Mifflin & Associates, Inc.

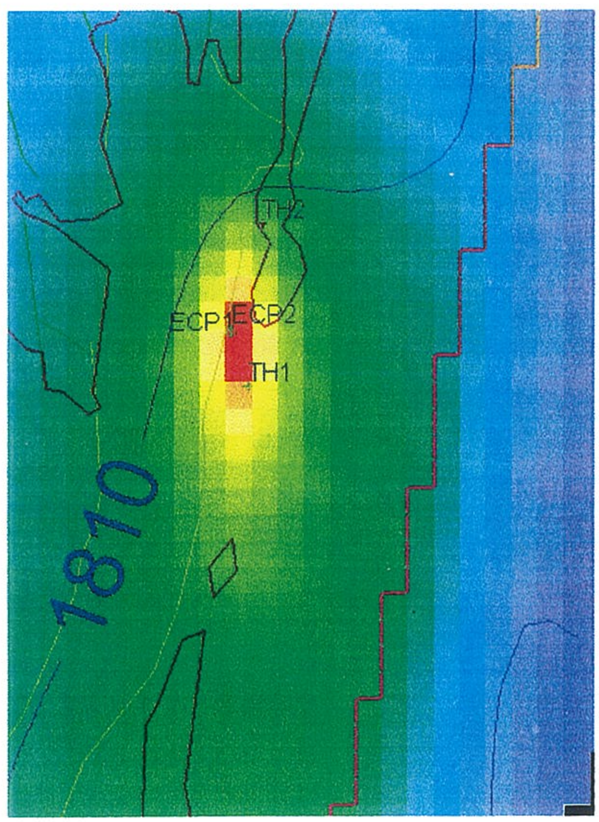
HYDROGEOLOGIC AND GROUNDWATER MODELING ANALYSES for the MOAPA PAIUTE ENERGY CENTER

A Calpine Company Project
In Cooperation with the Moapa Band of Paiute Indians

CALPINE

Moapa Indian Reservation
Clark County, Nevada

THE GREAT SEAL OF THE MOAPA BAND OF PAIUTES 1875



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1.0 Executive Summary

An extensive regional hydrogeologic database, and new hydrogeologic information developed in this study at Belly Tank Flat and surrounding areas of the Moapa Indian Reservation, Nevada, are the basis for this assessment of the long term groundwater supply for the proposed Moapa Paiute Energy Center (Project). Exploratory drilling and test pumping were performed between March and December 2000 in and around Belly Tank Flat, the Project site. The Belly Tank Flat area of the Moapa Indian Reservation will support a well field in the Carbonate Aquifer producing 7,000 acre-feet per year (afy) for up to 45 years, the Project life. The Project is equidistant from the northern and southern most areas of the Arrow Canyon Range Cell, and 15 miles from existing water development or regional spring discharge.

The Project is within the Arrow Canyon Range Cell, an approximate 40 by 30-mile region dominated by carbonate-rock terrain where groundwater fluid potentials are almost uniform. The Carbonate Aquifer in this Cell is a potential source of water for a large region, including the Project. About 15 miles to north of the Project site, in the Muddy River Springs Area, an average of 51 cubic feet per second (cfs) (≈37,000 afy) flows to the area in the Carbonate Aquifer. The Project site is within the California Wash hydrographic basin #218, where at this time, groundwater withdrawals are minimal.

The Arrow Canyon Range Cell, based on geochemical, isotopic, and water-level data, contains two distinct flow fields as described in this investigation:

- A northern flow field originates from mixing of end-member waters from Pahranagat Valley, southern Meadow Valley Wash, and the Sheep Range discharges at the Muddy River Springs Area.
- A southern flow field, first recognized in this study, displays nearly flat hydraulic gradients in some areas, an overall southerly regional gradient, generally uniform isotopic compositions, and water geochemistry that differs from the northern flow field. It lacks any component of Meadow Valley Wash water, and may originate from a mix of roughly 4,000 afy of northern regional flow with up to 6,500 afy of groundwater derived from the Sheep Range.

Calibration studies of a steady state groundwater model (GFLOW) yield ≈9,500 afy of flux in the southern flow field as compared to ≈10,500 afy of flux suggested by the above stated isotopically constrained water balance of potential source waters to the southern flow field. These independently derived estimates indicate the general order of magnitude of flux that may be present in the southern flow field, but the estimates should be considered soft numbers.

The two flow fields are separated by an interface zone within 10 miles of the Project area where no physical basis for separation of the two flow fields has been recognized.

The objectives of groundwater modeling analyses established in the study are 1) to evaluate the long term availability of groundwater resources and 2) study credible regionally propagated impacts resulting from pumping 7,000 afy for as many as 45 years. The Analytic Element Method (GFLOW) was adopted and calibrated with observed water levels and spring flows for a regional steady state model. This approach helped to evaluate regional groundwater flow and to establish aquifer and boundary conditions for a 40 x 40 mile finite difference grid (MODFLOW transient state analyses) centered over the Project area. A 7-day aquifer test at the Project area helped to establish aquifer properties of transmissivity and storage that were utilized in the modeling. Three prescribed boundary condition scenarios were used in the MODFLOW transient state analyses to explore and bound a range of credible system responses to pumping from the proposed well field at Belly Tank Flat. The modeling analyses result from combinations of computer-based calculations and professional judgment. The modeling analyses incorporate:

- Highly developed hydraulic continuity in the Carbonate Aquifer between the northern and southern flow fields, a conservative approach that allows (encourages) pumping impacts to be projected into the northern flow field.
- Three transient scenarios of boundary conditions that address the level of uncertainties related to regional conditions and sparse data.

The three transient scenarios, established by varied boundary conditions, forecast regional drawdowns and the percentages of reduction in groundwater flow to the Muddy River Springs Area after 25 and 45 years of pumping 7,000 afy at the Project site. Within this modeling framework two are considered bounding scenarios to address hydrogeologic uncertainty, Cases 2 and 3, below.

The Case 2 boundary condition scenario incorporates prescribed heads at the model boundaries where there is transmissive terrain. This is the non-conservative case that allows induced inflow to compensate pumping effect.

The Case 3 boundary condition scenario is the overly conservative case, which prescribes flux at the model boundaries, forcing all water pumped from the proposed well field over time to be derived from storage in the 40 x 40 mile modeled domain or captured flux from the northern flow field. It therefore forecasts the greatest impacts on flows to the Muddy River Springs Area over time and produces the greatest regional drawdowns. Although extremely unlikely, Case 3 useful for discussions of environmental impacts because effects compatible to those associated with Case 3 have already been expressed in the historic record.

The most probable boundary condition scenario, Case 1, incorporates a combination of prescribed constant heads and fluxes at the model boundaries (the hybrid case).

1.1 Forecasts Derived from Modeling Analyses

The following table gives the model-derived forecasts of decreases in regional flux to the Muddy River Springs, absent any physical barrier between the northern and southern flow fields.

Modeling Forecasts of Decreases in Regional Flux to the Muddy River Springs Area Project Area Pumping 7,000 afy

	25 years		45 years
Run ID	**Discharge Decrease, %**	**Run ID**	**Discharge Decrease, %**
Case 1 Hybrid25yr	0.7	Case 1 Hybrid45yr	1.3
Case 2 Head25yr	1.1	Case 2 Head45yr	1.1
Case 3 Flow25yr	7.5	Case 3 Flow45yr	10.4

Case 1 and Case 2 would produce very minor impacts on flow and no impacts on aquatic habitat.

Case 3, which mirrors historic effects in many respects, begins to produce significant decreases in groundwater flow to the Muddy River Springs Area by 25 years. About half of the water extracted at 45 years from the Project well field in Case 3 (about 5 cfs) would be derived from the flow field contributing to the Muddy River Springs Area. The flux of the northern flow field to the Muddy River Springs Area is approximately 51 cfs and a 5 cfs reduction would be likely manifested as approximately 3 cfs of reduction in baseflow from the local Carbonate Aquifer fed alluvial aquifer to the headwater Muddy River channels, and a total of about 2 cfs of reduction in distributed discharge from the springs of the area.

It is emphasized that magnitudes of the impacts on the discharge area hydrologic features with the Case 3 reductions of flow forecasted at 25 and 45 years are generally within the historic envelope of flow and aquatic habitat conditions. Local pumping impacts, annualized, are twice as large, and natural long term variations due to drought and wet periods are about the same order of magnitude (5 or 6 cfs). However, during prolonged multiyear drought periods, some intermittent flow segments of the uppermost reaches of the Muddy River would likely become ephemeral channels without baseflow periods, and transitions of short reaches from perennial to intermittent flow would likely occur as far downstream as the Big Muddy Spring area. Discharge to spring supported aquatic habitats would be reduced by up to 10% less flow than historic minimums during extreme multiyear drought periods. The impacted river channel segments are currently, for the most part, intermittent, displaying baseflow supported flows for up to several months each year. Most if not all spring flows would persist, and spring flow supported aquatic habitats would not likely be subject to significant changes.

The Case 3 projected hydrologic and aquatic habitat impacts in the Muddy River Springs Area are judged unlikely due to the extremely conservative assumptions imbedded in the Case 3 model analysis. The two flow fields with distinctive water geochemistries suggest that the well developed hydraulic continuity imbedded in the model between the two flow fields is likely absent, and if so, there would be more limited or no impacts on spring flow. The water geochemistry evidence for deeply circulated regional flow in the general vicinity of the pumping center suggests an upwelling zone between the pumping center and spring area. This would likely have an equal or stronger net affect on a northward propagating pumping cone as the prescribed head boundaries applied in Case 1 and Case 2 (located at ≥20 miles from the pumping center). The interface zone between the two flow fields is less than 10 miles from the Project area, and a zone of upwelling of deeply circulated water would likely behave similar to a constant head boundary, but with a stronger net effect of limiting northward propagation of pumping impacts due to its proximity to the pumping center.

A monitoring program has been designed and implemented by Calpine Company and the Moapa Band of Paiutes, and is providing continuous records of barometric pressure and water levels at one site and water levels at 4 locations at and surrounding the proposed pumping center. The new monitoring wells complement and extend monitoring in the Muddy River Springs Area and Coyote Spring Valley. The monitoring well network is designed to allow recognition of regionally propagated pumping effects decades prior to measurable impacts at sensitive areas, as well as provide databases needed for groundwater model refinements. Plans for mitigation could be activated in accordance with model projections.

1.2 General Conclusions

1. Water balances based on isotopic signature of mixing water sources and steady state regional model calibration indicate as much as 10,500 afy of flux may occur in the southern flow field. The regional steady state modeling calibration (GFLOW) indicates about 9,500 afy of flux exiting the southeastern portion of the cell southeast of the Apex Industrial area. The two independently derived estimates are comparable, but these estimates are clearly soft numbers. Other estimates have been both larger and smaller, and they too are accompanied by considerable uncertainty.
2. The primary source of groundwater in the Project area is regional flow in a separate flow system (southern flow field) than that supplying the Muddy River Springs Area (northern flow field), based on fluid potentials, geochemical, and isotopic evidence. The modeling analyses do not impose any physical barrier between the two flow fields to assure conservative forecasts. The evidence for an upwelling regional water source supplying the southern flow field reduces the probability that impacts from Project pumping will be propagated to the Muddy River Springs Area.
3. Geochemical data, isotopic data, and an ≈200 foot difference in fluid potentials of waters in the Belly Tank Flat area and Rogers/Blue Point Springs area, as well as variable spring discharges at Rogers/Blue Point Springs area support a projection of no impacts at the Rogers/Blue Point Springs area due to Project pumping.
4. Two bounding modeling scenarios both of which conservatively assume the range of credible system responses to the production of 7,000 afy from the Project area. Case 2, judged to be somewhat non-conservative, produces essentially no decreases in discharge in the Muddy River Springs Area for over 45 years, no impact at Rogers and Blue Point Springs, and therefore, no impacts on aquatic habitat. Case 3, highly conservative and unlikely, would produce significant reduction of flows by 25 years and 45 years, but still not of a magnitude to markedly impact perennial flow supported aquatic habitats. Approximately 5 cfs of reduced flow to the Muddy River Springs Area is forecasted at 45 years in Case 3.
5. There will be no significant impacts to groundwater users to the south because of the

deep water table and forecasted small-scale drawdowns that would result from prolonged Project pumping.

6. The Project is accompanied by a monitoring well network designed to establish refined knowledge of regional aquifer characteristics which in turn allow improved model forecasts. The monitoring well network is in place and operating. It is designed to recognize greater than anticipated water-level declines between the Project area and Muddy River Springs Area. The monitoring well records will allow accurate forecasts of pumping impacts of regional scale decades before unacceptable impacts could develop in surrounding areas.

In summary, within the limitations of the local and regionally available databases, this study projects a groundwater-resource base that support the proposed Project. The most probable regionally propagated pumping impact over 45 years produced by 7,000 afy of production at the Project site, Belly Tank Flat, would not produce significant impacts on regional discharge areas of the Carbonate Aquifer. The Project would produce small regionally propagated water-level declines over large areas. A monitoring well network has been designed and implemented to verify and refine these forecasts.

2.0 Introduction

2.1 Purpose of this Report

This report summarizes and interprets regional databases and establishes modeling analyses for the proposed 7,000 acre-feet per year (afy) of groundwater extraction from the California Wash hydrographic basin, Clark County, Nevada (Figure 1) by the Moapa Band of Paiutes and Calpine Company, for purposes of electric power generation.

The modeling analyses studied the regional flux and storage conditions of the Carbonate Aquifer in and around the Project area, and the extent and nature of impacts if such waters are withdrawn for beneficial use. A model of the regional, steady-state flow was developed using GFLOW (Haitjema, 1995), a modeling environment based on the Analytic Element Method (AEM). Three scenarios and associated impacts of the proposed 7,000-afy appropriation were evaluated using numerous MODFLOW (McDonald and Harbaugh, 1988) simulations to estimate 25 and 45-year drawdowns in the site area and hydrologic impacts in major spring areas to the northeast and southeast. A fundamental, conservative assumption has been incorporated into these modeling scenarios that allows for pumping impacts to be efficiently propagated into flow fields supplying the regional spring area to the north, even though hydrochemical and isotopic databases provide evidence that such well-developed regional hydraulic continuity may not be present.

Finally, a comprehensive data set are provided as appendices to this report and include:

- Appendix A, ECP-1 Aquifer Tests Summary Report
- Appendix B, Geochemical and Isotopic Data for the Arrow Canyon Range Cell and Surrounding Areas
- Appendix C, Horizontal and Vertical Elevation Control and Water Levels for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring and Moapa Areas
- Appendix D, Nevada State Engineer Hydrographic Basin Abstracts of Active Water Rights Status, Current Through 8/17/00
- Appendix E, Monitoring Plan, Moapa Band of Paiutes
- Appendix F, A Summary of Groundwater Development Impacts in the Upper Muddy River Valley

A full listing of boundary conditions exported by GFLOW and used to establish a model flow field in the sub-regional MODFLOW domain are provided, as well as diagrams of all parameter zones incorporated in these models.

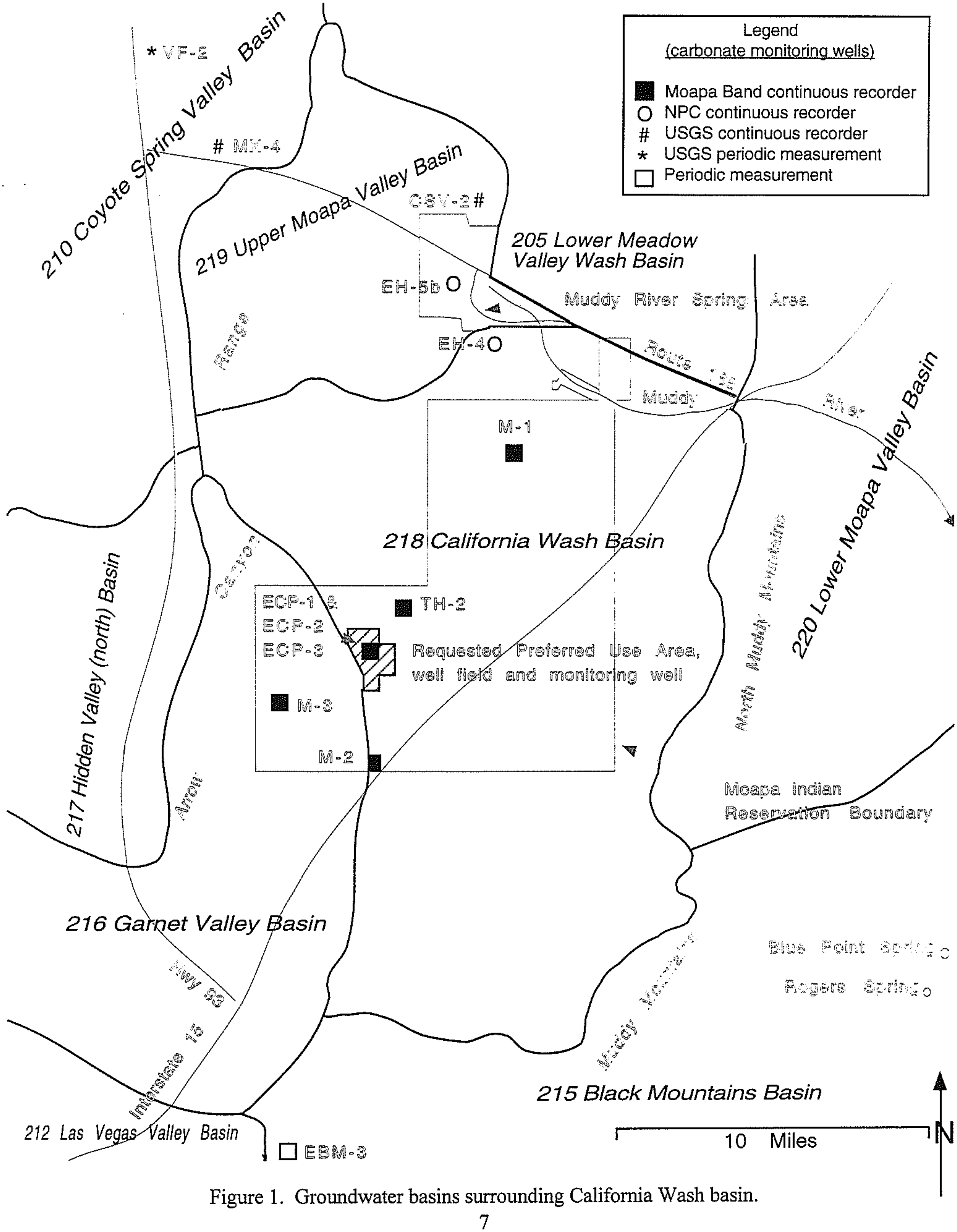


Figure 1. Groundwater basins surrounding California Wash basin.

2.2 Model Considerations and Background

Modeling analyses and evaluations of hydrologic data from wells and springs have been made to study the effects of the production of 7,000 afy from the Carbonate Aquifer in and around Belly Tank Flat of the Moapa Indian Reservation, an area included by the Requested Preferred Use Area (Figure 2). The proposed 7,000 afy of production on the Moapa Indian Reservation would be the first major pumping stress on the Carbonate Aquifer other than local, heavy production in the Muddy River Springs Area. The production for power generation would occur for a minimum of 25 years and renewable for 20 years for a total of 45 years based on leased water-right agreements between the Moapa Band of Paiutes and the Calpine Company. The well field is distant (15 and 22 miles) from existing production from, or springs fed by, the carbonate rock aquifers.

The large transmissivities measured in the Carbonate Aquifer in the Belly Tank Flat Well Field (Appendix A) and other local areas far to the north (MX-4 and Muddy River Springs Area) and south (Apex and Nevada Cogeneration well field), and the small differences in water-level elevations suggest that well-developed regional hydraulic continuity might extend throughout much of the extent of the Arrow Canyon Range Cell (Mifflin, 1992) an area as large as approximately 40-mile (N-S) by 30 mile (E-W). Small fluid-potential gradients apparently persist throughout a portion of this carbonate terrain in an area 30-mile (N-S) by 10-mile (E-W). However, there is compelling evidence that groundwater flow within the Arrow Canyon Range Cell is compartmentalized into at least two distinct flow fields, a northern and southern flow field. Portions or all of seven groundwater management basins are superposed on the Arrow Canyon Range Cell of the Carbonate Aquifer (Figure 1).

The most refined approach to projecting potential impacts in time and space is through groundwater modeling that incorporates transient responses to pumping and geologically appropriate boundary conditions. Pumping cones of depression in the potentiometric surface will vary over time and these variations and projected effects on spring flow are the subject of modeling analyses. The carbonate-rock terrain that constitutes the Arrow Canyon Range Cell incorporates both recharge areas and one major spring discharge area, and is bounded by generally less permeable basin or bedrock lithologies. Boundary conditions adopted in modeling analyses are critical to the accuracy of predictive modeling results, yet very poorly documented by direct measurement or observation in the region under study. Therefore, model boundaries must be prescribed through use of varying degrees of professional judgement and refined during the model calibration process. To an important extent, the flow-field databases within the cell yield indirect evidence of the distribution and probable nature of the boundary conditions, but fail to constrain the modeling analyses to a single or unique configuration that confidently simulates the natural system. Therefore, even though the modeling codes that have been applied are extremely useful in terms of accurate simulation of groundwater flow fields and transient changes which may occur due to pumping stresses, uncertainties remains in the application of boundary conditions and flow-field over such a large area.

Applications of boundary conditions and flow-field properties included:

- A trial-and-error process of varying aquifer properties and boundary conditions until the model produces a reasonable representation of *both* the fluid-potential surface in the area

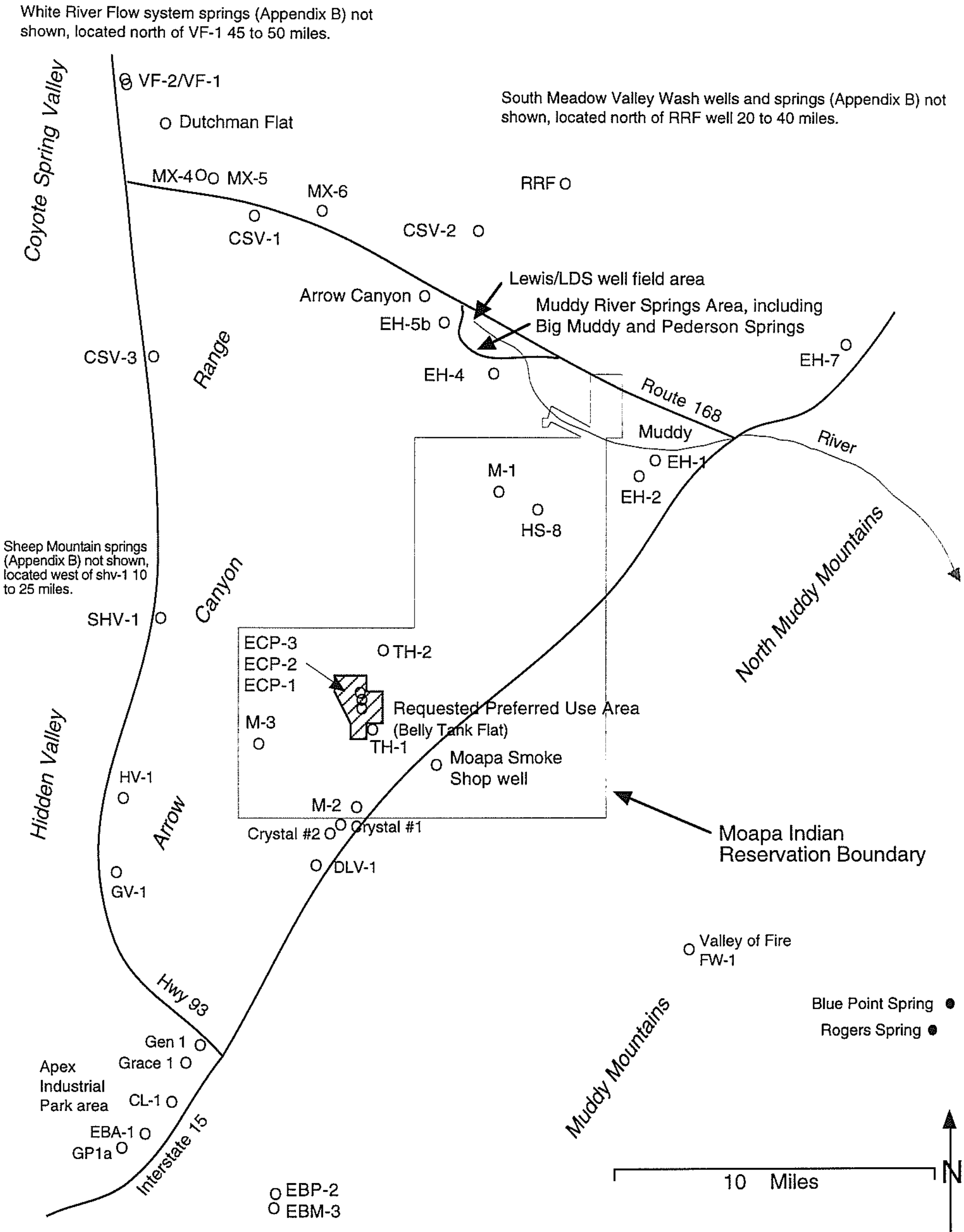


Figure 2. Map showing well and spring locations referenced in Appendix B and used in this report.

of interest and discharge rates at the regional spring areas. This process of stepwise refinement constrains the flow model to what has been observed, and restricts the range of boundary condition scenarios that calibrate the model.

- Applying expert judgment from the perspective of isotopic and geochemical databases (Appendix B). Such independent databases help identify possible sources of recharge, and quantify mixing relations and hydrologic mass balances.

Evidence has been assembled to support that there are two flow fields in the Arrow Canyon Range Cell:

- the northern flow field which discharges at the Muddy River Springs Area, and

- the southern flow field, a deeper-sourced flow field that is identified in the southern portion of the cell which probably upwells in the vicinity of the Belly Tank Flat.

Isotopic data indicate that the Rogers-Blue Point area of discharge is unlikely to be a discharge point for the Arrow Canyon Range Cell waters. Multiple lines of evidence indicate that well developed hydraulic continuity between the southern flow field and Rogers and Blue Point Springs is absent, and therefore these springs are not subject to impacts induced by the Calpine Project (Project) pumping stresses.

3.0 Regional Databases

3.1 Geology

The regional aquifer is a westward-thickening section of Paleozoic carbonate rocks, in part unconformably overlain by generally fine-grained sediments of the Muddy Creek Formation, (Figure 3), (Longwell and others, 1965; Bohannon, 1983). Structurally, the Paleozoic rocks have experienced two major episodes of deformation:

- Compression characterized by thrust faults and intense folding during the Cretaceous Sevier Orogeny, and

- Normal faulting during subsequent Basin and Range extension.

Locally, thick sections of Mesozoic redbeds, Middle Tertiary volcaniclastic sediments, and late Tertiary Muddy Creek Formation form aquitards in contact with the more transmissive carbonate rocks. Exposed upper Paleozoic strata near the Project area are steeply dipping to vertical, and constitute the lower plate of the Dry Lake Thrust (Longwell and others, 1965). The carbonate rocks of the Arrow Canyon Range Cell are bounded along the east side by an extensional fault that down drops the Muddy Creek Formation and Middle Tertiary volcaniclastic rocks, and on the south by the Las Vegas Shear Zone and related eastern splay faults. The diagrammatic hydrostratigraphic sections shown on Figures 4 and 5 illustrate these relations.

3.1.1 Hydrogeology Background

The hydrogeology of the Arrow Canyon Range Cell is recognized as unique yet poorly

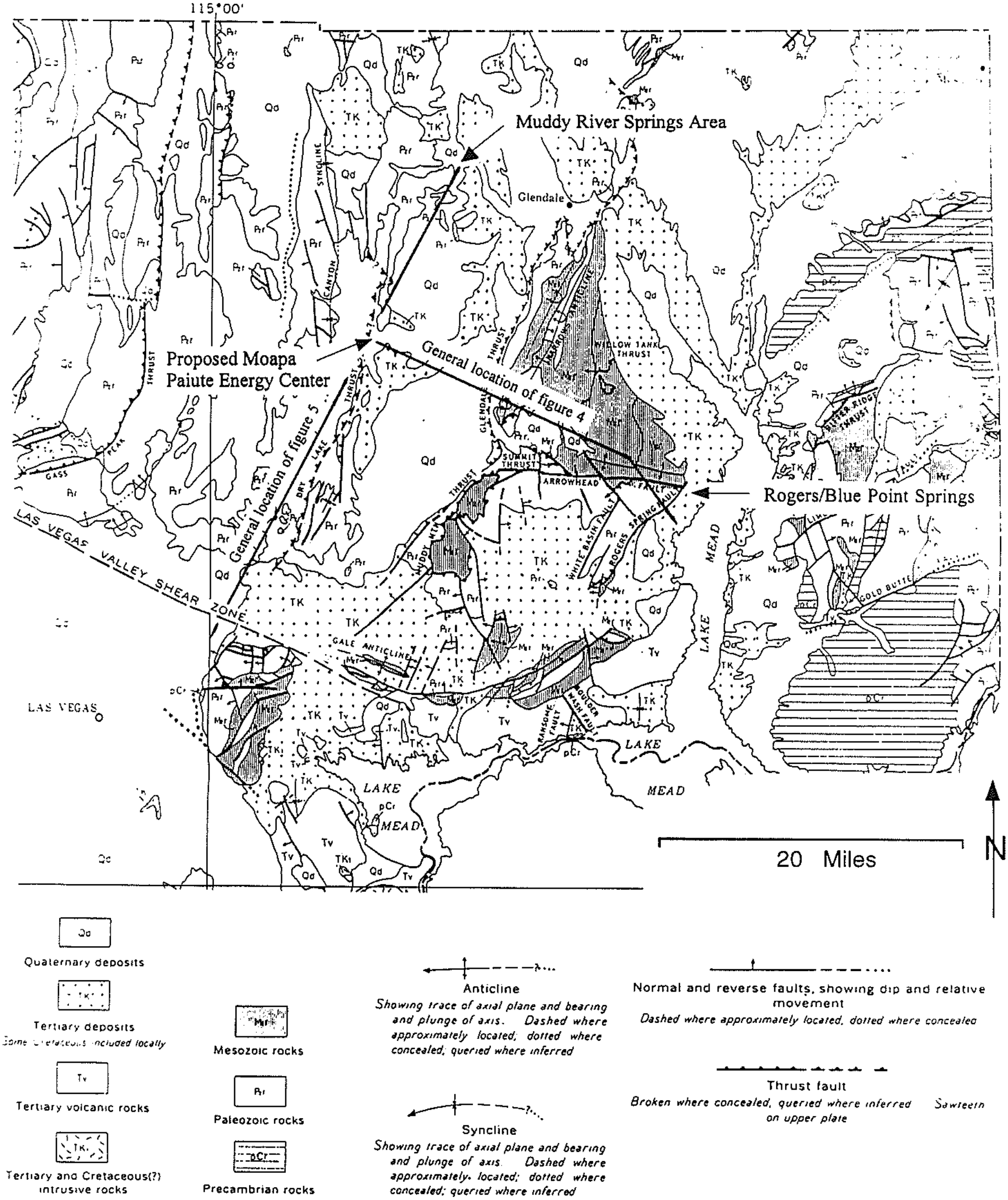


Figure 3. Tectonic base map used to define boundaries of modeling domains (modified from Longwell and others, 1965).

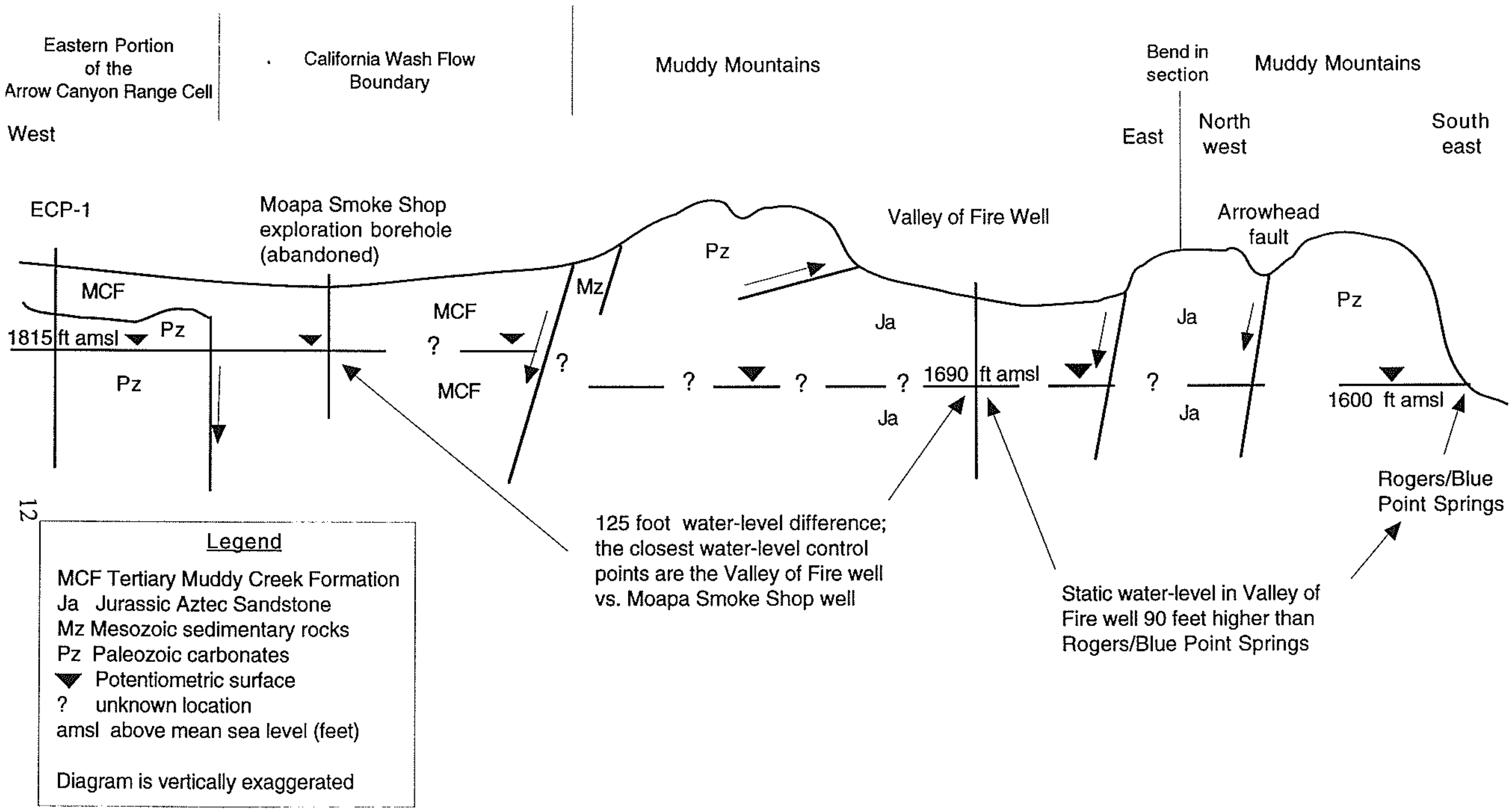


Figure 4. A diagrammatic 22 mile cross section showing the interpreted hydrogeology from the Moapa Paiute Energy Center (MPEC) area (ECP-1) in the west to Rogers/Blue Point Springs in the east (refer to Figure 3 for general location). Note the 200 foot change in water level from the Arrow Canyon Range Cell and California Wash Boundary region to the Muddy Mountains area and Rogers/Blue Point Springs.

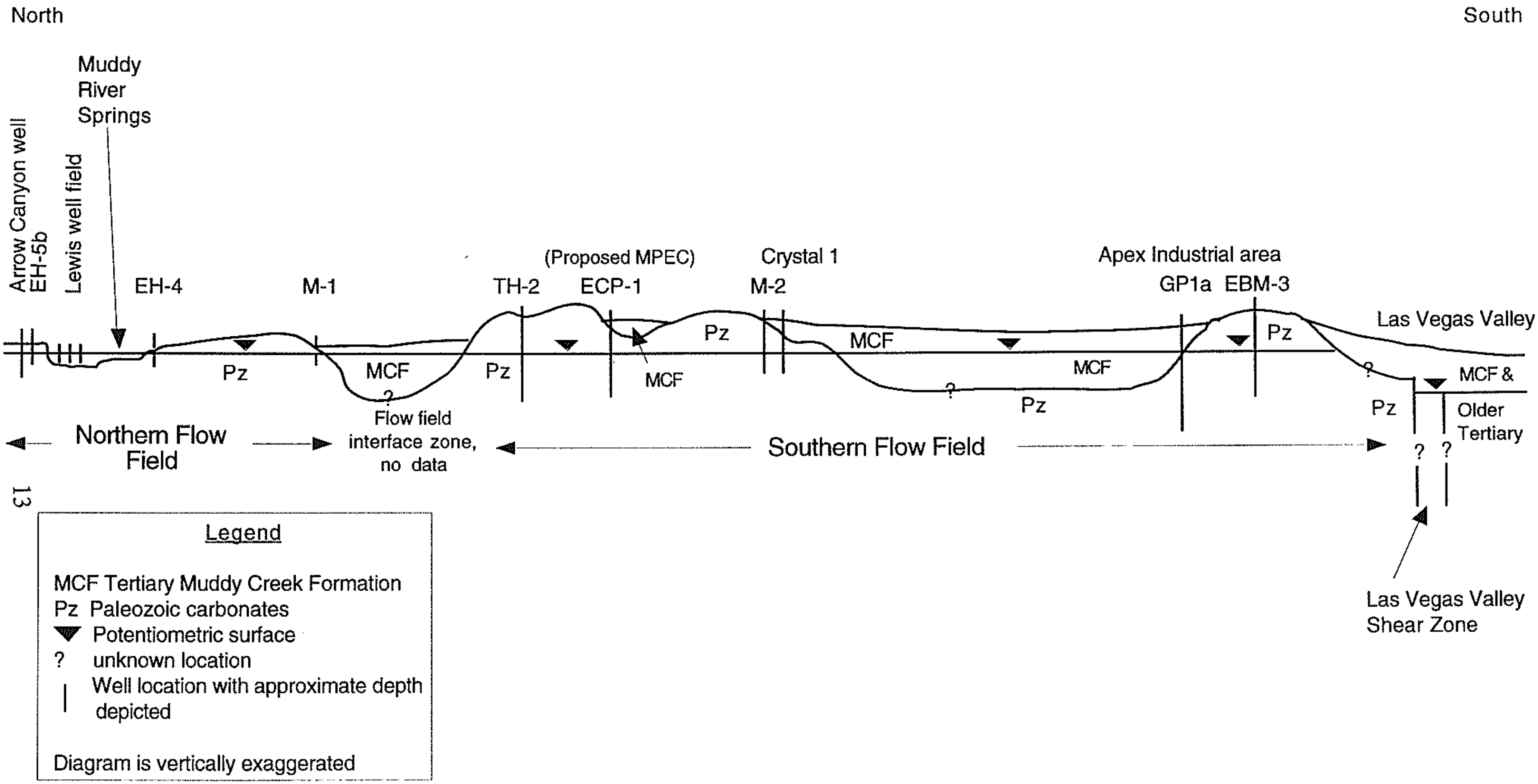


Figure 5. An approximate 40 mile north-south diagrammatic cross section showing the interpreted hydrogeology from the Muddy River Springs area in the north to Las Vegas Valley in the south (refer to Figure 3 for general location). Northern and southern flow field groundwater show different geochemical and isotopic signatures and are separated by an interface zone. The general location and nature of the interface zone is shown.

understood in terms of detailed documentation. This and other studies have expanded hydrogeologic databases and identified important relationships, but there remains a high degree of uncertainty concerning conditions at depth due to the sparse data in this vast and complex terrain.

Mifflin (1988) reviewed the dominant factors which determine the hydrogeologic characteristics of the Great Basin, which are applicable to the Arrow Canyon Range Cell and include:

1. Extensional faulting has resulted in marked topographic differences and lithologic contrasts between geologically diverse range blocks and intermontane sedimentary basins. The Arrow Canyon Range Cell consists, at least in part, of carbonate rock terrain of the Sheep Range on the west and the Las Vegas Range in the southwest, the basement carbonate terrain of Hidden Valley – Coyote Spring Valley basin structural block, the Arrow Canyon Range and related extensions in the central region, and the Dry Lake Range to the east and intervening basins. These basins and ranges are generally north-south trending structural blocks composed primarily of Paleozoic carbonate rocks, with the intermontane basins partially filled with a relatively shallow veneer of Cenozoic basin deposits directly overlying Paleozoic carbonate rocks. Bounding the eastern domain of the Arrow Canyon Range Cell is the intermontane extensional basin, the southern Meadow Valley Wash - California Wash formed by downfaulted Tertiary sediments (at least 4,000 feet thick) which acts as a regional barrier to carbonate terrain flow.
   The Meadow Valley Wash – California Wash basin, bounding the Arrow Canyon Range Cell on the east, hydrogeologically differs from many intermontane basins in that there are only limited extents of Quaternary and Holocene alluvial aquifers inset within the fine-grained Muddy Creek Formation sediments. Those that do exist form local, but relatively shallow transmissive, alluvial aquifers in the centralized areas of the basin along the Muddy River, Meadow Valley Wash, and California Wash. The thin alluvial aquifers inset into the Muddy Creek Formation generally are highly transmissive and initially yielded good quality water, but water qualities have markedly declined in some areas (Meadow Valley Wash) due to pumping induced migration of Muddy Creek Formation water into the heavily pumped alluvial aquifer. The majority of groundwaters of the Meadow Valley Wash – California Wash basin sediments are not closely related to Arrow Canyon Range Cell carbonate terrain water, but the Muddy River – Moapa Valley alluvial gravel aquifers are directly related to Muddy River Springs Area discharge.
2. Regional patterns of precipitation combined with terrain altitude results in the highest mountain ranges receiving the majority of precipitation that becomes recharge. The carbonate terrain is efficient in retaining a relatively high percentage of precipitation as recharge, and well to the north of the Arrow Canyon Range Cell, the mountain ranges of east central Nevada, nearly all carbonate terrain, may contribute to the regional interbasin flow of White River Flow System of Eakin (1966), some of which flows to the south of the Pahranagat shear zone and into the Arrow Canyon Range Cell. The recharge values in the mountainous terrain adjacent and within the Arrow Canyon Range Cell have been estimated through various techniques, but there is considerable uncertainty as to real values of recharge or even patterns of flow. There is little direct recharge from precipitation in basin lowlands.
3. Surface drainage and groundwater flow systems may or may not be congruent, i.e.,

confined to hydrographic basins. In the arid terrain of southern Nevada, the interbasin flow in the carbonate rock terrain often ignores the hydrographic basins of surface water drainage. The Arrow Canyon Range Cell, which is interpreted to be constituted by two flow fields (described in this report), incorporate several surface-water hydrographic basins with drainage integrated to the Colorado River (White River – Coyote Spring Valley, Muddy River (upper Moapa Valley), California Wash, Lower Meadow Valley Wash, and small areas of Black Mountains and Las Vegas Valley surface-water drainage) and two hydrographically closed basins, Hidden Valley, and Dry Lake Valley (Garnet Valley) (Figure 1).

4. Quaternary climate variations produced more effective moisture and associated groundwater recharge and surface-water runoff in paleohydrologic systems that have imprinted existing hydrologic systems in a variety of often subtle, but important ways. The Carbonate Aquifer transmissive nature within the Arrow Canyon Range Cell may be related to former discharge areas and much larger fluxes, and the localization of the Muddy River Springs Area is the result of pluvial climate headward erosion cycles of the White River – Muddy River drainage system graded to the Colorado River. In the Glendale area, for example, the alluvial aquifer is inset into the Muddy Creek Formation, is either late Quaternary or Holocene in age, and incorporates only a maximum of 35 feet of basal, highly sorted and productive sands and gravels. The overall basin geomorphologies are related to a prolonged down cutting history of erosion of the Muddy Creek Formation in the drainages that are integrated with the Colorado River. In hydrogeologically closed basins, Quaternary and Holocene coarse alluvial deposits bury the fine-grained Muddy Creek Formation, and provide extensive basin aquifers.

3.1.2 Arrow Canyon Range Cell Hydrologic Boundaries

The Arrow Canyon Range Cell is composed of a series of north-south trending structural blocks related to extensional faulting (which began in Oligocene or early Miocene and continues to present) that are almost entirely composed of Paleozoic carbonate rock (Figures 3, 4, and 5). The structurally downfaulted block, Hidden Valley – Coyote Spring Valley, remains structurally high enough to form a basin floored by Paleozoic carbonate rocks that appear to dominate that hydrology of the basin; that is, the alluvial/Muddy Creek Formation basin deposits are limited in thickness and extent, and do not form large thick body of saturated sediments that dominate the groundwater hydrology. Throughout the region, thick Quaternary aged deposits are often transmissive, whereas middle and late Tertiary basin sediments, such as Horse Spring Formation and Muddy Creek Formation, are less transmissive and most faces are aquitards. The Arrow Canyon Range Cell is bounded on the east side by the Hogan Springs Fault zone, a several mile wide zone of north – south oriented lineaments, some of which have vertical displacements, east side downthrown. These lineaments localize Muddy River Springs Area conduits to the alluvial gravels near the Lewis well field and to several spring areas, as well as localize extensive paleo-discharge spring deposits that occur from the White Narrows area to the west into the carbonate rock terrain. At EH2b, west of the Reid Gardner generation station, 4,000 feet of Muddy Creek – Horse Spring Formations indicate the minimum throw along this fault zone, and further to the south, in the general vicinity of Hogan Spring, a middle to late Quaternary pediment surface is displaced by a relatively young fault movement on one of the lineaments. Hogan Spring and Jackass Spring are seep springs associated with these lineaments, and are at elevations that suggest sources from the carbonate aquifer. Seeps and springs in the northern area of California

Wash (e.g., Nungwu and springs and seeps near the Hidden Valley Ranch) are not known to be associated with features that would localize discharge from the Arrow Canyon Range Cell.

The southern boundary of the Arrow Canyon Range Cell is the Las Vegas Valley Shear Zone, which appears to be a structural zone of Tertiary rocks juxtaposed against Paleozoic carbonate rocks (Figures 3 and 5). In Las Vegas Valley the Las Vegas Valley Shear Zone is buried by basin sediments, and it is interpreted as a major right lateral strike-slip fault zone. Nevertheless, it is clear that whatever the detailed nature of the structure, it behaves as a barrier to flow, and leakage from the Arrow Canyon Range Cell into the Las Vegas Valley groundwater basin is either highly localized, or very minor, as evidence for Arrow Canyon Range Cell water is generally unrecognized. The eastward splay of the Las Vegas Valley Shear Zone appears to be the zone of possible outflow from the Arrow Canyon Range Cell. Another possibility of southern outflow is flow in the fault zone the bounds the west side of Frenchman Mountain. There have not been detailed studies focused on outflow from the Arrow Canyon Range Cell, and such studies are hindered by the general absence of useful wells in the candidate areas for outflow.

The western boundary of the Arrow Canyon Range Cell remains undefined by water-level control, but is assumed to be in the Las Vegas Range – Sheep Mountain Range zone, constituted by mounded groundwater related to recharge. The limited water-level data in Hidden Valley and south Coyote Spring Valley indicates the Cell extends into these areas at a minimum. The northern boundary of the Arrow Canyon Range Cell may be defined as the Pahranagat Shear Zone. There is a regional step down in fluid potentials south of this major structure as compared to fluid potentials observed in Pahranagat Valley, where there are three major carbonate terrain springs that discharge waters classified as derived from regional carbonate rock flow systems (Mifflin, 1968). Eakin (1966) and Mifflin (1968) as well as all subsequent investigators, recognized interbasin flow southward to the Coyote Spring Valley area, but the estimated amounts have varied and are difficult to confidently quantify.

3.1.3 General Hydrogeology Concepts Considered and Developed in this Study

Important hydrogeologic questions revolve around the Carbonate Aquifer of the Arrow Canyon Range Cell. Aquifer characteristics (and distribution) such as porosity, thicknesses, regional scale transmissivities, and sources and sinks of fluxes remain defined by very limited databases.

The general thickness of the carbonate terrain participating in the flow fields remains generally unknown. The stratigraphic thickness of the Paleozoic section in the area is in excess of 10,000 feet, and folding and thrusting (low angle) has the potential to both decrease or increase the total thicknesses of carbonate rock strata that participate in groundwater circulation. Petroleum test wells in the carbonate rock province of the Great Basin suggest depth of active circulation locally may be 12,000 feet deep. However, the total thickness of the carbonate rocks, as well as the thicknesses of well developed vertical hydraulic continuity, remains generally unknown.

The older compressional structures (folds and low angle thrust faults) are not known to control the hydrology (distribution of hydraulic conductivity) of the Carbonate Aquifer. Rather, the much younger extensional faulting and associated fracturing, and subsequent dissolution provide the majority of secondary hydraulic conductivity. There are likely more transmissive areas than others based on exploratory test drilling, and at least some transmissive areas display paleo karst development (solution cavities) in settings where the carbonate rocks are buried by the Muddy Creek Formation. The most transmissive areas recognized to date are the MX-4 - MX-5 - MX-6 - Muddy River Springs Area corridor, and more localized transmissive areas occur in the Apex – Nevada Cogeneration Associates and Belly Tank Flat areas. Many areas display local evidence for paleodischarge (ancient spring discharge) and the karstic developments may relate, in part, to spring conduits.

This current study developed a pump test in Belly Tank Flat that yielded excellent databases for aquifer property analyses. Other controlled pump tests (Apex, Nevada Cogeneration well field, Arrow Canyon well, and MX-5) have varied durations and database utilities, but all indicate highly transmissive aquifers properties. Nevertheless, other wells are less productive, such as TH-2, TH-1, Chemical Lime (Apex) and Dry Lake LLC test production well. This wide range of well yield and apparent aquifer properties is not uncommon in terrain where hydraulic conductivity is related to secondary features such as fractures and solution cavities.

The thickness of the active portion of the aquifer is unknown by direct evidence. The abnormal temperatures observed in the Belly Tank Flat area and at the Muddy River Springs Area suggest deep circulation in a thick, active, aquifer zone, through upwelling (which is clearly the case in the Muddy River Springs Area) or through bouyancy-induced vertical circulation due to deeply-penetrating vertical hydraulic continuity. Upwelling is the postulated source of the southern flow field water (discussed later in the text) because of the distinctive water geochemistry and the isotopic signatures, and general uniformity around the Belly Tank Flat area. Available information suggests that the thickness of the Carbonate Aquifer in the Belly Tank Flat is around 5,000 feet, and the water temperatures in the Muddy River Springs Area argue for a similar thickness for the average source zone. There are no data that directly demonstrate thickness. If the average porosities are smaller than those adopted in the analyses of this study, a thicker aquifer zone is indirectly indicated by barometric efficiency relationships. Nevertheless, a 5,000 foot thick aquifer with well developed vertical hydraulic continuity is highly unusual if not unique, and additional data and analyses are warranted.

Evidence for a vertical component of fluid potential change has not been noted in the drilling of 14 boreholes where careful records of water levels were taken as the boreholes were deepened after first water was encountered and measured (MAI-constructed boreholes). Therefore, it is clear that the general unconfined water-table state is common in much of the Arrow Canyon Range Cell. There are areas where confined conditions could exist based on the geology, but large extents, where the water levels are within the carbonate rocks, are likely to be unconfined (water table) conditions.

3.2 Fluid Potential

The fluid potential gradients of the groundwater flow fields of the region are represented by observed depths to water in wells (water-level elevations) and elevations of discharge points at spring areas. The fluid potential of an aquifer is used to estimate a gradient (which supports a flow direction) and as indicators to barriers to flow such as varied permeability zones, faults, sink and source areas. However, the unique Arrow Canyon Range Cell carbonate-rock aquifer characteristics of great thickness and possible well developed vertical hydraulic continuity coupled with small fluid potential gradients may limit the utility of water-level elevations.

Water-level elevations measured in some wells may be reflecting the average density of groundwater due to markedly varying thicknesses of the aquifer resulting from the total depth of vertical hydraulic continuity with well bore. Therefore, density differences (due either to temperature or dissolved-solids differences) could give rise to head differences of a few tenths of a foot even if fluid potentials were identical.

3.2.1 Static Water Levels

Static water levels measured in wells completed in the Carbonate Aquifer are the basis for determining the potentiometric surface or changes in fluid potential to help predict the direction of groundwater flow. It is difficult to analyze water levels in a bounded area such as the Arrow Canyon Range Cell, where the difference in water level (referenced to mean sea level) between wells is small or non-existent. An important part of this work was the performance of accurate field surveys to benchmark each observation well and depth to water measurements (Appendices C and E).

The water levels measured on Moapa Indian Reservation and surroundings areas (Figure 6) were verified by field surveys and equipment calibrations (Appendix C, Table C2). The static water levels in a portion of the Arrow Canyon Range Cell (about 300 square miles) were measured at 1,815 ft +/- 3 ft above mean sea level (amsl), this small variance follows the initial definition of the Arrow Canyon Range Cell by Mifflin (1992). With the help of modeling analyses, a gentle east-southeast gradient, a southeast groundwater flow direction and a north-south dominant anisotropy was interpreted. No systematic changes in water level with depth have been observed in the six holes drilled and completed during this study on the Moapa Indian Reservation. Upwelling is inferred based on abnormal water temperatures and hydrogeologic data supporting the existence of the southern flow field. Vertical hydraulic continuity of the aquifer appears to be well developed and no fluid potential increases with depth have been observed during drilling of 6 boreholes in the project area and at 10 other boreholes in carbonate rock within the Arrow Canyon Range Cell. In one area of the northern segment of Coyote Spring Valley, paired boreholes (VF-1 and VF-2) display greater fluid potential in overlying basin fill as compared to the underlying Carbonate Aquifer, suggesting active recharge (Figure 2 and Appendix C). The water-level data collected is one of the criteria for calibration of the models that were applied in scenario development and prediction of outcomes.

3.2.2 Aquifer Pump Testing

Several important objectives were satisfied by the pump test of ECP-1, the first exploration borehole at Belly Tank Flat completed as a production well. Because of varying problems with other pump tests in the Arrow Canyon Range Cell, the resulting databases were often of limited value for analytical purposes. The ECP-1 seven-day pump test yielded an excellent database useful for delayed yield (fracture drainage) studies necessary for characterizing aquifer responses to long term pumping effects, and demonstrated the projected performance of production wells in the Belly Tank Flat for the Project water supply. At the time of the pump test an expanded monitoring program was in the planning stage and currently consists of the wells shown in Appendix E, Table E-1. Figure 7 shows the test design and borehole stratigraphy.

In order to obtain large-scale estimates of aquifer parameters in the Project area and allow sufficient time for delayed-yield effects to develop, a 7-day aquifer test was conducted in July of

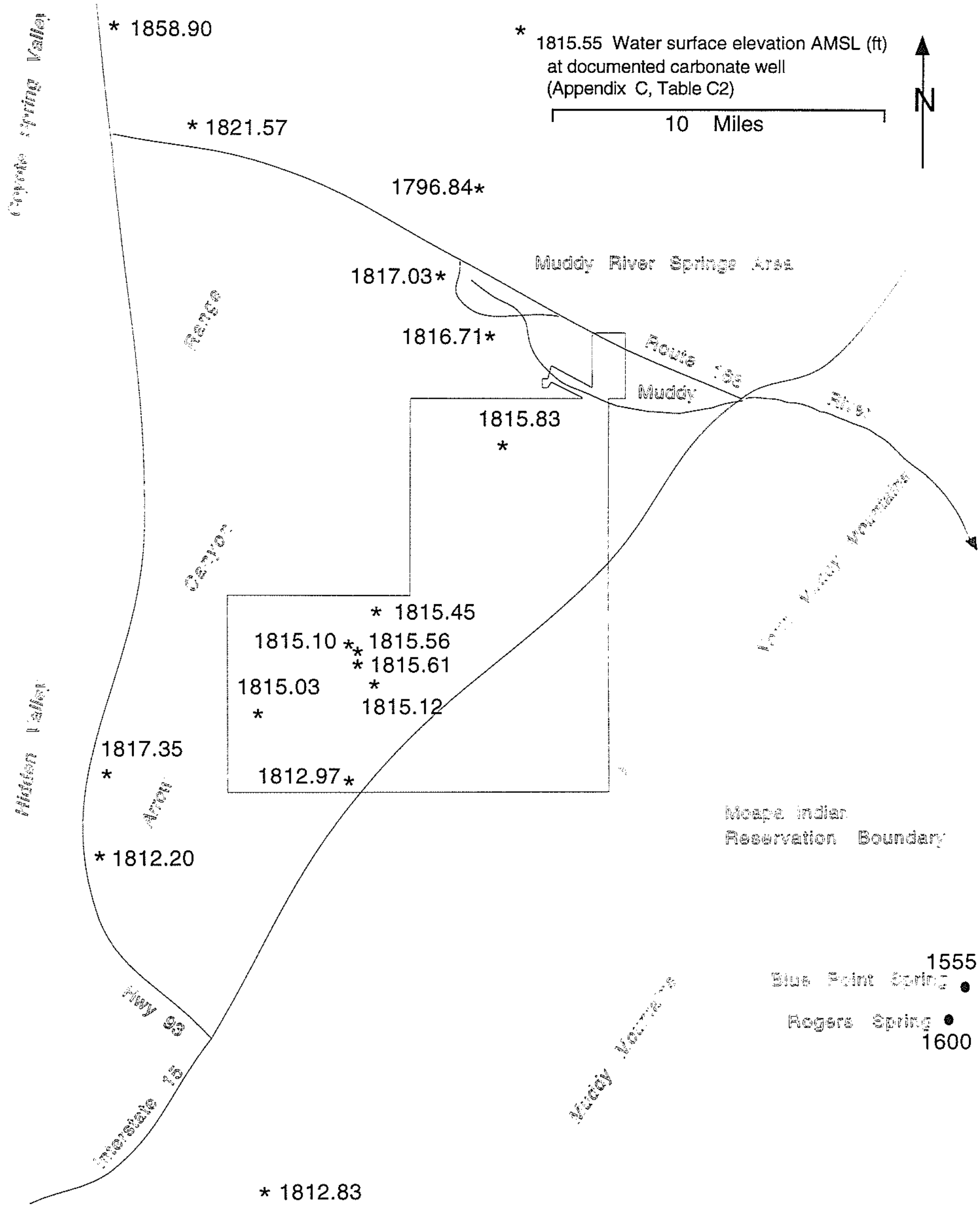


Figure 6. Arrow Canyon Range Cell carbonate aquifer fluid potentials.

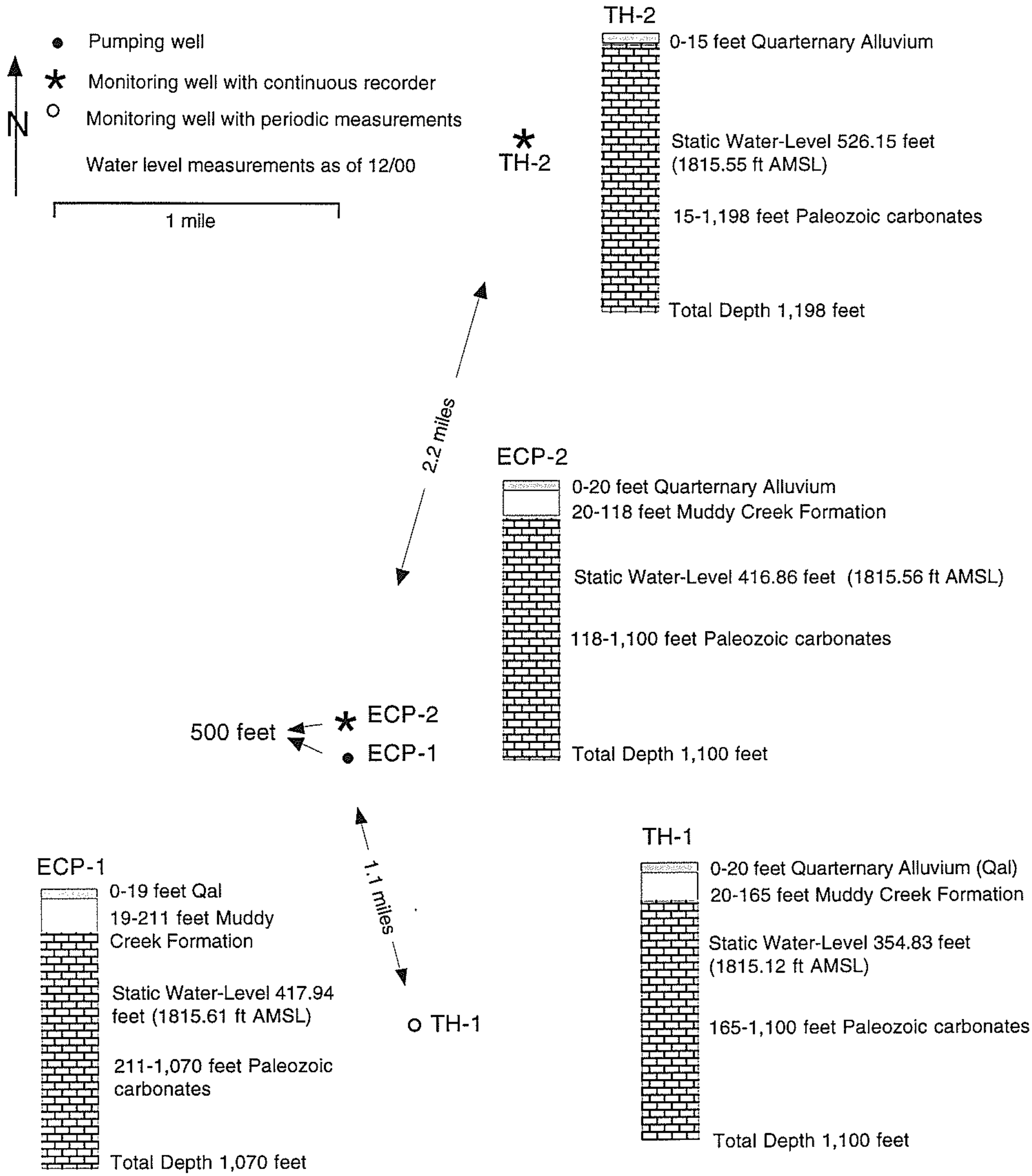


Figure 7. Moapa Paiute Energy Center seven day test pumping monitoring network and borehole stratigraphy.

2000 (Appendix A), with the following conditions:

- Steady discharge of 1005 gpm from ECP-1 for 7 days; a 2-hour 20-minute pump failure had negligible influence on outcome
- Continuous water-level observations at ECP-2 and TH-2, manual water-level measurements at TH-1, and continuous barometric-pressure record at TH-2
- Analyzable response at ECP-2 and TH-2; signal-to-noise at TH-1 roughly 1:1 (provisional analyzable)

The major findings of the 7-day aquifer test were as follows:

- Transmissivities on order of 50,000 to 100,000 ft^2/day
- Unconfined conditions indicated by response curves; specific yield S_y order of 0.03
- Existence of barometric effects in the unconfined system is thought to be due to an effective pneumatic cap (Muddy Creek Formation)
- On the basis of aquifer test and barometric efficiency data the estimated hydraulic conductivity of Arrow Canyon Range Cell was increased and the thickness estimate was corroborated by the application of the barometric efficiency and storativity (Appendix A, p20) to support model refinement

3.2.3 Dynamic Water Levels: Application of a Tidal Method for Aquifer Storage

A specific yield S_y of the order of 0.03 has been used to characterize the storage conditions in the Project model based on aquifer tests described in Appendix A. To test the validity of this S_y value the tidal method described by Jacob (1950) and Ferris (1951) has been utilized. This method demonstrates the consistency between parameters estimated from pumping response and those derived from analysis of the lag and attenuation at MX-4 of large-scale effects of seasonal pumping in the Muddy River Springs Area (primarily the Lewis well field; Figure 2). Although this analysis applies to the region where transmissivities are thought to be two to five times higher than in Belly Tank Flat, it offers strong evidence of unconfined conditions in an important portion of the model domain.

The tidal method is a simple technique for estimating aquifer diffusivity (defined as the quotient of transmissivity and storage, T/S) based upon the response of water levels in an aquifer to periodic water-level changes at a boundary. There are two possible mechanisms for tidal propagation: (1) movement of water into and out of an unconfined aquifer, and (2) compression and expansion of the aquifer-fluid system due to tidal loading. The attenuation of the tidal signal at locations in the aquifer remote from the tidal boundary is normally described by two quantities, *tidal efficiency* and *lag* (Smith, 1999).

3.2.3.1 Relevant Data

To apply the tidal method, monitoring data from the Muddy River Springs Area groundwater withdrawal (Lewis and LDS well fields) and the MX-4 well in Coyote Spring Valley were analyzed. Review of the multi-year record of water levels and groundwater withdrawals (Mifflin and Adenle, 1994, 1996, and Mifflin, 1995 of Appendix F) has made possible the analysis of MX-4 response to annual cycles of pumping in the Muddy River Springs Area. Calendar year 1991 was selected for detailed analysis for of the following reasons:

- There was no groundwater withdrawal from the largest Muddy River Springs Area well fields for the three months prior to May, 1991, when production ramped up abruptly
- Water-level measurements at MX-4 were recorded more frequently than at any time before or since, consequently a water-level drop of 1.3 ft beginning near the end of July is evident
- Drought conditions, prevalent from 1987 and ending in 1992, were still occurring
- The Landers Earthquake, which appears to have caused a 0.6-ft rise in water levels at EH-4 and EH-5b, had not yet occurred
- The Arrow Canyon Well had not yet begun significant groundwater withdrawal

The most important piece of missing data is the average drawdown in the Carbonate Aquifer beneath the Lewis wellfield (the largest pumping center), which represents the tidal signal seen about 90 days later at MX-4, 9.2 miles away. This sub-Lewis-wellfield signal is needed to accurately derive the tidal efficiency. Quarterly water-level measurements made by Mifflin & Associates from 1992 through1995 are used to estimate this "forcing function" beneath the Lewis wellfield for 1991 (Appendix F).

The carbonate-rock monitoring wells EH-5b and EH-4, 0.5 and 2 miles from the Lewis wellfield, respectively, appear to respond to Muddy River Springs Area pumping with annual drawdowns of about 2 ft but without clearly resolvable lag; these are the nearest monitoring wells to the pumping center that are completed in carbonate rock. Average seasonal drawdowns in alluvium in the Lewis wellfield are of the order of 10 ft. Corresponding drawdowns in carbonate rock directly beneath the Lewis wellfield are not known, but clearly are bounded by values in the alluvium (about 10 ft) and those in nearby carbonate rock (about 2 ft). According to Mifflin and Adenle (1996, p. 20-21) Nevada Power Company alluvial wells LDS East and LDS Central appear to be in good hydraulic connection with the regional carbonate aquifer (diagrammatically illustrated in Appendix F), but matching individual pumping centers in the Muddy River Springs Area to the drawdowns in carbonate monitoring wells cannot be resolved with available data. The scoping calculations presented here utilize an interpolated value of 5 ft to represent drawdown in carbonate rock beneath the Lewis well field.

3.2.3.2 Basis of Method

Tidal efficiency, *TE*, relates the magnitude of head fluctuations in the aquifer to the amplitude of fluctuations at the tidal boundary. In mathematical notation,

$$TE = R_a / F_a$$

where F_a is the forcing amplitude at the tidal boundary, and R_a is the response amplitude at a point in the aquifer.

Lag is a measure of the speed of propagation of a tidal signal as it moves through the aquifer

$$lag = F_\theta - R_\theta$$

where F_θ is the phase of tidal forcing and R_θ is the phase of tidal response at a point in the aquifer. Tidal efficiency and lag in one-dimensional, semi-infinite and homogeneous aquifer with uniform transmissivity are derived by solving the equation of 1-D transient groundwater flow (Ferris, 1951) with a tidal or harmonic boundary condition at x=0,

$$\partial^2 h/\partial x^2 = s/T \bullet \partial h/\partial t$$

$$h(0,t) = H_a cos(\omega t - H_\theta)$$

where H_a is the amplitude of head fluctuations at the tidal boundary [L] and H_θ is the phase measured in radians. The groundwater flow problem described by these linear equations can be decomposed into a steady-state flow problem and a harmonic flow problem that comprises one or more frequencies. For the single (annual) frequency considered here, the harmonic solution is rearranged to yield efficiency-based and lag-based expressions for diffusivity (T/S) in terms of tidal efficiency and lag

$$T/S = \pi x^2/(\ln TE)^2 P$$

$$T/S = x^2 P/4\pi(lag)^2$$

where P is the period [T] of the tidal signal (365 days in these analyses) and $\omega = 2\pi/P$ is the corresponding angular frequency [T^{-1}].

3.2.3.3 Results of Analysis

Applying the tidal method using 1991 data from MX-4 as the response and the estimate for drawdown in the carbonate aquifer beneath the Lewis wellfield as the forcing function, we find R_a = 1.3 ft and F_a = 5 ft; therefore tidal efficiency $TE = R_a/F_a = 0.26$. The efficiency-based diffusivity estimate using this value of *TE* is $T/S = 1.12 \times 10^7$ ft^2/day. Using the *lag* estimate of 90 days, the lag-based expression gives $T/S = 8.47 \times 10^6$ ft^2/day. The mean of these independent estimates using the tidal method is close to $T/S = 10^7$ ft^2/day.

