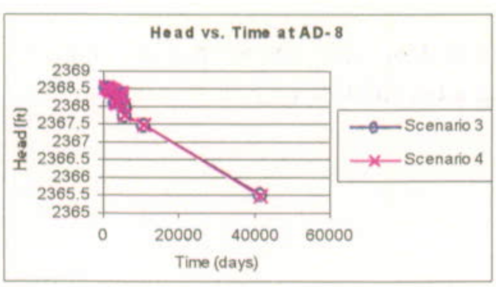

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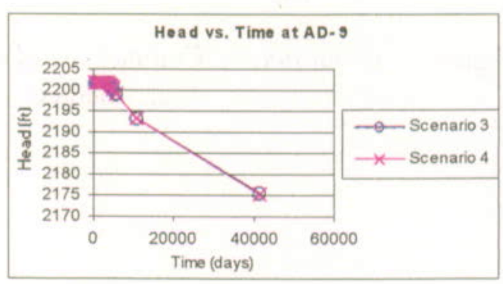

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Figure 38. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model L2)

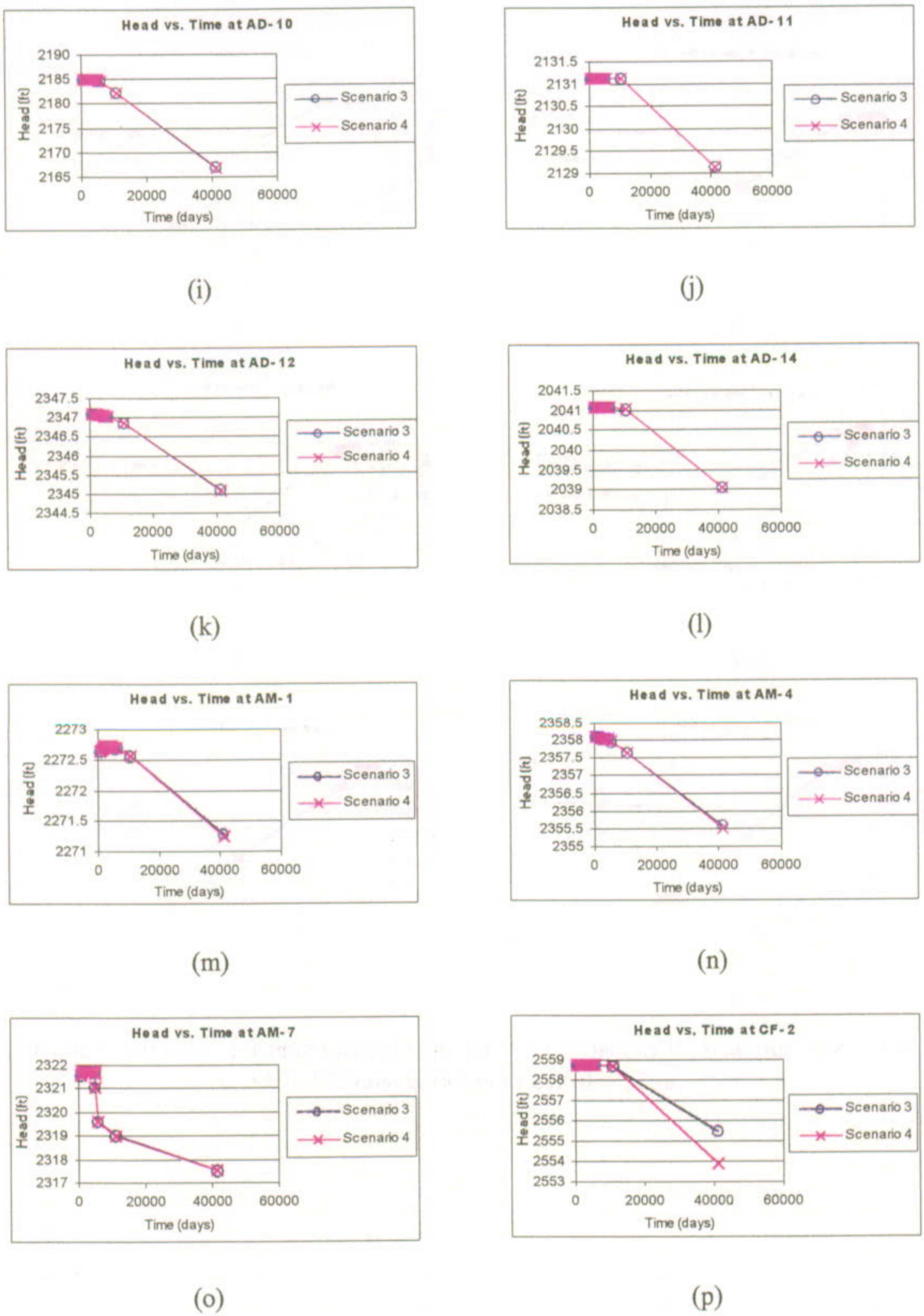
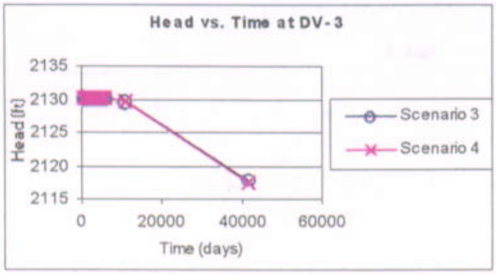


Figure 38 *(Continued)*. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model L2)



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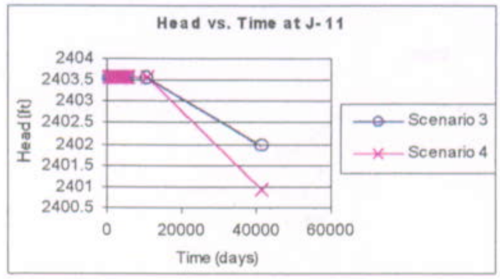

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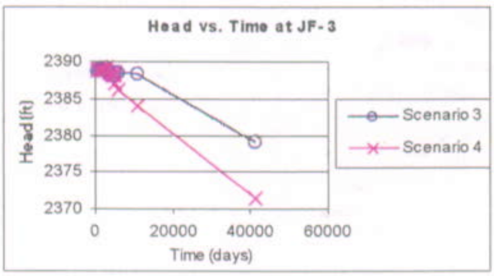

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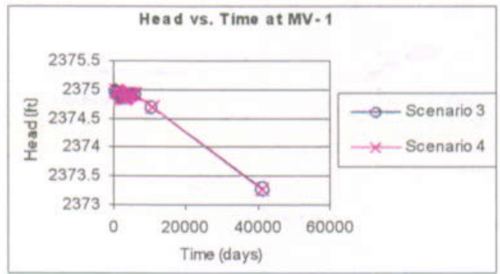

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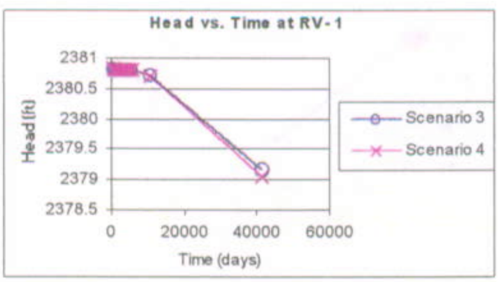

