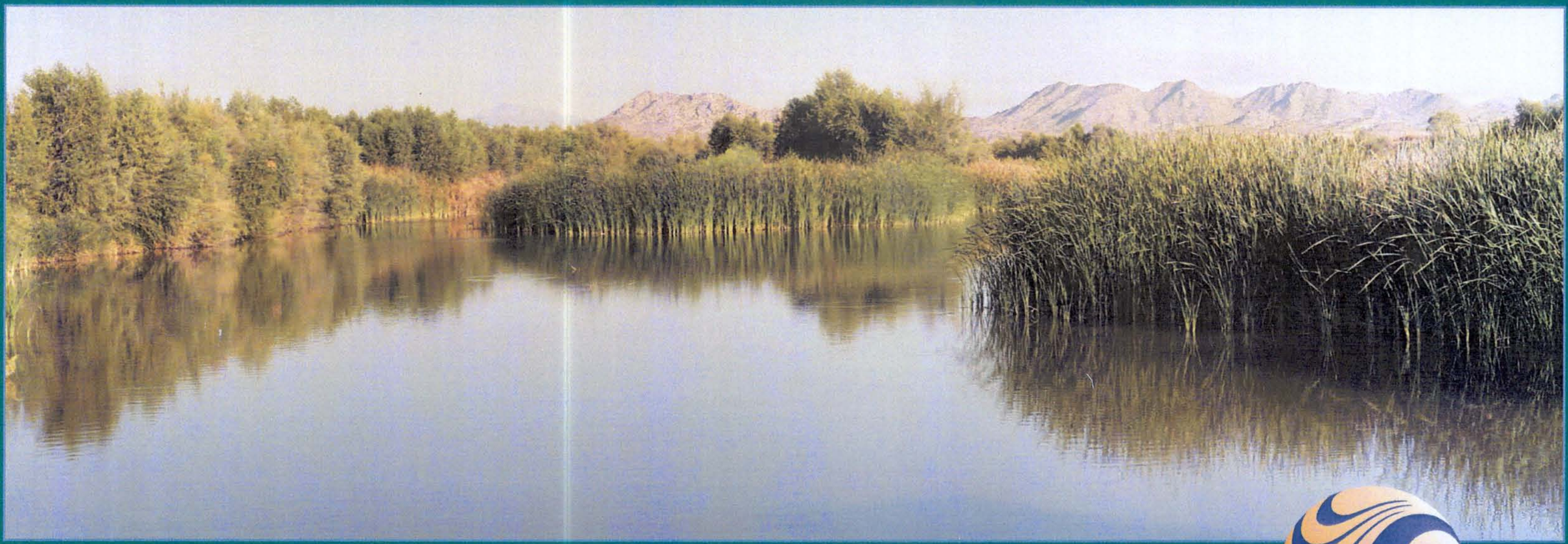
Attachment 6
GROUNDWATER EVALUATION

El Rio Watercourse Master Plan and Area Drainage Master Plan

Contract FCD 2001C024
Stantec Project No. 82000240



April 2003
Revised November 2005
Revised January 2006

Stantec

FINAL REPORT

Groundwater Evaluation
El Rio Project Area

23 January 2006

Prepared for:

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by

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Executive Summary

The Maricopa County Flood Control District (District) through the El Rio Watercourse Master Plan and Area Drainage Master Plan is planning facilities within the floodplain and floodway that provide protection from flooding and meet a public recreational need while preserving a riparian habitat unique to the Phoenix metropolitan area. It is the District's objective to provide opportunities for multiple uses within the El Rio Corridor including recreational, educational, wildlife habitat, riparian restoration, and other related components. To reach these goals, it is important to understand the impact that the area's groundwater resources have on the riparian plant and animal communities.

The El Rio portion of the Gila River Valley is part of a larger alluvial system characterized by broad alluvial basins bordered by block-faulted mountain ranges. Over time, through-flowing streams deposited interbedded sequences of sands, gravels and clays; while slower moving water deposited finer grained sediments. The resulting alluvial aquifer is a heterogeneous system characterized by a wide range of physical characteristics varying both laterally and vertically. This system has been subdivided into units that display enough similarity in their flow characteristics to be treated as a single hydrogeologic entity.

Groundwater flows into the area along both the eastern and northwestern boundaries, reflecting recharge from the Agua Fria and Salt Rivers on the east and the Hassayampa system to the west. As flow approaches the bedrock narrows at Gillespie dam, the narrows reduces the area through which this volume of water flows. As a result, the groundwater system builds the elevation head needed to move water through the only natural drain on the system.

The inflows to the aquifer include recharge from the Gila River, from canals in the area, from infiltration of precipitation, from Waste Water Treatment Plant discharges, from applied irrigation, and from run-off from mountains bordering the area. Inflow also occurs in the groundwater system across the eastern and western project boundaries since these boundaries do not coincide with an impermeable boundary.

Outflows from the aquifer include pumping, discharge from the groundwater system to the Gila River, evaporation from water surfaces directly in contact with the groundwater (gravel pits) and transpiration by plants. Outflow also occurs along portions of the eastern, northern and western boundaries of the project area.

In much of the El Rio area, irrigated agriculture remains the dominant land use. Fields are irrigated using sprinklers, rows, flood and furrow application; and excess irrigation water historically applied to these fields characteristically reached the local water table as recharge. As agricultural fields are converted to urban uses and more water-efficient irrigation practices decrease the amount of water being applied for irrigation, recharge to the aquifer system is decreasing. Although these changes decrease the volume of return flow reaching the groundwater, irrigated agriculture still provides the main source of recharge within the El Rio area. As the El Rio area continues to urbanize, water use will change and so will the location and design of the extraction wells used. Any of these changes may impact the development of mixed-use projects proposed for El Rio.

The El Rio groundwater model simulates the groundwater and surface water interaction within the El Rio project area and can be used to evaluate the long-term sustainability of the recommended alternative. The model can be used to identify areas of the project that are most influenced by changes in the regional groundwater and river systems. Of concern is the potential groundwater level rise within the area as the agricultural pumpage ceases and upstream recharge projects come on line or, conversely, the potential for dramatic groundwater level declines as the current drought progresses and municipal demand increases.

The ADWR's Salt River Valley Model, developed using the USGS program MODFLOW, formed the basis for the El Rio model. Model calculated hydraulic heads are similar to those measured with time, and the comparison of the 2001 contour map of measured heads with model calculated heads show similar shape and gradients. The calibrated base model was used to set up the model to evaluate potential scenarios. Based on the results of the eight scenarios, the reduction in recharge as agricultural land is retired, coupled with the decrease in pumping in the upper layer and the possible increase in pumping from the lower layers could result in declines in head beneath the river of as much as 20 feet.

To provide a more refined view of future conditions in one of the El Rio areas considered for initial development, a more detailed model was needed. The area selected by the District for the detailed model is the area between Watson and Dean Roads within the project area. The detailed model area is 1.4 miles wide and 2 miles long and is centered on the Gila River. Various scenarios incorporating probable variations in pumping and recharge were examined.

The scenarios show that heads near the river may rise or decline depending on the changes that are occurring in the El Rio area. The magnitude of changes are such that riparian and wetland vegetation could be stressed as depths to water fall below or rise above rooting depths. One means of mitigating the effects of the changes in groundwater is to develop a tiered contingency plan that can be implemented as changes occur. Proactive management of the project should begin with selecting wells in which groundwater heads can be monitored. Wells should be selected in the regional aquifer to provide both early warning of changes but should also be monitored in areas of critical vegetation within the project.

The possible changes in groundwater levels beneath the river indicate that it is possible that a time will come when the groundwater levels are below the rooting depths of the riparian and wetland vegetation within the El Rio area. A contingency plan for implementation of mitigation measures such as limited irrigation or increased flows in surface streams near critical habitat needs to be developed. The plan should identify locations to monitor groundwater heads with time and use the changes in heads to trigger response strategies to mitigate impact of groundwater changes on the river habitat.

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ACRONYMS

ADEQ	Arizona Department of Environmental Quality
ADMP	Area Drainage Master Plan
ADWR	Arizona Department of Water Resources
AF	Acre feet
AF/Year	Acre Feet per Year
AMSL	Above Mean Sea Level
ARM	Absolute Residual Mean
BWCDD	Buckeye Water Conservation and Drainage District
CAP	Central Arizona Project
cfd	cubic feet per day
cfs/mile	Cubic feet per second per mile
DATS	Desert Agricultural and Technical Systems
District	Maricopa County Flood Control District
ft^3/ft^2/day	cubic feet per square feet/day
K	Hydraulic Conductivity
Kv	Vertical Hydraulic Conductivity
LAU	Lower Alluvial Unit
MAU	Middle Alluvial Unit
mg/L	milligrams per liter
Montgomery	Errol L. Montgomery and Associates
mya	Million Years Ago
RID	Roosevelt Irrigation District
S	Storage
SRP	Salt River Project
SRV	Salt River Valley
TDS	Total Dissolved Solids
TMR	Telescopic Mesh Refinement

UAU	Upper Alluvial Unit
USGS	United States Geological Survey
uS/cm	micro Siemens per centimeter
WCMP	Watercourse Master Plan
WWTP	Wastewater Treatment Plant(s)

INTRODUCTION

The Maricopa County Flood Control District (the District) exercises regulatory control of the floodplain areas within the county. Although this control is most frequently associated with protecting and regulating development in flood prone areas, the El Rio Watercourse Master Plan (WCMP) and Area Drainage Master Plan (ADMP) envision a higher purpose, that of planning facilities within the floodplain and floodway that provide protection from flooding and meet a public recreational need while preserving a riparian habitat unique to the Phoenix metropolitan area. The alternatives under consideration go beyond protecting existing and future residents from the 100-year flood event to include recreational uses that enhance the benefit of the floodplain area to local communities. To this end, the WCMP/ADMP represents a joint effort by the Maricopa County Flood Control District, Maricopa County, the Town of Buckeye, and the Cities of Avondale and Goodyear.

The alternatives being considered include traditional structural flood control solutions, non-structural flood control solutions and a combination of both. These solutions will be based upon environmental conditions, system hydrology, hydraulics, lateral migration potentials, and sediment trends of the Gila River. It is the District's objective to provide opportunities for multiple uses within the El Rio Corridor including recreational, educational, wildlife habitat, riparian restoration, and other related components.

To reach these goals, it is important to understand the impact that the area's groundwater resources have on the riparian plant and animal communities. Although most of the alluvial basins associated with Arizona's major drainage systems host large, well-defined aquifers, many of these are located at depths well below the overlying stream channels. For this reason, no interconnection between the surface water and groundwater systems exists. In the El Rio area, this is not the case. Here, the area's history of geologic upheaval coupled with human intervention in the normal course of surface water movement have combined to create a riparian area where groundwater that may have flowed hundreds of feet below the surface in other parts of the basin is forced to the surface and reappears as stream flow through much of this reach. Shallow groundwater levels and flowing streams, uncharacteristic of other parts of the Gila River drainage, are common in El Rio's environs, as are riparian vegetation and habitat.

The WCMP and ADMP of the El Rio Project will include areas with riparian vegetation that rely on a dependable supply of water. Rooting depths for this vegetation, and its ability to withstand variations in the depth to water, are critical to the success of the project. The formation and maintenance of these groundwater systems, their interaction with local surface water resources and the impact of current and future land development on the groundwater and surface water systems are the focus of this report.

EL RIO STUDY AREA LOCATION

The El Rio WCMP and ADMP will identify and evaluate possible alternatives for providing flood control along a 17.5-mile reach of the Gila River from the confluence of the Gila River with the Agua Fria River to the bridge on State Route 85, south of Buckeye. Although the WCMP/ADMP will be confined to the floodplain within this reach, it is important to recognize that the local groundwater system extends well beyond the floodplain and can be affected by changes in pumping patterns, well depths, pumping volumes and recharge in adjacent areas. For that reason, the evaluation of the groundwater system within the El Rio area extends from the confluence of the Agua Fria and Gila Rivers on the east to the Hassayampa River watershed on the west encompassing all of Townships 1 North and 1 South, Ranges 1 through 4 West, as shown on Figure 1.

The Goodyear-Avondale-Buckeye metropolitan area is experiencing rapid growth. The direct impact of this growth is a decrease in the acreage devoted to irrigated agriculture and an increase in commercial, residential and industrial use beginning in the 1970s. As a result, although urban

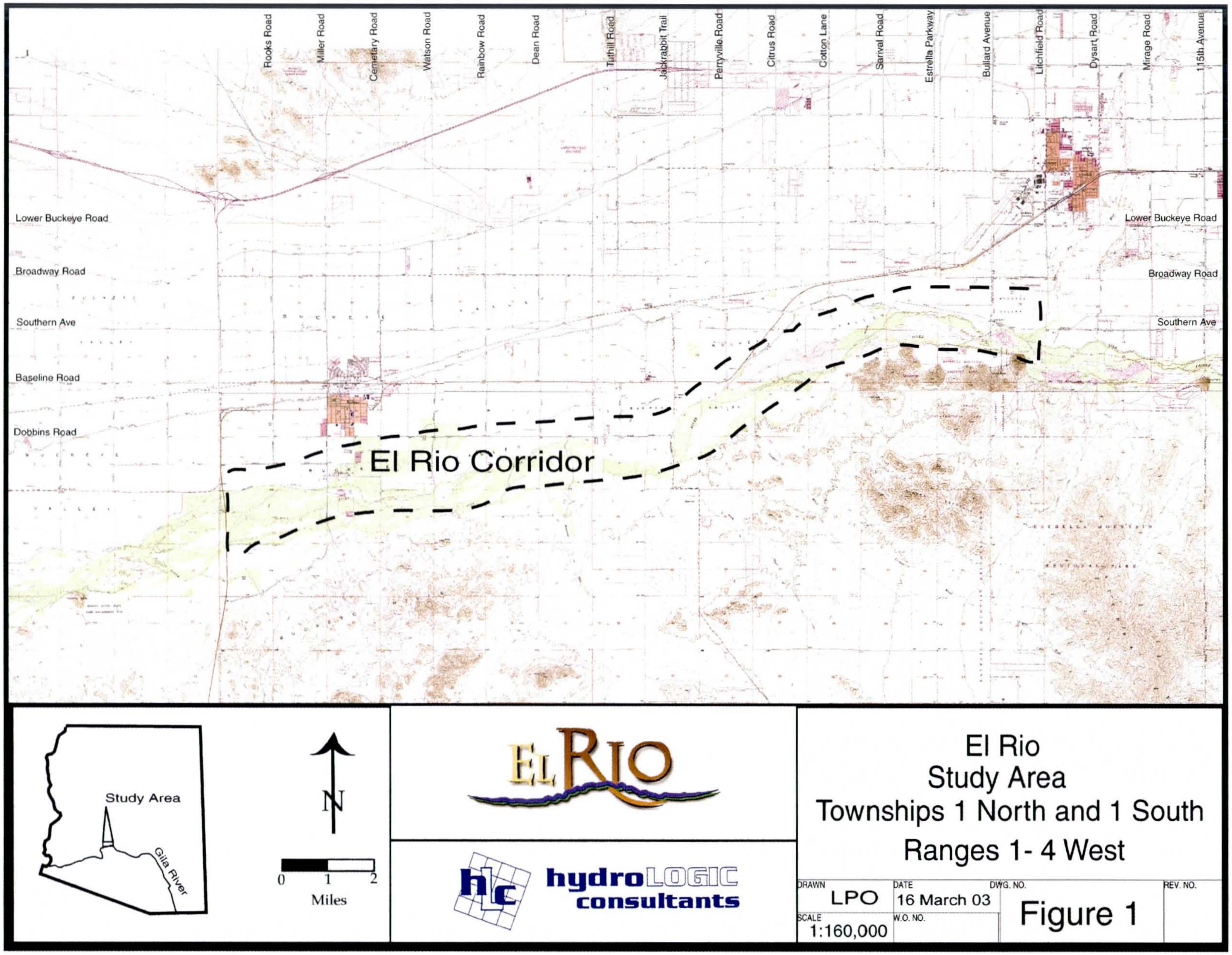
Rooks Road
Miller Road
Cemetary Road
Watson Road
Rainbow Road
Dean Road
Tuthill Road
Jackrabbit Trail
Perryville Road
Citrus Road
Cotton Lane
Sarival Road
Estrella Parkway
Bullard Avenue
Litchfield Road
Dysart Road
Mirage Road
115th Avenue
Lower Buckeye Road
Broadway Road
Southern Ave
Baseline Road
Dobbins Road
El Rio Corridor
Study Area
Gila River
N
0 1 2
Miles
EL RIO
hydroLOGIC consultants
El Rio
Study Area
Townships 1 North and 1 South
Ranges 1- 4 West
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Figure 1

water demands are less than those of agriculture, the aquifer recharge from excess agricultural applications ceases. Excess urban effluent is channeled to treatment plants and becomes riparian recharge along the Salt River Channel. These changes in recharge type and location change the dynamics of the groundwater system.

PAST RESEARCH

W.T. Lee, a geologist with the United States Geological Survey (USGS) (Lee, 1905), authored one of the earliest documents dealing with aquifer conditions in the area in 1905. According to Lee, groundwater development in the basin began in the late 1800s as agriculture expanded and erratic flows in the rivers could not meet the increased demand with any regularity. Early wells were predominantly large, hand-dug holes designed to reach a water table that was usually within 30 feet of the land surface. Lee recognized that groundwater development would increase in the valley and that some attempt should be made to document predevelopment conditions. The resulting report provides a detailed look at historical conditions and formed the basis for the steady-state conceptual model discussed later in this report.

Subsequent to Lee's work, numerous authors tackled the task of documenting aquifer conditions over time in the Gila River groundwater system. These were reviewed in the course of compiling the current study. Those that proved most useful were the Salt River Valley (SRV) modeling reports by various authors published under the auspices of the Arizona Department of Water Resources (ADWR). Because of the extensive data gathering capabilities of this state agency, ADWR had already compiled pumpage and recharge data, canal flow information and data on aquifer characteristics.

In addition to reports published by the state and federal agencies, numerous documents authored by private consultants within the area were on file at the Arizona Department of Environmental Quality (ADEQ) or were made available. Additional data were gathered from various theses on file at Arizona's universities. A report by Phillip Hutton (1983) provided insight into the flow characteristics of the local aquifer. Additional data on recharge from Salt River flood events were obtained from professional papers and reports by Briggs and Werho (1969), Mann and Rohne (1983), and Turner (1983).

The hydrogeologic setting of the SRV was described in detail by the ADWR in a series of reports dealing with development of the SRV Model. These documents relied on work done by Brown and Pool (1989) on the hydrogeology of the western part of the SRV. The hydrogeologic interpretation presented herein is taken predominantly from the ADWR report with modifications based upon more recent investigations. ADWR revised the SRV Model in 2002.

WELL IDENTIFICATION

The locations of wells within the El Rio project area are described using the USGS's cadastral numbering system. A description of this system is located in Appendix A.

EL RIO PHYSICAL SETTING

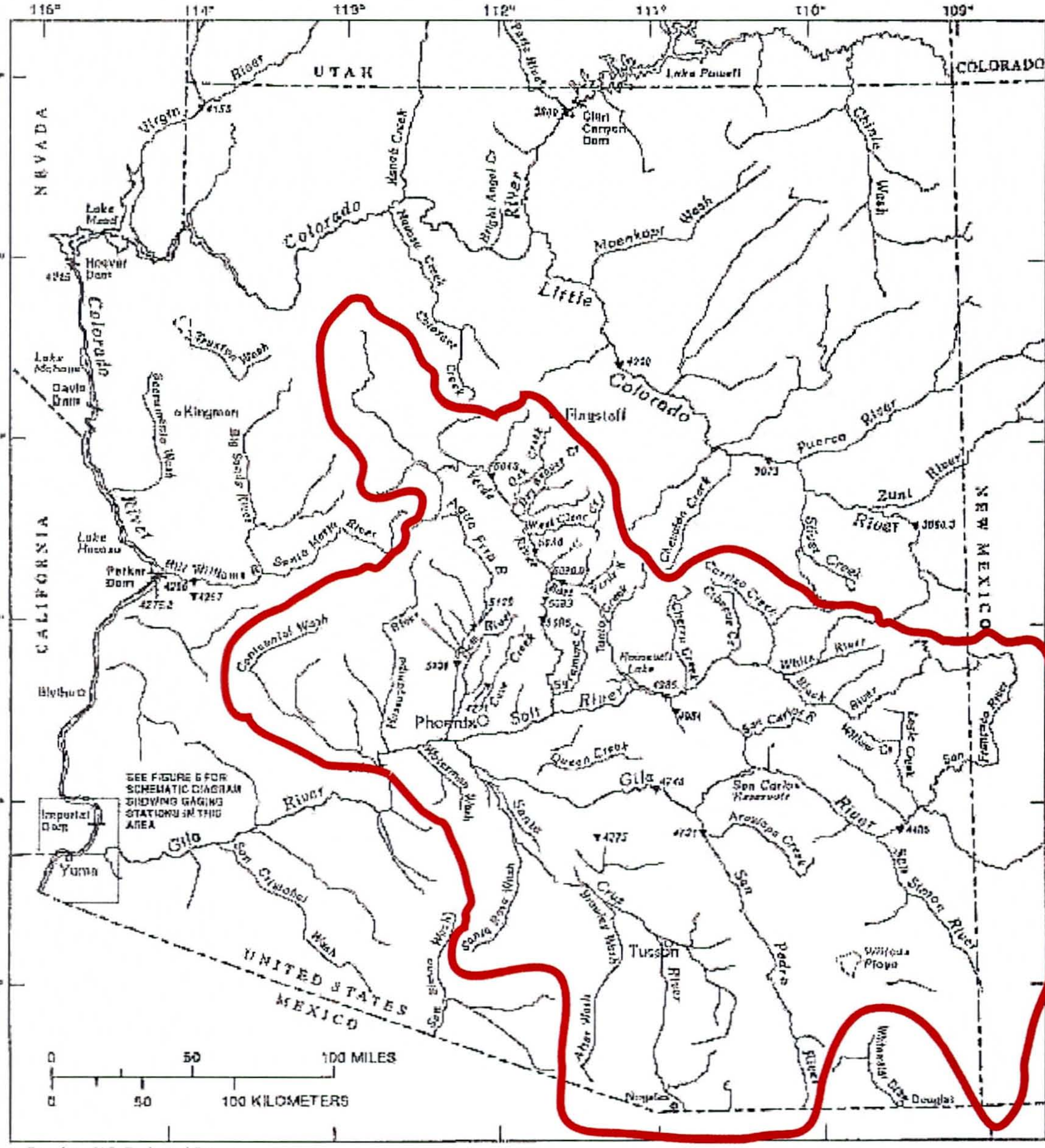
PHYSIOGRAPHY

The El Rio Groundwater Study Area covers 288 square miles encompassing residential, commercial and agricultural areas between the Sierra Estrella Mountains and Buckeye Hills on the South and the White Tank Mountains on the north. The area is roughly centered on the Town of Buckeye. Topography in the project area is characterized by a broad, flat-lying alluvial plain cut by low stream terraces and floodplains located in and adjacent to the Gila River and other unnamed washes. Alluvial fans have formed adjacent to the mountain fronts. Elevations through the El Rio Planning area range from 850 feet above mean sea level (amsl) near the Gila River to 1,774 ft amsl in the mountains bordering the project area. Land surface elevations gradually decrease to the west where the Gila River drainage is constrained by the geologic narrows at Gillespie Dam.