Therefore, to evaluate the validity of parameters utilized in the model, parameters used for the conceptual model include hydraulic conductivity K = 60 ft/day, thickness b = 5,000 ft, and specific yield S_y = 0.03 gives diffusivity $T/S = Kb/S_y = 10^7$ ft^2/day. In the model, described in Section 4.0, a high-K corridor extending northwestward from the Muddy River Springs Area was assigned a hydraulic conductivity of 100 ft/day, and was surrounded by a transition region of 50 ft/day. The tidal method yields results that are in excellent agreement with Belly Tank Flat aquifer test interpretations, and support model parameter assignments.

3.2.4 Summary

In summary, the Belly Tank Flat ECP-1 pump test analytical results are consistent with independent lines of evidence reviewed above. Pump and step-drawdown testing of the carbonate aquifer near the proposed pumping center yielded data to compute a range of transmissivity of 50,000 to 100,000 ft^2/day, hydraulic conductivity of 20 ft/day and specific yield S_y of 0.03 and S of 0.008. Unconfined conditions were justified on the basis of drilling observations (cuttings and no water-level changes after first water) barometric records, computation of S (0.003) by the conventional and Tidal Method for aquifer storage. A porosity reported by the US Geological Survey of 0.047 was used in the analyses. The tests support prolong pumping at 1,000 gallons per minute with minimal drawdown at the pumping well. Thermal gradient, barometric efficiency and the storativity were used to verify the estimated of thickness of the aquifer of 5,000 feet. The details and results of the aquifer pump tests at ECP-1 are presented in Appendix A, ECP-1 Aquifer Test Summary Report.

3.3 Geochemistry and Isotope Hydrology

The evolution and concentration of cation and anion constituents in groundwater and the concentration of isotopes of deuterium (H^3) and oxygen 18 (O^{18}) in groundwater are useful to track the evolution of water in aquifers from infiltration (recharge areas) to discharge points (wells, springs, lakes, rivers, other receptors) along a flow path. The flow path can be theorized as that path a molecule of water takes from the point of origin to a discharge point (location). At the point of origin the infiltrating water has a distinctive stable isotopic signature based on the fractionation history up to that point and maintains this characteristic signature until mixed with other water sources with differing signatures.

The water chemistry (cation and anion) generally evolves in concentrations of cation and anion constituents along flow paths through geologic media due to pathway interactions with minerals encountered. Careful analyses of the isotopic signatures and water chemistries may allow definition of flow paths, evidence for mixing water sources, and identification of related or unrelated water over large areas.

In the Arrow Canyon Range Cell, water chemistries and isotopic signatures are generally very distinctive, so much so that a few wells that have been interpreted to be closely associated with the carbonate aquifer (for example CSV-3 and SHV-1, Appendix B), but yielding anomalous water chemistry and isotope signatures, are likely influenced by the overlying basin sediments. Such data points have not been relied upon for water levels or geochemistry.

The isotopic signatures of deuterium and oxygen-18 combined with the water chemistries of the Arrow Canyon Range Cell (Appendix B) are the basis for describing two separate populations of water that define two separate flow fields in the Carbonate Aquifer, the northern and southern flow fields. Stiff and Piper diagrams are typically used to differentiate and compare the origin and evolution of water and illustrate local similarities and regional differences in the composition of groundwater in and adjacent to the Arrow Canyon Range Cell (Appendix B, Figures B1 and B2). By presenting the quantities and relative proportions of the major dissolved cations and anions, waters that share common origins often are recognized. Waters that are significantly different with respect to their ionic compositions either occupy different positions on an evolutionary pathway, or are unrelated.

The stiff diagrams of Figure B-1, Appendix B, dramatically illustrate the patterns of water chemistries of the Carbonate Aquifer in the Arrow Canyon Range Cell and adjacent areas. An indication of initial water chemistry in recharge areas is illustrated by the perched spring waters of the Sheep Range, where TDS is generally less and the waters have a Ca-Mg or Mg-Ca bicarbonate signature.

Based on geochemical data analyzed at the Muddy River Springs Area-Coyote Springs Valley flow field (northern flow field) and flow field water of the Project area (southern flow field) are different. Waters discharging in the Muddy River Springs Area and in Coyote Spring Valley (up gradient wells) have bicarbonate as their predominant anion and total dissolved solids (TDS) generally less than 600 mg/l. Waters of the southern Arrow Canyon Range Cell display water chemistries of 900 to 1000 TDS, with sulfate and chloride as predominant anions. Isotopic signatures are similar with respect to deuterium values, but southern flow field waters are slightly lighter than northern flow field waters in Oxygen-18 ratios. In a general sense, both flow fields appear to be closely related isotopically, but are clearly different in terms of water chemistries. There is no evidence of the southern flow field (poorer quality water) in the Muddy River Springs Area discharge. Waters discharging at Rogers and Blue Point Springs are much more saline than groundwater of the Arrow Canyon Range Cell; TDS values are 2,900 and 4,000 mg/l, respectively, probably originating from dissolution of the evaporite minerals gypsum and halite along groundwater flow paths, (Appendix B).

A spectrum of stable isotopic compositions is in evidence in the study area (Appendix B). The isotopically lightest waters, such as those at MX-4 and VF-2 (del D=-101.0) are interpreted to represent waters recharged thousands of years ago during the generally colder pluvial (ice age) climates or to be from recharge in a more northerly, colder climatic setting. In contrast, isotopically heavier waters, such as Mormon Well Spring in the Sheep Range (del D=-91.8) or the Hidden Valley Stock Well (del D=-90.5) are considered to be much younger and locally derived. The differences in isotopic composition are because of: 1) the differing extent to which these waters have been subjected to fractionation before precipitation and 2) to evaporation, which drives the isotopic composition toward heavier values. Isotopic compositions are useful because they are insensitive to most chemical reactions and will not change substantially unless the water is subjected to evaporation or mixed with another water type. Isotopic compositions support the interpretation of the mixing of groundwater along a flow path within one or more flow fields.

Rogers and Blue Point Springs water (del D =-92.0 and -93.0, respectively) are isotopically similar to waters with evidence of local origins indicating that hydrodynamically these springs are not fed by groundwater from the Arrow Canyon Range Cell. Secondly, the Calpine production well ECP-1 (del D=-99.0) and observation well TH-1 (del D=-99.0) is intermediate in isotopic composition between MX-4 (del-D=-101.0) and Big Muddy Spring (del D=-97.8). The USGS estimated that 38% Sheep Range water mixes with 62% Coyote Spring Valley water to produce Big Muddy Spring water (Thomas and others, 1997, p. C46). Geochemical and isotopic evidence indicates that the flow field of Belly Tank Flat and areas to the south and that supplying the Muddy River Springs Area are two separate flow fields, and allows an estimate of groundwater flux that may be present in the southern flow field.

3.3.1 Hydrochemical Evidence that Belly Tank Flat Waters are Unrelated to Muddy River Springs Area Waters

The concept of chemical evolution, the net effect of solution-mineral interactions and mixing along ground-water flow paths, can be used to infer relationships (or the absence of relationships) between water types. In the Arrow Canyon Range Cell of the regional carbonate aquifer, three distinct water types are present (Appendix B analyses, Figures B-1 and B-2).

Muddy River Springs type	Na - HCO_3	TDS	610-640 mg/l
Belly Tank Flat type	Ca - SO_4	TDS	750-900 mg/l
Apex type	Na - SO_4	TDS	$\approx$ 1,000 mg/l

The possible of a hydraulic connection between Belly Tank Flat and the Muddy River Springs Area is evaluated by looking for a mechanism that could cause one type of water to evolve compositionally into the other.

This exercise will focus on dissolved calcium and sulfate, both of which are constituents of the common rock-forming mineral gypsum (CaSO4 • 2H2O). Available analyses (Thomas and others, 1996; Appendix B of this report) give the following data:

Location	Ca^{2+} mg/l	SO_4^{2-} mg/l
Big Muddy Spring	66	190
Calpine Well ECP-1a	120	290

The saturation index of calcite in water from carbonate-rock aquifers of southern Nevada indicate near-equilibrium conditions (Thomas and others, 1996, p. C44) that is, any addition of dissolved calcium would be moderated by precipitation of dissolved calcium as calcite. This is known as the common-ion effect. Noting that ECP-1a water has higher dissolved calcium and sulfate than Big Muddy Spring water, therefore the hypothesis is tested that water resembling that discharging at Big Muddy Spring could have evolved into ECP-1a water by dissolving gypsum along its flow path is probable. A disproportionate increase of sulfate over calcium in the resultant water is expected if this hypothesis is valid, since dissolved calcium is buffered in the presence of calcite. Instead, a proportional increase of calcium over sulfate is observed:

$$\Delta \text{Ca} = (120\text{-}66)/66 = .82\text{, or } 82\% \qquad \Delta \text{SO}_4 = (290\text{-}190)/190 = .53\text{, or } 53\%$$

These relations argue against a water characteristic of the Muddy River Springs Area evolving, through gypsum dissolution, to the water characteristic of Belly Tank Flat. Gypsum dissolution accompanied by common-ion precipitation of calcite has probably influenced the evolution of Belly Tank Flat waters, but because there is no disproportionate increase in SO_4 over Ca in Muddy River Springs Area waters, it appears that Belly Tank Flat waters did *not* evolve from Muddy River Springs Area waters.

Derivation of Apex-type waters from Belly Tank Flat-type waters is not problematic

Location	Na^+ mg/l	Ca^{2+} mg/l	SO_4^{2-} mg/l
Calpine Well ECP-1a	110	120	290
Georgia Pacific GP-1a	129	120	380

Additional gypsum dissolution and possibly ion exchange could produce Apex area waters from a precursor resembling Belly Tank Flat waters, since there is a proportionate increase in dissolved sodium over calcium in the more southerly waters, and elevated sulfate.

3.3.2 Isotopic Evidence of Flow System Configuration

The stable isotopes of hydrogen and oxygen have proven to be extremely useful hydrologic tracers, primarily because they are conservative, that is, their abundance in groundwater are not influenced by most chemical reactions. Climate and contributing recharge areas impart an isotopic "fingerprint" to groundwater, allowing sources of the water to be inferred from its isotopic composition. If representative-mixing end-members can be identified, the relative contributions of the end-members to a suspected mixture can be inferred from considerations of isotopic abundance.

Muddy River springs waters are isotopically distinct from Belly Tank Flat and Apex waters (Appendix B, Figure B-3). The latter are isotopically lighter with respect to Oxygen-18 than Muddy River springs waters, suggesting greater age; deuterium values of the two groups overlap, and display greater variation in Muddy River springs-Coyote Spring Valley waters than in southern flow field waters. Waters occurring in the Belly Tank Flat and Apex areas, if originating from a different flow system than that supplying Muddy River Springs Area, this may be supported by utilizing mixing calculations with isotopic indicators.

The principle of mixing model analyses is demonstrated by the following mixing calculation and illustrates the use of isotopic compositions of Big Muddy Spring and the Valley of Fire well to explain Rogers Spring water as a mixture of these two hypothetical end-members (Appendix B). The basic relationship is

$$xC_1 + (1-x)C_2 = C_3$$

where C_1 and C_2 are concentrations of a conservative constituent in the mixing end-members, and C_3 is the concentration of that constituent in the mixture, and x is the mixing fraction of C_1. Rogers Spring water as a mixture of waters observed at Big Muddy Spring and Valley of Fire Well water is postulated; the del ^{18}O values for these waters are:

C_1	Big Muddy Spring	-13.0
C_2	Valley of Fire Well	-10.6
C_3	Rogers Spring	-12.2

Given these concentrations,

$$\begin{aligned} x &= (C_3-C_2)/(C_1-C_2) \\ &= -1.6/-2.4 \\ &= 0.666 \end{aligned}$$

which indicates 2 parts Big Muddy Spring water mixed with 1 part Valley of Fire Well water would yield the Oxygen-18 composition observed at Rogers Spring. Although this example is for illustrative purposes only, it demonstrates two parts Muddy River spring-type water (regional flow mixed with local recharge (one part) could yield the observed isotopic signature).

The U.S. Geological Survey (Thomas and others, 1996) has studied the origins of groundwater in the Muddy River Springs Area by considering stable isotopic compositions of potential source waters in the region. The USGS Mixing Model for the Muddy River springs is based on 2-step mixing using deuterium compositions in hypothetical mixing end-members, as calculated below:

> Step 1. 64% (14,000 afy) White River Flow System water (del D = -109 permil) + 36% (8,000 afy) Southern Meadow Valley Wash Flow System water (del D = -87 permil) to Coyote Spring Valley Water (del D = -101 permil)
>
> Step 2. 62% (22,000 afy) Coyote Spring Valley Water (del D = -101 permil) + 38% (14,000 afy) Sheep Range water (del D = -93 permil) to Muddy River springs (del D = -98 permil)

These results challenge earlier estimates regarding the origin of the Muddy River springs. Notably, the estimated Sheep Range contribution to Muddy River Springs (14,000 afy) is greater than the Maxey-Eakin based estimate of recharge for the entire Sheep Range (11,000 afy). The estimated White River Flow System contribution to Muddy River springs (14,000 afy) is much less than the 35,000 afy proposed by Eakin (1966), and less than the 18,000 afy underflow from Pahranagat Valley to Coyote Spring Valley estimated by Welch (1988) or the 16,500 to 19,000 afy by Kirk and Campana (1990).

Adopting the USGS findings concerning water balance in the region and the earlier estimates of underflow to Coyote Spring Valley from Pahranagat Valley results in a conceptual model that is consistent with all studies cited above. A mixing model for Belly Tank Flat is as follows:

- Conceptually there is deep southward flow of White River Flow System water (del D = -109 permil) beneath Coyote Spring Valley, but no contribution from the Meadow Valley Wash Flow System

- This deep underflow of White River Flow System water from the north mixes with Sheep Range water (del D = -93 permil)

- The Hidden Valley Dry Lake LLC production well HV-1 (del D = -97 permil) would be 25% White River Flow System water and 75 % Sheep Range water

- Belly Tank Flat and Apex area waters (del D = -99 permil) would be 38% White River Flow System water and 62% Sheep Range water

- If the southern flow field waters include the 4,000 afy that flows southward from Pahranagat Valley but does not discharge at Muddy River springs, another 6,500 afy from the Sheep Range (doubling the Maxey-Eakin estimate) is required for isotope balance in Belly Tank Flat. Therefore, as much as 10,000 afy of flux may occur in the southern flow field (the Belly Tank Flat - Apex area).

According to this model, derivation of Belly Tank Flat and Apex waters directly from Muddy River Springs Area waters is improbable. This finding is consistent with all USGS and DRI hydrologic balances cited above, and with geochemical evidence indicating that Muddy River springs - type water is not a precursor to Belly Tank Flat - Apex waters in terms of chemical evolution.

The above analysis and the GFLOW regional modeling steady state calibration (Section 4.4) both yield similar 9,000 to 10,000 afy estimate of flux for the southern flow field. Specific analyses in Thomas others (1996, Appendix B) suggest that underflow to northeastern Las Vegas Valley is plausible but there are no waters recognized that fit both the isotopic and geochemical signatures of the southern flow field waters. Two observations are made:

- First, the Craig Ranch Country Club well #2 (analysis #66, del D=-106) is extremely light isotopically, resembling White River flow system waters.

- Second, the Lake Mead Base well #3 (analysis # 64, del D=-101.5 and -103 for duplicate analyses) is intermediate isotopically and in terms of total dissolved solids between White River / Craig Ranch water and Apex water.

While not particularly compelling, these data are consistent with deep underflows from the north mixing with Las Vegas Valley groundwater along the northern and northeastern margins of Las Vegas Valley.

Summarizing, two populations of water are recognized:

1. A northern flow field that is discharging in the northern portion in the Muddy River Springs Area
2. A southern flow field that is in part a deeply circulated regional flow system upwelling within the central part of the Arrow Canyon Range Cell, and evolving to a more sodic, higher TDS water as it flows southward.

Both flow fields are clearly characteristic of regional flow systems in carbonate rock terrain in terms of water chemistries (see Mifflin, 1968) but with isotopic signatures and water chemistries that are best explained by different mixing histories. These are very suggestive of Toth's (1963) and Freeze and Witherspoon's (1967) conceptual and theoretical studies of local, intermediate and regional flow-systems (Figure 8). The Sheep Range may be an important contributor to both flow fields. The northern flow field discharges at the Muddy River Springs Area and fits an intermediate configuration flow system with shorter flow paths than occur at depth and with important contributions from "local" sources (southern Meadow Valley Wash) that apparently do not contribute to the deeper system. The southern flow field, with very uniform water chemistry (Appendix B) characterized by a greater load of the relatively conservative ions (Na, K, Cl, SO4) conforms to a deep regional flow system configuration with longer flow paths and less local flow contributions. In conceptual diagrams and idealized modeling analyses, the most

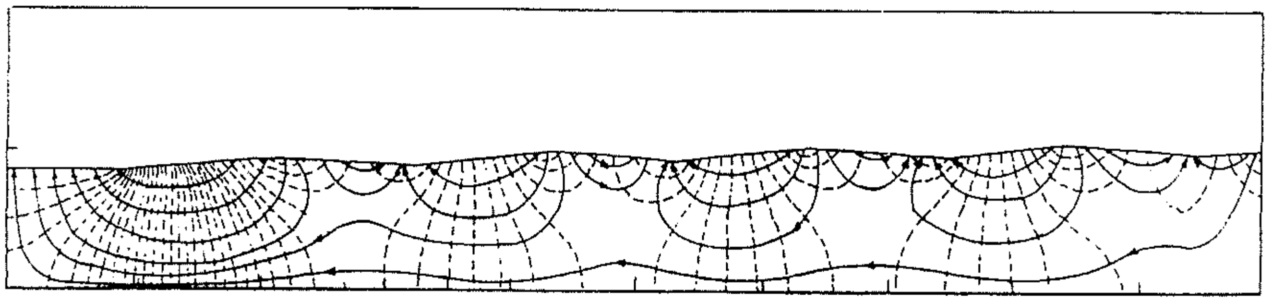


Figure 8. Freeze and Witherspoon's (1967) numeral solution to Toth's (1963) conceptual model of regional groundwater flow. Water that enters the flow system may be discharged locally or intermediately, or may be transmitted to a regional discharge area. Solid lines with arrows on diagram represent groundwater flow paths, with the beginning of a line a recharge area and the terminus of a line a discharge area.

deeply circulated, longest flow path waters (regional) ascend to shallower levels at or near a regional barriers to flow, and may be overlain by more local circulation cells or flow systems with overall shorter flow paths, Figure 8.

The discussed relationships observed in the Arrow Canyon Range Cell are suggestive of a deeply circulated regional flow system upwelling within the southern part of the Arrow Canyon Range Cell of the Regional Carbonate Aquifer, and an intermediate regional system discharging in the northern portion at the Muddy River Springs Area. Nevertheless, lacking specific physical evidence of a flow barrier between the southern flow and the northern flow field, the combined area, as one hydraulic continuum, was modeled and described in this report. This allows pumping cones of the southern flow field to migrate into the northern flow field and impact Muddy River spring flows to various degrees.

3.4 Hydrogeology of the Muddy River Springs Area

The Muddy River Springs Area was believed to represent the primary area of discharge for the majority, if not all, of the White River Regional Flow System (Eakin, 1966). The flux to this area passes through Coyote Spring Valley and adjacent areas. On average, approximately 51 cubic feet per second (cfs) of flow reaches the area and discharges through spring flow, base flow to the Muddy River channel, and through evapotranspiration. Local pumping stresses and associated groundwater diversions occur in the carbonate aquifer, as well as the alluvial aquifer which also is in hydraulic continuity with the carbonate aquifer. A detailed inventory and monitoring program sponsored by Nevada Power Company began in 1987 to augment more limited monitoring of some springs and the Muddy River discharge at Warm Spring Road Bridge (USGS). This expanded monitoring has been continued to the present, and demonstrates a relatively complex hydrologic system, in which it is difficult to measure variations and correlate the causes of such measured variations (Appendix F).

During a State Engineer hearing of several protests to water rights applications 55450 and 58269 by the Moapa Valley Water District, the hydrologic relationships of water development in the area and measured impacts as well as characteristics of the hydrologic systems were summarized and entered into the hearing record by Mifflin & Associates, Inc. (Appendix F). The key relationships are outlined in the summary and supported by an Appendix of figures, tables, and graphs.

A good understanding of this important locus of groundwater discharge is required if the effects of distant pumping centers in the Carbonate Aquifer are to be determined. Pumping impacts recognized in monitoring wells near the Muddy River Springs Area have been analyzed to provide perspectives on effects that might propagate toward the spring area from distant pumping centers. Appendix F details the nature of pumping impacts recognized and interpreted in this area to support several relationships used in model development. A logical symmetry argument is as follows: if signals representing pumping stresses in the Muddy River Springs Area are propagated southward and detected in the Belly Tank Flat area, then signals propagated north from the Calpine Project would be subject to the same physical controls. It is therefore very important to understand the "forcing function" (see discussion of the tidal method in Section 3.2.3) represented by pumping in the Muddy River Springs Area now that a new monitoring network capable of detecting its effects is in place in the southern flow field (Appendix E).

The appropriate storativity to assign to large, unexplored tracts of Carbonate Aquifer is indicated by the delayed responses to pumping stresses in wells affected by activities in the Muddy River Springs Area. Delays that range from 3 months at approximately 9 miles distance (MX-4) to as little as a few days in a closely adjacent Carbonate-Aquifer well (EH-5b) are summarized and hydrographs presented in Appendix F . The lag and attenuation of the pumping signals with time and distance are illustrated graphically by a set of figures that demonstrates delayed responses to local-area pumping stresses arising from substantial storage in the aquifer.

Based on the above, around the Muddy River Springs Area extensive reaches of the Carbonate Aquifer behave as an unconfined system requiring a certain amount of dewatering before pumping stresses are transmitted over large distances. However, locally, there are areas where confinement also exists, which is compatible with areas where the Muddy Creek Formation and/or other Tertiary strata may overlie Paleozoic carbonate rocks within the zone of saturation. Large areas within the Arrow Canyon Range Cell, however, are underlain by Paleozoic carbonate terrain that either crops out well above the level of regional saturation, or though partly covered by younger sediments, the unconformable contact is well above the regional saturation. Therefore, it is concluded that distant pumping cones will likely be delayed in transmission over long distances due to a predominance of water-table conditions, particularly in the region of the southern flow field north of Belly Tank Flat.

Impacts from major pumping stresses that occur in the southern flow field, if they indeed are able to propagate northward into the northern flow field, would likely be reflected as modulated water-level declines in a relatively small portion of the northern flow field. This scenario would result in very small, and very slowly-increasing declines in regional flow to the spring area. Because of the secular nature of the effects of drought and wet periods and delays to responses of the northern flow field, recognition through monitoring in the Muddy River Springs Area would be unlikely until the impacts were at least greater than the range of secular changes (about 5 cfs annualized) due to the natural variations in multi-year recharge periods. However, it is possible to identify if pumping effects are reaching the northern flow field through water-level monitoring in a monitoring program that has been designed and implemented (Appendix E). It is anticipated that the pumping at the Belly Tank Flat well field would yield a distinctive pumping signal, just as the Muddy River Springs Area pumping signal can be traced to the MX-4 area. In this manner it is anticipated that pumping impacts entering the northern flow field would be identified long before they would be measurable in the Muddy River Springs Area.

Extensive monitoring in the Muddy River Springs Area indicates that some aquatic habitats may be impacted by existing local pumping stresses on a seasonal basis. However, these local seasonably distributed pumping impacts are poorly correlated with aquatic habitat in the area. The magnitude of pumping-produced hydrologic variations are two to three times greater than natural hydrologic variations that appear to be real from the long-term records (Appendix F). Working to moderate impacts on many aquatic habitats is the locally confined nature of the Carbonate Aquifer in the spring areas and conduits that feed the alluvial aquifer; there are head losses within the feeder conduits, and therefore fluid potential variations deep in the Carbonate

Aquifer do not necessarily result in proportional decreases in discharge supplied by conduits. The result is that flows may be decreased in conduit-fed hydrologic features, but few flows, if any, have been markedly reduced or totally eliminated. The exception may be the base-flow discharge from the unconfined alluvial gravels in the uppermost reaches of the Muddy River channels. Upstream from the area of Big Muddy Spring, pre-1961 perennial flow reaches may have been reduced to seasonal flow in local segments of the river channel. All observations are based on detailed monitoring accomplished from 1987 through 1995, when water levels in the Carbonate Aquifer in the Muddy River Springs Area generally recovered every year to historic levels even during periods of drought, as shown in Appendix F.

3.5 Conceptual Models

3.5.1 Conceptual Model of the Arrow Canyon Range Cell

Conceptual models develop as knowledge and experience increases with time. They are fundamental in understanding observed natural phenomena and, as new information is developed, tested or refined, to better predict the characteristics of natural and generally very complex systems. The amount of relevant data determines the confidence in the conceptual model. Many groundwater basins are lacking in data to confidently project water resources available. The data within the Arrow Canyon Range Cell is not abundant, however much is of high quality and there exists data that describe the aquifer hydraulics locally.

Mifflin (1992) recognized similar fluid potentials within the Carbonate Aquifer over an extensive region, extending on the north from the Muddy River Spring Area to as far south as the Apex-Pabco area (Figure 6). Mifflin (1992) called it the Arrow Canyon Range Cell of the White River Flow System, speculating that it may be a large body of essentially stagnant water, a subterranean embayment with possible hydraulic continuity with the active flow system discharging at the Muddy River Springs Area at the northeast corner of the Cell. At the time data points (wells) were very sparse, isotopic analyses were unpublished, and geochemistry known only in the extreme north and south of the Cell. The eastern and southern boundaries, the Hogan Spring Fault Zone and the Las Vegas Shear Zone and its eastern splay, respectively, were recognized. Fluid potential gradients were recognized to the northwest of the Muddy River Springs Area at the MX and other wells, and the Sheep Range was assumed to be the western boundary.

3.5.1.1 Flow Fields

This study has confirmed the relatively uniform fluid potentials (but with firmer evidence for slight gradients). A number of additional data points for fluid potentials (Figure 6) and geochemistry and isotopic signatures (Appendix B) have become available. These new data indicate two separate populations of water associated with two flow fields (northern and southern flow fields) that likely incorporate similar waters from a distant northern source area, but differ in terms of their more locally-derived components. This in turn suggests deeply-circulated waters that either bypass (or flow under?) the Coyote Spring Valley-Muddy River Springs Area flow field that occurs in the northern area of the Arrow Canyon Range Cell.

The northern flow field originates from mixing of at least three end-member sources of water in Coyote Spring Valley, and discharges into the Muddy River Springs Area. Coyote Spring Valley is recharged by regional underflow from Pahranagat Valley, the Sheep Range, and Meadow Valley Wash, in proportions estimated by the U.S. Geological Survey (USGS) using isotopic mass balance.

The uniformity of the isotopic signatures associated with the southern flow field, as well as geochemistry of the water, indicates that most mixing of Sheep Range waters into regionally-derived flow must either occur at depth or considerably up-gradient of the Belly Tank Flat and monitoring well TH-2 area. Only the new M-3 monitoring well (Figure 2 and Appendix B) suggests a somewhat possible of westerly-derived waters. The primary upwelling zone is postulated to be near or at the area of TH-2, ECP-1, and TH-1, and that farther to the south in the Apex - Nevada Cogeneration Associates (NCA) well field area the flow field waters have traveled laterally and have passed through more Muddy Creek Formation to evolve to somewhat higher concentrations of conservative ions derived from evaporite minerals (Figure B-2). The HV-1 data suggest a more local component of water (water isotopically heavier) has been mixed into the more deeply-circulated component of flow in the deep test well, that is over 2,000 feet into the saturated zone, and with similar water chemistry of the Apex area. A configuration of deep regional flow from the north, similar to theoretical configurations of Toth (1963) and Freeze and Witherspoon (1967; Figure 8) best explains the databases developed to date.

3.5.2 Conceptual Model Issues

Unresolved questions are two-fold: 1) What is the nature of the interface between the northern and southern flow fields, and 2) Where does the flux of the southern flow field go? The first is an important question in terms of modeling analyses of pumping impacts from the Belly Tank Flat well field. The uncertainty raised by the questions encouraged adoption of a conservative modeling approach that may be, overall, too conservative in terms of the propagation of pumping cones northward into the northern flow field, with resulting capture, over time, of northern flow field waters. If the interface zone (Figure 5) is a local zone of decreased hydraulic continuity within the Paleozoic rocks due to faulting and/or a less permeable zone of strata, the propagation northward of the pumping effects would be impeded, and either reduce or eliminate impacts in the northern flow field. On the north side of this interface zone at the M-1 monitoring well, the geochemical data suggests an edge zone of the northern flow field, and preliminary interpretation of the short monitoring record to date suggests hydraulic continuity with the Muddy River Springs Area. Because of the relatively uniform fluid potentials to the north and the north-south structural grain in the carbonate terrain, a conservative approach in the modeling analyses was adopted by embedding into the model the same highly-developed N-S transmissivity evident from aquifer-test data in the Belly Tank Flat area.

The issue of total flux through the southern flow field is important in terms of water resource management. A range of estimates of the magnitude of this flux has been obtained through the modeling process, but it is accompanied by uncertainty. For example, if relatively small changes are made to regional aquifer properties, and/or gradients, or western boundary area recharge, and the calibration value would change. It is clear that considerable flux is necessary to meet the strong evidence for a gradient between the central and southern areas, but aquifer properties are just as important, and they are unproven over very large areas. One consequence of this uncertainty is that while modeling analyses described below have provided order-of-magnitude flux estimates the question of specific outflow locations may never be resolved. Outflow locations may be to the southeast in a highly faulted zone north of Frenchman Mountain, or perhaps dispersed along the Las Vegas Shear Zone, or even south along the frontal fault zone on the west side of the Frenchman Mountain structural block. The problem of outflow recognition is twofold; 1) sparse or no data points in many areas, and 2) mixed water from wells typically designed to capture water from any producing zone, beginning in uppermost saturated alluvial fill and continuing to the total depth of the well. Therefore, the only areas where there may be opportunity to recognize Arrow Canyon Range Cell waters is from wells that do not penetrate saturated alluvium.

This aspect of uncertainty is not significant in terms of projecting impacts from the Project, as the fluid potentials in the Las Vegas basin are significantly lower. There are no recognized water sources that are of similar geochemistry, and therefore impacts from even markedly lowered water levels within the Carbonate Aquifer of the Arrow Canyon Range Cell along the Las Vegas Shear Zone would not likely produce any measurable or recognized impacts. Further, based on the discontinuity of water levels between the Arrow Canyon Range Cell and all adjacent areas to the south and southeast of the projected trace of the Las Vegas Shear Zone, and the highly faulted Tertiary strata exposed to the east along the eastward splay of the Las Vegas Shear Zone, much or all of the outflow may be distributed and pass through strata rich in evaporites. Only in the Lake Mead Basin area and south of Pabco are there candidate waters in terms of permissible water chemistry and isotopic signatures without opportunity for major dilution by low-TDS waters.

4.0 Modeling Analyses

Modeling analyses derive from a combination of professional judgment and applications of flow equations, and forecasts may or may not prove to be accurate over time. They are extremely useful, nevertheless, because the modeling codes are, in themselves, very powerful tools that allow for analysis of flow in complex geologic settings that could not be quantitatively evaluated in any other manner. They allow the study of spatial and temporal impacts of groundwater development, often and provide insight into problem areas where databases are necessary. Model forecasts should be tested and refined through monitoring wherever possible, allowing stepwise improvements in accuracy.

4.1 Previous Modeling Studies

Others have conducted comprehensive modeling studies at regional, sub-regional, and local scales in the general area. The one known regional study was sponsored by Federal agencies, two known sub-regional studies by the Las Vegas Valley Water District (District), and one local study by Nevada Power Company (NPC). After careful review and evaluation, some have a potential to be non-conservative, as outlined below.

4.1.1 Regional Model

A two-layer model of the simulated effects of pumping from 17 basins in east central and southern Nevada (Schaefer and Harrill, 1995) reported the potential effects of a proposed 180,800 afy appropriation *for a period of 30 years* by the Las Vegas Valley Water District. This work was requested by several Departments of the Interior agencies, and performed by the U.S. Geological Survey. A two-layer MODFLOW grid, originally developed for the Great Basin Regional Aquifer-System Analysis (RASA) project, was applied (Prudic and others, 1993). The model grid contains 61 rows by 60 columns, and cells 5 miles wide by 7.5 miles long.

The Schaefer and Harrill study resulted in qualified predictions of effects on water levels including: 670 ft decline in Garden Valley, a 22 percent decrease of the flow in Muddy River Springs and groundwater discharge by evapotranspiration (54% decrease in Spring Valley) if steady-state conditions were established in the distant future. The report noted, "results reported should be used only as indications of possible generalized effects". At 30 years into the simulation, roughly comparable to the cases considered evaluated for the proposed MPEC, a 10% decrease in the flow of Muddy River Springs was predicted. According to Schaefer and Harrill (1995, p.7) general-head boundaries (GHB's) were prescribed along the northeast, northwest, southeast, and southwest borders of the model, i.e. on all sides (citing Prudic and others, 1993, p. 18). This appears to be inconsistent with the statement (Schaefer and Harrill, 1995, p. 42) that "The boundaries for this simulation do not allow additional water to be made available to the groundwater system of the Great Basin...". It is unclear, therefore, how conservative these predictions of pumping effects actually are, given the incomplete description of the boundary conditions applied to this model. A GHB is a prescribed-head boundary with some resistance, designed to simulate a more distant constant head and thereby "soften" what would otherwise act as a nearby source of infinite amounts of water. GHB's would allow inflow of additional water to the model domain. The southeastern and southwestern boundaries appear to be impacted by the simulated withdrawals, and should therefore yield some additional water.

4.1.2 Sub-Regional Model of California Wash and Coyote Spring Valley

Sub-regional models of the California Wash (Hydrographic Basin 218) and Coyote Spring Valley (Hydrographic Basin 210) have been prepared by Montgomery Engineers for the Las Vegas Valley Water District. The first (Wildermuth and others, 1990) was an assessment of the groundwater resource potential of the California Wash Basin, and was conducted to estimate the impacts of the District's proposed 20,000 afy diversions from the Basin. The model consisted of a 2-layer MODFLOW grid, 32 rows by 30 columns and grid spacings of about one mile. Using prescribed heads on the east and west borders of the model grid and prescribed inflows to the north, the conclusion was reached that steady-state inflow and outflow are about 22,000 afy, in contrast to the work done by Rush (1968), who estimated about 9,000 afy. This increase is attributed to "...subsurface inflow in the consolidated rocks flowing through the Basin from the west to the east." (Wildermuth and others, 1990, p. 14).

On page 24 of the Montgomery report it is stated: "The model boundaries are rectangular and have been set arbitrarily far from the hydrographic boundaries. This was done to insure [sic] that assumptions on the model boundaries will not bias drawdown estimates". In contrast to this assumption, modeling analyses conducted relative to the MPEC indicates that using the scale of this model, six to ten miles from the east and west boundaries is too close for a prescribed-head boundary and a general-head boundary could have been used to lessen the effect of induced inflow.

In addition, the treatment of resistance between the two model layers in the Montgomery report is questioned. Given the major differences in head between upper and lower aquifers for all modeling runs, the effective resistance for most of the model area must be close to infinity. The consequence of this high resistance (low leakance) is that wells are forced to draw water from the prescribed-head boundaries. The net effect is to minimize potential impacts on regional spring flow and shallow water levels.

4.1.3 Sub-Regional Model of Coyote Spring Valley

A sub-regional steady-state model of Coyote Spring Valley (Buqo and others, 1992) was also developed to study the District's water-right filings. The model consists of a 2-layer MODFLOW grid, 49 rows by 24 columns and one-mile grid spacing. The presence of the sensitive environment at the Muddy River Springs Area was recognized as an important factor to be taken into account for a development scheme. The study concluded that undeveloped water resources are available in Coyote Spring Valley, especially in the carbonate aquifer. However, there was an absence of any transient analyses of pumping stresses on the basin even though storage properties were assigned to the hydrostratigraphic model units. Transient analyses could have predicted impacts on the regional springs.

4.1.4 Sub-Regional Model of the Muddy River Springs Area

A local three-layer model of the Muddy River Springs Area was developed by Bredehoeft and Hall (1996), to assess the hydrologic impacts of proposed pumping of 6.2 cfs by the Moapa Valley Water District in the Warm Springs - Moapa area. The Bredehoeft study utilized a MODFLOW grid with a locally refined mesh. The model predicted that while impacts on water levels would be minimal, river/spring flow would decrease by exactly the amount pumped from the well. The report also contains a compilation of seasonal pumping and response trends.

4.1.5 Summary of Previous Modeling Efforts

Such analyses correlate most closely with the bounding Case 2 modeling scenario of this study (Section 4.6) which incorporate constant head model boundaries. The previous models do not address uncertainty associated with this natural system. A goal in this study is to bound uncertainty related to hydrologic boundary conditions, while maintaining an underlying conservative assumption of regional hydraulic continuity.

4.2 Model Code Selection

The groundwater modeling presented here is based on a comprehensive literature review, data collection, analysis and interpretation, professional familiarity and experience with the area of interest (Arrow Canyon Range Cell) and the choice of models that will satisfy the following objectives:

- Prediction of the effects of pumping 7,000 afy from the Belly Tank Flat site for 25 and 45 year periods from the Paleozoic carbonate aquifer in the California Wash Basin

- Prediction of the effects of pumping on the Muddy River Springs Area approximately 15 miles northeast of the Project area

- Prediction of the effects on pumping in the Apex Industrial Area 15 miles south of the Project area

- Prediction of the effects of pumping on the Rodgers/Blue Point Springs area 22miles southeast of the Project area.

The model developments are tools to enhance the understanding of a complex hydrogeologic system. A philosophical distinction between a model and a simulator is made; the latter is a comprehensive predictor of a full range of effects, whereas the former is an efficient path to improved understanding of natural system. Modeling is developed with the specific intent of improving forecasts of future effects on water levels in the interior of the sub-regional model domain.

A stepwise approach was developed where the model evolves iteratively relative to the objective and level of detail as the understanding of the hydrogeological system increases by the modeling process. The approach described herein integrates two complementary modeling technologies.

4.2.1 The Analytic Element Method (AEM)

The Analytic Element Method (AEM), as implemented in the computer program GFLOW 2000 (Haitjema, 1995), was selected for the analysis of regional groundwater flow conditions in the Arrow Canyon Range Cell surrounding the California Wash Basin, and in assessing potential long-term impacts on existing water resources resulting from pumping at the Proposed Project site. The AEM does not utilize a model grid nor require checks on mass balance. The AEM is appropriate to analyze areas where the lateral extent of the flow field is large compared to its thickness and where hydrogeologic data are sparse. The ease with which various scenarios of pumpage, material-property distributions, or recharge, for example, can be examined and adjusted formed an incentive to apply this technology to the project.

In particular, the AEM proved useful in screening the numerous conceptual models of regional flow that might apply to the Arrow Canyon Range Cell and environs. In the absence of a model grid the AEM could be applied to a very large domain without loss of local detail. Regional variations of recharge and aquifer transmissivity were accounted for by inhomogeneity domains in the AEM GFLOW 2000 model. Fault zones, believed to offer obstruction to flow, could be represented as no-flow boundaries or boundaries with a specified resistance to flow. GFLOW 2000 facilitates the extraction of local MODFLOW models, whereby the conditions on the MODFLOW grid perimeter are obtained from the GFLOW regional solution to groundwater flow. This MODFLOW extract feature was used to create a local MODFLOW model of the project area and its surroundings to analyze possible regional transient effects of the proposed project on regional water levels and groundwater discharge in the Muddy River Springs Area. The approach to groundwater modeling by using that regional AEM model GFLOW to define boundary conditions for a sub-regional MODFLOW model have been documented in the peer reviewed literature, e.g., Hunt et al. (1998 a & b), Hunt and Krohelski (1996).

4.2.2 MODFLOW Sub-regional analyses of groundwater flow

MODFLOW Sub-regional analyses of groundwater flow, and in particular transient phenomena, were analyzed using the finite-difference code MODFLOW (MacDonald and Harbaugh, 1988), as implemented in the Groundwater Vistas (Environmental Simulations, Inc., 1999) modeling environment. MODFLOW grids were extracted from GFLOW 2000 (Figure 9) ,with material properties (hydraulic conductivity, storage and porosity), recharge, (three zones), boundary conditions (constant head, river, well, general head boundary (GHB), and no flow domains) and calibration targets (heads and spring discharges), Figures 10 through 14.

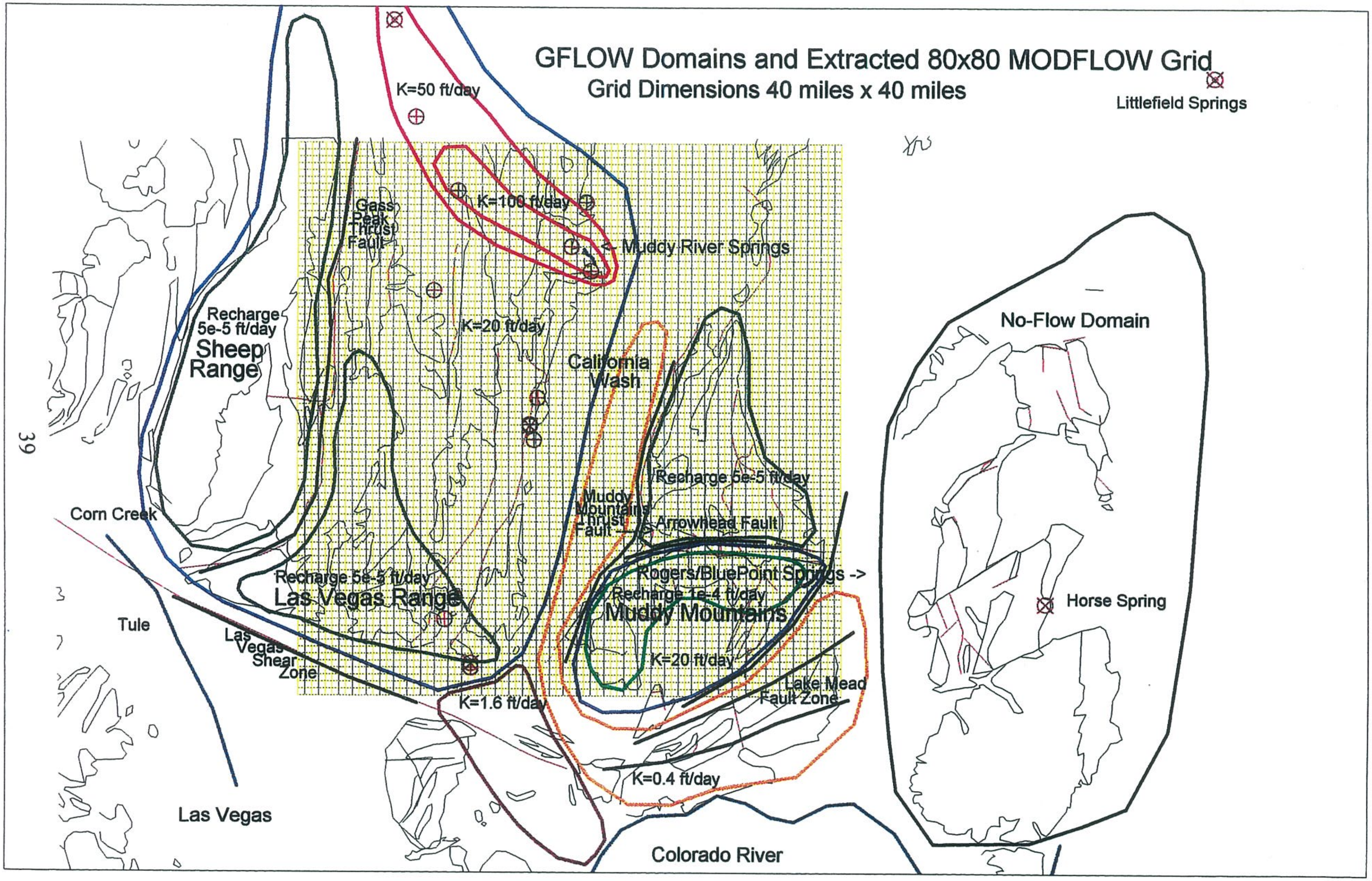
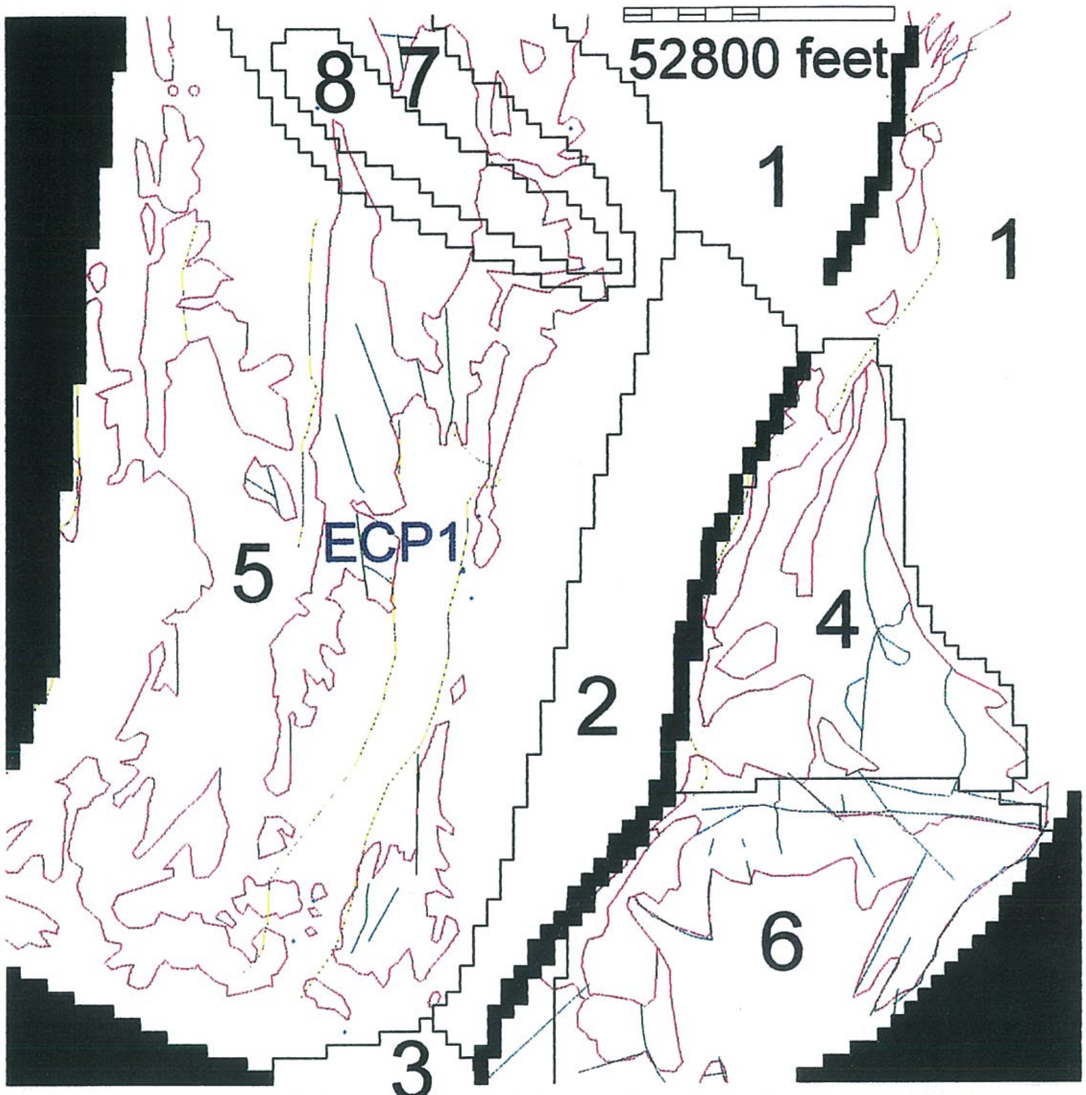


Figure 9. GFLOW domains (hydraulic conductivity and recharge) with superposed 80 x 80 MODFLOW grid. Refer to text for description of domains. North is at the top of the page.



MODFLOW Hydraulic Conductivity Zones

Zone 1	Kx=0.1 ft/day Ky=0.1 ft/day	Zone 5	Kx=5 ft/day Ky=30 ft/day
Zone 2	Kx=0.4 ft/day Ky=0.4 ft/day	Zone 6	Kx=20 ft/day Ky=20 ft/day
Zone 3	Kx=1.6 ft/day Ky=1.6 ft/day	Zone 7	Kx=50 ft/day Ky=50 ft/day
Zone 4	Kx=2 ft/day Ky=2 ft/day	Zone 8	Kx=100 ft/day Ky=100 ft/day

Single Layer ,Type 1, Thickness 5000 feet

Figure 10. MODFLOW vertical and horizontal conductivity. Black are no flow boundaries. North is at the top of the page.

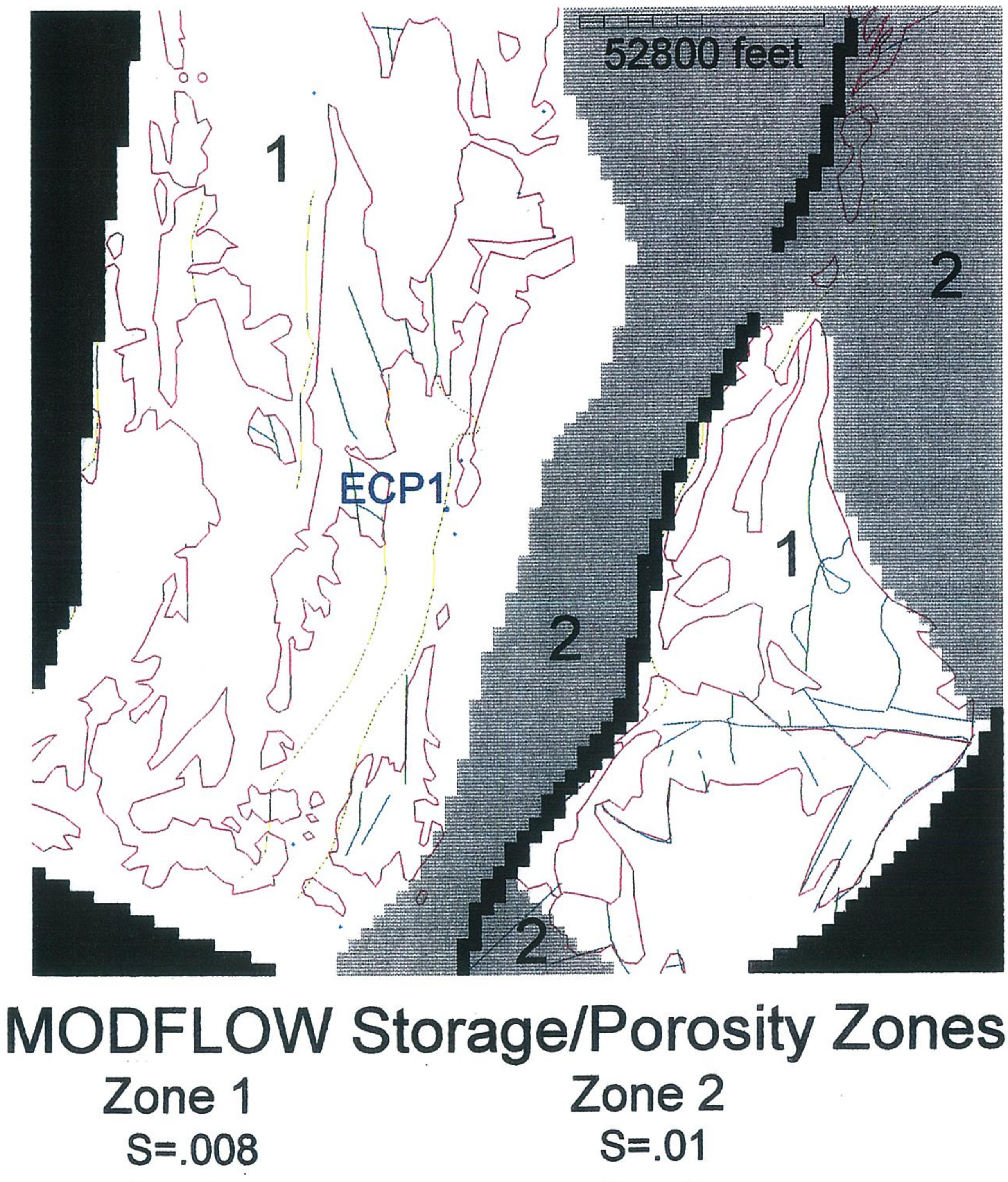


Figure 11. MODFLOW storage and porosity zones. Black are no flow boundaries. North is at the top of the page.

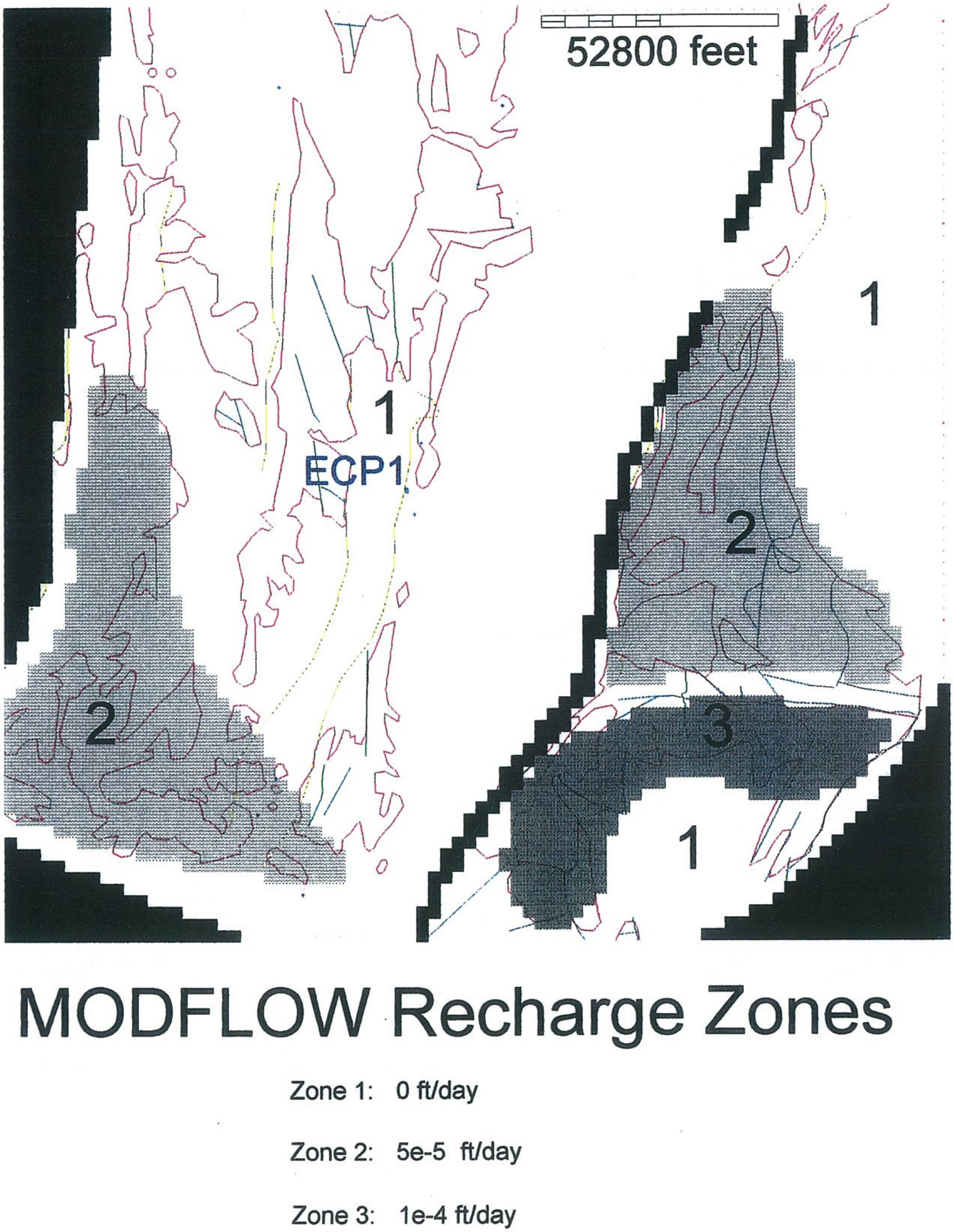


Figure 12. MODFLOW recharge zones. Black are no flow boundaries. North is at the top of the page.

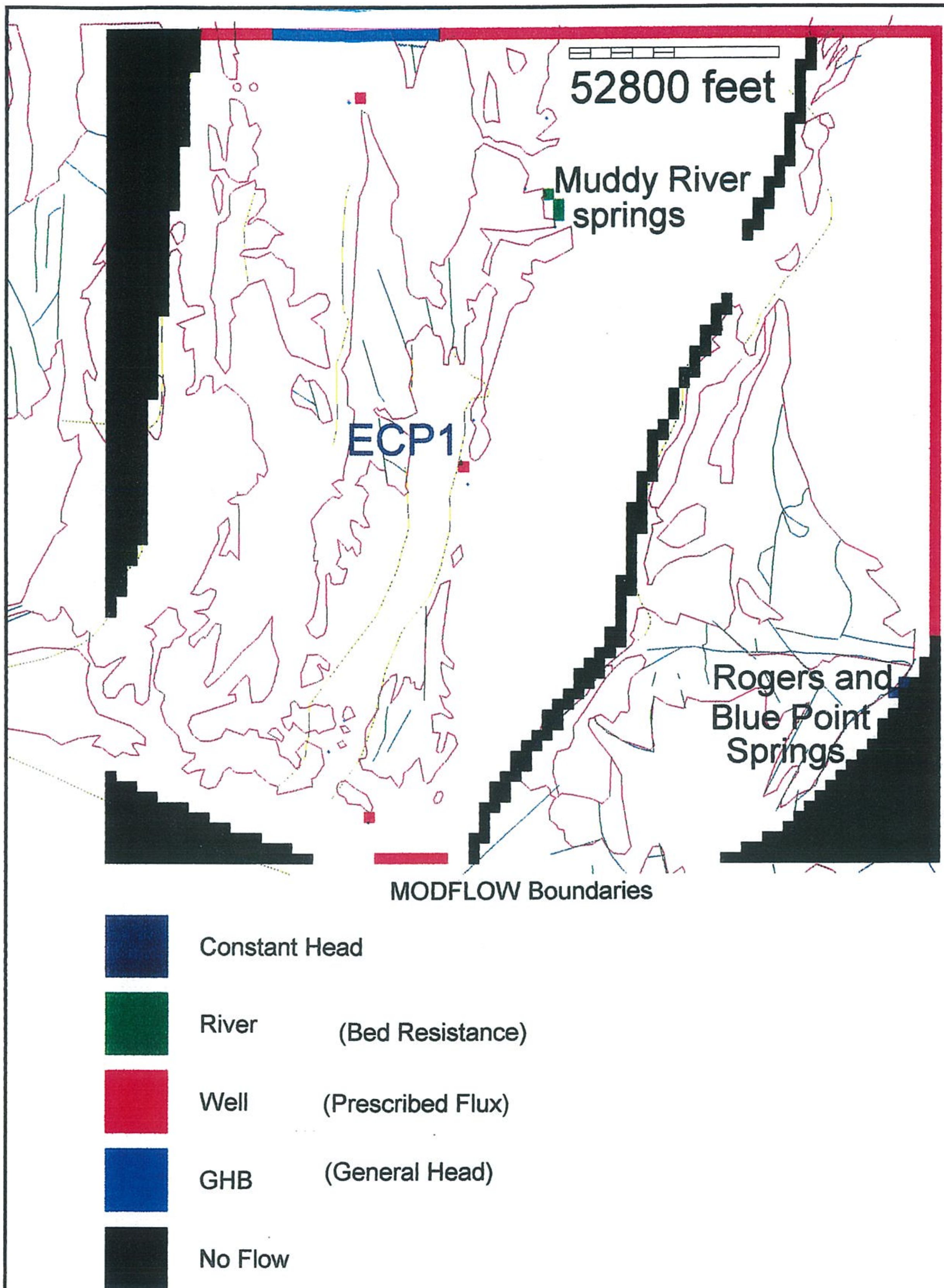
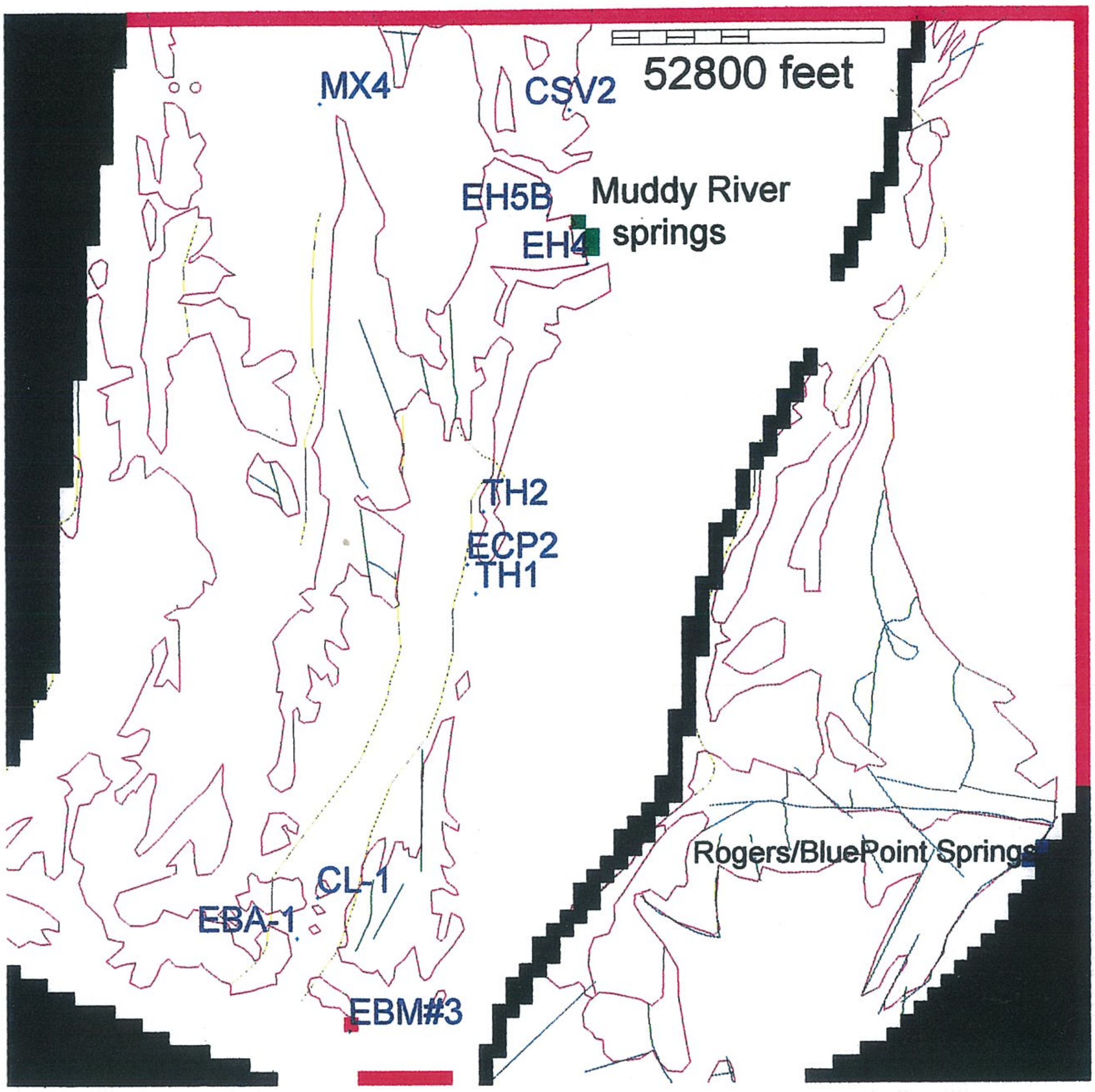


Figure 13. MODFLOW boundary types. North is at the top of the page.



MODFLOW Calibration Targets

Basis for calibration:

1. Observed head in surveyed wells, and
2. Measured discharge in spring outflow areas.

Figure 14. MODFLOW calibration targets as head and discharge. Refer to figure 13 for boundary types. North is at the top of the page.

The following denotes the utility of this modeling approach:

- The requirement to evaluate transient effects on Muddy River springs is satisfied

- Regional modeling using the AEM as implemented in GFLOW 2000 had constrained material-property distributions sufficiently to warrant mesh-building

- GFLOW 2000 supports automated generation and export of MODFLOW grids, facilitating a seamless transition to transient evaluations

- MODFLOW is one of the most and widely-understood finite-difference codes in existence

- MODFLOW has become extremely applicable through the Groundwater Vistas modeling environment

- In addition to material properties, MODFLOW boundary condition files can be exported by GFLOW

- Minor adjustments to material-property boundaries and recalibrations to include anisotropy provided a consistent set of alternate conceptual models based on differing boundary conditions

4.3 Assumptions and Constraints

Fundamental requirements for a successful modeling effort include knowledge of hydrogeologic boundary conditions and the distribution of material properties within the study area including:

- Far-field boundary conditions were established using elevations of perennial streams and water levels in springs and wells associated with the Carbonate Aquifer of southern Nevada.

- Major streams and regional carbonate-aquifer springs were utilized as far-field, specified-head boundary conditions. Known total discharge to the Muddy River Springs Area on the order of 50 cfs and from the Rogers - Blue Point Spring area on the order of 5 cfs were used as calibration targets, as were heads in wells surveyed specifically for this project.

- Near field conditions were established by the analysis of a 7-day aquifer test at well ECP-1 that yielded transmissivity estimates of 5×10^4 to 1×10^5 ft^2/day and evidence of unconfined conditions (Appendix A).

- Anisotropy of the aquifer in a north-south direction was observed by the results of the pumping response at ECP-1 and was incorporated into the sub-regional model during the calibration process.

- An aquifer thickness of 5,000 feet was estimated from groundwater temperatures in the Muddy River Springs Area inferring that depths of circulation of several thousand feet would be required for the geothermal gradient to warm groundwater to observed temperatures.

- An analysis of the relationship between barometric efficiency and storativity (Walton, 1996, p.18) was used to obtain an independent estimate of aquifer thickness (4,739 feet), which is in general agreement with the 5,000-foot estimate from thermal data (Appendix A, p. 20).

- A porosity value of 0.047 (4.7%) was used, based on the average porosity of carbonate rocks in the Coyote Spring Valley obtained from geophysical logs and reported by the USGS (Berger,1992).

- Given the maximum transmissivity indicated by pumping experiments, 10^5 ft^2/day, and an estimated thickness of 5,000 feet, the nominal hydraulic conductivity, K is computed as 20 ft/day.

- The near-field value of K was adjusted upward in the high-permeability corridor extending northwest from Muddy River Springs Area

- The near-field value of K was adjusted downward outside the carbonate-dominated sub region that underlies the study area.

- Fine-grained Tertiary sediments of the Muddy Creek and Horse Spring Formations occupy a band several miles wide within the high-permeability "Arrow Canyon Range Cell" (Mifflin, 1992). This band is designated as a sub-regional domain or low-permeability domain that extends to infinity in the AEM. These Tertiary sediments have yielded transmissivity estimates of 251 ft^2/day (Pohlmann and others, 1988) and 605 ft^2/day (Johnson and others, 1986). A hydraulic conductivity value of 0.4 ft/day was arrived at by trial-and-error during model calibration, and appears to be generally consistent with the limited aquifer-test data.

- A conservative assumption is incorporated into all modeling scenarios. The Carbonate Aquifer transmissivity and anisotropic characteristics in the Belly Tank Flat area is modeled as extending northward unmodified into the flow field that supplies water to the Muddy River Springs. This hydraulic connection, however, might not be present because there is neither evidence for discharge of the waters typical of the southern flow field in the Muddy River Springs Area nor evidence of northern flow field waters to the south. The assumption of hydraulic continuity as adopted allows the Belly Tank Flat pumping cone to efficiently extend north and south, and therefore impact the flow field in the north that supplies the Muddy River Springs. A physical (stratigraphic or structural) barrier would limit the northward migration of the Belly Tank Flat Well Field pumping cone into the Muddy River Springs flow field, and cause actual pumping impacts on spring area discharge to be less than projected.

4.4 Conceptual Model and Modeling Design

The most fundamental and significant element of the conceptual model is that groundwater flow in the region of interest can be adequately represented by Dupuit-Forchheimer flow in a single, unconfined layer. These conditions are met because the lateral extent of the aquifer system is large compared to its thickness as the distances between features are over ten times the aquifer thickness. Summarizing:

- There is no geologic evidence that a multi-layer model is warranted because within the zone of saturation, Tertiary sediments and Mesozoic red beds are known to generally bound, rather than stratigraphically cap upper Paleozoic carbonate rocks of the Arrow Canyon Range Cell. There are relatively small localized areas of exception.