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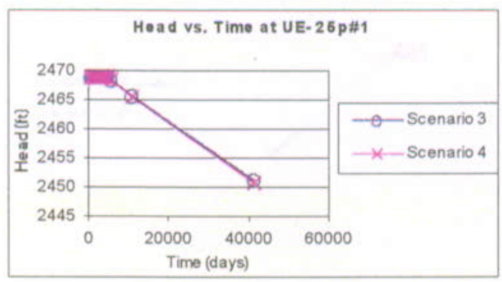


(v)

Figure 38 *(Continued)*. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model L2)

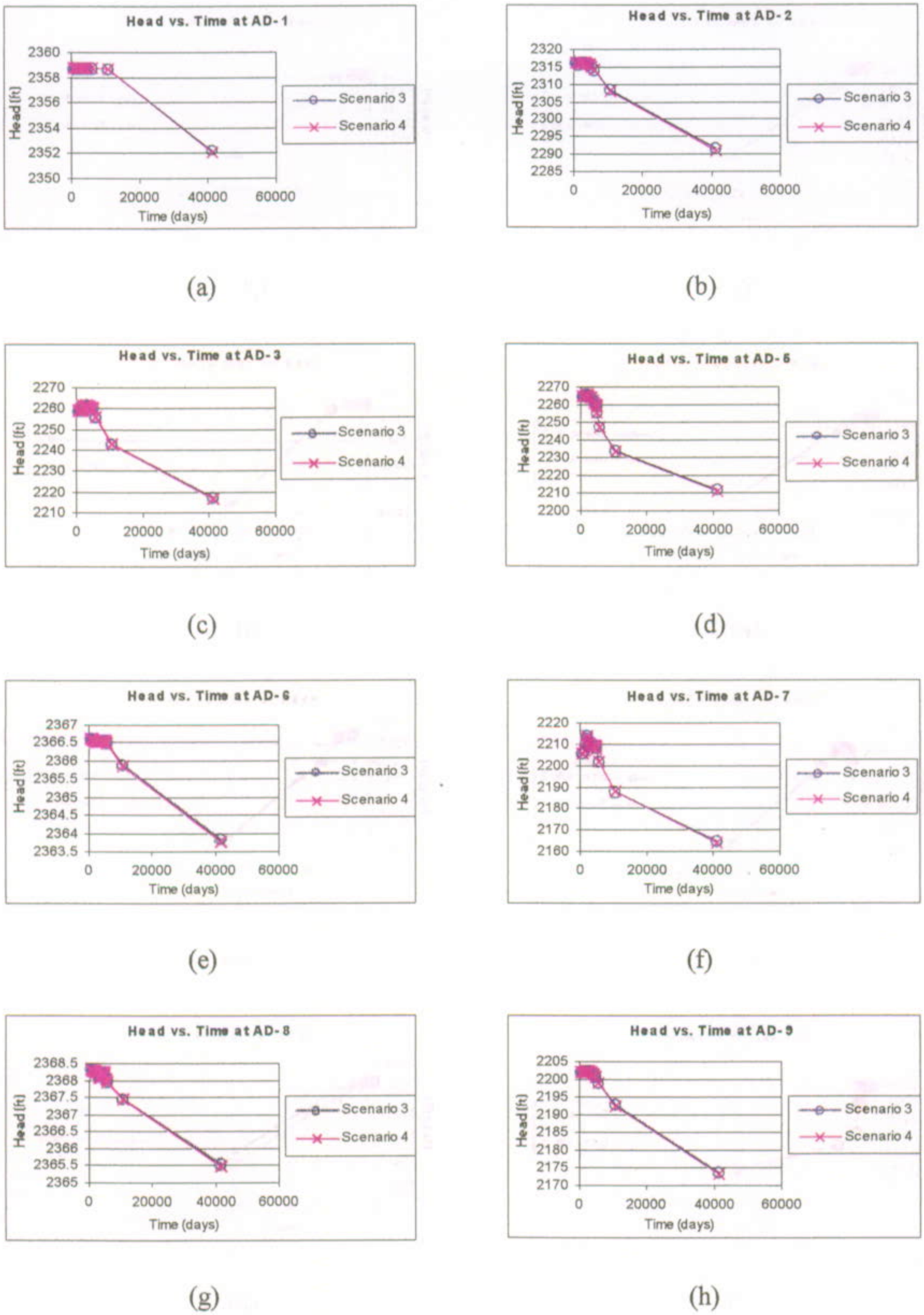
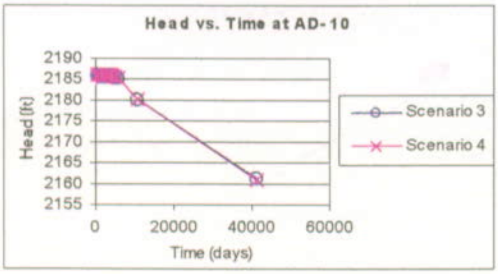


Figure 39. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model H1)



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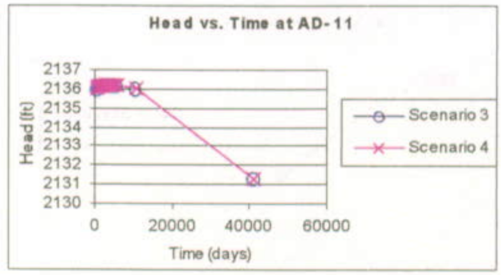

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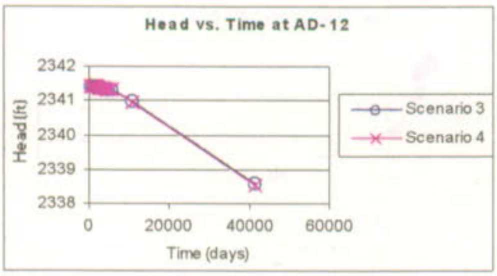

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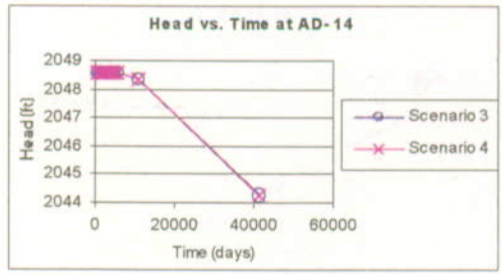
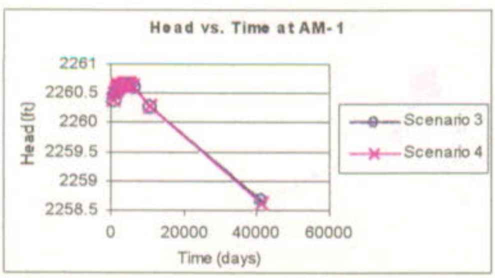
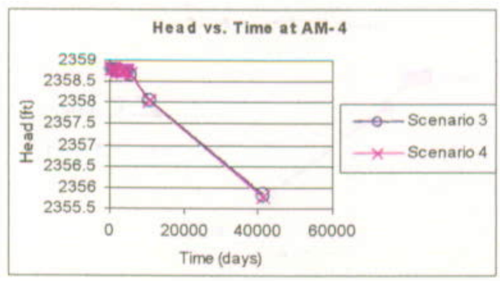