The high water table and flowing river that characterize the El Rio area are unique within Arizona's portion of the Gila River drainage. Draining more than half of Arizona and portions of New Mexico and Mexico, the Gila River is ephemeral through most of its course with surface flow only in response to intense rainfall. The drainage basin above Gillespie Dam covers approximately 50,000 square miles and funnels not only all of the surface water in this area, but all of the groundwater, as well, to the one narrow point constrained by the geologic structure of the valley at the narrows at Gillespie Dam (Figure 2).

CLIMATE

Hot summers and cool winters characterize the El Rio study area, which is located within the Sonoran Desert Climatic Region of Arizona. Average maximum temperatures reach a high of



Base from U.S. Geological Survey
State base maps, 1:500,000
Arizona, 1974; Nevada, 1985
New Mexico, 1965; and Utah, 1950

Gila River Drainage

Gila River Drainage Basin
Above Gillespie Dam

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105° F in July and a low of 65° F in January. Minimum temperatures range from an average of 80° F in July to an average of 39° F in January (ADWR, 1991).

Annual precipitation averages 7.2 inches across the valley with the majority occurring during the summer months of July through September and the winter months of December through March. Little precipitation occurs during the spring and fall. Average annual evaporation is approximately 72 inches, with the greatest evaporation occurring during the hot summer months (Corkhill, et al, 1993).

Although these represent average conditions, in evaluating the aquifer system associated with El Rio it is important to recognize that floral and faunal communities present will experience the extremes that comprise both ends of the temperature and precipitation spectra. Recent research by Gray, et al, (manuscript in progress) at the University of Arizona indicates that Arizona's climate has historically fluctuated between long periods (on the order of 30 years) of below normal rainfall or drought, followed by a like period of above average rainfall. The last drought period ended in the early 1970s. If this sequence persists, the area is entering another period of below normal rainfall that can be expected to last for decades. This issue will be addressed more fully later in this report in sections dealing with historic water levels, pumping and groundwater modeling.

VEGETATION

Vegetative communities in the El Rio Study area vary with land surface topography, availability of water, and anthropogenic effects on the environment. Upper Sonoran grasses and forbs are present in the higher elevations and undeveloped portions of the alluvial fans. Agricultural fields dominate the floodplain and older river terraces while riparian plant communities occupy the areas within the active floodway and portions of the flood plain near the river.

These riparian areas are of primary importance in implementation of the District's goals with the El Rio project. Riparian plant communities are those adjacent to and affected by surface or ground water of perennial or ephemeral water bodies such as rivers, streams, lakes, ponds, playas, or drainage ways. Their importance includes reduction of flooding, stabilization of stream banks, shading for temperature control, and habitat and food source for animals both on the land and in the water. A healthy aquatic ecosystem can be expected to obtain most of its nutrients directly from the riparian area rather from upland areas and land uses.

LAND USE

Predominant land uses within the project area are agricultural, urban residential, office complexes, strip malls, and light industrial. The area demonstrates the slow urbanization of agricultural lands that can have a dramatic effect on the underlying aquifer system. Four of the area's growing communities, Goodyear, Avondale, Tolleson and Buckeye, have well fields tapping the aquifer that feeds the El Rio area. As these communities grow, their water needs will increase, gradually supplanting agricultural pumping.

In this area most agricultural water is delivered by either the Roosevelt Irrigation District or the Buckeye Water Conservation and Drainage District (BWCDD). Water used to irrigate agricultural properties is either pumped from beneath the land on which it is used or imported by canal from surface or groundwater sources outside the area. The excess irrigation water returns to the local aquifer as deep seepage of irrigation return flow. By contrast, in urban scenarios, the water is still pumped from the aquifer in almost the same locations as with agriculture; however, the effluent water is conveyed to a treatment facility often miles away and ultimately discharged to a system far removed from that of its origin.

The ultimate impact of urbanization is complicated by the fact that the average water use for an acre of residential property is approximately half that of an acre of agriculture. In addition, in the El Rio area, agricultural wells tapped only the upper portions of the underlying multi-layer aquifer while municipal supply wells will, in all likelihood, tap deeper systems. As a result, the problem of assessing the impact of change on the aquifer over time is multidimensional and requires an examination of the historical uses of water in the area as well as future water use scenarios.

HISTORICAL WATER USE

Predevelopment Conditions

Prior to the late 1800s much of this portion of the Gila River drainage was gently sloping grasslands, used primarily as open range. Little groundwater was needed because surface supplies were plentiful. More emphasis was placed upon mining in the bordering mountain ranges than agriculture. It was these mining activities, however, that would be instrumental in bringing about the first subjugation of the rangeland to irrigated agriculture. The mines in the hills surrounding Wickenburg relied almost solely upon mules to power equipment and haul ore. Mules needed feed and lots of it. As a result, local mining concerns contracted with farmers in the valley to grow the large quantities of oats, hay and alfalfa required to keep their mines operating. As the mines grew, so did irrigated agriculture and the irrigation districts that conveyed surface water from the Agua Fria and Salt Rivers along with pumped groundwater to meet the increasing agricultural demands.

Cultural Modifications That Impact Surface Flows and Groundwater

Agricultural development within the El Rio area brought with it modifications to the groundwater system and to the Gila River. Agriculture changed the locations of discharges from the groundwater system, as well as the type and location of recharge to the groundwater.

Agricultural Development

The agricultural development was not without impact on the local aquifer system. The availability of large quantities of water led to regular application of volumes in excess of that required by the crops. The unused water seeped into the underlying sediments and local water levels began to rise until waterlogging of the agricultural fields became a major problem. To alleviate this situation, wells were installed for the express purpose of lowering water levels to a point at which the agricultural properties could be worked. The water pumped by these wells was conveyed via canal for discharge to the Gila River. These dewatering wells are still in use today, strategically placed along several miles of fields adjoining the Gila River floodplain.

It is important to recognize that the water extracted by these wells carries with it the agricultural chemicals applied to the fields. As a result, the impact of the discharge from the dewatering wells on the local ecosystem must be evaluated. In addition, the loss of this flow at the points of discharge, should pumping patterns change in the future, needs to be evaluated when considering the development and implementation of any alternative scenario.

The BWCDD operates 11 dewatering wells located in the western portion of the study area. These wells, placed in operation between 1960 and 1980, are used to lower the groundwater table as a part of the agricultural operations. These dewatering wells represent both withdrawals from the groundwater system and inflow to the surface water system.

Water conservation regulations have resulted in decreased quantities of agricultural tailwater discharges to the Salt and Gila Rivers. Very few of the agricultural drains are gauged and the total quantity and quality of the agricultural drainage water cannot be verified. Salt River Project (SRP) discharges water to the Gila River to meet water rights requirements of the BWCDD. The discharge point is immediately upstream of the Agua Fria River junction with the Gila River.

Modifications to River Flow

Prior to development of irrigated agriculture along its watercourse, the Gila River was a perennial stream with navigable reaches. Historical accounts from November 1849 tell of the voyage of a 16-foot boat carrying several people from the location of present-day Coolidge to Yuma along the Gila River (ADWR, 1993). Like the Gila, the Salt River flowed perennially before the late 1800s (Lee, 1905).

The Salt River originates in eastern Arizona draining approximately 6,000 square miles of the Mogollon Rim area in the east-central part of the state as it flows southwest, through the cities of Mesa, Tempe, and Phoenix, and into the Gila River near Laveen. Flow in the Salt River is currently regulated by a system of five dams for water supply, hydroelectric power, and flood control. Granite Reef Dam, the last structure on the Salt, diverts almost all of the Salt and Verde River flows into the SRP canal system for agricultural, municipal, and industrial water use. Downstream from the dam, most of the Salt River is ephemeral, flowing mainly in response to flooding or reservoir releases. Approximately the last 8 miles of the Salt River are perennial (Brown and others, 1977) due to effluent discharge from the City of Phoenix 23rd and 91st Avenue wastewater treatment plants (WWTP).

There are five WWTP that discharge in or around the El Rio Area. Principal among these are the 23rd Avenue WWTP, 91st Avenue WWTP, and Tolleson WWTP. The Avondale and Goodyear WWTP deliver their discharges for artificial recharge.

The creation of perennial flow in the lower reaches of the Gila River in the El Rio area has created habitat for numerous floral and faunal species. Those with probably the most direct impact on flow in the area are beavers. By creating impoundments behind their dams, the beavers have enhanced recharge to the groundwater and created an environment that fosters the growth of riparian vegetation that is dependent on shallow groundwater. These dams and impoundments can change both flow velocities and the depositional environment.

Other activities in the floodplain that impact both the hydrologic budget and water movement include the pits created during the mining of sand and gravel from the river channel. The gravel pits provide a direct conduit to the groundwater system, in some areas enhancing recharge and in others providing a discharge point for shallow groundwater.

Modifications to Groundwater

In addition to WWTP discharge to the rivers, other anthropogenic surface water sources in the area may also be sources of recharge to the local groundwater. Principal among these surface water sources are irrigation canals operated by the BWCDD and the Roosevelt Irrigation District across the study area. These canals receive water from WWTP discharge, the SRP system, and groundwater supplies. The Beardsley canal, which is located across the northern part of the study area, transports water from the Agua Fria River. The Central Arizona Project (CAP) canal is also a surface water source in the northern part of the study area as recharge projects using Colorado River water are developed on the Agua Fria River. Irrigation return flow that is captured in basins at the downgradient edges of fields also supplies recharge to the groundwater.

All of these surface-water sources in the riverbeds, canals, and catchment ponds have a direct effect on both the groundwater quantity and quality in the El Rio area.

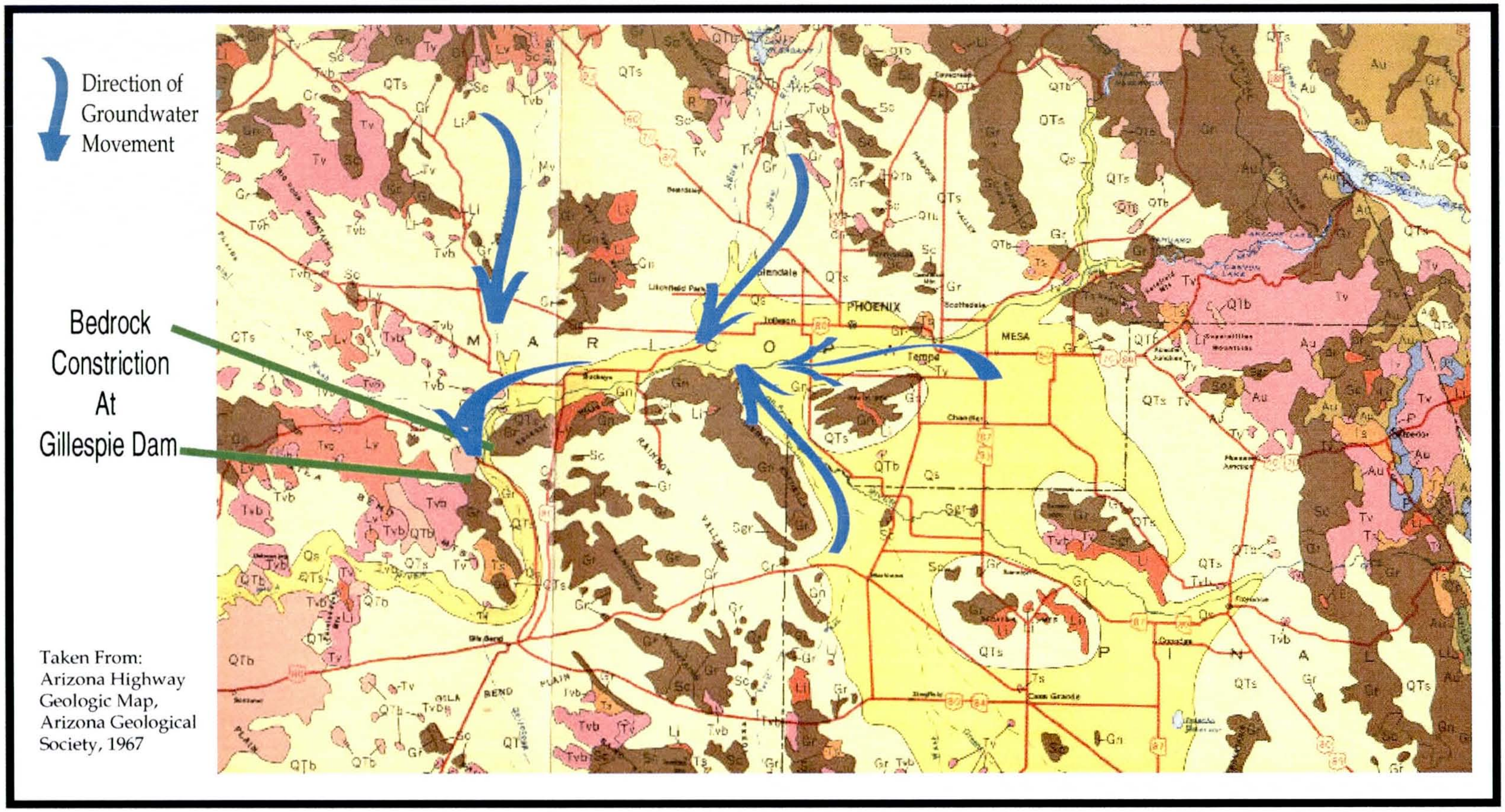
GEOLOGY

The geology of the El Rio area has been described in numerous documents ranging from map series to reports published under the auspices of the USGS, the U.S. Bureau of Reclamation and Arizona Bureau of Mines. The following paragraphs provide a synopsis of this past work and are intended to establish a basic understanding of primary lithologic units present in the El Rio area.

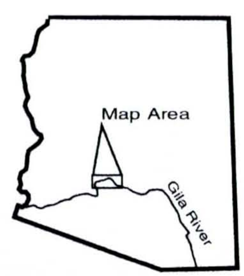
LITHOLOGY

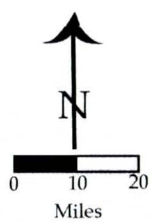
The Basin and Range Physiography observed today was formed as a result of high-angle block faulting between 15 and 8 million years ago (Brown and Pool 1989). The El Rio portion of the Gila River system is part of a series of down-dropped valleys associated with the Basin and Range Physiographic Province of South-Central Arizona. Characterized by broad alluvial plains bordered by block-faulted mountain ranges, these valleys were created over time as sediments were eroded from the mountains and deposited within the down-dropped basins (Figure 3). The igneous, metamorphic, and sedimentary rocks that comprise the mountains are extensively folded or faulted, while the basins contain thick stratified deposits of gravel, sand, silt, clay, evaporites, and volcanic rocks. The unconsolidated units are generally coarse grained at the basin margins and become finer grained in the central part of the basins.

The geologic units within the El Rio area include the hydrologic bedrock, which consists of the Red Bed conglomerate and three alluvial units. The alluvial deposits are divided into three major units, the Lower Alluvial Unit (LAU), the Middle Alluvial Unit (MAU) and the Upper Alluvial Unit (UAU). The LAU is predominantly a conglomerate intermixed with finer grained lenses. Although few wells in the area penetrate more than the upper alluvial units, a typical geologic cross section (Figure 4) was developed using published information from nearby areas.



Taken From:
Arizona Highway Geologic Map,
Arizona Geological Society, 1967





EL RIO

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Geologic Map Showing Bedrock Controls on Gila River Drainage

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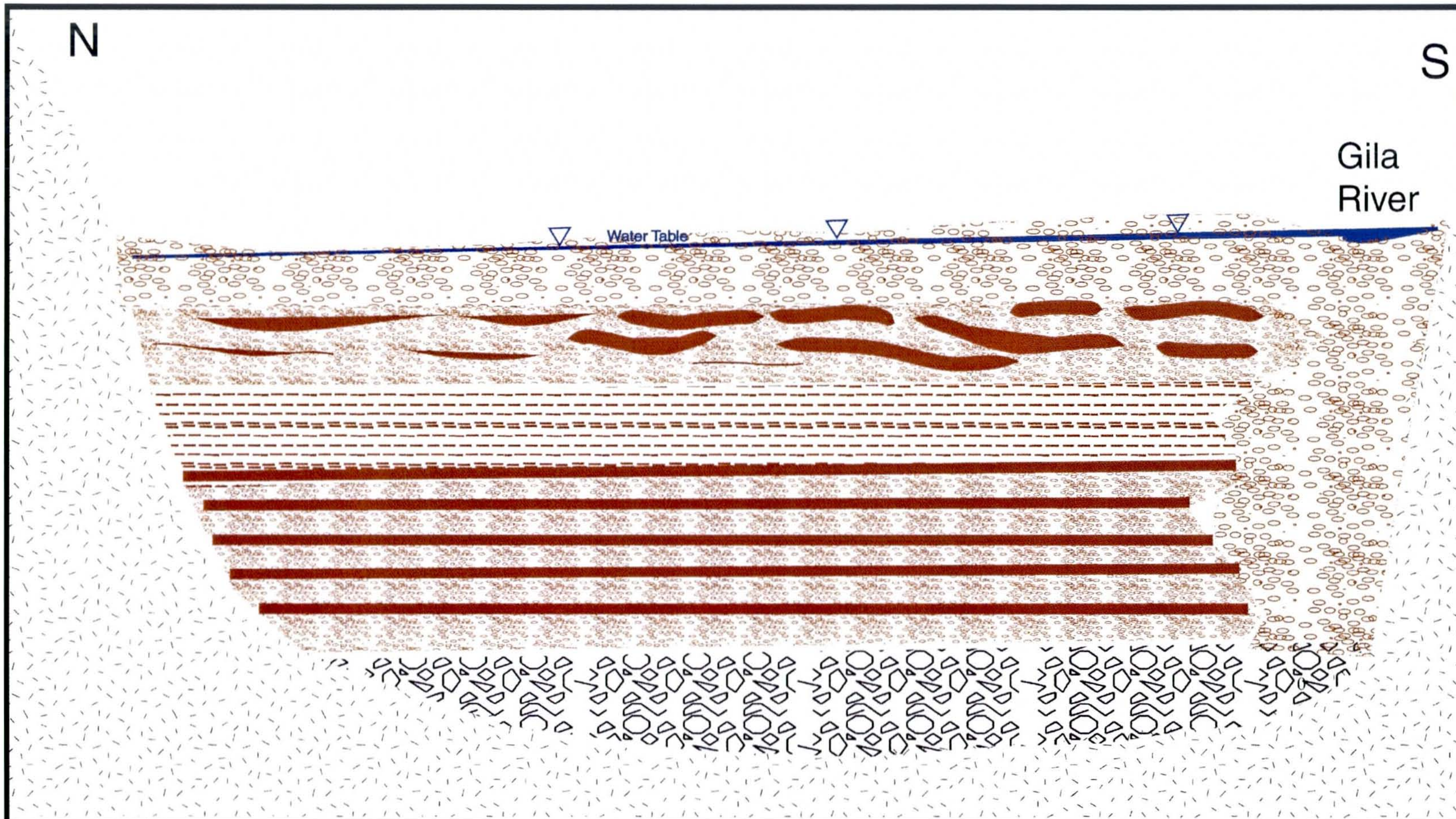

- Upper Portion of the Upper Alluvial Unit (UAU1)
- Lower Portion of the Upper Alluvial Unit (UAU2)
- Upper Portion of the Middle Alluvial Unit (MAU1)
- Lower Portion of the Middle Alluvial Unit (MAU2)
- Lower Alluvial Unit (LAU)
- Hydrologic Bedrock Unit (Redbeds & Granite)

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Typical North-South Geologic Cross-Section El Rio Area

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The MAU is a thick sequence of finer grained sediments that represent a low energy depositional environment. Many of the finer-grained deposits in the MAU are associated with ancient playa environments due to the extensive evaporite deposits encountered. As more through-flowing streams developed, the lithologic sequence grades into fluvial sands and gravels interspersed with clays most commonly associated with backwater areas. More rounded sands and graded gravels found in modern alluvial fans can also be found distributed along the margins of the valley in the MAU. Within the El Rio area, the MAU is defined by thick clay sequences characterized by drillers as *hard brown clay* or *sticky red/brown clay* depending upon location.

The UAU is comprised of gravel, sand and silt with small amounts of clay, usually in a sand matrix. Within the El Rio area, the unit is unconsolidated and grades from predominantly gravel and cobbles near the Gila River to finer floodplain deposits in adjacent areas.

DEVELOPMENT OF GILA RIVER DRAINAGE

Major drainage patterns in Arizona began developing during the Laramide uplift of mountains that began in Utah and Colorado (approximately 70 million years ago (mya)) and continued in the southwest and across Arizona by about 40 mya. Regional uplift, accompanied by flexing and faulting was largely completed by about 30 mya; among its effects were gentle northeasterly tilting of the Plateau and further arching of the Mountain Region. This uplift served to disrupt the southwesterly drainage. Numerous small streams cut the rising mountains before complete disruption occurred, and these form a part of the present drainage system (Lance, 1960). The Basin and Range topography observed today in the southern part of Arizona was developed at this time as some of the disrupted drainage was diverted into newly formed basins. Pediments and other erosional surfaces were locally developed before the basin fill accumulated and were gradually buried by later sedimentary sequences.

At this point in time, the Gila River drainage was well developed. Small streams issuing from surrounding mountains contributed to the sediment load of the stream and the high-energy flow deposited layers of cobbles and boulders on top of the older rocks flooring the basins. As volcanic activity increased, a lava flow blocked the Gila River at a point generally coincident with present day Gillespie Dam, slowing the flow and creating a large lake throughout the Gila and Salt River Valleys. The remnants of this lake can be seen in the lithologic sequences of materials penetrated by local wells (Figure 4).

Flooring the basin is a dense conglomerate (LAU) comprised of large cobbles and boulders laid down by the high-energy ancestral Gila River. Over time these became cemented and any pore spaces that might have held water filled with fine, chemical cement. Above the conglomerate is the MAU, which is normally divided into two sections. The lower section is comprised of interbedded sands, gravels and clays indicative of a floodplain depositional environment that was gradually being inundated for greater periods of time with each successive flood. The upper part of the MAU is characterized by thick deposits of lakebed clays indicating that the flow in the Gila had become completely blocked and that a low energy system prevailed above the narrows at Gillespie Dam. It is interesting to note that the MAU pinches out near the basin margins and is absent beneath the Gila River in the El Rio area. The absence of the MAU beneath the Gila River suggests that there was still through-flow. River movement was constrained by the Buckeye Hills and Sierra Estrella Mountains to the south. The Gila maintained sufficient energy through this reach to convey fine sediments downstream depositing only heavier sands and gravels. Over time, deposition in the basins continued, the lakes drained and the Gila and its tributaries again flowed in defined channels. The fine sands, gravels and clays that comprise the UAU were deposited on top of the finer grained sediments with each successive flood event in the basin. In the El Rio area it is these upper sedimentary sequences that comprise the most developed aquifer.