- No credit is taken for large-scale leakage resistance between layers, which would artificially isolate shallow and deep systems in the model

- A direct hydraulic connection with the Muddy River Springs Area is embodied in the model, although a growing body of geochemical and isotopic evidence suggests that the springs are fed by a completely different flow system than that supplying Belly Tank Flat

- The lateral extent of the model domain is great as compared to its vertical thickness, and head changes with depth have not been observed while drilling in carbonate rocks in the Project area; these suggest that a 2-D Dupuit-Forchheimer model is applicable

- There are no conceptual difficulties with deep underflow occurring beneath a discharge area, as pointed out by Haitjema (1995) in his discussions of 3-D flow in a Dupuit-Forchheimer model.

A single-layer model was also judged to be more appropriate for the locally relevant California Wash area than the two- and three-layer models used in previous studies. The choice of a single-layer conceptual model is clearly supported in the Glendale area, where Johnson and others (1986) report at least 4,000 feet of fine-grained sediments at the eastern margin of the Arrow Canyon Range Cell and no evidence of substantial eastward underflow. In the Belly Tank Flat area, there is no known basis for subdividing the saturated zone into more than one layer. In addition, a section of Tertiary sediments was observed in exploratory boreholes a few miles to the east in the vicinity of Moapa Tribal Enterprises that is similar to that observed at Glendale supporting the assumption of the application of a one-layer model, (Figure 2).

In addition to the Paleozoic carbonates, which are the most transmissive rocks of the region, there are thick sections of Mesozoic and Cenozoic sedimentary and volcaniclastic rocks that were judged to be generally an order of magnitude and locally two orders of magnitude lower in permeability then the carbonates. Salt deposits in the Muddy Creek Formation east of Overton Arm would be expected to be highly non-transmissive, (Figure 3). Steep potentiometric gradients across the Las Vegas Shear Zone from the Apex area to Las Vegas Valley imply the existence of a structural flow barrier south Arrow Canyon Range Cell (Figure 5). As a result, the Lake Mead Fault Zone was inferred to be a hydraulic barrier based on the model calibration process. There appears to be subsurface leakage of on the order of 10,000 afy across this barrier southward out of the California Wash Hydrographic Basin into an area characterized by complex faulting, gypsiferous rocks and no known potable groundwater resources. Stable isotopic data and regional fluid-potential gradients suggest that the Gass Peak Thrust (the western MODFLOW boundary) is not a water-tight barrier to eastward flow from the Sheep Range to the Project area. In order to maintain conservatism it has been modeled as a no-flow boundary to maintain consistency with the historical treatment of the "Lower Clastic Aquitard" that outcrops along this important structure. The Sheep and Las Vegas Ranges may in fact be significant sources of subsurface inflow, as assumed by Wildermuth and others (1990) and suggested by the isotopic data contained in Appendix B; Figure B-3.

The nature of the interface zone (a six mile gap with no data) between the two flow fields with characteristic waters is important with respect to how pumping cones may spread from pumping centers within the two regions of the Arrow Canyon Range Cell, (Figure 5). Normally, it could be assumed that the two flow fields, with distinct water populations, would not be in close hydraulic continuity. However, because no major differences in water-level elevations or hydrogeologic features that would limit transmissivity between the two flow fields are detected, a conservative assumption is applied to the modeling scenarios that describes well-developed hydraulic continuity between the two. This assumption allows efficient propagation of pumping impacts from one flow field to the other, and it is an important assumption in terms of when, and how strong, the Belly Tank Flat pumping impacts are manifested at the Muddy River Spring Area, as an example.

The correct conceptualization of the configurations and characteristics of regional carbonate-rock flow systems may prove useful in predicting the water-resource potential of the Carbonate Aquifer throughout much of the Carbonate Rock Province of the Great Basin. The potential for exceptionally large volumes of storage in close hydraulic continuity with a deep regional system as compared to more intermediate-scale flow systems, such as the one supplying Muddy River Springs Area, exists. If the southern flow field of the Arrow Canyon Range Cell proves not to be in close hydraulic continuity with adjacent flow systems, the water-resource potential of the southern Arrow Canyon Range Cell is enhanced. Current databases and the developing conceptual model of two independent flow fields argue for a large southern region of the Arrow Canyon Range Cell to be isolated (in terms of propagating pumping impacts) from adjacent groundwater basins.

Modeling using the Dupuit-Forchheimer assumption of horizontal flow is consistent with recognition of a probable upwelling zone within the model domain. The conceptual model developed from isotopic and geochemical data indicates separate sources of water in the northern and southern flow fields, some of which is deeply circulated. Mathematically and conceptually, distributed recharge and upwelling are equivalent. As an example, the recharge specified for the Las Vegas Range could be considered upwelling recharge, or a combination of both. Calibration of the GFLOW model could probably be improved by increasing distributed flux and disassociating it from local topography, but such changes would be conjectural until controls on upwelling are better understood. Similarly, the induced inflows allowed by the prescribed-head boundaries in Cases 1 and 2 are analogous to the effects of an upwelling zone. In effect, new water from beyond the model domain is made available as the system is stressed by pumping, lessening the net impact. It is cause-and-effect relationships such as these, and not the geometric details of the vertical dimension, that the modeling analyses have explained.

4.5 The Base Case, Regional, Steady-State GFLOW Model

The base case model shown on Figure 15 was constructed by successive refinements of hydraulic conductivities in the model sub-regions while maintaining prescribed heads at Muddy River Springs and Rogers/Blue Point Springs:

- Thickness of the aquifer was assumed to be 5,000 feet throughout the model domain
- Hydraulic conductivities in the Belly Tank Flat region were estimated through a process of_manual calibration of the regional steady-state flow model; several hundred GFLOW runs were required to obtain a satisfactory match to observed conditions.
- Hydraulic conductivities were adjusted using targets of observed water levels and maintaining the outflow in the Muddy River Springs Area near 51 cfs, and Rogers/Blue Point Springs near 5 cfs (double actual measured discharge).
- A barrier to eastward flow was prescribed in the vicinity of the Muddy Mountains Thrust in order for discharge to occur in the Muddy River Springs Area
- A high-permeability corridor extending northwestward from the Muddy River Springs Area was prescribed for sufficient groundwater discharge to occur

Scenarios that correctly predicted outflows at the two major spring areas (Muddy River Springs Area and Rogers/Blue Point Springs) and a good approximation of regional water levels were computed within a small variance in residuals. Table 1 shows wells that were used as calibration targets, (Figure 2).

Table 1. Target Wells and Heads used in Model Calibration

Target ID	Grid Coordinate	Grid Coordinate	Target Heads, ft	Improved Estimates
	X	Y	September 2000	December 2000
EH5b	106,148	171,630	1,817	1,817.03
CSV2	110,414	192,028	1,796.8	1,796.84
EH4	113,891	162,172	1,816.7	1,816.71
EBA-1	56,752	28,878	1,818.7	1,819.99
CL-1	60,803	36,935	1,815	1,815.38
MX4	61,640	193,464	1,821.6	1,821.57
EBM#3	66,886	10,594	1,811	1,812.83
ECP2	90,259	103,123	1,812.9	1,815.56
TH1	91,935	97,296	1,813.3	1,815.12
TH2	93,412	113,540	1,814	1,814.45

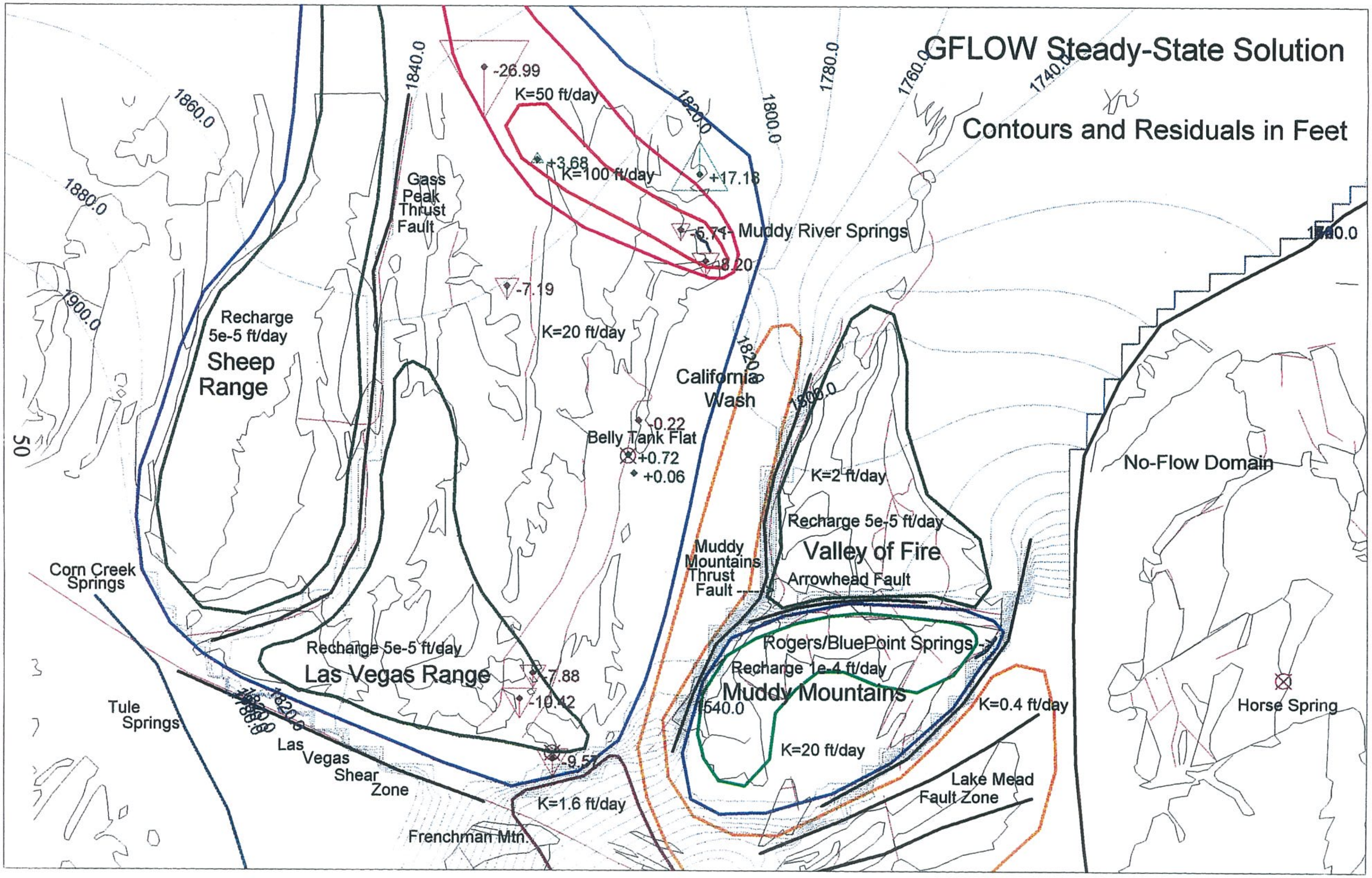


Figure 15. GFLOW steady-state solution showing fluid potential contours in feet above mean sea level (amsl) and residuals in feet at calibration points. North is at the top of the page.

Generated flow paths were evaluated qualitatively for their consistency with isotopic data. The model domain was subdivided into central and outer regions each with smaller zones where material-property or recharge adjustments could be applied. The quantitative features of the base case regional model are shown on Figure 15 and are summarized with detail below:

1. **Arrow Canyon Range Cell and Muddy Mountains Block of the Carbonate Aquifer**. A large region of K=20 ft/day, shown in blue outline in the left-central portion of Figure 15, encloses the Project area. This central region includes the Sheep Range and Gass Peak thrust, and is bounded on the south by the Las Vegas Valley shear zone. The eastern boundary of the central region generally follows the North Muddy Mountains, but is offset to the west from the north Muddy Mountains to accommodate a strip of Tertiary volcaniclastic rocks inferred to be several miles wide that was encountered while drilling borehole EH-2a near Reid Gardner station (Johnson and others, 1986). The Muddy Mountains block was also assigned K=20 ft/day since it is underlain by carbonates lithologically and stratigraphically similar to those of the Arrow Canyon Range Cell.

2. **Tertiary Sediments of the Muddy Creek and Horse Spring Formations**. The thick section of Tertiary sediments reported by Johnson and others (1986) is thought to underlie California Wash in a structural block that parallels the North Muddy Mountains, effectively cutting off eastward flow from the Arrow Canyon Range Cell. Portions of the Las Vegas Shear Zone and Lake Mead Fault Zone have been included in this crescent-shaped zone of K=0.4 ft/day, shown in orange outline east and south of the Muddy Mountains on Figure 15.

3. **North Muddy Mountains and Valley of Fire**. The Valley of Fire block, shown as a pear-shaped outline of dark green in Figure 15, was assigned K=2 ft/day. The boundary between the Muddy Mountains and Valley of Fire follows the Arrowhead Fault.

4. **Gypsiferous Sediments of the Southern Outflow Zone**. A key element of the conceptual model presented herein is that regional flux exits the Arrow Canyon Range Cell through a southern outflow zone, represented by purple outline near bottom center of Figure 15. Calibration of the model scenarios required that such a zone exist to allow water to drain from the southern margin of the Arrow Canyon Range Cell so that water levels in the Apex area could be approximated. The hydraulic conductivity estimate of 1.6 ft/day was an outcome of the calibration process.

5. **Outer Region**. The outer region, extending from the border of the Central Region to infinity, is assigned k=0.1 ft/day (Shown as the white background).

6. **Nested Muddy River Springs-Coyote Spring Valley High-K Zones**. A high-permeability zone in the vicinity of the MX4 well, shown in nested red outlines in the top cent portion of Figure 15, is indicated by cavernous conditions and aquifer-test results suggesting transmissivities of several million gallons per day per foot. This zone was assigned a hydraulic conductivity k=50 ft/day by trial and error to achieve the desired quantity of outflow at Muddy River Springs. A core zone within the High-K zone was assigned K=100 ft/day. This zone defines a high-transmissivity area surrounding the Muddy River Springs

where a relatively flat potentiometric gradient is observed in boreholes. The substantial head differences between the springs are attributed to head losses in the discharge conduits.

7. **Las Vegas Shear Zone-Lake Mead Fault Zone.** The Las Vegas Shear zone joins the Lake Mead Fault Zone in the vicinity of the Hamblin - Cleopatra Volcano, southeast of the Muddy Mountains. Discrete zero-permeability horizontal flow barriers have been associated with individual strands of these major faults (Shown as black lines on Figure 15).

8. **Muddy Mountains and Gass Peak Thrust Faults.** Heads that are uniformly greater than 1800 feet AMSL west of the North Muddy Mountains and up to 200 feet lower (1,600 feet AMSL) in the Valley of Fire - Rogers Spring area suggest a step-down from west to east, most likely due to the presence of a barrier to eastward flow of groundwater. A discrete, zero-permeability horizontal flow barrier was associated with the Muddy Mountains Thrust from east of Apex to east of Glendale. Similarly, the Gass Peak Thrust was treated as a no-flow boundary, using a discrete zero-permeability horizontal-flow barrier (both are shown as black lines on Figure 15).

9. **Sheep Range Recharge.** The Sheep range was included in the model based on USGS interpretations of its significance as a source area for Muddy River Spring discharge. Sheep Range Central-Region has been assigned a recharge rate of 5×10^{-5} ft/day, equivalent to 0.02 ft/yr. This recharge area is shown in dark green outline in the left-central portion of Figure 15.

10. **Las Vegas Range Recharge**. The Las Vegas Range was assigned a recharge rate of 5×10^{-5} ft/day, as shown in dark green outline in the lower left portion of Figure 15.
11. **Northern Muddy Mountains Recharge**. The Northern Muddy Mountains were assigned a recharge rate of 5×10^{-5} ft/day. The recharge area is the same pear-shaped, dark green outline that was assigned K=2 ft/day.
12. **Muddy Mountains Recharge.** The Muddy Mountains were assigned a recharge rate of 10^{-4} ft/day (0.03 ft/yr) to support model spring flow from Rogers and Blue Point Springs that are roughly double observed values. The rationale for this approach was that unrecognized eastward underflow beneath the spring area warranted consideration in the model. As understanding of the region evolved and it became clear that Rogers and Blue Point Springs and essentially isolated from the Arrow Canyon Range Cell, this recharge rate remained as a historical artifact of the calibration process.
13. **Regional Recharge.** A large rectangular area surrounding the Central Region was made available for assignment of regional recharge. The base case value was zero.

The regional, steady-state (GFLOW 2000) model illustrates the isolation of Rogers and Blue Point Springs from the southern flow field of the Arrow Canyon Range Cell. Regional water levels and appropriate spring flows could not be reproduced without an extensive and effective barrier to eastward groundwater flow in the vicinity of the Muddy Mountains and Glendale Thrust faults (Figure 3). Similarly, the presence of a highly transmissive corridor extending northwestward from the Muddy River Springs Area was revealed, consistent with observations at wells MX-4 and MX-5, which are in this corridor. Finally, the GFLOW model provided a basis for selecting a subdomain for detailed analysis of alternative scenarios, and for specification of boundary conditions surrounding this smaller area.

The steady-state model also provides an estimate of flux leaving the southern flow field. Summing the individual outflows in row 80, columns 24 through 35 of the exported MODFLOW grid (Table 2) gives 9,543 afy. Outflow on the order of 10,000 afy is consistent with estimates based on isotopic mass balance, and with MODFLOW Case 2 (described below).

4.6 Transient Sub-Models: Extraction and Application of MODFLOW Grids
A finite-difference grid geometry was defined and GFLOW results extracted to define boundary conditions for sub-regional, transient simulations. Initially, two identical grids were exported as sets of MODFLOW input files, each consisting of 6,400 square grid blocks, each individual block 1/2 x 1/2 mile in dimension. The first grid, designated FlowGrid, was extracted with flux boundary conditions defined, and the second, designated HeadGrid, contained heads derived from the GFLOW solution. The results are contained in Table 2.

The three alternative conceptual models consist of MODFLOW grids extracted from GFLOW and different sets of boundary conditions. Minor re-calibrations were required as boundary conditions were re-defined, but material properties and geometry are the same for all three scenarios. The manner in which the boundaries between adjacent material property zones are represented is quite different in GFLOW and MODFLOW, and "clean up" of the exported grids is thought to have been the reason the new (MODFLOW) models required individual recalibration. Consider two subzones within a larger background zone, and the modeler wishes to represent the subzones as sharing a common boundary. In GFLOW, a "screen" of the background materials will remain between the two subzones as they are brought closely adjacent. If the "screen" properties are very different from either of the subzones, flow between the subzones will be misrepresented. There are obviously workarounds to avoid these geometries, but workarounds are not always feasible or necessary. In the present study a barrier to flow (the Muddy Mountains – Glendale Thrust) was associated with one harder "screen" between subzones, so recalibration requirements were minor. Solutions were sensitive, however cleanup of the model grid in the southern outflow area (southeast of Apex), and recalibrations resulted in a range of outflows that varied by a factor of 3 (Table 3).

The MODFLOW boundary conditions used in the transient state scenarios are 1) the constant head boundary scenario, which supplies an unlimited supply of water when pumping cones reach the boundary; 2) the prescribed flux boundary scenario, which prescribes the supply of water to the model domain; the supply is finite, and no induced recharge along the boundaries occurs when water levels are lowered, and 3) a hybrid boundary response scenario, where some boundaries are prescribed flux and some are prescribed heads. In any given terrain situation, some areas of a model boundary are more realistic with a constant head boundary and some are more realistic with a prescribed flux boundary.
The three bounding condition scenarios are:

Case 1, is a *hybrid* of a combination of *constant head and prescribed flux boundaries*, distributed on the basis of regional relationships and considered the *most probable boundary condition scenario.*

Table 2: Heads and Fluxes Extracted from GFLOW

Values in BLUE were utilized in runs HeadGrid and TransHG
Values in RED were utilized in runs FlowGrid and TransFG
Values in PURPLE were utilized in runs HybridBC and TranHYB
Values in BLACK were included with no-flow boundary cells, which include all cells not given explicitly below.

NOTES related to calibration of hybrid case:

1. Hybrid heads are uniformly 5 feet lower than extracted values.
2. Hybrid fluxes in cells R80C27-R80C33 are double the average of extracted values in those cells.

NOTES on boundary conditions at SPRINGS:

1. Muddy River Springs were represented by 3 river cells with H = 1758 ft, conductance = 22,400.
2. Rogers and Blue Point Springs were treated as prescribed-head "wells", H = 1590 ft, with no resistance.

Row	Col	Head (ft)	Q (ft3/day)	Hybrid H	Hybrid Q
1	9	1842.41	347100.0		
1	10	1841.64	224300.0	1836.64	
1	11	1840.86	165500.0	1835.86	
1	12	1840.15	135600.0	1835.15	
1	13	1839.49	117800.0	1834.49	
1	14	1838.86	106200.0	1833.86	
1	15	1838.25	98270.0	1833.25	
1	16	1837.64	92980.0	1832.64	
1	17	1837.03	231300.0	1832.03	
1	18	1836.45	227500.0	1831.45	
1	19	1835.85	226600.0	1830.85	
1	20	1835.20	231400.0	1830.20	
1	21	1834.50	247700.0	1829.50	
1	22	1833.79	297000.0	1828.79	
1	23	1833.28	268100.0	1828.28	
1	24	1832.83	257500.0	1827.83	
1	25	1832.46	250100.0	1827.46	
1	26	1832.16	186400.0	1827.16	
1	27	1831.75	177100.0	1826.75	
1	28	1831.28	170800.0	1826.28	
1	29	1830.78	166100.0	1825.78	
1	30	1830.25	162300.0	1825.25	
1	31	1829.69	158900.0	1824.69	
1	32	1829.12	156100.0	1824.12	
1	33	1828.47	55970.0	1823.47	
1	34	1827.80	54650.0	1822.80	
1	35	1827.11	53370.0	1822.11	
1	36	1826.42	51940.0	1821.42	
1	37	1825.72	50280.0	1820.72	
1	38	1825.03	48390.0	1820.03	
1	39	1824.34	46300.0	1819.34	
1	40	1823.67	44020.0	1818.67	
1	41	1823.02	41460.0	1818.02	
1	42	1821.62	-14.5	1816.62	
1	43	1821.86	-1213.0	1816.86	
1	44	1820.46	-1142.0	1815.46	
1	45	1818.02	-814.9	1813.02	
1	46	1815.31	-537.3	1810.31	
1	47	1812.60	-360.7	1807.60	
1	48	1809.95	-273.1	1804.95	

Table 2 continued: Heads and Fluxes Extracted from GFLOW

1	49	1807.46	-239.9	1802.46	
1	50	1805.03	-225.6	1800.03	
1	51	1802.56	-205.3	1797.56	
1	52	1800.02	-169.7	1795.02	
1	53	1797.47	-118.8	1792.47	
1	54	1794.86	-58.9	1789.86	
1	55	1792.23	5.2	1787.23	
1	56	1789.62	69.2	1784.62	
1	57	1787.02	130.2	1782.02	
1	58	1784.47	186.6	1779.47	
1	59	1781.94	238.6	1776.94	
1	60	1779.50	285.2	1774.50	
1	61	1777.10	327.0	1772.10	
1	62	1774.79	363.9	1769.79	
1	63	1772.59	396.4	1767.59	
1	64	1770.42	425.1	1765.42	
1	65	1768.35	449.6	1763.35	
1	66	1766.36	471.1	1761.36	
1	67	1764.44	488.7	1759.44	
1	68	1762.63	503.6	1757.63	
1	69	1760.84	515.6	1755.84	
1	70	1759.16	524.8	1754.16	
1	71	1757.55	532.0	1752.55	
1	72	1756.02	536.8	1751.02	
1	73	1754.57	539.9	1749.57	
1	74	1753.18	541.0	1748.18	
1	75	1751.87	540.6	1746.87	
1	76	1750.65	538.9	1745.65	
1	77	1749.44	536.1	1744.44	
1	78	1748.32	531.7	1743.32	
1	79	1747.25	526.6	1742.25	
1	80	1746.29	43.3	1741.29	
56	1	1825.86	32280.0		
57	1	1826.33	43470.0		
58	1	1826.77	53660.0		
59	1	1827.13	59210.0		
60	1	1827.43	63220.0		
61	1	1827.66	66420.0		
62	1	1827.84	68880.0		
63	1	1827.96	70710.0		
64	1	1828.03	71960.0		
65	1	1828.04	72660.0		
66	1	1828.01	72820.0		
67	1	1827.93	72430.0		
68	1	1827.80	71490.0		
69	1	1827.63	70010.0		
70	1	1827.43	68090.0		
71	1	1827.20	66080.0		
72	1	1826.96	64760.0		
73	1	1824.93	2018.0		
74	1	1825.61	1571.0		
80	24	1664.59	-86320.0		
80	25	1659.77	-90050.0		
80	26	1654.60	-93970.0		
80	27	1648.86	-95540.0		-189550.0
80	28	1642.59	-94910.0		-189550.0
80	29	1636.03	-92750.0		-189550.0
80	30	1629.59	-92210.0		-189550.0
80	31	1623.46	-93880.0		-189550.0
80	32	1617.57	-95940.0		-189550.0

Table 2 continued: Heads and Fluxes Extracted from GFLOW

80	33	1611.89	-98190.0		-189550.0
80	34	1606.46	-100900.0		
80	35	1601.33	-104300.0		
80	36	1597.06	-7257.0		
80	37	1591.83	-30890.0		
80	38	1586.82	-30760.0		
80	39	1580.56	-29730.0		
80	40	1573.40	-27110.0		
80	41	1565.06	-4144.0		
80	42	1567.72	-27360.0		
80	43	1567.68	-23820.0		
80	44	1567.64	-21720.0		
80	45	1567.62	-19730.0		
80	46	1567.62	-17410.0		
80	47	1567.65	-15620.0		
80	48	1567.71	-14470.0		
80	49	1567.82	-16600.0		
80	50	1567.93	-16390.0		
80	51	1568.04	-15640.0		
80	52	1568.15	-14630.0		
80	53	1568.26	-13510.0		
80	54	1568.37	-12490.0		
80	55	1568.49	-11780.0		
80	56	1568.60	-11520.0		
80	57	1568.71	-11620.0		
80	58	1568.83	-11820.0		
80	59	1568.97	-11190.0		
80	60	1567.99	-259.0		
2	80	1745.17	-470.6	1740.17	
3	80	1744.03	-462.5	1739.03	
4	80	1742.80	-453.0	1737.80	
5	80	1741.54	-442.1	1736.54	
6	80	1740.27	-429.6	1735.27	
7	80	1738.83	-415.8	1733.83	
8	80	1737.37	-400.2	1732.37	
9	80	1735.83	-383.4	1730.83	
10	80	1734.27	-364.1	1729.27	
11	80	1732.61	-343.6	1727.61	
12	80	1730.89	-321.4	1725.89	
13	80	1729.09	-297.4	1724.09	
14	80	1727.27	-272.0	1722.27	
15	80	1725.29	-245.4	1720.29	
16	80	1723.34	-217.8	1718.34	
17	80	1721.30	-189.1	1716.30	
18	80	1719.23	-159.6	1714.23	
19	80	1717.03	-130.9	1712.03	
20	80	1714.84	-102.3	1709.84	
21	80	1712.59	-75.1	1707.59	
22	80	1710.25	-49.8	1705.25	
23	80	1707.90	-27.0	1702.90	
24	80	1705.52	-7.2	1700.52	
25	80	1703.07	8.6	1698.07	
26	80	1700.58	20.5	1695.58	
27	80	1698.03	27.0	1693.03	
28	80	1695.44	28.7	1690.44	
29	80	1692.82	25.0	1687.82	
30	80	1690.08	15.1	1685.08	
31	80	1687.32	-1.0	1682.32	
32	80	1684.46	-23.6	1679.46	
33	80	1681.52	-53.2	1676.52	

Table 2 continued: Heads and Fluxes Extracted from GFLOW

34	80	1678.47	-90.9	1673.47
35	80	1675.31	-137.1	1670.31
36	80	1671.98	-193.9	1666.98
37	80	1668.56	-262.4	1663.56
38	80	1664.97	-344.5	1659.97
39	80	1661.23	-443.6	1656.23
40	80	1657.32	-562.0	1652.32
41	80	1653.21	-703.8	1648.21
42	80	1648.88	-874.2	1643.88
43	80	1644.38	-1079.0	1639.38
44	80	1639.67	-1329.0	1634.67
45	80	1634.78	-1636.0	1629.78
46	80	1629.75	-2022.0	1624.75
47	80	1624.56	-2517.0	1619.56
48	80	1619.37	-3169.0	1614.37
49	80	1614.47	-4044.0	1609.47
50	80	1610.52	-5144.0	1605.52
51	80	1609.24	-5768.0	1604.24
52	80	1612.33	-4481.0	1607.33
53	80	1617.72	-2379.0	1612.72
54	80	1622.46	-529.4	1617.46
55	80	1624.84	927.9	1619.84
56	80	1623.65	2068.0	1618.65
57	80	1618.10	3007.0	
58	80	1409.95	2902.0	

Case 2, is a *constant head* boundary scenario, considered to be a *less probable bounding scenario* that is optimistic in terms of the induced recharge on responses to water-level declines.

Case 3, is a *prescribed flux* boundary scenario, a *bounding scenario* that is *least probable*, as only the fluxes of steady state enter and leave the modeling domain, this boundary condition maximizes water-level declines as it does not allow for any induced recharge at the modeling domain boundaries.

The transient modeling included the re-calibration of steady-state conditions using the grids representing each of the three alternative conceptual models. These runs provide initial heads required to begin the transient simulations; it is the differences between the transient solutions and these starting heads that define drawdowns in the models. Current conditions represented by the steady-state solutions are shown on Table 3.

Table 3. Current Conditions Represented by Steady State Solutions

Boundary Type	Run ID	Q_{south} (afy)	Q_{mrs} (cfs)	Head-save File
n/a	GFLOW	9,543	47.8	n/a
Case 1, Hybrid Figure 16	Hybrid BC2	6,450	54	HybridBC.hds
Case 2, Head BC Figure 17	HeadBC2	9,170	54	HeadGrid.hds
Case 3, Flux BC Figure 18	FlowBC2	3,050	50	FlowGrid.hds

4.6.1 Case 1: The Hybrid Boundary Condition, the Most Probable Response Scenario
The Case 1 hybrid boundary condition, the most probable response scenario prescribes that head remains constant with time north and east of the Muddy River, but flow across the domain boundary remains constant south and west of the Project area. The results of Hybrid25yr Figure 19, illustrates that this case is a compromise between the credible but unrealistic Case 3 and the perhaps optimistic Case 2. The prescribed-head boundary condition on the north and east edges of the model domain and the prescribed-flow condition on the south and west were applied to the domain. To achieve calibration it was necessary to lower heads 5 feet from their Case 2 values, restrict the Case 3 inflow from the southern Las Vegas Range and outflow along the Lake Mead Fault Zone to zero flux, and double outflow from a strip of 7 grid blocks along the southern model boundary. As a result, groundwater discharge to the Muddy River Springs Area decreases by only 0.7% after 25 years. The results of Hybrid45 Figure 20, predicts that in 45 years groundwater discharge in the Muddy River springs Area will decrease by 1.3%.

The cone of depression for Case 1 is asymmetric in a north-south direction; the prescribed-head boundary is protecting the Muddy River Springs Area. Although outflow is held to a constant value to the south, in reality this Belly Tank Flat pumping would cause a reduction in these natural outflows and capture water that would otherwise be lost to the postulated outflow zone in the southeast corner of the Arrow Canyon Range Cell.

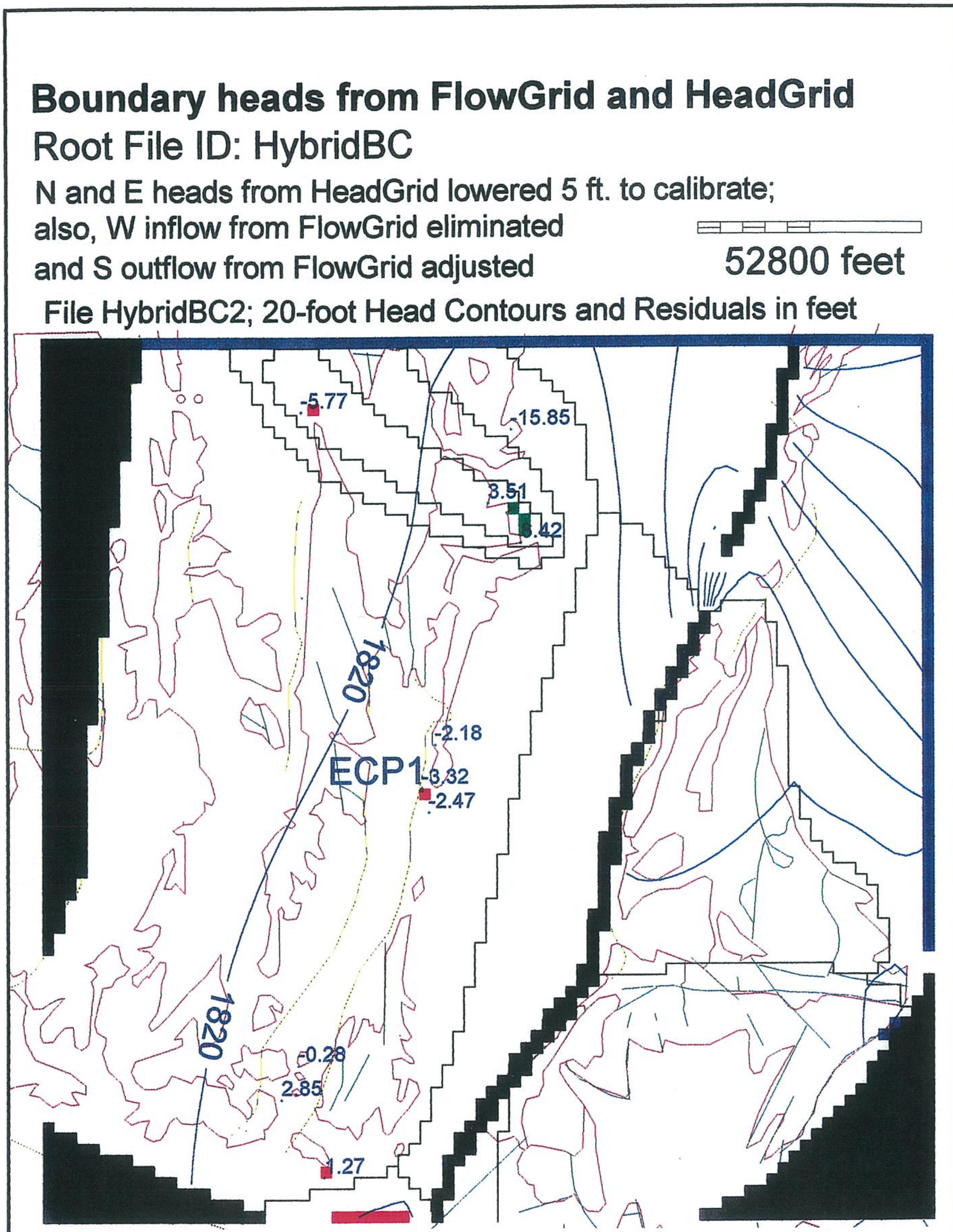


Figure 16. Case 1, the hybrid boundary condition, the most probable scenario, steady state solution. Refer to figure 13 for boundary types. North is at the top of the page.

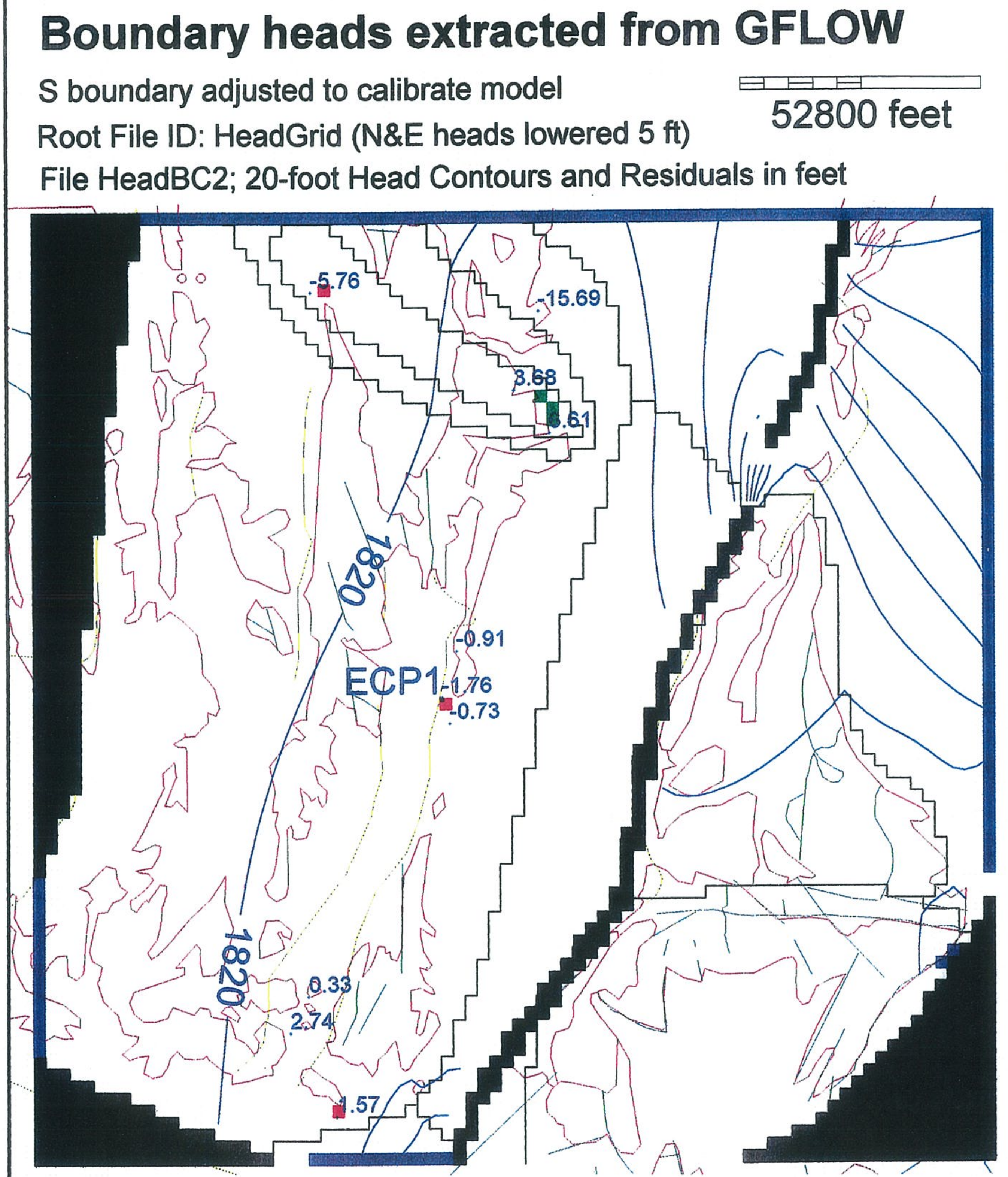


Figure 17. Case 2, the constant head boundary condition, the less probable scenario, steady state solution. Refer to figure 13 for boundary types. North is at the top of the page.

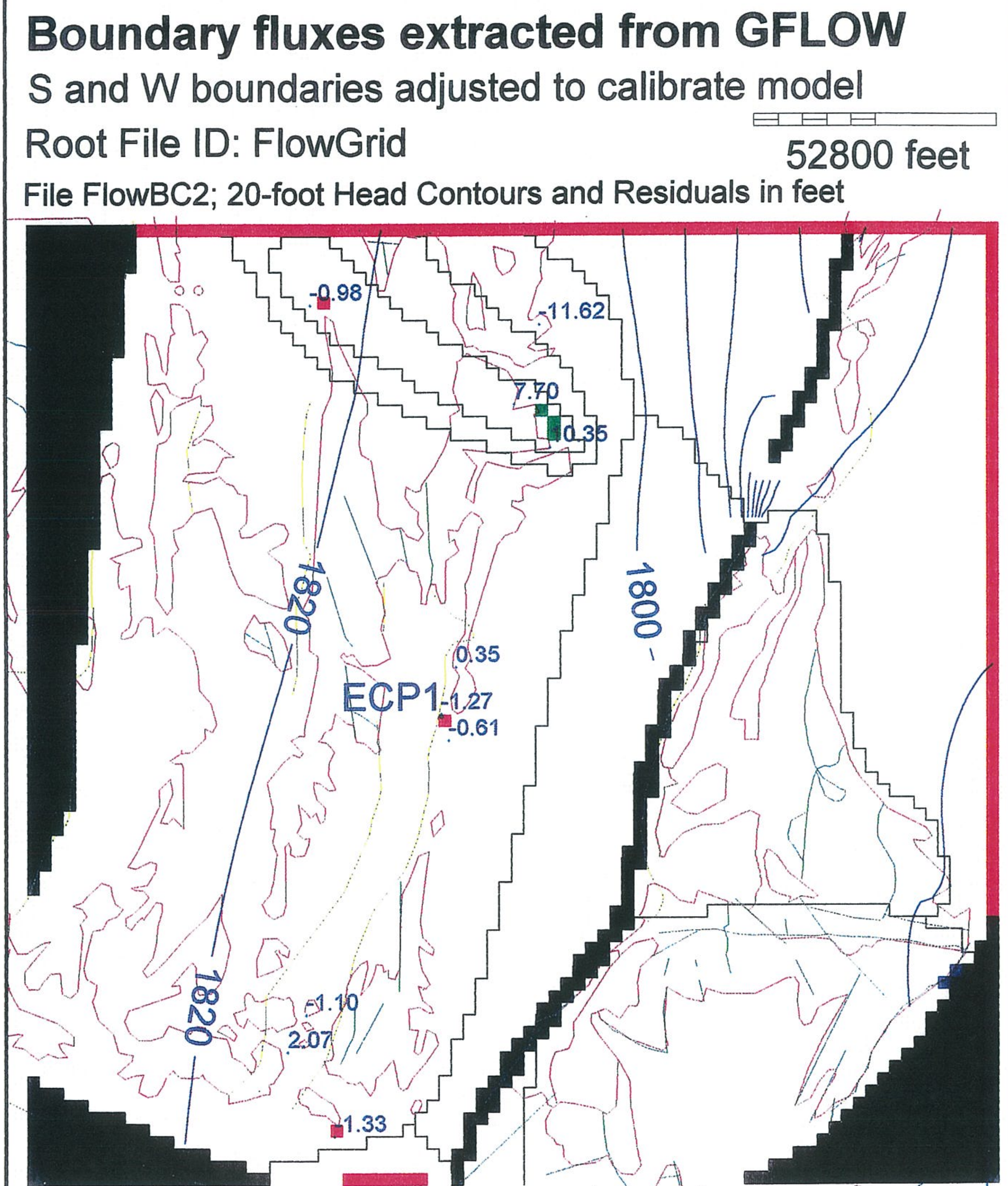


Figure 18. Case 3, the prescribed flux boundary condition, the least probable scenario, steady state solution. Refer to figure 13 for boundary types. North is at the top of the page.

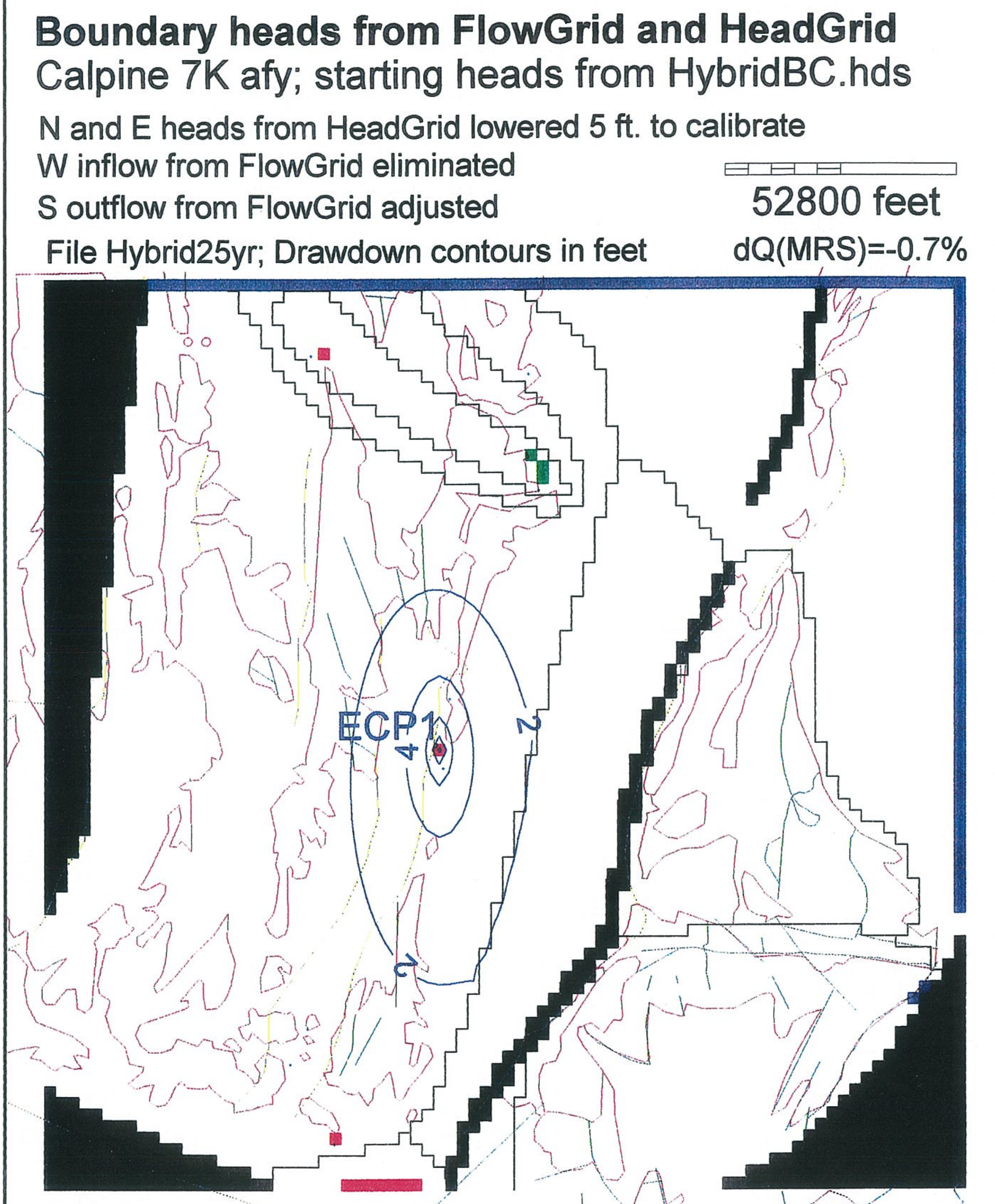


Figure 19. Case 1, the hybrid boundary condition, the most probable scenario, 25-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

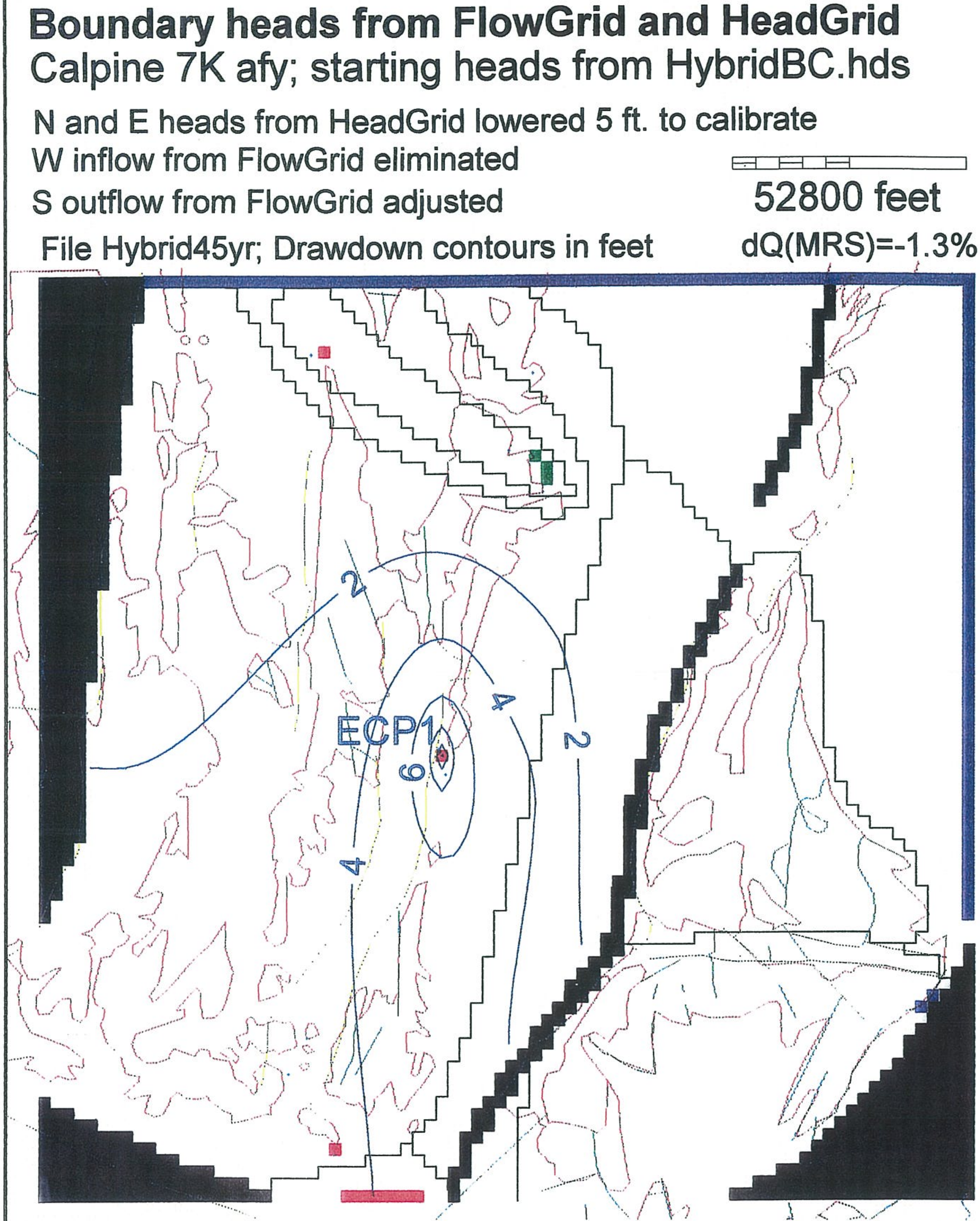


Figure 20. Case 1, the hybrid boundary condition, the most probable scenario, 45-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

4.6.2 Case 2: The Constant Head Boundary Condition, the Less Probable Bounding Scenario

The Case 2 constant head boundary condition, the less probable bounding scenario, prescribes that head (water level) at the domain boundary remains constant with time. In dramatic contrast to Case 3, this case is where heads at the model boundary remain constant with time and allow pumped water to be compensated by induced "recharge" at the model boundary (an unlimited supply of imaginary water in some areas).

The results of Head25yr Figure 21, illustrates the application of a constant-head boundary, an unlikely scenario with respect to some boundary conditions. Impacts on groundwater discharge to the Muddy River Springs Area were minimal, amounting to 1.1% reduction after 25 years. The results of Head45yr Figure 22, predicts that 1.1% (unchanged) reduction occurs at 45 years. The cone of depression from this scenario is much more restricted at any point in time than in the following Case 3 and is (by definition) zero at the model boundaries.

4.6.3 Case 3: The Prescribed Flux Boundary Condition, the Least Probable Bounding Scenario

The Case 3 prescribed flux boundary condition, the least probable bounding scenario prescribes flux across the domain boundary that remains constant with time. Case 3 scenario for pumping would be constant inflows and outflows at the model boundary. Any extraction of water would ultimately be compensated by a decrease in groundwater discharge elsewhere. Depletion of stored water would mitigate these effects in a temporal sense, but given sufficient time the end result would be the same regardless of the system's storage capacity.

The results of Flow25yr shown on Figure 23 illustrates the extent to which groundwater discharge at the Muddy River Springs Area will be impacted after 25 years of pumping 7,000 afy from the Belly Tank Flat well field. A decrease in groundwater discharge in the Muddy River Springs Area of 7.5% (3.8 cfs), is forecasted at 25 years. The cone of depression is elongate in a north-south direction due to the system anisotropy, and asymmetrical about the center of pumping due to hydraulic barriers west of the North Muddy Mountains. The results of Flow45yr shown on Figure 24 illustrates that groundwater discharge in the Muddy River Springs Area has decreased by 10.4% after 45 years. Since there are no inflows from outside the model domain in this scenario, all water must come from storage (which has a delaying effect on impacts), or ultimately from the Muddy River Springs Area. At infinite time, withdrawals from within the model domain would be exactly balanced by a decrease in groundwater discharge at the Muddy River Springs Area.

4.7 Conclusions Derived from Modeling Analyses

Based on the analyses described above, uncertainty in sub-regional boundary conditions results in forecasts and a range of possible responses in terms of reduced discharge with the assumed condition of well-developed hydraulic continuity and transmissivity between the northern and southern flow fields. However, independent isotopic and geochemical evidence suggest that such connection may be absent. Impacts on spring flow may be minimal either with or with out the well developed hydraulic continuity case based on regional upwelling near the pumping center that has the same net effect as the prescribed-head boundaries that have incorporated in

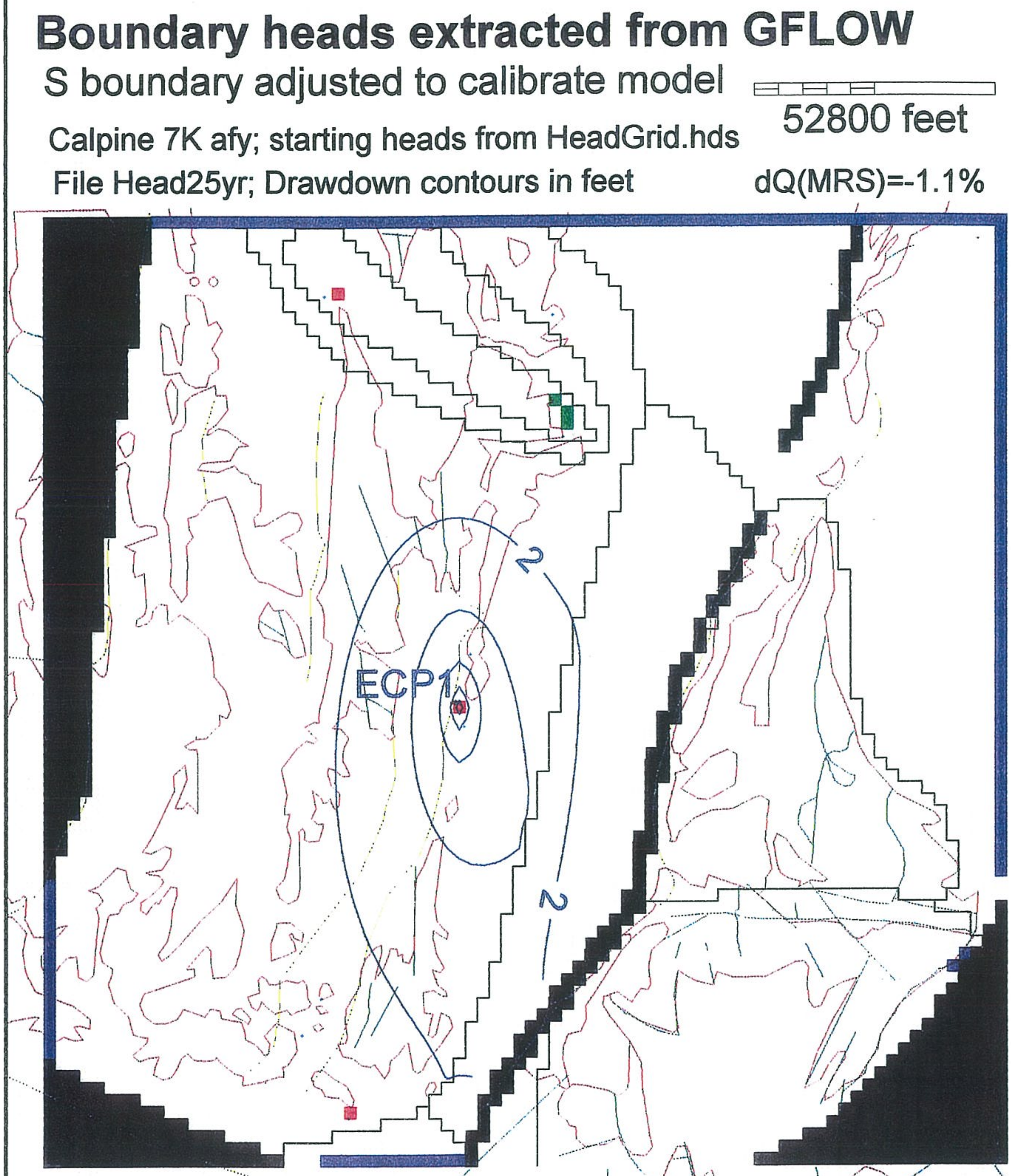


Figure 21. Case 2, the constant head boundary condition, the less probable scenario, 25-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

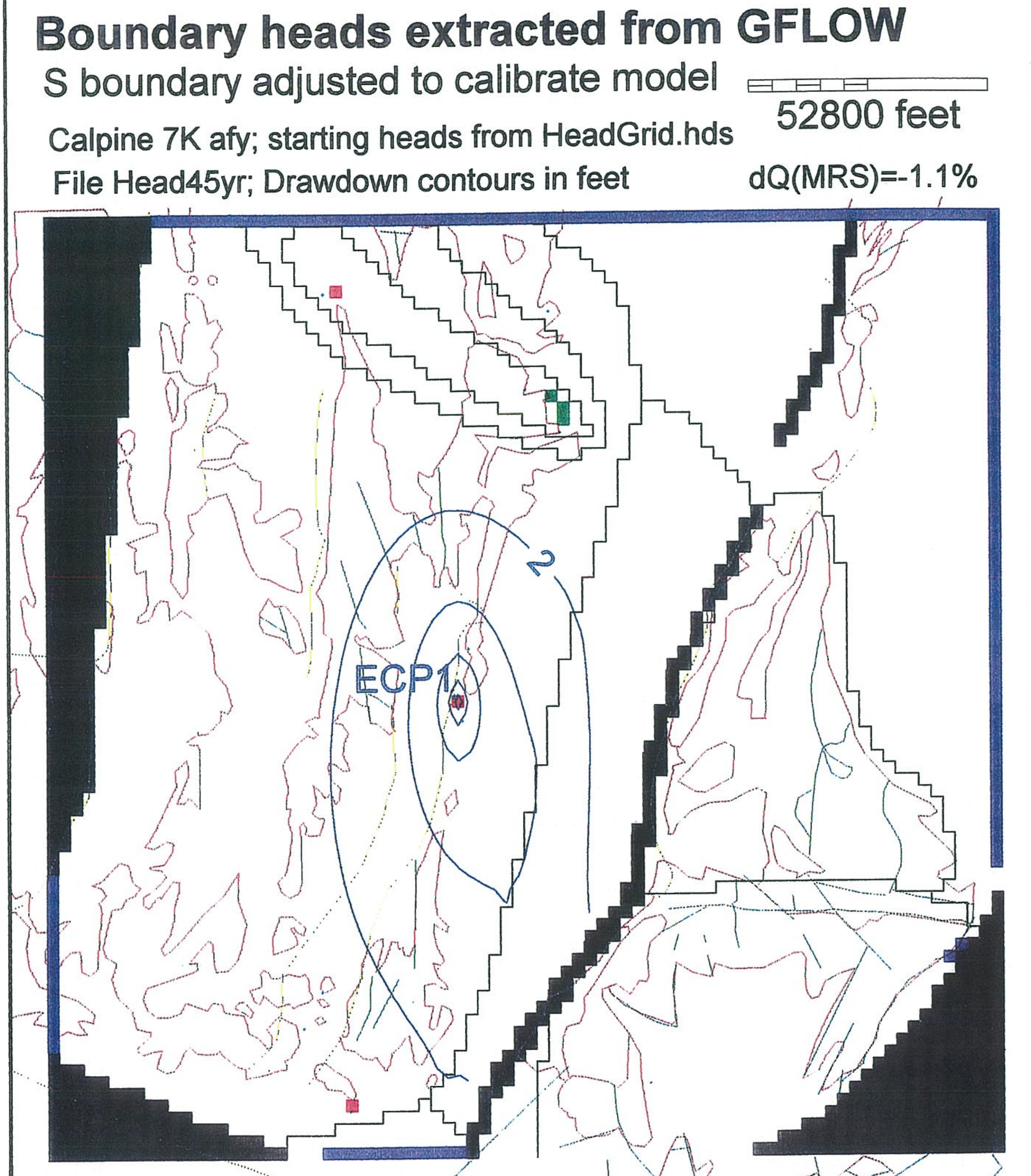


Figure 22. Case 2, the constant head boundary condition, the less probable scenario, 45-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

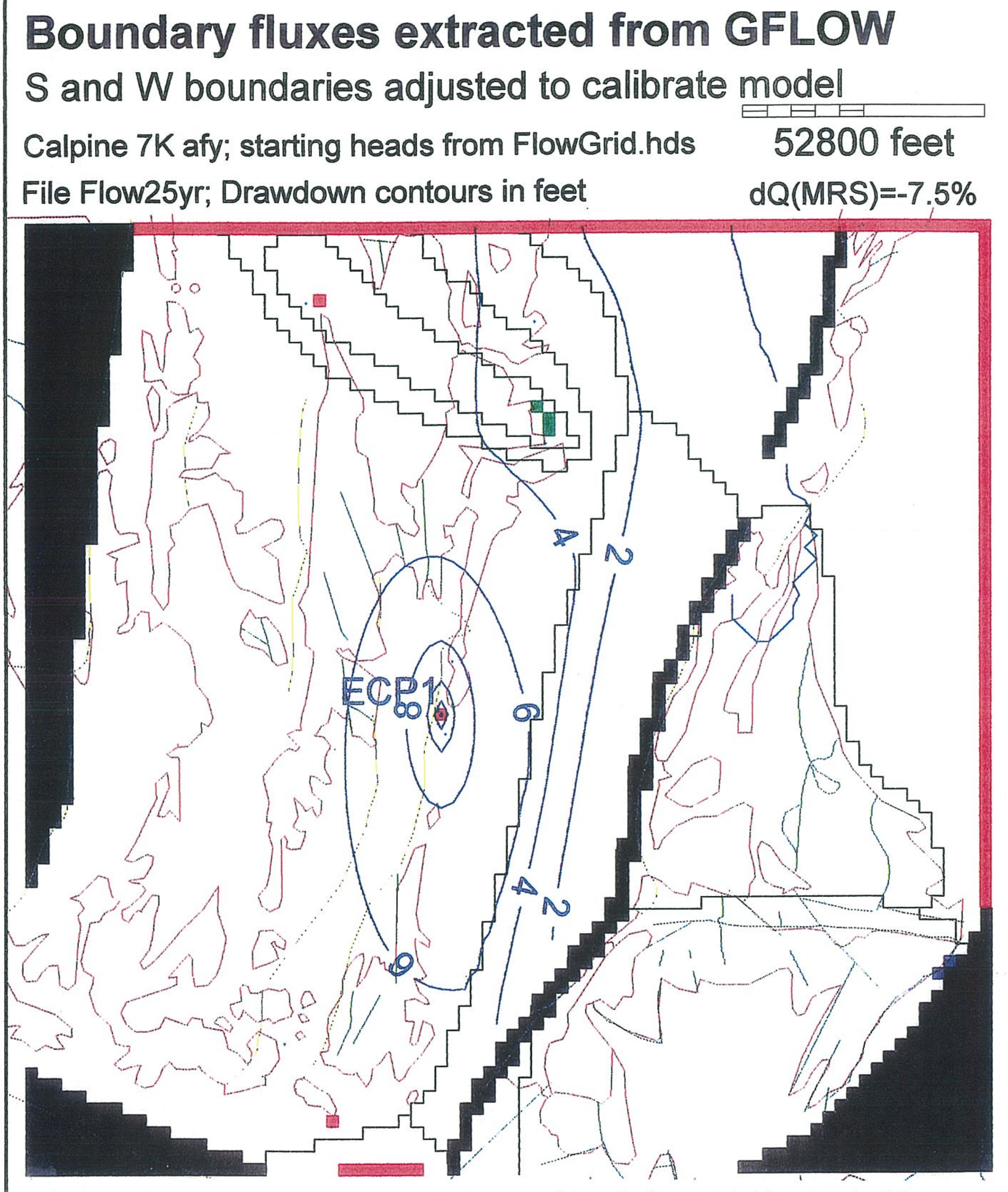


Figure 23. Case 3, the prescribed flux boundary condition, the least probable scenario, 25-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

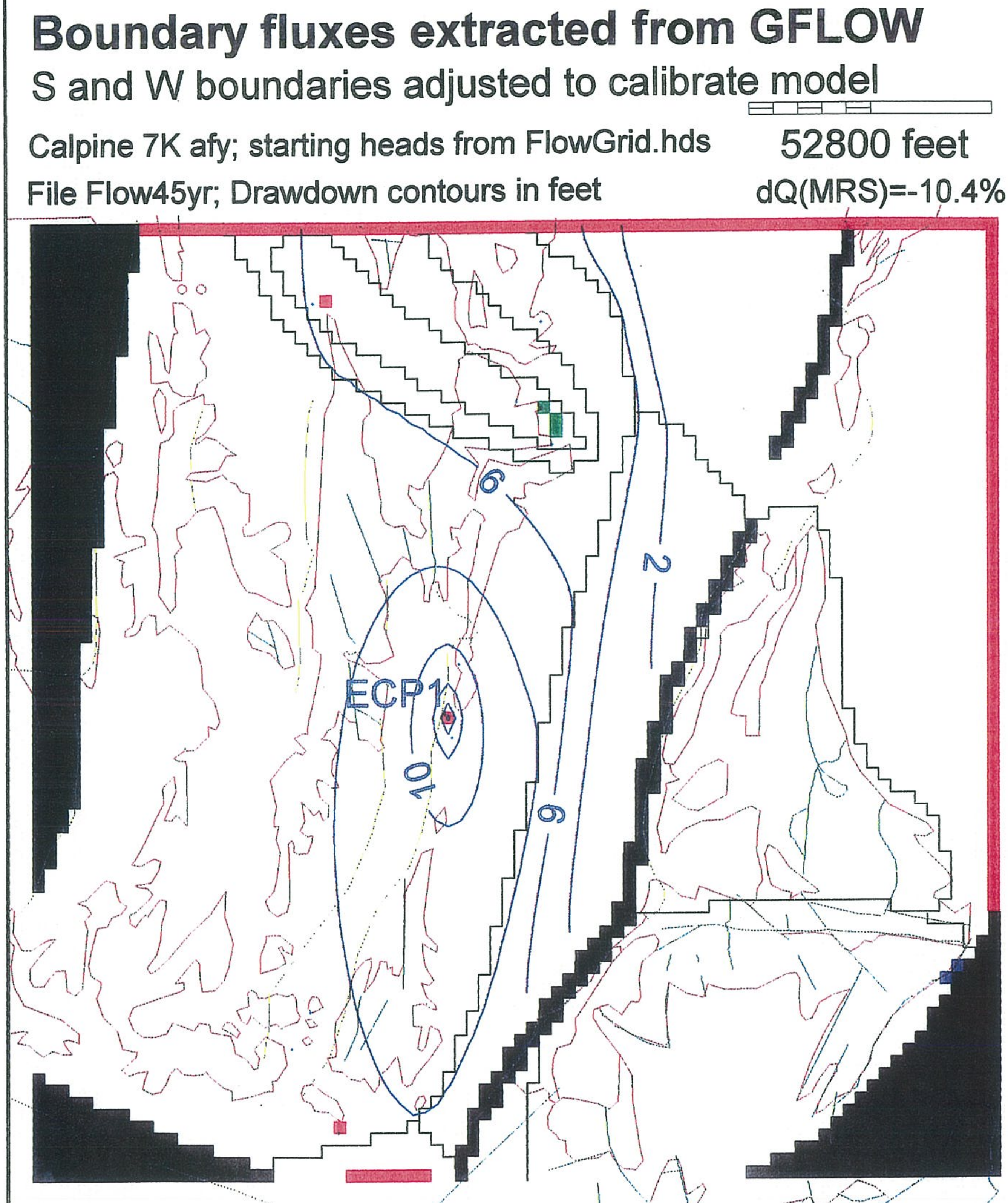


Figure 24. Case 3, the prescribed flux boundary condition, the least probable scenario, 45-year solution. Refer to figure 13 for boundary types. North is at the top of the page.

two of the scenarios, Case 1 and Case 2. The modeling results are summarized in Table 4.

Table 4. Transient Effects on Muddy River Springs Area resulting from the Belly Tank Flat Pumping

	25 years		45 years
Run ID	**Discharge Decrease, %**	**Run ID**	**Discharge Decrease, %**
Case 1 Hybrid25yr	0.7	Case 1 Hybrid45yr	1.3
Case 2 Head25yr	1.1	Case 2 Head45yr	1.1
Case 3 Flow25yr	7.5	Case 3 Flow45yr	10.4

The following are conclusions from the modeling analyses and supporting information:

1. Modeling analyses indicate that between 3,000 and 9,000 afy of flux occurs in the southern portion of the Arrow Canyon Range Cell of the Regional Carbonate Aquifer. These estimates are an outcome of the model calibration process, which could not be successfully accomplished without allowing for outflow to the south.