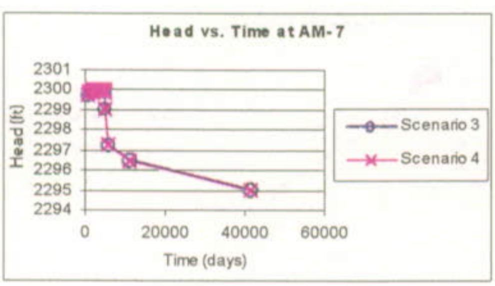
(l)



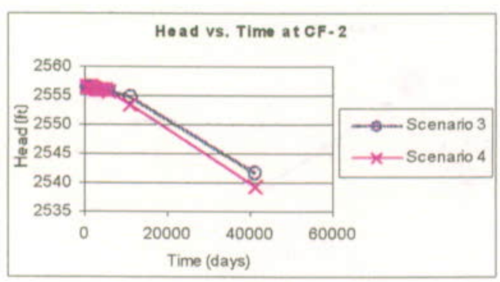
(m)



(n)



(o)



(p)

Figure 39 *(Continued)*. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model H1)

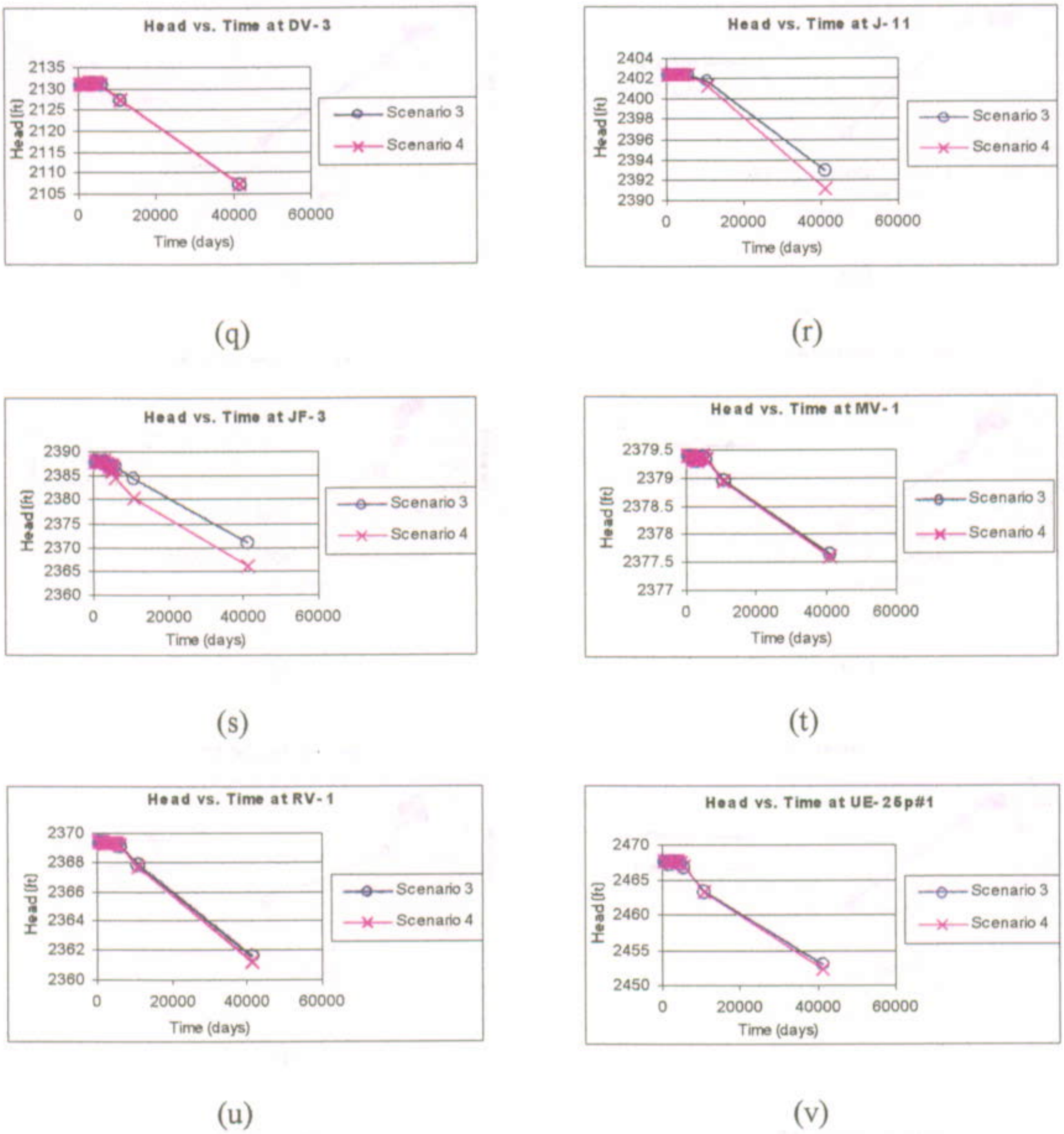


Figure 39 *(Continued)*. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model H1)