IMPORTANCE OF BEDROCK

The bedrock provides both a boundary to groundwater flow and a southern limit for movement of the Gila River. The absence of the finer grained sediments in the MAU in the El Rio area is a result of the bedrock along the southern boundary of the El Rio area constraining the Gila River path to this area.

IMPORTANCE OF TRIBUTARY STREAMS

The two major tributaries to the Gila River in the El Rio area are the Agua Fria River, located just east of the project boundaries, and the Hassayampa River, located just west of the project area. Both rivers influence the hydrology in the El Rio area by providing a source of sediment to the Gila during surface flow events, and by providing a more permeable zone for groundwater flow. Like the Salt and Gila Rivers, the sediments beneath the Agua Fria and Hassayampa Rivers are coarser grained and more permeable than the adjacent alluvial sediments. Recharge from flow in the rivers, whether natural or from aquifer storage and recovery projects, moves readily to the shallow groundwater system and is transmitted quickly downstream.

The flow from these streams serves to maintain the high water levels in the El Rio area. The Agua Fria contributes direct inflow while the Hassayampa aquifer provides sufficient subflow to restrict outflow from El Rio to the natural drainage point at Gillespie Dam. Flow from the aquifer in the Hassayampa River watershed regulates upstream flow and maintains high water levels in the El Rio area, especially during drought. Should groundwater levels in the Hassayampa be reduced by future development to the point where the groundwater flow direction in this area is reversed, water levels in the El Rio area would decline.

HYDROGEOLOGY

The El Rio portion of the Gila River Valley is part of a larger alluvial system characterized by broad alluvial valleys bordered by block-faulted mountain ranges. The character of the aquifer systems depended on the depositional environment under which the sediments were laid down. Through-flowing streams deposited interbedded sequences of sands, gravels and clays; slower moving water deposited finer grained sediments. The resulting alluvial aquifer is a heterogeneous system characterized by a wide range of physical characteristics varying both laterally and vertically. This system has been subdivided into units that display enough similarity in their flow characteristics to be treated as a single hydrogeologic entity.

The largest and most extensive source of groundwater is the pore spaces in the alluvial deposits that fill the basins. Where saturated, the upper part of the alluvial deposits is a productive aquifer and groundwater generally occurs under unconfined conditions. Groundwater in the deeper deposits occurs in the permeable lenses of sand and gravel; the occurrence is greatly influenced by the heterogeneity of the material. A wide range exists in the vertical interconnection between lenses or layers of coarse material and in the lateral continuity of the lenses. The result is that groundwater may occur under either unconfined or locally confined conditions.

Water stored in the alluvial deposits has been accumulating for thousands of years, and recharge is limited. Possible sources of recharge are infiltration of direct precipitation and runoff, seepage from permanent surface water bodies, and irrigation return flow. Although precipitation is the ultimate source of all groundwater, it serves as a direct source of recharge to the alluvial basins only during abnormally wet years. Most of the precipitation that falls on the basin floors is lost to evaporation or transpiration. Infiltration of runoff is the single most important source of recharge to the groundwater systems in undeveloped basins. In basins with agriculture, irrigation return flow becomes an important source of recharge.

In most basins, groundwater moves from the basin margins, where it originates as recharge from runoff in the mountains, toward the axis of the basin or to a point where discharge occurs, either naturally or by pumping. The rate of groundwater movement in the alluvial deposits generally is a few feet to a few hundred feet per year.

Groundwater flow regimes in the El Rio area are dominated by regional pumping centers with recharge supplied from excess agricultural irrigation, canal leakage, and occasional flood events. Groundwater movement within the region is predominantly controlled by the areal distribution of recharge and pumping. Several geologic features exert control over the direction of groundwater movement on a local scale. These include the location and distribution of non-waterbearing formations, locally discontinuous and regionally extensive fine-grained or consolidated deposits, the "bedrock highs" in the southern and the north central part of the area, and the presence of the Luke Salt Body.

HYDROGEOLOGIC UNITS

The three water-bearing units within the El Rio area are the LAU, MAU and UAU.

LAU

The LAU yields little water to wells locally and was considered to contribute only marginal amounts of water to the overlying systems in the El Rio area. Because of its depth and low yield, few wells have penetrated the LAU so the entire thickness of the unit is not known. The ADWR used hydraulic conductivities in the LAU in the El Rio area that ranged from 10 to 30 feet/day near the Gila River and 10 to 20 feet/day in sediments away from the river. The hydraulic conductivities are averages for each one-square mile area that is represented by the model grid.

MAU

By contrast, although predominantly comprised of finer grained silts, clays and silty sands, the MAU contains enough sand and gravel deposits to yield significant quantities of water to wells and is considered a major aquifer.

Within the El Rio area, the uppermost portion of the MAU was considered to be that portion of the lithologic sequence characterized by at least 40 feet of material often, but not always, referred to as *Hard Brown Clay* or *Sticky Brown Clay*. This marks the transition point between the MAU and the UAU. Below this point, the lithology usually shows a marked increase in the amount of fine-grained material present.

The finer grained sediments in the upper portion of the MAU limit flow between the MAU and UAU. In many parts of the Salt River Valley, the finer-grained sediments in the MAU function as a confining unit, providing a low permeability hydraulic barrier that creates two separate aquifers, one in the shallower UAU and the second in the MAU. That the MAU functions as a confining unit is demonstrated by hydrographs for wells screened in a specific unit and a comparison of the water levels in the wells as the water levels respond to pumping. Where the MAU is present, it limits movement of both water and contamination from the UAU to the deeper water bearing zones.

Geologic logs for wells in the El Rio Project area indicate that the MAU is present away from the Gila River, but that the finer grained sediments of the MAU are missing near the River. This means that there is a communication between shallow groundwater and deeper groundwater near the river, and that the effects of pumping from the deeper MAU in areas away from the River, may be felt in wells adjacent to the River. Where the MAU is present the pumping from deeper units has minimal impact on the shallow groundwater. In the El Rio area, this could mean that, as pumping is converted from irrigation to municipal uses and the wells are deepened to access the better quality water in the deeper units, the effects from pumping may be felt in the shallow groundwater near the river.

The thickness of the MAU ranges from less than 120 feet to more than 500 feet in the El Rio area. The ADWR used hydraulic conductivities in the MAU in the El Rio area that ranged from 8 to 25 feet/day near the Gila River and 6 to 20 feet/day in sediments away from the river. The hydraulic conductivities are averages for each one-square mile area that is represented by the model grid.

UAU

The upper unit of the basin fill is comprised of gravel, sand and silt with small amounts of clay, usually in a sand matrix. Within the El Rio area, the unit is unconsolidated and grades from predominantly gravel and cobbles near the Gila River to finer floodplain deposits in adjacent areas. The UAU is the most highly productive unit of the three and most water production wells in the El Rio area extract a large portion of their water from this source.

Subdivision of UAU

Although the lithology of the UAU is distinctive in most areas of the basin, enough gradation exists within the unit to allow separation into two sublayers. The uppermost layer is comprised of loose surface soils grading downward into interfingered sand and gravel lenses. Clay lenses, when present, are thin and usually characterized as *clayey sands*. Although the upper portions of this layer are saturated throughout the El Rio area, the layer does dewater in the areas nearest pumping wells. Termed UAU_1 for purposes of identification, the breakpoint between this and the lower UAU_2 is the point where clay lenses within the unit appear to increase in number to the point where the increase appears to reflect a clay content in excess of 30 percent.

Because it is saturated and highly permeable, the UAU is the most highly developed unit within the aquifer system in the El Rio area. Few wells extend into the MAU. Unfortunately, the same characteristics that make this an excellent aquifer also make it an active pathway for agricultural chemicals to the Gila River. Water level measurements have been collected in some areas since the 1920s and the driller's logs on file with the ADWR attest to the shallow nature of most wells. In addition, these measurements reflect not only historic drought impacts but also the gradual rise in water levels due to agricultural recharge that led to water logging of some fields.

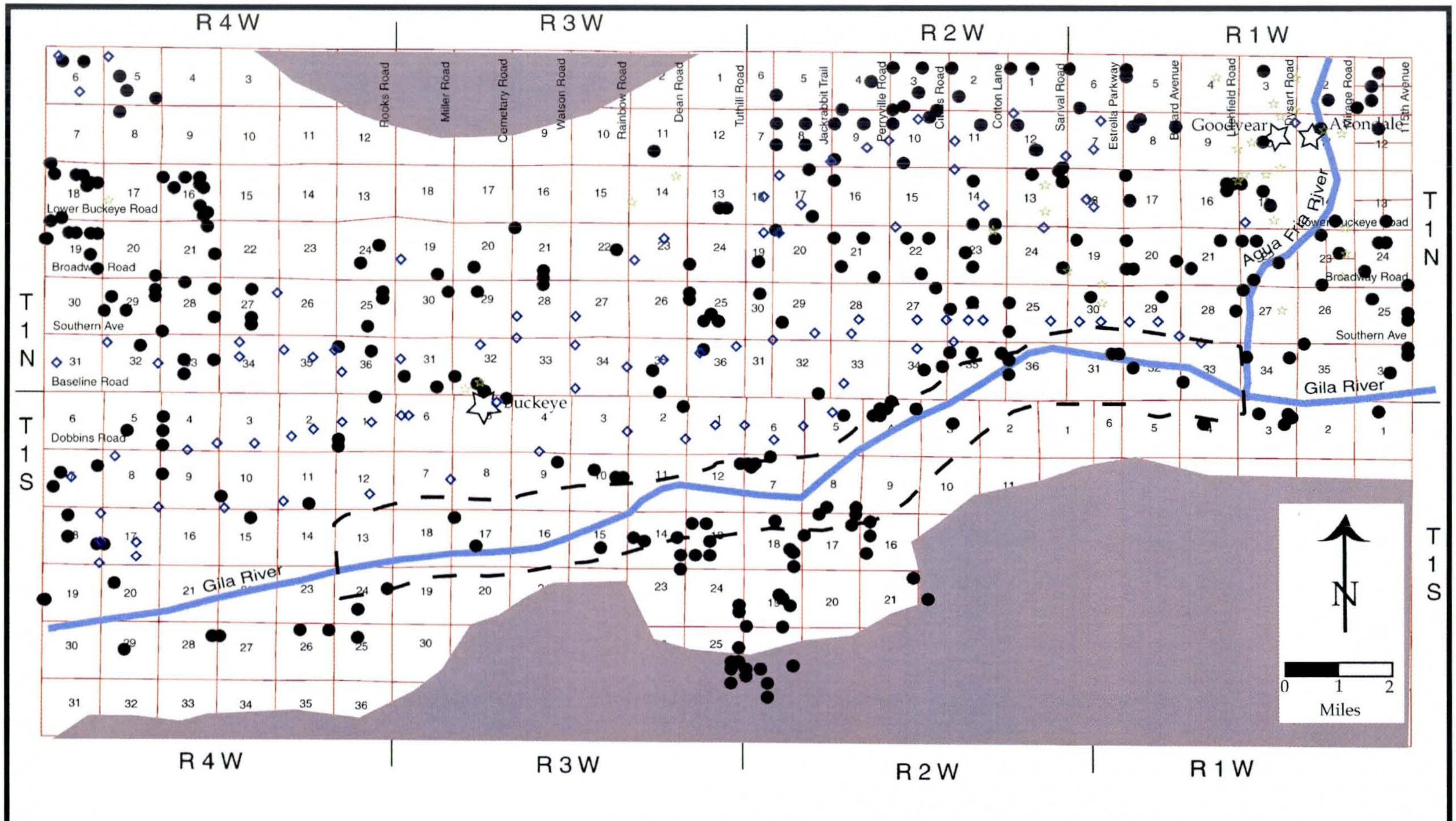
The thickness of the UAU in the El Rio area varies from less than 40 feet to approximately 200 feet. The ADWR used hydraulic conductivities in the UAU in the El Rio area that ranged from 50 to 100 feet/day near the Gila River and 20 to 50 feet/day in sediments away from the river. The hydraulic conductivities are averages for each one-square mile area that is represented by the model grid.

SURFACE WATER FLOW

In the El Rio area, surface water flow is derived from runoff from precipitation, groundwater discharge, discharge from WWTP, and inflow into the area via the Gila, Salt, and Agua Fria Rivers. The Salt and Agua Fria Rivers originate as perennial streams in the Central highlands province where an annual precipitation of 15 to 40 inches is sufficient to maintain the year-round flow of many streams. After emerging onto the valley floor, the Gila, Salt, and Agua Fria Rivers historically provided recharge to and acted as discharge points from the groundwater systems beneath the El Rio area. Over time, as these rivers were controlled by reservoir storage, the surface water flow regime changed from perennial to intermittent, and associated with this change was a parallel change in recharge to the groundwater system. Presently, the recharge once derived from streamflow is being supplanted, in part, by seepage from canals and irrigated fields.

GROUNDWATER CONFIGURATION

Information from the ADWR 55 database (Appendix B) indicates that there are approximately 2,800 wells registered within the El Rio area. The wells are both exempt and non-exempt, and they're used to pump water for irrigation, domestic, municipal and dewatering uses and for water quality monitoring. Figure 5 shows the location of the non-exempt wells used to pump water for municipal systems and irrigation.



- Non-Exempt Private Well
- Irrigation Company Well
- Municipal Well
- El Rio Corridor
- Bedrock
- River

EL RIO

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Registered Non-Exempt Wells in the El Rio Area

DRAWN	DATE	DWG. NO.	REV. NO.
LPO	16 March 03	Figure 5	
SCALE 1:160,000	W.O. NO.		

Hydraulic Heads 1998-2000

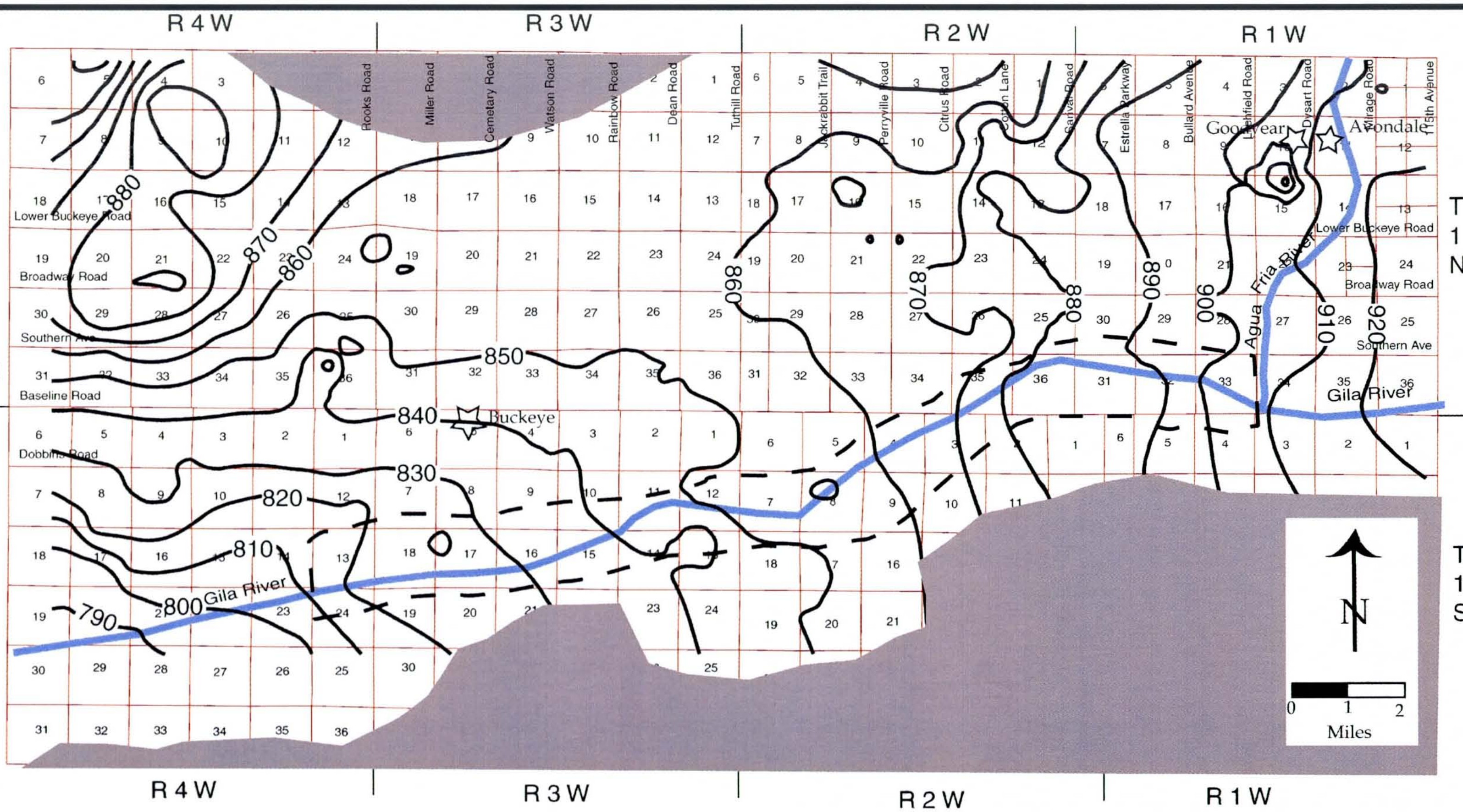
Groundwater elevation data within the study area are available from ADWR (Appendix C). These data, along with additional measurements collected by the BWCDD and Stantec Consulting, Inc, were used to compile a contour map of the water table elevations (Figures 6 and 7). These maps were used to evaluate the reasonableness of groundwater elevations calculated by the El Rio model.

The first map was compiled using data spanning three years to ensure adequate aerial coverage. Although in some areas this might lead to significant error, in the El Rio area, wells with continuous annual measurement exhibited less than half a contour interval (5 feet) of change during this period. Areas with anomalously high or low outlying points were reexamined to assess whether or not they were representative of static groundwater conditions in the area. Those that appeared to be either measurements in pumping wells or older measurements that fell outside the envelope of accuracy required for compilation of an accurate map were discarded.

In addition, during the fall and winter of 2002 and the spring of 2003 the ADWR compiled a new suite of water level measurements throughout the El Rio area. This time frame allowed for data to be collected during a period of reduced agricultural pumping. These measurements provided the data necessary to construct a more current water table contour map (Figure 7).

The contour maps show that in the El Rio area, groundwater flow is toward the southwest at an average gradient of approximately 6 feet per mile, generally following the Gila River. Depths to water average less than 10 to 20 feet in most portions of the study area (Figure 8). These water levels have not fluctuated dramatically, at points near the river, over the last ten years.

Based upon Figures 6 and 7, groundwater flows into the area along both the eastern and northwestern boundaries, reflecting recharge from the Agua Fria and Salt Rivers on the east and the Hassayampa system to the west. As flow approaches the narrows at Gillespie dam, the narrows reduces the area through which this volume of water flows. As a result, the groundwater



— 920 — Groundwater Elevation Contour (feet above mean sea level) (Contour Interval: 10 feet)

El Rio Corridor

Bedrock

River

EL RIO

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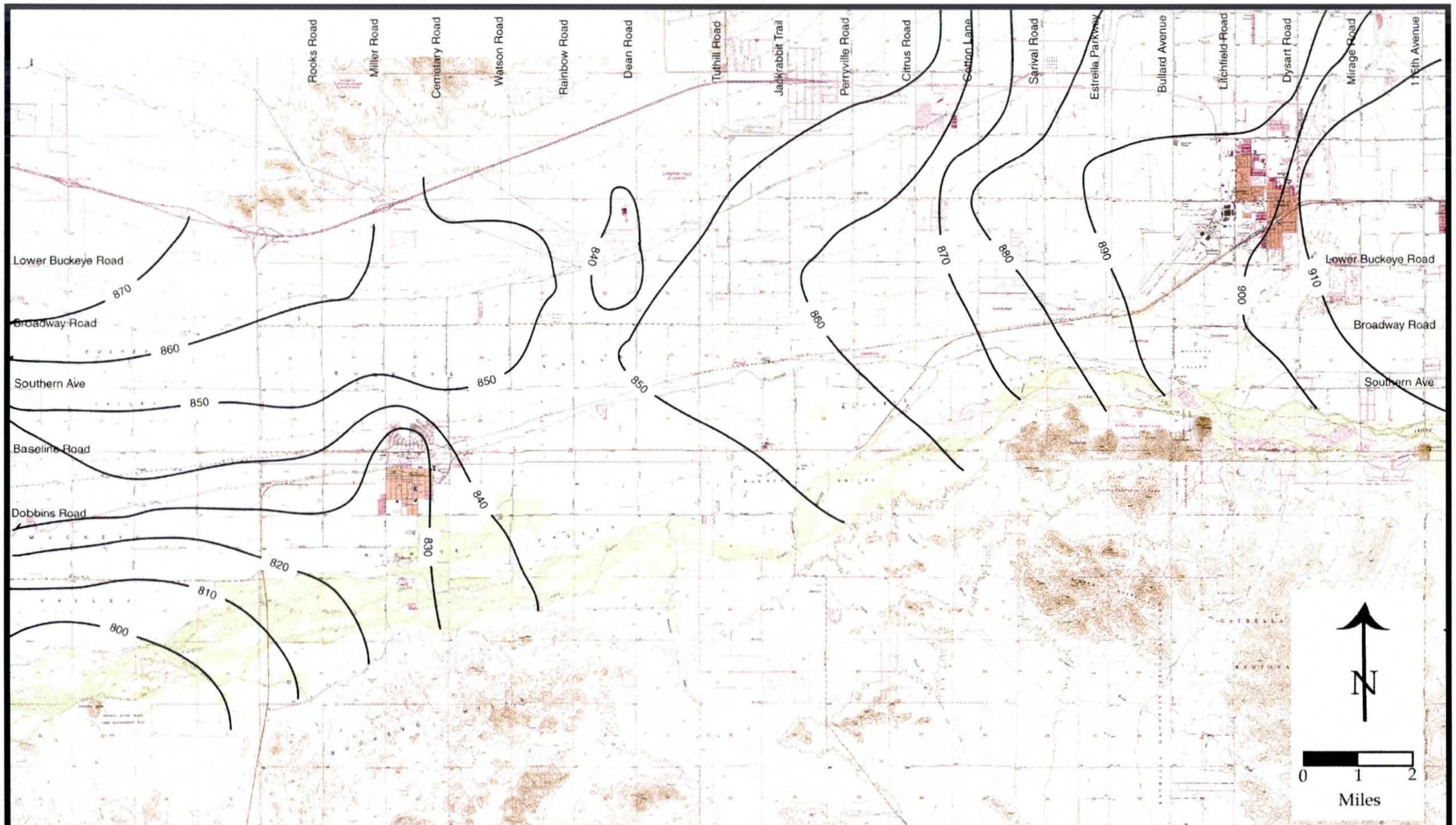
Groundwater Elevations Using Data Collected by ADWR 1998 - 2000

DRAWN	DATE	DWG. NO.	REV. NO.
LPO	16 March 03	Figure 6	
SCALE 1:160,000	W.O. NO.		