2. Bounding scenarios and a more probable scenario forecast a range of system responses to production of 7,000 afy. The most probable response scenario would produce minimal impacts in discharge in the Muddy River Spring Area after 45 years and no impact at Rogers and Blue Point Springs. The prescribed flux boundary condition, the least probable bounding scenario, is over conservative and would produce significant impacts before 45 years.

3. There are no foreseen impacts to groundwater users to the south given depths to water in the region of hundreds of feet and maximum drawdowns of only several feet for the life of the Project.

4. The modeling analyses point out the potential for, and indeed the need for, characterizing the water-resource potential of the still-unperturbed Arrow Canyon Range Cell of the Carbonate Aquifer. This can be accomplished through careful monitoring of the effects of Belly Tank Flat pumping, (7,000 afy) which could, on the basis of conservative modeling projections, be sustained for decades without adverse consequences.

5. Boundary condition responses are uncertain and this aspect of uncertainty can not be resolved without observations of responses to large pumping stresses. If the conceptual model of upwelling deeply-circulated flow proves correct, and it seems necessary in terms of the geochemical and isotopic characteristics of the southern flow field, upwelling in the general area of Belly Tank Flat leads to a boundary condition that may well limit the magnitude and spread of the pumping cone. A pumping cone reaching the upwelling zone effectively encounters a recharging boundary, which, as demonstrated in the Case 1 and Case 2 scenarios, has the effect of limiting impacts at the Muddy River

Springs Area to 1 percent of discharge at 45 years.

5.0 Discussion and Conclusions

There are new relationships that have developed from widely distributed but sparse databases relevant to the Arrow Canyon Range Cell. This study has developed and analyzed new hydrogeologic data from the Moapa Indian Reservation, central to the Arrow Canyon Range Cell. The process has generated a new level of understanding, confidently documenting two distinct flow fields: a northern flow field discharging at the Muddy River Springs Area, a southern flow field probably discharging southeast of the Apex Industrial Area. There is little question that the Carbonate Aquifer of the Arrow Canyon Range Cell is very unusual, if not unique, in terms of its great apparent thickness, hydraulic continuity across major structural features, very low fluid potential gradients in the southern flow field, and regional origins of flow.

Some key uncertainties have been revealed by modeling analyses conducted during this study, notably the magnitude of steady-state flux beneath Belly Tank Flat. There is little question that the Carbonate Aquifer has the resource potential to supply the 7,000 afy for the proposed Moapa Paiute Energy Center. There is also good evidence for considerable total flux, but no matter what assessment technique adopted, the soft numbers will remain soft until it there are opportunities to observe transient responses to major pumping stresses.

Forecasting regionally transmitted pumping impacts decades into the future without records of large-scale transient responses and comparable magnitude in key areas does not allow high confidence in constrained modeling analyses. A basic decision was necessary as to how to treat the interface zone between two flow fields that were evident from field data but not explicit in the model. The decision was made to conservatively treat the aquifer as highly transmissive through the interface zone. The three modeling cases may therefore all be over-conservative, and not fully bound what is credible within the context of the geochemical databases of the region. Two flow fields may indeed be separated by an extensive region with limited transmissive properties, but, because such has not been identified by a candidate geologic feature, the conservative and more defensible approach as been to evaluate the consequences of a highly transmissive connection between the Belly Tank Flat and Muddy River Springs Area.

The Case 1 and Case 2 scenarios simulate reasonably well the effect of an upwelling zone of the Belly Tank Flat area, whether or not hydraulic continuity exists between the two flow fields. A nearby upwelling source of essentially a constant head boundary could limit or prevent the migration of the pumping cone to the Muddy River Springs Area.

It is worth noting that even if the level of current understanding were to prove highly flawed, that even the least probable Case 3 scenario assures a protracted period of time before pumping impacts would become large enough to be important at the discharge area. A monitoring plan (Appendix E) has been designed and implemented to document pumping impacts that would develop along a transect between the Muddy River Springs Area and the Belly Tank Flat pumping center, with three carbonate aquifer monitoring wells, TH-2, M-1, and EH-4 located between the two areas. Net drawdowns in water levels developed at either end of the transect of monitoring wells should document and confirm the pumping cone propagation well before any adverse impacts of important magnitude would develop, and allow model predictions to be tested by observation.

5.1 Projected Impacts on Muddy River Springs Area

Three modeling scenarios were developed by varying boundary conditions to demonstrate the range of credible impacts of 7,000 afy pumping stress from the Belly Tank Flat area on the Muddy River Springs Area, assuming hydraulic continuity between the areas. The modeling scenarios bound the impacts in a conservative manner. Table 4 summarizes the results for operation of the proposed project for 25 years, the length of the proposed lease, and for 45 years, the length of the proposed lease plus the possible 20-year lease extension.

The Case 1 scenario, a hybrid case, which incorporated both prescribed head and prescribed flux boundaries, is judged the most probable response of the natural system to pumping, and produces a decrease in the Muddy River Springs Area discharge of about 1% at 25 years and 1.3% in 45 years. These are equivalent to about 0.5 cfs of the 51 cfs which, on average, flows to the discharge area. For perspective, the natural regional flux to the discharge area based on analyses of monitoring records probably ranges from about 47 cfs to 54 or 55 cfs (Appendix F, page 27). The actual discharge of the Muddy River as measured below the Muddy River Springs Area has been decreased by more than 10 cfs due to the local groundwater diversions which began in the spring area in 1959 (Appendix E, Figure E-2).

The Case 2 scenario, a less probable case with prescribed-head boundaries, would result in the reduction of the Muddy River Springs Area discharge by approximately 1 % in 25 years and 1.1 % in 45 years. Case 2 and Case 1 are almost identical in results because they share large areas where the boundaries of the model can yield additional water by responding as they are impacted by pumping effects, inducing flux to the model domain.

The Case 3 scenario, the least probable case with prescribed-flux boundaries, forces all new withdrawals to be supplied from within the model domain, from storage, and from diversion of the Muddy River Springs Area flow field. After 25 years of operation it forecasts 7.5% reduction in flow to Muddy River Springs Area. If the pumping under Case 3 were to continue for 45 years, the reduction in flow to the discharge area gradually increases to approximately 10%, or about 5 cfs.

It is important to note that nearby pumping stresses in the Muddy River Springs Area had produced greater annualized reductions in stream flow at the Warm Springs Road gauging station by the mid-1990's than those projected to occur for the Case 3 scenario after several decades of pumping (Appendix F). Because of the seasonal variation in water demands, for several months each year the pumping impacts are more than double Case 3 annualized average impact of 5 cfs at 45 years, or 20 times those forecast for Cases 1 and 2. These pumping centers are located within the general discharge area, and therefore produce very strong effects on local hydrologic features.

None of the three modeling scenarios at 25 years produces impacts on Muddy River Spring Area flows that are large enough to be confidently separated out as attributable pumping impact based on discharge observations alone, because of the pre-existing pattern of relatively long term secular (natural) variations in flow. Uncertainties in gauging accuracy and natural variations (effects of drought and wet years) in the discharge of the springs and the river results in uncertainty of measurement of approximately 10% of the flow or 5 cfs. Therefore, a very slow acting change in regional flow that is less than 10% of the existing flow could be statistically demonstrated once it had been expressed in the record for several years, but not with confidence as to the causes. If, as in Case 3, reductions began to exceed roughly 10% of discharge approximately 45 or so years after pumping began, recognition of impact is likely, but actual magnitude of impact from the project pumping would be difficult to evaluate. Until then, the plus or minus 10% accuracy of stream flow measurements and natural variations of the same order of magnitude might prevent confident separation of the Case 3 scenario impacts from pre-existing or other contributing causes of variations. The important role of modeling analyses in the monitoring program is apparent, where net drawdowns within the impacted flow fields are projected and monitoring well records are continuously available for comparison with projections.

Any reduction of flows that result from the proposed project would be distributed uniformly over the annual flow regimen and throughout the multitude of discharge features. In contrast, in a seasonal sense the local area pumping impacts are not as well distributed, thus they are intensified during portions of the annual cycle. It has been observed that even with large seasonal fluctuations in flow resulting from the localized pumping there has been little or no documented aquatic habitat loss. Such a result attests to the buffering effect produced by the carbonate aquifer discharging via both conduits to springs and in a distributed fashion to the local alluvial gravel aquifer (see Appendix F diagrammatic cross section, p. 25).

5.2 Impacts on Aquatic Habitats

The Case 3 scenario, an improbable bounding case because of the highly conservative prescribed flux boundary conditions presents a useful hydrologic state for consideration of maximum credible impacts on aquatic habitats of the Muddy River Spring Area. The historic record (Appendix F, p. 27) demonstrates that the strong, seasonal, local pumping impacts in the discharge area are about double (when annualized) the projected Case 3 scenario impact of 5 cfs at around 45 years of pumping 7,000 afy at Belly Tank Flat. The well-documented secular variations, caused by 6 years of drought (1985-91) and back-to-back wet years (1992-93), have resulted in a natural range of about 5 to 6 cfs of discharge variation as well. For much of the detailed historic records, uniformly superposing the forecasted 45-year 5-cfs decrease in flow to the area would result in changes within the historic range of observed hydrology and associated impacts on aquatic habitats. During future prolonged (multiyear) droughts hydrologic states would be potentially changed, and the nature of these may be projected based on observations derived from the historic records.

Roughly one-third of discharge from the Carbonate Aquifer passes via conduits directly to springs and two-thirds directly to the alluvial aquifer. Assuming that about two-thirds of the 5-cfs reduction in flow (3 cfs) would occur to the alluvial aquifer, the headwater reaches of the Muddy River would experience the most impact (with reduced baseflow discharge to intermittent and perennial channels). These occur from decreases in baseflow discharges that would be upstream of Warm Springs Road Bridge (an undocumented location on the LDS farm) to around Big Muddy Spring area. The other 2 cfs of reduction would be distributed as approximately 10%

reduction in spring flows, and probably some decreases in evapotranspiration losses. Much of the decreases in baseflow discharge fall within the historic envelope of channel flows and associated aquatic habitat conditions; impacts on aquatic habitats would be similar to past years of heavy local pumping stresses and/or drought periods of the record. However, during future prolonged drought periods, up to about 3 cfs (annualized) reduced baseflow discharge into these uppermost river channels would occur, perhaps eliminating some presently intermittent flow segments, and causing transitions of short channel reaches from perennial to intermittent flow, as far downstream as Big Muddy Spring. Such may or may not reduce the Muddy River Springs Area quality aquatic habitat, as these uppermost intermittent channel reaches currently carry flows only for up to several months each year. Beginning at Big Muddy Spring, perennial channel flows are great enough, if reduced by about 10% of the historic record, to maintain aquatic habitats of the river channels. Most of the about 2 cfs reduction routed through conduits to spring discharge areas during the drought years would likely be manifested as about 10% reduction in flows below historic minimum flows.

Based on these historic observations and assumptions that the complex hydrologic systems would behave similar to observed hydrologic responses, no impacts on aquatic habitats resulting from the markedly smaller impacts forecasted for the most probable scenario, Case 1 or Case 2 are projected for even prolonged drought periods. However, if the least probable bounding Case 3 were to occur during prolonged drought, the majority if not all of hydrologic impacts with potential to alter aquatic habitats would occur in the upper channel reaches of the Muddy River where there is baseflow discharge to both intermittent and perennial channel reaches of the headwaters area of the Muddy River.

5.3 Project Area Drawdown Impacts

Pump and step-drawdown testing of the carbonate aquifer near the proposed pumping center yielded data to compute a range of transmissivity of 50,000 to 100,000 ft^2/day, hydraulic conductivity of 20 ft/day and specific yield S_y of 0.03 and S of 0.008. A porosity reported by the US Geological Survey of 0.047 was used in the analyses. The tests support the feasibility of prolonged pumping at 1,000 gallons per minute with minimal drawdown except at the pumping well. Two additional exploration boreholes in the same area have been subjected to air lifted pumping tests, and indicate similar production potential. Thermal characteristics of groundwater, barometric efficiency, and geologic information were used to evaluate the estimated of thickness of the aquifer at 5,000 feet. Modeling forecasts for Case 1, the most probable response scenario, after 25 years estimated drawdowns north and south of the pumping location are forecast at 2 feet 8 miles distant and 10 miles distant, respectively, Figure 19. After 45 years, the drawdowns are forecast to be 2 feet to the north and up to 4 feet at the south boundary 20 miles distant as a result of the Belly Tank Flat pumping (Figure 20). Other modeling scenarios forecast distant drawdowns that do not exceed several feet over the 45-year period.

5.4 Rogers and Blue Point Springs

Pumping impacts on Rogers/Blue Point Springs were also considered. Analysis of available hydrogeological data indicates that the origin of water discharging at Rogers/Blue Point Springs appears to be in part local, and in part possibly regionally derived flow. The Rogers/Blue Point Spring is not subject to impacts from the Project however. These conclusion are based on multiple lines of evidence including:

1. Isotopic evidence indicates the minimum contribution of local recharge is approximately one third of the flow to Rogers and Blue Point Springs, (based on mass balance calculations using stable isotopic data from Thomas and others, 1996). These results are obtained using Big Muddy Spring Area (northern flow field) and Valley of Fire well water as mixing end members, and by assuming that Valley of Fire well water from Aztec Sandstone was locally recharged. Although the modeling assumed even more local origins in the Muddy Mountains, the flow system supporting these important springs may originate as far away as the Mormon Mountains, as postulated by Pohlmann and others (1998). Such a flow system would necessarily be isolated from any potentiometric trough associated with the lower Muddy River.

2. The discharge history of Rogers Spring (based on unpublished National Park Service records) is highly variable at times, which would require corresponding large-magnitude water-level fluctuations in the Arrow Canyon Range Cell if the Spring were to be fed primarily by this aquifer. This follows by observing a head difference of approximately 200 feet between the Arrow Canyon Range Cell and the two springs. The observed flow variations of up to 50% at the spring area would require up to 100 feet of head variation in the Arrow Canyon Range Cell, if it were to be the primary source of water for the springs. Therefore, since almost no variation in head has been observed in the Arrow Canyon Range Cell, it is unlikely to be a primary source of water for the springs, and small water-level declines of several feet over 45 years can not result in any credible impacts.

3. The physiography of the Muddy Mountains suggests an environment of effective recharge. There is little evidence of active channel erosion in the high carbonate terrain, suggesting that precipitation infiltrates rather than running off into active runoff channels. This is in marked contrast to active channel conditions on surrounding bajadas, where evidence of frequent runoff events involving sediment transport and down cutting is widespread. The flow variations in the spring discharge record are best correlated with a major component of local recharge, possibly superposed on a component of regional flow from the north.

5.5 Monitoring Program

Recognizing and assessing regional impacts is best accomplished through a carefully designed monitoring program. A useful monitoring network is in place, operating, and will be maintained throughout the period of pumping. The results will be the basis for modeling refinements at periodic intervals. The monitoring network is designed to allow real time recognition of regionally propagated pumping effects, decades prior to their becoming detectable at sensitive areas. Plans for mitigation could be activated if necessary.

Appendix E outlines the monitoring initiated by the Calpine Corporation and the Moapa Band of Paiutes to complement monitoring already established within the Arrow Canyon Range Cell. Integral to the overall monitoring strategy is the existing monitoring in the Muddy River Springs Area, which includes water-level monitoring in the local aquifers, and gauging spring and river discharges. In addition, monitoring of discharge at Rogers and Blue Point Springs is established and has yielded important records that lend insight into source(s) of the flows. The design for expanded monitoring that has been adopted by the Moapa Band to augment existing monitoring networks is a series of monitoring wells finished in the Carbonate Aquifer north, west, and south of the Belly Tank Flat Well Field. In this manner the extent and magnitude of water-level changes over time will be established in directions where it is feasible to monitor the Carbonate Aquifer within the Moapa Indian Reservation boundary. Monitoring wells TH-2, M-1, and EH-4 (Figure 2) are aligned between the proposed Belly Tank Flat well field and the Muddy River Springs Area, and will allow pumping signals propagating out of or into either area to be recognized. Monitoring wells M-2 and M-3 are also ideal to identify and document water-level signals that may propagate toward or away from other pumping centers south and southwest, respectively, of the Reservation boundaries.

6.0 Conclusions

Conclusions of the groundwater analyses are summarized below:

- Three modeling scenarios were used to bound the range of potential impacts on discharge in the Muddy River Springs Area. Only under Case 3, the prescribed flux boundary condition, an improbable bounding scenario, are observable changes to the Muddy River Springs Area hydrology predicted, and these would occur only during prolonged drought periods.

- A substantial body of evidence from isotopic hydrology, comparison of dynamic water-levels, geologic evidence of compartmentalization, and geomorphologic evidence of effective local recharge argues against hydraulic continuity between the Project area and the Rogers/Blue Point Spring area. As a result of these empirical observations, supported by model calibration requirements, no impacts on these springs are predicted.

- There will be no significant impacts to distant groundwater users because of small-scale drawdowns beyond the immediate vicinity of the well field.

7.0 Acknowledgements

A number of individuals and organizations have contributed to the database development effort and modeling analyses. Jeff Johnson, Erin Cole, and Gavin Kisinger of the Las Vegas Valley Water District; Karl Pohlmann of the Desert Research Institute; Van Robinson of the Moapa Valley Water District; and Richard Willer of Nevada Power Company (NPC) were key sources of hydrologic information. Jon Wilson of the U.S. Geological Survey and Don Shettel of Geoscience Management collaborated with Mifflin & Associates, Inc. (MAI) personnel on hydrologic and geochemical field measurements, respectively. Randy Felix (MAI) was the on-site supervisor of drilling operations, and Jack Johnson (MAI) was responsible for conducting field measurements around the clock to produce an excellent data set from the 7-day aquifer test. Nevada Cogeneration Associates and Georgia Pacific granted access to their monitoring wells. Jim Werle of Converse Consultants coordinated NPC monitoring at the Crystal switching station during the aquifer tests. U.S. Department of Interior representatives from the National Park Service, U.S. Fish and Wildlife, Bureau of Indian Affairs, Bureau of Land Management, and U.S. Geological Survey provided valued comment and criticism in a technical review workshop organized by PBS&J.

Members of the Moapa Band of Paiutes have set a positive tone in a complex cooperative effort;

in particular, we owe past and present Chairpersons Candace Grayman, William Anderson, and Eugene Tom a debt of thanks for their consistent support in maintaining the momentum of the Project. Tribal Council members Calvin Meyers and Anthony Frank, and tribal member Colleen Trujillo directly participated in drilling and testing operations and/or were instrumental in coordinating activities. Their efforts materially improved on the timely execution of the program.

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APPENDIX A

ECP-1 Aquifer Tests

Summary Report

ECP-1 Aquifer Tests

Summary Report
prepared by Cady Johnson August 25, 2000
minor editorial revision December, 2000

Overview

Two aquifer tests utilizing borehole ECP-1 as the production well were conducted July 21 and July 30, 2000. The first, a step-drawdown test, began at 8:30 PM on July 21 and ended at 2:44 AM on July 22. As indicated in Figure 1, the test showed that ECP-1 is capable of sustained production of 1000 gpm (192,500 ft^3/day) with estimated well losses of 81 feet and aquifer losses of 25 feet.

The second test was a 7-day constant-discharge test utilizing observation wells ECP-2, TH-1, and TH-2. Distances to the observation wells are 500 feet, 1 mile, and 2.3 miles, respectively (Table 1). Water levels in ECP-2 and TH-2 were recorded by a Stevens AxSys datalogger, but were measured manually at TH-1. Barometric pressure was recorded at the TH-2 wellhead.

			Dist. From ECP-1	
	meters N	meters E	m	ft
ECP-1	4,046,586	696,726	0	0
ECP-2	4,046,738	696,726	152	499
TH-1	4,044,962	697,237	1,703	5,586
TH-2	4,049,913	697,687	3,463	11,362

Table 1. UTM coordinates of Calpine boreholes, July, 2000

Production well ECP-1 was pumped at a steady rate of 1005 gpm for 7 days beginning at 8:50 PM on July 23, except for an interruption caused by equipment failure between 4:09 PM and 6:29 PM on July 24. There was full data recovery from the observation wells.

Methods

The computer program AQUITEST (William C. Walton, 1996, "Aquifer Test Analysis with Windows Software") was used to perform barometric pressure corrections and derive aquifer parameters from pumping response. AQUITEST was chosen for the excellent documentation available in the companion textbook; however, the graphical output is somewhat primitive in terms of labeling and input files cannot exceed 100 data points.

Barometric-pressure adjustments were accomplished by first defining a trend period and a change period to allow calculation of barometric efficiency, then applying barometric efficiency corrections to the raw water-level data. The corrected data were then fit to type curves to obtain parameter estimates. These are standard, automated procedures in the protocol of Walton (1996).

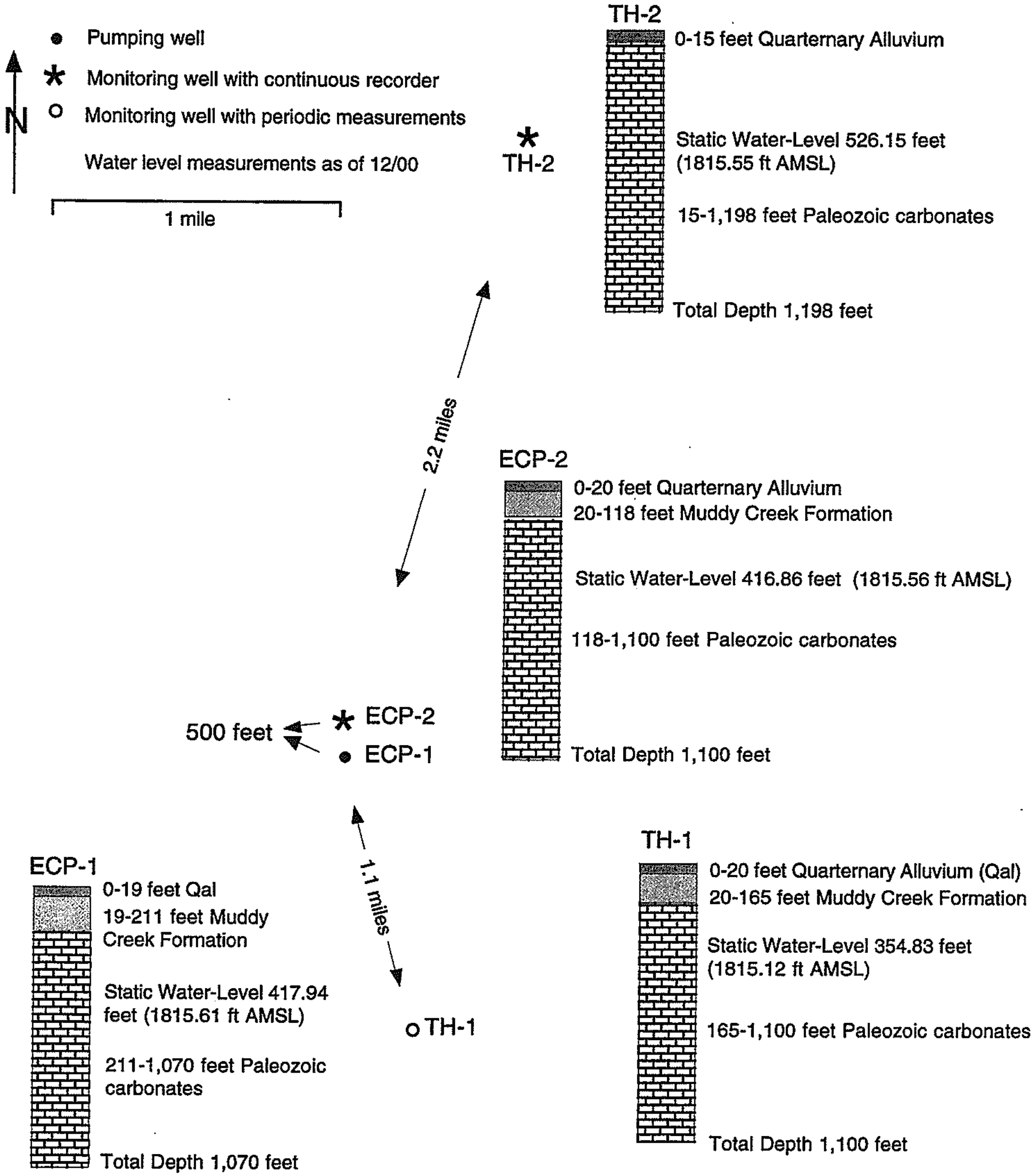


Figure A 1. Moapa Paiute Energy Center seven day test pumping monitoring network and borehole stratigraphy.

Appendix A , Figure A 1

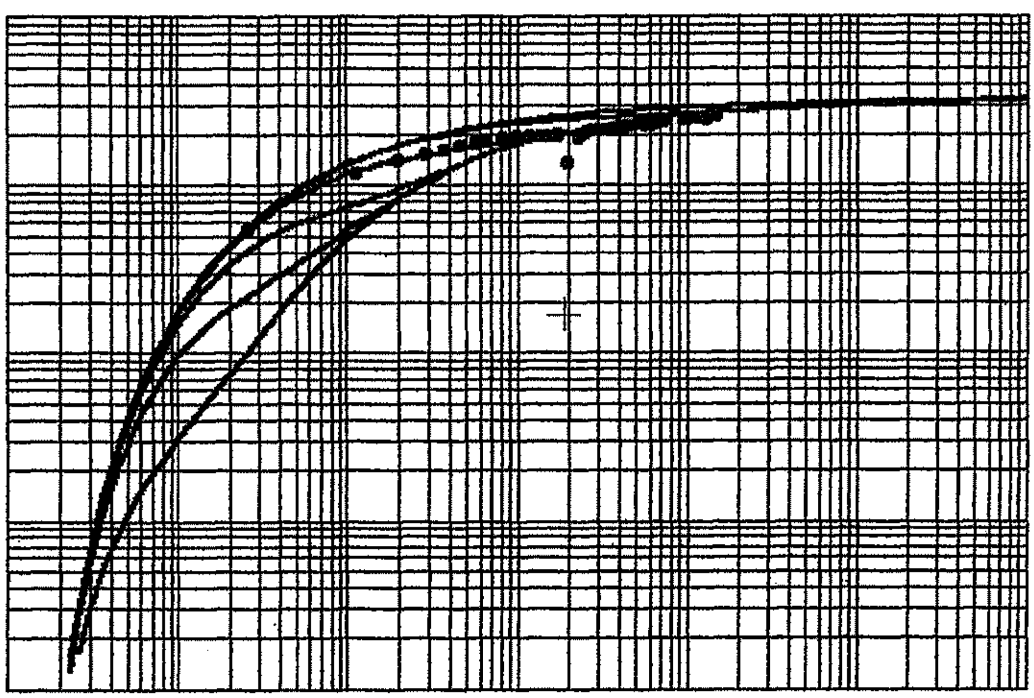
Results

Drilling records from the wells utilized for this study indicate unconfined hydrologic conditions; the barometric perturbations are enigmatic and therefore warrant some discussion. It appears that the great depths to saturation (minimum 350 feet) and low-permeability cover give rise to a system that is air-tight on a 6-hour (diurnal) time scale.

In order to obtain meaningful barometric corrections while limiting data files to 100 points or less, 6-hour averages of barometric pressure were used throughout the 7-day antecedent trend period needed for the barometric efficiency calculation. The idea is to select a "quiet" period of time after which the barometer makes a pronounced jump that is accompanied by a water-level change, and to utilize these cause-and-effect changes (with knowledge of antecedent trends) to calculate the barometric efficiency. Averaging during the "quiet" period is of little consequence. Figure 2 and the accompanying spreadsheet table illustrate the barometric correction setup for ECP-2, and Figure 3 and accompanying table document the process at TH-2. Figures 4 and 5 give raw and corrected drawdowns for ECP-2 and TH-2, respectively. Note also the increasing sampling interval after pumping began at day 11.87, necessary due to the 100-point data limit. Antecedent data were insufficient for meaningful barometric corrections at observation well TH-1.

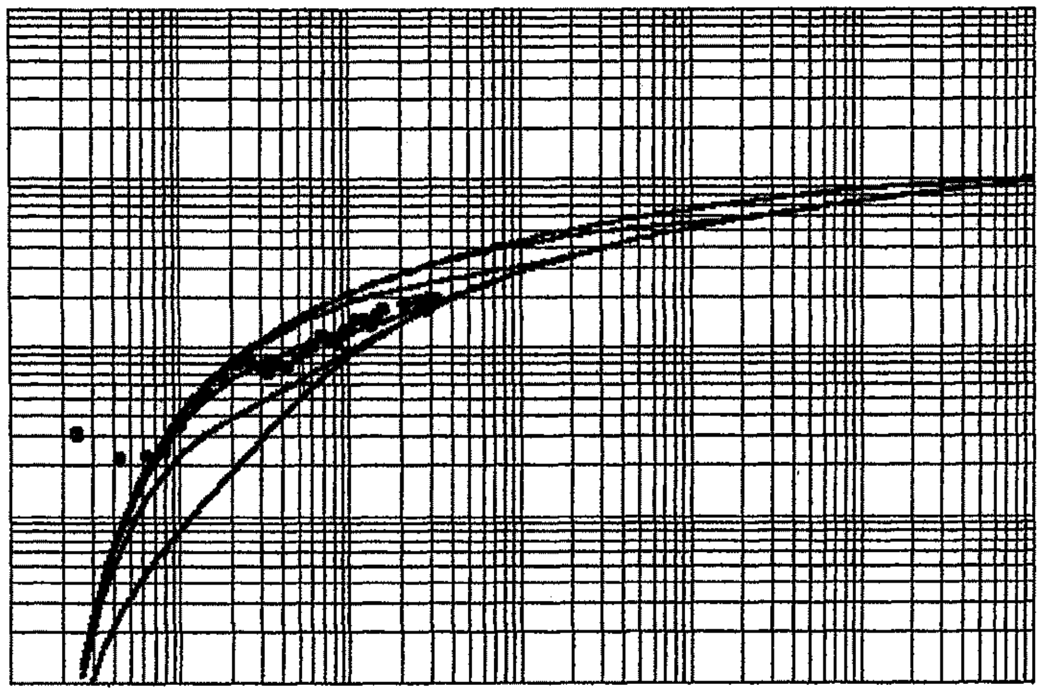
ECP-2 Response

Adjusted ECP-2 Drawdowns fit to Unconfined Type Curve



TH-2 Response

Adjusted TH-2 Drawdowns fit to Unconfined Type Curve



Parameter Estimates

The processing steps and curve-matching gave the following results for aquifer parameters:

ECP-2

Match Point Coordinates

Well Function = 1.689E+00
1/U Argument = 1.895E+02
Beta Argument = 3.643E-01
Drawdown = 2.375E-01 ft
Elapsed Time = 8.800E-01 day

TH-2

Match Point Coordinates

Well Function = 6.248E-01
1/U Argument = 5.286E+00
Beta Argument = 9.679E-01
Drawdown = 1.787E-01 ft
Elapsed Time = 1.136E+00 day

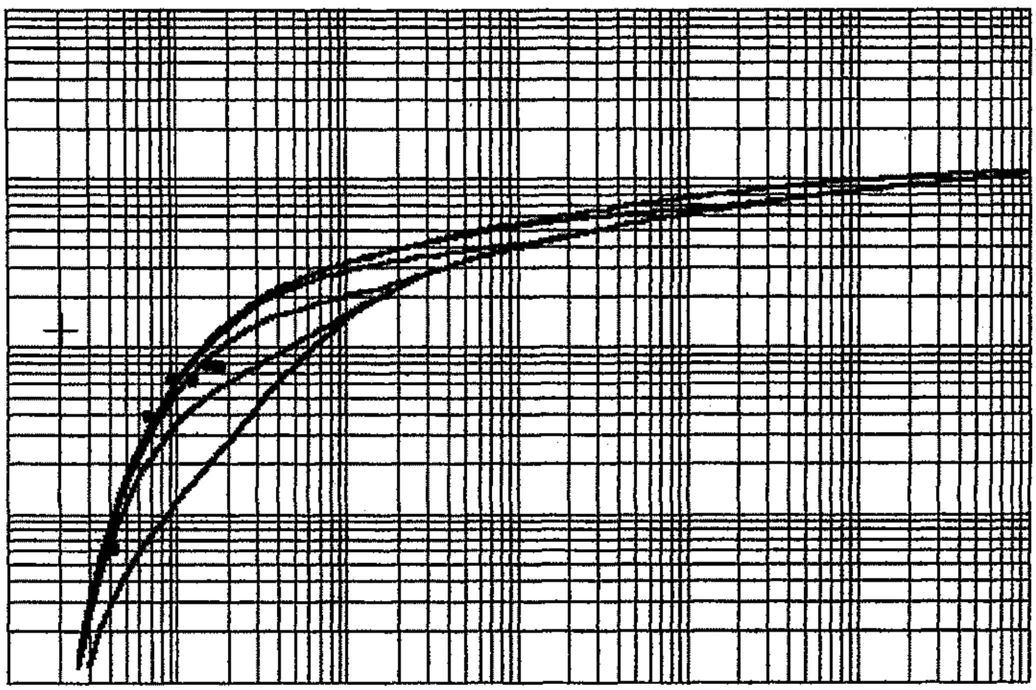
Aquifer System Hydraulic Characteristics

Aquifer Transmissivity = 1.095E+05 ft^2/day
Aquifer Storativity = 8.136E-03
Aquifer Specific Yield = 3.089E-02
Vertical Hyd. Cond. = 7.712E+01 ft/day

Aquifer Transmissivity = 5.382E+04 ft^2/day
Aquifer Storativity = 3.138E-04
Aquifer Specific Yield = 1.162E-03
Vertical Hyd. Cond. = 5.861E-01 ft/day

TH-1

Daily Average TH-1 Drawdowns fit to Unconfined Type Curve



TH-1 results are included here only for completeness; the signal-to-noise ratio of these data was so great (about 1) that a reasonable time-drawdown plot could be obtained only by averaging across the semi-diurnal fluctuations, i.e. taking daily averages of water level. Since the signal did not arrive at TH-1 the first day, only six points are available for plotting. These give the following result:

Match Point Coordinates

Well Function = 1.271E+00
1/U Argument = 2.073E-01
Beta Argument = 6.933E-01
Drawdown = 2.443E-01 ft
Elapsed Time = 7.855E-01 day

Aquifer System Hydraulic Characteristics

Aquifer Transmissivity = 8.011E+04 ft^2/day
Aquifer Storativity = 3.890E-02
Aquifer Specific Yield = 1.459E-01
Vertical Hyd. Cond. = 1.975E+00 ft/day

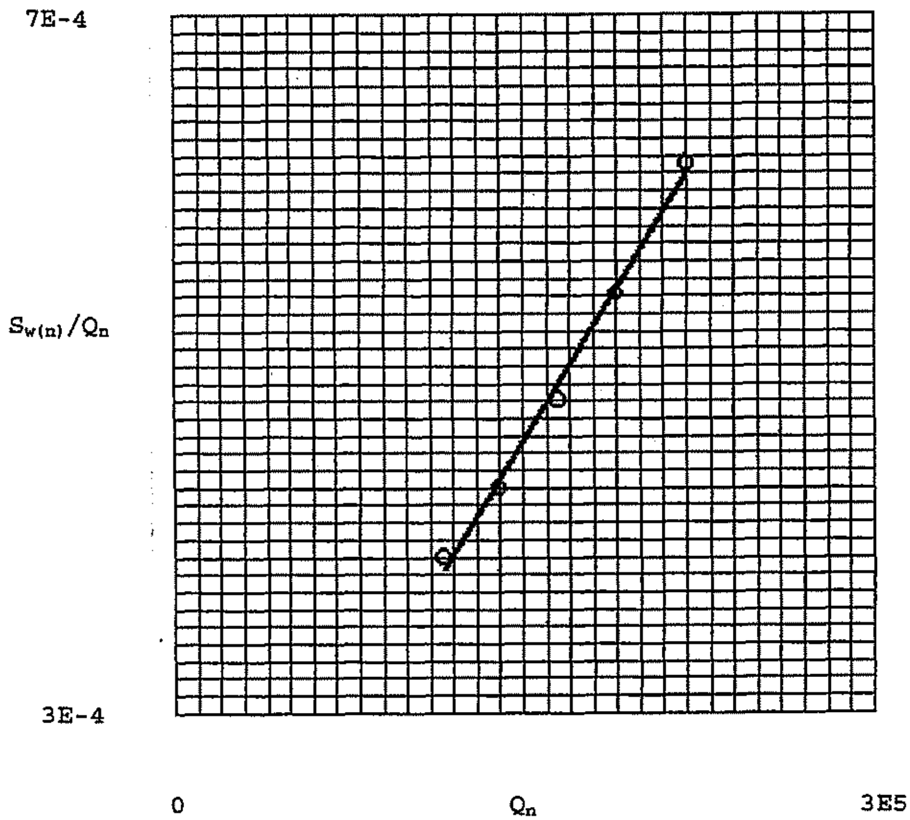
Conclusion

Transmissivities of 50,000 to 100,000 ft^2/day and unconfined conditions are indicated by the test data. The observation that barometric effects are expressed in an unconfined system is thought to be due to an effective pneumatic cap over the aquifer system. Since estimated transmissivities vary by only a factor of two, there are no indications of extreme anisotropy in the project area.

Figures to accompany Summary Report: "ECP-1 Aquifer Tests"

Figure 1

ECP-1 Step Drawdown Test
July 21-22, 2000



Data Summary

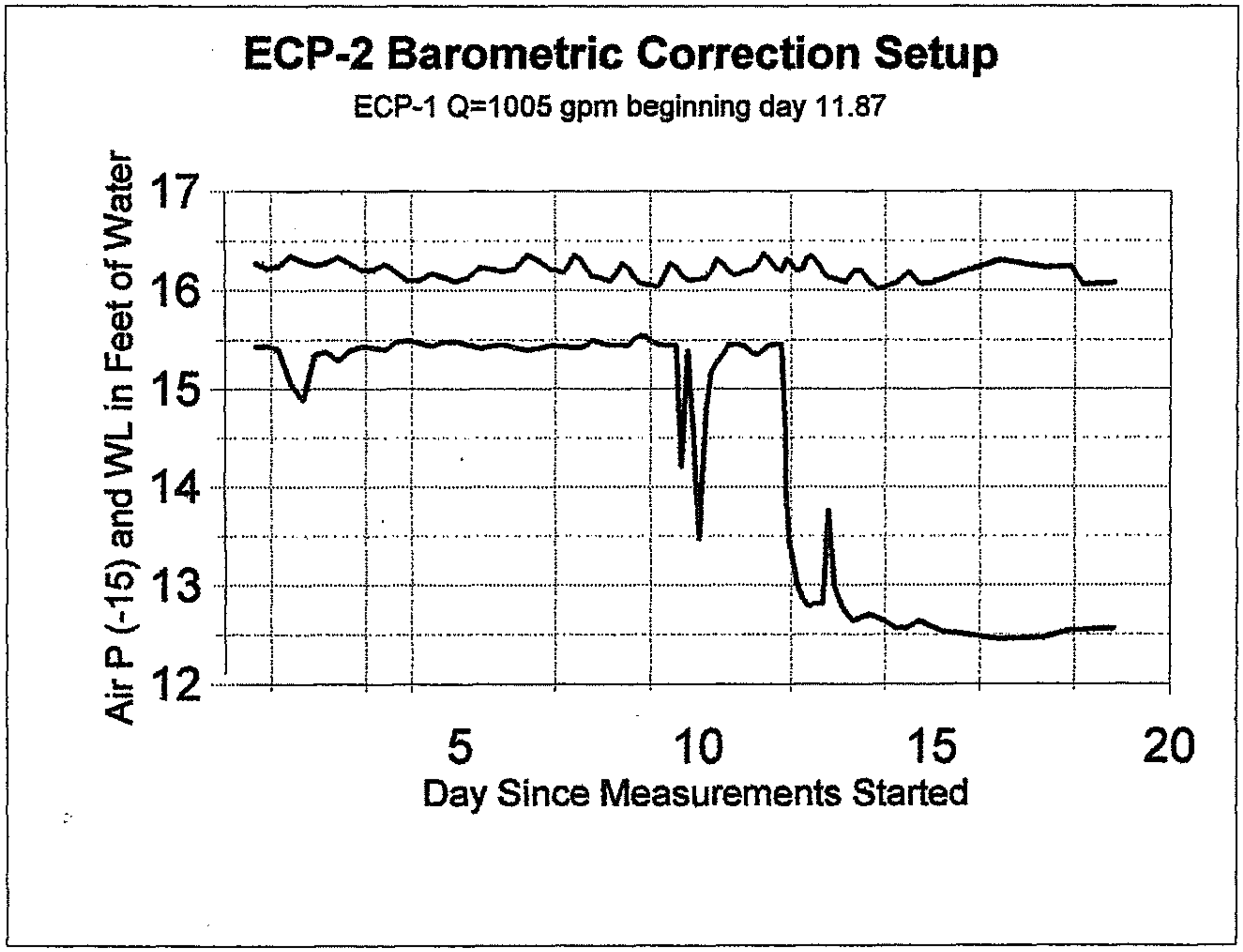
date	time	swl	delta s	Q gpm	Q ft3/day
21-Jul-00	8:30:00 PM	415.2	0	0	0
21-Jul-00	10:00:00 PM	460.5	45.3	603	116086
21-Jul-00	11:00:00 PM	475.3	14.8	725	139572
22-Jul-00	12:00:00 AM	494.5	19.2	857	164984
22-Jul-00	1:30:00 AM	518.0	23.5	986	189818
22-Jul-00	2:44:00 AM	550.6	32.6	1142	219850

Straight Line Analysis Results

B-factor = 1.285E-04
Well loss coefficient C = 2.188E-09

For discharge rate = 1.925E+05 (1000 gpm)
Aquifer loss = 2.474E+01 (25 ft)
Well loss = 8.108E+01 (81 ft)

Figure 2



ECP-2 Barometric Correction Setup
ECP-1 Q=1005 gpm beginning day 11.87
Air P (-15) and WL in Feet of Water
17
16
15
14
13
12
5
10
15
20
Day Since Measurements Started

ECP-2 Pumping Response and Barometric Pressure for 7-Day Test Drawdown Adjustments

3-point smoothing for 6-hr average to day 7 for trend, then 3-hour data until test begins

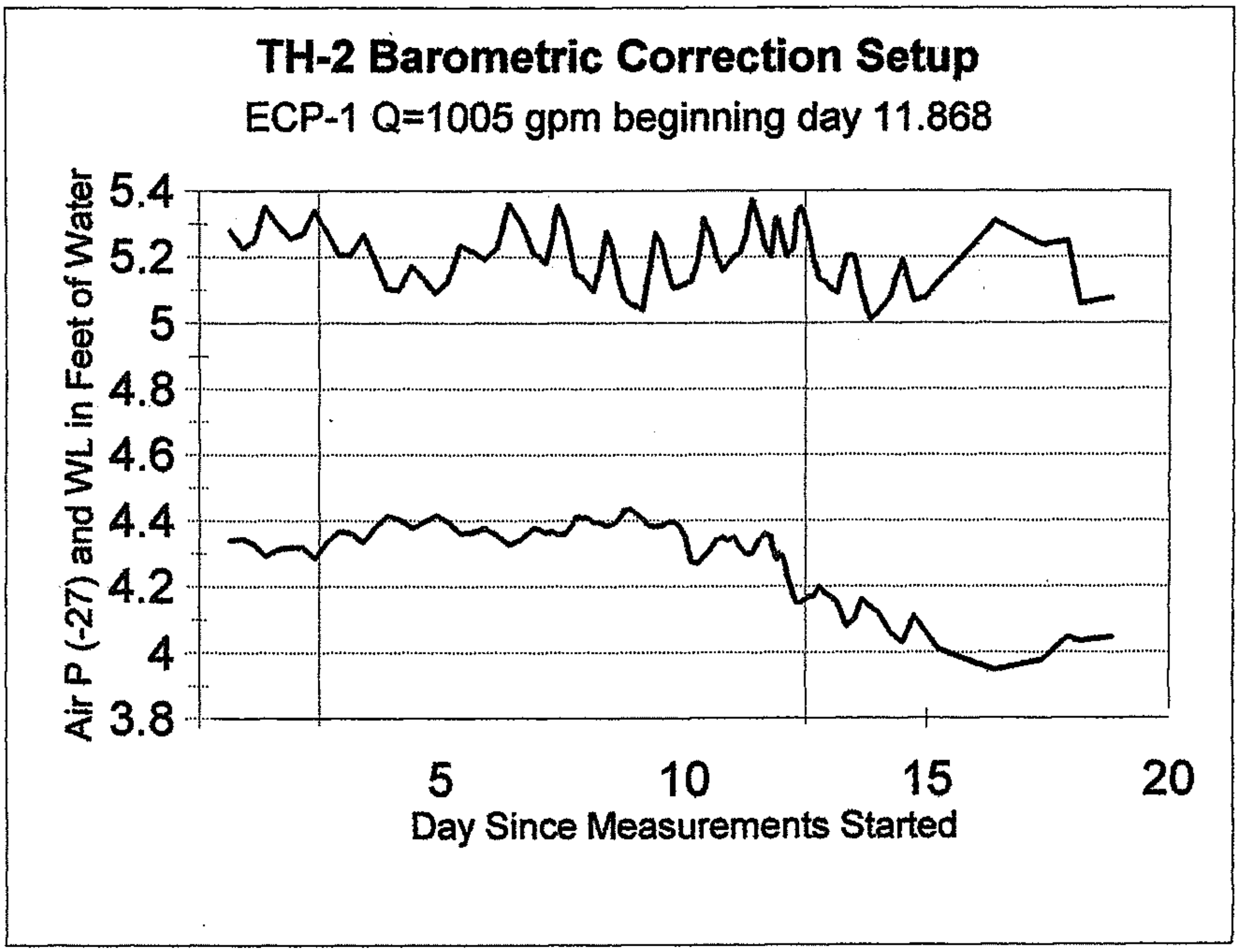
start@day 36719

Pumping was 1005 gpm from ECP-1 beginning 8:50 PM July 23, 2000 (began @11.868 days)

seq no	date	time	bp (ft h2O)	t (days)	wl (feet)	bp-15	pump t
1	07/12/00	04:00 PM	31.278	0.67	15.433	16.28	start trend period for BE
2	07/12/00	10:00 PM	31.228	0.92	15.433	16.23	
3	07/13/00	04:00 AM	31.248	1.17	15.403	16.25	
4	07/13/00	10:00 AM	31.352	1.42	15.057	16.35	
5	07/13/00	04:00 PM	31.297	1.67	14.887	16.30	
6	07/13/00	10:00 PM	31.256	1.92	15.343	16.26	
7	07/14/00	04:00 AM	31.272	2.17	15.380	16.27	
8	07/14/00	10:00 AM	31.340	2.42	15.287	16.34	
9	07/14/00	04:00 PM	31.279	2.67	15.387	16.28	
10	07/14/00	10:00 PM	31.207	2.92	15.430	16.21	
11	07/15/00	04:00 AM	31.207	3.17	15.423	16.21	
12	07/15/00	10:00 AM	31.268	3.42	15.397	16.27	
13	07/15/00	04:00 PM	31.190	3.67	15.480	16.19	
14	07/15/00	10:00 PM	31.104	3.92	15.493	16.10	
15	07/16/00	04:00 AM	31.100	4.17	15.467	16.10	
16	07/16/00	10:00 AM	31.172	4.42	15.433	16.17	
17	07/16/00	04:00 PM	31.138	4.67	15.477	16.14	
18	07/16/00	10:00 PM	31.091	4.92	15.483	16.09	
19	07/17/00	04:00 AM	31.125	5.17	15.450	16.13	
20	07/17/00	10:00 AM	31.234	5.42	15.417	16.23	
21	07/17/00	04:00 PM	31.216	5.67	15.437	16.22	
22	07/17/00	10:00 PM	31.194	5.92	15.453	16.19	
23	07/18/00	04:00 AM	31.227	6.17	15.423	16.23	
24	07/18/00	10:00 AM	31.360	6.42	15.393	16.36	
25	07/18/00	04:00 PM	31.304	6.67	15.417	16.30	
26	07/18/00	10:00 PM	31.213	6.92	15.440	16.21	end trend period for BE
27	07/19/00	01:00 AM	31.20	7.04	15.43	16.20	
28	07/19/00	04:00 AM	31.18	7.17	15.43	16.18	
29	07/19/00	07:00 AM	31.25	7.29	15.43	16.25	
30	07/19/00	10:00 AM	31.35	7.42	15.42	16.35	
31	07/19/00	01:00 PM	31.32	7.54	15.42	16.32	
32	07/19/00	04:00 PM	31.22	7.67	15.45	16.22	
33	07/19/00	07:00 PM	31.15	7.79	15.50	16.15	
34	07/19/00	10:00 PM	31.14	7.92	15.48	16.14	
35	07/20/00	01:00 AM	31.12	8.04	15.46	16.12	
36	07/20/00	04:00 AM	31.10	8.17	15.45	16.10	
37	07/20/00	07:00 AM	31.17	8.29	15.45	16.17	
38	07/20/00	10:00 AM	31.28	**8.42**	15.45	16.28	start change period for BE
39	07/20/00	01:00 PM	31.23	8.54	15.45	16.23	
40	07/20/00	04:00 PM	31.14	8.67	15.51	16.14	
41	07/20/00	07:00 PM	31.08	8.79	15.54	16.08	
42	07/20/00	10:00 PM	31.06	8.92	15.53	16.06	end change period for BE
43	07/21/00	01:00 AM	31.05	9.04	15.48	16.05	
44	07/21/00	04:00 AM	31.04	9.17	15.46	16.04	
45	07/21/00	07:00 AM	31.15	9.29	15.45	16.15	
46	07/21/00	10:00 AM	31.27	9.42	15.45	16.27	
47	07/21/00	01:00 PM	31.24	9.54	15.45	16.24	
48	07/21/00	04:00 PM	31.17	9.67	14.21	16.17	
49	07/21/00	07:00 PM	31.11	9.79	15.39	16.11	
50	07/21/00	10:00 PM	31.11	9.92	14.48	16.11	Step-Drawdown test
51	07/22/00	01:00 AM	31.12	10.04	13.48	16.12	Step-Drawdown test
52	07/22/00	04:00 AM	31.13	10.17	14.70	16.13	
53	07/22/00	07:00 AM	31.19	10.29	15.17	16.19	start WL trend period for test
54	07/22/00	10:00 AM	31.32	10.42	15.28	16.32	
55	07/22/00	01:00 PM	31.27	10.54	15.35	16.27	
56	07/22/00	04:00 PM	31.20	10.67	15.45	16.20	
57	07/22/00	07:00 PM	31.16	10.79	15.46	16.16	

58	07/22/00	10:00 PM	31.18	10.92	15.45	16.18		
59	07/23/00	01:00 AM	31.20	11.04	15.43	16.20		
60	07/23/00	04:00 AM	31.21	11.17	15.37	16.21		
61	07/23/00	07:00 AM	31.27	11.29	15.35	16.27		
62	07/23/00	10:00 AM	31.37	11.42	15.40	16.37		
63	07/23/00	01:00 PM	31.32	11.54	15.45	16.32		
64	07/23/00	04:00 PM	31.24	11.67	15.46	16.24		
65	07/23/00	07:00 PM	31.20	11.79	15.46	16.20	end WL trend period for test	
66	07/23/00	09:00 PM	31.29	11.88	14.73	16.29	0.0069	
67	07/23/00	10:00 PM	31.32	11.92	13.84	16.32	0.0486	
68	07/23/00	11:00 PM	31.30	11.96	13.53	16.30	0.0903	
69	07/24/00	12:00 AM	31.27	12.00	13.35	16.27	0.1319	
70	07/24/00	01:00 AM	31.25	12.04	13.23	16.25	0.1736	
71	07/24/00	02:00 AM	31.23	12.08	13.14	16.23	0.2153	
72	07/24/00	03:00 AM	31.20	12.13	13.03	16.20	0.2569	
73	07/24/00	04:00 AM	31.21	12.17	12.96	16.21	0.2986	
74	07/24/00	06:00 AM	31.23	12.25	12.87	16.23	0.3819	
75	07/24/00	08:00 AM	31.33	12.33	12.81	16.33	0.4653	
76	07/24/00	10:00 AM	31.35	12.42	12.79	16.35	0.5486	
77	07/24/00	12:00 PM	31.32	12.50	12.81	16.32	0.6319	
78	07/24/00	02:00 PM	31.26	12.58	12.81	16.26	0.7153	
79	07/24/00	04:00 PM	31.19	12.67	12.81	16.19	0.7986	pump failure
80	07/24/00	07:00 PM	31.13	12.79	13.76	16.13	0.9236	1609 to 1829
81	07/24/00	10:00 PM	31.12	12.92	13.00	16.12	1.0486	
82	07/25/00	01:00 AM	31.10	13.04	12.82	16.10	1.1736	
83	07/25/00	04:00 AM	31.09	13.17	12.73	16.09	1.2986	
84	07/25/00	08:00 AM	31.20	13.33	12.64	16.20	1.4653	
85	07/25/00	12:00 PM	31.20	13.50	12.67	16.20	1.6319	
86	07/25/00	04:00 PM	31.09	13.67	12.70	16.09	1.7986	
87	07/25/00	08:00 PM	31.01	13.83	12.67	16.01	1.9653	
88	07/26/00	12:00 AM	31.03	14.00	12.64	16.03	2.1319	
89	07/26/00	06:00 AM	31.08	14.25	12.56	16.08	2.3819	
90	07/26/00	12:00 PM	31.19	14.50	12.57	16.19	2.6319	
91	07/26/00	06:00 PM	31.07	14.75	12.64	16.07	2.8819	
92	07/27/00	12:00 AM	31.08	15.00	12.59	16.08	3.1319	
93	07/27/00	06:00 AM	31.12	15.25	12.53	16.12	3.3819	
94	07/28/00	10:00 AM	31.31	16.42	12.453	16.31	4.5487	
95	07/29/00	09:00 AM	31.24	17.38	12.468	16.24	5.5070	
96	07/29/00	10:00 PM	31.25	17.92	12.546	16.25	6.0487	
97	07/30/00	04:00 AM	31.06	18.17	12.546	16.06	6.2987	
98	07/30/00	08:00 PM	31.08	18.83	12.562	16.08	6.9653	

Figure 3



TH-2 Barometric Correction Setup
ECP-1 Q=1005 gpm beginning day 11.868
Air P (-27) and WL in Feet of Water
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
5
10
15
20
Day Since Measurements Started

TH-2 Pumping Response and Barometric Pressure for 7-Day Test Drawdown Adjustments

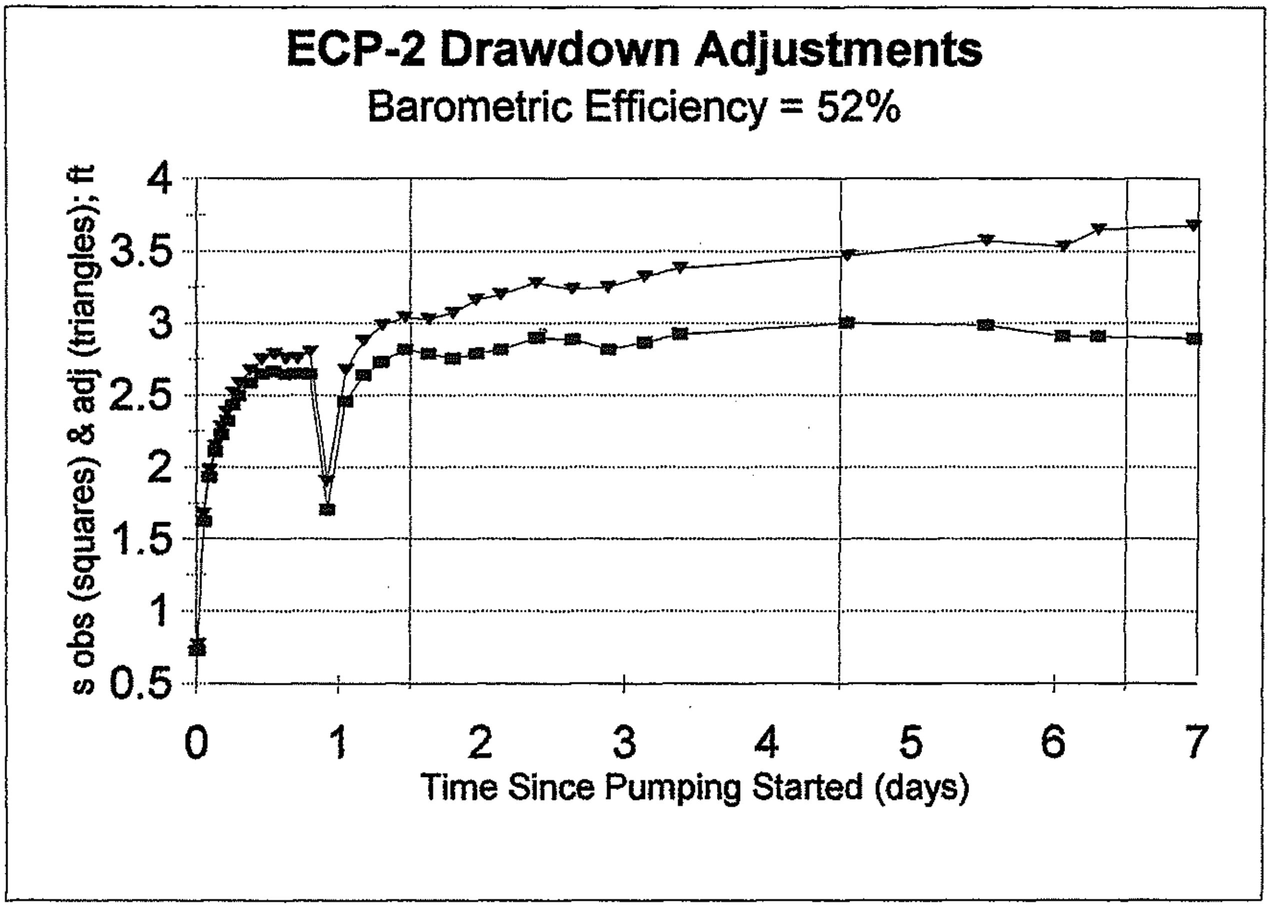
3-point smoothing for 6-hr average to day 7 for trend, then 3-hour data until test begins

Pumping was 1005 gpm from ECP-1 beginning 8:50 PM July 23, 2000 (began @11.868 days)

seq no	date	time	bp (ft h2O)	t (days)	wl (feet)	bp-26	pump t
1	12-Jul-00	04:00:00 PM	31.278	0.67	4.341	5.278	start trend period for BE
2	12-Jul-00	10:00:00 PM	31.228	0.92	4.346	5.228	
3	13-Jul-00	04:00:00 AM	31.248	1.17	4.328	5.248	
4	13-Jul-00	10:00:00 AM	31.352	1.42	4.291	5.352	
5	13-Jul-00	04:00:00 PM	31.297	1.67	4.313	5.297	
6	13-Jul-00	10:00:00 PM	31.256	1.92	4.318	5.256	
7	14-Jul-00	04:00:00 AM	31.272	2.17	4.318	5.272	
8	14-Jul-00	10:00:00 AM	31.340	2.42	4.285	5.340	
9	14-Jul-00	04:00:00 PM	31.279	2.67	4.332	5.279	
10	14-Jul-00	10:00:00 PM	31.207	2.92	4.366	5.207	
11	15-Jul-00	04:00:00 AM	31.207	3.17	4.361	5.207	
12	15-Jul-00	10:00:00 AM	31.268	3.42	4.335	5.268	
13	15-Jul-00	04:00:00 PM	31.190	3.67	4.381	5.190	
14	15-Jul-00	10:00:00 PM	31.104	3.92	4.415	5.104	
15	16-Jul-00	04:00:00 AM	31.100	4.17	4.403	5.100	
16	16-Jul-00	10:00:00 AM	31.172	4.42	4.377	5.172	
17	16-Jul-00	04:00:00 PM	31.138	4.67	4.394	5.138	
18	16-Jul-00	10:00:00 PM	31.091	4.92	4.417	5.091	
19	17-Jul-00	04:00:00 AM	31.125	5.17	4.396	5.125	
20	17-Jul-00	10:00:00 AM	31.234	5.42	4.360	5.234	
21	17-Jul-00	04:00:00 PM	31.216	5.67	4.364	5.216	
22	17-Jul-00	10:00:00 PM	31.194	5.92	4.376	5.194	
23	18-Jul-00	04:00:00 AM	31.227	6.17	4.357	5.227	
24	18-Jul-00	10:00:00 AM	31.360	6.42	4.327	5.360	
25	18-Jul-00	04:00:00 PM	31.304	6.67	4.344	5.304	
26	18-Jul-00	10:00:00 PM	31.213	6.92	4.378	5.213	end trend period for BE
27	19-Jul-00	01:00:00 AM	31.20	7.04	4.37	5.202	
28	19-Jul-00	04:00:00 AM	31.18	7.17	4.36	5.181	
29	19-Jul-00	07:00:00 AM	31.25	7.29	4.37	5.254	
30	19-Jul-00	10:00:00 AM	31.35	7.42	4.36	5.355	
31	19-Jul-00	01:00:00 PM	31.32	7.54	4.36	5.316	
32	19-Jul-00	04:00:00 PM	31.22	7.67	4.38	5.220	
33	19-Jul-00	07:00:00 PM	31.15	7.79	4.41	5.150	
34	19-Jul-00	10:00:00 PM	31.14	7.92	4.41	5.142	
35	20-Jul-00	01:00:00 AM	31.12	8.04	4.41	5.119	
36	20-Jul-00	04:00:00 AM	31.10	8.17	4.39	5.097	
37	20-Jul-00	07:00:00 AM	31.17	8.29	4.39	5.168	
38	20-Jul-00	10:00:00 AM	31.28	8.42	4.39	5.276	start change period for BE
39	20-Jul-00	01:00:00 PM	31.23	8.54	4.39	5.230	
40	20-Jul-00	04:00:00 PM	31.14	8.67	4.40	5.142	
41	20-Jul-00	07:00:00 PM	31.08	8.79	4.43	5.079	
42	20-Jul-00	10:00:00 PM	31.06	8.92	4.44	5.059	end change period for BE
43	21-Jul-00	01:00:00 AM	31.05	9.04	4.42	5.053	
44	21-Jul-00	04:00:00 AM	31.04	9.17	4.40	5.041	
45	21-Jul-00	07:00:00 AM	31.15	9.29	4.39	5.147	
46	21-Jul-00	10:00:00 AM	31.27	9.42	4.38	5.272	
47	21-Jul-00	01:00:00 PM	31.24	9.54	4.39	5.240	
48	21-Jul-00	04:00:00 PM	31.17	9.67	4.39	5.165	
49	21-Jul-00	07:00:00 PM	31.11	9.79	4.40	5.108	
50	21-Jul-00	10:00:00 PM	31.11	9.92	4.39	5.111	Step-Drawdown test
51	22-Jul-00	01:00:00 AM	31.12	10.04	4.35	5.119	Step-Drawdown test
52	22-Jul-00	04:00:00 AM	31.13	10.17	4.28	5.126	
53	22-Jul-00	7:00:00 AM	31.19	10.29	4.27	5.191	start WL trend period for test
54	22-Jul-00	10:00:00 AM	31.32	10.42	4.29	5.316	
55	22-Jul-00	1:00:00 PM	31.27	10.54	4.31	5.271	
56	22-Jul-00	4:00:00 PM	31.20	10.67	4.34	5.203	
57	22-Jul-00	7:00:00 PM	31.16	10.79	4.35	5.158	
58	22-Jul-00	10:00:00 PM	31.18	10.92	4.34	5.180	

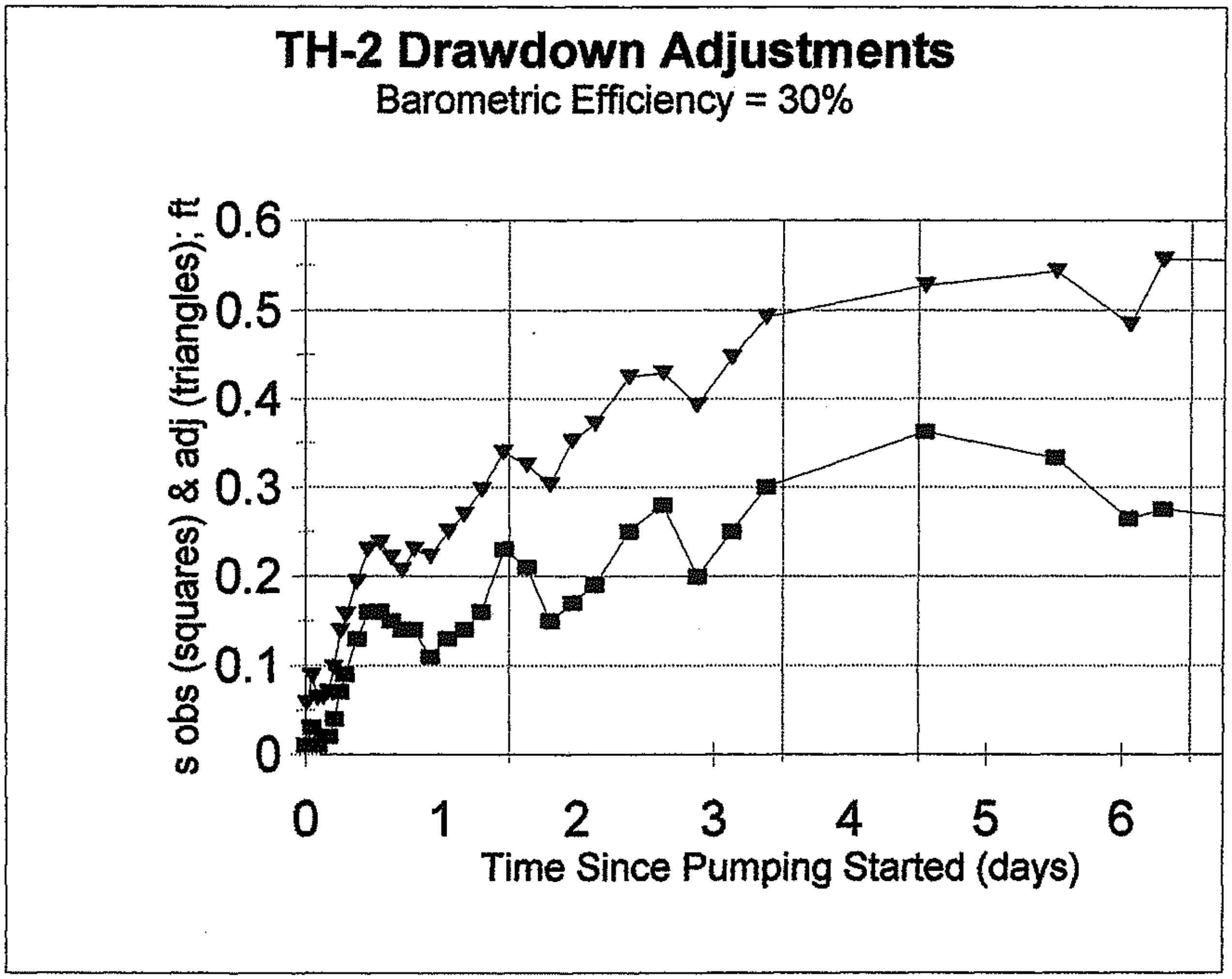
59	23-Jul-00	1:00:00 AM	31.20	11.04	4.35	5.203		
60	23-Jul-00	4:00:00 AM	31.21	11.17	4.32	5.214		
61	23-Jul-00	7:00:00 AM	31.27	11.29	4.30	5.271		
62	23-Jul-00	10:00:00 AM	31.37	11.42	4.30	5.373		
63	23-Jul-00	1:00:00 PM	31.32	11.54	4.34	5.316		
64	23-Jul-00	4:00:00 PM	31.24	11.67	4.36	5.237		
65	23-Jul-00	7:00:00 PM	31.20	11.79	4.35	5.203	end WL trend period for test	
66	23-Jul-00	9:00:00 PM	31.29	11.88	4.30	5.293	0.0069	
67	23-Jul-00	10:00:00 PM	31.32	11.92	4.28	5.316	0.0486	
68	23-Jul-00	11:00:00 PM	31.30	11.96	4.30	5.305	0.0903	
69	24-Jul-00	12:00:00 AM	31.27	12.00	4.29	5.271	0.1319	
70	24-Jul-00	1:00:00 AM	31.25	12.04	4.29	5.248	0.1736	
71	24-Jul-00	2:00:00 AM	31.23	12.08	4.27	5.225	0.2153	
72	24-Jul-00	3:00:00 AM	31.20	12.13	4.24	5.203	0.2569	
73	24-Jul-00	4:00:00 AM	31.21	12.17	4.22	5.214	0.2986	
74	24-Jul-00	6:00:00 AM	31.23	12.25	4.18	5.225	0.3819	
75	24-Jul-00	8:00:00 AM	31.33	12.33	4.15	5.327	0.4653	
76	24-Jul-00	10:00:00 AM	31.35	12.42	4.15	5.350	0.5486	
77	24-Jul-00	12:00:00 PM	31.32	12.50	4.16	5.316	0.6319	
78	24-Jul-00	2:00:00 PM	31.26	12.58	4.17	5.259	0.7153	
79	24-Jul-00	4:00:00 PM	31.19	12.67	4.17	5.191	0.7986	pump failure
80	24-Jul-00	7:00:00 PM	31.13	12.79	4.20	5.135	0.9236	1609 to 1829
81	24-Jul-00	10:00:00 PM	31.12	12.92	4.18	5.124	1.0486	
82	25-Jul-00	1:00:00 AM	31.10	13.04	4.17	5.101	1.1736	
83	25-Jul-00	4:00:00 AM	31.09	13.17	4.15	5.090	1.2986	
84	25-Jul-00	8:00:00 AM	31.20	13.33	4.08	5.203	1.4653	
85	25-Jul-00	12:00:00 PM	31.20	13.50	4.10	5.203	1.6319	
86	25-Jul-00	4:00:00 PM	31.09	13.67	4.16	5.090	1.7986	
87	25-Jul-00	8:00:00 PM	31.01	13.83	4.14	5.010	1.9653	
88	26-Jul-00	12:00:00 AM	31.03	14.00	4.12	5.033	2.1319	
89	26-Jul-00	6:00:00 AM	31.08	14.25	4.06	5.078	2.3819	
90	26-Jul-00	12:00:00 PM	31.19	14.50	4.03	5.191	2.6319	
91	26-Jul-00	6:00:00 PM	31.07	14.75	4.11	5.067	2.8819	
92	27-Jul-00	12:00:00 AM	31.08	15.00	4.06	5.078	3.1319	
93	27-Jul-00	6:00:00 AM	31.12	15.25	4.01	5.124	3.3819	
94	28-Jul-00	10:00 AM	31.31	16.42	3.95	5.310	4.5487	
95	29-Jul-00	09:00 AM	31.24	17.38	3.98	5.238	5.5070	
96	29-Jul-00	10:00 PM	31.25	17.92	4.05	5.248	6.0487	
97	30-Jul-00	04:00 AM	31.06	18.17	4.04	5.059	6.2987	
98	30-Jul-00	08:00 PM	31.08	18.83	4.05	5.077	6.9653	