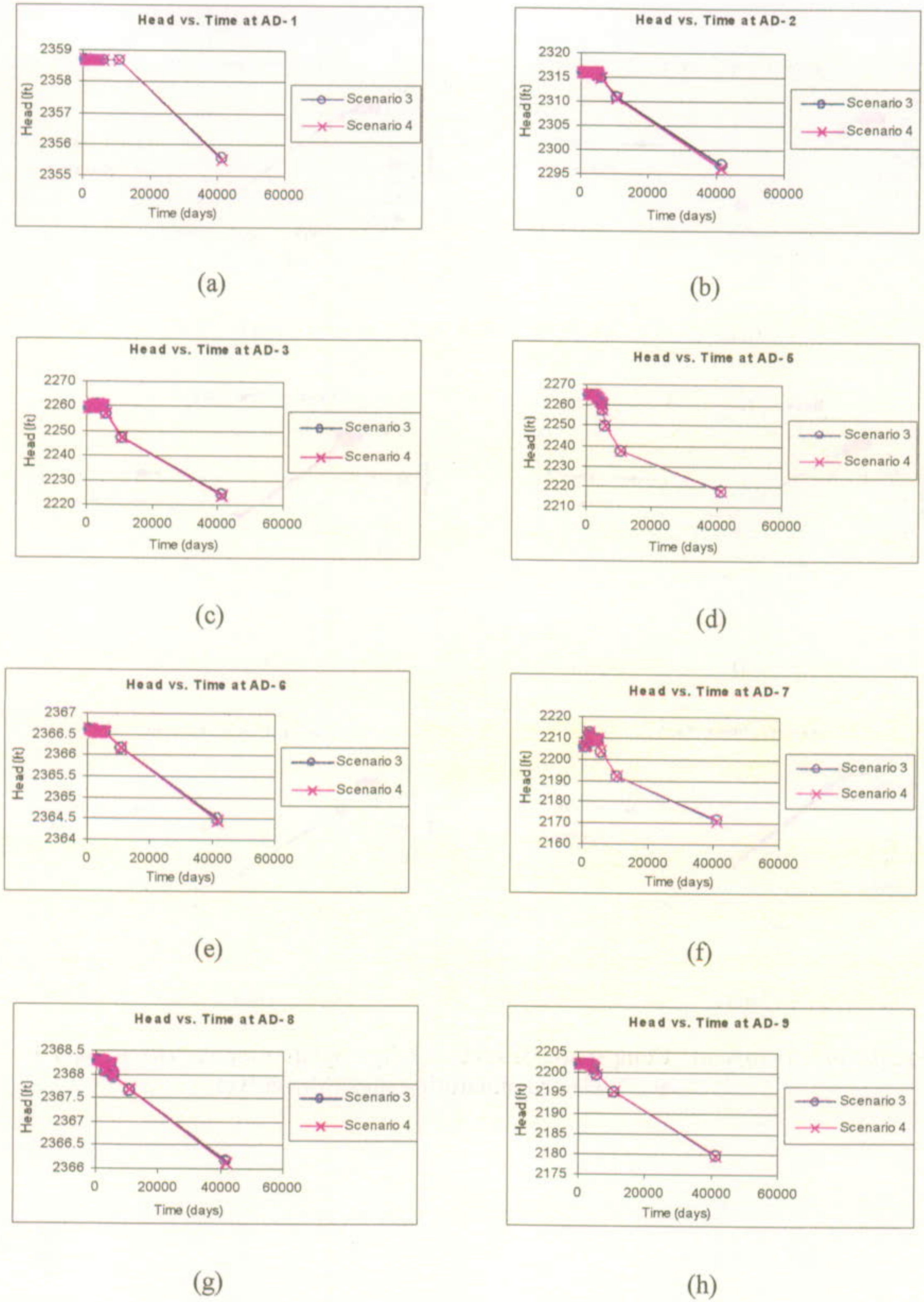


Figure 40. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model H2)

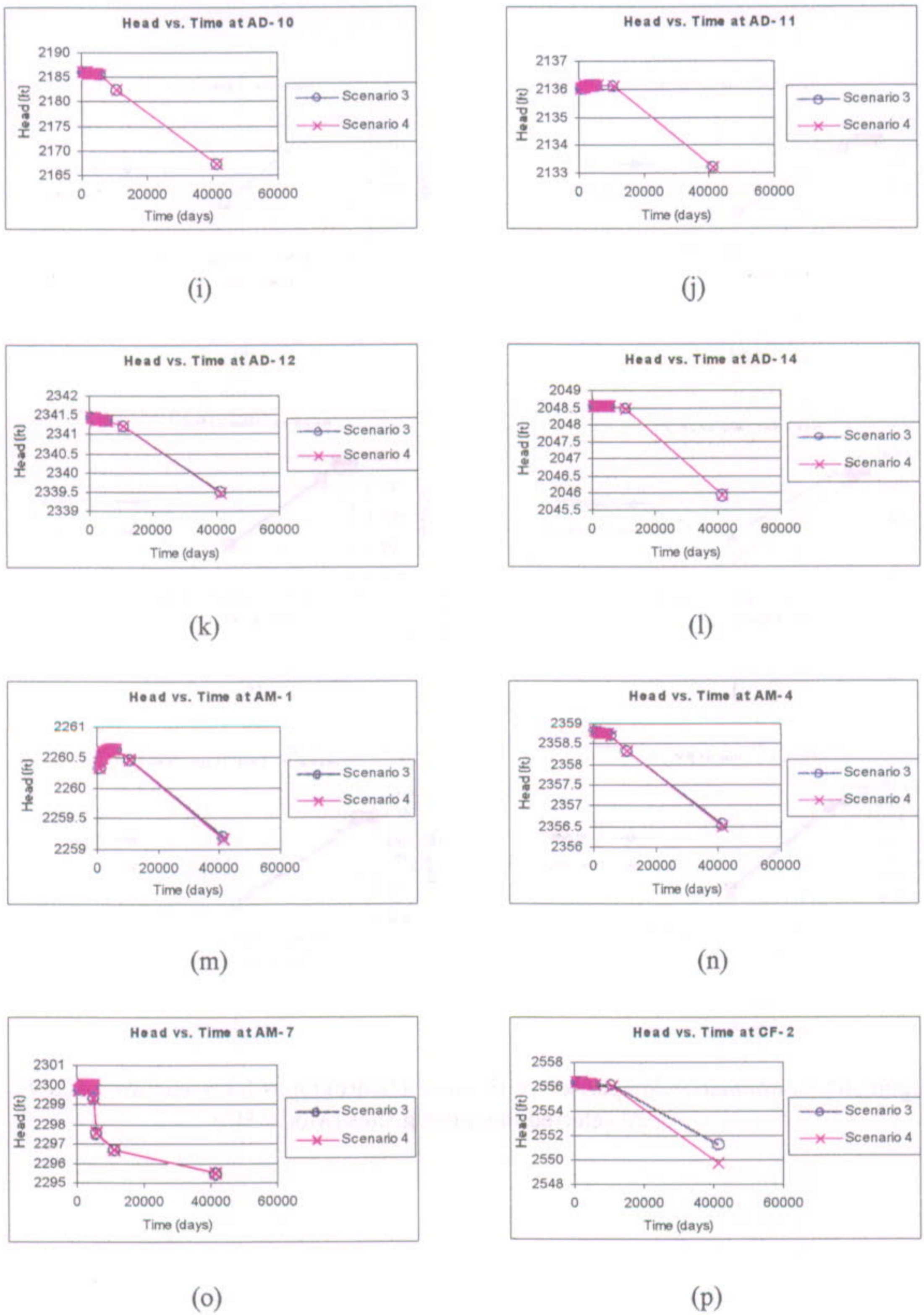
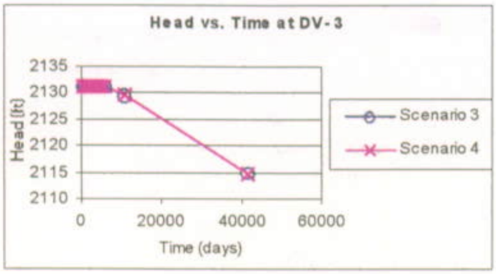
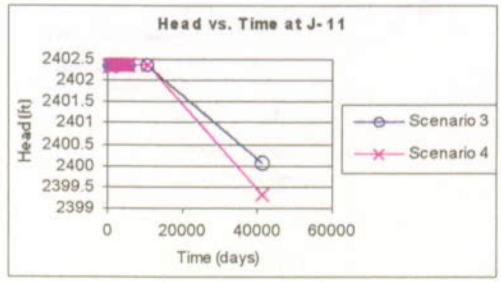


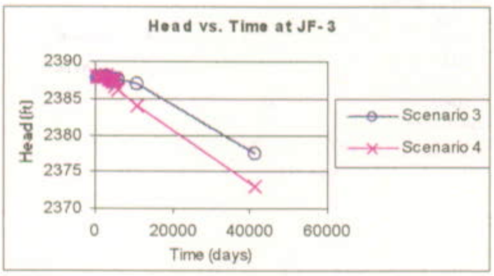
Figure 40 *(Continued)*. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model H2)



(q)



(r)