- 800 — Groundwater Elevation Contour (feet above mean sea level) (Contour Interval: 10 feet)

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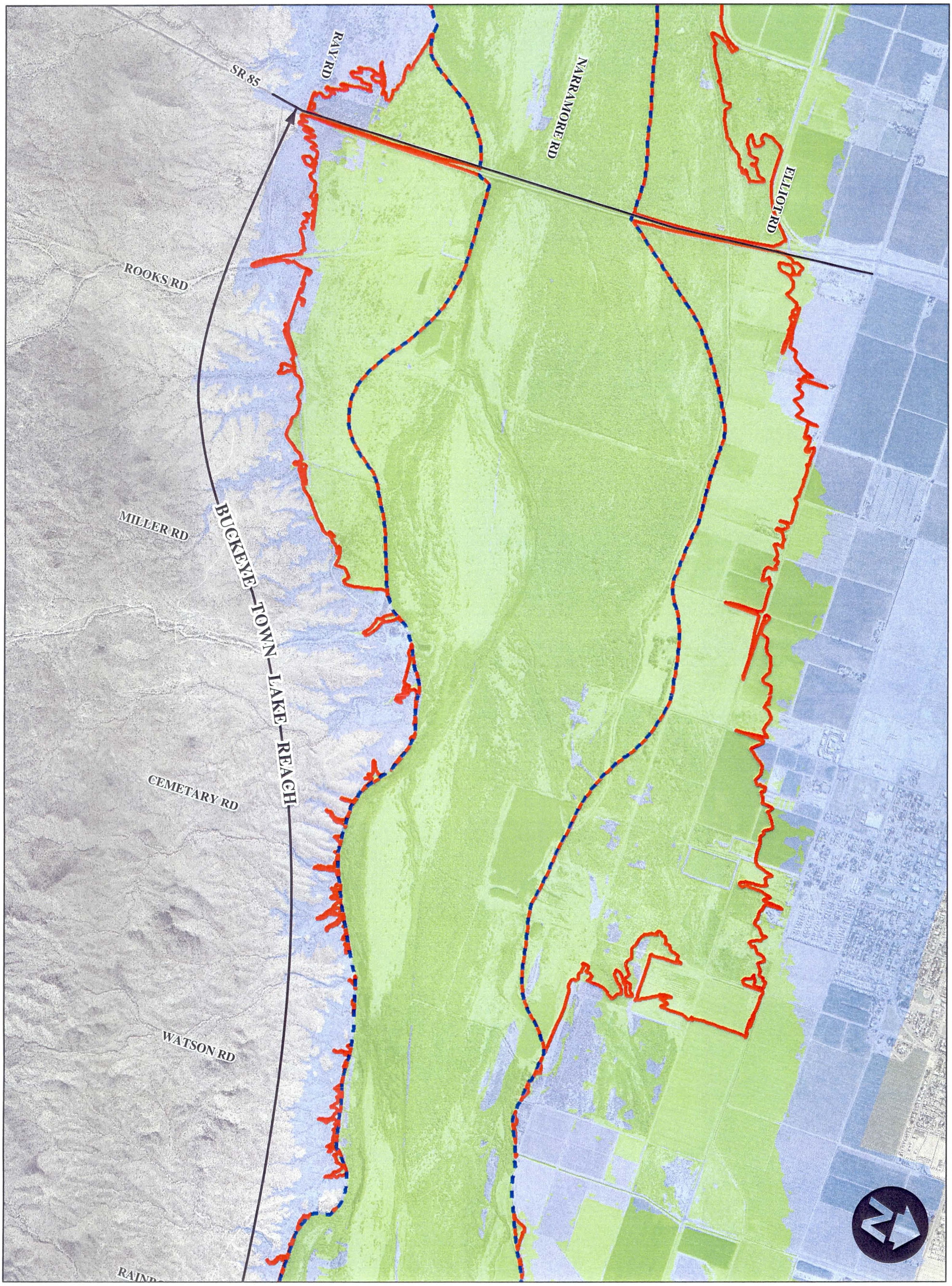
Groundwater Elevations 2002 - 2003

(from ADWR measurements)

DRAWN	DATE	DWG. NO.	REV. NO.
LPO	13 Nov. 05	Figure 7	
SCALE 1:160,000	W.O. NO.		



Flood Control District
of Maricopa County
2801 W. Durango St.
Phoenix, AZ 85009

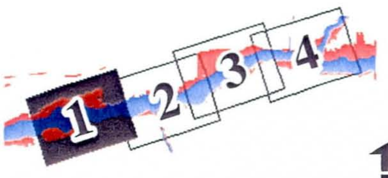
Stantec Consulting Inc.
8211 S. 48th St.
Phoenix, AZ 85044

100-Year Flood Zones

- Floodway
- Zone AE
- Zone A
- Zone AH

Depth to Groundwater

- < 3m
- 3m - 10m



N

EL RIO WATERCOURSE MASTER PLAN

FIGURE 8 - DEPTH TO GROUNDWATER
SHEET 1 OF 4 (BUCKEYE TOWN LAKE REACH)
11 NOV 2005

0 1,000 2,000 4,000
1 Inch = 2000 Feet

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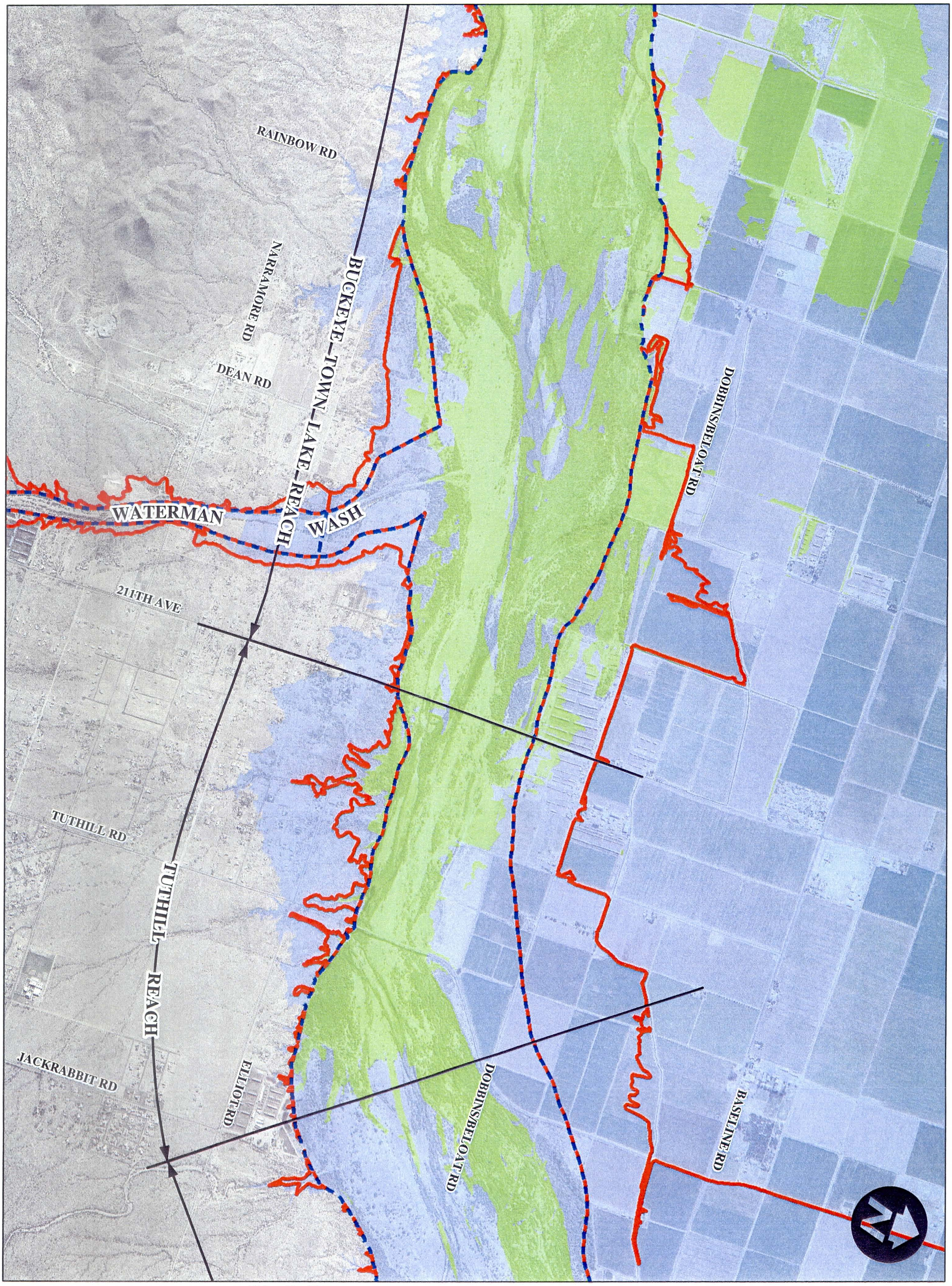

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Phoenix, AZ 85009

Stantec Consulting Inc.
8211 S. 48th St.
Phoenix, AZ 85044

100-Year Flood Zones
- Floodway
- Zone AE
- Zone A
- Zone AH

Depth to Groundwater
- < 3m
- 3m - 10m

1 2 3 4

N

EL RIO WATERCOURSE MASTER PLAN

FIGURE 8 - DEPTH TO GROUNDWATER
SHEET 2 OF 4 (TUTHILL REACH)
11 NOV 2005

0 1,000 2,000 4,000
1 Inch = 2000 Feet

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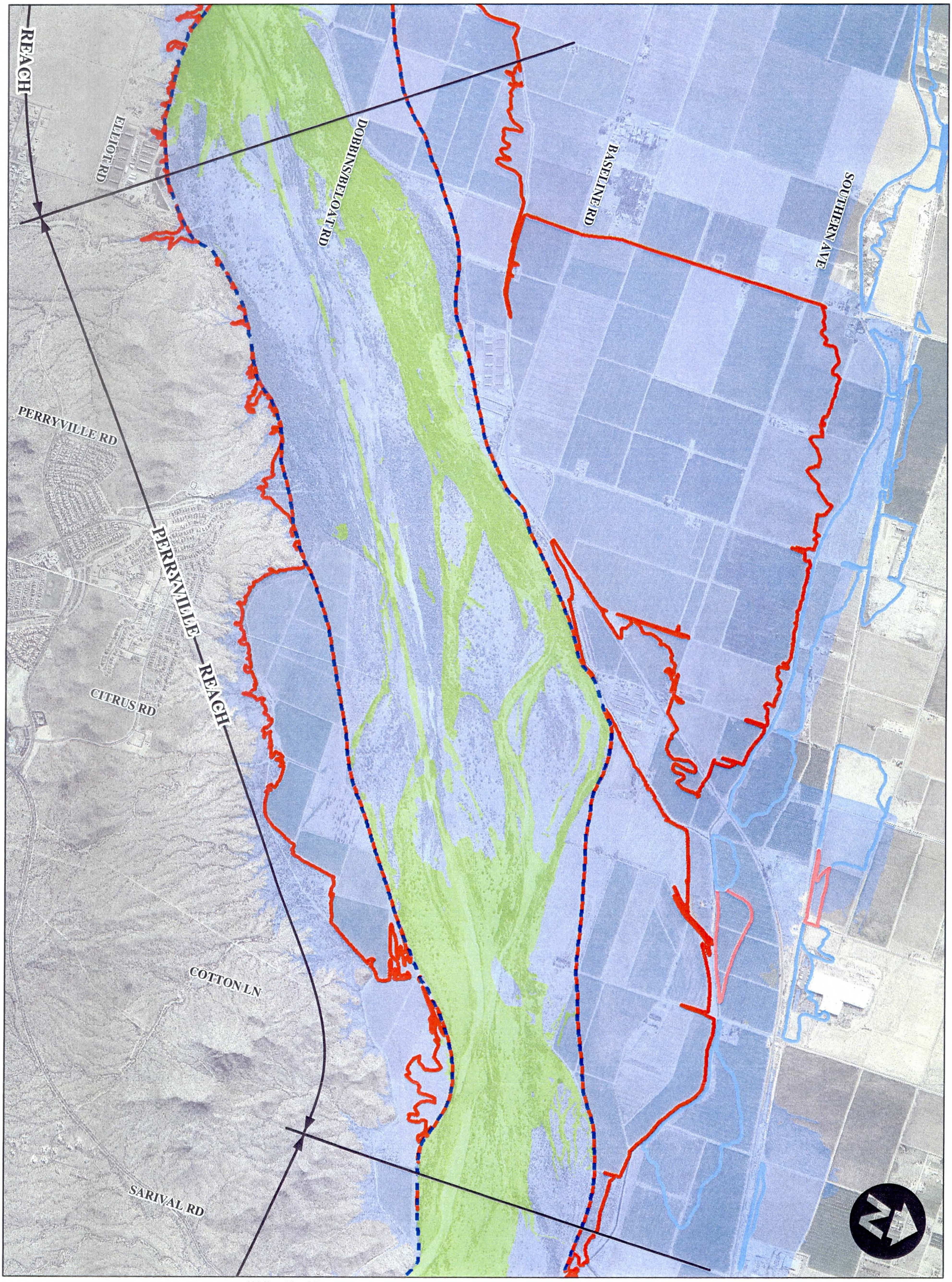

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of Maricopa County
2801 W. Durango St.
Phoenix, AZ 85009

Stantec Consulting Inc.
8211 S. 48th St.
Phoenix, AZ 85044

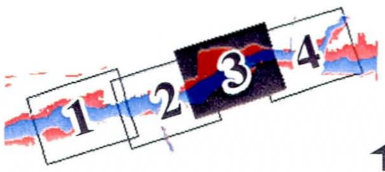
Stantec

100-Year Flood Zones

- Floodway
- Zone AE
- Zone A
- Zone AH

Depth to Groundwater

- < 3m
- 3m - 10m



N

EL RIO

EL RIO WATERCOURSE MASTER PLAN

FIGURE 8 - DEPTH TO GROUNDWATER
SHEET 3 OF 4 (PERRYVILLE REACH)
11 NOV 2005

0 1,000 2,000 4,000

1 Inch = 2000 Feet

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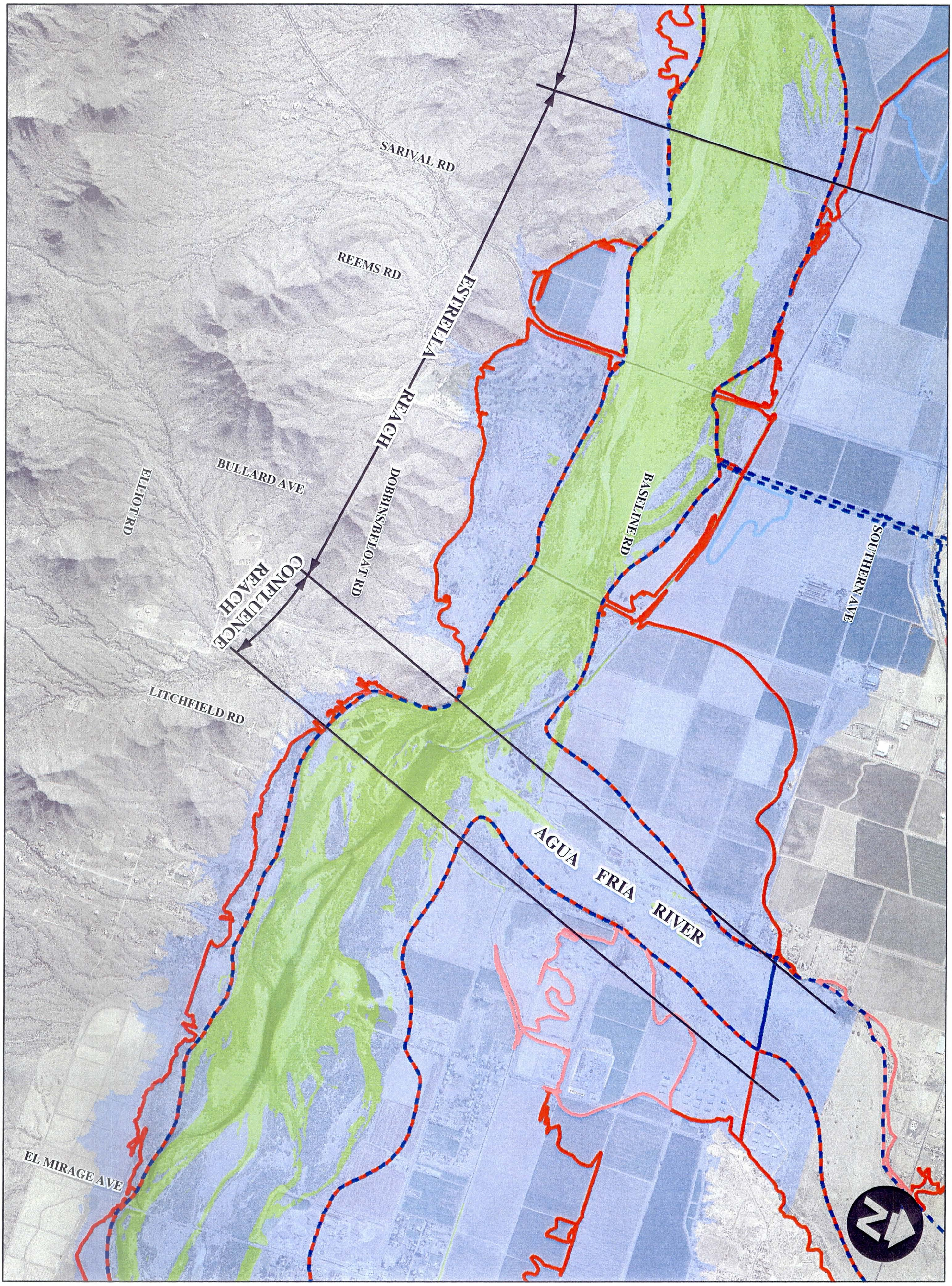

Flood Control District of Maricopa County
2801 W. Durango St.
Phoenix, AZ 85009

Stantec Consulting Inc.
8211 S. 48th St.
Phoenix, AZ 85044

Stantec

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EL RIO WATERCOURSE MASTER PLAN

FIGURE 8 - DEPTH TO GROUNDWATER
SHEET 4 OF 4 (ESTRELLA REACH)
11 NOV 2005

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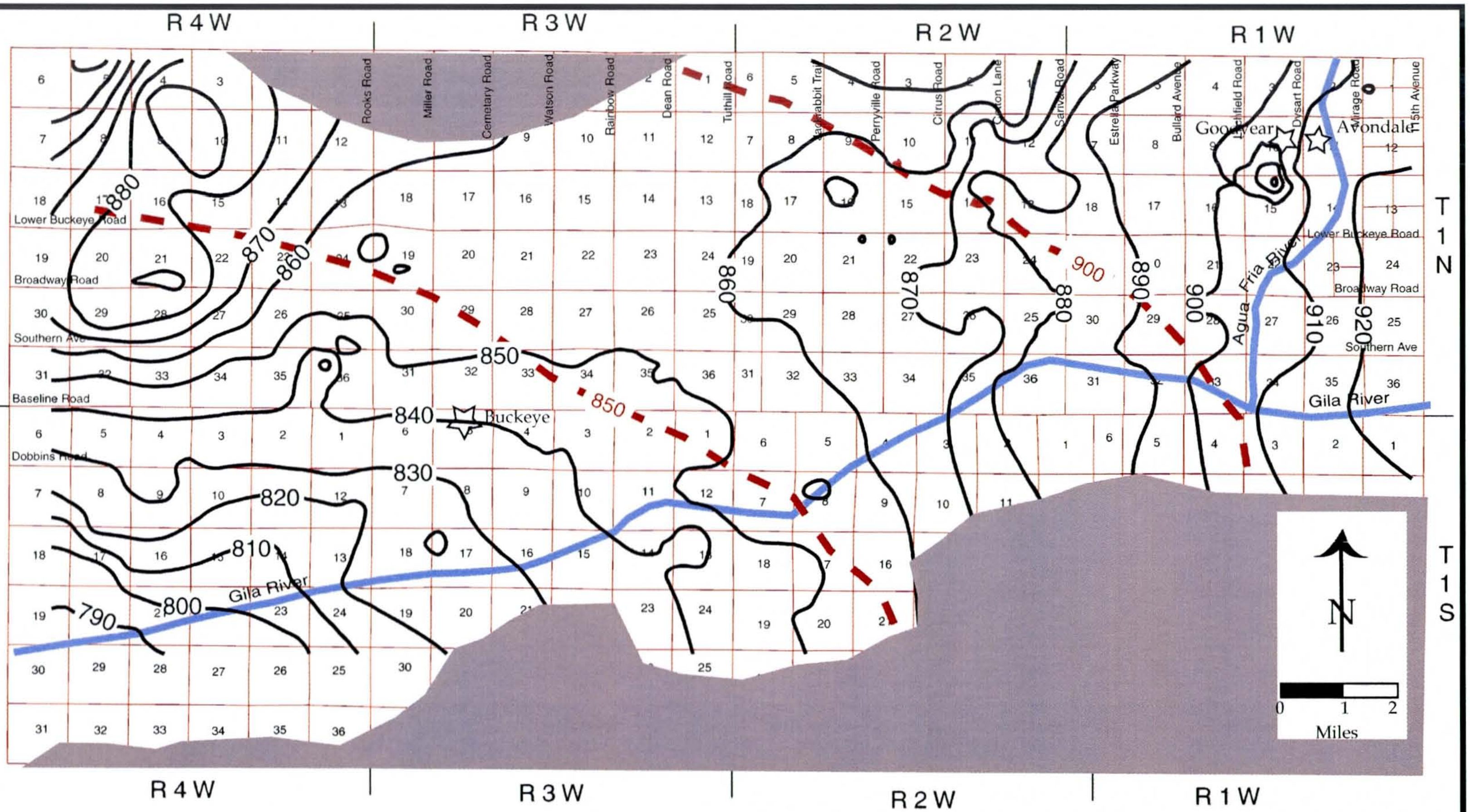
system builds the elevation head needed to push large quantities of water through the only natural drain on the system. This increase in head is reflected in the smaller spacing between water table contours along the western portion of the study area when compared to contour spacing on the eastern boundary.

Predevelopment Groundwater Elevations

In many parts of the Gila River system groundwater levels have declined over time. Aquifers that had historically been in hydraulic connection with the river have dropped to levels where no interconnection with the river system exists. Although this is not the case in the El Rio area, the impact of historic groundwater development was deemed useful in assessing the potential for future impacts as the area's groundwater use increases. In 1986, Freethey and Anderson examined the predevelopment hydrologic conditions in this area and produced a map series showing groundwater elevations extrapolated from the few wells available. Groundwater elevation contours taken from their maps are shown in Figure 9. Although water levels away from the river have declined over time, in the El Rio planning area no change appears evident. This is not meant to indicate that no change has occurred over the intervening time period; but rather that water levels in the area appear to fluctuate around some median level. As stated earlier, that level is the result of the geologic controls on both surface and groundwater flows in the area. Although the lack of significant change in a 100-year period is worthy of note, it is important to recognize that fluctuations in these water levels have occurred within that time period in response to droughts.