Figure 4



ECP-2 Drawdown Adjustments
Barometric Efficiency = 52%
s obs (squares) & adj (triangles); ft
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
Time Since Pumping Started (days)

Figure 5



TH-2 Drawdown Adjustments
Barometric Efficiency = 30%
s obs (squares) & adj (triangles); ft
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
Time Since Pumping Started (days)

Figure 6

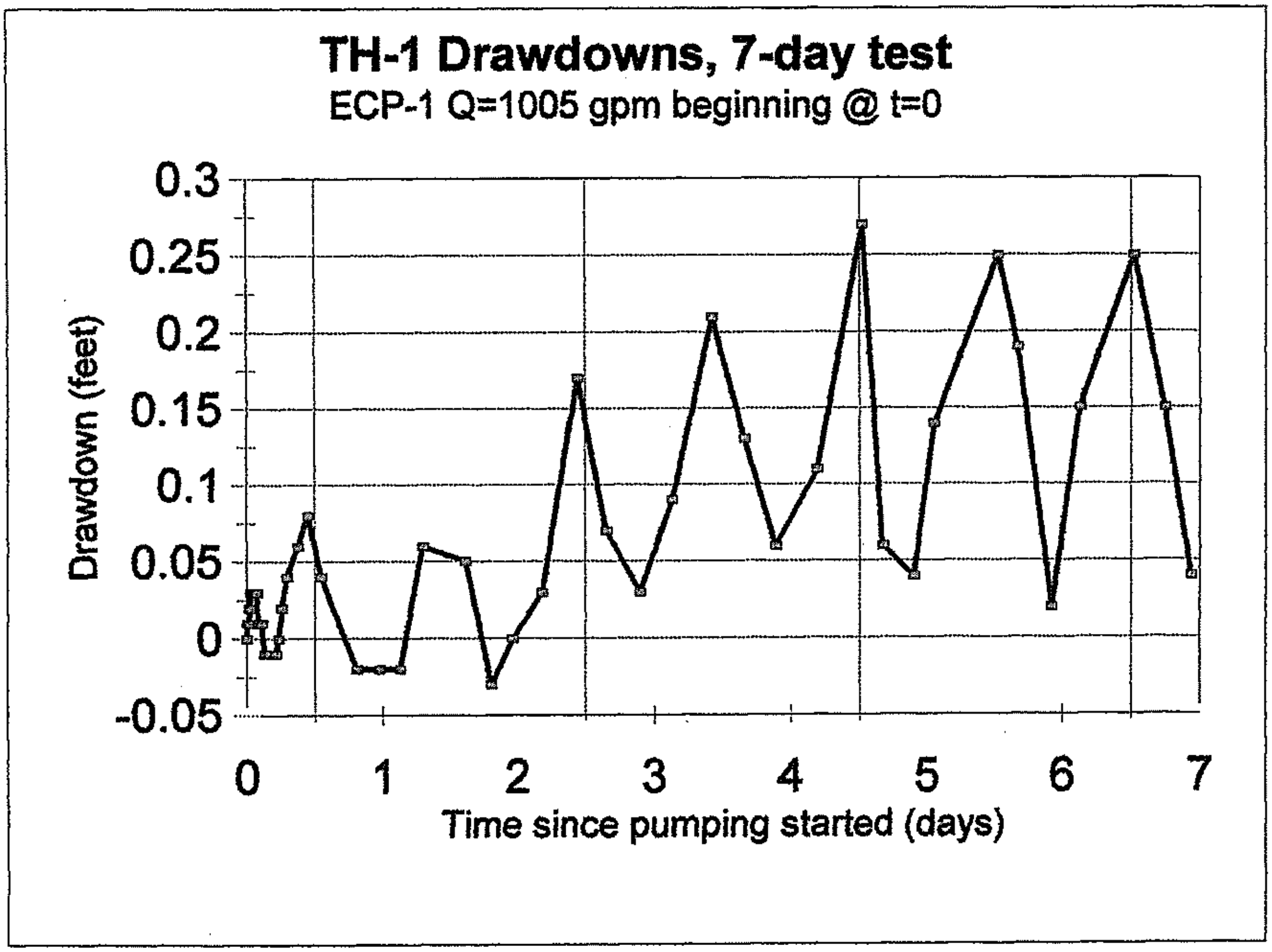
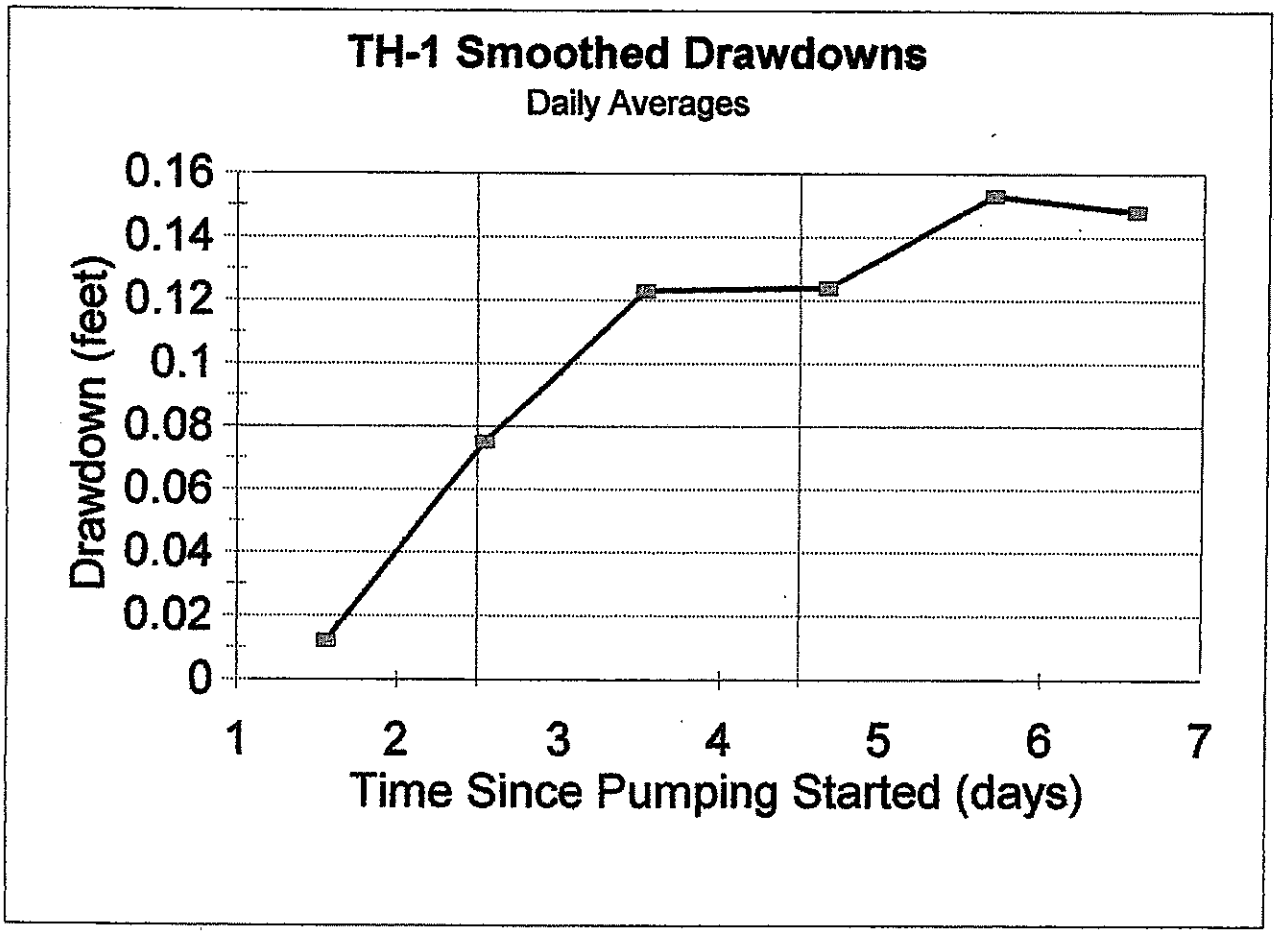

TH-1 Drawdowns, 7-day test
ECP-1 Q=1005 gpm beginning @ t=0
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
Drawdown (feet)
0
1
2
3
4
5
6
7
Time since pumping started (days)

Figure 7


TH-1 Smoothed Drawdowns
Daily Averages
Drawdown (feet)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
Time Since Pumping Started (days)

TH-1 Water Level and Drawdown Summary for 7-day Test

Pumping was 1005 gpm from ECP-1 beginning 8:50 PM July 23, 2000

Date	Time	t (days)	386-WL	t pump	s (ft)
23-Jul-00	07:43 PM	11.822	30.86		
23-Jul-00	08:00 PM	11.833	30.86		
23-Jul-00	08:10 PM	11.840	30.86		
23-Jul-00	08:20 PM	11.847	30.85		
23-Jul-00	08:45 PM	11.865	30.80		
23-Jul-00	08:50 PM	11.868	30.80	**pump on**	
23-Jul-00	08:53 PM	11.870	30.80	0.0021	0
23-Jul-00	08:56 PM	11.872	30.80	0.0042	0
23-Jul-00	09:00 PM	11.875	30.79	0.0069	0.01
23-Jul-00	09:05 PM	11.878	30.79	0.0104	0.01
23-Jul-00	09:10 PM	11.882	30.79	0.0139	0.01
23-Jul-00	09:15 PM	11.885	30.79	0.0174	0.01
23-Jul-00	09:20 PM	11.889	30.78	0.0208	0.02
23-Jul-00	09:25 PM	11.892	30.78	0.0243	0.02
23-Jul-00	09:30 PM	11.896	30.78	0.0278	0.02
23-Jul-00	09:35 PM	11.899	30.77	0.0313	0.03
23-Jul-00	09:40 PM	11.903	30.77	0.0347	0.03
23-Jul-00	09:45 PM	11.906	30.77	0.0382	0.03
23-Jul-00	09:50 PM	11.910	30.77	0.0417	0.03
23-Jul-00	10:00 PM	11.917	30.77	0.0486	0.03
23-Jul-00	10:10 PM	11.924	30.77	0.0556	0.03
23-Jul-00	10:20 PM	11.931	30.77	0.0625	0.03
23-Jul-00	10:30 PM	11.938	30.77	0.0694	0.03
23-Jul-00	10:40 PM	11.944	30.77	0.0764	0.03
23-Jul-00	10:50 PM	11.951	30.79	0.0833	0.01
23-Jul-00	11:00 PM	11.958	30.79	0.0903	0.01
23-Jul-00	11:30 PM	11.979	30.79	0.1111	0.01
24-Jul-00	12:00 AM	12.000	30.81	0.1319	-0.01
24-Jul-00	12:30 AM	12.021	30.81	0.1528	-0.01
24-Jul-00	01:00 AM	12.042	30.81	0.1736	-0.01
24-Jul-00	02:00 AM	12.083	30.81	0.2153	-0.01
24-Jul-00	02:32 AM	12.106	30.80	0.2375	0
24-Jul-00	03:02 AM	12.126	30.78	0.2583	0.02
24-Jul-00	04:00 AM	12.167	30.76	0.2986	0.04
24-Jul-00	05:50 AM	12.243	30.74	0.3750	0.06
24-Jul-00	07:47 AM	12.324	30.72	0.4563	0.08
24-Jul-00	10:03 AM	12.419	30.76	0.5507	0.04
24-Jul-00	04:25 PM	12.684	30.82	0.8160	-0.02
24-Jul-00	08:23 PM	12.849	30.82	0.9813	-0.02
25-Jul-00	12:00 AM	13.000	30.82	1.1319	-0.02
25-Jul-00	04:00 AM	13.167	30.74	1.2986	0.06
25-Jul-00	11:35 AM	13.483	30.75	1.6146	0.05
25-Jul-00	04:10 PM	13.674	30.83	1.8056	-0.03
25-Jul-00	08:00 PM	13.833	30.80	1.9653	0
26-Jul-00	01:12 AM	14.050	30.77	2.1819	0.03
26-Jul-00	07:35 AM	14.316	30.63	2.4479	0.17
26-Jul-00	12:30 PM	14.521	30.73	2.6528	0.07
26-Jul-00	06:22 PM	14.765	30.77	2.8972	0.03
27-Jul-00	12:08 AM	15.006	30.71	3.1375	0.09
27-Jul-00	07:10 AM	15.299	30.59	3.4306	0.21
27-Jul-00	12:50 PM	15.535	30.67	3.6667	0.13
27-Jul-00	06:17 PM	15.762	30.74	3.8938	0.06
28-Jul-00	01:31 AM	16.063	30.69	4.1951	0.11
28-Jul-00	09:20 AM	16.389	30.53	4.5208	0.27
28-Jul-00	01:00 PM	16.542	30.74	4.6736	0.06
28-Jul-00	06:35 PM	16.774	30.76	4.9063	0.04
28-Jul-00	10:12 PM	16.925	30.66	5.0569	0.14
29-Jul-00	09:28 AM	17.394	30.55	5.5264	0.25
29-Jul-00	12:58 PM	17.540	30.61	5.6722	0.19

29-Jul-00	07:00 PM	17.792	30.78	5.9236	0.02
30-Jul-00	12:05 AM	18.003	30.65	6.1354	0.15
30-Jul-00	09:30 AM	18.396	30.55	6.5278	0.25
30-Jul-00	02:50 PM	18.618	30.65	6.7500	0.15
30-Jul-00	07:20 PM	18.806	30.76	6.9375	0.04

Corroboration of Aquifer Thickness

An aquifer thickness of 5000 feet was inferred from groundwater temperatures in the Muddy River Springs area; depths of circulation of a few thousand feet would be required for the geothermal gradient to warm groundwater to observed temperatures. An analysis of the relationship between barometric efficiency and storativity (Walton, 1996, p.18) was used to obtain an independent estimate of aquifer thickness, which is in general agreement with the 5000-foot estimate from thermal data. A porosity value of 0.047 (4.7%) was used, based on the average porosity of carbonate rocks in the Coyote Spring Valley obtained from geophysical logs and reported by the USGS (Berger,1992). To summarize corroboration of the thickness estimate,

- We observe a water-level change ΔW in response to a barometric-pressure change ΔB
- Barometric efficiency BE is defined as $\Delta W/\Delta B$, and is related to the aquifer storativity S in the following manner (Ferris and others, 1962, p. 90):

$$S = (\gamma \theta b \beta)[1/BE]$$

- Using early response, prior to the onset of delayed yield, we found $S=6.37\times10^{-4}$
- Our records of water level and barometric pressure indicate that BE is nominally 50% (0.50)
- We let porosity $\theta=0.047$ based on USGS geophysical logs (Berger, 1992)
- Bulk density and compressibility of water are physical constants: $\gamma=62.4$ lb/ft^3, $\beta=2.3\times10^{-8}$ ft^{2}lb
- Solving for thickness b, we obtain b=4739 ft, remarkably close to our 5000-ft initial estimate

APPENDIX B

Geochemical and Isotopic Data
For the
Arrow Canyon Range Cell and Surrounding Areas

Raw Data
Stiff Diagrams
Piper Diagram
Stable Isotope Plot

Table B1: Geochemical and Isotopic Data for the Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

ID Number	Name	North Latitude	West Longitude	Collection Date	Lab Analyzing Data	Reference
CSV-2	MRS4 well	364650	1144320	1/26/86	USGS	1
MX-6	CV7 well	364604	1144713	1/26/86	USGS	1
MS-1	Big Muddy Spring	364320	1144248	7/22/81	USGSa	1
PS-1	Pederson Spring	364236	1144254	3/00/70	USGS	1
ECP-1a	Calpine test well	363246	1144807	4/7/00	NEL, DRI	6
ECP-1	Calpine well	363246	1144807	7/27/00	NEL	6
ECP-2	Calpine well	363245	1144807	12/7/00	NEL	6
ECP-3	Calpine test well	-	-	10/31/00	NEL	6
TH-1	Moapa well	363153	1144748	4/7/00	NEL, DRI	6
DLV-1	Dry Lake Valley well	362718	1145038	7/1/85	USGS	1
Gen 1	Genstar well	362329	1145414	3/31/86	USGS	1
Grace 1	Grace Petroleum well	362258	1145500	4/26/82	USGS	1
GP1a	Georgia Pacific well	362028	1145536	9/30/86	USGS	1
EPB-2	NV Cogeneration well	361731	1145319	6/21/90	DRI	3
EBM-4	NV Cogeneration well	361740	1145314	-	-	5
VF-2	CV-2 well	365230	1145644	2/5/86	USGS	1
VF-1.	CV-1 well	365232	1145544	1/6/88	USGS	1
MX-4/5	CV4/5 wells	364744	1145332	-	USGS	1
CSV-3	CV3 well	364127	1145530	10/7/87	USGS	1
SHV-1	Hidden Valley Stock well	363308	1145530	3/28/86	USGS	1
HV-1	DLLLCHidden Valley	-	-	6/5/00	DRI	9
DDL-2*	Desert Dry Lake well	365711	1151151	3/18/87	USGS	1
LS-1*	Lamb Spring	365642	1150621	5/19/88	USGS	2
SS-1*	Sheep Spring	365342	1150653	5/19/88	USGS	1,2
WRS-1*	White Rock Spring	364230	1151420	-	USGSa	1
SM-1*	Sawmill Spring	364050	1151034	5/19/88	USGS	2
MW-1*	Mormon well Spring	363838	1150552	-	USGSa	1,2
WS-1*	Wamp Spring	363830	1150412	3/20/87	USGS	1
WG-1*	Wiregrass Spring	363800	1151229	-	USGSa	1
FW-1	Valley of Fire well	362521	1143252	6/24/85	DRI	1
BP-1	Blue Point Spring	362321	1142526	7/1/85	USGS	1
RS-1	Rogers Spring	362239	1142638	unknown	USGS	1
EH-1	Nevada Power Co	-	-	10/3/85	DRI	7
EH-2	Nevada Power Co	-	-	10/14/85	DRI	7
EH-7	Nevada Power Co	-	-	3/19/87	USGSa	1
RRF	Railroad Farrier well	-	-	2/4/84	USGS	1
M-1	Moapa Monitor well	363815	1144244	10/11/00	NEL	6
M-2	Moapa Monitor well	362936	1144848	10/17/00	NEL	6
M-3	Moapa Monitor well	363130	1145139	10/21/00	NEL	6
KSV-1†	Willow Spring	370534	1144952	2/3/84	USGS	1
KSV-2†	Grapevine Spring	370808	1144202	2/3/84	USGS	1
KSV-3†	Kane Spring	371446	1144221	2/2/84	USGS	1
KSV-4†	Boulder Spring	371612	1143844	2/2/84	USGS	1
Jen-1†	Jensen well	371103	1142752	4/10/85	USGS	1
Ran-1†	Randono well	371926	1143008	2/3/84	USGS	1
Brad-1†	Bradshaw well	372057	1143238	2/1/84	USGS	1
RR-1†	Railroad well	372104	1143202	1/31/84	USGS	1
Ash"	Ash Spring	372749	1151134	n/a	USGS	1,4
Crystal"	Crystal Spring	373153	1151358	n/a	USGS	1,4

Units used are mg/l unless otherwise noted

Table B1: Geochemical and Isotopic Data
for the
Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

ID Number	Na	K	Ca	Mg	Cl	HCO3	SO4	SiO2	Fluoride
CSV-2	100	10	60	27	61	276	160	30	2.3
MX-6	87	10	58	25	53	271	159	30	2.1
MS-1	96	10	66	26	61	270	190	29	2.1
PS-1	110	8.8	75	26	59	280	190	25	2.1
ECP-1a	110	17	120	52	150	200	290	20	2.2
ECP-1	110	14	110	46	110	160	270	10	2.1
ECP-2	93	14	110	44	120	180	260	20	2.3
ECP-3	99	13	100	45	120	180	260	11	2.3
TH-1	110	15	110	49	130	180	240	7.3	2.2
DLV-1	120	13	110	48	170	210	360	21	2.1
Gen 1	140	1.3	120	47	180	226	370	23	1.6
Grace 1	140	16	120	46	190	230	360	21	1.6
GP1a	129	12	120	46	200	226	380	23	1.4
EPB-2	134	15.9	120	54.5	183	225	388	20.3	1.4
EBM-4	134	21	117	53	217	199	374	21	-
VF-2	81	11	47	21	34	303	90	34	1.7
VF-1	34	1.2	41	7.5	42	156	20	14	0.5
MX-4/5	81	11	46	20	34	295	105	33	1.9
CSV-3	38	10	51	25	26	299	54	24	1.2
SHV-1	86	12	33	30	64	245	90	27	1.2
HV-1	120	12.9	101	53.2	148	223	358	19.1	-
DDL-2*	35	5.7	22	27	8.9	207	48	49	0.6
LS-1*	8.7	0.6	37	41	8.6	289	24	12	0.2
SS-1*	7.9	1.1	31	40	7.1	276	13	13	0.2
WRS-1*	14	7.2	37	30	10	275	8.5	46	0.2
SM-1*	1.8	0.6	12	29	2.1	162	5.9	6.1	0.2
MW-1*	12	0.6	77	42	18	395	13	16	0.1
WS-1*	10	2.1	71	13	4.9	293	8.4	24	0.2
WG-1*	3	1.7	70	33	3.1	370	7	12	0.1
FW-1	39	8.2	118	53	21	164	449	8.3	0.2
BP-1	360	23	510	170	500	160	2300	18	1.4
RS-1	290	20	430	136	333	163	1633	18	1.4
EH-1	-	-	-	-	-	-	-	-	-
EH-2	-	-	-	-	-	-	-	-	-
EH-7	-	-	-	-	-	-	-	-	-
RRF	-	-	-	-	-	-	-	-	-
M-1	110	13	94	41	74	240	220	23	-
M-2	110	15	110	50	140	170	290	17	-
M-3	79	14	130	49	100	190	300	14	-
KSV-1†	56	4.6	20	2.7	22	140	34	65	1.1
KSV-2†	17	2.3	75	22	27	280	40	22	0.9
KSV-3†	20	5.9	44	13	17	210	14	60	2.8
KSV-4†	12	2.3	21	4.9	7.8	100	6	41	1.7
Jen-1†	100	7.2	55	14	45	340	80	56	2.1
Ran-1†	100	8.4	46	14	44	350	63	54	2.3
Brad-1†	120	11	85	28	52	550	76	63	2.3
RR-1†	98	8.8	42	14	42	300	60	51	2.3
Ash"	29	7.7	46	15	8	259	33	30	0.9
Crystal"	22	5.3	44	22	8.7	258	33	24	0.3

Units used are mg/l unless otherwise noted

Table B1: Geochemical and Isotopic Data for the Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

ID Number	Temp°C	pH	EC µmhos/cm @25°C	Constituents Sum/TDS(7)	Constituents TDS(8)	Dissolved Oxygen	Deuterium (permil)	Oxygen-18 (permil)
CSV-2	27.0	7.4	1000	590	-	4.0	-98.0	-12.85
MX-6	33.5	7.2	980	560	-	3.7	-97.0	-12.95
MS-1	32.5	7.2	930	610	-	3.0	-97.8	-12.90
PS-1	32.2	-	1000	640	-	-	-97.0	-12.75
ECP-1a	30.5	8.1	1100	894	996	-	-99.0	-13.50
ECP-1	30.5	7.5	897	754	757	-	-	-
ECP-2	29.7	8.0	1170	750	727	-	-	-
ECP-3	30.6	8.2	1050	742	771	-	-	-
TH-1	-	7.6	-	832	917	-	-99.0	-13.40
DLV-1	29.0	7.3	1400	960	-	2.0	-97.5	-13.30
Gen 1	24.0	7.4	1500	1000	-	4.8	-97.0	-13.05
Grace 1	26.5	7.3	1600	1000	-	0.5	-96.0	-13.70
GP1a	31.0	7.0	1570	1000	-	5.5	-98.0	-13.45
EPB-2	-	7.9	1580	-	-	-	-	-
EBM-4	-	6.8	1463	1136	-	-	-	-
VF-2	34.0	7.4	800	470	-	2.9	-101.0	-13.0
VF-1	28.0	7.0	460	230	-	-	-94.0	-12.6
MX-4/5°	34.7	7.3	750	480	-	2.9	-101.0	-13.0
CSV-3	41.0	7.4	650	380	-	-	-	-
SHV-1	25.0	7.8	820	470	-	3.8	-90.5	-11.2
HV-1	-	7.9	1400	922	-	-	-97.0	-12.9
DDL-2*	19.0	8.0	400	300	-	-	-98.0	-13.1
LS-1*	13.5	7.7	500	n/a	-	6.1	-92.5	-13.2
SS-1*	15.0	7.8	520	n/a	-	6.6	-96	-13.35
WRS-1*	12.5	7.5	420	290	-	5.7	-83.5	-9.8
SM-1*	-	-	-	-	-	-	-92.0	-12.9
MW-1*	11.2	7.4	670	370	-	5.1	-91.8	-12.7
WS-1*	7.0	8.1	320	420	-	-	-81.0	-10.6
WG-1*	8.6	7.3	560	310	-	5.4	-94.3	-12.8
FW-1	28.0	7.4	1100	780	-	-	-82.0	-10.6
BP-1	30.0	7.0	3800	4000	-	3.4	-93.0	-12.4
RS-1	30.0	7.4	3800	2900	-	2.3	-92.0	-12.2
EH-1	-	-	-	-	-	-	-96.0	-13.4
EH-2	-	-	-	-	-	-	-99.0	-12.1
EH-7	-	-	-	-	-	-	-91.0	-12.45
RRF	-	-	-	-	-	-	-97.5	-12.5
M-1	29.2	8.1	983	636	666	-	-	-
M-2	29.0	8.1	1130	817	781	-	-	-
M-3	27.8	8.0	1410	779	680	-	-	-
KSV-1†	-	7.5	-	270	-	-	-88.0	-11.6
KSV-2†	-	7.3	-	340	-	-	-87.5	-12.0
KSV-3†	-	7.2	-	280	-	-	-86.5	-11.9
KSV-4†	-	7.9	-	140	-	-	-87.0	-12.6
Jen-1†	-	7.7	840	520	-	-	-88.5	-11.6
Ran-1†	-	7.6	760	500	-	-	-87.5	-11.7
Brad-1†	-	7.3	1100	710	-	-	-88.5	-11.4
RR-1†	-	7.6	730	460	-	-	-86.0	-11.6
Ash"	-	7.2	460	290	-	-	-108.0	-14.1
Crystal"	-	7.3	410	290	-	-	-109.0	-14.3

Units used are mg/l unless otherwise noted

Table B1: Geochemical and Isotopic Data for the Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

ID Number	C-13 (permil)	C-14 (pmc)	H3 pCi/L	Carbonate Well or spg	Number of samples
CSV-2	-5.5	8.4	4.0	yes	1
MX-6	-8.0	8.4	1.8	yes	1
MS-1	-6.0	6.7	<1.0	yes	1
PS-1	-	-	-	yes	1
ECP-1a	-	-	-	yes	1
ECP-1	-	-	-	yes	1
ECP-2	-	-	-	yes	1
ECP-3	-	-	-	yes	1
TH-1	-	-	-	yes	1
DLV-1	-4.2	3.0	7.0	possible	1
Gen 1	-4.9	1.5	<1.0	possible	1
Grace 1	-	-	-	yes	1
GP1a	-5.5	2.7	<0.3	yes	1
EPB-2	-	-	-	yes	1
EBM-4	-	-	-	yes	1
VF-2	-6.1	7.0	<1.0	yes	1
VF-1	-	-	-	no	1
MX-4/5	-	7.6	<2.0	yes	2
CSV-3	-	-	-	no	1
SHV-1	-	-	<1.0	possible	1
HV-1	-	-	-	yes	1
DDL-2*	-5.3	1.3	<0.6	yes	1
LS-1*	-	-	-	yes	-
SS-1*	-	-	-	yes	-
WRS-1*	-8.3	-	-	yes	2
SM-1*	-	-	-	yes	-
MW-1*	-9.9	-	-	yes	3
WS-1*	-	-	-	yes	1
WG-1*	-10.2	96.8	89.6	yes	8
FW-1	-8.5	18.7	-	no	1
BP-1	-5.3	7.2	-	yes	1
RS-1	-4.05	1.6	-	yes	-
EH-1	-	-	-	no	1
EH-2	-	-	-	no	1
EH-7	-	-	-	no	1
RRF	-	-	-	possible	1
M-1	-	-	-	yes	1
M-2	-	-	-	yes	1
M-3	-	-	-	yes	1
KSV-1†	-	-	-	probable	1
KSV-2†	-	-	-	probable	1
KSV-3†	-	-	-	probable	1
KSV-4†	-	-	-	probable	1
Jen-1†	-	-	-	probable	1
Ran-1†	-	-	-	probable	1
Brad-1†	-	-	-	probable	1
RR-1†	-	-	-	probable	1
Ash"	-	-	-	probable	1
Crystal"	-	-	-	probable	1

Table B1: Geochemical and Isotopic Data for the Arrow Canyon Range Cell and Surrounding Areas, southern Nevada

Legend and References

* Located in the Sheep Mountains
† Located in Southern Meadow Valley
" Part of the White River Flow System

1 Thomas, J.M., Welch, A.H., and Dettinger, M.D., 1996, Geochemistry and isotope hydrology of representative aquifers in the Great Basin of Nevada, Utah, and adjacent states: U.S. Geological Survey Professional Paper 1409-C, 100 p.

2 Schafer, D.H., Morris, T.M., and Dettinger, M.D., 1992, Hydrogeologic and geophysical data for selected wells and springs in the Sheep Range area, Clark and Lincoln Counties, Nevada: U.S. Geological Survey Open File Report 89-425, 26 p.

3 Mifflin and Associates, Inc., 1990, Water quality analysis for Nevada Cogeneration Associates. Inc.

4 Winograd, I. J. and Pearson, F.J.., 1976, Major Carbon-14 anomaly in a regional carbonate aquifer-Possible evidence for megascale channeling, south central Great Basin, Water Resources Research, v. 12, no. 6, p. 1125-1143.

5 Geraghty & Miller, 1994, Water quality analysis for Nevada Cogeneration Associates, Inc.

6 Mifflin and Associates, Inc., 2000, Water quality analysis for Calpine Company

7 Calculated by multiplying HCO_3 by 0.4916 to make comparable to residue upon evaportation value (per reference 1 above)

8 TDS value from residue upon laboratory evaporation

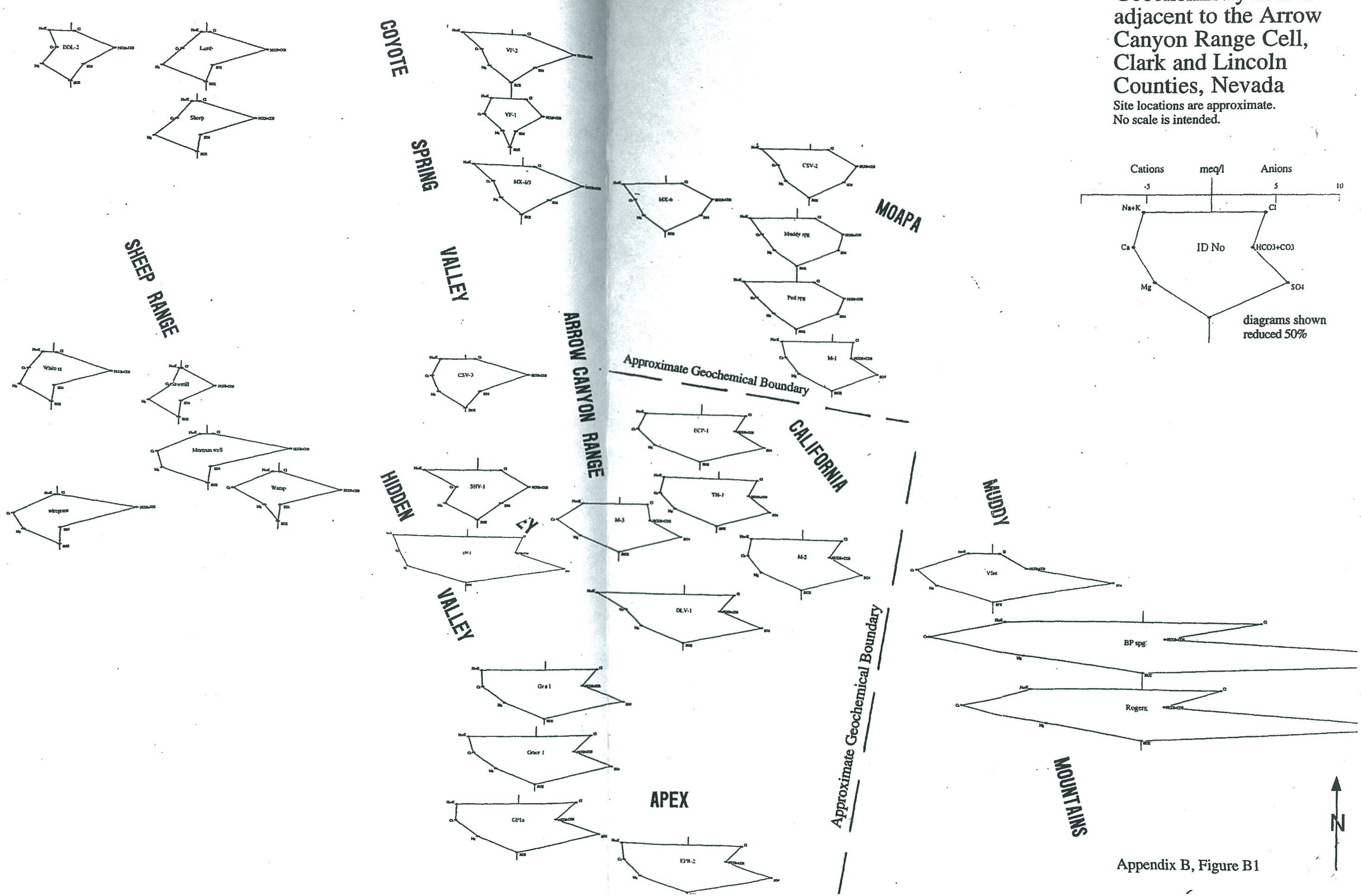
9 Southern Nevada Water Authority (SNWA)

MX 4/5° USGS average for Deuterium and Oxygen is shown. Measured value for MX-4 is -102.5 and -13.0 and MX-5 is -99.5 and 12.9, respectively.

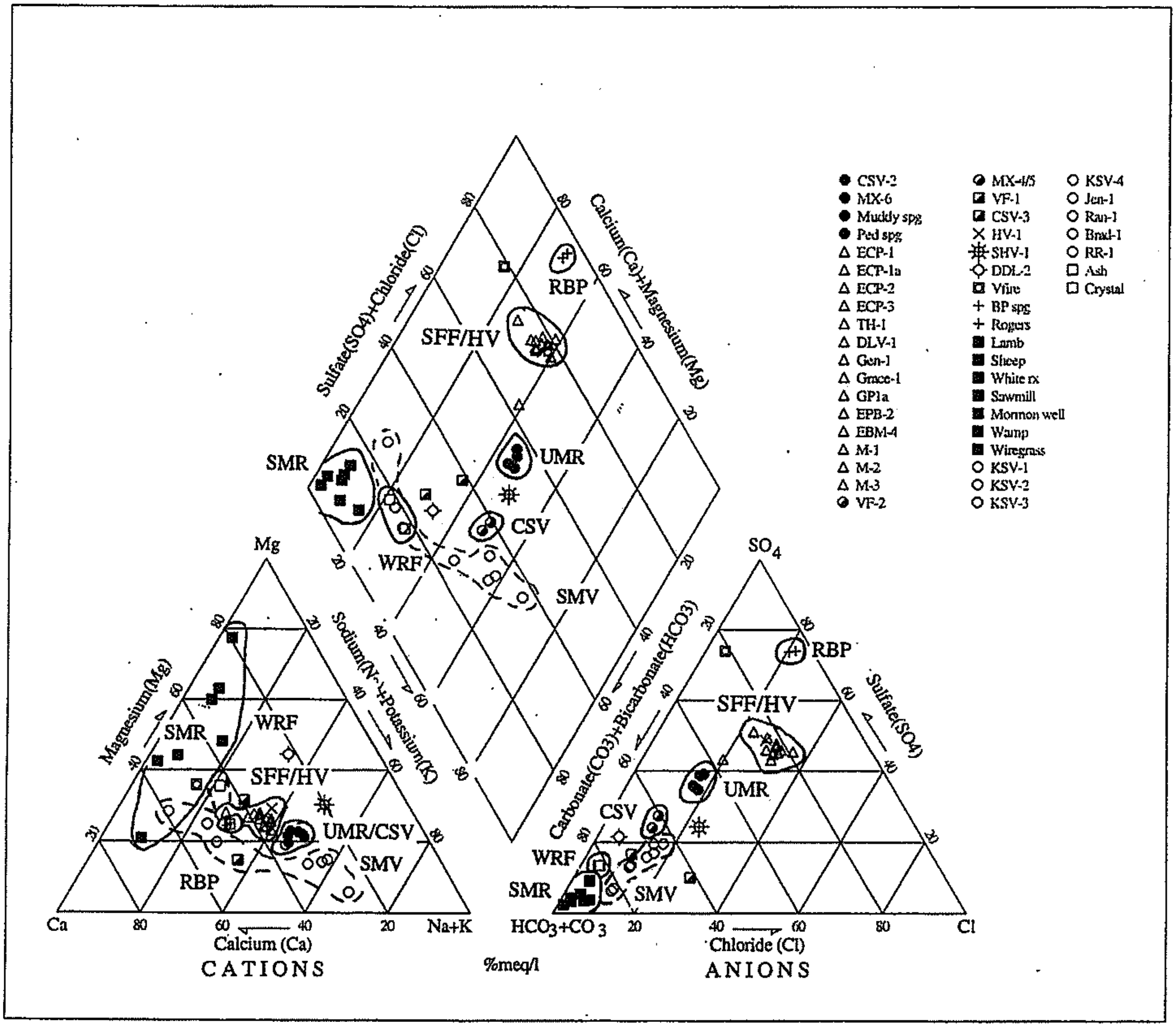
USGSa average of multiple measurements

Stiff Diagrams of Geochemistry in and adjacent to the Arrow Canyon Range Cell, Clark and Lincoln Counties, Nevada

Site locations are approximate.
No scale is intended.

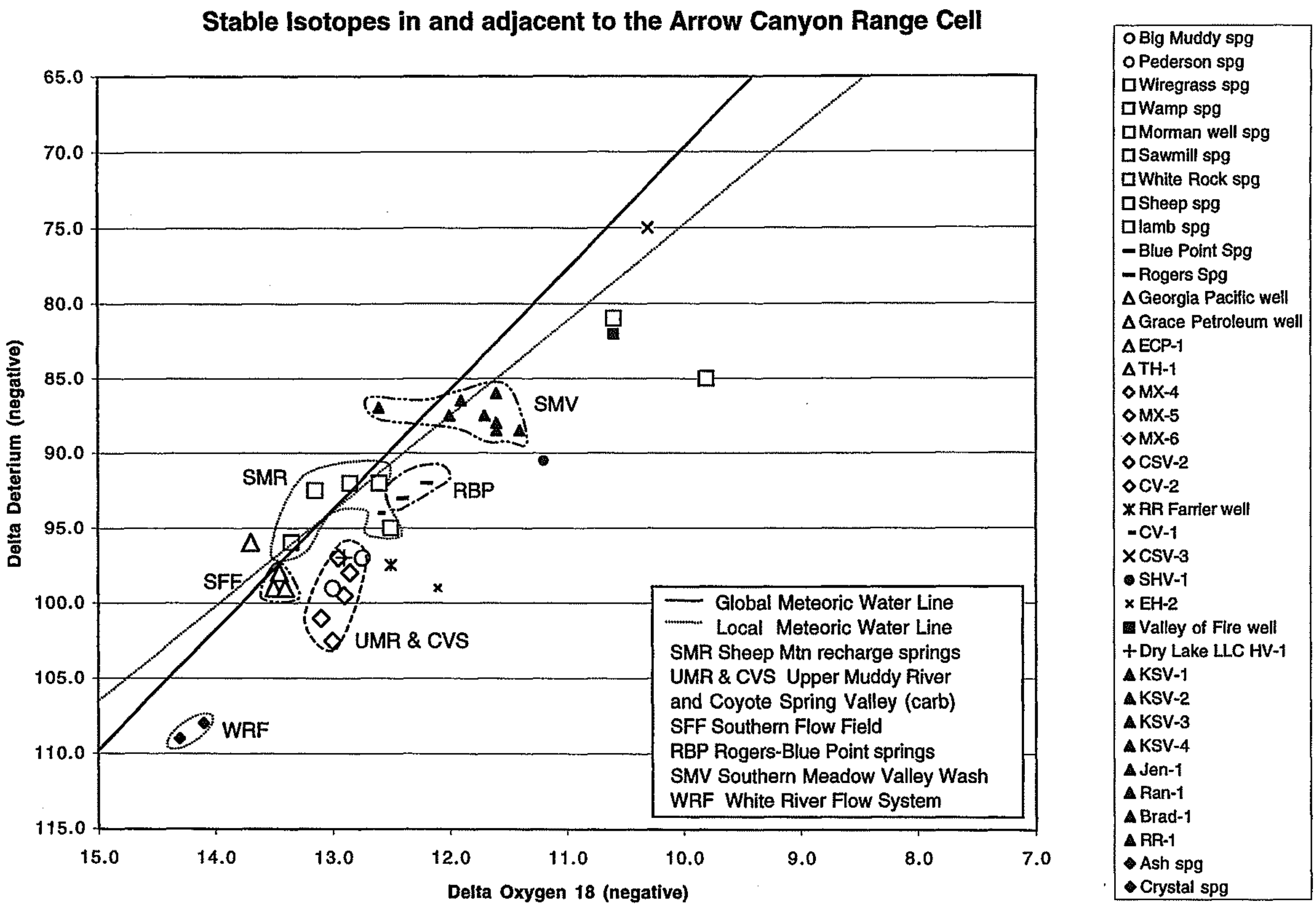


Appendix B, Figure B1



SMR	Sheep Mtn. recharge springs	RBP	Rogers-Blue Point springs
SFF	Southern flow field carbonate wells	WRF	White River Flow System
UMR	Upper Muddy River carbonate wells & springs	SMV	Southern Meadow Valley Wash
CSV	Coyote Spring Valley carbonate wells	HV	Hidden Valley carbonate well

Figure B2. Geochemistry in and adjacent to the Arrow Canyon Range Cell



Appendix B, Figure B3

APPENDIX C

Horizontal and Vertical Elevation Control
And Water Levels

For

Carbonate Rock and Associated Wells Located
In the
Apex, California Wash, Hidden Valley,
Coyote Spring, and Moapa Areas

Lincoln and Clark Counties, Nevada

Appendix C, Table C1

Horizontal and Vertical Elevation Control for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring, and Moapa Areas, Lincoln and Clark Counties, Nevada

Data Source					2000 Johnson Professional Surveying			2000 PBS&J			2000 USGS computer database	
Well Number	Well Name	Well Name 2	UTM Zone 11 Easting	UTM Zone 11 Northing	88 datum MAI^^ sfc elev (ft)	88 datum MAI^^ flange (ft)	88 datum MAI^^ measure pt (ft)	88 datum MAI^^ sfc elev (ft)	88 datum MAI^^ flange (ft)	88 datum MAI^^ measure pt (ft)	USGS° MP correction (negative) (ft)	USGS° MP correction established
VF1	CV1										2.1	3/18/92
VF2	CV2	CE-VF-2	684598°°	4082712							0.9	9/12/87
CSV3	CV3		685386°°	4062379							1.5	9/13/87
MX4	CV4	CE-DT-4	688003^^	4074274	2174.7	n/a	2175.69				1.0	6/1/86
MX5	CV5	CE-DT-5	688160°°	4073972							1.1	11/13/90
CSV1	CV6		690832°°	4070947							1.3	12/17/85
MX6	CV7	CE-DT-6	697525°°	4071192							1.3	3/14/85
EH-4	MRS2		703929^^	4064736	1932.2	n/a	1933.54					
EH-5b	MRS3		701569^^	4067619	1843.5	n/a	1845.03					
CSV2	MRS4		703217^^	4072967	2188.3	n/a	2189.29				1.3	9/11/87
SHV-1	H1	Hidden Valley	685841°°	4047065							0.6	11/2/87
DF-1	Dutchman Flat										1.3	3/14/85
EBM-3	NV Cogen		689602^^	4018535	2388.4	2388.88	2389.88					
EBA-1	Georgia Pacific		686513^^	4024108	2425.7	2425.95	2426.99					
CL-1	Chem Lime		687748^^	4026564	2284.7	n/a	2286.48					
xtal-1	NPC Crystal											
xtal-2	NPC Crystal											
ECP-1	Calpine		696735^^	4046586	2230.7	2231.00	n/a	2229.8	2230.31	2233.55		
ECP-2	Calpine		696726^^	4046738	2229.4	2230.90	2233.07	2228.5	2230.50	2232.42		
ECP-3	Calpine							2242.3	2243.43	2243.63		
TH-1	Moapa		697237^^	4044962	2167.7	n/a	2170.29					
TH-2	Moapa		697687^^	4049913	n/a	2340.04	2341.70					
GV-1	Garnet Valley	Dry Lake LLC	683063"	4033946								
HV-1	Hidden Valley	Dry Lake LLC	684198"	4035619								
M-1	M-1							1895.71`	1896.64``	1898.11		
M-2	M-2							2108.77`	2109.42``	2111.02		
M-3	M-3							2235.34	2236.53``	2238.03		
HS-8	Hogan Springs well							1873.38	1877.24```			

MP = Measurement Point
sfc = ground surface
grd = ground surface

Appendix C, Table C1

Horizontal and Vertical Elevation Control for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring, and Moapa Areas, Lincoln and Clark Counties, Nevada

Data Source	1981 & 2000 USGS computer database/Ertec			2000 SNWA	2000 MAI conversion		DRI	1981 USGS/Ertec Data		2000 Integrated Water Resources	
Well Number	29 datum USGS * ° sfc elev (ft)	88 datum''' USGS * ° sfc elev (ft)	USGS * ° survey type and accuracy (ft)	29 Datum SNWA ** Pad elev (ft)	88 Datum SNWA ** Pad elev (ft)	SNWA MP ** correction (negative) (ft)	DRI*** MP elev (ft)	29 Datum ERTEC grd elev (ft)	ERTEC top casing negative(ft)	88 Datum Dry Lake Co Pad elev (ft)	88 Datum Dry Lake Co MP elev (ft)
VF1	2464.2°	2,466.6	Level, 0.1	2464.2††				2464.18	grd level		
VF2	2,466.9	2,469.3	Level, 0.1	2466.9††		0.9	2466.9	2466.86	1.18		
CSV3	2,414.3	2,416.9	Level, 0.1	2414.3††		1.59	2414.3				
MX4	2,172.6		Level, 0.1	2182.0^		1.0	2172.6	2172.58	1.20		
MX5	2169.1'	2,171.4	Level, 0.1	2177.0^		1.0	2169.1	2169.08†	n/a		
CSV1	2,158.6	2,160.9	Level, 0.1	2158.6††		1.3					
MX6	2,274.6	2,276.8	Level, 0.1	2281^				2274.57	1.34		
EH-4							1932.77				
EH-5b							1842.69				
CSV2	2,185.9		Level, 0.1				2187.2				
SHV-1			Level, 0.1	2648.8††°	2651.4'''	0.6				2652.26	2652.75
DF-1	2222'		map, 10	2223.6††		1.5					
EBM-3											
EBA-1											
CL-1											
xtal-1											
xtal-2											
ECP-1											
ECP-2											
ECP-3											
TH-1											
TH-2											
GV-1										2991.18	2692.70
HV-1										2695.95	2699.85
M-1											
M-2											
M-3											
HS-8											

MP = Measurement Point
sfc = ground surface
grd = ground surface

Appendix C, Table C1

Horizontal and Vertical Elevation Control for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring, and Moapa Areas, Lincoln and Clark Counties, Nevada

Legend

*OFR 87-679
** SNWA data
*** DRI data
† elevation: top of rebar set 0.05 ft above grd at well casing
†† ERTEC survey data used (per Gavin Kistinger, SNWA)
††° Possible ERTEC survey data used (per Gavin Kistinger, SNWA)
^ SNWA elevation using a resource grade GPS, ± 6 feet vertical (per Gavin Kistinger, SNWA)
° usgs computer database
°°usgs lat-longs converted to UTM
'usgs computer database uses an elevation of 2222 feet determined from a map
with a 10 foot accuracy
" Dry Lake LLC/ Integrated Water Resources, Inc. survey data (2000)
'" MAI conversions from 29 to 88 datum
¨ top of eight inch steel casing
¨¨ top of six inch steel casing
` pad elevation

^^ MAI elevations and horizontal established with a survey grade GPS. Survey notes include:
TH-2 and CSV-2: upper measurement is top of casing = measuring point
TH-1 measuring point is the top of 1" stand pipe which is 0.82 feet above the surveyed well head elevation of 2169.47 feet
Eh5b upper measurement is right edge of box lip
Eh4 upper measurement is left edge of box lip
MX-4 ground level measurement is cement pad elevation at gate. USGS determined ground level at casing 2174.76 and top of casing measurement point at 2175.69
CL-1 lid thickness is 0.11 feet
EBA-1 lid thickness is 0.035 feet
EBM-3 upper measurement is top of casing = measuring point
Vertical accuracy is ±0.02 feet except for CSV-2 is ±0.06 feet and EBM-3 is +0.07 feet

Appendix C, Table C2

Water Levels for Carbonate Rock and Associated Wells Located in the Apex, California Wash, Hidden Valley, Coyote Spring, and Moapa Areas, Lincoln and Clark Counties, Nevada

Well Number	Well Name	88 datum Elevation measure pt (ft)	Depth water level (ft)	88 datum AMSL water elevation (ft)	Elevation Survey Source	Date of water measurement meter used
VF1*	CV1	2468.7	549	1919.7	USGS/Ertec	6/24/00 USGS calibrated meter
VF2	CV2	2470.2	611.30	1858.90	USGS/Ertec	8/17/00 USGS calibrated meter
CSV3*	CV3	2418.4	594.89	1823.51	USGS/Ertec	8/17/00 USGS calibrated meter
MX4	CV4	2175.69	354.12	1821.57	MAI	8/17/00 USGS calibrated meter
MX5	CV5	2172.5			USGS/Ertec	
CSV1*	CV6	2162.2	348.66	1813.54	USGS/Ertec	8/17/00 USGS calibrated meter
MX6	CV7	2278.1	457.5	1820.6	USGS/Ertec	Average of four USGS measurements in 1981
EH-4	MRS2	1933.54	116.83	1816.71	MAI	Average 10/1-3/31 for 1987 -1997, DRI recorder measurement
EH-5b	MRS3	1845.03	28.00	1817.03	MAI	Average 10/1-3/31 for 1987 -1997, DRI recorder measurement
CSV2	MRS4	2189.29	392.45	1796.84	MAI	8/17/00 USGS calibrated meter
SHV-1**	Hidden Valley	2652.75	836.60	1816.15	Dry Lake LLC	8/17/00 USGS calibrated meter, Dry Lake LLC measured 828.75 = 1824.00 on 6/4/00
EBM-3	NV Cogen	2389.88	577.05	1812.83	MAI	8/21/00 USGS calibrated meter
EBA-1	Georgia Pacific	2426.99	607	1819.99	MAI	1990 MAI open hole after borehole's total depth
CL-1	Chem Lime	2286.48	471.1	1815.38	MAI	5/21/99 MAI airline measurement
xtal 2	NPC Crystal		256.34			8/21/00 USGS calibrated meter
ECP-1	Calpine	2233.55	417.94	1815.61	MAI	12/05/00 MAI calibrated meter
ECP-2	Calpine	2232.42	416.86	1815.56	MAI	12/05/00 MAI calibrated meter
ECP-3	Calpine	2243.63	428.53	1815.10	MAI	12/05/00 MAI calibrated meter
TH-1	Moapa	2169.95	354.83	1815.12	MAI	12/05/00 MAI calibrated meter
TH-2	Moapa	2341.70	526.25	1815.45	MAI	12/04/00 MAI calibrated meter
M-1	Moapa	1898.11	82.28	1815.83	MAI	12/04/00 MAI calibrated meter
M-2	Moapa	2111.02	298.05	1812.97	MAI	12/04/00 MAI calibrated meter
M-3	Moapa	2238.03	423.00	1815.03	MAI	12/04/00 MAI calibrated meter
GV-1	Garnet Valley	2692.70	880.5	1812.20	Dry Lake LLC	6/4/00 Integrated Water Resources, Inc. measurement
HV-1	Hidden Valley	2699.85	882.5	1817.35	Dry Lake LLC	5/10/00 Integrated Water Resources, Inc. measurement

* none carbonate well

** possible carbonate well

APPENDIX D

Nevada State Engineer Hydrographic Basin Abstracts

Of

Active Water Rights and Applications and Relative Status

Current through August 8, 2000

Appendix D

Nevada State Engineer Hydrographic Basin Abstracts of Active Water Rights and Applications and Relative Status current through 8/17/00 for

Basin Number	Basin Name
210	Coyote Spring
215	Black Mountains
216	Garnet Valley
217	Hidden Valley
218	California Wash
219	Muddy River Spgs
220	Lower Moapa V.

Abbreviations

App	Water right application
Cer	Certificate
Per	Permit
RFA	Ready for action
RFP	Application protested
VST	Vested
STK	Stock
Wld	Wildlife
Ind	Industrial
MM	Mining and milling
Mun	Municipal
Qm	Quasimunicipal
Irr	Irrigation
Pwr	Power
Com	Commercial
Env	Environmental
UG	Underground
MGA	Million gallon annually
AFA	Acre feet annually

NEVADA DIVISION OF WATER RESOURCES
WATER RIGHTS DATABASE

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

Selection Criteria: BASIN IN (210,215,216,217,218,219) AND APP_STATUS IN (APP,CER,PER,RFA,RFP,RVP,VST,RES,RLP,DEC)

APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
***** START OF SECTION FOR BASIN NUMBER: 210 *****																	
3294		1391	03/08/1915	CER	SPR	NW	SE	24	11S	63E	0.013	STK			2.92 MGA	LI	BALLOW, RACHAEL; SCHLARMAN, RACHAEL
4213		468	11/11/1916	CER	SPR	SW	NE	12	11S	61E	0.025	STK			5.89 MGA	LI	LAMB, WM. G.; LAMB, WM. S.
10449		2721	12/04/1939	CER	RES	NE	NW	05	09S	64E	0.013	STK			2.92 MGA	LI	LDS
10478		3946	03/18/1940	CER	STR	SW	SE	11	10S	62E	0.007	STK			5.00 AFA	LI	BUCK HORN CATTLE CO
11641		3370	07/26/1946	CER	SPR	NE	SE	35	11S	61E	0.001	WLD			0.24 MGA	LI	FISH AND WILDLIFE SERVICE-U.S.
11645		3366	07/26/1946	CER	SPR	NE	SE	29	14S	61E	0.001	WLD			0.14 MGS	CL	FISH AND WILDLIFE SERVICE-U.S.
12632		3791	09/13/1948	CER	SPR	SE	NE	01	13S	61E	0.003	WLD			0.71 MGA	LI	FISH AND WILDLIFE SERVICE-U.S.
13519		3785	10/16/1950	CER	SPR	NW	NE	30	14S	61E	0.000	STK			0.02 MGA	CL	FISH AND WILDLIFE SERVICE-U.S.
19306		6011	11/01/1960	CER	SPR	SE	SE	30	14S	61E	0.001	STK			0.04 AFA	CL	FISH AND WILDLIFE SERVICE-U.S.
19708		6069	03/31/1961	CER	SPR	NE	SE	07	15S	62E	0.001	STK			0.02 MGA	CL	FISH AND WILDLIFE SERVICE-U.S.
19709		6070	03/31/1961	CER	SPR	NE	SW	12	15S	61E	0.001	STK			0.09 MGA	CL	FISH AND WILDLIFE SERVICE-U.S.
46777			03/31/1983	PER	UG	SE	SE	23	13S	63E	10.000	IND	Y	0.00	5,000.00 AFA	CL	NEVADA POWER COMPANY

SPECIAL HYDROGRAPHIC ABSTRACT

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
49414			09/27/1985	PER	UG	SE	SE	23	13S	63E	6.000	IND	Y	0.00	4,000.00 AFA	CL	SOUTHERN NEVADA WATER AUTHORITY
49608			12/30/1985	PER	UG	NW	NE	26	13S	63E	10.000	IND	Y	0.00	5,000.00 AFA	CL	NEVADA POWER
49660			01/27/1986	PER	UG	SW	NW	13	11S	63E	0.138	IND	Y	0.00	100.00 AFA	LI	COYOTE SPRINGS INVESTMENT, LLC
49661			01/27/1986	PER	UG	SE	NE	10	12S	63E	0.138	IND	Y	0.00	100.00 AFA	LI	COYOTE SPRINGS INVESTMENT, LLC
49662			01/27/1986	PER	UG	SE	NE	10	13S	63E	0.138	IND	Y	0.00	100.00 AFA	CL	COYOTE SPRINGS INVESTMENT, LLC; SOUTHERN NEVADA WATER AUTHORITY
49978			07/15/1986	PER	UG	SW	NW	13	11S	63E	2.000	IND	Y	0.00	1,447.93 AFA	LI	COYOTE SPRINGS INVESTMENT, LLC
49979			07/15/1986	PER	UG	SE	SE	28	11S	63E	2.000	IND	Y	0.00	1,447.93 AFA	LI	COYOTE SPRINGS INVESTMENT, LLC
49980			07/15/1986	PER	UG	NE	NE	03	12S	63E	2.000	IND	Y	0.00	1,447.93 AFA	LI	COYOTE SPRINGS INVESTMENT, LLC
49981			07/15/1986	PER	UG	SE	NE	10	12S	63E	2.000	IND	Y	0.00	1,447.93 AFA	LI	COYOTE SPRINGS INVESTMENT, LLC
49982			07/15/1986	PER	UG	NW	SE	29	12S	63E	2.000	IND	Y	0.00	1,447.93 AFA	LI	COYOTE SPRINGS INVESTMENT, LLC
49983			07/15/1986	PER	UG	NW	NW	03	13S	63E	2.000	IND	Y	0.00	1,447.93 AFA	CL	COYOTE SPRINGS INVESTMENT, LLC
49984			07/15/1986	PER	UG	SE	NE	10	13S	63E	2.000	IND	Y	0.00	1,447.93 AFA	CL	SOUTHERN NEVADA WATER AUTHORITY

NEVADA DIVISION OF WATER RESOURCES
WATER RIGHTS DATABASE

SPECIAL HYDROGRAPHIC ABSTRACT

RUN DATE: 08/17/00

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
49985			07/15/1986	PER	UG	NE	NE	20	13S	63E	2.000	IND	Y	0.00	1,447.93 AFA	CL	COYOTE SPRINGS INVESTMENT, LLC
49986			07/15/1986	PER	UG	NE	NE	21	13S	63E	2.000	IND	Y	0.00	1,447.93 AFA	CL	COYOTE SPRINGS INVESTMENT, LLC
49987			07/15/1986	PER	UG	NE	NE	01	13S	63E	2.000	IND	Y	0.00	1,447.93 AFA	CL	COYOTE SPRINGS INVESTMENT, LLC
54055			10/17/1989	RFP	UG	SE	SW	05	13S	63E	6.000	MUN		0.00	1,415.46 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
54056			10/17/1989	RFP	UG	SE	SE	32	13S	63E	6.000	MUN		0.00	1,415.56 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
54057			10/17/1989	RFP	UG	SE	NW	16	14S	63E	6.000	MUN		0.00	1,415.46 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
54058			10/17/1989	RFP	UG	NE	NE	01	13S	63E	10.000	MUN		0.00	2,359.10 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
54059			10/17/1989	RFP	UG	NW	NW	19	13S	64E	10.000	MUN		0.00	2,359.10 MGA	CL	LAS VEGAS VALLEY WATER DISTRICT
61458			08/11/1995	PER	UG	SW	NE	24	11S	62E	1.000	MM	Y		200.00 AFA	LI	BEDROC, INC.
62462			09/13/1996	PER	SPR	E2	W2	24	11S	62E	0.350	MM	Y		200.00 AFA	LI	PIPES, WILLIAM B.
62865			02/20/1997	RFP	UG	SE	NW	13	11S	62E	0.500	MM				LI	C.S., INC.
63272			07/24/1997	RFP	UG	SE	SW	23	12S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63273			07/24/1997	RFP	UG	SE	NE	25	12S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63274			07/24/1997	RFP	UG	NE	NE	15	13S	63E	10.000	QM				CL	COYOTE SPRINGS

SPECIAL HYDROGRAPHIC ABSTRACT
RUN DATE: 08/17/00

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
																	INVESTMENT LLC
63275			07/24/1997	RFP	UG	SE	SE	23	12S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63276			07/24/1997	RFP	UG	NE	SW	36	11S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63867			02/24/1998	RFP	UG	NW	SW	12	13S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63868			02/24/1998	RFP	UG	NW	SW	13	13S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63869			02/24/1998	RFP	UG	SW	SW	11	13S	63E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63870			02/24/1998	RFP	UG	NE	SW	07	13S	64E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63871			02/24/1998	RFP	UG	NW	SW	18	13S	64E	10.000	QM				CL	COYOTE SPRINGS INVESTMENT LLC
63872			02/24/1998	RFP	UG	SE	SW	11	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC
63873			02/24/1998	RFP	UG	SW	SW	25	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC
63874			02/24/1998	RFP	UG	SW	SW	13	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC
63875			02/24/1998	RFP	UG	SW	SW	36	11S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC
63876			02/24/1998	RFP	UG	NE	NE	22	11S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT LLC

NEVADA DIVISION OF WATER RESOURCES
WATER RIGHTS DATABASE

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64039			04/17/1998	RFP	UG	NE	SE	28	14S	63E	10.000	QM				CL	DRY LAKE WATER, LLC
64186			06/03/1998	RFP	UG	NW	SE	36	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64187			06/03/1998	RFP	UG	SW	SE	35	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64188			06/03/1998	RFP	UG	NE	SW	34	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64189			06/03/1998	RFP	UG	NE	SW	27	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64190			06/03/1998	RFP	UG	NW	NE	25	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64191			06/03/1998	RFP	UG	NW	SW	24	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
64192			06/03/1998	RFP	UG	NE	SW	26	12S	63E	10.000	QM				LI	COYOTE SPRINGS INVESTMENT, LLC
V01353			03/08/1915	VST	SPR	NE	SW	13	11S	62E	0.125	STK			1.10 MGA	LI	LDS
V01808			03/21/1921	VST	SPR				13S	64E		STK				CL	LYTLE, GEORGE H.
V04545			10/24/1985	VST	UG	E2	W2	24	11S	62E	0.350	IRR		0.00	4.00 AFS	LI	PIPES, WILLIAM B.
***** END OF SECTION FOR BASIN NUMBER: 210 *****																	
***** START OF SECTION FOR BASIN NUMBER: 215 *****																	
6061		1408	04/21/1920	CER	STR	SW	NE	13	17S	68E	0.316	IRR		31.55	228.00 AFA	CL	ARMFIELD, LYMAN; WARD, ERNEST G.