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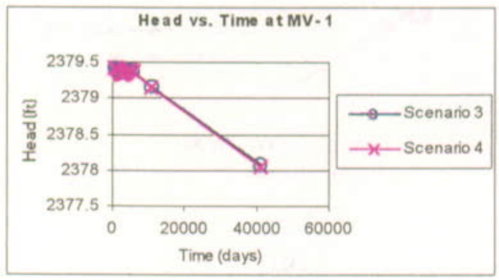
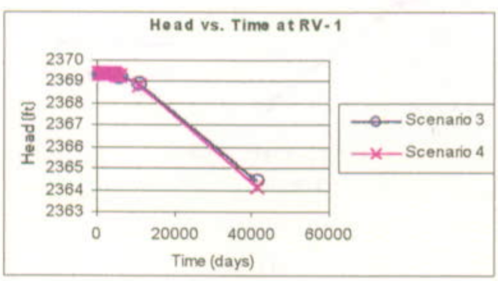
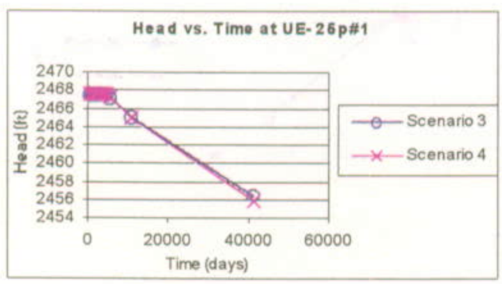


(t)



(u)



(v)

Figure 40 *(Continued)*. Comparison of simulated hydrographs for Scenarios 3 and 4 at 22 selected monitoring sites (Model H2)

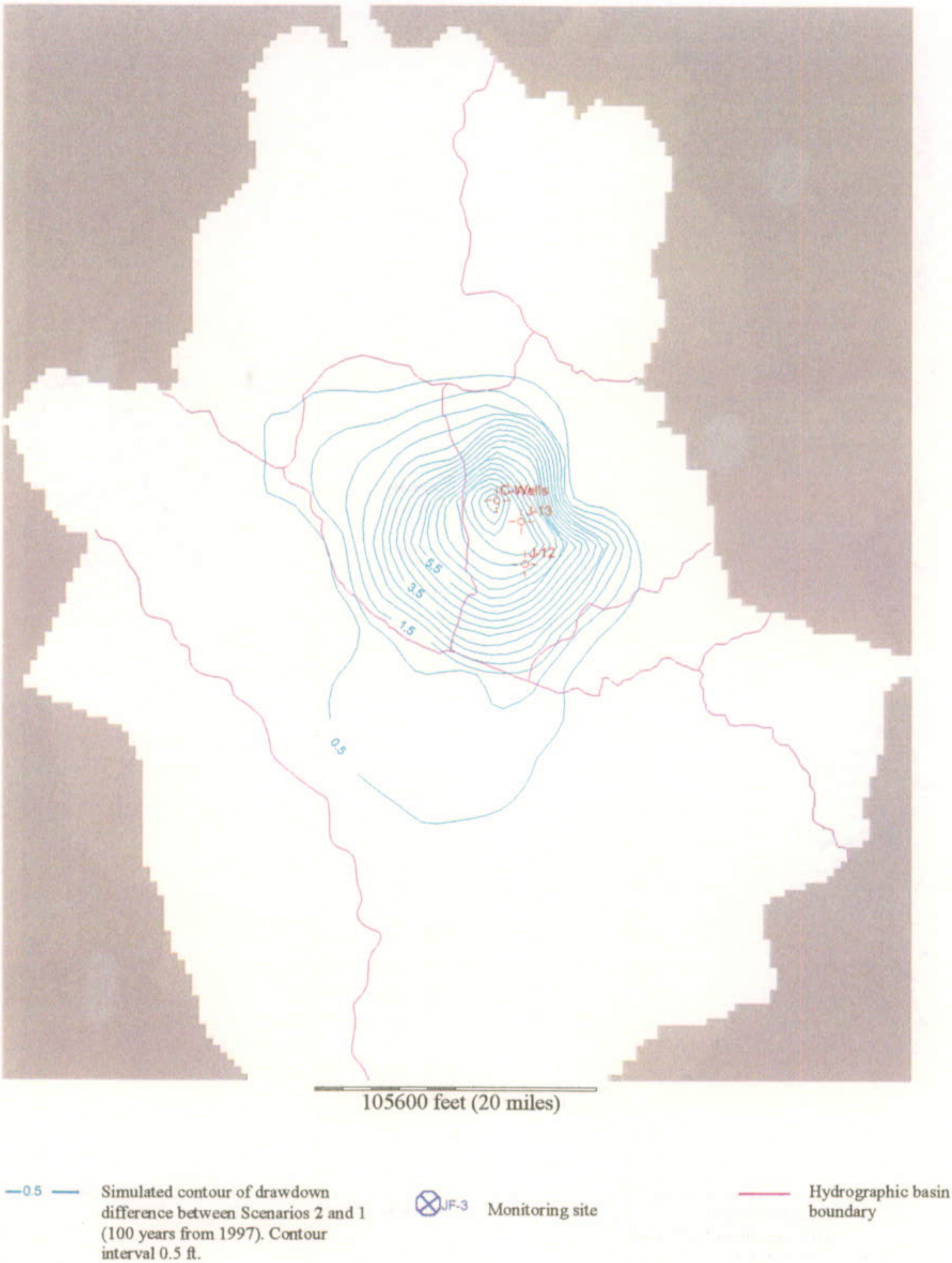


Figure 41 (a) Drawdown difference between Scenarios 2 and 1 (Top layer of Model L1)
(Senior rights pumping at 1997 level)