Historic Drought Conditions

The USGS and others have measured fluctuations in precipitation over time for decades. In addition to quantifying the volume, spatial and temporal variability of precipitation, various researchers have correlated these data with changes in river flow. Very often, however, the results generated by this research were limited by the availability of data for a particular area. As an example, if a long period of below average precipitation was followed by a corresponding period of above average precipitation, unless the data set spanned more than one cycle, only the trend could be attested to, not the cycle. Although a somewhat oversimplification, in terms of



— 920 — Groundwater Elevation Contour
(Contour Interval: 10 feet)

920 Predevelopment Groundwater Elevation Contour
(Contour Interval: 50 feet)
(from Freethy and Anderson, 1986)

Bedrock

River

(elevations in feet above mean sea level)

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Comparison of Predevelopment and 2000 Groundwater Elevations

DRAWN	DATE	DWG. NO.	REV. NO.
LPO	16 March 03	Figure 9	
SCALE	W.O. NO.		

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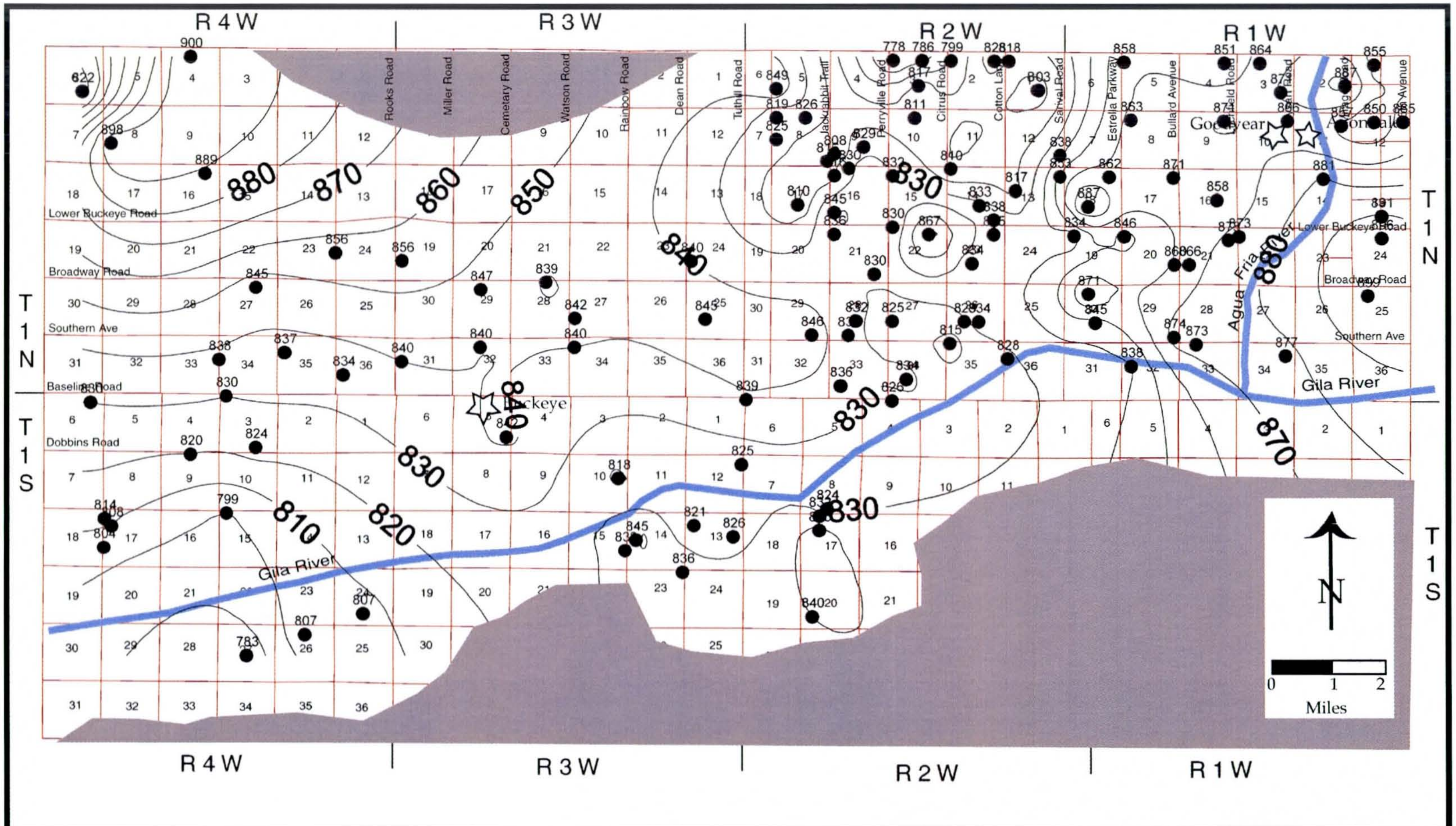
surface water, statistical calculations must be used to estimate the volume of a 100-year storm until 100-years worth of data is collected. What was needed was a method of extending the period of record further back in time to periods when data aren't available.

In the mid-1970s, researchers recognized that tree rings not only filled the temporal data gap, but allowed spatial examination of water availability as well. Simply put, during periods of low water availability, plant growth is stunted and trees, which produce annual growth rings, exhibit a narrower ring pattern indicating restricted flow of water to the leaves and reduced evapotranspiration. During periods of high water availability the reverse is true and tree rings are wider. Because some tree species in the semiarid southwest react dramatically to the availability of water and have long lives, the precipitation record could be extended into the unrecorded past through close examination of the tree growth pattern.

Recent paleoclimatic research, based in part on tree ring data, indicates that Arizona has experienced regular drought cycles over the past hundred years or more. These cycles appear to be sixty years in length, i.e. thirty years of above average rainfall followed by thirty years of below normal rainfall. If this cycle persists, a period of above average rainfall has just ended and the next thirty years can be expected to exhibit below normal precipitation patterns. If this is true, the water table contours and corresponding depths to water that are evident in the El Rio area today may not be present in the future when the District is attempting to implement the El Rio program.

The ADWR water level files provided the data necessary to examine the impact of the drought on El Rio. The last drought period was fully developed around 1965. The USGS has measured groundwater levels in selected wells with some regularity. Periodically they engage in an extensive measurement program involving numerous wells. Such a program was undertaken in 1962 (Appendix C). Based upon these measurements, a second water table contour map was compiled to reflect drought conditions (Figure 10). From this, it can be seen that water levels in much of the El Rio area declined during the drought. The largest change appeared in the eastern portion of the area where water levels declined almost 40 feet. This was in direct contrast,



850	Groundwater Elevation Contour Drought Period 1960 - 1962 (Contour Interval: 10 feet)
807	Measured Groundwater Elevation (Data from USGS)
	Bedrock
	River

(elevations in feet above mean sea level)

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Groundwater Elevations During Drought Period 1960 - 1962

DRAWN	DATE	DWG. NO.	REV. NO.
LPO	16 March 03	Figure 10	
SCALE	W.O. NO.		

hydroLOGIC consultants

however with the western portion of the study area where almost no decline was evident. This variation in drought response reflects the impact of the narrows at Gillespie Dam on local water levels.

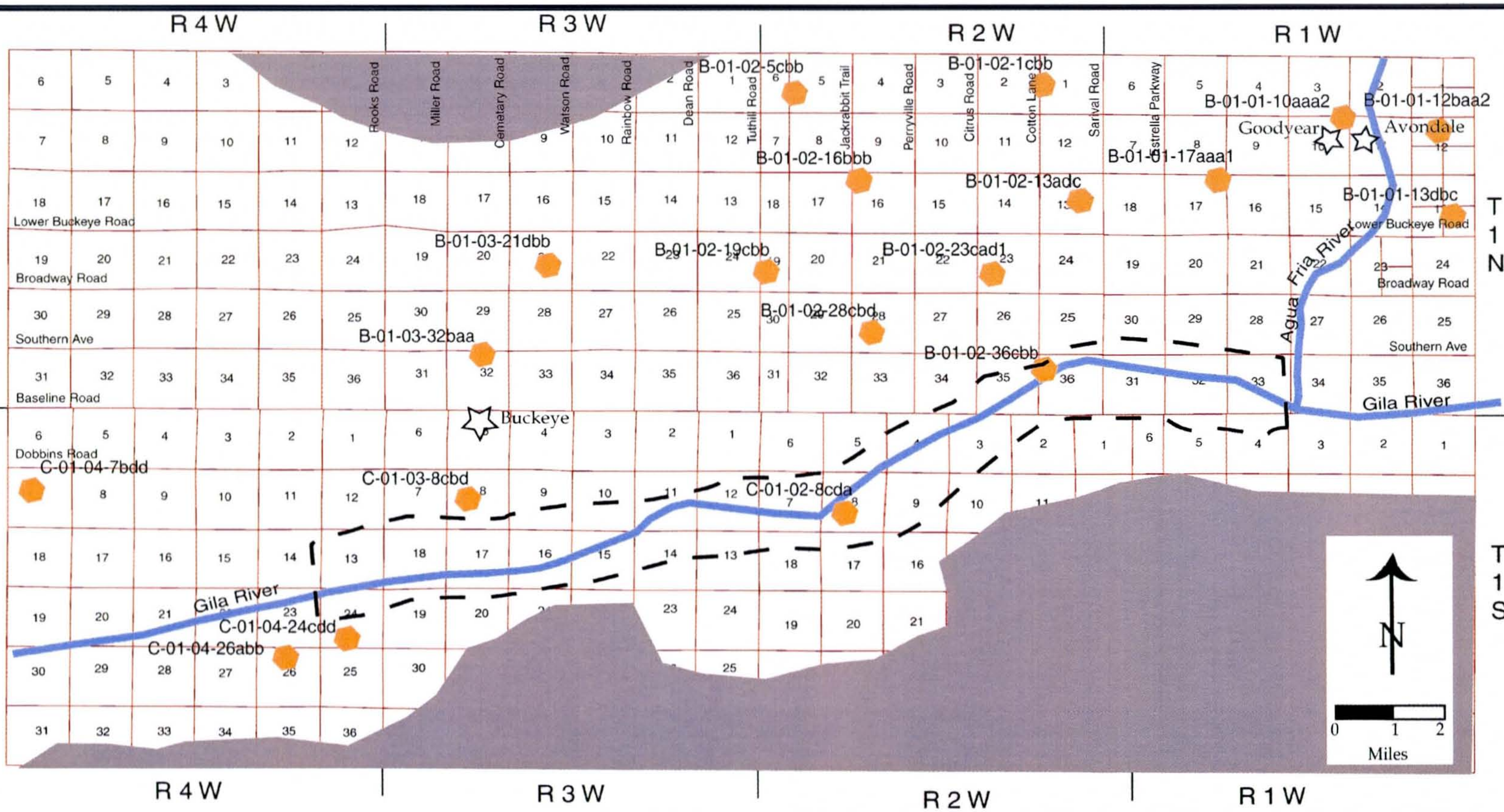
It should be noted, however, that the drought apparently did not peak until about 1965. Although there were insufficient data to create a map for 1965, the few wells that were measured that year in the eastern portion of the study area had water levels nearly twenty feet lower than in 1962.

Water Level Changes with Time

The first water level data for wells in the El Rio area in the ADWR database is from 1928 for the well located at T1N R2S 13adc. Water level measurements for multiple wells weren't available until the mid-1940s. Of the 2,800 wells in the area, approximately 19 wells have water level measurements with more than 20 years of data, some beginning in the mid-1940s and extending through 2001.

The hydrographs for these wells show the response in the groundwater to changes in pumping, to changes in recharge from precipitation, and to changes in culturally modified recharge with time. Five hydrographs that best illustrate changes within the El Rio Project area are included in the text. An additional 14 hydrographs are included in Appendix D. The locations of these hydrographs are show in Figure 11.

The first hydrograph is for well B-01-02-13adc (Figure 12), which is located approximately 3 miles north of the Gila River (Figure 11). Despite its distance from the river, it was selected because it has the earliest data for any well in the area with groundwater level measurements beginning in 1928 and continuing through 1968. The hydrograph shows a relatively stable water table (910 feet msl) until the mid-1940s when extensive pumping begins in the area. Water levels decline steadily until the late 1960s and the last measurement from 1968 shows water levels beginning to recover from the effects of the drought. Although data aren't available after 1968, water levels from other wells in the area show that water levels have recovered to approximately 890 feet amsl in the area of the well.



C-01-03-8cbd Hydrograph Location with Casastral Location Number

El Rio Corridor

Bedrock

River

EL RIO

hydroLOGIC consultants

Locations of Selected Hydrographs

DRAWN	DATE	DWG. NO.	REV. NO.
LPO	16 March 03	Figure 11	
SCALE 1:160,000	W.O. NO.		

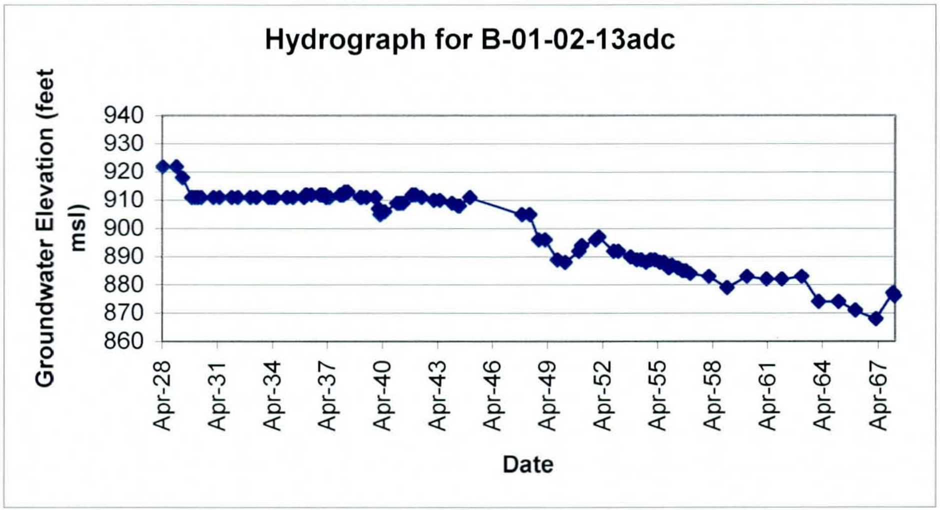


Figure 12. Hydrograph for B-01-02-13adc

The second hydrograph is for well B-01-02-36bbc (Figure 13), south of B-01-02-13adc along the river (Figure 11). Although the water level measurements in this well don't begin until 1951, the hydrograph does show the groundwater response to the drought in the 1960s, and the recovery and stabilization in water levels from the 1980s through 2000. Water levels appear to decline 15 feet beginning in 2000.

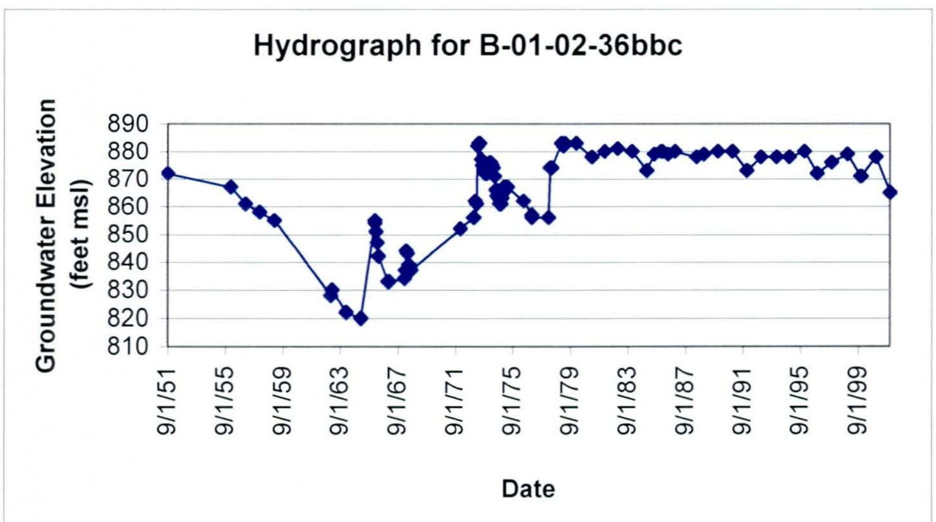


Figure 13. Hydrograph for B-01-02-36bbc

The third hydrograph is for well C-01-02-8cda (Figure 14), which is located approximately 4 miles west of the previous hydrograph along the Gila River (Figure 11). Water level measurements began in 1956 and the hydrograph shows the effect of the drought in the early 1960s on groundwater, and shows the recovery in the 1980s and 1990s. Although a water level decline is shown in the late 1990s and 2000, the decline is less than for the last well, 5 feet.

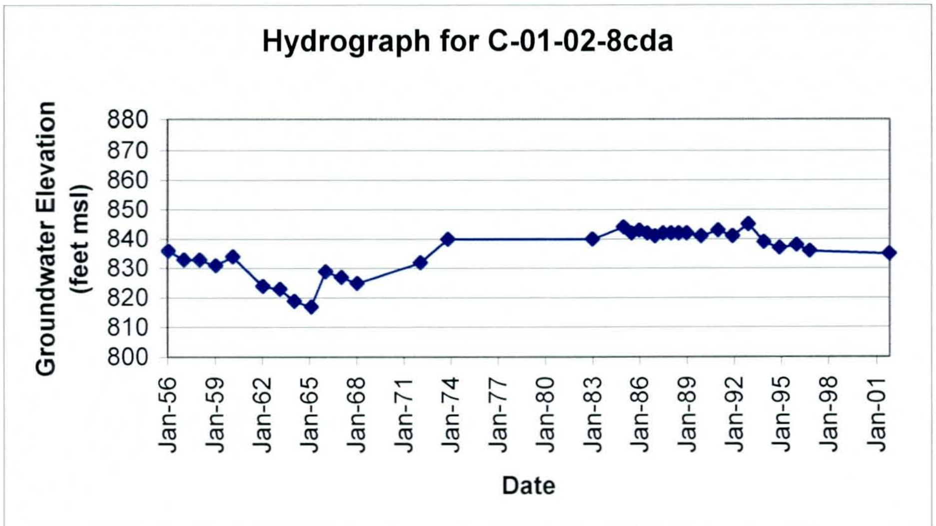


Figure 14. Hydrograph for C-01-02-8cda

The fourth hydrograph (Figure 15) is located in the western portion of the El Rio Project area, approximately 9 miles west of the previous hydrograph location (Figure 11). The well is approximately 1 mile south of the river. The hydrograph shows that water levels in this well have remained stable since 1982 when the first measurement was collected. There doesn't appear to be a response to the drought conditions that began in the mid-1990s. Although this hydrograph doesn't show the groundwater response in this area to the drought in the mid-1960s, the hydrograph for C-01-04-24cdd (Figure 16), which is 0.5 miles from the fourth hydrograph, does have data from the 1950s through 1978.

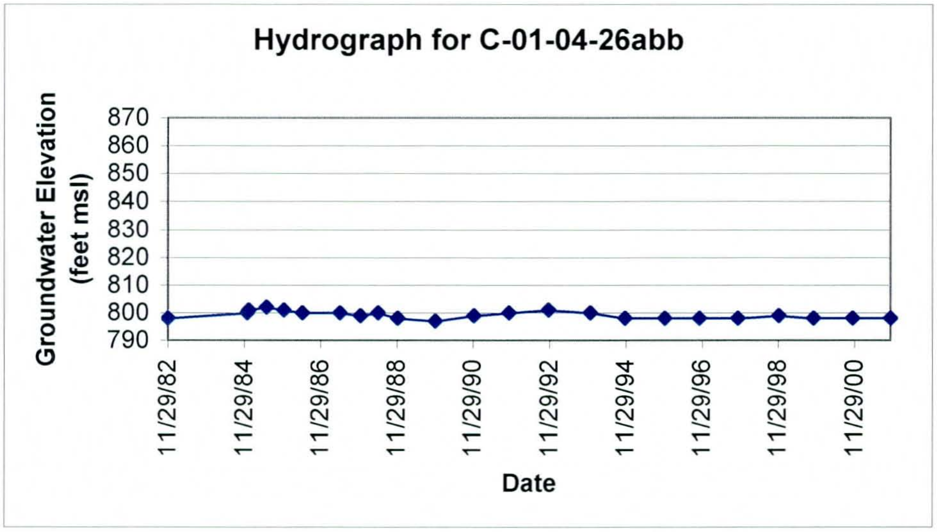


Figure 15. Hydrograph for C-01-04-26abb

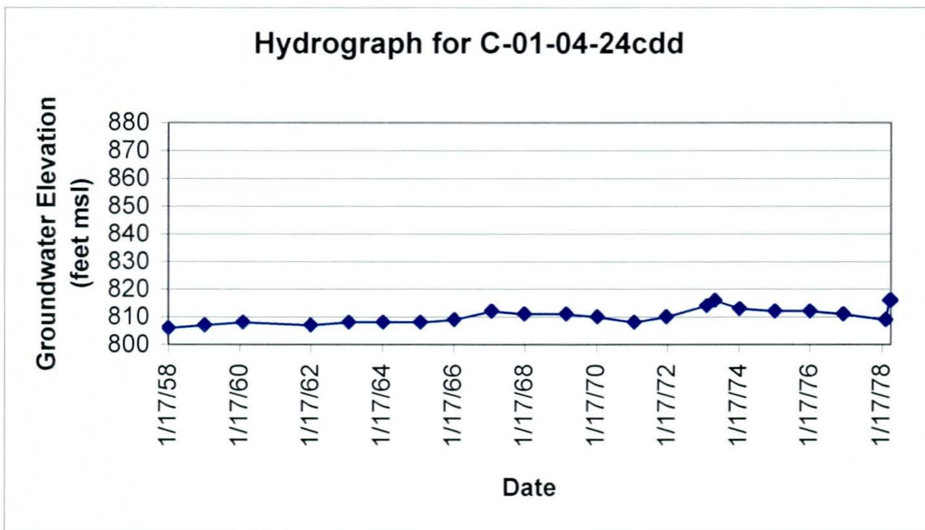


Figure 16. Hydrograph for C-01-04-24cdd

C-01-04-24cdd is located adjacent to the river approximately 0.5 miles east of the fourth well. Groundwater in this area, closest to the western edge of the El Rio Project area, shows no decrease in water levels during the drought in the mid-1960s and no response to pumping during the 1950s.

WATER BUDGET

The volume of water available in the El Rio project area depends on the water budget for the area. Figure 17 shows a conceptual water budget for the El Rio area. The water budget is defined as water held in storage within the aquifer, and the changes in that storage with time as water flows into the aquifer and out of the aquifer.

The inflows to the aquifer include recharge from the Gila River, from canals in the area, from infiltration of precipitation, from WWTP discharges, from applied irrigation, and from run-off from mountains bordering the area. Inflow also occurs in the groundwater system across the eastern and western project boundaries since these boundaries do not coincide with an impermeable boundary.