NEVADA DIVISION OF WATER RESOURCES
WATER RIGHTS DATABASE

SPECIAL HYDROGRAPHIC ABSTRACT

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10092		4476	02/16/1937	CER	SPR	SE	SE	12	18S	67E	0.440	WLD		0.00	0.00 *	CL	BLM
15725			06/06/1954	RFP	SPR	NW	NE	07	18S	68E	1.000	MM		0.00	0.00	CL	MCDONALD, W. H.
16129			02/23/1955	RFA	SPR	SW	SE	06	18S	68E	1.500	OTH				CL	MCDONALD, W.H.
19936		5621	06/23/1961	CER	UG	SW	SW	05	19S	68E	0.248	QM		0.00	58.50 MGA	CL	LAKE MEAD; NATIONAL PARK SERVICE-U.S.
29368		9933	05/05/1975	CER	UG	NW	NE	30	17S	67E	0.016	QM	Y	0.00	0.78 MGA	CL	PARKS DIVISION-NEVADA
CHANGE BY:	48816			-CER													
29814			11/28/1975	PER	OSW	NE	NW	11	22S	64E	638.000	MUN		0.00	0.00	CL	COLORADO RIVER RESOURCES; STATE OF NEVADA
CHANGE BY:	53766T			-WDR													
41206		11261	04/30/1980	CER	UG	SW	SW	25	22S	64E	0.170	COM		0.00	12.30 MGA	CL	LAKEVIEW COMPANY; THE GOLD STRIKE INN (DBA)
41786		11262	07/16/1980	CER	UG	SW	SW	25	22S	64E	0.150	COM		0.00	22.58 MGA	CL	LAKEVIEW COMPANY; THE GOLD STRIKE INN (DBA)
42678		14933	10/16/1980	CER	UG	SE	SE	28	21S	63E	0.152	MM		0.00	15.54 MGA	CL	MEEK, LEROY; THOMPSON, CHARLES
CHANGE BY:	47477 64578			-RFP -APP													
46029			08/18/1982	PER	UG	NE	NW	23	21S	63E	5.000	QM	Y	0.00	716.87 MGA	CL	LAKE LAS VEGAS JOINT VENTURE, INC.
46030			08/18/1982	PER	UG	NE	NE	22	21S	63E	5.000	QM	Y	0.00	716.87 MGA	CL	LAKE LAS VEGAS

SPECIAL HYDROGRAPHIC ABSTRACT

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																	JOINT VENTURE, INC.
47477	42678		12/01/1983	RFP	UG	SE	NE	28	21S	63E	0.891	MM		0.00	75.00 MGA	CL	MEEK, LEROY; THOMPSON, CHARLES
48816	29368	13552	02/01/1985	CER	UG	NW	SW	30	17S	67E	0.045	QM	Y	0.00	1.46 MGA	CL	CONSERVATION AND NATURAL RESOURCES
53829			09/08/1989	PER	UG	NW	SW	22	21S	63E	1.000	QM	Y	0.00	235.90 MGA	CL	LAKE LAS VEGAS JOINT VENTURE, INC.
53831			09/08/1989	PER	UG	NW	NE	15	21S	63E	1.000	QM	Y	0.00	235.90 MGA	CL	LAKE LAS VEGAS JOINT VENTURE, INC.
CHANGE BY:	56233			-WDR													
55268			09/13/1990	RFP	UG		LT0326		21S	63E	5.000	QM		0.00	2,016.25 AFA	CL	THREE KIDS ENTERPRISES, INC.
55269	54129		09/13/1990	PER	UG			01	20S	63E	1.150	IND	Y	0.00	271.29 MGA	CL	NEVADA COGENERATION ASSOCIATES #1; NEVADA COGENERATION ASSOCIATES #2
56150	53830		04/05/1991	PER	UG	NE	NE	15	21S	63E	1.000	QM	Y	0.00	723.97 AFA	CL	LAKE LAS VEGAS JOINT VENTURE INC.
58031	55270		08/31/1992	PER	UG	NE	SE	13	19S	63E	1.150	PWR	Y		832.57 AFA	CL	NEVADA COGENERATION ASSOCIATES #1; NEVADA COGENERATION

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																	ASSOCIATES #2
58032	55271		09/13/1990	PER	UG	NE	SE	13	19S	63E	2.300	PWR	Y		1,665.00 AFA	CL	NEVADA COGENERATION ASSOCIATES
58047			09/04/1992	PER	UG	SE	SW	08	20S	65E	1.500	MM	Y		718.00 AFA	CL	OGLEBAY NORTON COMPANY
58048			09/04/1992	PER	UG	SW	SE	08	20S	65E	1.500	MM	Y		718.00 AFA	CL	OGLEBAY NORTON COMPANY
58049			09/04/1992	PER	UG	NE	SE	08	20S	65E	1.500	MM	Y		718.00 AFA	CL	OGLEBAY NORTON COMPANY
58050			09/04/1992	PER	UG	SE	NW	08	20S	65E	1.500	MM	Y		718.00 AFA	CL	OGLEBAY NORTON COMPANY
58051			09/04/1992	PER	UG	SW	SE	05	20S	64E	1.500	MM	Y		718.00 AFA	CL	OGLEBAY NORTON COMPANY
58390		14303	12/11/1992	CER	OSW	SE	SW	22	21S	63E		QM			2,029.00 AFA	CL	LAKE AT LAS VEGAS JOINT VENTURE
58589			03/09/1993	RFP	STR	NE	NW	11	22S	64E	100.000	MUN			30,000.00 AFA	CL	SOUTHERN NEVADA WATER AUTHORITY
58590			03/09/1993	RFP	STR	NE	NW	11	22S	64E	700.000	MUN			150,000.00 AFA	CL	SOUTHERN NEVADA WATER AUTHORITY
58592			03/09/1993	RFP	UG	NE	SE	13	19S	63E	0.274	PWR				CL	NEVADA COGENERATION ASSOCIATES 1 & 2
58593			03/09/1993	RFP	UG	NE	SE	13	19S	63E	0.274	PWR				CL	NEVADA COGENERATION ASSOCIATES 1 & 2

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58594			03/09/1993	RFP	UG	SE	SE	13	19S	63E	0.274	PWR				CL	NEVADA COGENERATION ASSOCIATES 1 & 2
61597			10/10/1995	PER	UG	NW	SW	05	20S	64E	2.010	MM	Y		1,088.80 AFA	CL	OGLEBAY NORTON COMPANY
61598			10/10/1995	PER	UG	NE	NE	15	20S	64E	2.010	MM	Y		1,088.80 AFA	CL	OGLEBAY NORTON COMPANY
61599			10/10/1995	PER	UG	SW	NW	07	20S	65E	2.010	MM	Y		1,088.80 AFA	CL	OGLEBAY NORTON COMPANY
61600			10/10/1995	PER	UG	NE	NE	07	20S	65E	2.010	MM	Y		1,088.80 AFA	CL	OGLEBAY NORTON COMPANY
62691	52254		12/24/1996	PER	UG	SE	SE	29	20S	64E	0.750	MM	Y		542.98 AFA	CL	INTERNATIONAL SILICA CORPORATION
CHANGE BY:	64542			-ABR													
62692	52614		12/24/1996	PER	UG	NE	SE	29	20S	64E	0.750	MM	Y		543.01 AFA	CL	INTERNATIONAL SILICA CORPORATION
CHANGE BY:	63312 64541			-PER -ABR													
63312	62692		08/08/1997	PER	UG	NE	SE	29	20S	64E	0.395	MM	Y		285.96 AFA	CL	INTERNATIONAL SILICA CORPORATION
CHANGE BY:	64540			-ABR													
63313	62693		08/08/1997	PER	UG	NE	SE	29	20S	64E	0.330	MM	Y		78.63 MGA	CL	INTERNATIONAL SILICA CORPORATION

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
64041			04/17/1998	RFP	UG	NE	NW	36	19S	63E	10.000	QM				CL	DRY LAKE WATER, LLC
64578	42678		11/02/1998	APP	UG	SE	SE	28	21S	63E	0.500	QM			90.54 MGA	CL	THOMPSON, PHYLLIS E.
64960E			03/09/1999	PER	UG	NW	SW	05	19S	68E	0.005	ENV			0.01 MGS	CL	ECHO BAY RESORT (DBA); SEVEN RESORTS, INC.
66085E			02/17/2000	PER	UG	NW	SW	05	19S	68E	0.005	ENV				CL	(DBA) ECHO BAY RESORT; SEVEN CROWN RESORTS, INC
66108			02/28/2000	PER	UG	NE	NW	35	21S	63E	0.060	COM			0.44 MGA	CL	ADDI, PAUL
66163	64547		03/17/2000	PER	UG	SW	NW	18	19S	64E	2.000	QM	Y		592.06 AFA	CL	DRY LAKE WATER, L.L.C.
66164	64541		03/17/2000	PER	UG	SW	NW	18	19S	64E	0.190	QM	Y		137.55 AFA	CL	DRY LAKE WATER, L.L.C.
66165	64542		03/17/2000	PER	UG	SW	NW	18	19S	64E	0.750	QM	Y		542.98 AFA	CL	DRY LAKE WATER COMPANY, L.L.C.
66166	64540		03/17/2000	PER	UG	SW	NW	18	19S	64E	0.165	QM	Y		119.44 AFA	CL	DRY LAKE WATER COMPANY, L.L.C.
***** END OF SECTION FOR BASIN NUMBER: 215 *****																	
***** START OF SECTION FOR BASIN NUMBER: 216 *****																	
18140		5115	07/24/1959	CER	UG	SW	SW	21	17S	64E	0.070	DOM		0.00	16.51 MGA	CL	TRANSPORTATION DEPARTMENT-NEVADA
26277	24015	8462	08/30/1971	CER	UG	NW	NE	14	18S	63E	0.220	MM		0.00	49.00 MGA	CL	CHEMICAL LIME COMPANY OF

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
																	ARIZONA
CHANGE BY:	64880			-PER													
	65125T			-EXP													
50663			03/06/1987	PER	UG	SW	SW	04	18S	64E	1.340	MM		0.00	58.00 MGA	CL	GREAT STAR CEMENT CORPORATION
53322	52585		05/26/1989	PER	UG	SW	NE	18	18S	64E	0.010	IND		0.00	0.11 AFA	CL	REPUBLIC ENVIRONMENTAL TECHNOLOGIES
CHANGE BY:	59216T			-EXP													
	59237			-CER													
	60623			-ABR													
	61750			-WDR													
	62494T			-EXP													
	62934T			-EXP													
	62935T			-EXP													
	63585			-PER													
	63586			-PER													
	63587			-PER													
54073			10/17/1989	RFP	UG	SW	SW	32	17S	63E	10.000	MUN		0.00	0.00	CL	LAS VEGAS VALLEY WATER DISTRICT
54130			10/30/1989	RFP	UG	SE	NE	34	18S	63E	2.300	IND		0.00	0.00	CL	BONNEVILLE NEVADA CORPORATION
54232			12/14/1989	RFA	UG	NW	NW	16	18S	63E	0.300	COM		0.00	0.00	CL	KERR-MCGEE CHEMICAL CORPORATION
54348			01/19/1990	RFA	UG	SW	SW	12	18S	63E	0.300	IND		0.00	0.00	CL	ADAMS, JAMES W.
54349			01/19/1990	RFA	UG	SE	SE	11	18S	63E	0.150	IND		0.00	0.00	CL	ADAMS, JAMES W.
54350			01/19/1990	RFA	UG	NW	SE	11	18S	63E	0.300	IND		0.00	0.00	CL	ADAMS, JAMES W.

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
54351			01/19/1990	RFA	UG	SW	NE	11	18S	63E	0.230	IND		0.00	0.00	CL	ADAMS, JAMES W.
54352			01/19/1990	RFA	UG	SE	NW	11	18S	63E	0.230	IND		0.00	0.00	CL	ADAMS, JAMES W.
54483			02/26/1990	RFA	UG	NW	NW	16	18S	63E	1.000	COM		0.00	0.00	CL	KERR-MCGEE CHEMICAL CORPORATION
55099			07/19/1990	RFP	UG	SE	SE	07	18S	64E	1.000	IND		0.00	0.00	CL	CONSTRUCTION PRODUCTS INC.
55674	44664		01/24/1991	PER	UG	NW	NW	16	18S	63E	0.015	COM		0.00	10.02 AFA	CL	KERR-MCGEE CHEMICAL CORPORATION; KERR-MCGEE CHEMICAL LLC; WESTERN GYPSUM, INC.
CHANGE BY:	61041			-ABR													
	61367			-CAN													
	63261			-PER													
	63348			-PER													
	63356T			-EXP													
56855	50316	14449	10/22/1991	CER	UG	SE	NE	34	18S	63E	0.350	IND		0.00	46.97 MGA	CL	GEORGIA PACIFIC CORPORATION
57011			12/16/1991	RFA	UG	NW	NE	11	18S	63E	8.800	IND		0.00	0.00	CL	ADAMS, JAMES W.
59237	53322	15391	09/16/1993	CER	UG	NW	NE	19	18S	64E	0.250	IND			68.50 AFA	CL	REPUBLIC ENVIRONMENTAL TECHNOLOGIES
CHANGE BY:	60624			-PER													
60022	44173		04/27/1994	PER	UG	NW	SW	21	17S	64E	0.000	IND			0.00 MGA	CL	NEVADA POWER COMPANY
CHANGE BY:	63610T			-WDR													

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
	64452T			-EXP													
60624	59237		10/28/1994	PER	UG	SE	SE	07	18S	64E	0.001	IND	Y		0.11 AFA	CL	REPUBLIC ENVIRONMENTAL TECHNOLOGIES
CHANGE BY:	63590			-PER													
63261	55674		07/21/1997	PER	UG	NE	NE	14	18S	63E	0.149	COM	Y		100.00 AFA	CL	CHEMICAL LIME COMPANY OF ARIZONA
63348	55674		08/19/1997	PER	UG	N2		13	18S	63E	0.006	COM			4.00 AFA	CL	WESTERN GYPSUM, INC.
63585	53322		11/25/1997	PER	UG	NE	NW	20	18S	64E	0.001	IND	Y		0.11 AFA	CL	REPUBLIC ENVIRONMENTAL TECH., INC.
63586	53322		11/25/1997	PER	UG	SE	SE	07	18S	64E	0.149	IND	Y		40.78 AFA	CL	REPUBLIC ENVIRONMENTAL TECH., INC.
63587	53322		11/25/1997	PER	UG	NW	NE	19	18S	64E	0.100	IND	Y		27.50 AFA	CL	REPUBLIC ENVIRONMENTAL TECH., INC.
63588	61041		11/25/1997	PER	UG	SE	SW	19	18S	64E	0.290	IND	Y		194.00 AFA	CL	RUPUBLIC ENVIRONMENTAL TECH., INC.
63589	60623		11/25/1997	PER	UG	NW	NE	19	18S	64E	0.250	IND	Y		68.50 AFA	CL	REPUBLIC ENVIRONMENTAL TECH., INC.
63590	60624		11/25/1997	PER	UG	SE	SE	07	18S	64E	0.250	IND	Y		68.39 AFA	CL	REPUBLIC ENVIRONMENTAL TECH., INC.

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	POINT OF DIVERSION QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
64040			04/17/1998	RFP	UG	NW	NW	29	17S	64E	10.000	QM				CL	DRY LAKE WATER, LLC
64045			04/17/1998	RFP	UG	NE	NE	32	17S	63E	10.000	QM				CL	DRY LAKE WATER, LLC
64222			06/12/1998	RFP	UG	SE	SE	09	17S	64E	1.110	IND				CL	NEVADA POWER COMPANY
64223			06/12/1998	RFP	UG	SW	SW	10	17S	64E	1.110	IND				CL	NEVADA POWER COMPANY
64880	26277		03/01/1999	PER	UG	SW	SE	23	18S	63E	0.220	MM	Y		150.38 AFA	CL	CHEMICAL LIME COMPANY
***** END OF SECTION FOR BASIN NUMBER: 216 *****																	
***** START OF SECTION FOR BASIN NUMBER: 217 *****																	
38758			08/08/1979	RFA	UG	SE	SE	08	16S	63E	2.700	IRC		160.00	800.00 AFA	CL	PAGLIUSO, ERNEST P.
CHANGE BY:	66316			-RFA													
54074			10/17/1989	RFP	UG	SW	SW	25	16S	62E	10.000	MUN		0.00	0.00	CL	LAS VEGAS VALLEY WATER DISTRICT
64038			04/17/1998	RFP	UG	NW	NE	16	16S	63E	10.000	QM			7,239.70 AFA	CL	DRY LAKE WATER, LLC
CHANGE BY:	66162			-RFP													
66162	64038		03/17/2000	RFP	UG	SW	SE	21	17S	63E	10.000	QM			7,239.70 AFA	CL	DRY LAKE WATER, L.L.C.
66316	38758		04/28/2000	RFA	UG	SE	SE	29	17S	63E	2.700	IND				CL	NICHOLS, CHRIS D. (C/O); NORTH VALLEY HOLDINGS, LLC

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
***** END OF SECTION FOR BASIN NUMBER: 217 *****																	
***** START OF SECTION FOR BASIN NUMBER: 218 *****																	
12803			01/25/1949	RFP	UG	SE	SE	06	15S	66E	5.000	IRR		640.00	0.00	CL	HIDDEN VALLEY RANCH
26371	25355	9404	10/20/1971	CER	UG	NE	SW	25	14S	65E	0.370	IRR		18.00	90.00 AFA	CL	MOAPA VALLEY WATER COMPANY
50558			02/02/1987	PER	UG	NE	SW	05	15S	66E	0.040	ENV	Y	0.00	9.44 MGA	CL	NEVADA POWER COMPANY
50559		13823	02/02/1987	CER	UG	SE	SW	05	15S	66E	0.500	OTH		0.00	117.95 MGA	CL	NEVADA POWER COMPANY
50560			02/02/1987	PER	UG	NE	SW	05	15S	66E	0.040	ENV	Y	0.00	9.44 MGA	CL	NEVADA POWER COMPANY
53091 CHANGE BY:	66319T 66320		04/04/1989	PER -APP -RFA	UG	NW	SW	25	14S	65E	0.200	IRR		5.00	25.00 AFA	CL	WHEELER, ELMER
54075			10/17/1989	RFP	UG	NE	SW	04	16S	66E	10.000	MUN		0.00	0.00	CL	LAS VEGAS VALLEY WATER DISTRICT
54076			10/17/1989	RFP	UG	NW	NW	16	15S	64E	10.000	MUN		0.00	7,239.70 AFA	CL	LAS VEGAS VALLEY WATER DISTRICT
54202			11/30/1989	RFA	UG	NE	SE	29	14S	66E	3.000	IND		0.00	0.00	CL	OXFORD ENERGY COMPANY
57441E			04/16/1992	PER	UG	SW	NE	02	15S	66E	0.045	ENV			10.62 MGA	CL	TRANSPORTATION DEPARTMENT-NEVADA
64037			04/17/1998	RFP	UG	NE	NE	33	17S	65E	10.000	QM				CL	DRY LAKE WATER, LLC

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65197			06/14/1999	RFP	UG	SE	NW	31	16S	65E	0.500	COM				CL	MOAPA BAND OF PAIUTES
65722			12/15/1999	RFP	UG	NE	NW	27	16S	65E	1.000	MM				CL	STALLION SAND AND GRAVEL, LLC.
65944			01/28/2000	APP	UG			26	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65945			01/28/2000	RFP	UG			26	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65946			01/28/2000	RFP	UG			35	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65947			01/28/2000	RFP	UG			35	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65948			01/28/2000	RFP	UG			15	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65949			01/28/2000	RFP	UG			15	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65954			01/28/2000	RFP	UG			34	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
65955			01/28/2000	RFP	UG			34	16S	64E	6.000	PWR			3,500.00 AFA	CL	MOAPA BAND OF PAIUTES
66319T	53091		05/02/2000	APP	UG	NE	SE	10	17S	55E	0.200	MM			25.00 AFA	CL	WHEELER, ELMER
66320	53091		05/02/2000	RFA	UG	NE	SE	10	17S	65E	0.200	MM				CL	WHEELER, ELMER
66473			06/19/2000	APP	UG	NE	NE	15	16S	64E	6.000	PWR				CL	MOAPA BAND OF PAIUTES

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	S U P	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
66474			06/19/2000	APP	UG	SW	SE	15	16S	64E	6.000	PWR				CL	MOAPA BAND OF PAIUTES
66475			06/19/2000	APP	UG	SE	NE	15	16S	64E	6.000	PWR				CL	MOAPA BAND OF PAIUTES
66476			06/19/2000	APP	UG	SW	NW	23	16S	64E	1.000	PWR				CL	MOAPA BAND OF PAIUTES
***** END OF SECTION FOR BASIN NUMBER: 218 *****																	
***** START OF SECTION FOR BASIN NUMBER: 219 *****																	
6169	1611		06/14/1920	RFP	STR	NW	NE	16	14S	65E	1.000	IRR		100.00		CL	MOAPA & SALT LAKE PRODUCE CO.
6419	V01621	6795	03/09/1921	CER	STR	NW	NW	15	14S	65E	0.340	IRR		14.00		CL	LDS
18437		5683	11/20/1959	CER	UG	SE	SE	09	14S	65E	0.267	IRR		15.11	20.15 AFA	CL	CINKOWSKI, LOIS A.
CHANGE BY:	50934			-CER													
21466		6293	08/15/1963	CER	UG	SE	SE	08	14S	65E	1.000	IRR		36.64	183.20 AFA	CL	LEWIS, MALCOLM L.
22632	14345	7164	06/14/1965	CER	UG	NW	SE	08	14S	65E	1.500	IND		0.00	315.00 AFA	CL	NEVADA POWER COMPANY
22633	12774	7165	06/14/1965	CER	UG	SW	NE	08	14S	65E	1.500	IND		0.00	297.50 AFA	CL	NEVADA POWER COMPANY
22635	17754	7166	06/14/1965	CER	UG	SE	NE	08	14S	65E	1.200	IND		0.00	25.00 AFA	CL	NEVADA POWER COMPANY
CHANGE BY:	49842			-WDR													
22636	14344	7167	06/14/1965	CER	UG	NW	SE	08	14S	65E	1.500	IND		0.00	260.00 AFA	CL	NEVADA POWER COMPANY

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22738		8331	08/25/1965	CER	UG	NE	NE	22	14S	65E	0.250	COM		0.00	18.81 AFA	CL	CLAY, LENORE P.; CLAY, WAYNE J.; COOK, ANTONE R.; THORNTON, L.G.; THORNTON, PATRICIA
CHANGE BY:	27216			-CER													
22739	DMUD-266	10060	08/25/1965	CER	STR	NW	SE	16	14S	65E	1.000	MUN		0.00	235.85 MGA	CL	MOAPA VALLEY WATER DISTRICT; MUDDY VALLEY IRRIGATION CO. (32%); OVERTON WATER COMPANY
CHANGE BY:	28659			-CAN													
22949		7168	02/02/1966	CER	UG	SE	NE	08	14S	65E	2.945	IND	Y	0.00	433.00 AFA	CL	NEVADA POWER COMPANY
CHANGE BY:	49844			-WDR													
22950		7169	02/02/1966	CER	UG	SW	NE	08	14S	65E	2.945	IND	Y	0.00	433.00 AFA	CL	NEVADA POWER COMPANY
22951		7170	02/02/1966	CER	UG	NW	SE	08	14S	65E	2.945	IND	Y	0.00	433.00 AFA	CL	NEVADA POWER COMPANY
22952		7171	02/02/1966	CER	UG	NW	SE	08	14S	65E	2.945	IND	Y	0.00	433.00 AFA	CL	NEVADA POWER COMPANY
23600	21876	7316	01/11/1967	CER	STR	SE	SE	15	14S	65E	7.000	IND	Y	0.00	2,000.00 AFS	CL	MUDDY VALLEY IRRIGATION COMPANY
24185	22948	7172	10/20/1967	CER	UG	NW	NE	08	14S	65E	2.945	IND	Y	0.00	433.00 AFA	CL	NEVADA POWER COMPANY
24186	22634	7173	10/20/1967	CER	UG	NW	NE	08	14S	65E	1.340	IND		0.00	101.01 MGA	CL	NEVADA POWER

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APP#	CHANGE OF APP#	CERT#	FILING DATE	STAT	SRC	QQ	QTR	SEC	TWP	RNG	DIV RATE (CFS)	TYPE OF USE	SUP	ACRES IRRIGATED	ANNUAL DUTY	CO	OWNER OF RECORD
																	COMPANY
25310		7844	10/09/1969	CER	UG	SE	NE	08	14S	65E	1.200	IND		0.00	52.00 MGA	CL	NEVADA POWER COMPANY
CHANGE BY:	49843			-WDR													
25861		10944	11/12/1970	CER	SPR			16	14S	65E	0.432	IRR		113.50	1,980.14 AFA	CL	LDS
CHANGE BY:	26317			-CER													
	26318			-CER													
26316	25860	10951	09/15/1971	CER	STR	SE	SE	15	14S	65E	0.829	IRR		58.00	0.00 *	CL	LDS
26317	25861	10952	09/15/1971	CER	SPR	NW	SE	16	14S	65E	0.059	IRR		4.00	18.02 AFS	CL	LDS
26318	25861	10953	09/15/1971	CER	STR	SE	SE	15	14S	65E	0.536	IRR		37.50	0.00 *	CL	LDS
27216	22738	12758	01/02/1973	CER	UG	NW	SE	16	14S	65E	0.250	COM		0.00	0.45 MGA	CL	APCAR, FREDERIC S.
28791	21876	13445	10/11/1974	CER	SPR	SW	NW	16	14S	65E	3.000	MUN		0.00	694.73 MGA	CL	MUDDY VALLEY IRRIGATION CO.
CHANGE BY:	52351			-CAN													
29295	V01620	9609	03/25/1975	CER	OSW	SE	SE	15	14S	65E	1.357	IND			*	CL	LEWIS, LOU JEANNE; LEWIS, PAUL C.
29296	12244	9691	03/25/1975	CER	UG	NW	NW	23	14S	65E	0.576	IND		0.00	300.00 AFA	CL	BEHMER, B.R.; BEHMER, ROSEMARY; BROWN, RUTH
29298	25699	9750	03/25/1975	CER	UG	NW	NW	23	14S	65E	0.452	IND		0.00	327.50 AFA	CL	NEVADA POWER COMPANY
29764	22603	9661	11/13/1975	CER	STR	SE	SE	15	14S	65E	0.414	IND		0.00	0.00 *	CL	NEVADA POWER CO.
38871	12244	10166	08/28/1979	CER	UG	NW	NW	23	14S	65E	0.144	IRR		15.00	75.00 AFA	CL	EGTEDAR, ASCAR

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42100		10920	08/18/1980	CER	SPR	NE	NE	21	14S	65E	0.003	DOM			0.66 MGA	CL	PEDERSEN, LOREENA; PEDERSEN, RICHARD
46932			05/19/1983	PER	UG	NE	NE	35	13S	64E	2.000	MUN		0.00	325.90 MGA	CL	MOAPA VALLEY WATER DISTRICT
CHANGE BY:	59062T			-WDR													
	63496T			-EXP													
	64724T			-EXP													
50272	25697	13507	10/13/1986	CER	UG	NE	NE	22	14S	65E	0.230	IND	Y	0.00	99.51 AFA	CL	NEVADA POWER COMPANY
50273	25698	13508	10/13/1986	CER	UG	NE	NE	22	14S	65E	0.670	IND	Y	0.00	289.91 AFA	CL	NEVADA POWER COMPANY
50274	29328	13509	10/13/1986	CER	UG	NE	NE	22	14S	65E	1.000	IND	Y	0.00	432.70 AFA	CL	NEVADA POWER COMPANY
50275	12679	13510	10/13/1986	CER	UG	NE	NE	22	14S	65E	0.520	IND	Y	0.00	32.88 AFA	CL	NEVADA POWER COMPANY
50723	11960	13381	03/24/1987	CER	UG	NW	NW	15	14S	65E	0.320	IND	Y	0.00	88.00 AFA	CL	LDS
50724	13074	13382	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.920	IND	Y	0.00	162.55 AFA	CL	LDS
50725	26313	13383	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.302	IND	Y	0.00	65.00 AFA	CL	LDS
50726	26314	13384	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.302	IND	Y	0.00	65.00 AFA	CL	LDS
50727	26315	13385	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.271	IND	Y	0.00	60.00 AFA	CL	LDS
50728	26319	13386	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.580	IND	Y	0.00	158.00 AFA	CL	LDS
50729	26320	13387	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.440	IND	Y	0.00	120.00 AFA	CL	LDS

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50730	22559	13388	03/24/1987	CER	UG	SW	SW	09	14S	65E	0.117	IND	Y	0.00	25.00 AFA	CL	LDS
50731	25862	13389	03/24/1987	CER	UG	NW	NW	15	14S	65E	2.160	IND	Y	0.00	586.00 AFA	CL	LDS
50732	25864	13390	03/24/1987	CER	UG	NE	NE	16	14S	65E	2.330	IND	Y	0.00	930.00 AFA	CL	LDS
50733	25887	13391	03/24/1987	CER	UG	NE	NE	16	14S	65E	0.180	IND	Y	0.00	70.00 AFA	CL	LDS
50734	21876	13851	03/24/1987	CER	STR	SE	SE	15	14S	65E	3.500	IND	Y	0.00	1,000.00 AFS	CL	NEVADA POWER COMPANY (LESSEE)
50851	12679	14294	04/23/1987	CER	UG	NW	NW	23	14S	65E	0.288	IRR	Y	8.33	30.00 AFA	CL	PERKINS, G.M.; PERKINS, SHIRLEY
CHANGE BY:	56428 64840			-WDR -PER													
50934	18437	13581	05/14/1987	CER	UG	NE	NE	22	14S	65E	0.733	IND	Y	0.00	55.40 AFA	CL	NEVADA POWER COMPANY
52520	49825		09/19/1988	PER	UG	SE	NE	07	14S	65E	2.000	MUN		0.00	471.81 MGA	CL	MOAPA VALLEY WATER DISTRICT
52587	29297		10/04/1988	PER	UG	NW	NW	23	14S	65E	0.445	IND		0.00	322.50 AFA	CL	NEVADA POWER COMPANY
55450			11/09/1990	PER	UG	SE	NE	07	14S	65E	3.000	MUN		0.00	707.73 MGA	CL	MOAPA VALLEY WATER DISTRICT
56059			03/25/1991	RFA	UG	NE	NE	35	13S	64E	3.000	IND		0.00	0.00	CL	OXFORD ENERGY OF NEVADA INC.
56668		15097	08/15/1991	CER	SPR	SE	SE	16	14S	65E	3.500	WLD		0.00	825.69 MGA	CL	FISH AND WILDLIFE SERVICE-U.S.
58269			10/27/1992	PER	UG	SE	NE	07	14S	65E	5.000	MUN			1,179.55 MGA	CL	MOAPA VALLEY WATER DISTRICT
CHANGE BY:	66043			-RFP													

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58787			04/23/1993	RFP	UG	NE	SE	07	14S	65E	6.000	PWR				CL	MOAPA VALLEY WATER DISTRICT; OVERTON POWER DISTRICT
59253	43160	15460	09/20/1993	CER	UG	SW	NE	23	14S	65E	0.198	IRR		8.78	43.88 AFA	CL	LEAVITT, UTE
59256	43160	15104	09/20/1993	CER	UG	SW	NE	23	14S	65E	0.130	IRR		5.78	28.88 AFA	CL	WHITMORE, DAN; WHITMORE, LATRICE
59257	43160	15105	09/20/1993	CER	UG	SW	NE	23	14S	65E	0.068	IRR		3.00	15.00 AFA	CL	BRUNDY, LARRY
59369			11/05/1993	RFP	UG	NE	NE	33	13SH	64E	10.000	MUN				CL	MOAPA VALLEY WATER DISTRICT
61427			07/26/1995	PER	UG	SE	SW	09	14S	65E	0.007	COM			0.44 MGA	CL	S & R, INC.
63504	59254		10/14/1997	PER	UG	SW	NE	23	14S	65E	0.068	IRR		3.00	15.00 AFA	CL	KOLHOSS, KELLY; KOLHOSS, RUTH
63505	59254		10/14/1997	PER	UG	SW	NE	23	14S	65E	0.130	IRR	Y	0.00	28.88 AFA	CL	ROBINSON, MARLEY
63535	59255		10/28/1997	PER	UG	SW	NE	23	14S	65E	0.198	IRR	Y	8.78	43.88 AFA	CL	ROBINSON, MARLEY
64840	50851		02/08/1999	PER	UG	NW	NW	23	14S	65E	0.192	IRR	Y	3.33	19.98 AFA	CL	PERKINS, DAVID (C/O); PERKINS, G.M.; PERKINS, SHIRLEY
66043	58269		02/03/2000	RFP	UG	SE	NE	07	14S	65E	5.000	MUN				CL	MOAPA VALLEY WATER DISTRICT

***** END OF SECTION FOR BASIN NUMBER: 219 *****

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***** START OF SECTION FOR BASIN NUMBER: 220 *****																	
1802		296	08/22/1910	CER	SPR	SW	NW	20	16S	68E	0.560	IRR		56.00	280.00 AFA	CL	ANGELL, SANFORD A.
2860		554	12/18/1913	CER	SPR	SE	SW	07	16S	68E	0.354	IRR		35.45	177.25 AFA	CL	MORRISON, NORMAN H.
8321	DMUD-01618	2298	09/16/1927	CER	STR	SE	NE	21	15S	67E	0.014	IRR		0.70	3.50 AFA	CL	LOS ANGELES & SALT LAKE RAILROAD CO.
10188		5216	12/31/1937	CER	STR	NW	SE	19	16S	68E	2.500	IRR		0.00	2,247.28 AFA	CL	NATIONAL PARK SERVICE-U.S.
11632		4906	07/10/1946	CER	OSW	NW	SE	12	16S	67E	2.000	IRR		143.88	863.28 AFA	CL	PERKINS, JOHN F.; PERKINS, JOHN G.
CHANGE BY: 49332				-RFA													
13638		4119	02/15/1951	CER	STR	NE	SW	35	15S	67E	0.500	IRR		34.77	173.85 AFA	CL	ADAMS, LOUIS
18101		6059	07/10/1959	CER	UG	NW	SW	01	15S	66E	0.018	IRR		100.15	25.75 AFA	CL	LEWIS, PAUL C.
21847	DMUD-31	8324	02/26/1964	CER	STR	NW	NE	21	15S	67E	3.980	IRR	Y	3,498.66	1,436.75 AFS	CL	MUDDY VALLEY IRRIGATION CO
21873	1611	8325	03/16/1964	CER	STR	NW	NE	21	15S	67E	9.700	IRR	Y	3,498.66	4,078.83 AFS	CL	MUDDY RIVER IRRIGATION CO
21874	31	8326	03/16/1964	CER	STR	NW	NE	21	15S	67E	0.029	IRR	Y	3,498.66	17.09 AFA	CL	MUDDY VALLEY IRRIGATION CO
21875	1372	8327	03/16/1964	CER	STR	NW	NE	21	15S	67E	0.800	IRR	Y	3,498.66	288.79 AFS	CL	MUDDY VALLEY IRRIGATION CO
21876	DMUD-266	8328	03/16/1964	CER	STR	NW	NE	21	15S	67E	10.506	IRR	Y	3,498.66	13,256.63 AFA	CL	MUDDY VALLEY IRRIGATION CO.
CHANGE BY: 23600				-CER													

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	28791 50734			-CER -CER													
21877	31	8327	03/16/1964	CER	STR	NW	NE	21	15S	67E	4.252	IRR	Y	3,498.66	4,599.55 AFA	CL	MUDDY RIVER IRRIGATION CO
23872		8600	05/16/1967	CER	UG	NW	NW	22	15S	67E	0.890	MUN		0.00	0.00 *	CL	MOAPA VALLEY WATER CO.; OVERTON WATER DISTRICT
23949		7594	06/23/1967	CER	UG	SE	NW	02	16S	67E	0.070	IRR		2.50	12.50 AFS	CL	HORN, ERICH; HORN, LOUISE
24007		8601	07/18/1967	CER	UG	NW	NW	22	15S	67E	5.010	IRR		370.00	1,850.00 AFA	CL	MOAPA VALLEY WATER CO.; OVERTON WATER DISTRICT
CHANGE BY:	59394T 60979T 62176T			-EXP -EXP -EXP													
26329		8814	09/22/1971	CER	UG	NE	NE	34	15S	67E	1.300	IRR		75.93	379.65 AFA	CL	ROBISON, DELL H.; ROBISON, PEARL W.
26747		9232	05/26/1972	CER	UG	NW	NE	11	16S	67E	0.500	IRR		7.03	35.15 AFA	CL	LAHM, ROBERT L.
27411			04/16/1973	PER	STR	SW	NE	19	16S	68E	25.000	IRR		650.00	2,600.00 AFA	CL	WILDLIFE DIVISION-NEVADA
27412		13110	04/16/1973	CER	STR	SW	NE	19	16S	68E	10.000	WLD		0.00	666.40 AFA	CL	FISH AND GAME COMMISSION-NEVADA
28093		12168	02/11/1974	CER	UG	SW	SE	01	15S	66E	2.500	IRR		109.64	548.20 AFA	CL	LEWIS, PATRICIA; LEWIS, PAUL C.; LEWIS, PAUL R.

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29631		13246	09/05/1975	CER	UG		LT0407		15S	67E	1.000	COM		0.00	37.67 MGA	CL	LEWIS, PATRICIA; LEWIS, PAUL R.
30774		10003	10/19/1976	CER	UG	NE	NW	02	16S	67E	1.400	IRR		108.80	544.00 AFA	CL	MARSHALL, KARL
CHANGE BY:	66052			-RFA													
	66053			-RFA													
	66210			-RFA													
35590		13598	07/03/1978	CER	UG	NE	SW	34	15S	67E	0.021	IRR		3.04	15.20 AFA	CL	BUSH, JACQUELINE P.; BUSH, JAMES H.; IVAN WOLLENZIEN CHILDRENS TRUST; MITCHELL, TERESA; MITCHELL, TIM; PULSIPHER, CHARLES STACY; PULSIPHER, PAULA; WAITE, D. LANNY; WAITE, MAXINE; WHEELER, KATHY; WHEELER, PAUL; WOLLENZIEN, IVAN ROBERT; WOLLENZIEN, LORETTA LINA
36523		12764	01/24/1979	CER	UG	NE	NE	11	16S	67E	0.500	IRR		20.00	100.00 AFA	CL	RAMOS, MIGUEL
38683		11427	07/25/1979	CER	UG	NE	SW	02	16S	67E	0.250	IRD		4.51	22.58 AFA	CL	GAMBOA, DARLENE A.; GAMBOA, JOHN PETE
40167		11429	12/24/1979	CER	UG	NE	SW	15	15S	67E	0.033	IRR		4.94	14.70 AFA	CL	FAY, BOBBY B.; FAY, DORTHY M.; STREETT, DAWN; STREETT, KEVIN

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CHANGE BY:	56654			-PER													
43476		11420	04/08/1981	CER	UG	SW	NW	02	16S	67E	0.167	IRR		24.15	120.75 AFA	CL	LEAVITT, VALERIE CLAIRE; LEAVITT, WILLIAM J.
44473		15367	09/23/1981	CER	UG	NE	NE	13	16S	67E	0.981	IRR		120.90	604.50 AFA	CL	MOAPA VALLEY DAIRY FARMS
CHANGE BY:	52265			-ABR													
	52721			-CAN													
	52900			-CAN													
	53400			-RFA													
	58104			-ABR													
	60652			-WDR													
	64841			-WDR													
48763	29630		01/23/1985	PER	UG	SW	SW	01	15S	66E	1.000	IRR		40.00	200.00 AFA	CL	LEWIS, PATRICIA; LEWIS, PAUL R.
49332	11632		09/04/1985	RFA	OSW	NW	SE	12	16S	67E	2.000	IRR		143.88	863.28 AFA	CL	PERKINS, BRUCE G.; PERKINS, MURRAY L.
50947			05/20/1987	PER	UG	NW	NE	09	15S	67E	0.500	COM		0.00	32.60 MGA	CL	LAS VEGAS CEMENT CO. INC.
51749	11499	13380	01/06/1988	CER	UG	NW	NE	11	17S	67E	0.305	MM		0.00	46.79 MGA	CL	DBA SIMPLOT SILICA PRODUCTS; SIMPLOT INDUSTRIES
53400	44473		06/21/1989	RFA	UG	SE	NE	12	15S	66E	0.571	IRR		80.00	400.00 AFA	CL	MOAPA VALLEY DAIRY FARMS
56654	40167		08/08/1991	PER	UG	NW	SW	15	15S	67E	0.023	IRR		2.00	10.00 AFA	CL	STREETT, DAWN; STREETT, KEVIN

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59368			11/05/1993	RFP	UG	NW	NW	10	13S	67E	10.000	MUN				CL	MOAPA VALLEY WATER DISTRICT
59370			11/05/1993	RFP	UG	SW	NW	32	15S	67E	5.000	MUN				CL	MOAPA VALLEY WATER DISTRICT
59371			11/05/1993	RFP	UG	SE	SE	19	15S	67E	5.000	MUN				CL	MOAPA VALLEY WATER DISTRICT
61319			06/16/1995	PER	EFF	NE	NW	20	16S	68E	0.540	OTH			390.94 AFA	CL	CLARK COUNTY SANITATION DISTRICT
62066 CHANGE BY:	39719 66051		04/23/1996	PER -RFA	UG	NW	SW	01	15S	66E	0.940	MM			25.00 MGA	CL	LEWIS, PAUL R.
62846	52265		02/07/1997	PER	UG	SE	SE	21	15S	67E	0.173	IRR		122.30	125.00 AFA	CL	ISOLA, TOM; TAI ARABIAN RANCH; TOM ISOLA AND THE TAI ARABIAN RANCH
62847	58104		02/07/1997	PER	UG	SE	SE	21	15S	67E	0.173	IRR		122.30	125.00 AFA	CL	ISOLA, TOM; TAI ARABIAN RANCH; TOM ISOLA AND THE TAI ARABIAN RANCH
66051	62066		02/07/2000	RFA	UG	NW	SW	01	15S	66E	0.940	MM				CL	LEWIS, PAUL R.
66052	30774		02/07/2000	RFA	UG	NW	SW	01	15S	66E	0.257	MM				CL	LEWIS, PAUL R. (C/O); MARSHALL, MELVIN K.
66053	30774		02/07/2000	RFA	UG	SW	SW	01	15S	66E	0.515	MM				CL	LEWIS, PAUL R. (C/O); MARSHALL, MELVIN K.
66210	30774		03/24/2000	RFA	UG	NE	SE	12	15S	66E	0.615	MM			239.00 AFA	CL	(C/O) PAUL R.

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																	LEWIS; MARSHALL, MELVIN K.

***** END OF SECTION FOR BASIN NUMBER: 220 *****

APPENDIX E

Monitoring Plan

For

Moapa Band of Paiutes

APPENDIX E

Monitoring Plan
(Implemented and Proposed Elements)

Moapa Band of Paiutes - Calpine Company

Background

The proposed Calpine Power Generation Project (Project), with a projected consumptive use of 7,000 acre-ft./yr (afy) of production from the Carbonate Aquifer, elevates the importance of existing monitoring of groundwater levels and discharge relationships in the regional spring areas (Muddy River Springs Area, Rogers and Blue Point Springs near Lake Mead). However, because the Project is 15 miles from the nearest area of regional groundwater discharge, new monitoring wells to the north and south of the Belly Tank Flat Well Field are in operation to provide detection of both near- and far-field water-level changes. The Belly Tank Flat well field on the Moapa Indian Reservation (Fig. E-1) occupies a location about midway between the Muddy River Springs Area to the north and the Apex area to the south, areas where there is present development of the Carbonate Aquifer. Additional, heavier exploitation of the Carbonate Aquifer is possible in the future in these areas and other basins of the Arrow Canyon Range Cell. This Monitoring Plan will ensure that pumping impact in the Carbonate Aquifer associated with the Belly Tank Flat well field will be well-characterized both northward and southward. Figure E-1 illustrates the geographic relationships of the Belly Tank Flat well field, the new monitoring wells (shown by solid square symbols), and other monitoring wells within the Arrow Canyon Range Cell of the Carbonate Aquifer.

Objectives and Considerations

There are several basic objectives associated with monitoring the Carbonate Aquifer. First, because the aquifer is very extensive and poorly understood as to detailed behavior or responses when stressed by heavy pumping, an adequate network of widely-spaced monitoring wells is desirable to trace the development and extent of pumping cones that expand outward from the pumping center(s). In order to identify the manner in which individual pumping centers are contributing to net changes in water levels, it is also desirable to establish monitoring records of water levels closer to and therefore more clearly associated with individual pumping centers to document the unique characteristics of pumping signals (such as periodicities and magnitudes) produced by specific water-development activities.

Often the pumping history of the well(s) varies daily, monthly, or seasonally, and therefore may transmit a distinctive signal of water-level changes within the portion of the aquifer affected by the pumping. At the present time, the number of large production wells and/or well fields are limited in number and widely spaced, conditions ideal for the recognition of distinctive pumping signals in the water-level records. These signals may

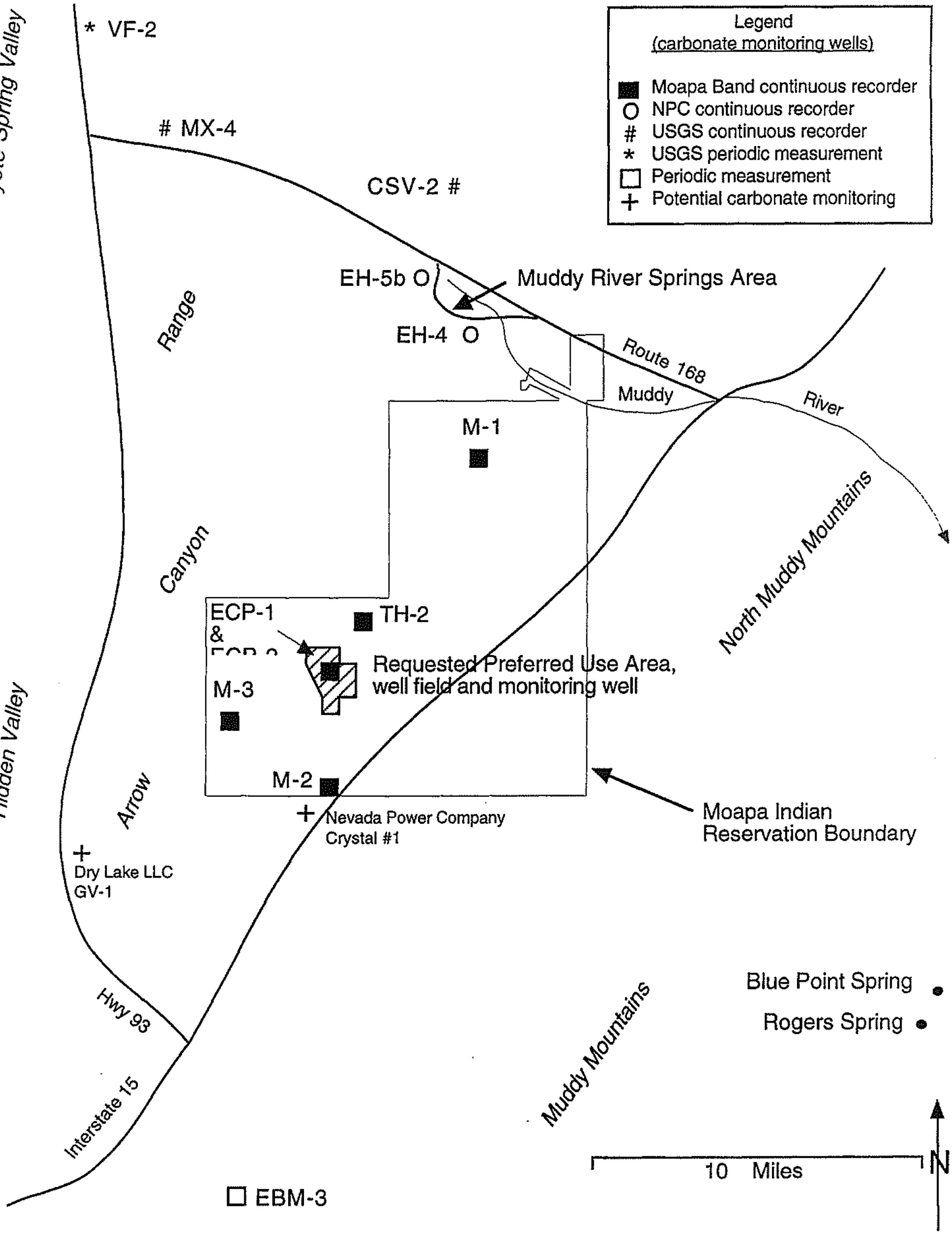

Figure E1. Moapa Band of Paiutes carbonate aquifer well monitoring status through 01/10/01.

vary in strength daily and/or seasonally as the water demands of individual users vary; water-level monitoring near these pumping centers will document the variations in signals. In this manner, characteristic signals of the local pumping stresses may be established, allowing individual components of net drawdown in the region to be discriminated. Furthermore, analyses of the response of aquifers to periodic pumping can be used to obtain large-scale estimates of transmissivity and storage without the expense of dedicated test pumping.

As pumping stresses travel outward to more distant regions of the Carbonate Aquifer, water-level changes become smaller, and short term variations may be dampened out to more uniform changes over time. It is important to establish water-level records which are sensitive enough to recognize water-level responses to natural stresses on the Aquifer that may be of similar magnitude as pumping-induced water-level changes. In monitoring accomplished to date, diurnal and longer-term natural water-level variations have been recorded that relate to barometric-pressure changes. Hourly measurements are ideal to record such "noise" in terms of water-level changes that are not related to any pumping signals of wells or well fields. Close into a large production well, or a well field, the pumping signals are large enough so that the natural signals are relatively small in comparison. However, several miles distant from the pumping centers, the natural signals may be of similar or larger magnitudes than those produced by short term pumping variations. Natural signals are usually systematic, due to the cyclic behavior of atmospheric heating and tidal forcing, and can be reduced (i.e. signal-to-noise ratio increased) by appropriate processing.

The proposed monitoring plan therefore has multiple objectives:

1) Of greatest interest is to establish long-term trends in water levels using continuous recorders in monitoring wells, and establish the causal relationships of the water-level trends. Longer-duration trends producing water-level changes may be related to pumping stresses on the aquifer, or they may be related to drought conditions or exceptionally wet years that causes recharge to vary over time. Multiyear declines and shorter-term recoveries have been observed in monitoring records established near the Muddy River Springs and up-gradient in Coyote Spring Valley. Separating out the natural long-term trends from long-term pumping effects normally requires long, continuous records that begin before pumping stresses occur at the monitoring location. The time-drawdown behavior of individual pumping centers is needed to resolve each separate contribution to net drawdown in the region.
2) Conduct an inventory of minor springs and seeps in the potentially-affected region to establish baseline conditions. Semiannual visits would be used to document changes to vegetation patterns, outflow quantity, or other characteristics.
3) Maintain the modeling environment in an appropriate state of readiness for validation exercises. The impacts of large-scale pumping will provide opportunities for model refinement, which should occur in concert with the

expanding database. A proactive approach to modeling will limit the potential for unpleasant surprises as transient characteristics of the large-scale system are revealed. Groundwater models will be recalibrated as new information becomes available.

Monitoring Design

The first priority of the Moapa Band/Calpine monitoring plan is to characterize the Belly Tank Flat well-field area aquifer properties (Appendix A). This has been accomplished by a monitoring well within the local pumping cone of at ECP-2 and monitoring at TH-2 and TH-1 during a 7-day aquifer test at ECP-1. To date, test wells ECP-2 and ECP-1 have been instrumented on an interim basis during and after drilling. At greater distances (monitoring wells M-1, M-2, and M-3), monitoring points have the potential to record and track the pumping stresses as they propagate with time outward from the well field area to the north, south, and west over greater distances. The far-field water-level declines due to pumping by the Project should be recognizable, if of impact-producing magnitude, decades before any important impacts develop at distant regional discharge areas. To the north, the Muddy River Springs Area is fed by discharge from the Carbonate Aquifer. It is not known with certainty if the Belly Tank Flat Well Field pumping stresses may be transmitted, over prolonged time, to this area or into the up-gradient flow field at a large enough magnitude to cause impacts on spring or river flows. It is important to note that the nature of the Muddy River regional discharge area is such that impacts on the discharge would not be measured with confidence until they were well developed. Water-level changes of great enough magnitude in the Carbonate Aquifer to produce important impacts on spring flow or river flow would be confidently recognized in the monitoring well records between the two areas decades before long-term decreases in flow could be resolved from a seasonally noisy record (Figure E-2, USGS internet data).

A secondary but very important priority is to identify, with confidence, all major pumping stresses that produce detectable changes in flow in the Muddy River Springs Area. This monitoring objective is demanding as well as important because nearby pumping stresses impact Muddy River flows, and some of these pumping stresses will likely increase in the future. Further, other water-right permits and applications for water rights may be acted upon during the time frame of the Moapa Band/Calpine lease agreement (45 years) to establish new pumping centers. Such may either 1) impact the Muddy River flows after only short periods of heavy pumping, if located upgradient in the Coyote Spring Valley area, or 2) tap the Carbonate Aquifer to the south of the Moapa Indian Reservation, and add significantly to the overall pumping stresses in the southern

Monitoring and Mitigation

Mitigation measures are not anticipated to be necessary for model forecast Project impacts to aquatic habitats in the Muddy River Springs Area. However, if observations of water-level drawdowns in monitoring wells TH-2, M-1, and EH-4 were to be consistent with or greater than those projected by Case 3 in the first 5 to 10 years, mitigation measures might be required to prevent impacts at the Muddy River Springs Area at advanced stages of the Project.

Consideration of mitigation strategies are judged important in the context of the purpose of the monitoring network and plan that has been established. The monitoring of the Carbonate Aquifer water-level responses to the proposed pumping allows for the model forecasts to be evaluated, and the model to be recalibrated if found to be inaccurate in projections through the available period of record. Secondly, the water-level records may also aid in recognizing the regional propagation and impacts of other pumping stresses, and therefore the combined, or cumulative regional impacts of all pumping stresses. These may be forecasted by modeling into the future, and determine not only the Project's impacts, but combined pumping impacts. Mitigation measures in terms of the Calpine Project should be considered within the context of which pumping center is producing the impacts that may have the potential to impact other senior water rights or aquatic habitats at a defined (forecasted) point in time.

The rate of development of pumping cones with regional extent are anticipated to be very slow based on Carbonate Aquifer properties determined from pump tests in several areas, and therefore mitigation strategies, most of which require time to design and implement, are feasible for the Project. Mitigation strategies, if indeed proven necessary by model projections, generally require predictions of the magnitude and timing of the potentially unacceptable impacts. Groundwater extraction during the first 5-10 years of Project operation would impose the appropriate pumping stress on the Carbonate Aquifer for refined modeling analyses. The water-level histories at monitoring wells distant from the Project pumping center (M-1, M-2, M-2, TH-2, and EH-4) will allow the directions and magnitudes of regionally propagated pumping stresses of the Project to be characterized using modeling technology.

In summary, the Monitoring Plan is designed to track Carbonate Aquifer water levels and regionally-propagated pumping impacts, refine groundwater model projections of future regional impacts, identify non-Project regional pumping impacts, forecast states of the hydrologic system that may require mitigation, and aid in the decision framework for mitigation measures that might become necessary. An effective monitoring program might even help the Project avoid costly and unjustified mitigation measures.

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Monitoring Supplement E-1

Groundwater Monitoring Protocols

February 2001

Purpose of this Document

This document provides standardized procedures for the installation, maintenance, and retrieval of hydrologic data from Stevens dataloggers comprising the part of the groundwater monitoring network for the Project. In addition, procedures for data management and archival are presented to ensure the quality and consistency of essential hydrologic information.

Scope of Water-Level Monitoring

There are several types of activities, beginning with the selection of an automatic data recording system and ending with retrieval and distribution of archived data, that constitute a successful monitoring program. Long-term water-level monitoring for the Project is being accomplished by submerged pressure transducers at selected wells. The transducers are suspended by a cable containing electrical conductors and a capillary tube that provide power and an atmospheric-pressure reference, respectively. Additional instrumentation is in place to sense barometric pressure, which is known to influence water levels. A Stevens AxSys datalogger senses 4-20 mA transducer current and records to non-volatile memory in user-defined pressure units (feet of water or inches of mercury, for example). The measurement system requires a minimum of 12 volts DC for operation.

Borehole conditions influence the choice of cable length and dynamic range of the transducer, and the configuration of wellhead support. Station logs provide a hardcopy record of manual observations such as water levels and battery voltages, and must be understood and utilized effectively to maintain calibration of the measurement system. Uncertainties in the elevation of the water table arise from the combined uncertainties of the surveyed elevation of the measuring point, measured depth to water below the measuring point, and pressure sensed by the transducer. It is therefore essential that depths to water be periodically measured and recorded, and that inaccuracies associated with individual measuring tapes be characterized.

Downloading and archival must be accomplished without loss or corruption of the basic data, and retrieval must provide a product whose format and content is unambiguous and useful to a broad cross-section of potential users. Records are downloaded from the dataloggers using a solid-state memory card, so a computer is not needed in the field. Data are uploaded for processing using Stevens AxRead software

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running on a Windows platform. After using a word processor (WordPerfect or equivalent) to assemble monthly records from each well, a spreadsheet program (Quattro Pro or equivalent) is used to perform some routine numerical conversions and to format the data for archival. Yearly records, organized by month, are written to a compact disk (CD) for distribution.

Specific Protocols

1. Downhole configuration and wellhead support.

The first consideration in selecting the transducer in the dynamic range that will be necessary to monitor the expected range of water-level fluctuations. For example, pre-test design calculations indicated that 11 feet of drawdown could occur at ECP-2 from pumping ECP-1, 500 feet away, for 7 days (figure 7). On that basis, a transducer with a dynamic range of 25 feet was selected. At TH-2, on the other hand, far from any proposed pumping, a more sensitive transducer with 10-foot dynamic range was selected. Cabling was selected to place the transducer between the water table and the limit of its dynamic range, i.e. 12.5 feet below water in ECP-2 and 5 feet in TH-2. Now that it is known that seasonal fluctuations in water elevation are less than a foot in the Project area, future transducers can be placed closer to the lower limit of their dynamic range below the water table. This will allow somewhat greater drawdowns to be recorded without cable adjustments.

Given that the combined weight of transducer and cable is on the order of 20 pounds, sturdy wellhead support is required. Every effort must be taken to limit the possibility of slippage, which would require a substantial recalibration effort and adjustments to data to maintain consistency in the record. All units are supported on 4-inch, ABS plastic sanitary tees, by wrapping the cable in a figure "8" as one would secure rope to a cleat. It is essential that there are no kinks in the tubing, as this would impair sensing of reference pressure. This setup also provides both access for manual water-level measurements and secure mounting for the junction box, and in the case of TH-2, a barometric-pressure transducer. Desiccant must be kept in the junction box to prevent condensation from blocking the reference pressure signal, and the bag of desiccant should be replaced when it swells to twice its original size. Openings at the wellhead should be sealed to the extent possible to prevent animals or debris from entering the borehole and interfering with the measurement process.

Equipment Checklist

A minimum of two persons are required for installation of transducer and cabling, one person is needed to suspend the weight of the cable while the other organizes the wellhead support and makes adjustments. Considerable equipment and preparation is needed for suspending a transducer in the borehole and hooking up a few wires. Safety of personnel is important during this process as is the security of the monitoring. Included are the ingredients of a proven system of wellhead support and layout of measurement apparatus that are reasonably secure from natural elements and vandals. For each one-channel installation the following is required:

Stevens water-level measurement system and related supplies
(1) Stevens AxSys MPU datalogger
(1) Stevens SDT-II pressure transducer with cable of appropriate length
(1) 12-volt automotive battery, freshly charged, with 5/16-inch threaded posts and wing nut
(1) 1/2-inch x 8-inch x 12-inch wood (to set under battery)
(1) 8-inch x 3/4-inch galvanized steel pipe nipple (to weight transducer and uncurl cable)
(1) 3/4-inch female adapter (to attach nipple to base of transducer)
(1) roll 1/2-inch teflon tape (for joining steel to plastic threads)

Slab and equipment vaults
pick (for digging holes for vaults)
shovel (ditto)
spirit level (to level concrete forms)
box 3 1/2-inch nails
claw hammer
(4) 4-foot lengths 2x4 lumber (for concrete forms)
(10-15) 60-pound bags pre-mixed concrete
(10-15) gallons water (1 gal per bag concrete) plus sufficient for cleanup
wheelbarrow (to mix and pour concrete)
hoe (to mix concrete)
4-foot length of 3/4-inch electrical conduit (to pass datalogger wiring through concrete slab)
(1) 12x16 rectangular sprinkler valve box (Home Depot #052063171135)
(1) 10-inch round sprinkler valve box (Home Depot #052063101118)

Plastic fittings and other supplies for wellhead support
(1) 4-inch ABS-DWV double tee (Home Depot #039923205506)
(1) 4-inch ABS threaded cleanout plug (for mounting junction box)
(2) 4-inch ABS end caps (to seal main openings of wellhead tee)
(1) 4-inch ABS threaded male adapter (base of wellhead system)
(1) 4-inch ABS threaded female adapter (mounts to well casing, accepts wellhead system)
(3) 3- inch (approximate) pieces of 4-inch ABS pipe (to mate female fittings)
whiteout ("liquid paper") for marking the black ABS plastic
(4) #8x3/4-inch pan head self-tapping screws (to secure junction box)
aluminum tape (to seal irregular holes in wellhead)

Hand tools and miscellaneous supplies
heavy gloves
measuring tape
electric driver-drill with drill bits from 1/16 to 3/8-inch (to start jigsaw cuts and drive

screws)
#1 phillips screwdriver and driver drill bit (to mount and open/close junction box)
electric jigsaw (to cut transducer access port)
hacksaw
half-round and rat-tail files (to dress transducer access port and wiring cutouts)
Safety glasses
"Red Hot Blue" or equivalent PVC/ABS cement
jewelers screwdriver with 3/32-inch blade (for tiny slotted screws on terminal strip)
desiccant for junction box (prevents condensation in reference pressure line)
whiteout ("liquid paper")

Electrical equipment and supplies
24-inch or larger nylon cable ties (to secure wire and cable to wellhead tee)
4 feet flex coil, spiral wrap or equivalent wire shield (to protect wire against rodents)
wire stripper
red-collar (22-18 AWG) 5/16 or 3/8-inch ring terminals (to fit battery posts)
crimping tool for solderless connectors

Station log box
(1) Rubbermaid "Servinsaver", 1-quart rectangular (Target #002030251)
(1) economy field book (Holman's)
(1) mercury thermometer (Holman's)
(1) penny for opening latches on datalogger cover
(3) bags Stevens desiccant (for junction box, datalogger faceplate, and station log box)
(1) pen with waterproof black ink

The objective is to provide a secure support for the transducer, which hangs in the hole on its cable, in a way that will not put any strain whatsoever on the junction box. The port must be large enough to insert and withdraw the transducer and its attached weight for servicing, and the support must not kink the transducer cable.

Fabrication requires no more than two hours if the supplies are on hand. Safety glasses are required during the installation process. Care must be taken when cutting the flats off that end cap. Cut a clean port in the tee, beneath where the cable is supported by one of the arms of the tee, and file smooth and round so the transducer cable does not lie taut across any sharp corners or edges. The junction box fits in one arm of the tee, screwed to the male cleanout plug which is cemented in place after cutting out the raised wrenching flats to provide a smooth base for mounting. Notches in opposite sides of that arm provides clean cable entry to the recessed box. Using whiteout ("liquid paper") as a layout marker works well on the black ABS plastic.

When attaching the piece of galvanized pipe to the base of the transducer as a cable weight, DO NOT STICK ANYTHING UP INTO THE TRANSDUCER. DO NOT BLOW INTO IT OR DROP IT. Make sure the transducer and its attached piece of galvanized pipe can be inserted and withdrawn from the tee; it is a tight fit in 4-inch pipe for the combined piece that is over a foot long. The main reason for using the threaded male adapter at the base of the tee is that filing and fitting may be accomplished before taking the equipment to the field. Everything opens up beneath the threaded male fitting, so if it fits it will pass into the well.

The arm of the tee opposite the junction box is sealed with an end cap and a stub of pipe, glued in place. The top is not sealed permanently; this is for access to measure water levels. Glue a pipe stub into and end cap, but not into the tee. This results is a cap with a slip fit that can be removed for water-level measurements. The measuring point will be the lip of the tee. Finally, seal the gaps around the transducer port with aluminum tape. In this way, no leaves, lizards, bugs, etc., will find their way into the monitoring well.

Secure the wraps of cable on the tee with the big cable ties, to minimize the possibility of cable slippage. Cover the cable with the protective sheath (spiral wrap or equivalent) to help protect it from rodents and bury the remainder. The battery is housed in the rectangular sprinkler box and the datalogger in the smaller round sprinkler box. The Battery sits on a piece of wood and the datalogger sits on the plastic container containing the station log.

Safety Considerations

Wear safety glasses when assembling all wellhead equipment. Use care when cutting the ABS fittings with the jigsaw have been previously covered. PVC cement may splash in your eyes as glue may squirt at least 10 feet when attaching fittings. Batteries, especially lead-acid batteries, contain acid which is a potential hazard. Do not across the positive and negative terminals with hand tools, etc. Transport with great respect, given their mass and sulfuric acid content.

Protective well cover removal requires proper technique and two persons. Wear gloves during removal and installation. Prior to placing hands in equipment vaults or protective covers inspect for black widows, scorpions, rattlesnakes, etc.

The electric field from the high-voltage power lines that run through the project area can give you a shock. Do not work under electric lines.

<u>2. Datalogger and battery.</u>

A 12-volt battery is need for set up of the Stevens AxSys MPU datalogger. Without power to the external leads, the display will remain blank even with the front-panel toggle switch in the "**ON**" position. Use a "maintenance-free" automotive/marine lead-acid batteries with threaded 5/16-inch terminal posts and wing nuts. The datalogger is shipped with non-terminated + and - wires, so these will need two red-collar (22-18 AWG) 5/16 to 3/8-inch ring terminals and a crimping tool to connect the datalogger to the battery. Power up and view the factory settings and make any adjustments that are needed, as outlined below. Check the settings before taking the datalogger to the field, especially if you are unfamiliar with the menu system and settings. Several of the factory settings will probably need to be reset prior to putting the datalogger in service:

1. **Time:** Use PACIFIC DAYLIGHT TIME. Adjust the clock an hour at the appropriate time to correspond with daylight savings and standard times. In the future clocks may be set to Coordinated Universal Time (formerly called Greenwich Mean Time),

2. **Channel ID:** This will, in most cases, be "FT H2O" for Channel 1. Only one recorder has a second channel (it records barometric pressure in inches of mercury, "IN HG").

3. **Interval:** Use 01:00:00 for hourly sampling.

4. Set **Dataview:**: to MIN/MAX. This is most convenient.

5. **Scale:** Set this to 0.000 for best precision.

6. **4 mA Reading** 0.000 and **20 mA Reading** 10.000 for a transducer with 0-10 foot range.

7. **System ID:** Name the well. There are 17 characters, for example, "SECTION 9 WELL M1."

8. **Card Copy:** Select **New Data Only**. The alternative is **All Data**, which will write everything in memory to the card; this is not wanted. When New Data Only is selected, a copy to the card will be followed by a prompt to Set new data mark (>) to accept or **MENU** to reject; always set a new data mark after doing a download.

The Stevens AxSys MPU datalogger and battery are installed in buried vaults near the well. The vaults are sprinkler valve boxes, which are judged to provide adequate concealment and protection for the equipment. Wiring is buried to the extent possible, with sufficient slack within the vaults to allow the datalogger and/or battery to be removed without being disconnected. Where exposed, wiring should be enclosed by spiral wrap or equivalent to protect against gnawing rodents. Since the dataloggers are kept underground, a bag of desiccant should be kept on the front panel, under the instrument cover. Press down on the latches when opening the cover to avoid damage to the plastic retainers.

3. Station log.

A surveyor's notebook, pen with waterproof ink, mercury thermometer, and bag of desiccant are stored in a Tupperware container in the datalogger vault. In this way site visits can be logged, along with pertinent data such as manual water level measurements and battery voltages. Slippage or stretching of the transducer cable and weak batteries should be recognizable by reference to the station log. Battery voltage should not be allowed to fall below 12.0 volts; a fresh battery is to be kept available for rotation through the system as batteries are removed for recharging. Additional, pertinent environmental information or station operation data should be recorded on the station log. In particular, offset values (described below) should be recorded prominently near the front of the station log.

4. Understanding OFFSET

"Offset" is a number. For example, imagine standing on a hill that is 1000 feet above sea level. Assume that the hilltop is 1000 feet above sea level, and there is a 2-foot bush on the hilltop that is measured with a yard stick. Then add the 1000-foot *offset*, and find that the top of the bush is 1002 feet above sea level. That is exactly what is done with a datalogger that does not utilize the exact values of interest.

It is important to understand offset as the AxSys MPU will only allow a record in the ranges -299.99 to +299.99, or -29.999 to +29.999. It is like the yardstick, that can not measure the whole thing of interest. There is a menu item called **Scale:** in the **>Channel Setup** menu (described below) that is used to select which range is used, use the sensitive range (three decimal places). So, what if we want to measure something that varies from 26.000 to 31.000? The system needs to be "tricked" since it can not handle numbers greater than 29.999. Set it to record, for example, 6.000 to 11.000 and add the constant value of 20.000 in later. That value of 20.000 is the *offset*. An understanding of the way offset is handled in the Stevens AxSys MPU is important because without this background the readings will be misleading.

It is possible to program the offset into the datalogger, so that the readings that are recorded have the offset added in and therefore correspond to what might be measured manually. The user may edit the reading between -499.99 and 19999.99 (0.00 scale) or -49.999 and 1999.999 (0.000 scale), using the keypad in the *Edit* mode. Changing the displayed reading in this way will produce an *offset* to the actual analog reading from the sensor. To view this offset, press the > key while in the "**Reading**" display, and the offset will be displayed directly below the reading. No offset has been applied for the reasons described below.

There are reasons not to use the built-in capabilities of the AxSys dataloggers to apply offsets in the field. First, the dataloggers have an internal lithium battery, so once programmed they will not lose their settings. WITH ONE EXCEPTION. If an offset is specified when programming the AxSys MPU, it will be lost if the front-panel switch is turned off. Second, the sensor at TH-2 has been calibrated, so it is known that the 4 to 20 mA signal representing barometric pressure corresponds to pressures between 23.997 and 30.001 inches of mercury (dataloggers can only record numbers in the range -29.999 to +29.999). The choices are to either use a tiny offset like 0.002, or alternatively to use 20 mA and cause a value of 29.999 to be recorded, instead of the strictly correct 30.001.

With the tiny offset, this would never be noticed when reviewing the data if it had been dropped due to the datalogger being turned off. With this approach, the whole purpose of calibration is defeated. It is reasonable, instead, to record numbers in the range 3.997 to 10.001 and add the constant 20 later, in the office. For example, a reading of 7.256 is actually 27.256, and there is no need to continually check whether re-programming of an offset is necessary. The offset value for each channel at each instrument station should of course be clearly recorded near the front of the station log so that it can be checked in the field when servicing the dataloggers.

5. Reading the AxSys datalogger display.

This section describes the operation of the Stevens AxSys Monitoring/Processing Unit (MPU) datalogger. Each MPU stores water-level data from a downhole sensor, and the system at borehole TH-2 also stores barometric-pressure data. A removable data card is used to extract and transport data from several MPU's to the office for processing. Generally, the dataloggers will be set up by Mifflin & Associates and will require no servicing other than periodic checks of battery voltage, battery changes, and data downloads. The purpose of this section is to familiarize field personnel with the menus and display, so that the operation of the datalogger can be verified during field visits.

In addition to the **MENU** key and **ON/OFF** toggle switch on the front panel, there are three keys labeled "_", "_ ", and ">". The MENU key enters information from the current (displayed) menu and advances the display to the next menu item. If the value is to be selected or edited (changed), modify it as desired with the "_", "_ ", and ">" keys. Then press **MENU** to enter the new value into memory and advance to the next menu. Do this if changing the sampling "**Interval:**" during a pumping test, for example, or adjusting the "**Channel ID:**" at TH-2 so to view the reading in the other channel. Note that for now the system is set up on PACIFIC DAYLIGHT TIME.

The "_" and "_ " keys have two possible effects, depending on the operation being performed. When a menu has an item that can be selected or edited, the *first* press of either key selects the *Edit* mode, causing that item to blink repeatedly on the display. The *second* (and subsequent) presses of either key cycle through possible selections of the blinking display item if it is a condition, or character values if it is a single alphanumeric character.

The ">" key has *three* possible effects, depending on the operation being performed.

(1) When a character value is being Edited, press ">" to advance to the next character in a character string.

(2) If a menu has just been selected and is preceded by a ">", press ">" to enter the next level of that menu.

(3) When in channel status menu, press ">" to jump to channel setup menu, providing a convenient means of setting up a multi-channel MPU.

Stevens provides complete user instructions for the setup of their instruments in a series of instruction booklets for transducers, dataloggers, software, etc. This information is not repeated here. The published instructions are not perfect, however. The data card reader presented several installation difficulties, as did the card-reading software. The technical representative of Stevens Water Monitoring Systems, Inc. is Larry Graeme (503/469-8000). The booklets are available through Mifflin & Associates, Inc.