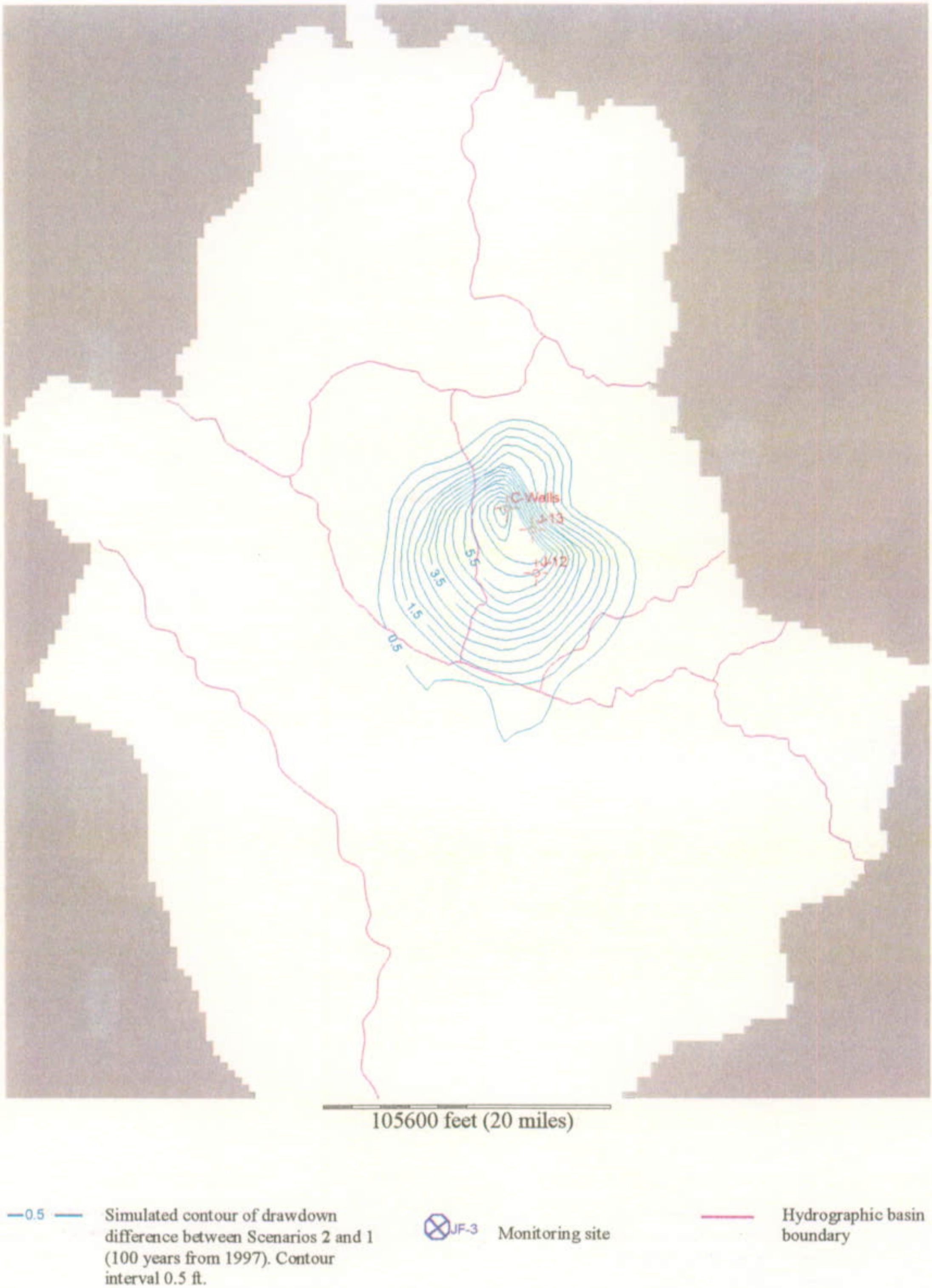


Figure 41 (b) Drawdown difference between Scenarios 2 and 1 (Top layer of Model L2)
(Senior rights pumping at 1997 level)

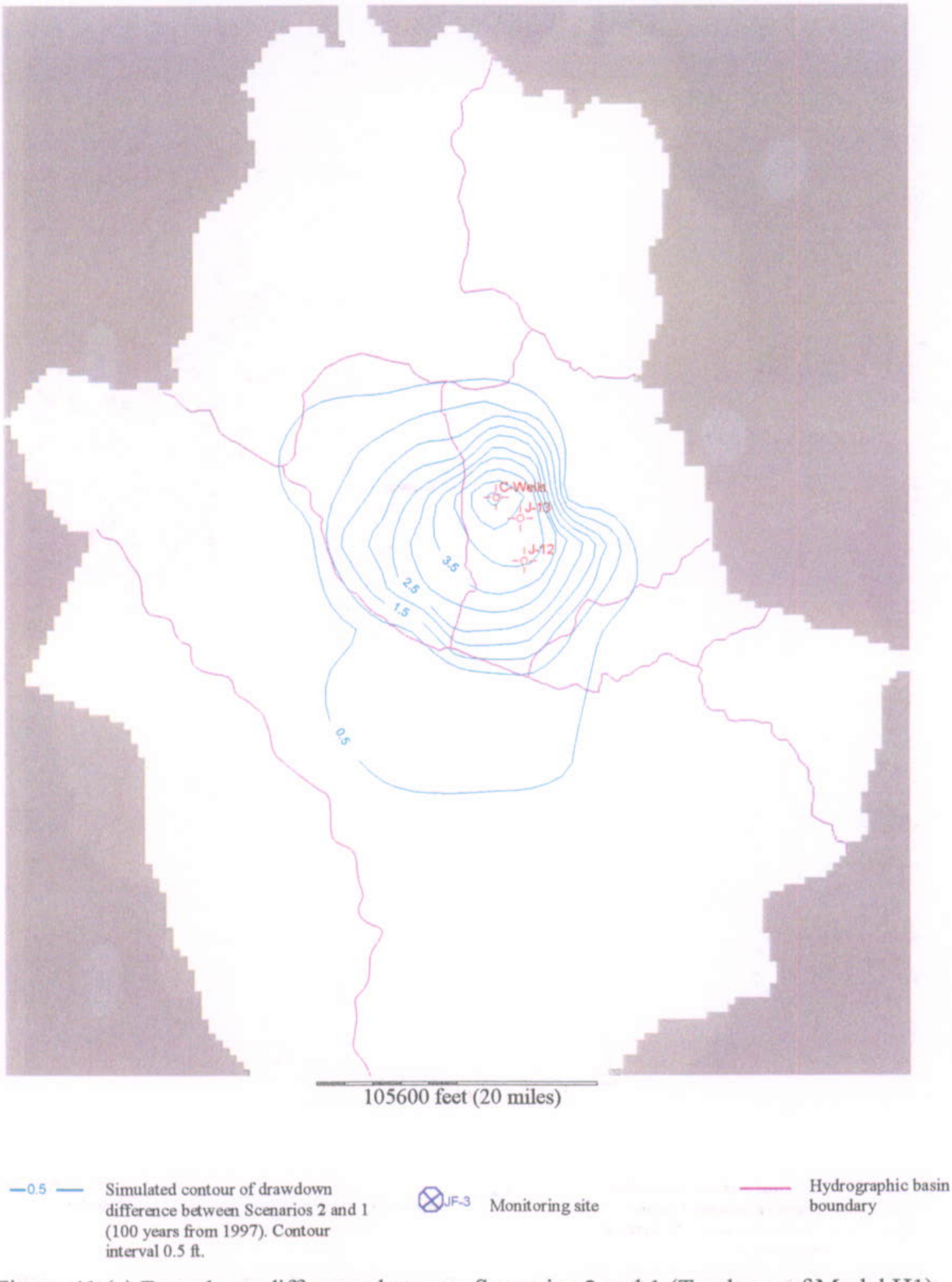


Figure 41 (c) Drawdown difference between Scenarios 2 and 1 (Top layer of Model H1)
(Senior rights pumping at 1997 level)