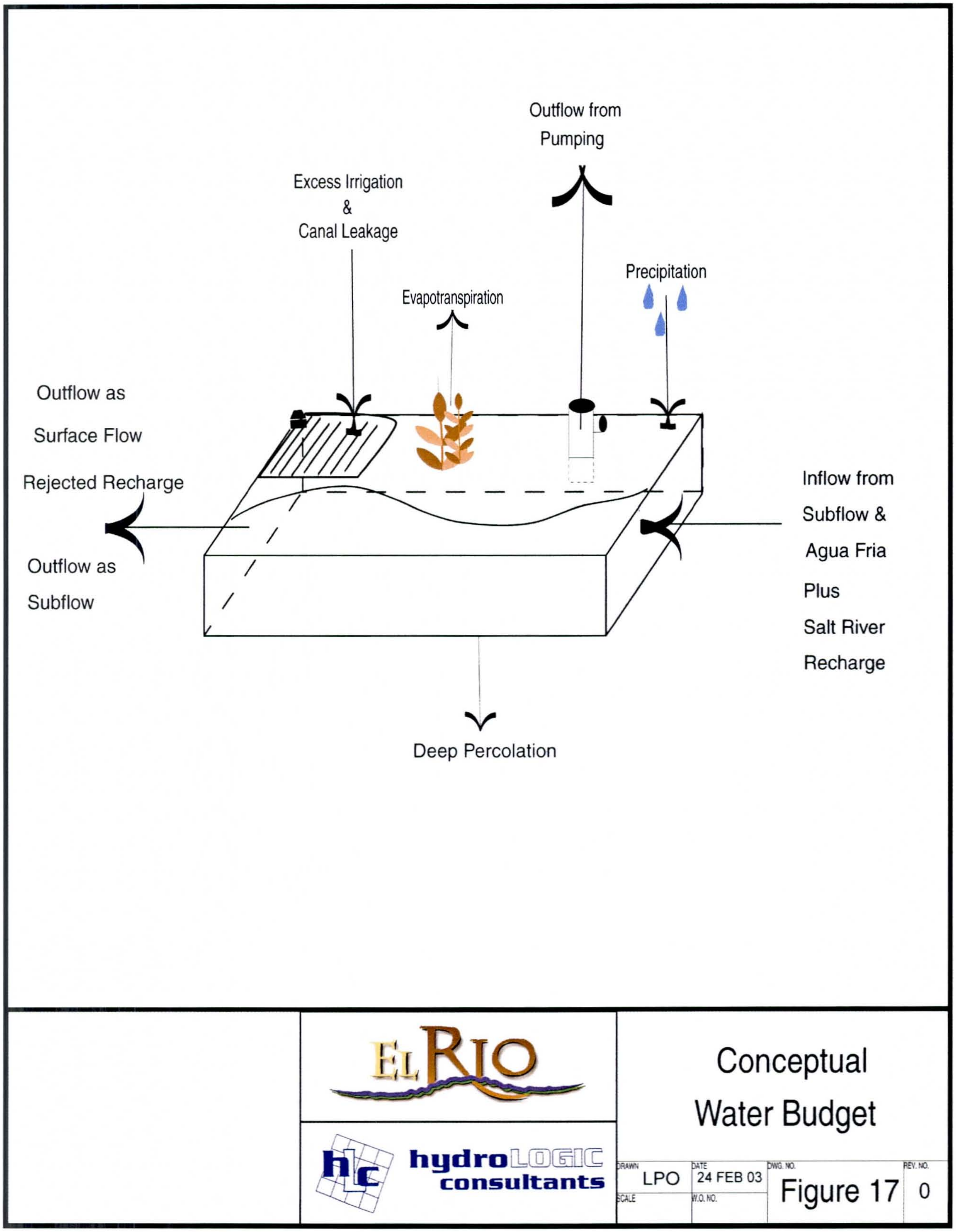
Outflows from the aquifer include pumping, discharge from the groundwater system to the Gila River, evaporation from water surfaces directly in contact with the groundwater (gravel pits) and transpiration by plants. Outflow also occurs along portions of the eastern, northern and western boundaries of the project area.

Inflows

Irrigation Company Canal Recharge

The ADWR estimated the recharge from canals, both lined and unlined, in the El Rio area as part of the work performed in developing the SRV Model. Although their calculations represented the *Maximum Potential Recharge* that might be expected from these sources, the volumes derived serve to indicate a source of recharge that may be lost as the area urbanizes.

Present day canal systems convey a combination of groundwater and surface water from the Salt River (when available) from the eastern portion of the valley to agricultural users in the west. Over time, these canal systems have evolved from simple earthen ditches to concrete lined waterways conveying thousands of acre-feet of water annually. The canals constitute a source of


Outflow from
Pumping
Excess Irrigation
&
Canal Leakage
Evapotranspiration
Precipitation
Outflow as
Surface Flow
Rejected Recharge
Outflow as
Subflow
Inflow from
Subflow &
Agua Fria
Plus
Salt River
Recharge
Deep Percolation
EL RIO
hydroLOGIC consultants
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recharge to the local aquifer system. Unlined (earthen) canals, contribute substantially more water to the aquifer than lined channels. Concrete lining, however, does not entirely eliminate seepage from these systems.

The infiltration rates for the canals and laterals within the area were taken directly from the SRV model (Corkhill, et. al., 1993). The rates were developed by the SRP and the Bureau of Reclamation for lined and unlined canals. According to SRP, the rate for unlined canals and major laterals ranged from 0.52 (cubic feet per square feet per day (ft^3/ft^2/day) in 1977 to 0.25 ft^3/ft^2/day in 1988. The decrease in rate was a result of the gradual lining of the canals. The Bureau of Reclamation estimated that infiltration rates for lined canals ranged from 0.05 ft^3/ft^2/day to 0.24 ft^3/ft^2/day (Bureau of Reclamation, 1976).

BWCDD

The ADWR estimated the maximum potential recharge from the unlined BWCDD canals using canal-specific infiltration rates from tests conducted by the Desert Agricultural and Technology Systems, Inc. (DATS) in 1987. These tests were conducted along various reaches of the canal system. The annual volume of recharge was estimated at approximately 32,000 acre-feet per year, assuming the infiltration rates are constant through time.

The seepage rates for the BWCDD Main and South Extension canals ranged from 0.2 - 3.3 cubic feet per second per mile (DATS, 1987). Recharge from the main canal was estimated at approximately 29,600 acre-feet/year (AF/Year) and the south extension at 2,800 AF/Year.

The estimated annual recharge per section was calculated by multiplying the calculated seepage rate by the length of canal within each section. The BWCDD canals were assumed to be full 11 months of the year. Seepage rates were assumed constant downstream to the next infiltration test location. The recharge volume per section was assumed constant throughout the entire study period.

Roosevelt Irrigation District

The maximum potential recharge from the Roosevelt Irrigation District (RID) canals was estimated using two separate methodologies. Volumetric flow measurements conducted in 1977 (Beck and Associates, 1984) were used to estimate recharge from 1978 through 1985. From 1986 to 1988, recharge was estimated by determining the canal's wetted area per section and multiplying by a representative infiltration rate. This second methodology was used since the main canal was relined in 1986 (RID, 1989). The volumetric flow measurements estimated recharge at approximately 18,900 AF/Year and the wetted area measurements estimated recharge at 1,900 AF/Year.

Agricultural Recharge

In much of the El Rio area, irrigated agriculture remains the dominant land use. Fields are irrigated using sprinklers, rows, flood and furrow application; and excess irrigation water historically applied to these fields characteristically reached the local water table as recharge. The volume of water that ultimately can be counted as recharge remains to be determined. Long, et. al. (1983) estimated that irrigation efficiency within the area is 60 percent. As a result, 40 percent of the water is available to move beneath the plant root zone to the groundwater.

As agricultural fields are converted to urban uses and more water-efficient irrigation practices decrease the amount of water being applied for irrigation, recharge to the aquifer system is decreasing. Although these changes decrease the volume of return flow reaching the groundwater, irrigated agriculture still provides the main source of recharge within the El Rio area.

None of the agencies in the area have mapped crop type in specific fields. However, one of the more comprehensive attempts to quantify recharge from agricultural fields was provided by the ADWR in Modeling Report No. 8 (Corell and Corkhill, 1994). ADWR examined the volume of water applied to agricultural fields across the valley, subtracted the expected runoff from over-irrigation, computed the crop requirements, and determined the average volume of water available for recharge from each irrigated acre. In most cases, this volume would not be immediately available to the aquifer because of the thickness of the unsaturated zone between the land surface and the groundwater. In the El Rio area, however, shallow water tables result in rapid addition of excess irrigation water to the local aquifer. On average, the estimated volume of water available for recharge from each acre of agricultural field in the area was 2.2 AF annually (Corell and Corkhill, 1994).

Recharge from the Gila River

The Gila River has historically played a major role in recharging the groundwater system in the El Rio area. Prior to the construction of upstream dams on the Salt River, the Gila was perennial in the El Rio area (Lee, 1905). As flows in the river diminished with the construction of upstream reservoirs, the river played an increasingly larger role as a source of recharge.

Although periodic storm events may increase the volume of water in the channel, they normally have little effect on the aquifer. Several attempts have been made to quantify the amount of recharge received by the aquifer during these events. Although water levels in local wells may be observed to rise during periods of high flow, if the year was wet enough to produce flood flows, there was usually sufficient precipitation to reduce the need for heavy irrigation pumping. In addition, with more surface water available for irrigation, agricultural fields may be over irrigated during these periods. This results in increased irrigation return flow to the aquifer. As a result, observed rises in water levels in wells adjacent to the river during flood flows can not be attributed entirely to recharge from the river.

In 1983, Turner prepared a report on incidental and natural recharge in the Phoenix Active Management Area to aid in developing strategies to achieve the management goal of safe yield mandated by law (Turner, 1983). In formulating his conclusions, Turner reviewed flood flow data spanning the period from 1911 to 1978 and reports by other authors analyzing these flood events. His overriding conclusion was "from the standpoint of quantities and the irregularity of occurrence, flood flows do not produce significant annual recharge." Only minor amounts of water were assumed to infiltrate downstream of 91^{st} Avenue due to high groundwater levels.

The underlying conclusion of this past research is that, within the El Rio area, recharge from the Gila River storm flows is highly localized and of little consequence from a volumetric standpoint. Stormflows are important in changing the direction of groundwater movement that may be experienced as a result of sudden rises in the water table. During drought periods, however, when local water levels decline, flow that would have appeared in the channel of the Gila as rejected recharge from upstream systems recharges the local aquifer.

Average Annual Water Budget

The average annual water budget for the El Rio Study area is based on data developed by the ADWR for their Salt River Valley groundwater flow model (Corkhill, et al 1993). The three-dimensional, transient model was developed for regional planning purposes using the U.S. Geological Survey program MODFLOW (McDonald and Harbaugh, 1989). It simulates groundwater flow for 1983 through 2002 in the Upper, Middle and Lower Alluvial Units. The model nodes are a square mile, which means that data within a specific node are averaged over that area. The model simulates recharge from irrigated agriculture, discharge from wells, recharge and discharge from the Gila River, evapotranspiration from riparian vegetation along the Gila River whose roots tap the groundwater and changes in the aquifer storage. The model covers the Phoenix Active Management Area, of which the El Rio Project area is a subset of the western portion of the model. Although the El Rio area was identified in the SRV model as an area of "insufficient data and low model confidence" by ADWR, the model still provides the best source of water budget information for this phase of the project.

The water budget for the UAU in the El Rio Study area is shown in Table 1. The largest inflow into the area, 144,872 AF/year, is from infiltration of agricultural irrigation. Recharge from the Gila River is approximately one-quarter of the agricultural recharge, 30,182 AF/year. Other inflows to the EL Rio area include flow across the eastern boundary (6,261 AF/year), flow across

Table 1. Average Annual Mass Balance for El Rio Study Area
Data from the ADWR Salt River Valley Model

		Inflow to El Rio Study Area (acre feet/year)	Discharge from El Rio Study Area (acre feet/year)
Underflow			
	Northern Boundary	0	5,086
	Eastern Boundary	6,261	0
	Western Boundary	4,429	533
	Southern Boundary	0	0
	Between UAU and MAU	8,168	76,829
Land Surface Recharge		144,872	0
Evapotranspiration		0	31,017
River		30,182	3,187
Pumping Wells		0	81,478
Change in Storage		9,039	4,819
	Total	202,950	202,950

the western boundary (4,429 AF/year) and flow from the MAU to the UAU (8,168 AF/year). The total average annual inflow is 202,950 AF/year.

The largest withdrawal of water from the El Rio Study area is water pumped by irrigation wells (81,478 AF/year), although flow from the UAU to the MAU as a result of pumping in the lower MAU is a close second (76,829 AF/year). Other discharges from the aquifer in the area include evapotranspiration by riparian vegetation (31,017 AF/year), flow to the river (3,187 AF/year) and outflow across the northern boundary (5,086 AF/year) and across the western boundary (533 AF/year).

As expected, the data show a direct connection between the UAU and the MAU with recharge that is not captured by pumping in the UAU moving deeper into the MAU. Some of the existing irrigation wells are screened across the UAU and MAU so that water is withdrawn from both units. As the usage changes from irrigation to municipal, it is likely that the new wells installed to meet the municipal demand will be screened only in the deeper water bearing units to eliminate poorer quality water in the shallow UAU. These data show that it is likely that as pumping from the UAU decreases, the decrease in pumping will be offset by an increase in the flow from the UAU to the MAU. It appears that flow in the river currently meets the evapotranspiration demand. As the area becomes urbanized, recharge from agriculture will decrease and eventually cease altogether.

Water Budget along the Gila River

The average annual water budget provided information regarding groundwater and surface water interaction in the El Rio groundwater study area. This included areas away from the Gila River. This section provides a preliminary water budget for each river mile, as simulated by the ADWR in the SRV model. Because the Gila River course isn't always east to west but may move diagonally across the square mile grid of the SRV model, the River miles do not correspond precisely to the River, but are averages to the square mile model cell that includes part of the

River path. Table 2 shows the inflows and outflows for each model cell in which ADWR simulated River flows. The data are for 1990.

Of the 21 model cells, five show discharge from the groundwater system to the Gila River. The other 16 cells show recharge to the groundwater from the River. Only one cell shows a decrease in water in storage, with the remaining cells showing an increase in storage. Wells are pumping from all but three of the cells. Twelve of the cells have groundwater flow moving from the UAU to the MAU. This general water budget demonstrates the complexity of the hydrologic system within the El Rio area.

REVIEW OF WATER QUALITY CONDITIONS

The groundwater quality in the El Rio area is impacted by both natural conditions and culturally modified activities. Shallow groundwater levels in the area are a result of the constriction in the area through which groundwater in the aquifers beneath the Salt River Valley are discharged. The natural processes that affect the groundwater quality in this area include the concentration of constituents in groundwater as plants remove water during evapotranspiration and by direct evaporation of water from the shallow groundwater surface. The groundwater quality is further impacted by human activities such as the recharge from agricultural irrigation and from the treated effluent discharged by 91st Avenue WWTP to the Salt River. These processes result in an increase in the total dissolved solids and nitrate concentrations.

The ADWR collected water quality samples from groundwater in the El Rio area in 1992 (Hammett and Herther, 1995). The water was analyzed for specific conductance and fluoride. Specific conductance, the ability of a water sample to conduct an electric current, is an indicator of the dissolved-solids concentration of a water sample. The total dissolved-solids (TDS) concentration can be approximated by multiplying the value of specific conductance, in microSiemens per centimeter at 25°C (uS/cm) by the factor 0.6 to obtain milligrams per liter (mg/L) in dissolved solids (Hammett and Herther, 1995).

Table 2: Water Budget Along the Gila River

(Acre-Feet/Year)

River Mile (From Eastern Boundary)	1	2	2	3	4	4	5	6	6	7	8	9	10	10	11	12	13	14	15	15	16
Lateral Inflow to area	298	332	2,005	1,087	1,130	-	665	225	145	874	570	1,076	842	78	376	345	274	304	295	99	188
Lateral Outflow from area	1,632	1,401	899	343	-	658	67	122	364	399	623	428	739	530	814	680	320	315	1,543	188	801
Recharge to Groundwater	52	154	2,656	2,486	3,059	267	207	1,153	213	711	302	85	210	262	157	-	-	-	15	577	336
Evapotranspiration	677	220	-	-	135	187	292	521	1,147	680	619	224	1,617	-	239	799	1,577	1,687	2,137	175	1,054
Inflow from Deeper Unit	-	-	-	-	-	-	-	-	-	-	105	441	-	-	-	-	-	-	-	-	-
Outflow to Deeper Unit	-	-	2,848	1,352	1,827	-	178	648	73	23	-	-	97	-	-	-	-	83	451	155	253
Storage inflow	22	30	48	53	90	20	31	26	23	20	12	25	70	20	20	-	9	37	68	29	52
Storage outflow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	-
Well	5	405	3,894	3,054	2,331	59	12	108	2	8	16	23	14	160	50	10	-	20	-	2	-
River Recharge to Groundwater	1,943	1,510	2,933	1,124	14	618	-	-	1,206	-	269	-	1,344	330	550	1,156	1,613	1,754	3,753	-	1,531
Discharge from Groundwater to River	-	-	-	-	-	-	355	6	-	495	-	951	-	-	-	-	-	-	-	184	-
Total IN	2,315	2,026	7,641	4,749	4,293	905	904	1,404	1,586	1,605	1,258	1,627	2,466	690	1,102	1,501	1,896	2,095	4,132	705	2,107
Total OUT	2,315	2,026	7,641	4,749	4,293	905	904	1,404	1,586	1,605	1,258	1,627	2,466	690	1,102	1,501	1,896	2,095	4,131	705	2,107
SRV Model Grid (Column, Row)	26,38	25,38	25,37	24,37	23,37	23,38	22,38	21,38	21,39	20,39	19,40	18,40	17, 40	17,41	16,41	15,41	14,41	13,41	12,41	12,42	11,42

Data from the ADWR Salt River Valley Model

The data collected by ADWR showed that specific conductance values of samples collected along the present and former course of the Gila River tend to be relatively high, with values generally exceeding 1,500 uS/cm (TDS of 900 mg/L). Near the town of Buckeye, which is in the western portion of the El Rio Project area, values in excess of 5,000 uS/cm are common (TDS of 3,000 mg/L). Specific conductance in the El Rio area ranged from 280 uS/cm (TDS of 168 mg/L) to 7,010 uS/cm (TDS of 4,206 mg/L). Hammett and Herter concluded that, as a rule of thumb for the Phoenix Active Management Area, specific conductance in the groundwater decreases with depth. The Federal government has set a secondary standard of the TDS concentrations in drinking water of 500 mg/L. The secondary standard is set for aesthetics, not health reasons.

Fluoride concentrations in the El Rio area ranged from 0.7 to 5.5 mg/L, with concentrations in many groundwater samples exceeding the Arizona maximum contaminant level for residential drinking water of 4 mg/L (Hammett and Herter, 1995). Fluoride is most commonly found when wells tap groundwater in unweathered bedrock detritus at depth. This is usually encountered near mountain fronts, where shallow bedrock predominates.

Errol L. Montgomery and Associates, Inc. (Montgomery) documented changes in the water logging conditions for the BWCDD in December 2000 (Montgomery and Associates, 2000). Part of the El Rio Project area is located within the BWCDD delivery area. The report compared water quality data for groundwater samples collected in 1984 and 2000 for 13 wells within the BWCDD. In 1984 the groundwater samples had an average TDS content of 3,900 mg/L, as compared to an average concentration of 3,400 mg/L in 2000. The major ions in the water were sodium, chloride and sulfate, and although total concentrations decreased by 13 percent, a decrease in chloride ions of 25 percent was offset by an increase in sulfate ions of 10 percent. Nitrate concentrations in the 13 wells sampled exceeded the MCL for drinking water, 10 mg/L. The conclusion reached by Montgomery was that the water beneath the BWCDD would not be acceptable for public-supply without treatment.

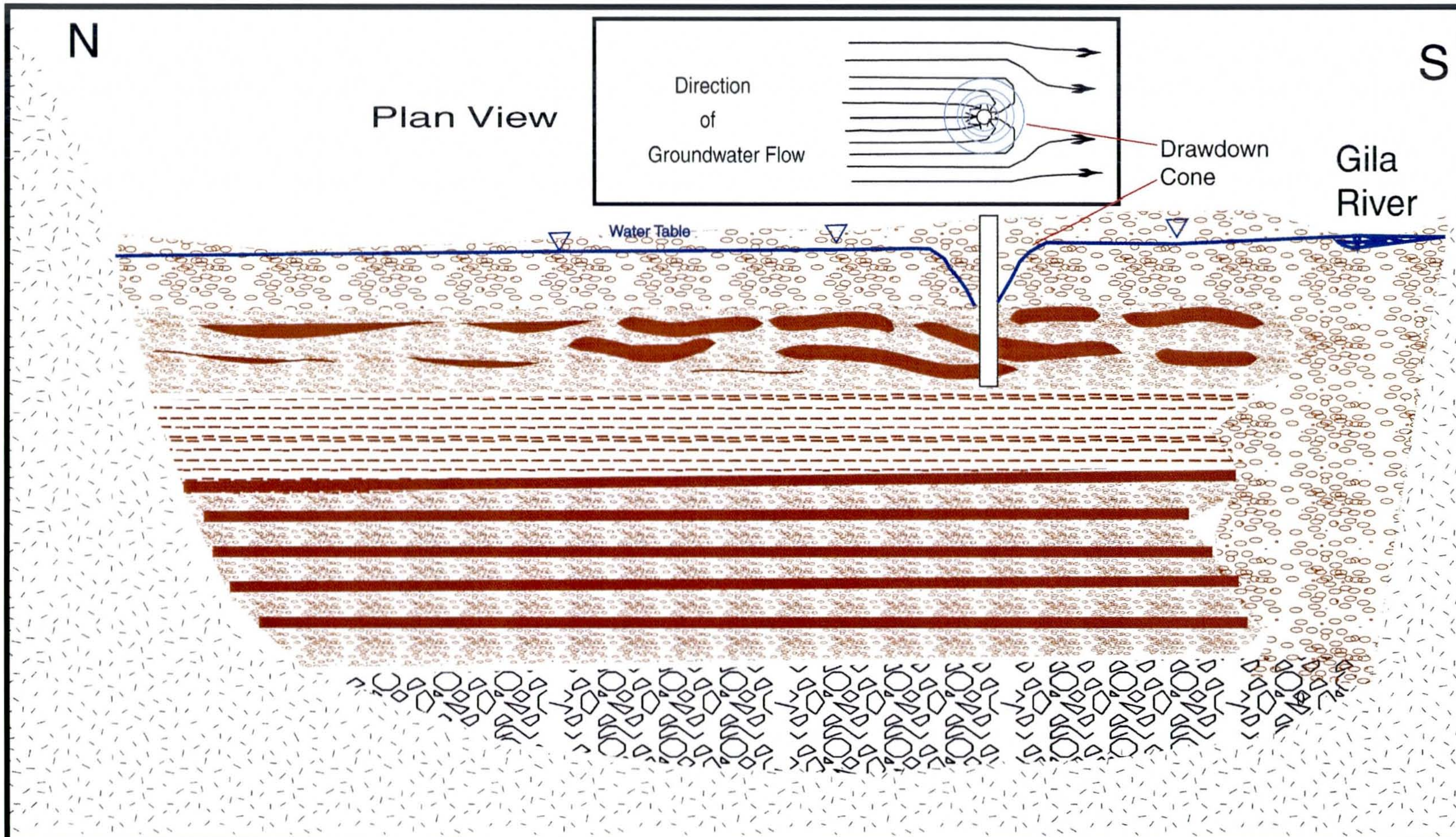
FUTURE CONDITIONS

As the El Rio area continues to urbanize, water use will change and so will the location and design of the wells used. Any of these changes may impact the development of mixed-use projects proposed for El Rio.