The input signal to the AxSys MPU (datalogger) is a small electrical current in the 4-20 milliamp (mA) range. This means that by using a downhole transducer that senses 0-10 feet of water pressure, it will send 4 mA to the datalogger if there is no water pressure, and 20 mA when the sensor is 10 feet under water. An important programming step is the selection by the user of how these values will be represented in the datalogger's memory. The concept of offset, described above, needs to be understood first because the "reading" displayed by the AxSys MPU depends on how the instrument is set up with respect to offset. It is important to understand what offset is and how to handle offset when setting up the dataloggers and checking their readings.

Assuming that the concept of offset is understood, the following are steps for understanding the menus and checking the settings and readings on the AxSys MPU datalogger. The whole idea is that during site visits to measure the water level and check it against the reading on the datalogger to see if there is some problem like cable slippage. Check the battery voltage and know what to record in the station log. Most important, as described in the next section, is to be able to download data from the AxSys MPU.

Wake the MPU up by depressing the **MENU** key for approximately 1 second. When the MPU is first powered up, it performs an initialization routine, as indicated on the display, and then switches to the channel status display:

>Channel: ANALOG 420
PWR: 12.4V 90XXX A

This is the channel status menu. Push **MENU** once to advance to the next menu item:

>Reading: 0000.000

The "Reading:" value is part of a menu structure containing 9 main levels; those menus preceded by a ">" have added menu levels. The user can cycle the display through the 9 main displays by repeatedly pressing the **MENU** key. The other menus are **Time:**, **Date:**, **Chan ID:**, **Interval:**, **>DataView:**, **>Channel Setup**, and **>System Setup**.

6. Extracting data from the datalogger.

Downloads are extremely simple. "Wake up" the datalogger by depressing the menu key for a couple of seconds, insert the solid-state data card, and the AxSys MPU will automatically perform the data transfer. The display will show

Copying to card...

____

A small green light (LED) to the right of the card slot will illuminate, and the second line of the display will display blocks that show copy progress. When the copy is complete, the LED will go off and the following message is displayed:

Set NEW DATA mark?

followed by alternating messages on the second line:

Press > to accept -or-
Press MENU to reject.

We press >, so future copies to the card will only include data recorded after the mark is set. This configures the system so that next time someone does a download they will just get the new data and not all data in the datalogger. After this last selection the display shows

Copy successful
****REMOVE DATA CARD****

The card must be removed at this time so recording can resume. Remove the card and that completes the download process.

7. Uploading from the card to your computer.

This section describes how to transfer the water-level and barometric-pressure data off the memory card onto the computer, what the resultant file looks like, and how to save and rename it. This is not a step-by-step guide to installation of the card reader and AxRead software, for it is somewhat troublesome and does not always proceed exactly as presented in the Stevens booklets. This guide is meant for the user who has (perhaps with assistance from Mifflin & Associates) installed the system on his or her computer and needs his or her memory refreshed prior to the monthly processing.

The data card is a PCMCIA-type, 256K "Flash" memory card. Although in principle it should be readable by any computer with a PCMCIA slot (i.e. most laptops), have been found that the CSM OmniDrive card reader must be used. The card reader connects to the parallel port and is controlled by a Windows driver. Installation difficulties seem to vary from computer to computer. For technical support contact CSM GmbH (in Germany) via their website at http://www.csm-gmbh.de/en_supportform.htm or by e-mail at csm@csm-gmbh.de Updates and additional downloads are available from http://www.csm-gmbh.de/en_index.htm.

Stevens provides AxRead software that can be configured to read the card and save the data to disk as a batch process. Installation difficulties had to do with configuring the parallel port, and several phone calls to Larry Graeme at Stevens (503/469-8000) were required before things worked properly. When installed, there will be a blue "S" AxRead icon on your desktop. Double-clicking it brings up the "AxSys Data Utility Program" window, from which you highlight "**AxSys Data Card Xfer...**" from the File menu, then select "**Batch Process**" from the pop-up submenu. The selection can also be made simply by pressing the **F5** key. This prompts to "**Insert Data Card**"; do it then click the "**OK**" button. A series of black and white DOS windows will appear and disappear, indicating progress of the various subtasks. Close them manually if they do not close themselves. When the card has been read, "**Processing Complete**" will appear in the "AxSys Data Utility Program" window. Now look at the data set and begin the monthly processing routine.

The files (one from each instrument) end up on the host computer strung together as one text file named "axtrxfer.txt" in the C:\Program Files\axread directory. This file must be re-named and saved before it is over-written by the next upload. Double-click its spiral-notebook icon to open it up. If Windows says it is too large for NotePad to open, click **Yes** to open it with WordPad. Use the naming convention FullDump_MM_DD_YY to designate these files with the download date, and store them in a folder called Raw Data Dumps in the Desktop\WtrLvls folder . The FullDump file downloaded from TH-2 and ECP-2 on October 3, 2000 looks like this:

```
0004.328 14:00:00 09/02/00 "SYS ID  CALPINE TH-2      "
0004.340 15:00:00 09/02/00
0004.343 16:00:00 09/02/00
                    .
                    .
                    .
0004.343 14:00:00 10/03/00
0004.336 15:00:00 10/03/00
0004.328 16:00:00 10/03/00



0007.543 14:00:00 09/02/00 "SYS ID  CALPINE TH-2      "
0007.523 15:00:00 09/02/00
0007.498 16:00:00 09/02/00
                    .
```

.

.

0007.468 14:00:00 10/03/00
0007.447 15:00:00 10/03/00
0007.422 16:00:00 10/03/00

0015.375 15:00:00 09/02/00 "SYS ID CALPINE ECP-2 "
0015.390 16:00:00 09/02/00
0015.406 17:00:00 09/02/00

.

.

.

0015.265 15:00:00 10/03/00
0015.265 16:00:00 10/03/00
0015.328 17:00:00 10/03/00

As is observed, there are three blocks of data representing the hourly measurements. Each block covers a period of time from September 2 to October 3 (most of the middle data have deleted out for brevity). Each line contains a reading, time, and date, and the first line of each block contains station identification. There are some blank lines between blocks and at the end of the file, which ends with the "^" symbol.

This format, designated "F3" in Stevens AxRead parlance, is the most convenient for subsequent import to a spreadsheet. Beware that the "F5" format, which is supposed to be best for spreadsheet use, does not work. The result is using a format with no channel identifiers. The only station with more than one channel is TH-2, and the other channel is Channel 1 which contains water levels and is written first. Channel 2 requires the offset value of 20.000 (discussed at length above) to be added back in.

8. Separating the records and organizing by month.

Two (or perhaps more) FullDump files are then cut up using any word processor to create monthly records for each sensor. The naming convention here is WELLIDwlMonthYY.txt or WELLIDbpMonthYY.txt, as appropriate. Continuing with the TH-2 September example, find the file FullDump_09_02_00 in the Raw Data Dumps directory; the bottom of the TH-2 water-level segment of that file (which covers the first part of September) looks like this:

0004.351 00:00:00 09/01/00
0004.343 01:00:00 09/01/00
0004.336 02:00:00 09/01/00

.

.

.

0004.317 11:00:00 09/02/00
0004.324 12:00:00 09/02/00
0004.332 13:00:00 09/02/00

Copy and paste the data from these first couple of days of September into a new file, "Save As" TH2wlSept00, then append it with a cut and paste of the September portion of FullDump_10_03_00, deleting the Station ID label ("SYS ID CALPINE TH-2") from the first line. One clean text file is the result containing the September, 2000 water level record from borehole TH-2, saved in the Processed Text directory:

0004.351 00:00:00 09/01/00
0004.343 01:00:00 09/01/00
0004.336 02:00:00 09/01/00

.

.

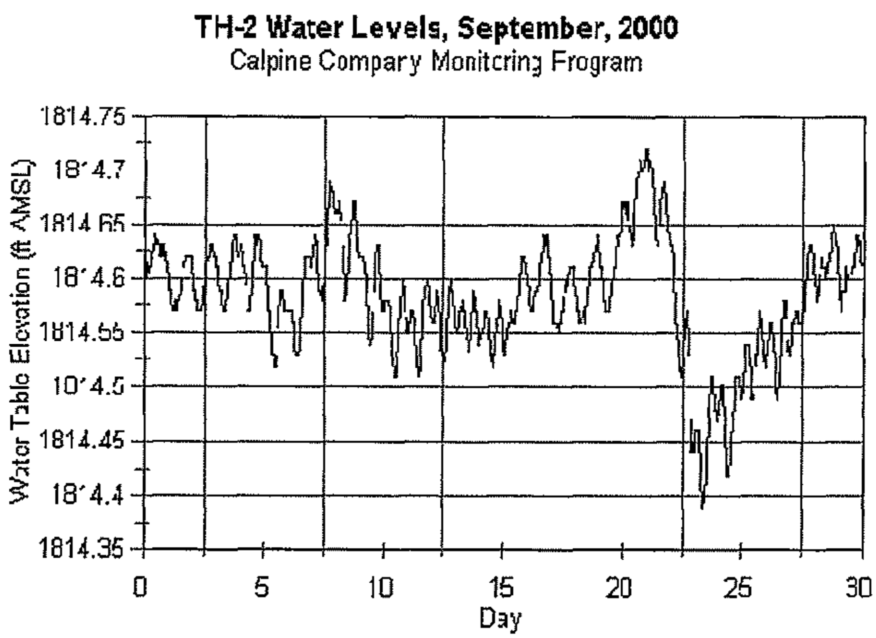
.

0004.362 21:00:00 09/30/00
0004.351 22:00:00 09/30/00
0004.343 23:00:00 09/30/00

It is named TH2wlSept00; then create files named TH2bpSept00 (with raw barometric-pressure data), ECP2wlSept00 with water levels from borehole ECP-2, and so on for any other sensors in the network.

The last step in archival of the monthly data is to read the monthly records into a spreadsheet program for a minimal amount of processing and re-formatting, and plot the data to check for integrity. This is where offset is added in to the barometric-pressure readings and convert the water pressures to water elevations using the wellhead elevations and cable lengths. Here is an example of the type of plot that can be prepared with a spreadsheet program:

Create a column defined as date+time and subtract the value of the first entry from all subsequent ones to get decimal day of the month. Convert the raw barometric-pressure reading to inches of mercury by adding the constant 20, as explained above, then convert this quantity to feet of water by multiplying by the constant 1.133. Convert water pressures to elevations using the surveyed elevation of the measuring point and cable length derived from manual water-level measurements (see discussion of cable length files, below). Templates (blank spreadsheets containing formulas and constants) are being prepared to facilitate these operations and keep them consistent from month to month. For now, just refer to the previous month's results for guidance. Then just plot the data with day on the x-axis and the parameter (water elevation or barometric pressure) on the y-axis, and save the hardcopy plots.



To prepare a spreadsheet using Quattro Pro, do the following:

1. Start up Quattro Pro using the calculator icon, then **OPEN** the text file with the monthly record. You'll need to navigate to the Desktop\WtrLevls\Processed Text folder and set the file type to **ASCII Text (*.txt)** in the lower left of the "Open File - Processed Text" window.

2. A "Quick Columns Expert" window comes up - choose "**Fixed Width Auto**" Parse Settings, the **OK** button.

3. Type "**=b1+c1**" in cell d1, then copy and paste this formula to the rest of the cells in column d.

4. Type "**=d1-d1**" in cell e1, then copy and paste this formula to the rest of the cells in column e.

5. In column f convert sensor readings to water elevations (**=surveyed MP elevation - cable length + sensor reading**) or barometric pressures in feet of water (**=(reading+20)*1.133**), as appropriate.

6. Save your work in Desktop\WtrLevls\Spreadsheet Format as a Quattro Pro file with the same root name as the text file you started with.

To plot the data from the spreadsheet, do the following:

1. Select the rightmost two columns of data in the spreadsheet by clicking and dragging to highlight them; the first will be decimal day, the other will be water elevation or barometric pressure.

2. Select "**Chart...**" from the **Insert** menu.

3. Click the **Next>** button when the first Chart Expert window appears.

4. Choose the **Line or Area** button from the second Chart Expert window, then click **Next>**.

5. Choose the top-right chart type button from the third Chart Expert window, then **Next>**.

6. The fourth Chart Expert window allows entry of a title, subtitle, and axis labels. Refer to the example above for guidance, then **Next>**.

7. In the last Chart Expert window the color scheme is chosen. Pick **No Change**, then click **Finish**. The cursor changes to a little histogram, allowing it to click/drag to define the area where the chart will be drawn. Do it, and save the work.

8. Cosmetic changes can now be made to the chart. In general, the fonts are too big, the data too light in color, and the number of days does not match the number of days in the month. After cleaning up these details and re-saving, print the chart.

The root names for the saved spreadsheet files should be the same as for the monthly text files, i.e. WELLIDwlMonthYY.qpw or WELLIDbpMonthYY.qpw are

Quattro Pro files containing water-level and barometric-pressure data, respectively for a full calendar month. At the end of the year a recordable CD will be prepared with the full years' data in a variety of formats, including popular .xls to facilitate use by Microsoft Excel users.

Cable Length Files

The length of the cable on which the pressure sensor is suspended in the borehole is critically important to the accuracy of the water-level measurements. The cable length is the distance between the surveyed measuring point on the wellhead and the pressure-sensing element, i.e. the sum of the depth to water and the height of water above the sensor. We should be able to measure the static water level with a well sounder, read the datalogger, and get the same sum no matter what the water level in the well, because these two values add to the cable length. However, it is not that simple. Watch the display on the datalogger, and it jumps around a little. Measure water levels a few times in a row, and they do not all come out exactly the same. We end up with some scatter in our estimates of cable length, which would make it difficult to recognize minor slippage or stretch-related increases in length. It is a judgement, at any point in time, as to what is the "best" estimate of cable length. Usually this will be the mean of available measurements, excluding spurious values, and the standard deviation will give us an estimate of the precision of the measurement. Accuracy, however is a different issue.

Side-by-side comparisons of measuring tapes used to measure depths to water have revealed differences on the order of one foot, requiring constant vigilance as to which tape is being used for a particular measurement. The question here is one of accuracy, i.e., which tape is closest to being correct? The potential errors associated to measured depths to water are much greater than the errors associated with wellhead surveys or of transducer readings. The challenge is how to report water-level records in a consistent fashion that will allow for upgrading as calibration of the measuring tapes is improved. Measurements, assumptions, and traceability information are contained in cable length files, key support documents that must accompany and be referenced from within each archive of water-level data.

Monitoring Supplement E-2

Procedure for Electric Well Sounder Cable Calibration
and
Water-Level Measurements Using Calibrated Cables

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I. Purpose

While quite precise, manual water-level measurements are often inaccurate due to such factors as poor manufacturing controls of electric well sounder cables (cables), downhole cable stretch, and damage. This procedure seeks to improve the accuracy of downhole water-level measurements through a side-by-side comparison of Calpine Project or Moapa Band of Paiutes (Project) cables with a calibrated steel tape (reference tape). A stepwise process for establishing downhole weights (Form A), elastic properties (Form B), and proportional length corrections (Form C) for cables used for measuring depths to water by Project personnel is presented. The procedure provides a basis for equipment intercomparisons and for referencing measurements to a traceable standard. The accuracy of water-level measurements is established through a two-step sequence of first adjusting field observations to a "zero-tension state" of the cable and then developing a proportional correction factor that can be applied to the adjusted observations. This allows a single proportional correction factor **C** (dimensionless) to be established for each cable. Form D outlines the use of a calibrated cable and data from Forms A, B, and C to convert observed water-level readings to accurate values.

II. Assumptions and Variable Definitions

The central assumption in this procedure is that Hooke's law of elasticity applies to the well sounder cable, that is, that cable stretch is a linear function of load (tension). This assumption is checked directly during the calibration process, as several tensions are applied to the well sounder cable and readings corresponding to known values on the reference tape are obtained. To accomplish a reproducible calibration, factors such as vertical vs. horizontal tension, cable stretch properties, and zero-tension state are part of the calibration process and are described below. This procedure does <u>not</u> include provisions for establishing thermal effects on Project cable length, i.e. the coefficient of thermal expansion.

A. Vertical vs. Horizontal Calibration

When a cable is suspended vertically to obtain a water-level measurement $\mathbf{R_{OBS}}$, its stretch characteristics will be completely different than when pulled under horizontal tension $\mathbf{W_H}$ during calibration. Each point on the cable will "feel" a pull from the weight of cable and probe below it, so the higher portions of the cable will stretch more than the lower portions. A vertical cable that obeys Hooke's law will exhibit overall stretch identical to the case where the probe weight plus *half* of the downhole cable weight is applied to the downhole cable. This is because the full weight of the cable and probe are "felt" only at the wellhead, and the tension decreases to only the probe weight at the bottom of the cable. Hooke's law is a statement of linearity, meaning that we can use a force $\mathbf{W_V}$ equal to half the cable weight plus probe weight to represent the tension causing stretch of a vertically suspended cable. Conceptually, we are simply distributing the stretch uniformly as if the cable were being pulled horizontally under tension $\mathbf{W_V}$. Form A provides the format for recording the weights of well sounder components and computing $\mathbf{W_V}$, the *effective* hanging cable weight associated with a water-level observation.

B. Cable Stretch Properties

The stretching properties of a specific cable must be established by direct measurement of its length under a range of tension loads. During calibration, readings from the cable are obtained at each 100-foot mark on the reference tape to help recognize cable damage or other sources of non-linearity in cable stretch. In this way an elastic constant, **k**, can be established that represents the relative elongation of the cable per pound of pull. In practice, **k** will be required (in conjunction with effective hanging cable weight $\mathbf{W_V}$ and cable reading $\mathbf{R_{OBS}}$) to adjust cable readings for tension effects prior to applying error corrections that are proportional to the adjusted readings. The dimensions of **k** will be lb^{-1}, i.e. "per pound".

To find **k**, lay out the cable alongside a reference tape, set the cable tension, and record the cable readings at 100-foot intervals as indicated by the steel tape. As the tension is increased, the readings opposite the reference marks will *decrease* as the cable stretches relative to the stationary reference tape. Form B provides the format for recording stretch data, and includes a hypothetical data set for an ideally elastic cable. The relative elongation of the cable is given by $\mathbf{(R_o-R_n)/R_o}$, where $\mathbf{R_o}$ is an original cable reading (at some fixed tension) and $\mathbf{R_n}$ is the new cable reading (at increased tension). If the horizontal tension increase in pounds is $\mathbf{W_H}$, we define $\mathbf{k=[(R_o-R_n)/R_o]/W_H}$, the relative elongation per pound of (additional) horizontal tension. Note that obtaining a *reading* at zero tension is impractical, since the cable would not lie straight and Hooke's law would not apply at very low values of tension. Relative elongation must be observed as increments of tension greater than the minimum needed to straighten the cable and overcome static friction with the ground are applied.

It is possible that a well-made cable will not exhibit significant stretch when subjected to the 5- to 25-pound tension range explored by this calibration procedure. In a case where the cable does not stretch measurably, the plot of reading vs. tension as given in Form B would be horizontal (i.e. constant), and extrapolation back to zero tension would be trivial; any reading at any tension would be equivalent to its corresponding zero-tension reading.

C. Zero-Tension State

Although a zero-tension cable reading cannot be obtained from observations, the concept of a zero-tension state is important to the error correction process. The zero-tension state of the cable is the starting point for applying corrections for systematic errors, i.e. those that are proportional to the cable reading. The idea is to first *compute* a zero-tension reading to remove stretch effects, then apply a proportional (to the magnitude of the reading) correction to the zero-tension cable reading. During calibration, the zero-tension cable reading opposite a reference mark is obtained by extrapolating a plot of cable reading vs. tension back to zero tension. When a cable is suspended in a borehole, we use algebra to rearrange the defining expression for **k** and find the zero-tension reading $\mathbf{R_Z}$ as $\mathbf{R_Z}=\mathbf{R_{OBS}}/[(1-\mathbf{k}(\mathbf{W}/2+\mathbf{p}))]$, where $\mathbf{R_{OBS}}$ is the actual cable reading, **W** is the weight of cable in the hole, and **p** is the probe weight. We define an effective downhole cable weight $\mathbf{W_V} = \mathbf{W}/2+\mathbf{p}$ (Form A).

III. Calibration

A. Equipment

1. Procure a 500- to 1000-foot, NBS-traceable steel (or equivalent, i.e. Invar) surveyors calibrated tape (reference tape) with documentation such as thermal correction data and certification papers; procure two appropriate and compatible tensioning devices (40-pound fish scales would be appropriate).

2. Procure a mechanical postage scale (or visit a post office to weigh the probe containing the sensing element of the Project cable), and a mercury thermometer for recording air temperature at the time of the calibration to assure accuracy of the reference tape.

3. Forms A (weights), B (stretch), C (proportional correction) and D (use of a calibrated well sounder) for recording, checking, and applying calibration data.

B. Procedure

1. Find a dry grassy area (a large park or golf course would be ideal) without interfering vehicular or pedestrian traffic where the Project cable can be laid out alongside the reference tape for direct comparison.

2. Establish the zero point of the Project cable with a water bucket, and mark the probe with a Sharpie pen or other indelible ink to facilitate alignment.

3. Weigh the entire Project well sounder, spool and all, using the fish scale to obtain total weight **s** (lb); record on Form A, Item 1.

4. Weigh the probe of the Project cable, using the postage scale, to obtain probe weight **p** (lb); record on Form A, Item 2. This could be done at a post office prior to unwinding the spool for calibration.

5. Lay out and stake the reference tape at the tension designated in the calibration documents, and record air temperature (Form A Note 3a).

6. Lay out the Project cable and weigh the empty spool with the fish scale, obtaining empty spool weight **e** (lb); record on Form A, Item 3. Estimate the force needed to overcome static friction between cable and grass by dragging the cable a short distance using the fish scale; record on Form A, Note 3a.

7. Calculate the cable weight by subtracting the empty spool weight **e** and the probe weight **p** from the total well sounder weight **s** to obtain the cable weight **c**: **c=s-e-p** (lb); record on Form A, Item 4.

8. Calculate the weight per unit length (**w**) in pounds per foot of the Project tape by dividing weight of the cable **c** by the length of the cable **a**: **w=c/a**.(lb/ft); record on Form A Items 5 and 6. Note that all cable weights are referenced to cable markings, not the reference tape. Note also that weight per indicated length will not change as the cable stretches.

9. Stake the Project cable alongside the reference tape so that the zero points align; some creativity may be required, depending on the configuration of the probe end that must be secured. Ring clamps and a turnbuckle might be useful, but a procedure such as this cannot anticipate all probe configurations that might be encountered. The idea is simply to keep the zero points aligned as various tensions are applied to the Project cable.

10. Using the fish scale attached to the cable spool, apply 5 pounds of tension to the Project cable.

11. Observe and record on Form B the reading from the Project cable opposite each 100-foot mark on the reference tape. These data will be used to check for discontinuities such as splice effects in the cable.

12. Repeat readings for 10-, 15-, 20-, and 25-pound loadings, completing the Form B table. Results (reading vs. load) from the longest cable readings should be plotted on Form B graph paper in the field as a check on linearity and to graphically obtain the corresponding zero-tension reading $\mathbf{R_Z}$.

13. Calculate the elastic constant **k** (lb^{-1}) of the cable from the Form B stretch data, using the longest cable-to-reference-tape readings available. Use a linear portion of the reading

vs. load graph (Form B) to obtain the relative elongation $(R_o-R_n)/R_o$ associated with a difference in horizontal tension W_H to obtain $k=[(R_o-R_n)/R_o]/W_H$.

IV. The Error Correction Process

A. Correction to Reading

In the simplest case of error correction the Form B graph is horizontal and we can neglect cable stretch. When a reading R_{OBS} is obtained from a Project cable, it differs from the "true" value **x** by some reading error E_R. For example, if we read 999 feet on the cable opposite the 1,000-foot mark on the reference tape, we have an error E_R of -1 feet and the corresponding reading correction C_R that should be applied is +1 feet. The proportional correction factor **C** is 1 foot for each 999 indicated feet of cable, or 1/999, and the correction to *any* reading C_R is simply the proportional correction **C** multiplied by the observed reading R_{OBS}. An example using these values is given in Form C.

B. Correction for Cable Stretch

The case where cable stretch is significant is only slightly more complex. The errors (and corrections) for a cable that stretches under its own weight are defined for the zero-tension state of the cable. Using the elastic constant **k** obtained in Step 13 above, the zero-tension reading for a tape suspended in a borehole is given by $R_Z=R_{OBS}/(1-kW_V)$, where R_{OBS} is the observed cable reading and $W_V = wR_{OBS}/2 + p$ is the *effective* downhole tension with **w** the weight of cable per foot and **p** the probe weight.

V. Summary

Now corrections to measured water levels are easy. We simply correct out the stretch, if necessary, then add (algebraically) a correction factor that is linearly proportional to the reading to the zero-tension reading to get an accurate water level. Validation of this procedure can be accomplished by side-by-side, in-hole comparisons of Project cables that have been calibrated in accordance with this protocol. Uncertainties in the process can be readily estimated from the goodness-of-fit of experimental data to the approximating linear functions.

VI. Appendices

Form A. Record of Weights

Form B. Record of Cable Stretch

Form C. Determination of Proportional Correction

Form D. Use of a Calibrated Well Sounder

Electric Well Sounder Cable Calibration

Form A - Record of Weights with Hypothetical Example

Purpose. This form provides a location for recording the weights of well sounder components and cable length so that weight per unit length of cable is available for stretch corrections.

1. Weight **s** of complete Project well sounder:

s = ___36___ Pounds

2. Weight **p** of probe at end of cable:

p = ___1___ Pounds

3. Weight **e** of empty spool, or partial spool if only part of the cable is being calibrated:

e = ___5___ Pounds

NOTE 3a: At time cable is laid out, record:
date ___________,
time___________,
temperature___________,
and weight (force) in pounds of pull needed to overcome static friction and drag the cable through the grass __________ Pounds.

4. Cable weight **c** by difference:

c = s-p-e = ___30___ Pounds

5. Total length **a** of cable being calibrated:

a = ___1000___ Feet

6. Weight per unit length **w** of well sounder cable:

w = c/a = ___0.03___ Pounds per foot

Given a reading $\mathbf{R_{OBS}}$, the effective downhole cable weight is given by

$$\mathbf{W_V = wR_{OBS}/2 + p}$$

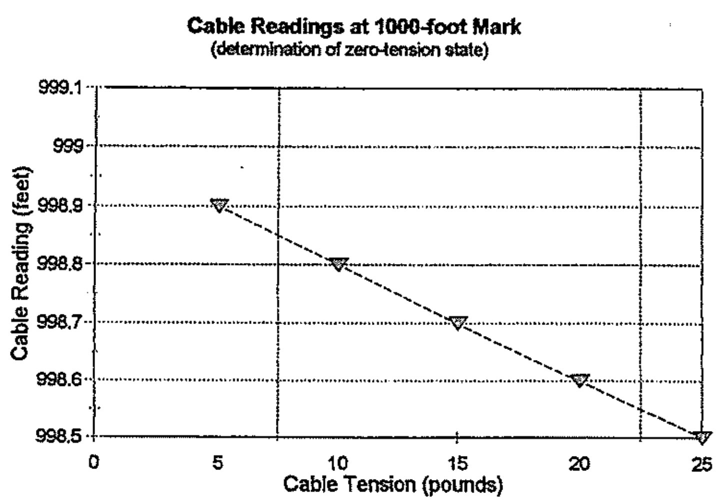
Electric Well Sounder Cable Calibration

Form B - Record of Cable Stretch with Hypothetical Example

Purpose. This form provides a location for recording cable readings as the Project well sounder cable is tested for stretch by applying several tension loads. These data allow an elastic constant and zero-tension state for stretch corrections to be computed.

	Cable Readings under Tension (ft)				
Reference Mark(ft)	5 lb	10 lb	15 lb	20 lb	25 lb
100.00	99.89	99.88	99.87	99.86	99.85
200.00	199.78	199.76	199.74	199.72	199.70
300.00	299.67	299.64	299.61	299.58	299.55
400.00	399.56	399.52	399.48	399.44	399.40
500.00	499.45	499.40	499.35	499.30	499.25
600.00	599.34	599.28	599.22	599.16	599.10
700.00	699.23	699.16	699.09	699.02	698.95
800.00	799.12	799.04	798.96	798.88	798.80
900.00	899.01	898.92	898.83	898.74	898.65
1,000.00	998.90	998.80	998.70	998.60	998.50

For greatest precision, graph the 1000-foot readings vs. tension, fit a straight line to the data, and obtain the zero-tension 1000-foot reading as the y-intercept of the best-fit line, in this case 999.0 ft:



The zero-tension reading corresponding to a reference mark is carried forward to Form C for development of the proportional correction. The elastic constant **k** is obtained from the stretch data using any two points on the tension vs. reading graph. If we choose the readings at 5 and 25 pounds of tension, $\mathbf{R_o}$=998.9, $\mathbf{R_n}$=998.5, $\mathbf{W_H}$=20 pounds and

$$\mathbf{k=[(R_o-R_n)/R_o]/W_H}$$

$$=[(998.9\text{ ft} - 998.5\text{ ft})/998.9\text{ ft}]/20\text{ lb}$$

$$=0.00002\text{ lb}^{-1}$$

The elastic constant is carried forward to Form D for use in computing the zero-tension reading from a downhole observation.

<u>Note:</u> The static friction between cable and grass is not explicitly considered in calculating **k** by this calibration procedure. As tension is applied, it will be necessary to walk the length of the cable and raise it to make sure the tension is distributed uniformly. This is especially important if crude splices (such as tape wraps) or other sources of roughness are present on the cable.

Electric Well Sounder Cable Calibration

Form C - Determination of Proportional Correction with Hypothetical Example

Purpose. This form allows data needed for a proportional correction $\mathbf{C}=\mathbf{C}_{RZ}/\mathbf{R}_Z$ to be recorded in a systematic fashion.

Mark (ft)	Zero-Tension Reading $\mathbf{R}_Z$ (ft)	Reading - Mark $\mathbf{E}_{RZ}$= Error (ft)	Zero-Tension Correction $\mathbf{C}_{RZ} = -\mathbf{E}_{RZ}$ (ft)	Proportional Correction $\mathbf{C} = \mathbf{C}_{RZ}/\mathbf{R}_Z$
1,000	999.00	-1.00	+1.00	0.001001

We find the "true" water level $\mathbf{x} = \mathbf{R}_Z+\mathbf{R}_Z\mathbf{C}$ where $\mathbf{R}_Z$ is the zero-tension reading and $\mathbf{C}$ is the proportional correction factor. In the example above,

$$\mathbf{R}_Z = 999 \text{ ft. and}$$
$$\mathbf{C}_{RZ} = 1 \text{ ft, so}$$
$$\mathbf{C} = \mathbf{C}_{RZ}/\mathbf{R}_Z = 1/999 = 0.001001$$

the "true" water level $\mathbf{x} = \mathbf{R}_Z+\mathbf{R}_Z\mathbf{C}$

$$= 999 \text{ ft} + 999 \text{ ft } (1/999)$$
$$= 999 \text{ ft} + 1 \text{ ft}$$
$$= 1{,}000 \text{ ft}$$

which is the value of the reference mark, as it should be. The **C**-value of course works for <u>any</u> zero-tension reading. If we had found $\mathbf{R}_Z$=416.07 feet, for example,

$$\mathbf{x} = 416.07 \text{ ft} + 416.07 \text{ ft } (1/999)$$
$$= 416.07 \text{ ft} + 0.42 \text{ ft}$$
$$= 416.49 \text{ ft.}$$

Electric Well Sounder Cable Calibration

Form D. Use of a Calibrated Well Sounder with Hypothetical Example

Purpose. This form sets forth the steps for converting a water level observation using a calibrated cable to an accurate depth to water.

Steps.

1. Read the indicated water level $\mathbf{R_{OBS}}$ on the cable using the appropriate measuring point, and record (at minimum) the well ID, water level, tape identifier, date, time, and your name;

2. Compute the effective cable weight $\mathbf{W_V} = \mathbf{wR_{OBS}}/2 + \mathbf{p}$ using data from Form A;

3. Compute the zero-tension reading $\mathbf{R_Z}=\mathbf{R_{OBS}}/(1-\mathbf{kW_V})$ using $\mathbf{W_V}$ from Step 2 above and $\mathbf{k}$ from Form B;

4. Apply proportional correction $\mathbf{C}$ from Form C to find the "true" depth to water $\mathbf{x} = \mathbf{R_Z}+\mathbf{R_Z C}$.

Example.

1. Say you measure a water level of 500.00 feet with a calibrated cable: $\mathbf{R_{OBS}} = 500.00$

2. From Form A, $\mathbf{w} = 0.01$ pounds per foot and $\mathbf{p} = 1$ pound, so

$$\mathbf{W_V} = (0.03\ \text{lb/ft})(500.00\ \text{ft})/2 + 1\ \text{lb}$$
$$= 8.5\ \text{lb}$$

3. From Form B, $\mathbf{k} = 0.00002$ so $\mathbf{R_Z} = (500.00\ \text{ft})/[1-(0.00002\ \text{lb}^{-1})(8.5\ \text{lb})] = 500.09$ ft

4. From Form C, $\mathbf{C} = 0.001001$, so $\mathbf{x} = 500.09\ \text{ft} + (500.09\ \text{ft})(0.001001) =$ <u>500.59 ft</u>

This is the "true" depth to water we were seeking. The same value should be obtained with any calibrated cable.

APPENDIX F

Summary of Ground-Water Development Impact

In the

Upper Muddy River Valley, Nevada

SUMMARY OF GROUND-WATER DEVELOPMENT IMPACTS IN THE UPPER MUDDY RIVER VALLEY, NEVADA

by

M. D. Mifflin

Mifflin and Associates, Inc.

Presented at:

Nevada State Engineer's Hearing on Applications 55450 and 58269

January 24, 25, 26 1995
West Charleston Branch Library
Las Vegas, Nevada

QUALIFICATIONS SUMMARY

DR. M.D. MIFFLIN, PRESIDENT & SENIOR HYDROGEOLOGIST, MIFFLIN AND ASSOCIATES, INC.

Education

- B.S., Geology, University of Washington, 1960.
- M.S., Applied Science, Montana State University, 1963.
- Ph.D., Hydrogeology, University of Nevada, Reno, 1968.

Experience

- 36 years of Professional Experience in the fields of geology and hydrogeology.
- Professional Specialties: Arid zone hydrogeology, paleohydrology, exploration and development of ground-water resources, international ground-water resource planning, assessment and development.
- Professional experience in Southern Nevada began in 1963, and first experience in the Upper Muddy River Valley began the same year.
- Experience began on the regional Carbonate Rock Province flow systems in 1965. Studied, defined the Carbonate Rock Province, and delineated the regional flow systems in Nevada in 1965 – 1968.
- Began water development research on the Carbonate Aquifer in 1976.
- Began Upper Muddy River Valley Carbonate Aquifer studies for Nevada Power in the mid-1980's (EH-4, EH-5b and other monitoring points established).
- Designed and executed the detailed NPC water resource inventory continuing and monitoring program in cooperation with DRI beginning in 1987.

OBJECTIVES OF PRESENTATION

- ☆ Review documented Hydrogeological Relationships of the Upper Muddy River Valley as established by water-level monitoring records, river gaging records, water balance studies, and regional ground-water studies.
- ☆ Review quantitative aspects from a water-balance perspective.
- ☆ Demonstrate that the MVWD Conceptual Hydrogeological Model is not credible.
- ☆ Demonstrate that MVWD pump-test interpretations and impact projections are the result of errors and omissions.
- ☆ Review the evidence that indicates the two protested MVWD applications, if granted and used, would produce unacceptable damage to existing senior water rights and endangered species habitat.
- ☆ Review the evidence which argues that the existing 2 cfs permit for the Arrow Canyon Well, if fully used, also has the potential to produce unacceptable impacts on senior water rights and endangered species habitat.
- ☆ Present recommendations consonant with the evidence.

UPPER MUDDY RIVER VALLEY
MVWD CONCEPTUAL MODEL
Key Points / Conclusions

- The Muddy Creek Formation acts as an aquitard to separate the regional Carbonate Aquifer from the Alluvial Aquifer.
- The Carbonate Aquifer is large and very transmissive, and Arrow Canyon Well permit applications would only cause minor drawdowns over prolonged time.
- There is little or no Carbonate Aquifer discharge to the Alluvial Aquifer or Muddy River Springs.
- There would be no significant impacts on senior water rights and endangered species habitat.
- The above are based on the MVWD Arrow Canyon pump-test interpretations and local well-log interpretations in Arrow Canyon Well area.

UPPER MUDDY RIVER VALLEY DOCUMENTED HYDROGEOLOGIC MODEL

- Approximately 51 cfs of remarkably steady flow reaches the Upper Muddy River Valley via the Carbonate Aquifer and discharges in the area.
- Average maximum winter flow was about 51 cfs (during cold weather, no evapotranspiration losses or diversions) between 1914 and 1961 water years.
- About 19 cfs has been measured in 1963 to discharge via conduits through the Alluvial Aquifer as localized spring discharge.
- About 32 cfs discharged as upward leakage from the Carbonate Aquifer to the Alluvial Aquifer and then discharged as baseflow to the Muddy River channels above Warm Springs Road Bridge during months of no evapotranspiration.
- The above establish the White River System regional Carbonate Aquifer discharge as measured in Muddy River flow at Warm Springs Road Bridge gaging station.

UNCONFINED ALLUVIAL AQUIFER (Arrow Canyon to LDS Farm Reach of Upper Muddy River Valley)

- Lenticular alluvial gravels display large transmissivities and unconfined aquifer behavior. Pumping cones migrate slowly, aquifer lenses dewater within the Lewis Well Field pumping cone.

- Deep, well-developed Lewis Well Field area pumping cone is recovering between October, when heavy pumping stops, and as late as the end of March, when heavy pumping begins. Full recovery of the pumping cone persists for zero to two months with the pre-1994 level of exploitation.

- Source of water for the full annual pumping cone recovery is leakage from the Carbonate Aquifer. Overall water quality is similar to the Carbonate Aquifer water quality. Water temperature varies with location; local slightly higher temperatures indicate localized areas of conduit connections from the Carbonate Aquifer to the Alluvial Aquifer.

- Calcium carbonate cement-sealed conduits pass *through* the Alluvial Aquifer, and *into* the Alluvial Aquifer, both on a local basis. These are active and paleospring conduit-orifice systems, respectively, and reflect Carbonate Aquifer heads and water chemistry.

- Most production wells produce from the Alluvial Aquifer lenses. However, LDS Central and LDS East are in paleoconduit zones and respond as if they are closely connected to the Carbonate Aquifer.
- The Lewis Well Field area pumping cone in the Alluvial Aquifer is transmitted to the Carbonate Aquifer. The Arrow Canyon Well pumping test demonstrated that the pumping stress in the Carbonate Aquifer was transmitted to the Alluvial Aquifer as well.
- The Muddy River channel and tributary channels are in hydraulic communication with the unconfined Alluvial Aquifer.
- Approximately 32 cfs of the 51 cfs of the annual Carbonate Aquifer discharge rate passes into the unconfined Alluvial Aquifer above the Warm Springs Road Bridge gaging station.
- Ground-water production in this reach of valley proportionally reduces the measured annual flow of the Muddy River at the Warm Springs Road Bridge gaging station.
- Pumping cone impact on measured Muddy River flow is delayed until the slowly expanding cone reaches the Big Muddy Spring area (about a five-month delay) and limits baseflow to the Muddy River channel until the cone fully recovers, historically between January and April.

CONFINED ALLUVIAL AQUIFER
(Warm Springs Bridge to White Narrows)

- Lenticular alluvial gravels display large transmissivities and confined aquifer behavior. Pumping cones migrate rapidly over large areas.
- Well-developed pumping cones recover with seasonal pumping cycles.
- Over-pumping has produced water-quality declines in some lenses. NPC well production is managed to prevent the water-quality impacts.
- The induced poor-quality water rapidly passes from the production well area in less than one year. The Muddy Creek Formation is the source of the poor-quality water.
- There is no evidence for hydraulic connections between the Muddy River and the confined Alluvial Aquifer throughout this reach of valley.
- The hydraulic separation between the Alluvial Aquifer and Muddy River occurs upstream of Warm Springs Bridge, but the detailed location has not been documented on the LDS Farm.

UPPER MUDDY RIVER VALLEY
WARM SPRINGS ROAD BRIDGE GAGE MEASUREMENTS AND GROUND-WATER DEVELOPMENT

- Gage records between 1914 and 1961 indicate about 51 cfs of regional Carbonate Aquifer discharge occurs, and may vary only about 2 cfs from the mean.

- Since 1961, measured annual Muddy River flow at the Warm Springs Road Bridge has decreased in response to ground-water development and river-water diversions above the gaging station.

- Measured ground-water development in the Alluvial Aquifer is not immediately reflected in the gaging records during the heavy pumping season, but it is fully accounted for in the gaging records on an annualized flow basis.

- Annual measured Muddy River flow adjusted for estimated annual evapotranspiration, measured annual Muddy River diversions, and measured annual ground-water pumpage above the gage yields adjusted Muddy River flows equal to pre-diversion/pre-ground-water development Muddy River flows of about 51 cfs.

ARROW CANYON WELL
121-DAY PUMPING TEST RESPONSES

- The 121-day Arrow Canyon Well pumping test produced widespread, but small, observed *net water-level changes* in both the Carbonate Aquifer and the Alluvial Aquifer.

- Establishing the *true drawdown* produced by the Arrow Canyon Well during the 121-day pump test is complicated by the seasonal water-level *recovery* from the Lewis Well Field area seasonal pumping.

- Total *recoveries* during the 121-day test were of similar relative magnitude as *true drawdowns*.

- Pumping stresses are algebraically additive at monitoring wells when more than one pumping-induced stress is acting. Therefore, *observed net water-level change* is equal to *true drawdown* (negative) plus *recovery* (positive).

- Long-term NPC monitoring well records have been used to estimate the rates of *recovery* at each monitoring well during the pump test (positive water-level changes) caused by the seasonal Lewis Well Field area pumping cone.

- A 1992/93 regional recharge event to the Carbonate Aquifer creates uncertainty in calculating *recovery* corrections. DRI has used years prior to the recharge event (1992/93) to estimate recovery rates (most conservative), whereas MAI incorporated 1992/93 rates with three prior year rates to incorporate a 25% weight of greater recovery rates at the higher water-level state.

- Arrow Canyon Well pump-test true *drawdowns* are about two times (DRI corrections) or three times (MAI corrections) the *observed net water-level change*.

- MVWD did not recognize the need for *recovery* corrections to establish *true drawdowns* in the Carbonate Aquifer, and failed to recognize Arrow Canyon Well pumping impacts of similar magnitude in the Alluvial Aquifer.

- *True drawdowns*, two or three times *observed net water-level changes*, result in Theis equation long-term drawdown projections that are two or three times those calculated by MVWD.

MAI

CARBONATE AQUIFER PARAMETERS AND PROJECTED IMPACTS

- Pump-test databases are of limited utility for determining accurate aquifer parameters to project future impacts because of three factors:
  - A. Recovery corrections are required but are of uncertain magnitudes.
  - B. The poor quality of observed drawdown datasets (scatter, small magnitudes, and limited early time data).
  - C. The leakage between the Carbonate Aquifer and Alluvial Aquifer — localized but complex boundary conditions.
- Hantush-Jacob leaky curves (Theis equation modified with leaky boundary conditions) produce reasonable aquifer parameters when recovery-corrected Carbonate Aquifer drawdown databases are plotted for early and mid-time periods.
- However, the future drawdown projections produced by uncertain aquifer parameters/complex boundary conditions must then be added to the senior right impacts. Confident analyses from the pump-test databases are unlikely using this general strategy.
- It is concluded that protested permit impacts are better estimated through analyses of the water-level monitoring records and water balances based on Muddy River flow at Warm Springs Bridge.

PRODUCTION HISTORY, AQUIFER RESPONSES, AND ARROW CANYON PUMPING TEST IMPACTS

- Ground-water production, river-diversion records, Muddy River stream-flow records, and monitoring-well hydrographs in the Alluvial Aquifer and Carbonate Aquifer document the timing of water extraction, water-level responses in the aquifers, and changes in spring and river discharge.

- An annual seasonal cycle of pumping cone development and recovery can be seen in the hydrographic records of both the Carbonate Aquifer and the Alluvial Aquifer.

- Muddy River discharge records at the Warm Springs Bridge document timing and amount of unconfined Alluvial Aquifer pumping cone impact on stream flow.

- Spring-flow records reflect pumping impacts on Carbonate Aquifer heads as well, but the records are compromised by above-gage diversions and other measurement problems.

- Lewis Well Field area pumping-cone developments and recoveries in the unconfined Alluvial Aquifer are transmitted to the Carbonate Aquifer. The hydrograph at MX-4 replicates the pumping-induced hydrograph at EH-5b and EH-4 with a three-month delay at nine miles of separation. The hydrograph at EH-4 (two miles of separation) demonstrates about a one-month delay. EH-5b responds within days at less than one-half mile from the center of the Lewis Well Field.

- Muddy River flow at Warm Springs Bridge correlates with degree of pumping cone recovery of the Alluvial Aquifer. The Lewis Well Field pumping cone migrates down-valley to impact river flow over a five-month period (April to August). River flow is reduced during the fall and winter months until complete cone recovery.

- Analysis of monthly records of the Muddy River flow at Warm Springs Bridge indicate that each month of full recovery of the Alluvial Aquifer is about equal to 0.5 cfs of annualized flow. Prior to 1994, zero to three months of full recovery has been observed.

- The 1994 (December, 1993 through November, 1994) Arrow Canyon Well production was about 2.7 cfs of annualized pumpage, and therefore exceeded the margin of 0 to 1.5 cfs for complete annual recovery.

- The regional recharge event of 1992/93 raised the water-level state of the Carbonate Aquifer by about 0.8 feet. The addition of the Arrow Canyon Well 1994 production established a net downward trend, through December, 1994, that dissipated the 0.8 water-level rise.

MA

ANALYTICAL STRATEGIES AND CONCLUSIONS MVWD ARROW CANYON WELL PERMIT APPLCATIONS

MVWD STRATEGY:

Arrow Canyon Well 121-day pumping test, application of Theis equation to observed net drawdown databases, projected water-level declines in the Carbonate Aquifer from the derived Transmissivity and Coefficient of Storage.

MVWD CONCLUSION:

Highly transmissive aquifer, no hydraulic communication with Alluvial Aquifer or Muddy River Springs, and only minor drawdown over 20 years. No evidence for an unacceptable impact for one or both permits if granted.

NPC STRATEGY:

Long-term detailed monitoring of Carbonate Aquifer and Alluvial Aquifer, analyses of Arrow Canyon pumping-test drawdown in both aquifers, analyses of water-level changes, ground-water production, spring and Muddy River flow.

NPC CONCLUSION:

Arrow Canyon Well impacts the Carbonate and Alluvial Aquifers, spring and river flow, and, if either or both applications were to be granted, unacceptable impacts on senior water rights and endangered species would occur.

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☹ ☺ Production data for 1994 indicate that the added-on Arrow Canyon Well production (December, 1993 to November, 1994) was about 2.7 cfs if annualized.

☹ The Carbonate Aquifer hydrographs illustrate that water-level recovery did not occur in 1994 as normal. The Alluvial Aquifer pumping cone was deeper in 1994.

☹ The 1992/93 recharge event caused about 0.8 feet of Carbonate Aquifer regional water-level rise. The combined NPC and Arrow Canyon Well production prevented the normal recovery, and about 0.8 feet of net decline occurred by December, 1994.

☹ ☺ The continued 1994 net decline in the Carbonate Aquifer verifies that the water balance-derived 0 to 1.5 cfs margin of available additional exploitation from the two aquifers is, unfortunately, approximately accurate.

☹ The protested MVWD applications, at 3 cfs and 5 cfs, are clearly sufficient to change the state of head in the Carbonate Aquifer when 2.7 cfs is sufficient to produce an unprecedented downward net loss of 0.8 feet in one year.

☹ ☹ The existing Arrow Canyon Well 2 cfs permit, when used, may also be sufficient produce a multi-year net downward trend in Carbonate Aquifer levels and associated impacts on the Alluvial Aquifer, river and springs.

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RECOMMENDATIONS

I. Do not permit the protested applications. The evidence is clear that either, or both combined, if pumped, would prevent the pumping cones from fully recovering on an annual basis. Drawdowns which carry over year after year will lower heads in the Carbonate Aquifer and Alluvial Aquifer and, instead of modest seasonal impacts on spring and river flow, quantitatively important changes in spring and/or river flow must occur as discharge is reduced by the magnitude of added Arrow Canyon Well production.

II. Review, on an annual basis, the hydrographs of the two aquifers as the permitted 2 cfs of the Arrow Canyon Well is added to the total ground-water production. The Arrow Canyon Well 1994 production of 2.7 cfs is more than the capacity of the two aquifer systems to sustain and continue to annually recover. The permitted 2 cfs may also prove to be more than the steady-state optimum.

III. Adjust, over several years of monitoring, the permitted production for the Arrow Canyon Well to the total amount that allows annual pumping cone recoveries.

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APPENDIX

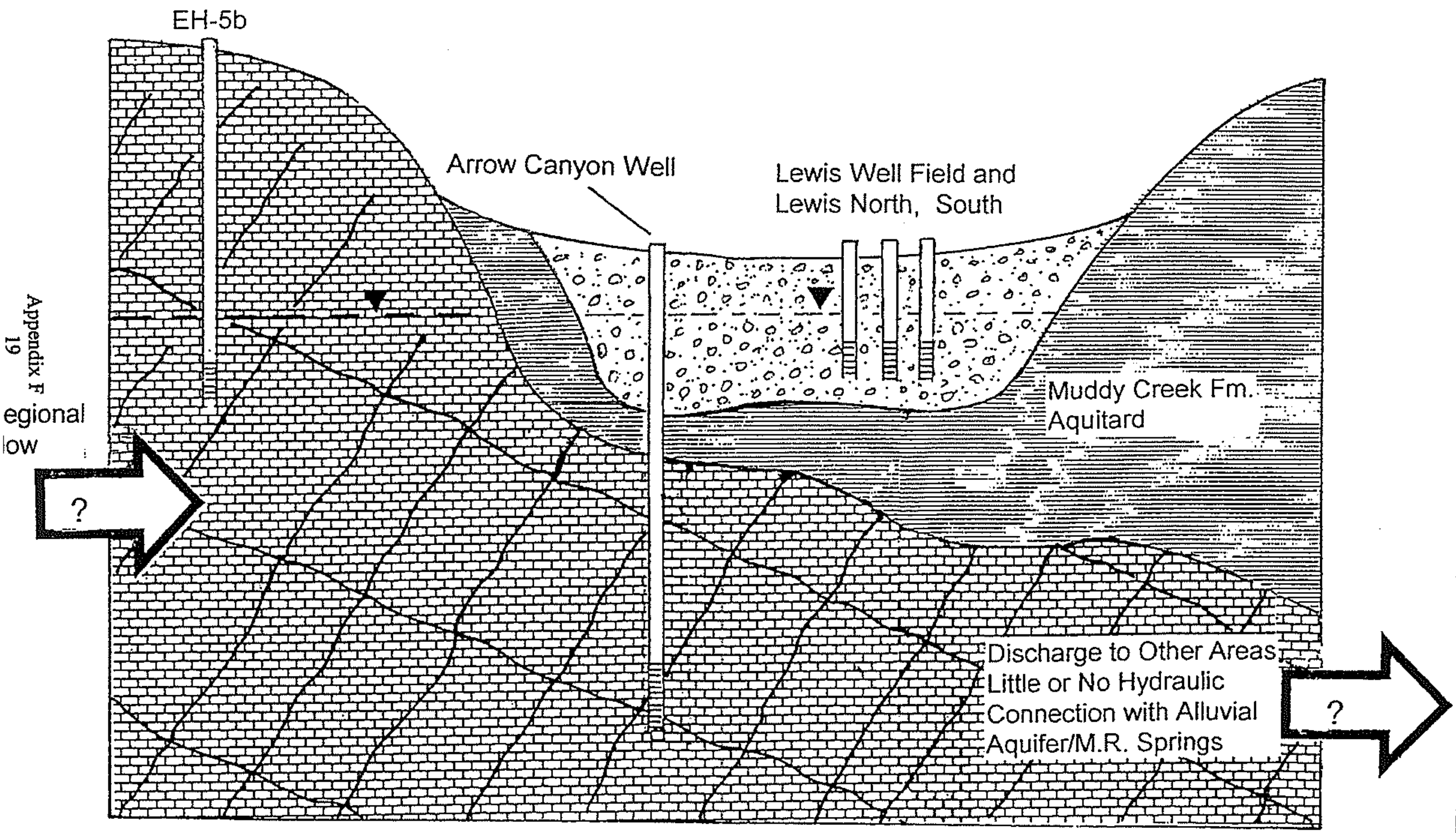
Figures and Tables Supporting

SUMMARY OF GROUND-WATER DELEVOPMENT IMPACTS IN THE UPPER MUDDY RIVER VALLEY, NEVADA

by
M.D. Mifflin

INCOMPATIBLE ELEMENTS OF THE MWVD CONCEPTUAL MODEL

I. Muddy River Springs are the location of regional White River System discharge and the documented amount of Carbonate Aquifer flux.
II. The Carbonate Aquifer is the only source of water for the annual recovery of the Lewis Well Field area Alluvial Aquifer pumping cone.
III. The Carbonate Aquifer is the only source of water (~51 cfs) for the Alluvial Aquifer discharge to the Muddy River and Muddy River Springs.
IV. The Lewis Well Field area pumping cone (Alluvial Aquifer) is transmitted to the Carbonate Aquifer monitoring wells (EH-5b, EH-4, MX-4).
V. The Arrow Canyon Well pumping stresses were transmitted to the Alluvial Aquifer monitoring wells during the pump test (Lewis North, others).



DIAGRAMMATIC, MVWD CONCEPTUAL MODEL HYDROGEOLOGICAL RELATIONSHIPS

1995

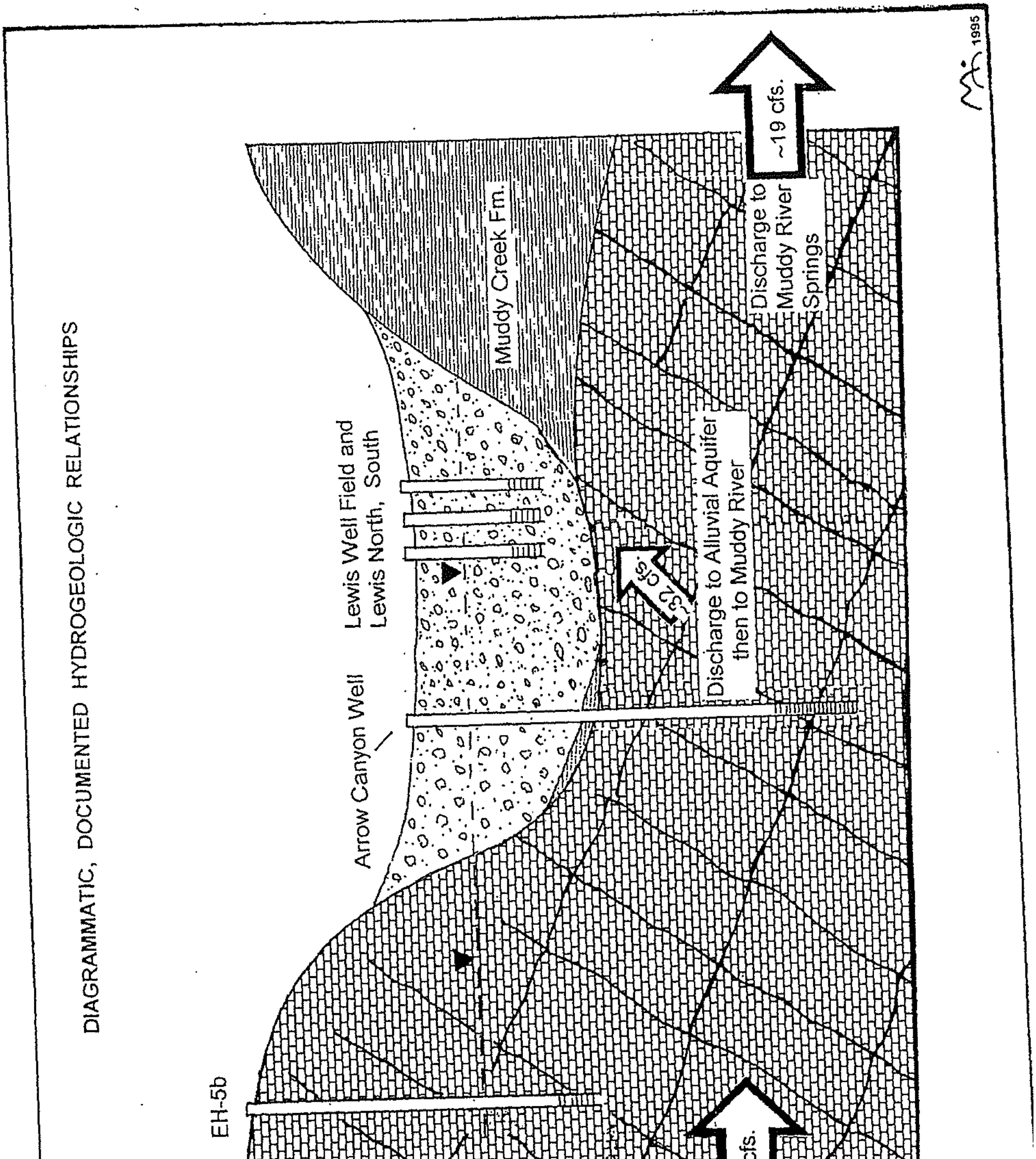
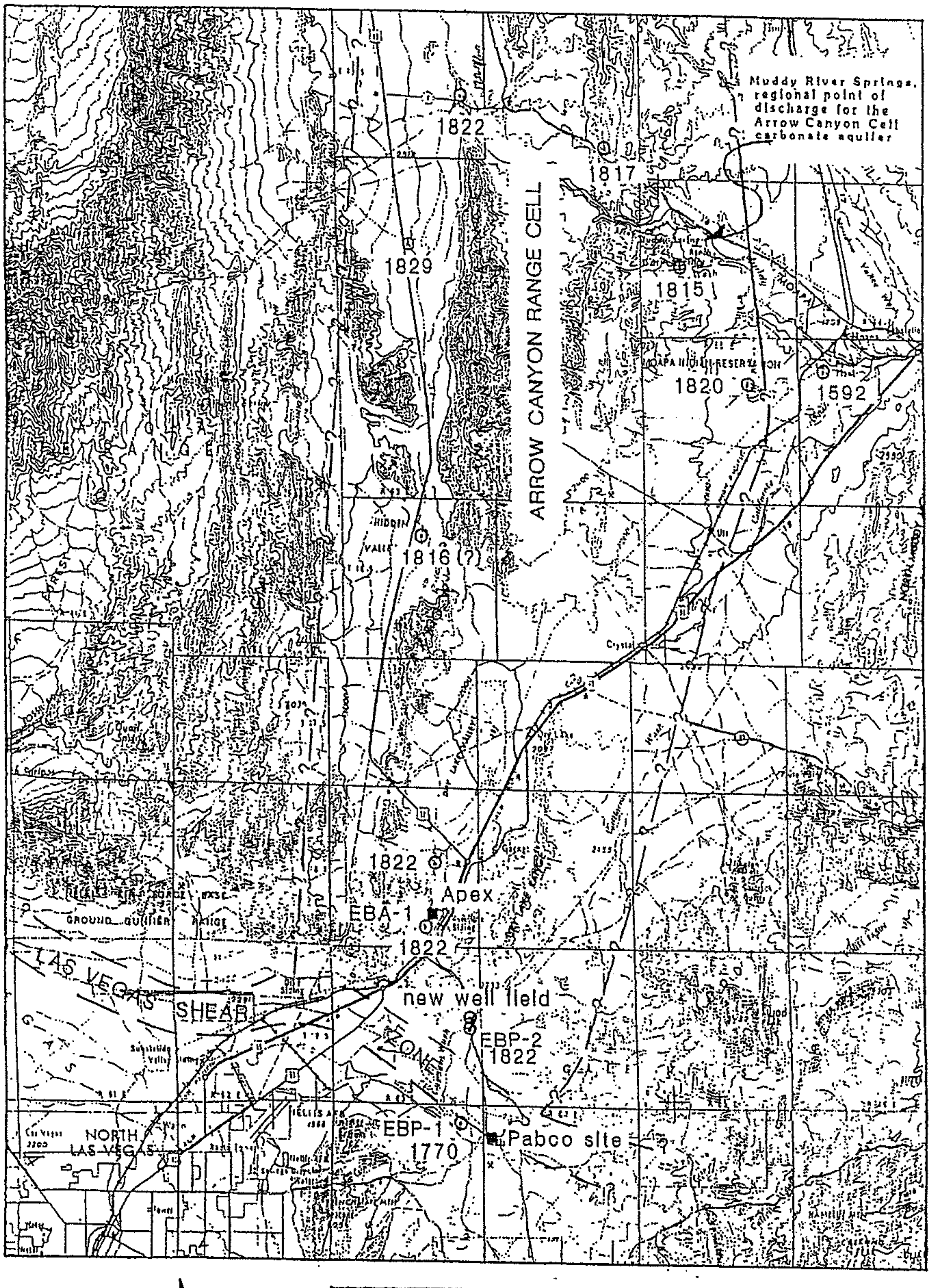
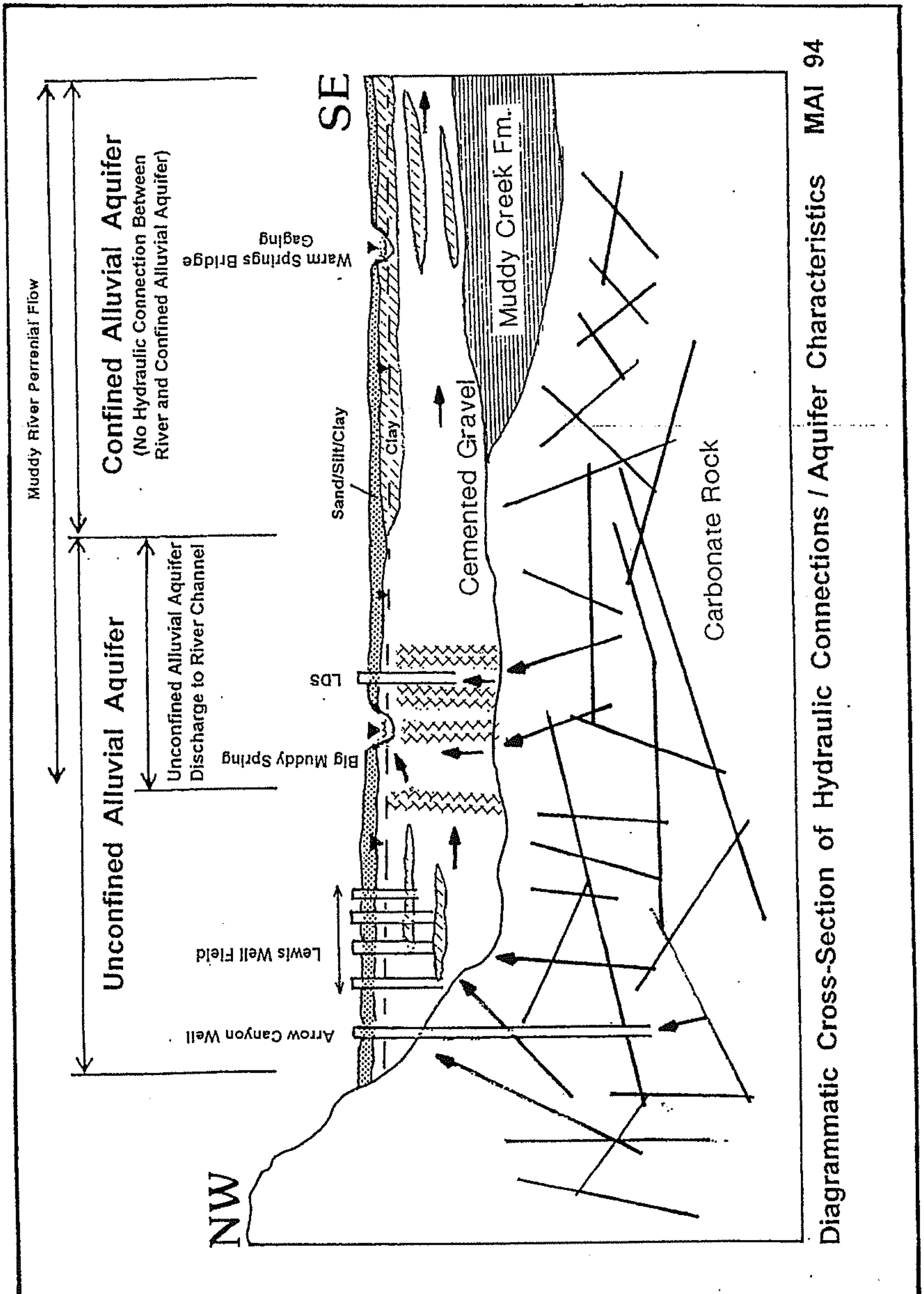

DIAGRAMMATIC, DOCUMENTED HYDROGEOLOGIC RELATIONSHIPS
EH-5b
Arrow Canyon Well
Lewis Well Field and
Lewis North, South
Muddy Creek Fm.
~32 cfs
Discharge to Alluvial Aquifer
then to Muddy River
Discharge to
Muddy River
Springs
~19 cfs.
~51 cfs.
Regional
Flow
1995

Figure 4



Appendix F

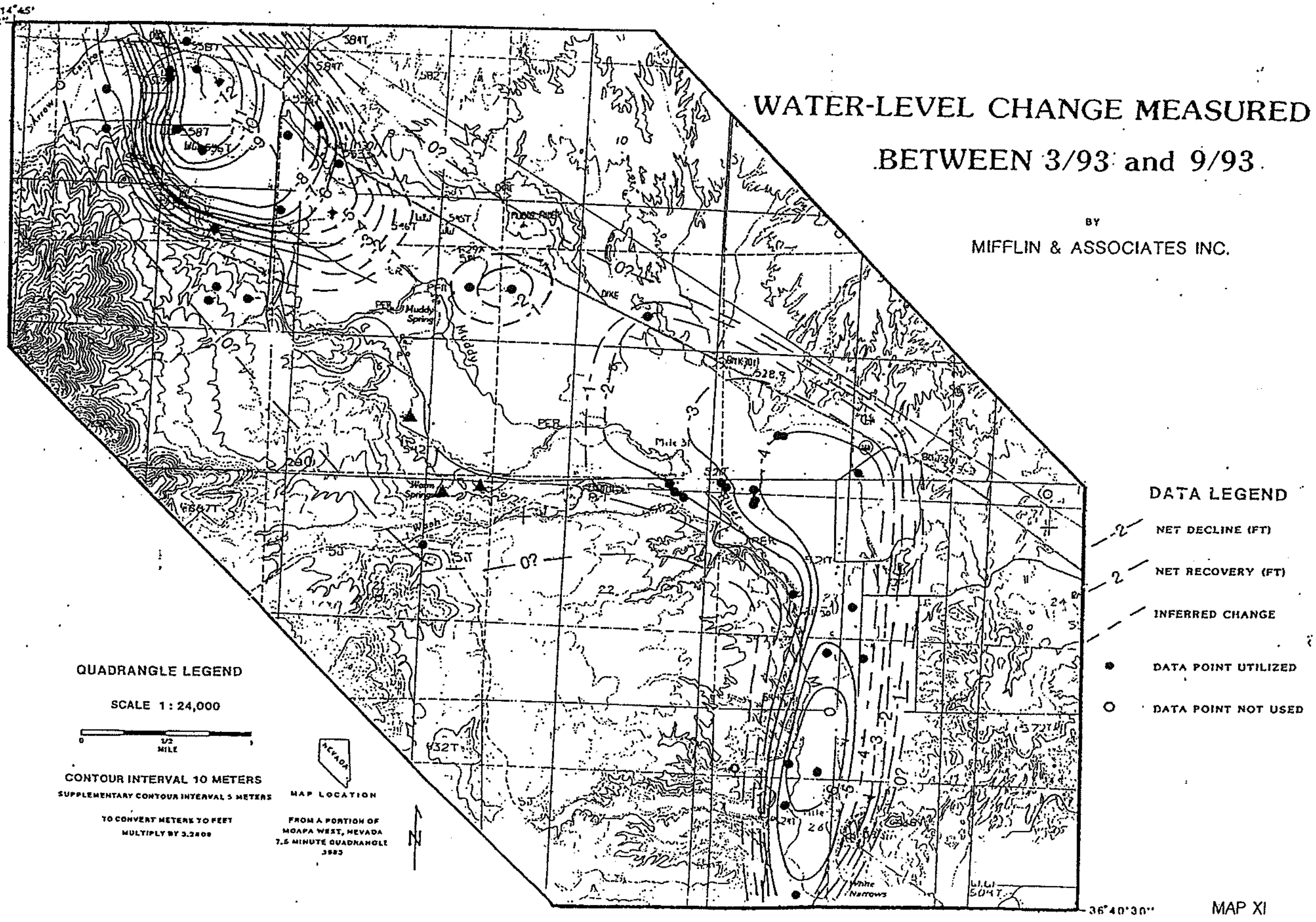


NW
SE
Muddy River Perrenial Flow
Unconfined Alluvial Aquifer
Confined Alluvial Aquifer
(No Hydraulic Connection Between
River and Confined Alluvial Aquifer)
Unconfined Alluvial Aquifer
Discharge to River Channel
Arrow Canyon Well
Lewis Well Field
Big Muddy Spring
LDS
Sand/Silt/Clay
Clay
Warm Springs Bridge
Gaging
Cemented Gravel
Muddy Creek Fm.
Carbonate Rock
Diagrammatic Cross-Section of Hydraulic Connections / Aquifer Characteristics
MAI 94

WATER-LEVEL CHANGE MEASURED BETWEEN 3/93 and 9/93

BY

MIFFLIN & ASSOCIATES INC.