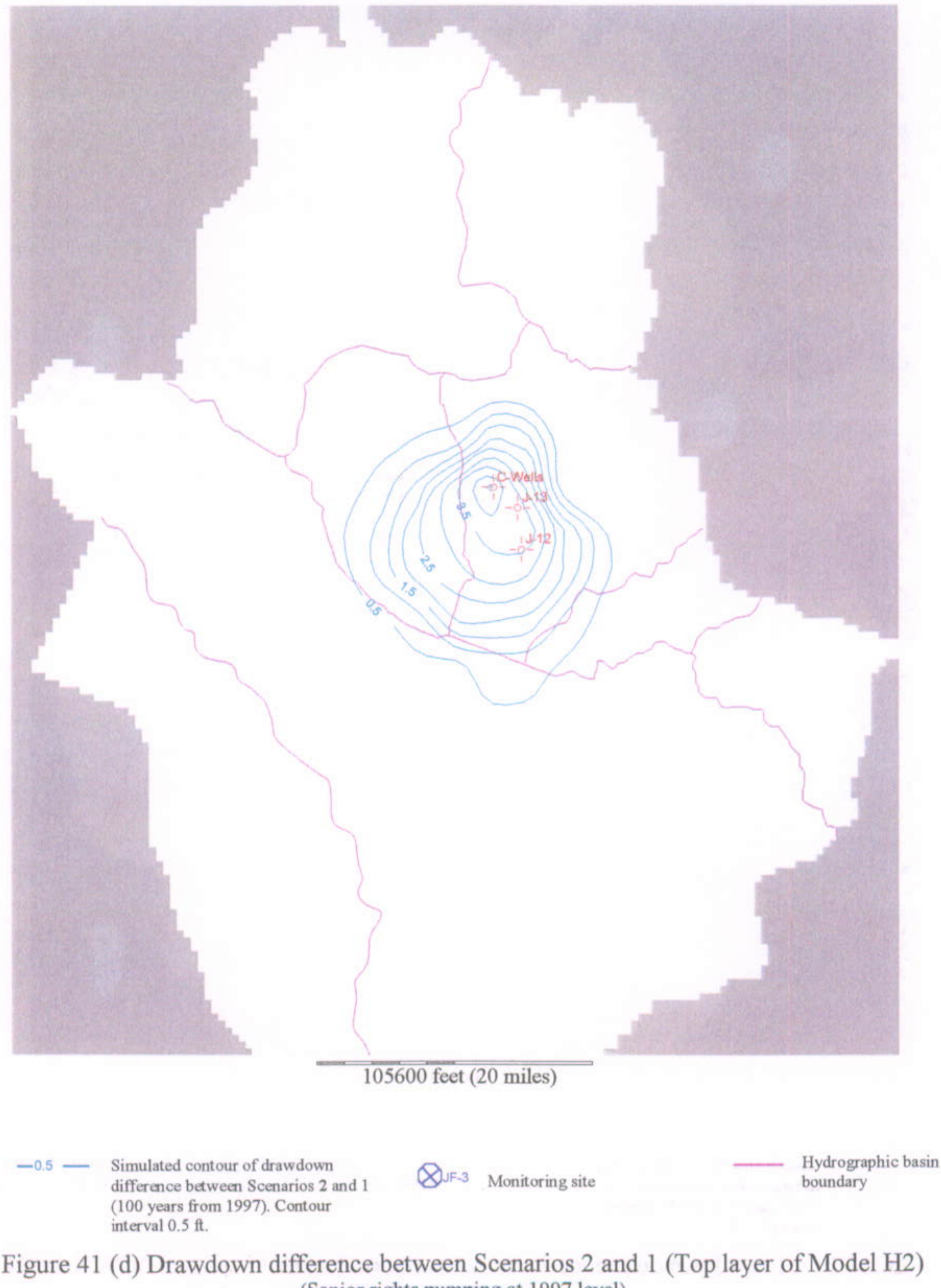


Figure 41 (d) Drawdown difference between Scenarios 2 and 1 (Top layer of Model H2)
(Senior rights pumping at 1997 level)

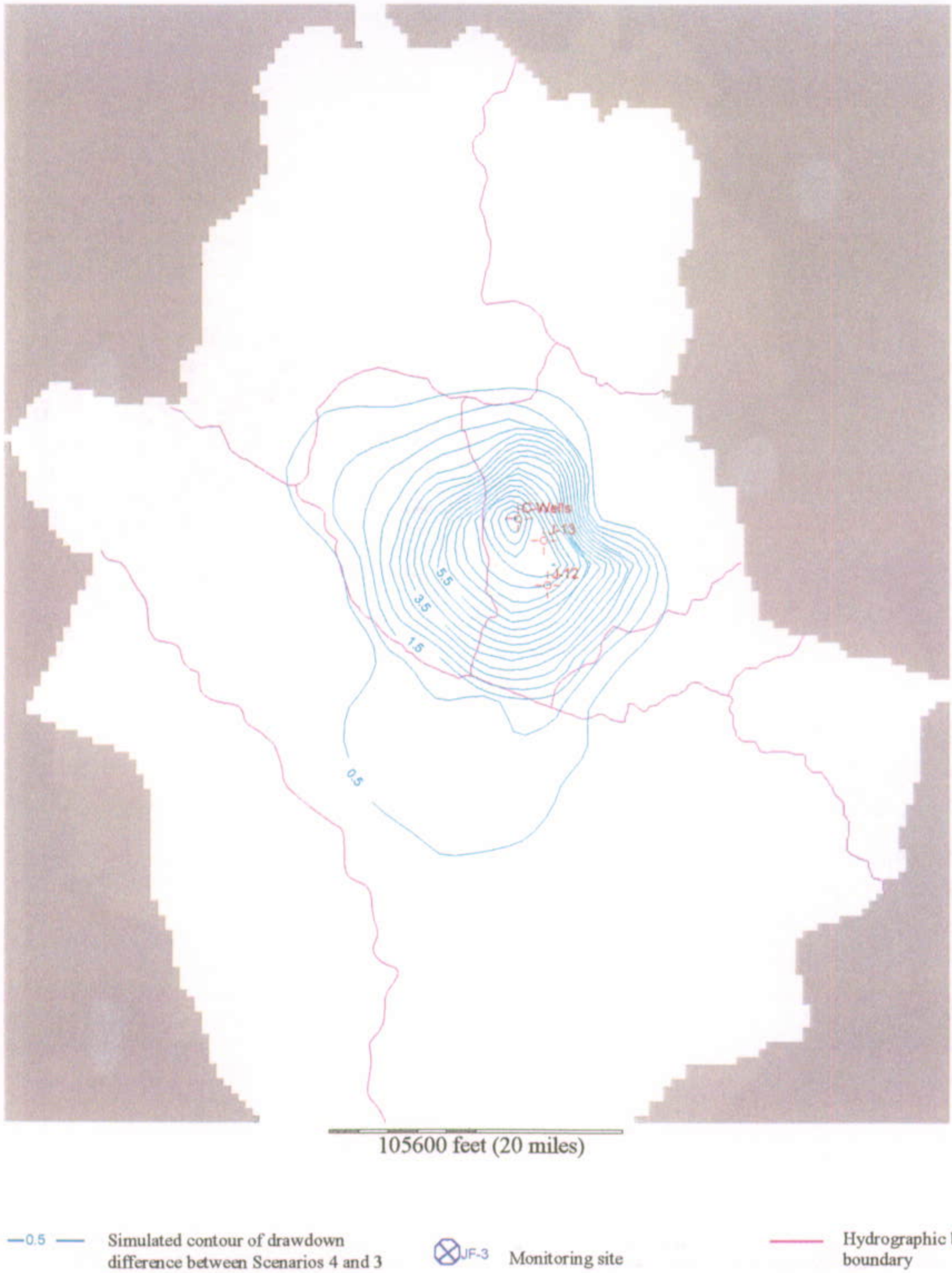


Figure 42 (a) Drawdown difference between Scenarios 4 and 3 (Top layer of Model L1)
(Senior rights pumping at maximum)