Changes in Well Depth

Water use patterns will be modified as agricultural fields are converted to subdivided lots. The ADWR has determined that urban water use is significantly less than agriculture. In general an average acre of irrigated agriculture requires twice the water needed for an average acre of single-family residences. Using this as a guide, the impact of urbanization in the El Rio area should be a rise in water levels as agricultural pumping is reduced. This may not be the case, however, because historic agricultural pumping has been offset by recharge from deep percolation of irrigation water. The ADWR estimated that approximately 40 percent of the water applied to the fields recharges the local aquifer. It would appear, then, that the net water use by agriculture in the area would be offset by deep percolation. This is still not a valid conclusion, however, because much of the irrigation water delivered to the fields is either pumped from wells outside the El Rio area or is treated sewage effluent. With the loss of this imported water, all water use in the area will come from the local aquifer. The major difference that can be expected to result from this change will be the difference in the portions of the aquifer tapped by wells.

Historically most wells pumped water for agricultural irrigation. Because sufficient groundwater was available at shallow depths, these wells were rarely constructed to depths of more than 200 to 300 feet. Almost all completions were in the UAU. Although the quality of this water is adequate for agricultural purposes it does not meet the quality criteria set for public water supplies. As a result, new public supply wells will have to tap the better quality water in the MAU. Because the UAU is an unconfined groundwater system, the drawdown associated with pumping wells describes a deep, narrow cone (Figure 18). The effect of these wells is to intercept recharge water that would otherwise end up as surface flow in the Gila River. Wells tapping the MAU, however, draw water from a confined aquifer separated from the overlying



- Upper Portion of the Upper Alluvial Unit (UAU1)
- Lower Portion of the Upper Alluvial Unit (UAU2)
- Upper Portion of the Middle Alluvial Unit (MAU1)
- Lower Portion of the Middle Alluvial Unit (MAU2)
- Lower Alluvial Unit (LAU)
- Hydrologic Bedrock Unit (Redbeds & Granite)

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Groundwater Flow Pattern from a well Pumping from the UAU

DRAWN	DATE	DWG. NO.	REV. NO.
LPO	16 March 03	Figure 18	
SCALE: Not To Scale	W.O. NO.		

water table system by a thick clay layer. Water levels observed in these wells are a response to changes in pressure and not to changes in water level content in the aquifer. Therefore, as wells in the MAU are pumped, the pressure on the system is reduced and the reduction in pressure is transmitted through the aquifer very rapidly over long distances (Figure 19). The effect of these wells is to draw water directly from the saturated sediments beneath the Gila, however, the velocity of movement would be small and the volume of water withdrawn may not exceed recharge from other upstream sources.

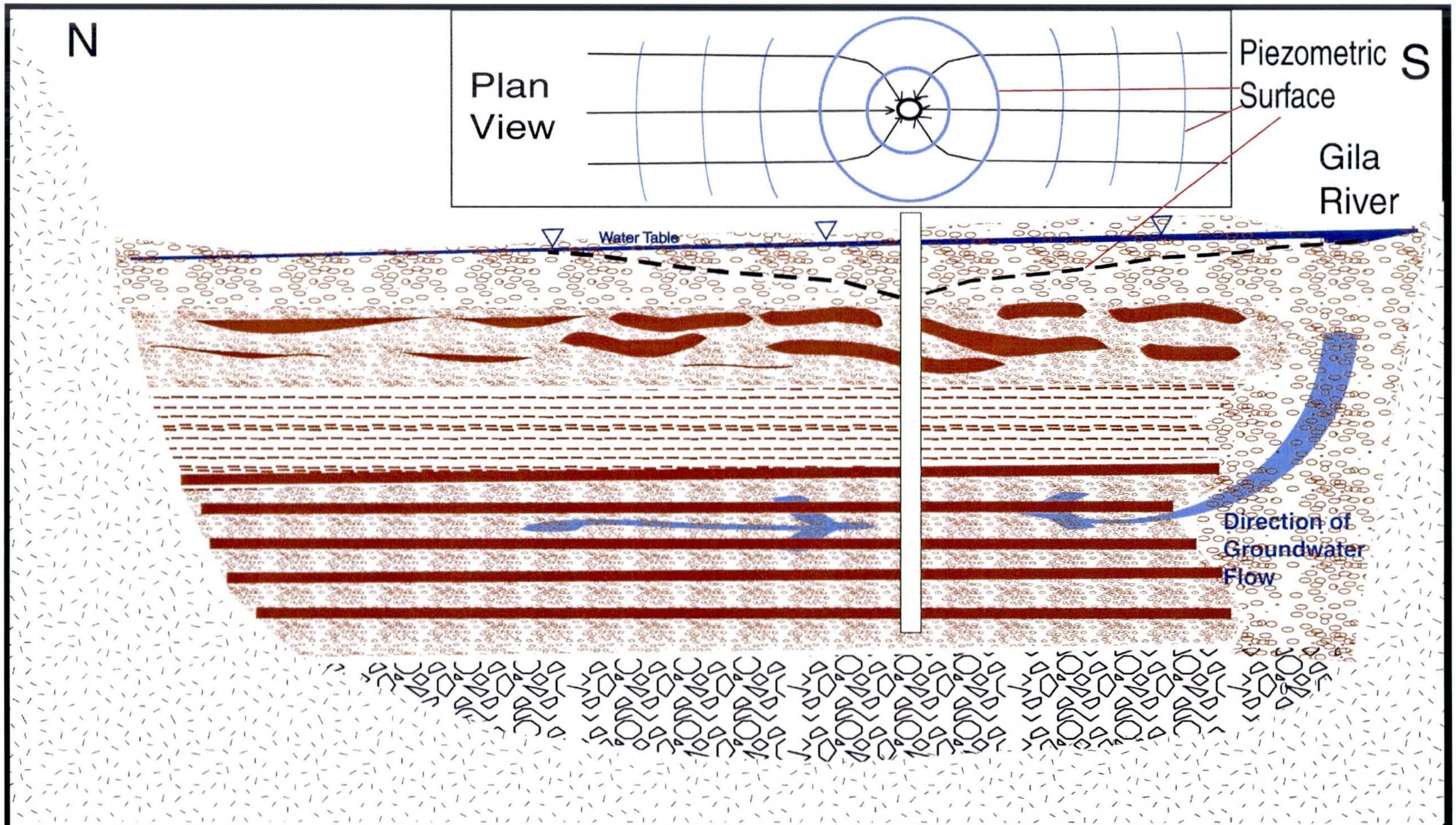
Change in Water Use

Possibly one of the most important changes resulting from urbanization will be that water pumped from the local aquifer to satisfy municipal and subdivision needs will not be returned to the aquifer. Effluent from these sources will be transported to treatment facilities outside the El Rio area and, from there, possibly routed to other uses.

A second modification to the system will result from pumping for planned communities in the Hassayampa area. This pumping will reduce heads in that area, possibly increasing flow from El Rio toward the west. During future drought periods, this could result in decreased water levels in the west end of the study area where none have been observed in the past.

Future Recharge Projects

One change that will definitely help water levels in the El Rio area will be in-channel recharge projects planned for the Salt and Agua Fria Rivers. Channel alluvium is not only highly conductive; but that conductivity is oriented preferentially in a downstream direction. As a result, a large portion of the water entering the stream channel alluvium along the Agua Fria system will, in all likelihood, reemerge as rejected recharge in the El Rio area, sustaining water levels near their current elevation.



- Upper Portion of the Upper Alluvial Unit (UAU1)
- Lower Portion of the Upper Alluvial Unit (UAU2)
- Upper Portion of the Middle Alluvial Unit (MAU1)
- Lower Portion of the Middle Alluvial Unit (MAU2)
- Lower Alluvial Unit (LAU)
- Hydrologic Bedrock Unit (Redbeds & Granite)

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Groundwater Flow Pattern from a Well Pumping from the MAU

DRAWN	DATE	DWG. NO.	REV. NO.
LPO	16 March 03	Figure 19	
SCALE: Not To Scale	W.O. NO.		

EL RIO GROUNDWATER FLOW MODEL

INTRODUCTION

The west Salt River Valley is currently undergoing changes in land use as cultivated land is converted from irrigated agriculture to urban residential. Associated with the land use changes are changes in the use of groundwater in the area. The transient changes will affect groundwater levels in the El Rio project area. A three-dimensional transient groundwater flow model can be used to help evaluate the changes.

Goals and Objectives

The objectives of the El Rio groundwater model are to simulate the groundwater and surface water interaction within the El Rio project area and to evaluate the long-term sustainability of the recommended alternative. Of particular interest are the changes that occur in the hydrology under various flood control alternatives, such as the dredging of a channel, and the changes in baseflow in the river as groundwater use within the adjacent area changes.

The model can be used to identify areas of the project that are most influenced by changes in the regional groundwater and river systems. Of concern is the potential groundwater level rise within the area as the agricultural pumpage ceases and upstream recharge projects come on line or, conversely, the potential for dramatic groundwater level declines as the current drought progresses.

Salt River Valley Model

There are two groundwater flow models that encompass all or part of the El Rio Project area, the ADWR SRV Model (1989) and the Tres Rios Model (2000). The models were designed for specific project objectives taking into account available data. The SRV model, a regional model with 1-mile square grid spacing, includes the entire El Rio area. The coarse grid spacing met the level of accuracy required by ADWR for regional water resource evaluation. The original model simulated flow from 1983 through 1988. It was updated in 2004 to simulate flow through 2002. The model has been used by ADWR as the basis for projections of water use, and by ADEQ and private consultants for site-specific models. Data and model files are public information.

ADWR used the USGS program MODFLOW to simulate groundwater flow in the Salt River Valley. The SRV model was the basis for the El Rio model.

MODFLOW Program

MODFLOW, as distributed by the USGS, is a public domain, three-dimensional, finite-difference program for solving the equations that define groundwater flow. It was designed as a modular program that could be readily updated as new capabilities were required. To solve the mathematical equations, the aquifer is subdivided into rows, columns and layers to describe the horizontal and vertical variations in the aquifer.

MODFLOW is a block-centered program, which means that the blocks or nodes created by the three-dimensional grid are defined at the center of the node. Each parameter can have only one value per node for any period of time; therefore, all aquifer parameters, hydrologic data, and inflows or outflows are averaged for each node. All program calculations, such as drawdown and head, are determined for the center of the node.

Standard MODFLOW packages used in the El Rio model include the Basic, Block Centered Flow, Well, Recharge, Evapotranspiration and Stream. The solution method is the pre-conditioned gradient 2.

MODFLOW does not calculate three-dimensional flow but uses a pseudo-three-dimensional flow scheme in which flow between layers is calculated using a vertical conductance term. MODFLOW cannot allocate pumping in wells that tap multiple layers, and does not reallocate pumping from shallow layers that dewater to deeper, saturated layers. For example, a 150 foot deep well may be screened across two model layers. The total discharge from the well is known, but the percentage of water removed from each layer is not known, so the discharge to each layer has to be allocated manually. If the shallow layer is dewatered early in the model simulation, the pumping from the shallower zone is eliminated, and not reallocated to the deeper layer. This results in less pumping than expected.

Although MODFLOW does have the capability to resaturate a layer that has been dewatered when water levels recover in the aquifer, activating this capability increases the time for a solution to be reached and may also cause the numerical solution to become unstable.

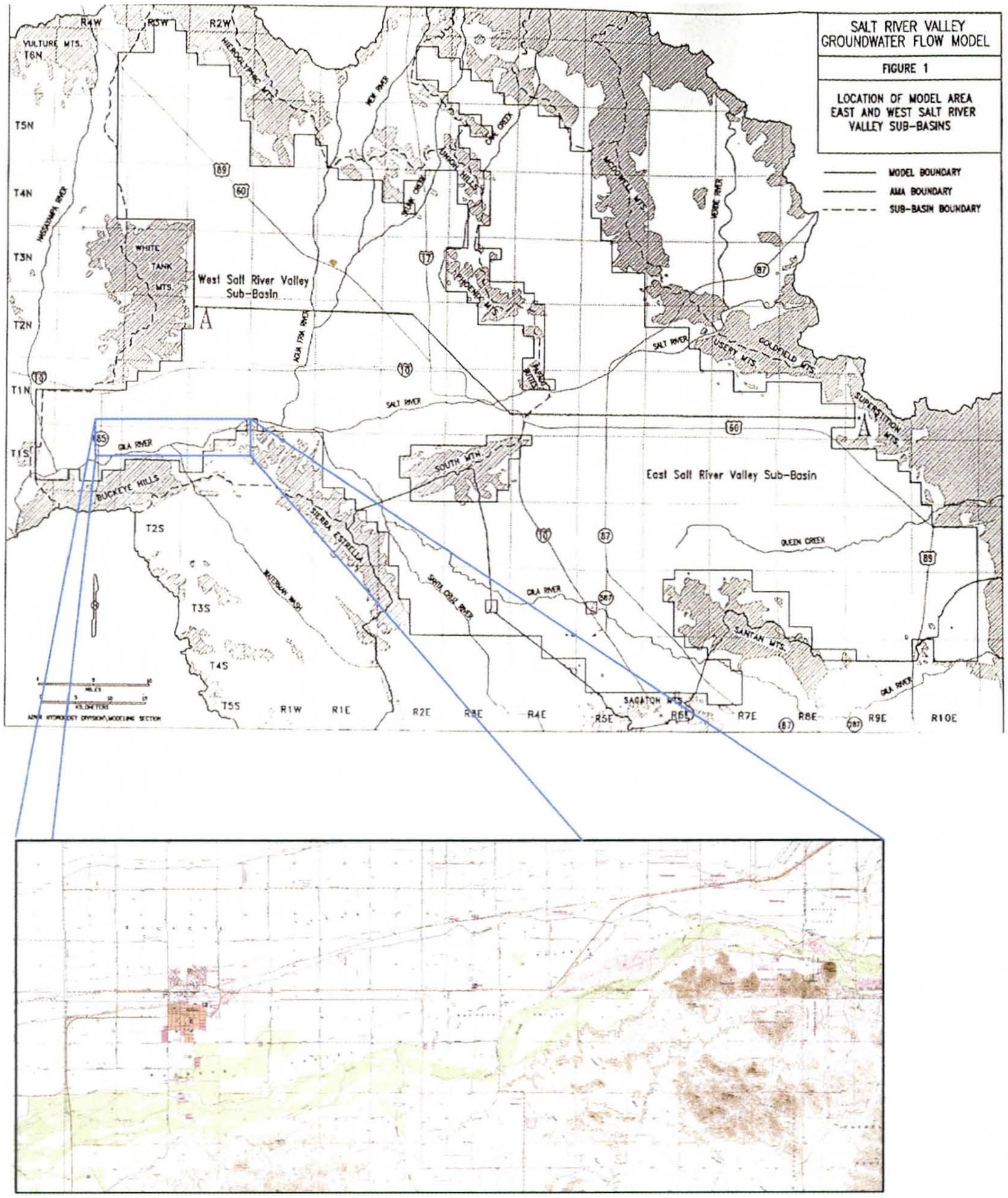
For a transient flow model like the El Rio model, data such as pumping or recharge change with time. The changes could be daily, but the finite difference scheme requires selection of a time period during which one data value for each parameter will be used in the flow equations. Real time data for pumping or recharge must be averaged for a stress period. Although the stress periods should be small enough that they are representative of the transient changes, the number of stress periods must be juxtaposed against the time it will take the model to run and the numerical errors that are introduced every time iteration occurs.

EL RIO BASE MODEL

The SRV model provided the starting point for the El Rio Base Model. Although the grid spacing is 1 square mile, telescopic mesh refinement (TMR) was used to window out the hydrologic data from the calibrated SRV model to develop the El Rio model. As with the SRV model, MODFLOW was used to simulate groundwater flow. A pre-/post- processor Groundwater Vistas was used to conduct the TMR, edit input data arrays, run MODFLOW and view the model output.

Model Area

The groundwater flow model for the El Rio area (El Rio model) is 7 miles wide by 17 miles long (Figure 20). It encompasses portions of Townships 1 North and 1 South, Ranges 1, 2, 3 and 4 West. The El Rio project area is located along the southern edge of the model area. The area was selected so that hydraulic boundary conditions along the northern boundary would have minimal impact on the El Rio project area. The eastern boundary was selected to correspond to



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El Rio Model Area
with Respect to
ADWR SRV Model

DRAWN 07 Nov. 05

Figure 20

the location of the Agua Fria River. The western boundary was selected to be 1 mile west of the El Rio project area.

Basic Conceptual Model

The SRV model simulated groundwater flow from 1984 through 2003. The basic conceptual model used by ADWR for the SRV model in the El Rio project area included the following assumptions:

- Three aquifers were simulated. The upper alluvial unit, which is coarse grained sands and gravels; a middle finer grained unit; and a lower sand unit. The three layers are more interconnected near the Gila River and less connected away from the river.
- Outflow from the groundwater system occurs along portions of the western boundary, as pumping from wells, as evapotranspiration from plants whose roots tap the groundwater system, and as discharge to the Gila River where the river bottom elevations are lower than the groundwater elevations.
- Inflow to the groundwater system is from infiltration from the Gila River where river stage is above the groundwater elevation; from infiltration of applied irrigation and from irrigation canals; and across portions of the northern and eastern model boundaries.
- During the 20 year simulation period, the Gila River does not have perennial flow within the area and contributes limited recharge to the groundwater system.

Model Development

The development of the El Rio model followed three steps, 1) creation of data arrays using TMR, 2) modification of the data arrays using site specific data, and 3) model calibration.

Telescopic Mesh Refinement

The development of the El Rio model began with using the TMR procedure to select in the SRV model the area to be modeled. The TMR created the finer grid, five nodes per mile and 35 rows by 85 columns from the SRV model, which is 1 node per mile and 7 rows by 17 columns within the El Rio area. It assigned data from the coarser grid SRV model to the corresponding nodes in the finer grid.

Because the El Rio model boundaries do not correspond with hydrologic boundaries along the eastern, northern and western area, the TMR procedure assigned variable constant heads to those boundaries based on the water levels calculated by the SRV model. The southern boundary corresponds to a no-flow boundary created by less permeable bedrock.

Point data such as aquifer parameters (hydraulic conductivity and storage) and recharge were transferred directly from the 1 mile nodes in the SRV model to the 25 nodes that encompass each of the SRV nodes in the El Rio model. Continuous data, such as initial heads and the top and bottom elevations of the model layers, were assigned to the El Rio model by interpolating between the data in the SRV model.

Because the pumping rates in the SRV are summed for the 1 mile nodes in the SRV model, the TMR procedure transferred the pumping from the 1 mile node to one node in the center of the 25 nodes in the El Rio model. The SRV pumping data were not used in the El Rio model.

Modification of Data Arrays

The data arrays used in the El Rio Model include:

- Active nodes in model area
- Hydraulic conductivity (K)
- Storage Coefficient/Specific Yield (S)
- Recharge
- Top and bottom elevations of each model layer
- Initial Heads
- Vertical Conductivity (K_v)

These arrays were initially set by the TMR process. Comparison of well completion information and measured hydraulic heads with the model data showed that the data in the SRV model did not correspond well with the site specific data. The active nodes in the model area were modified, as were the hydraulic heads, and bottom and top elevations to more closely match measured data in the area.

The SRV pumping data were deleted from the El Rio model and data from 181 wells imported into the model. Data imported included the state plane coordinates for each well, pumping rate for each of the stress periods, and the top and bottom screen elevations. These wells were defined as analytical wells in Groundwater Vistas. Groundwater Vistas allocated pumping between the model layers based on aquifer parameters and screened interval.

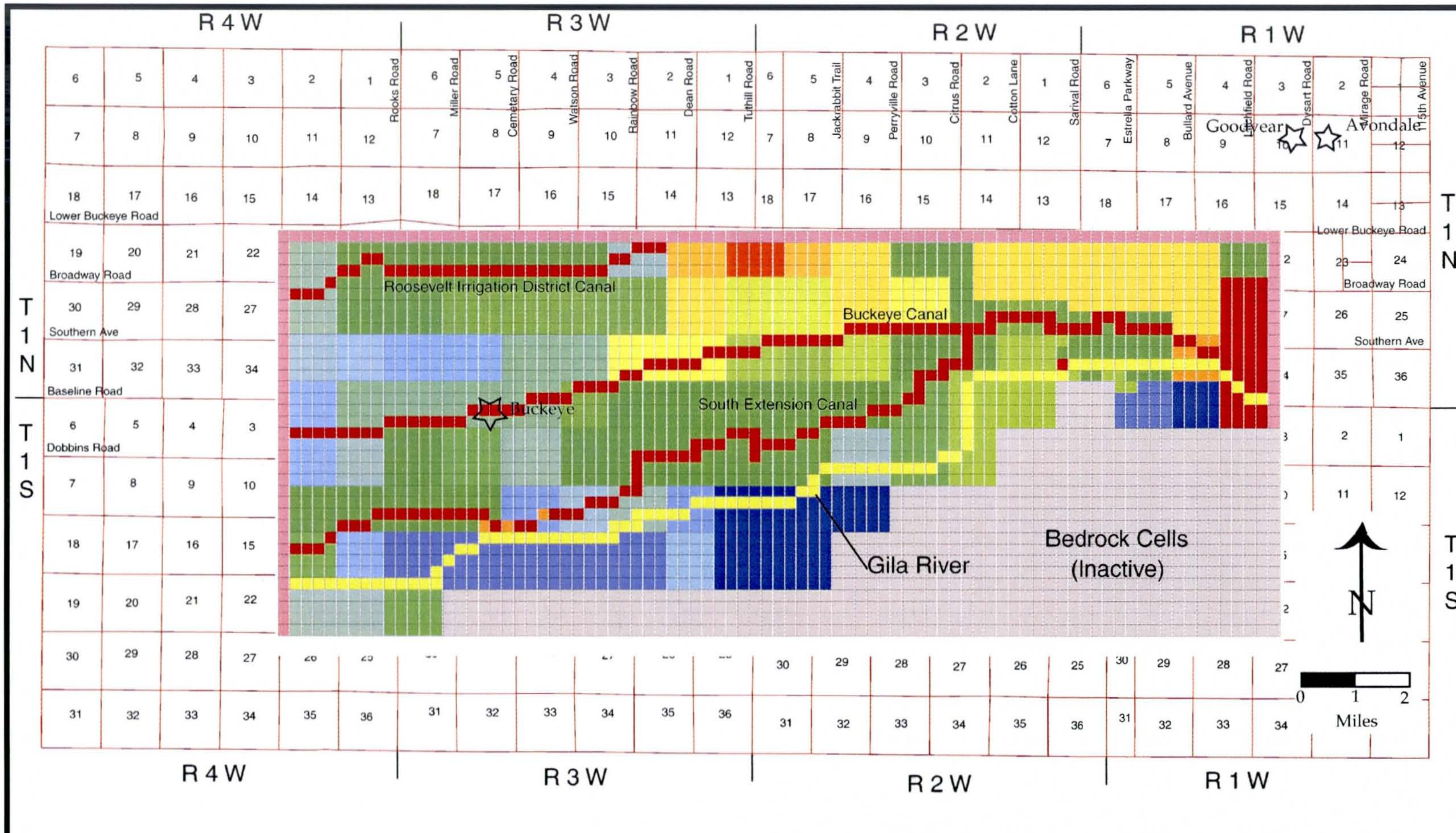
The stream widths, bottom elevations, and roughness coefficients were entered into Groundwater Vistas using data extracted from the hydraulic cross sections for the Gila River (Stantec, 2005). An average number was used for each node crossed by the river.