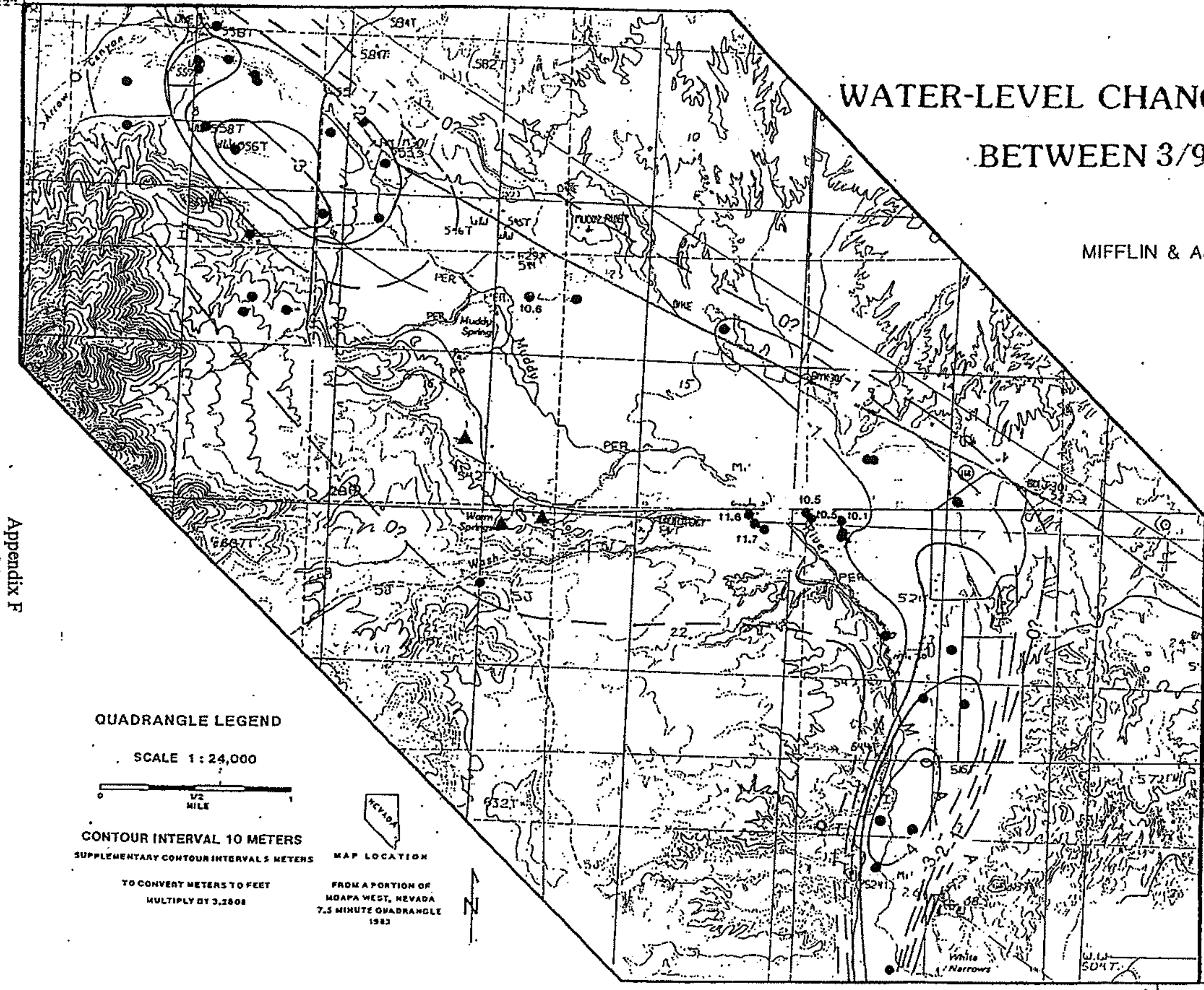


MAP XI

WATER-LEVEL CHANGE MEASURED
BETWEEN 3/93 and 12/93

BY

MIFFLIN & ASSOCIATES INC.



DATA LEGEND

- -2- NET DECLINE (FT)
- 2 NET RECOVERY (FT)
- — — INFERRED CHANGE
- ● DATA POINT UTILIZED
- ○ DATA POINT NOT USED

MAP XIV

QUADRANGLE LEGEND

SCALE 1 : 24,000

0 — 1/2 MILE — 1

CONTOUR INTERVAL 10 METERS

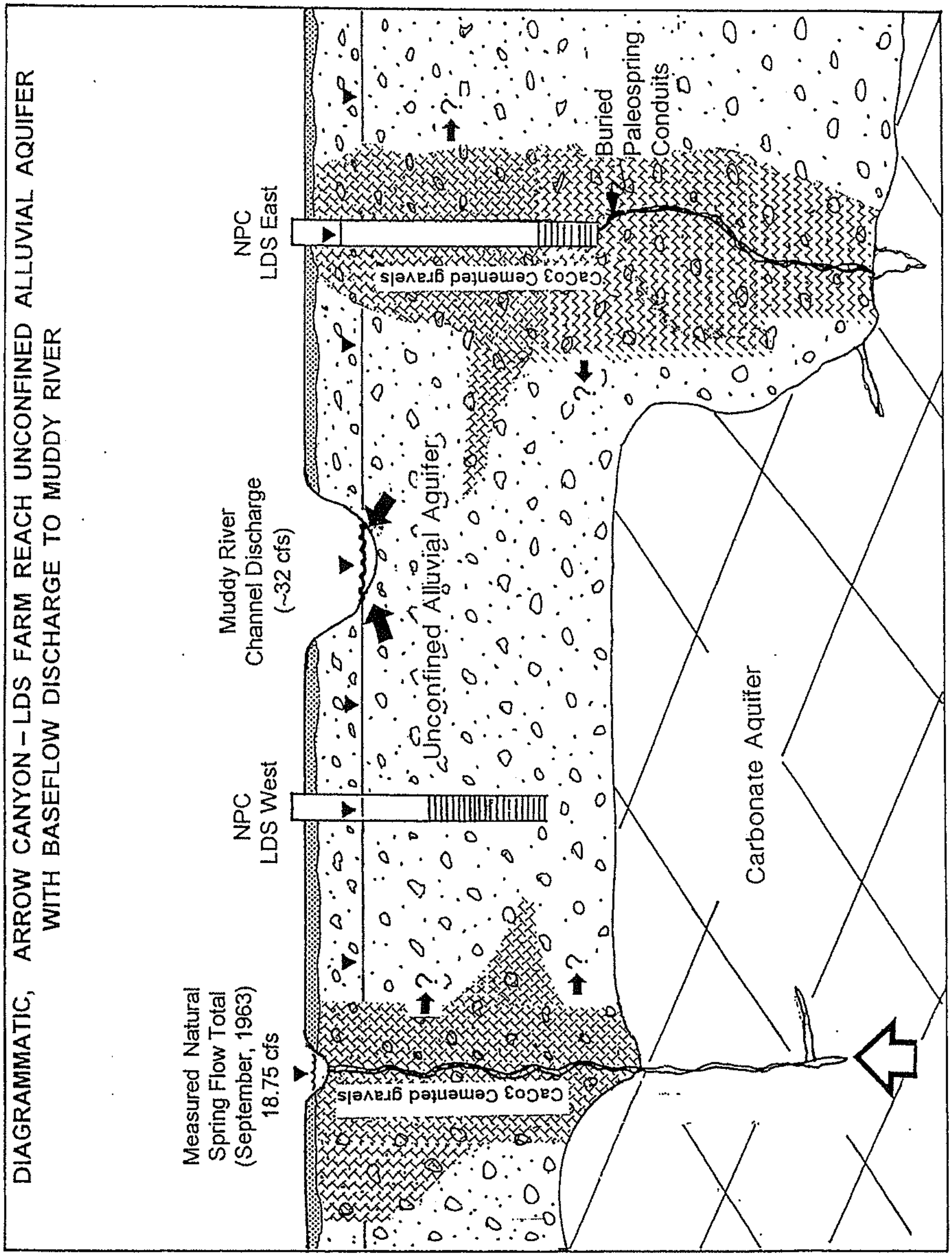
SUPPLEMENTARY CONTOUR INTERVALS METERS

TO CONVERT METERS TO FEET MULTIPLY BY 3.2808

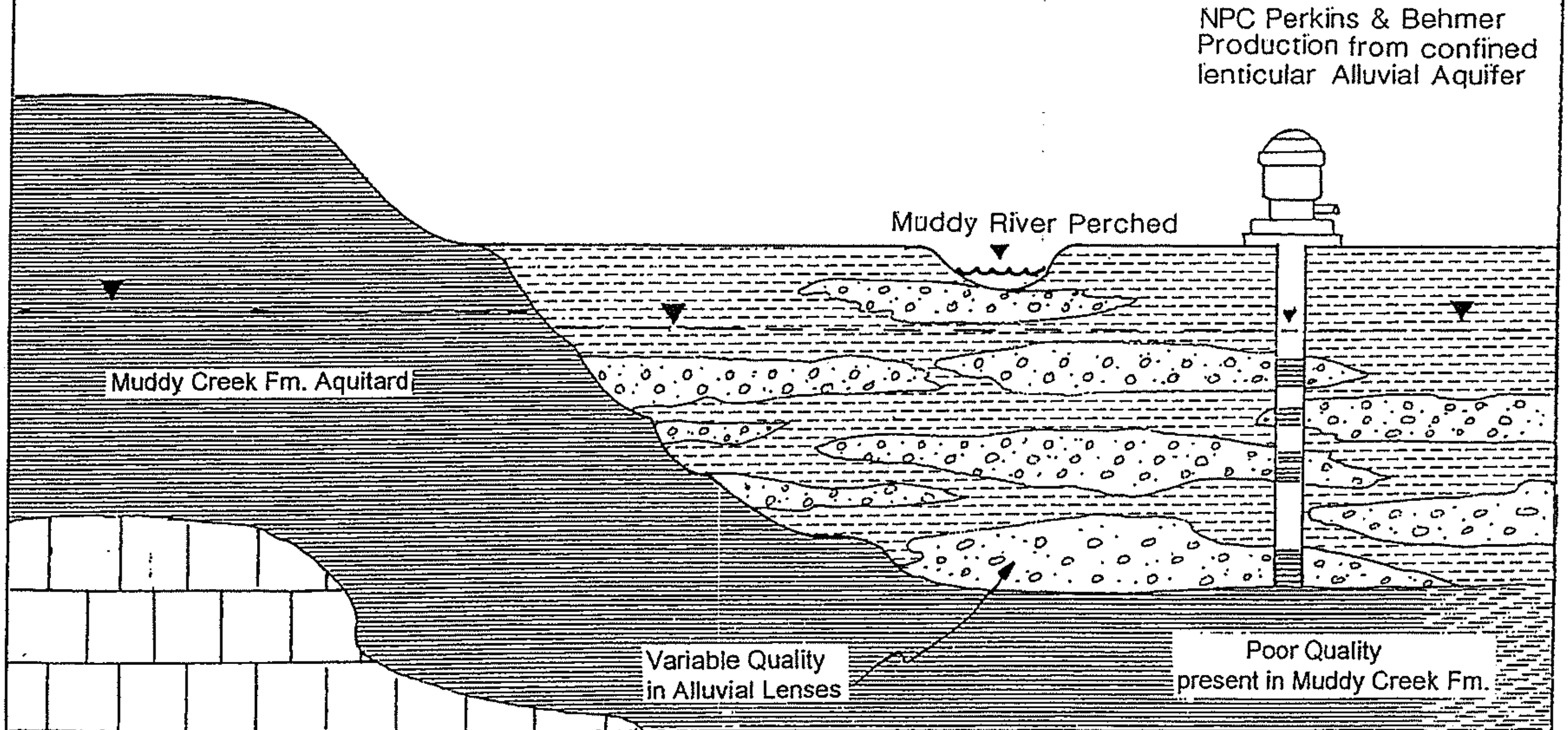
MAP LOCATION

NEVADA

FROM A PORTION OF MOAPA WEST, NEVADA 7.5 MINUTE QUADRANGLE 1983


DIAGRAMMATIC, ARROW CANYON - LDS FARM REACH UNCONFINED ALLUVIAL AQUIFER
WITH BASEFLOW DISCHARGE TO MUDDY RIVER
Measured Natural
Spring Flow Total
(September, 1963)
18.75 cfs
CaCo3 Cemented gravels
NPC
LDS West
Muddy River
Channel Discharge
(~32 cfs)
Unconfined Alluvial Aquifer
NPC
LDS East
CaCo3 Cemented gravels
Buried
Paleospring
Conduits
Carbonate Aquifer
1995

WARM SPRINGS BRIDGE – PERKINS RANCH – WHITE NARROWS REACH OF THE UPPER MUDDY RIVER VALLEY



Muddy River is perched above Alluvial Aquifer, and well production does not impact river flow in this reach. Over-pumping causes poor-quality water to leak from the Muddy Creek Formation to alluvial lenses, which may show variations in quality over time. Pumping cones spread rapidly in the Alluvial Aquifer within this reach due to confinement. Diagrammatic.

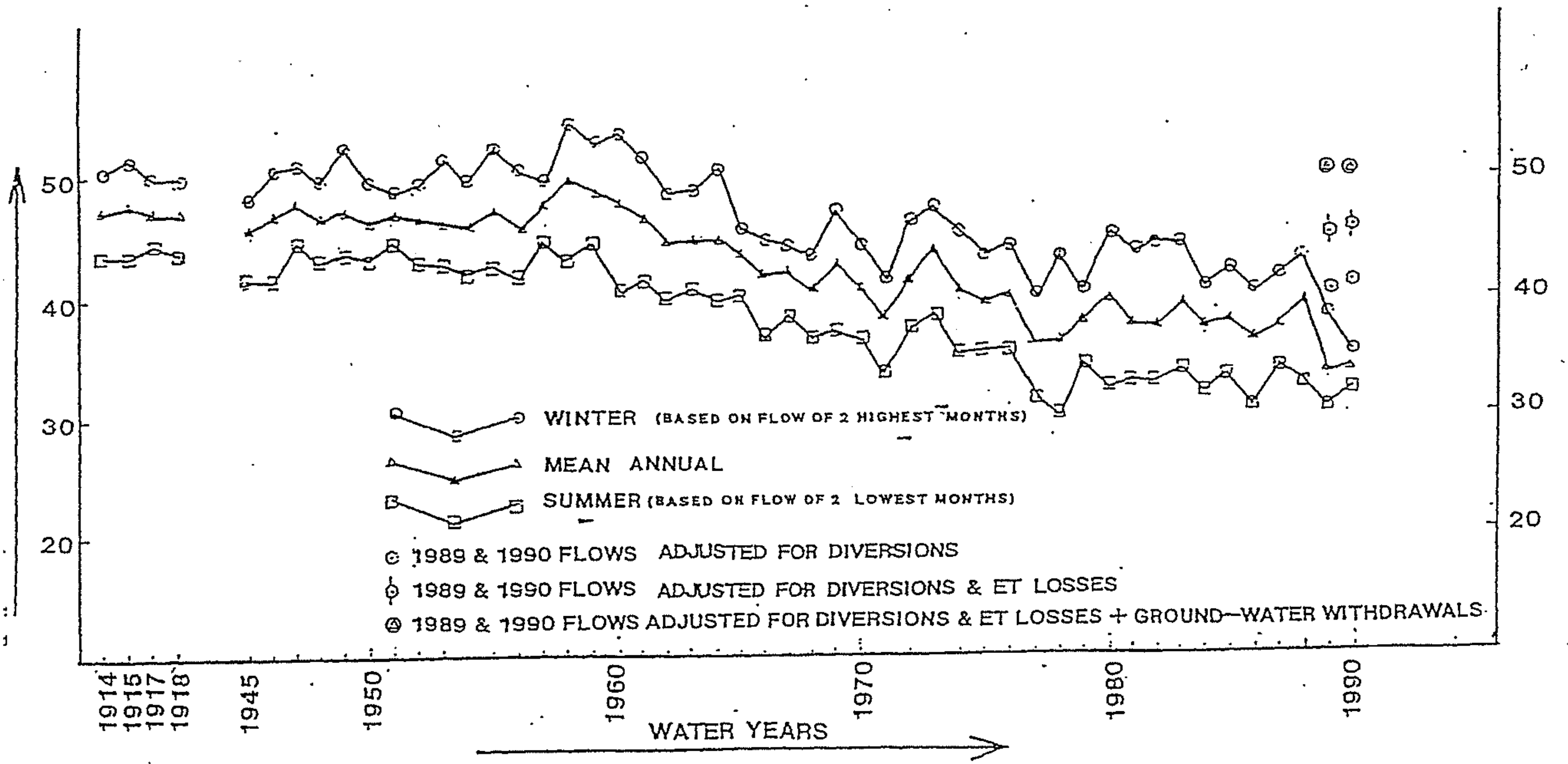


Figure 1. Historical Comparison of Mean Annual, Maximum Winter, and Minimum Summer Discharge, Muddy River At Warm Springs Road, Nevada, Data Modified from U.S.G.S. (from Mifflin, et al., 1991)

TABLE 2
1989 And 1990 Water Year Muddy River Flows
Adjusted for Diversions and ET Losses

WATER YEAR 1989 (mean monthly flows in cfs)

	O	N	D	J	F	M	A	M	J	J	A	S	Mean Annual
M.R. Gage	31.5	34.3	38.8	35.8	38.6	32.9	31.3	35.8	33.6	31.0	30.4	30.7	(33.7)
NPC Divs.	4.4	3.9	3.6	6.6	4.8	7.9	8.4	1.6	1.7	1.6	1.8	1.7	(6.6)
MVWD Divs.	2.5	2.0	1.9	1.9	1.3	2.6	2.9	3.1	3.9	3.3	3.0	3.2	
M.R. Gage Divs.	38.4	40.2	44.3	44.3	44.7	43.4	42.6	40.5	39.2	35.9	35.2	35.6	
Est. ET Losses	4.5	2.9	m	m	m	3.9	5.7	7.2	9.1	8.7	7.7	6.2	(4.7)
Total Adjusted	42.9	43.1	44.3	44.3	44.7	47.3	48.3	47.7	48.3	44.6	42.9	41.8	(45.0)

WATER YEAR 1990 (mean monthly flows in cfs)

	O	N	D	J	F	M	A	M	J	J	A	S	Mean Annual
M.R.Gage	29.4	34.0	34.5	36.7	34.6	31.9	35.9	39.2	35.7	33.4	[32.8] 61.1	32.2	(34.2)
NPC Divs.	6.2	5.8	8.6	7.2	8.1	8.0	5.7	0.8	0.8	1.3	0.7	1.1	(6.9)
MVWD Divs.	2.4	2.4	1.7	1.9	1.6	2.3	2.0	2.4	3.7	3.3	3.5	2.0	
M.R.Gages Divs.	38.0	42.2	44.8	45.8	44.3	42.2	43.6	42.4	40.2	38.0	37.0	35.3	
Est. ET Losses	4.5	2.9	m	m	m	3.9	5.7	7.2	9.1	8.7	7.7	6.2	(4.7)
Total Adjusted	42.5	45.1	44.8	45.8	44.3	46.1	49.3	49.6	49.3	46.7	44.7	41.5	(45.8)

m = minor, probably less than 0.5 cfs
[ ] = flood flow subtracted

(from Mifflin, et al., 1991)

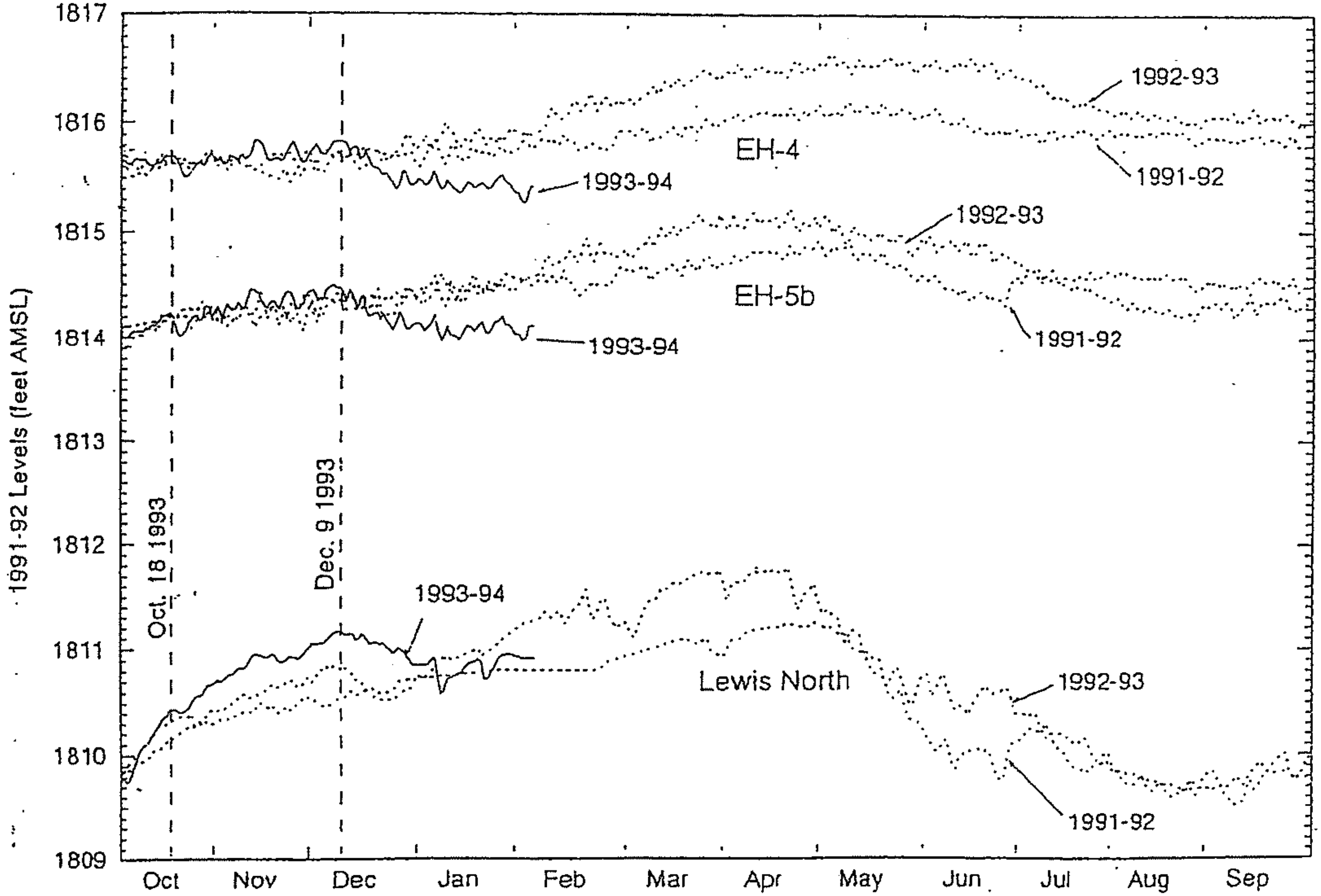
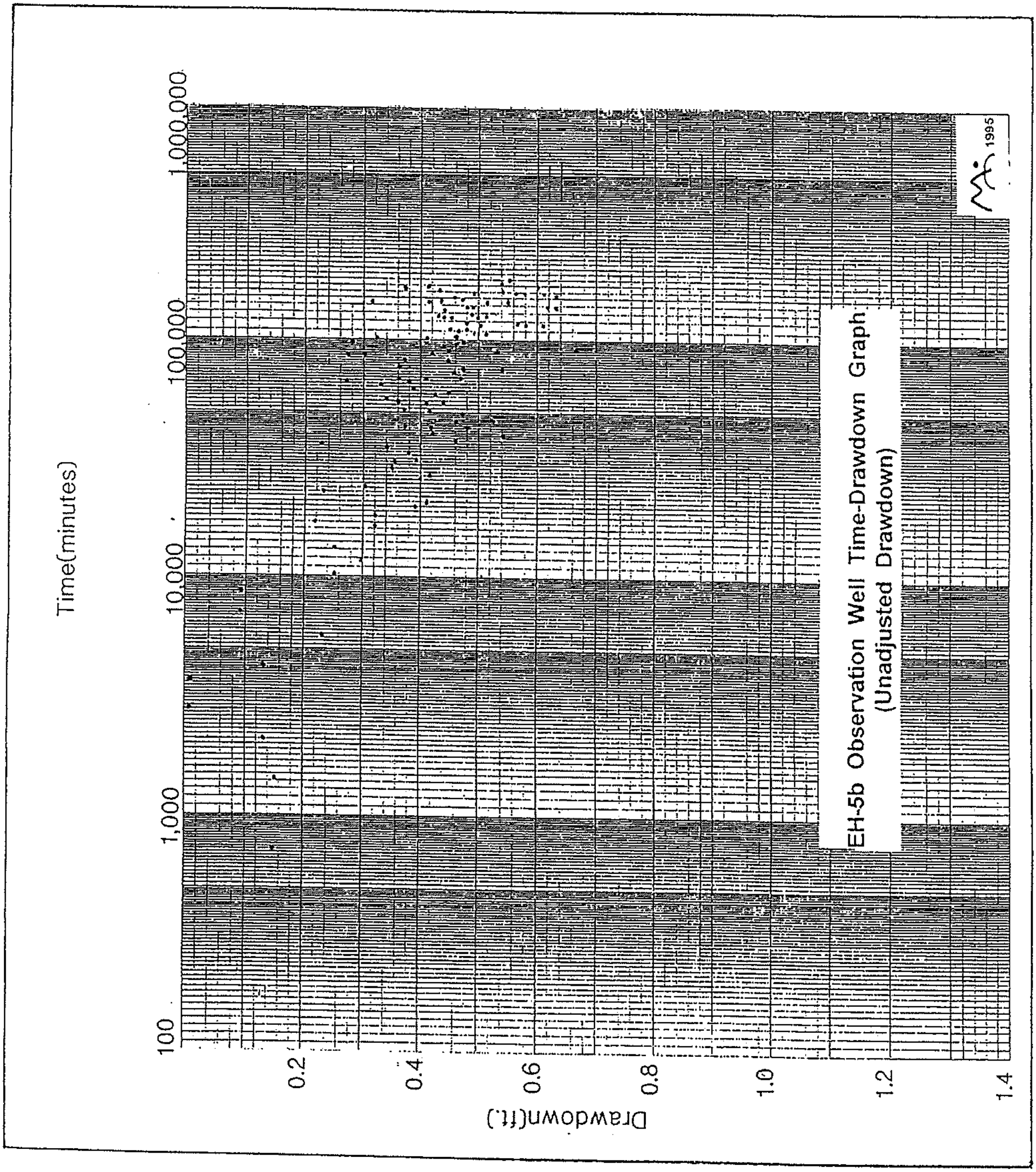
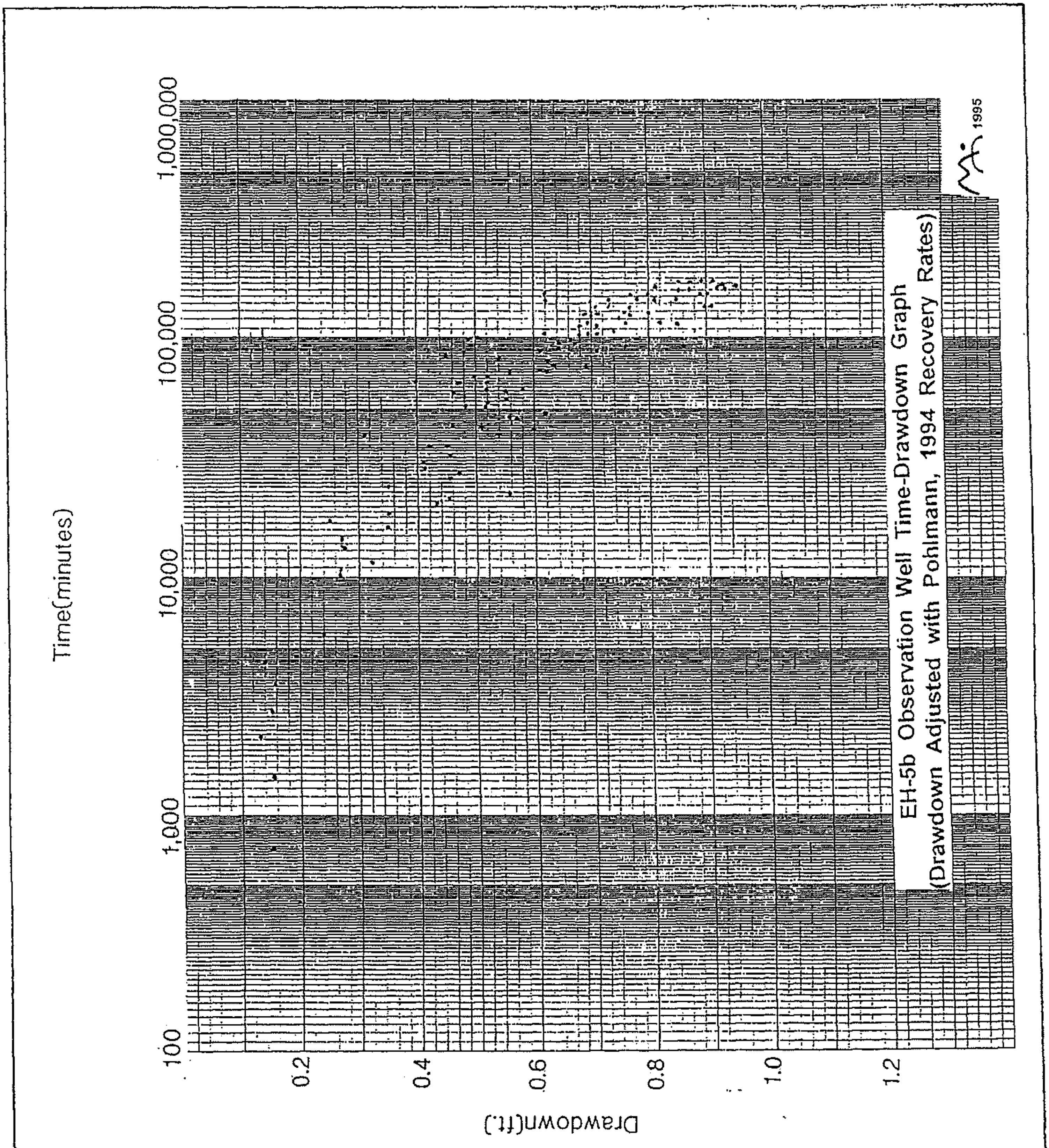
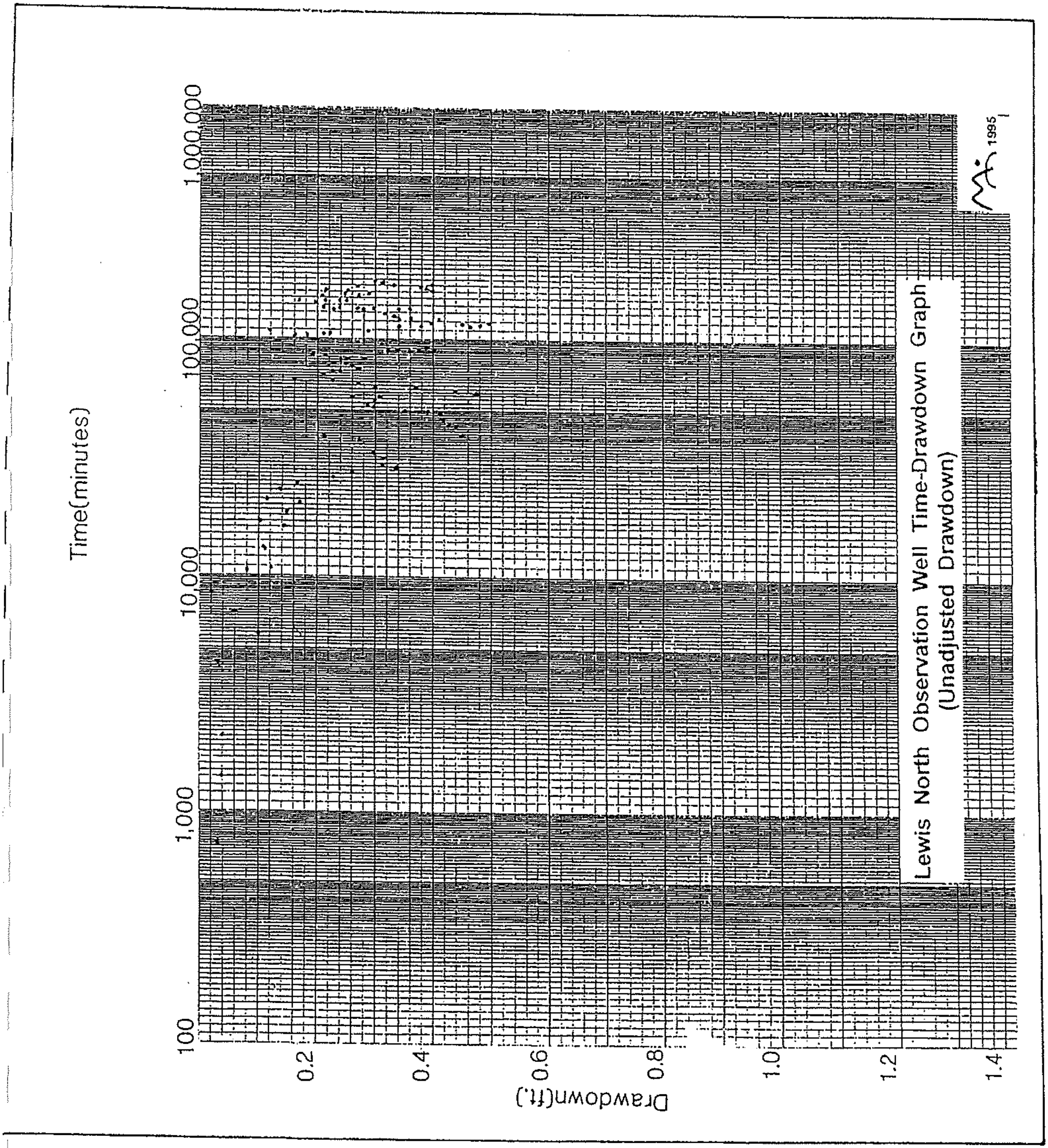


Figure 5. Relative ground–water levels in selected wells in the upper Muddy River Valley for the period 1 September 1991 through 5 February 1994. Wells EH–4 and EH–5b monitor the carbonate aquifer and well Lewis North monitors the alluvial aquifer. 1992–93 and 1993–94 levels have been normalized to 1 September 1991 for comparison. *Pohlmann (1994)*

ATTACHMENT 2


Time(minutes)
100
1,000
10,000
100,000
1,000,000
Drawdown(ft.)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
EH-5b Observation Well Time-Drawdown Graph
(Unadjusted Drawdown)
1995


EH-5b Observation Well Time-Drawdown Graph
(Drawdown Adjusted with Pohlmann, 1994 Recovery Rates)
Time(minutes)
100
1,000
10,000
100,000
1,000,000
Drawdown(ft.)
0.2
0.4
0.6
0.8
1.0
1.2
1995



Lewis North Observation Well Time-Drawdown Graph
(Unadjusted Drawdown)
Time(minutes)
100
1,000
10,000
100,000
1,000,000
Drawdown(ft.)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1995

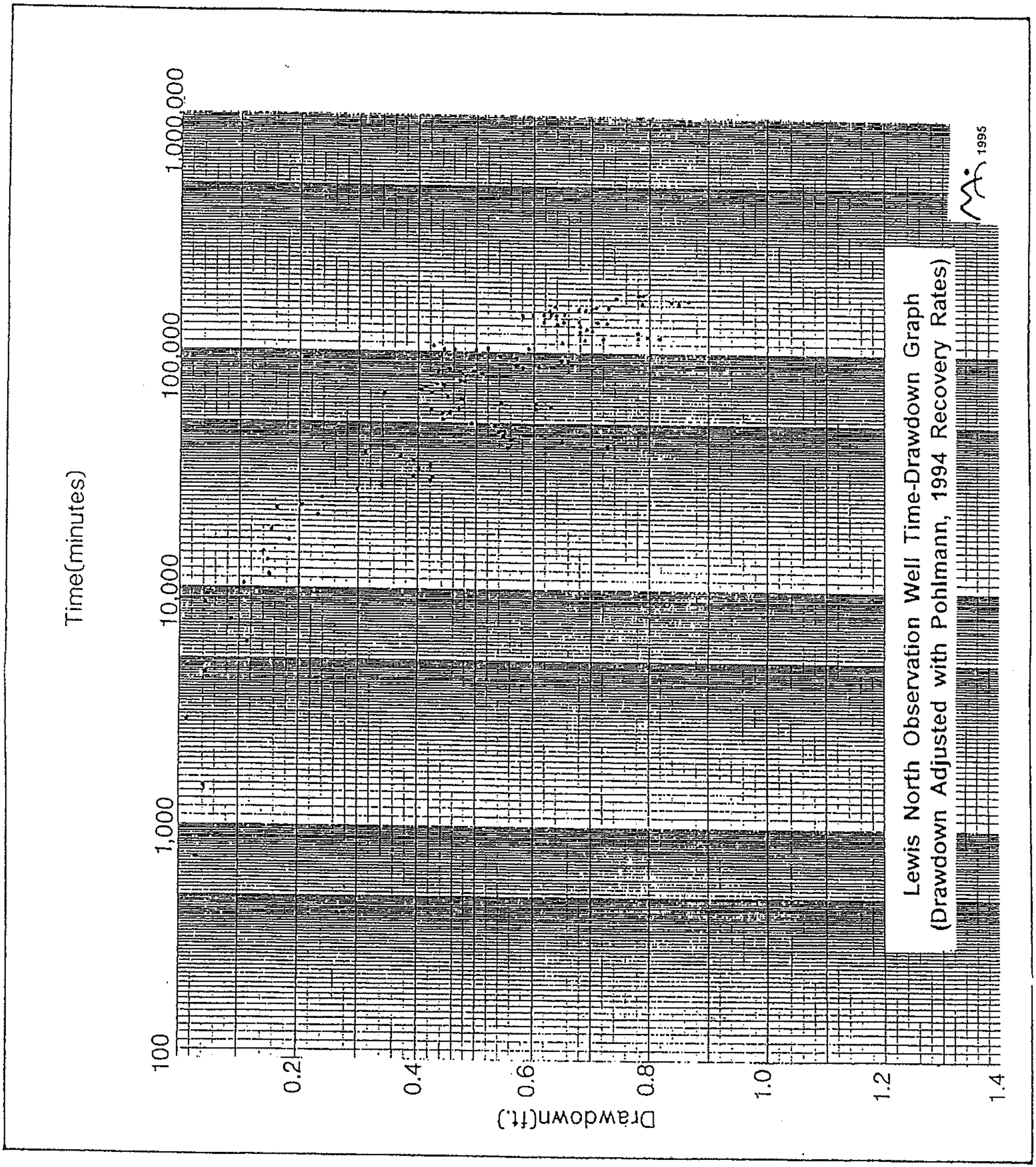

Lewis North Observation Well Time-Drawdown Graph
(Drawdown Adjusted with Pohlmann, 1994 Recovery Rates)
Time(minutes)
100
1,000
10,000
100,000
1,000,000
Drawdown(ft.)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1995

FIG.1 : ARROW CANYON 121-DAY PUMPING TEST DISTANCE-DRAWDOWN GRAPH

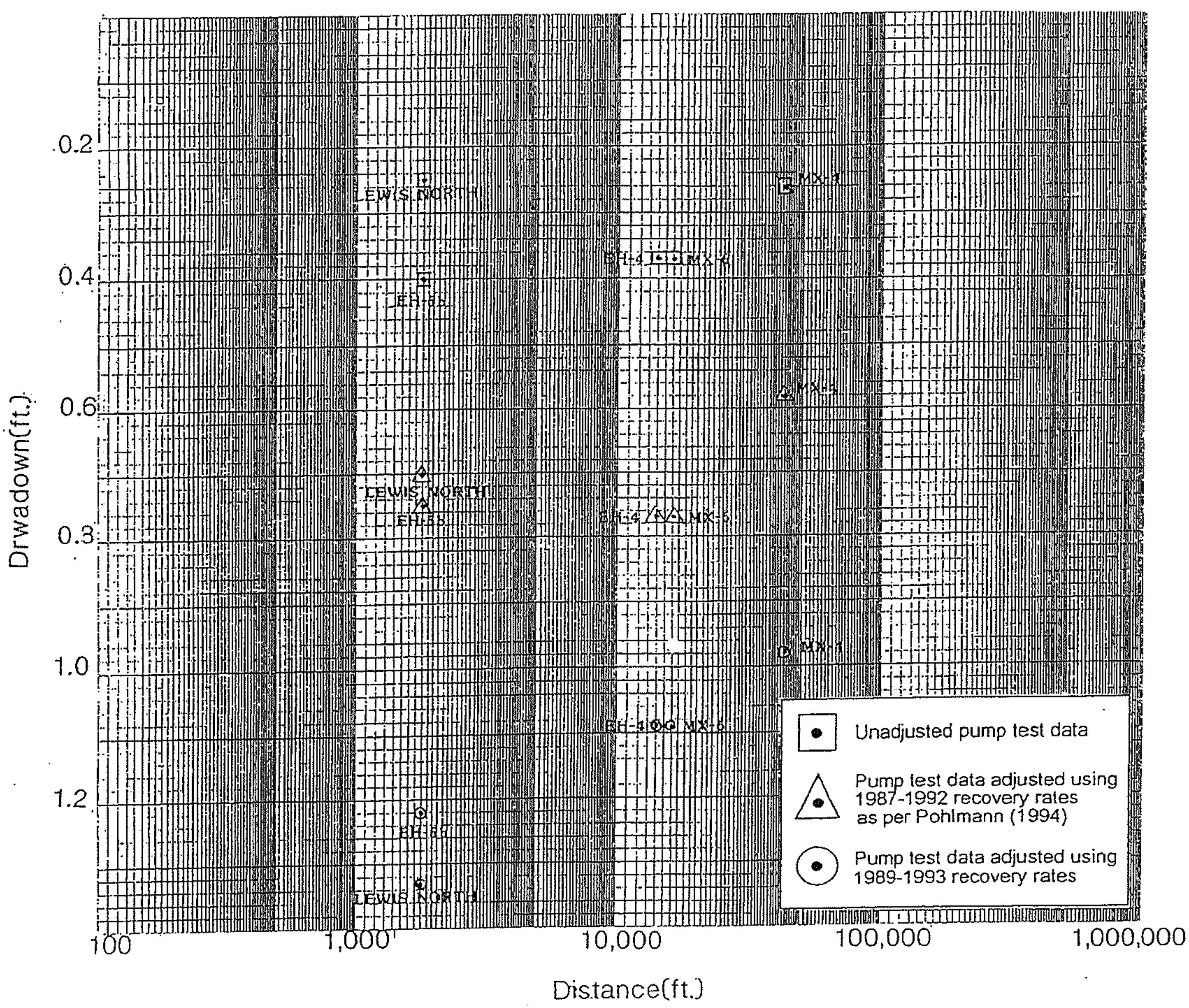


TABLE 2

TRANSMISSIVITIES AND STORATIVITIES BASED ON THE LATE TIME DATA OF THE TIME-DRAWDOWN GRAPH FOR MX-4, MX-6, EH-5b AND LEWIS NORTH

WELL	Q (Pumping Rate) (gpm)	Δs (ft.) (Drawdown per One Log Cycle)	t_o (Zero Intercept on Time-Axis) (minutes)	T (Transmissivity) gpd./ft.	S (Storativity)
MX-4	2,900	1.2	37,000	638,000	0.0026
MX-6	2,900	1.2	35,000	638,000	0.0176
EH-5b	2,900	1.08	19,000	593,488	0.7248
Lewis North	2,900	1.3	20,000	588,923	0.7577

ATTACHMENT 1

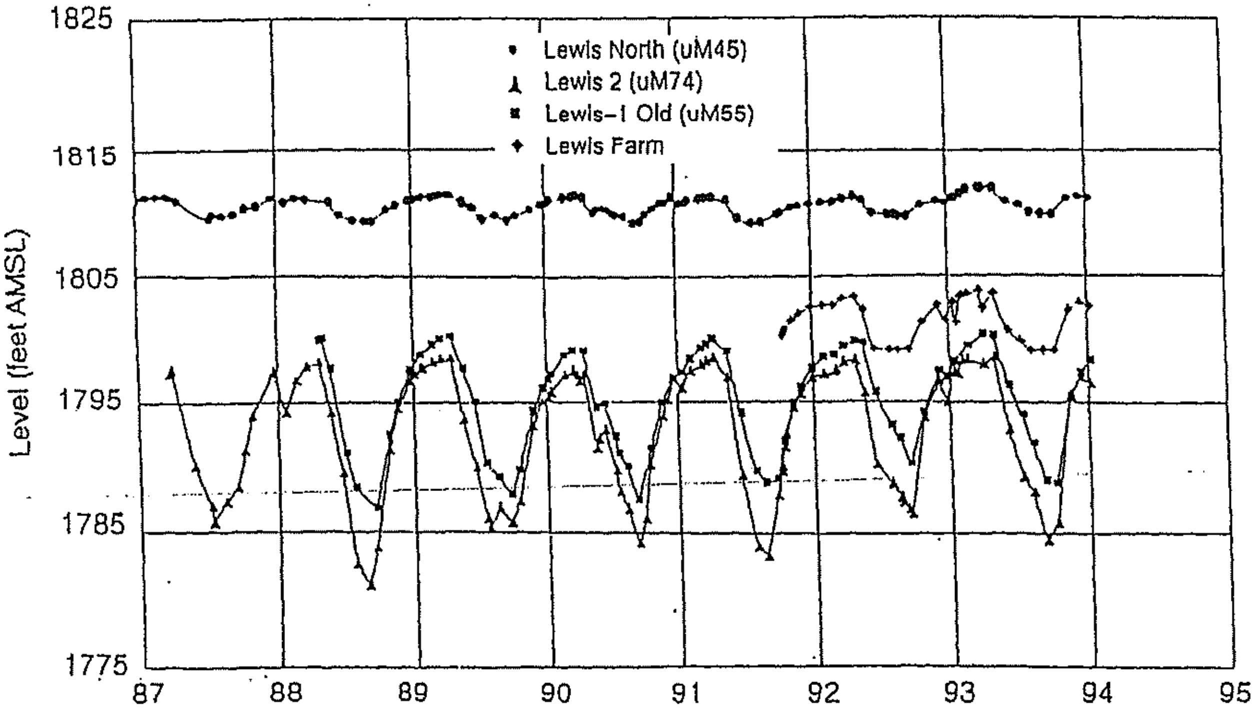


Figure C-1 Pohlmann (1994)

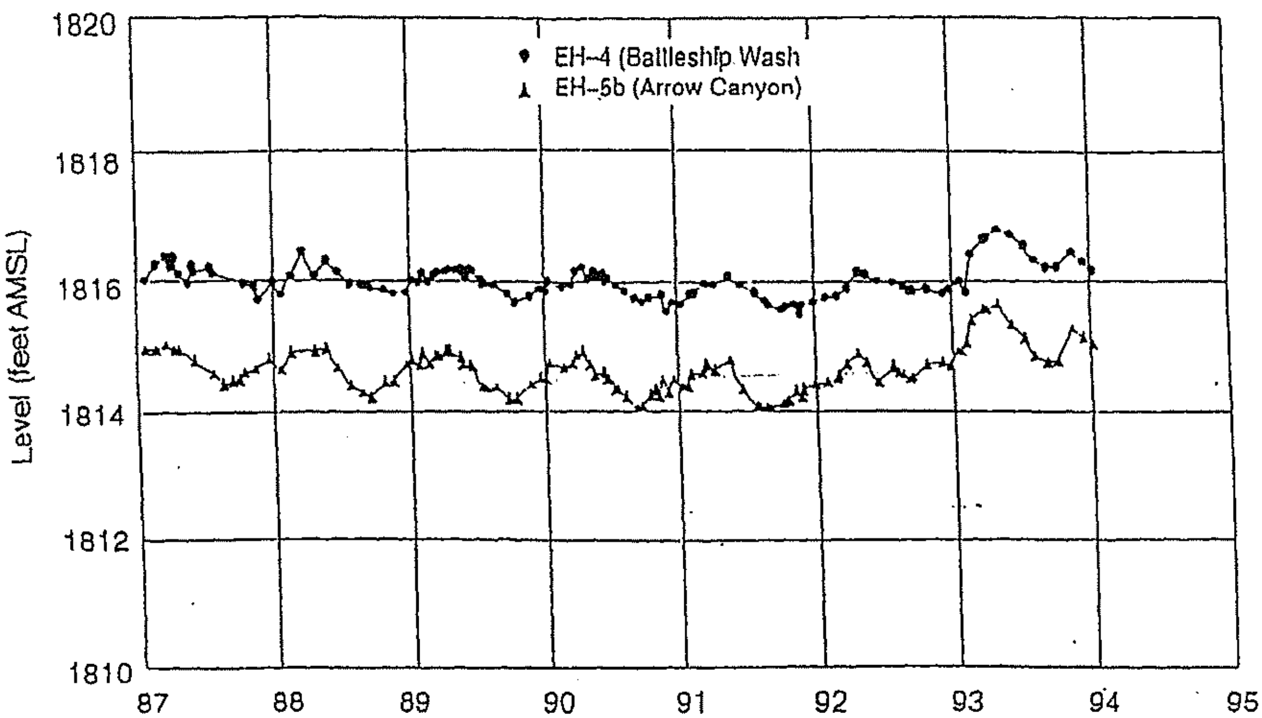


Figure C-2 Pohlmann (1994)

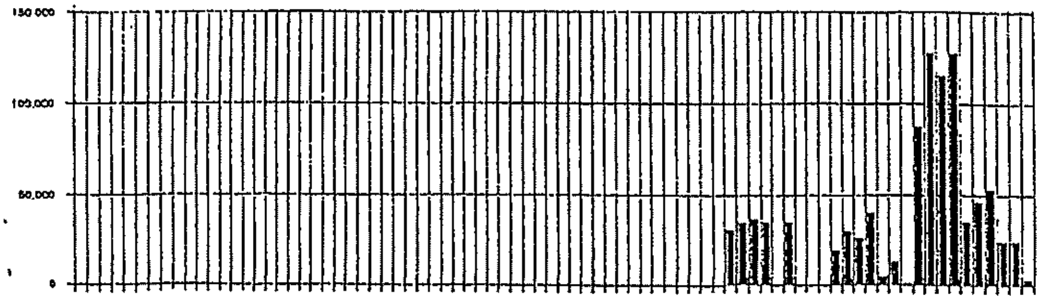


FIG. 6a. : Arrow Canyon Well Production ('000s of gallons) Aug. 1992 - Sept. 1994

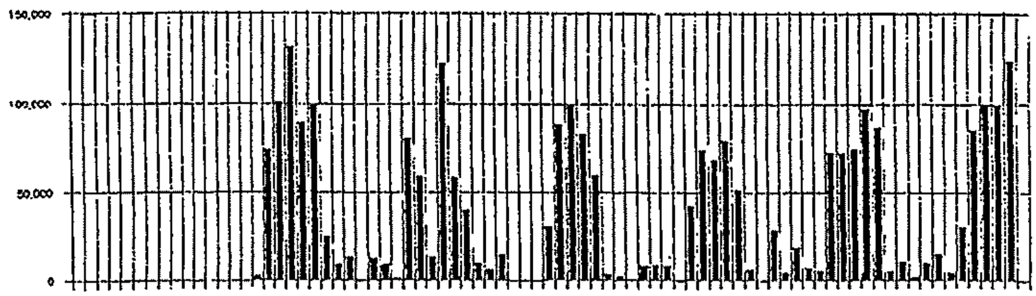


FIG. 6b. : Lewis Well Field Monthly Diversions ('000 of gallons) 1989 - 1994

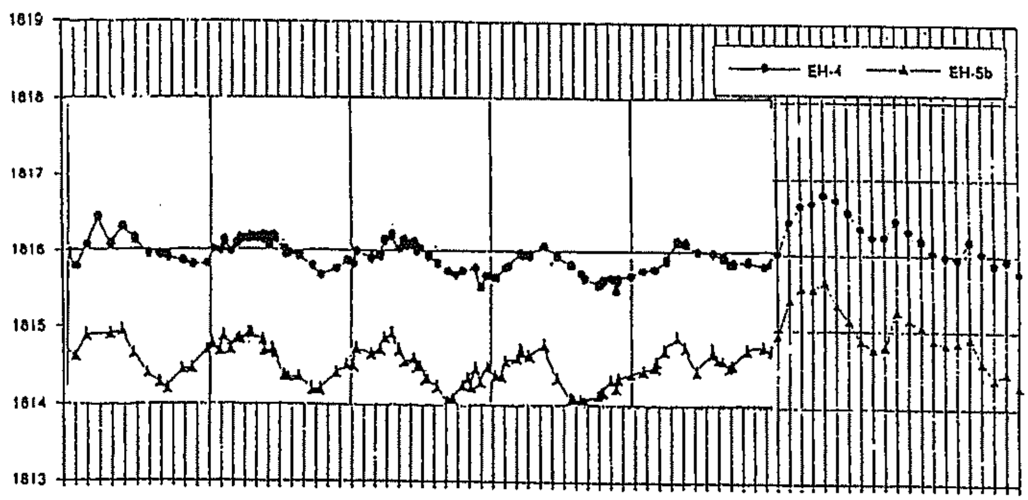


FIG. 6c. : Hydrograph of EH-4 & EH-5b for January 1988 through September 1994

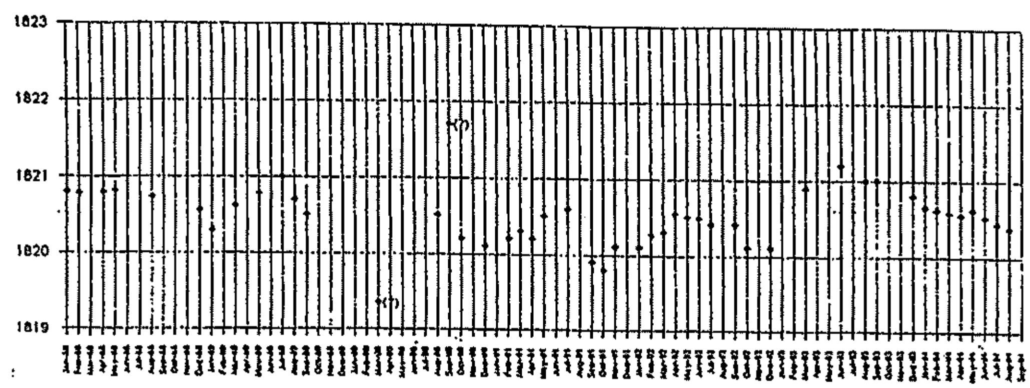


FIG. 6d. : Hydrograph of MX-4 for January 1988 through August 1994

Appendix F

1995

MUDDY SPRING

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1989	6.97	7.07	7.11	7.17	7.16	7.19	7.36	7.39	7.43	7.07	7.21	7.21
1990	7.13	7.27	7.58	7.36	7.29	7.37	7.45	7.15	7.10	7.00	7.03	7.25
1991	7.52	7.28	6.70	6.93	6.85	7.13	8.26	7.86	7.49	7.70	7.26	7.16
1992	7.69	7.47	7.99	6.40	7.45	7.46	7.28	7.50	7.53	7.08	6.94	5.73
1993	7.23	7.47	7.54	8.39	9.22	8.15	6.98	6.69	6.64	6.43	6.58	6.57
1994	7.33	7.02	7.17	7.33	7.02	7.02	7.17	7.02	8.29	8.79		

PEDERSON SPRING

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1989	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.19	0.20	0.21	0.19
1990	0.18	0.18	0.18	0.20	0.21	0.21	0.23	0.23	0.23	0.22	0.22	0.22
1991	—	0.21	0.21	0.19	0.19	0.18	—	0.20	0.20	0.22	0.21	0.20
1992	0.20	0.19	0.19	0.18	0.20	0.21	0.22	0.21	0.20	0.22	0.22	0.22
1993	0.22	0.23	0.22	0.23	0.24	0.24	0.25	0.25	0.26	0.27	0.22	0.22
1994	0.23	0.25	0.24	0.23	0.22	0.23	0.22	0.24	0.25	—	0.27	

WARM SPRINGS WEST

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1989	3.33	3.46	3.48	3.37	3.41	3.47	3.43	3.52	3.46	3.48	3.44	3.55
1990	3.50	3.78	3.73	3.76	3.84	4.02	3.79	3.94	3.87	3.87	3.89	3.80
1991	3.60	3.53	3.57	3.75	3.81	3.61	3.73	3.32	3.69	3.64	3.57	3.53
1992	3.58	3.63	4.00	3.35	3.37	3.23	3.14	3.12	3.20	3.19	3.17	3.38
1993	3.20	3.37	3.53	3.61	3.71	3.74	3.73	3.70	3.57	3.37	3.41	3.29
1994	4.06	4.12	4.06	4.06	4.06	3.82	3.70	3.76	3.76			

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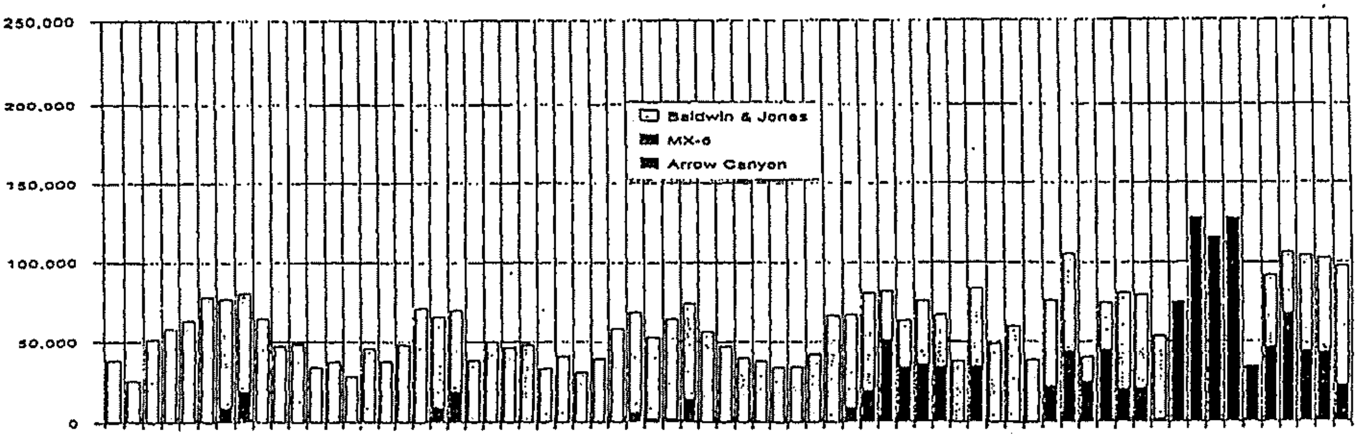
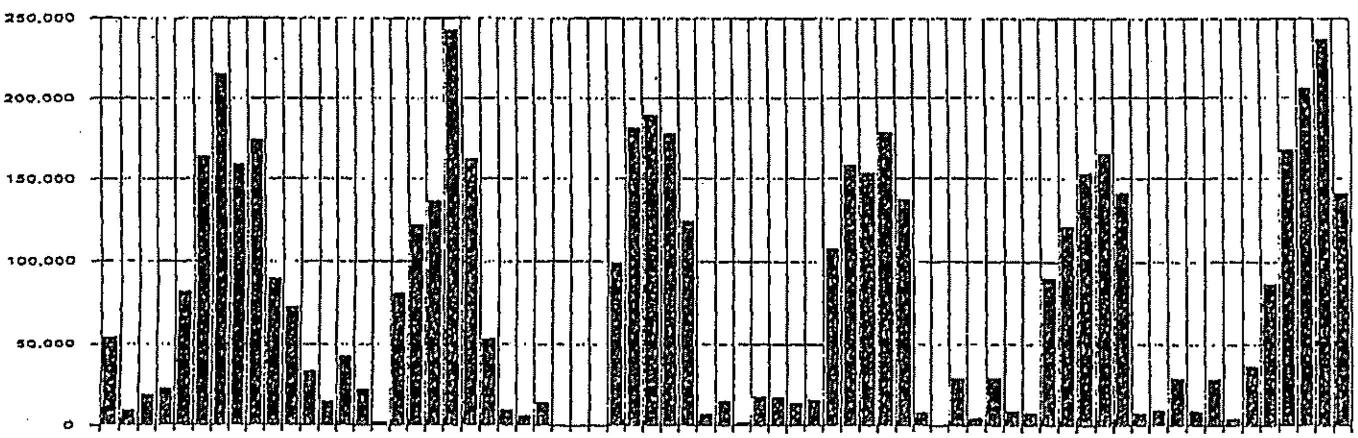
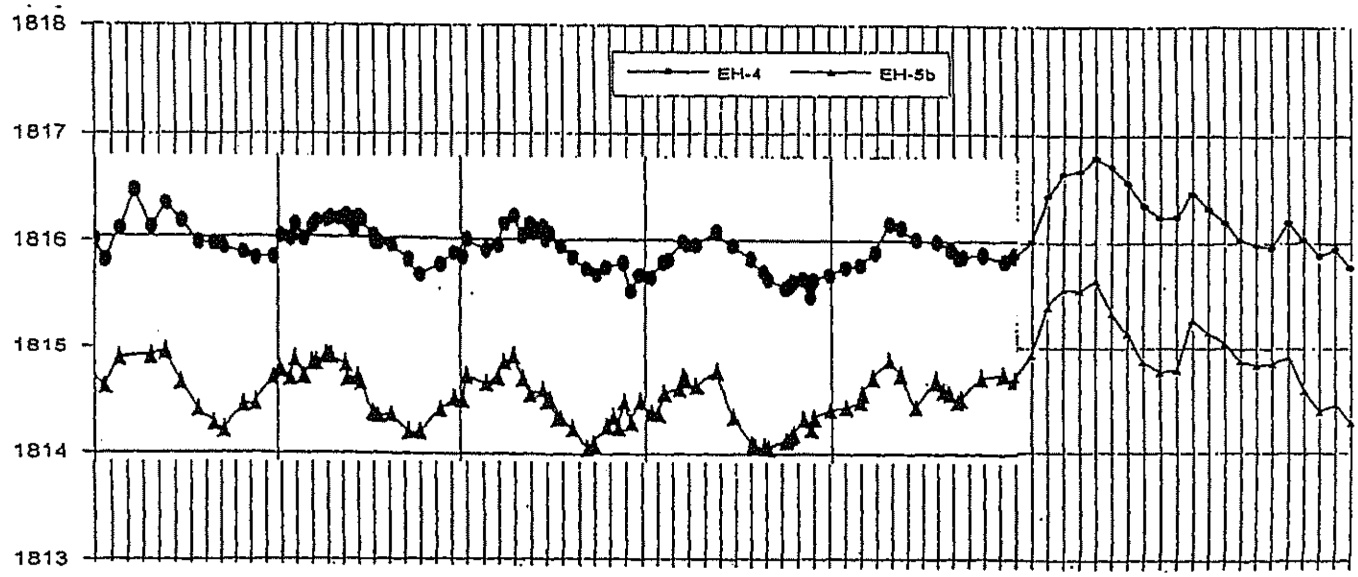


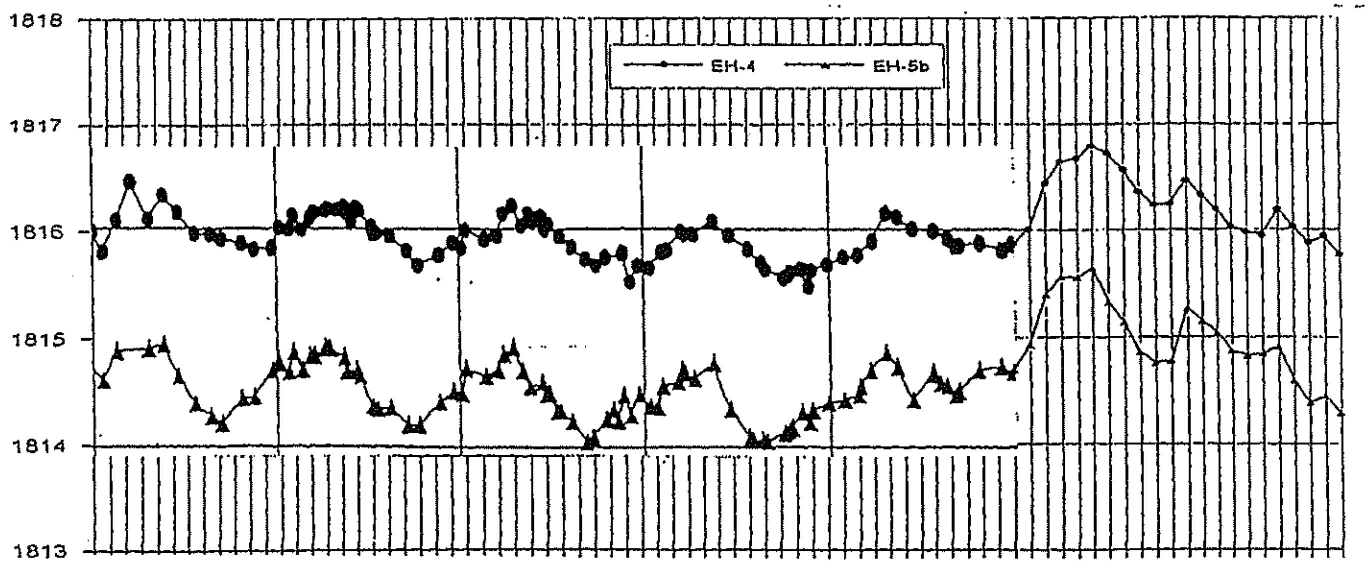
Arrow Canyon and MX-6 Wells, Baldwin and Jones Springs Diversions ('000 gallons) 1989–1994



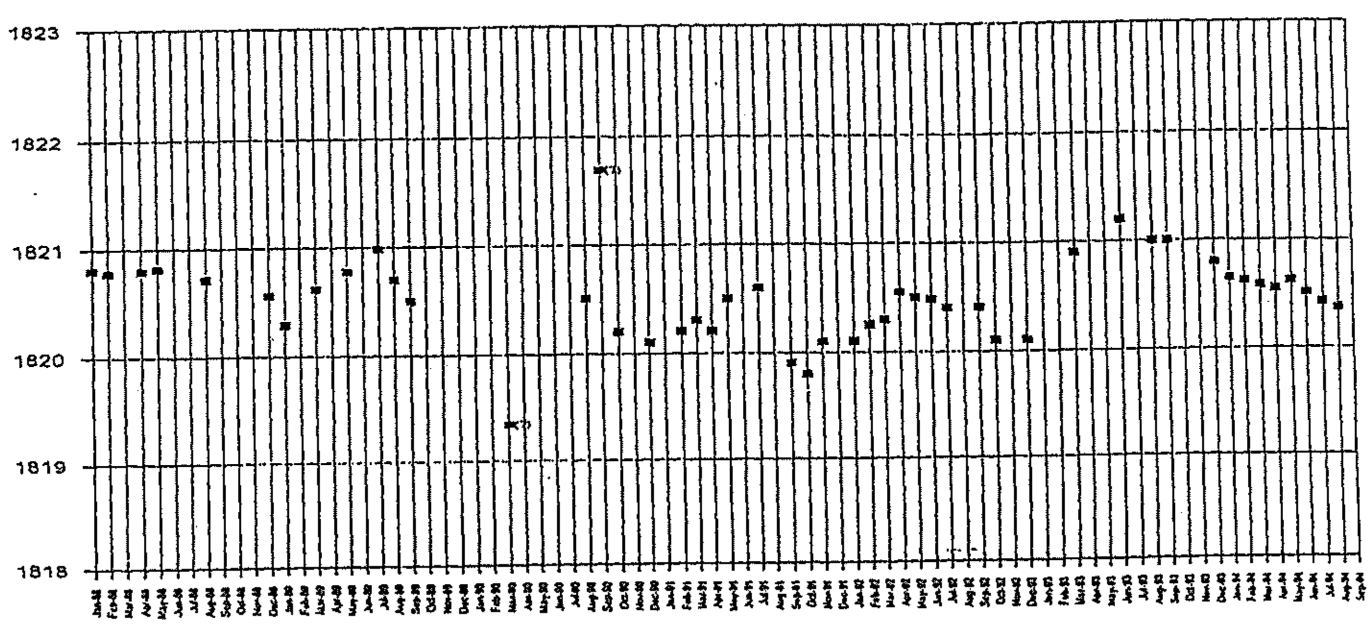
Lewis/LDS West and LDS East/LDS Central Well Fields Diversions ('000 gallons) 1989–1994



Hydrographs of EH-4 & EH-5b for January 1988 through September 1994



Hydrographs of EH-4 & EH-5b for January 1988 through September 1994



Hydrograph of MX-4 for January 1988 through August 1994