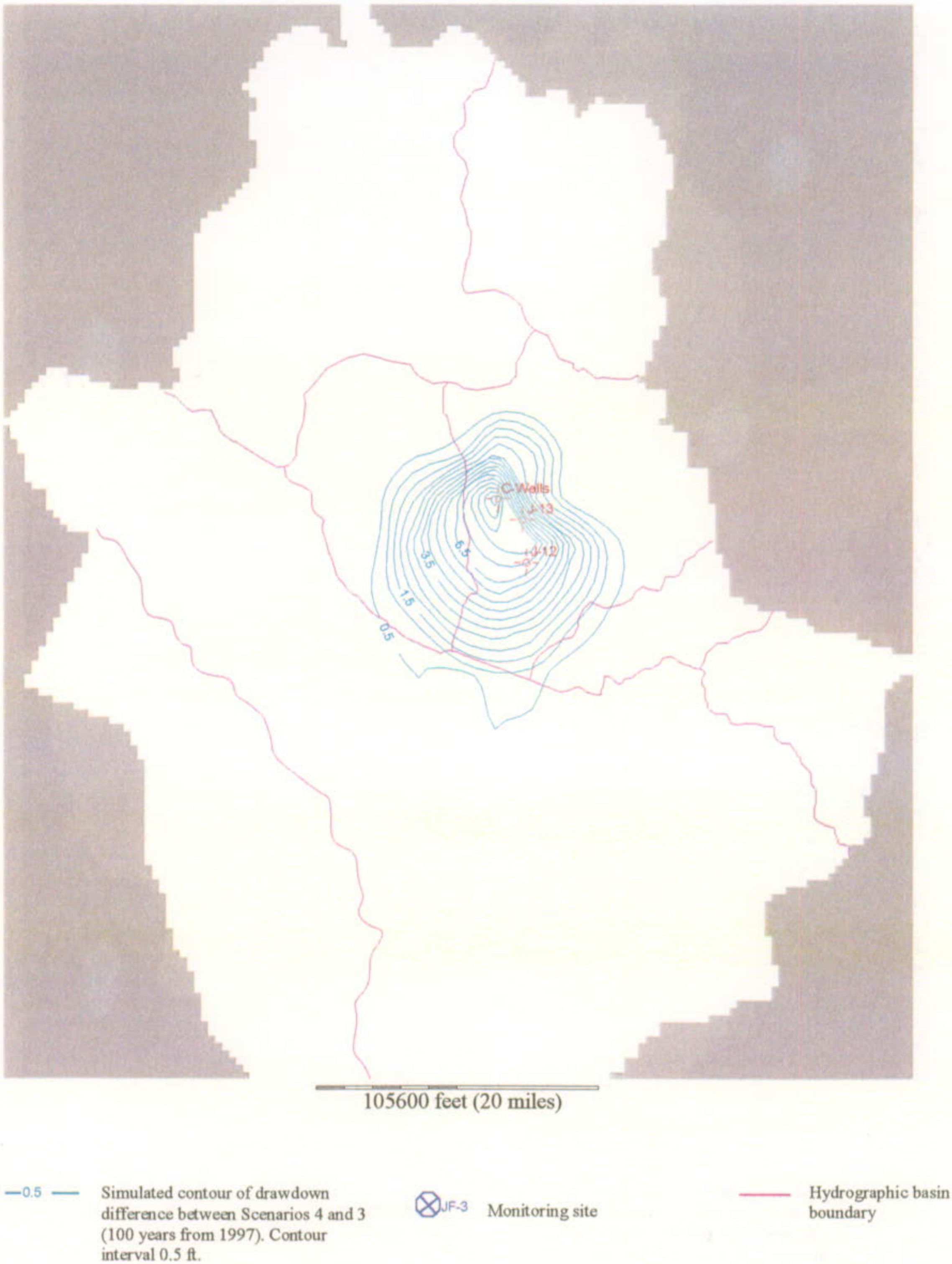


Figure 42 (b) Drawdown difference between Scenarios 4 and 3 (Top layer of Model L2)
(Senior rights pumping at maximum)

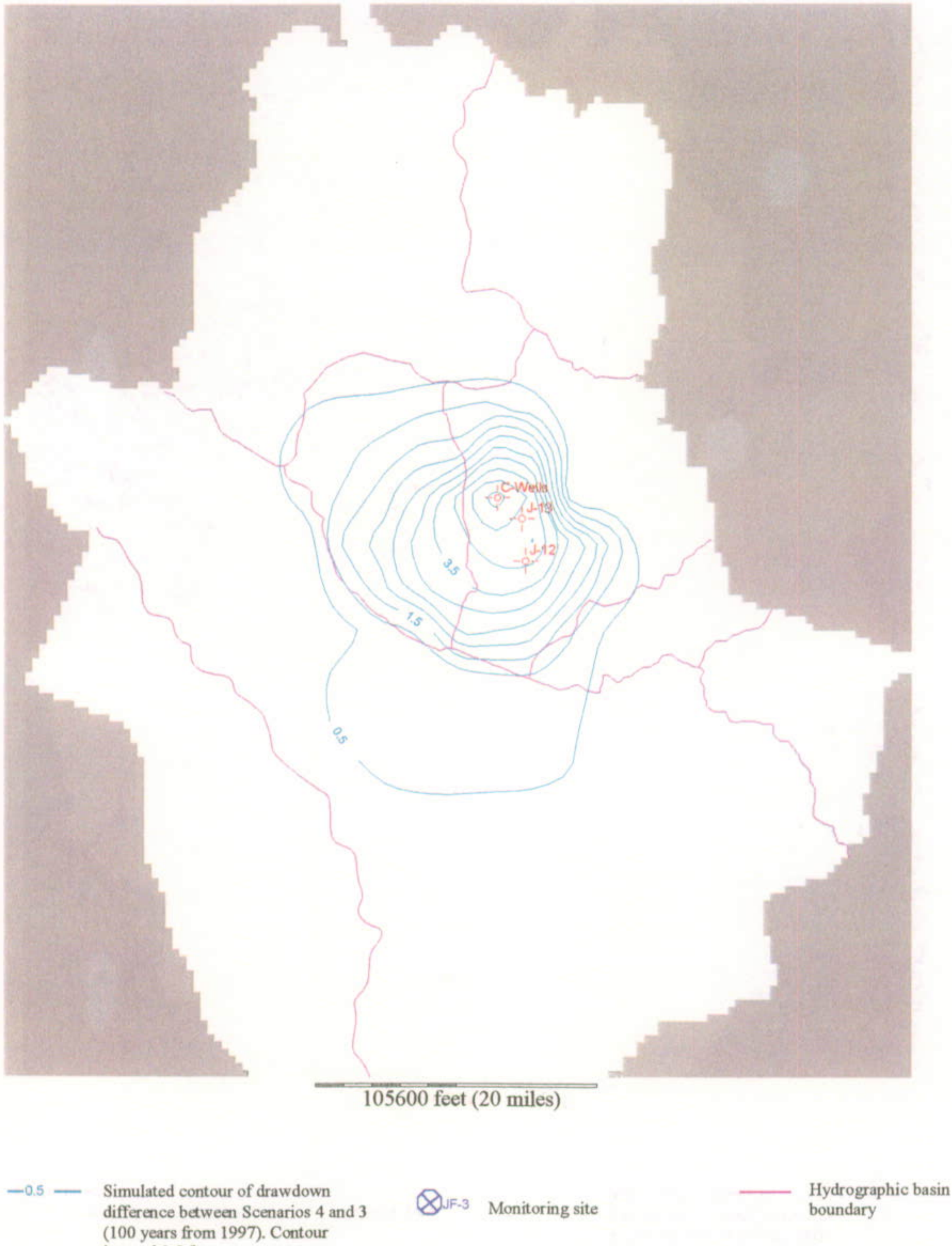


Figure 42 (c) Drawdown difference between Scenarios 4 and 3 (Top layer of Model H1)
(Senior rights pumping at maximum)

Figure 42 (d) Drawdown difference between Scenarios 4 and 3 (Top layer of Model H2)
(Senior rights pumping at maximum)

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