The recharge array created by the TMR from the SRV model remained the same except for the nodes that include the RID, Buckeye and Arlington canals (Figure 21). The recharge rates in these nodes were set equal to the rates calculated by the SRP for unlined canals.

The SRV model initial heads were lower than those measured in the El Rio area. This meant that the variable constant heads set by the TMR were also lower than the corresponding water levels. In addition, review of hydrographs in the El Rio area showed that water levels along the model boundaries varied less than 5 feet over the 20 year period. Based on this information, the transient constant heads were converted to steady-state constant heads for the 20 year simulation.

Calibration

The major assumption in developing the scope of work for the El Rio model was that minimal calibration would be required since the data were derived from the calibrated SRV model. This was not a valid assumption as demonstrated by the differences in measured heads and those used in the SRV model. The El Rio model had to be calibrated once the data arrays were modified to reflect the site specific data. Model calibration, or matching the model simulated data to observed data, is an iterative process by evaluating the match in calibration targets.



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Distribution of Recharge

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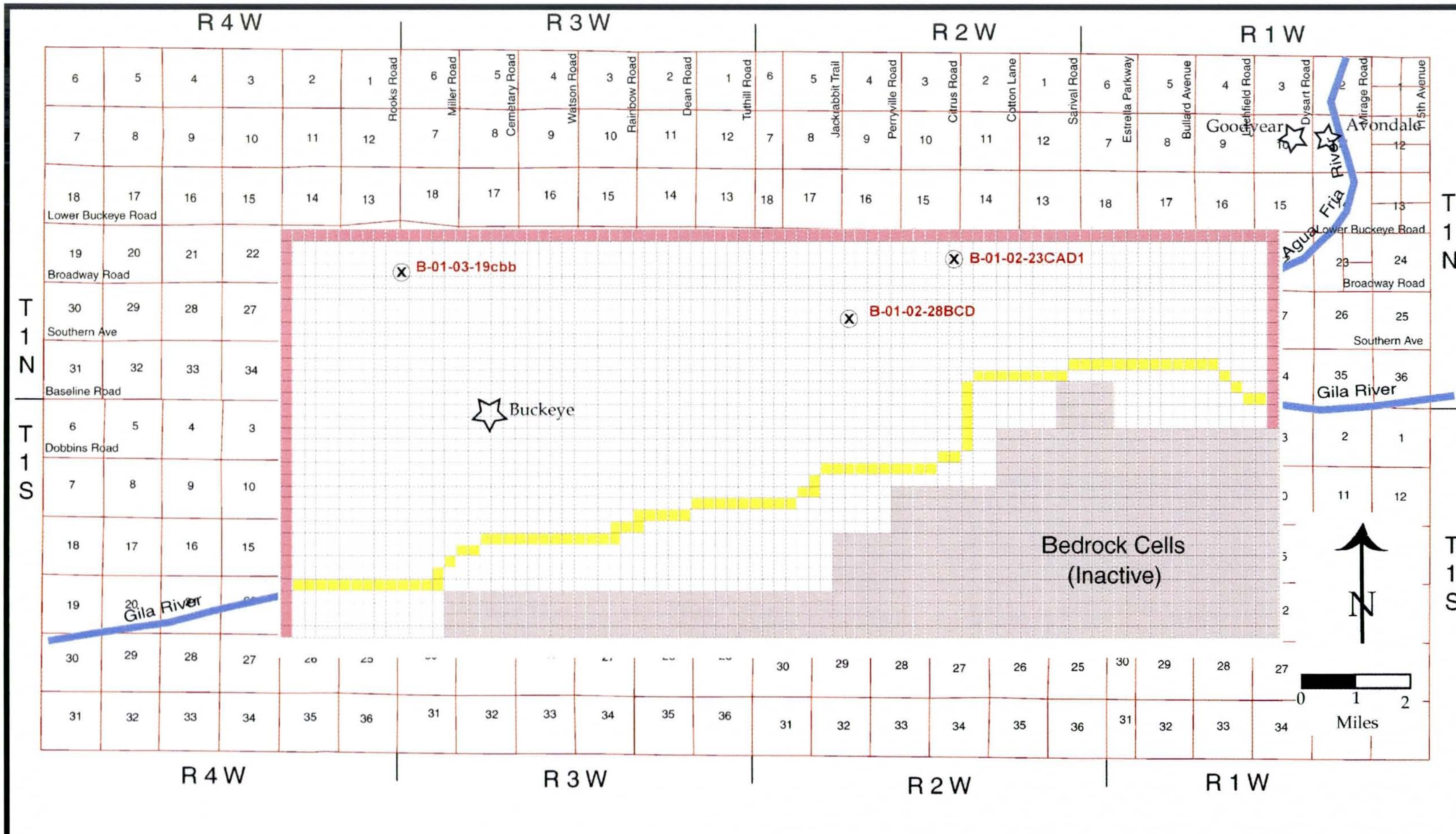
RAB	7 Nov, 05	Figure 21	
SCALE 1:160,000	W.O. NO.		

A calibration target is defined as "a point in space and time where one of the model dependent variables has been measured" (Environmental Simulations, Inc., 2004). The El Rio calibration uses the hydraulic head map from 2001, as well as hydrographs from select wells. There are 9 wells in the El Rio area for which water level hydrographs are available with data covering the 20-year calibration period. Three of the targets are completed in layer 1, one in layer 2, and five in layer 3. The target locations in layers 1 and 3 are shown in Figures 22 and 23.

Many of the wells in the El Rio area are screened across multiple layers. GWV assigns the calibration targets to the layer in which the bottom elevation of the screen occurs. The residual or difference between the model calculated value and the measured value at the calibration target provides one way to evaluate the ability of the model to simulate the aquifer conditions.

Another method for evaluating a model calibration is to compare groundwater elevation contour maps generated with the observed data with model-generated groundwater elevation contour maps. The objective is to qualitatively compare the flow direction, spacing of the contours and shape of the contours. The two maps should be similar.

The modeling process follows an iterative sequence of steps. The first step is to run the model. Once the model run is complete, the modeler reviews the model mass balance. If the mass balance is reasonable and the mass balance error is small, the model calculated heads and hydrographs are reviewed. This involves checking for the difference between the observed and calculated heads, the shape of the head contours and the correspondence between the observed and measured heads in the hydrographs and on the contour maps. Each of these reviews provides information regarding the calibration of the model. Where discrepancies between the calculated and observed data exist, the conceptual model and the data used in the model must be reevaluated to determine if changes should be made to the data arrays. If changes can be supported, they are made in the data arrays and the model is rerun. The process continues until the model results are acceptable.



Well Location (B-01-03-19cbb is cadastral location)

River Nodes

Boundary Nodes (Constant Head)

Inactive Nodes (Bedrock Boundary)

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Model Grid, Boundary Conditions and Target Wells Layer 1

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RAB	7 Nov, 05	Figure 22	
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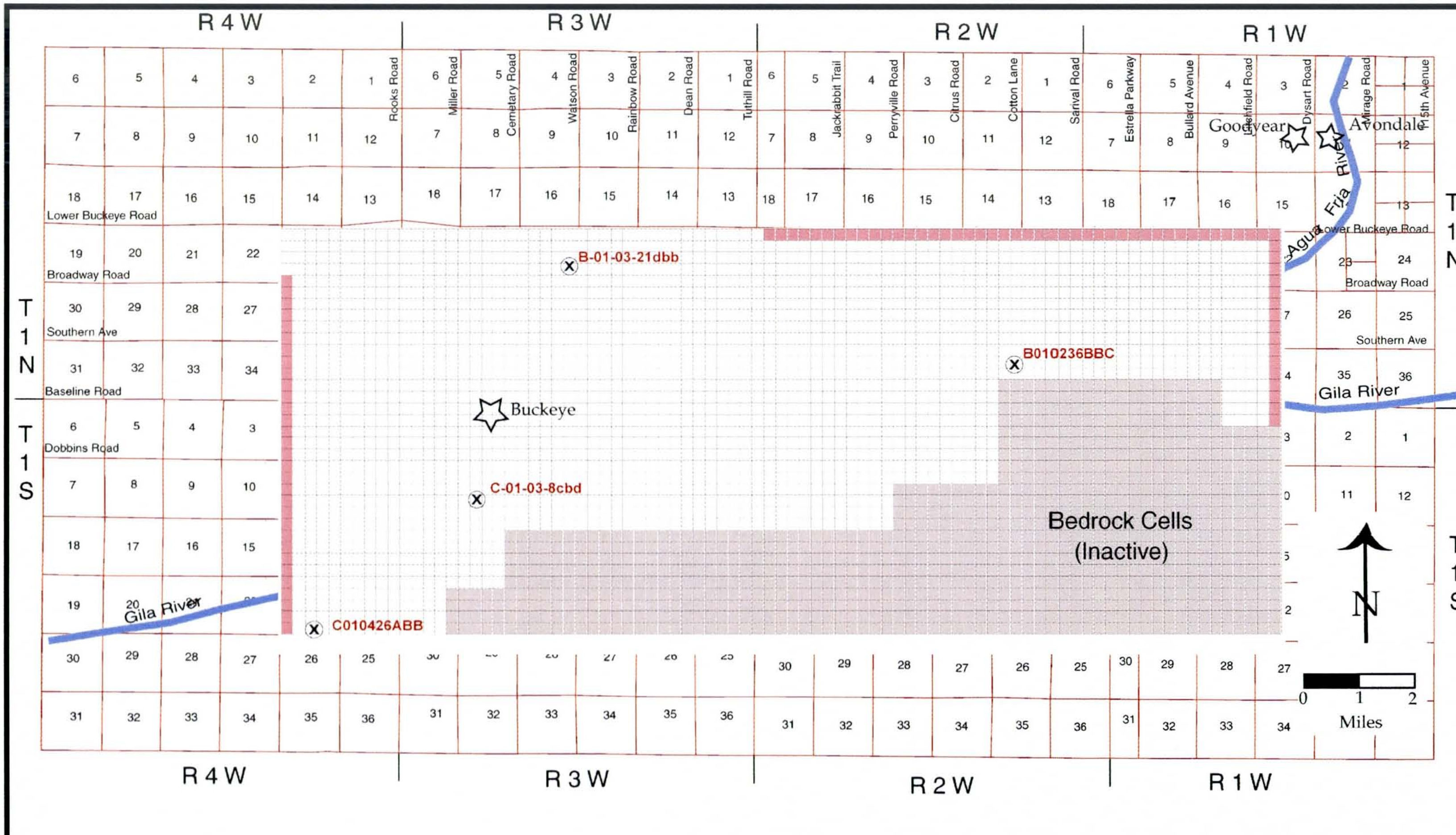

Well Location (C-01-03-8cbd is cadastral location)

Boundary Nodes (Constant Head)

Inactive Nodes (Bedrock Boundary)

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Model Grid, Boundary Conditions and Target Wells Layer 3

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RAB	7 Nov, 05	Figure 23	
SCALE 1:160,000	W.O. NO.		

The El Rio model was considered calibrated when:

- the mass balance error was less than 1 percent.
- the model calculated head contours and the head contours for the measured data were similar in shape and spacing.
- hydrographs of calculated heads and measured heads were similar.
- model statistics were reasonable. The model statistics were considered reasonable when the standard deviation of the differences divided by the range in heads was less than 10 percent, the residual mean and the absolute residual mean (ARM) were both close to zero.

It took approximately 10 model runs to obtain a calibrated model. Changes made to the data include increasing the canal recharge rate to the upper end of that measured by SRP, increasing the interconnection between the upper, middle and lower layers near the river in all three layers, and decreasing it away from the river. The hydraulic conductivity arrays were simplified. The hydraulic conductivities in the middle layer were decreased and in the lower layer were increased. All data values remained within the range in data used in the SRV model. The calibrated El Rio model file is named ElRioBase. The model input and output files are located on a CD in Appendix E.

The mass balance for the calibrated model is shown in Table 3.

Table 3: Volumetric Mass Balance for El Rio Base Model

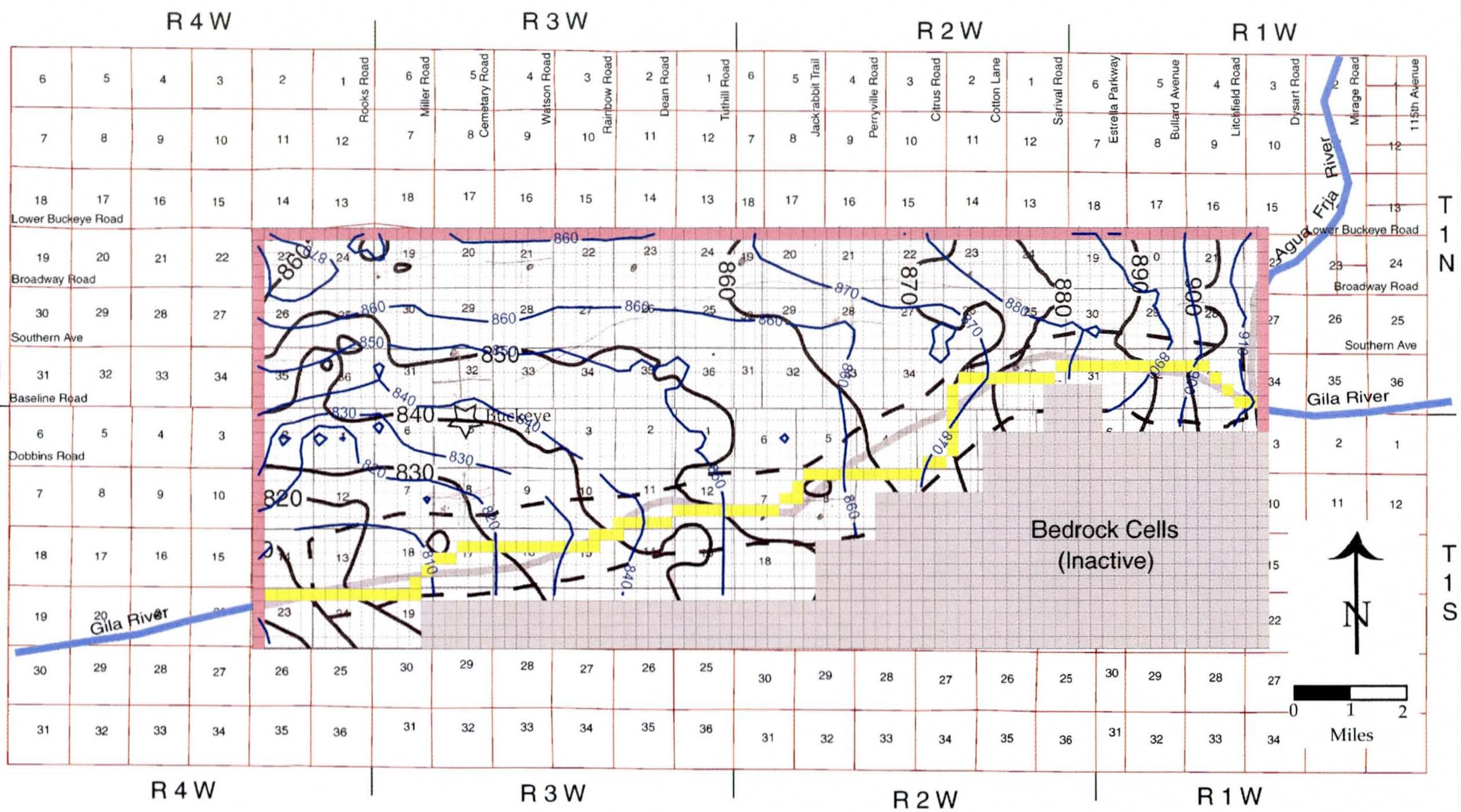
AT END OF TIME STEP 12 IN STRESS PERIOD 18

CUMULATIVE VOLUMES (ft^3)		RATES FOR THIS TIME STEP (ft^3/day)	
IN:		IN:	
---		---	
STORAGE =	0.46447E+10	STORAGE =	0.21413E+06
CONSTANT HEAD =	0.20188E+11	CONSTANT HEAD =	0.3794E+07
WELLS =	0.0000	WELLS =	0.0000
RECHARGE =	0.79917E+11	RECHARGE =	0.10947E+08
ET =	0.0000	ET =	0.0000
STREAM LEAKAGE =	0.28106E+10	STREAM LEAKAGE =	029605E+06
TOTAL IN =	0.10756E+11	TOTAL IN =	0.15252E+08
OUT:		OUT:	
----		----	
STORAGE =	0.38914E+10	STORAGE =	0.27383E+06
CONSTANT HEAD =	0.12672e+11	CONSTANT HEAD =	0..27383E+07
WELLS =	0.58427E+11	WELLS =	0.10083E+08
RECHARGE =	0.0000	RECHARGE =	0.0000
HEAD DEP BOUNDS =	0.52675E+10	HEAD DEP BOUNDS =	0.10266E+07
ET =	0.29759E+11	ET =	0.35641E+07
STREAM LEAKAGE =	0.28106E+10	STREAM LEAKAGE =	029605E+06
TOTAL OUT =	0.10756E+12	TOTAL OUT =	015252E+08
IN - OUT =	-131,060.	IN - OUT =	-17
PERCENT DISCREPANCY =	0.00	PERCENT DISCREPANCY =	0.00

The ARM is 3.22 with a residual mean of -0.96. The standard deviation divided by the range is 0.046.

The comparison of observed hydraulic heads to model heads (Figure 24) shows a reasonable similarity in hydraulic gradients, contour shape and direction of flow. The hydrographs for the 7 targets with the most complete data show reasonable correlations measured and model calculated heads (Figure 25).

The plot of the measured versus model calculated heads are evenly distributed around a 45 degree line indicating minimal bias across the model area (Figure 26).



River Nodes

Inactive Nodes (Bedrock Boundary)

Measured Heads (feet amsl)

Model Computed Heads (feet amsl)

Contour Interval = 10 feet

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Comparison of Computed and Measured Hydraulic Heads

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RAB	7 Nov, 05	Figure 24	
SCALE 1:160,000	W.O. NO.		

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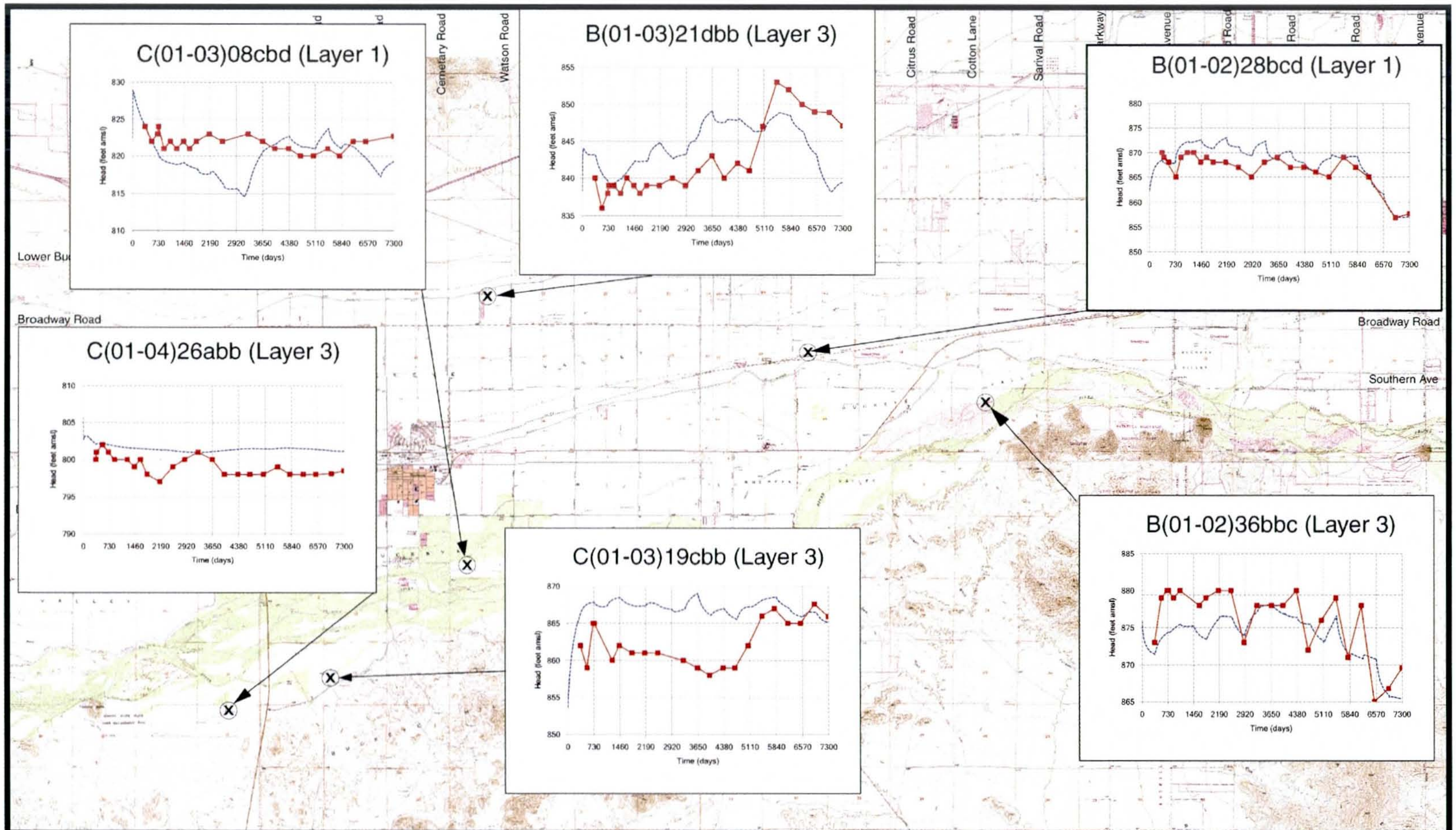

Model Calculated Heads (feet amsl)

Observed Heads (feet amsl)

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Target Well Locations with Hydrographs

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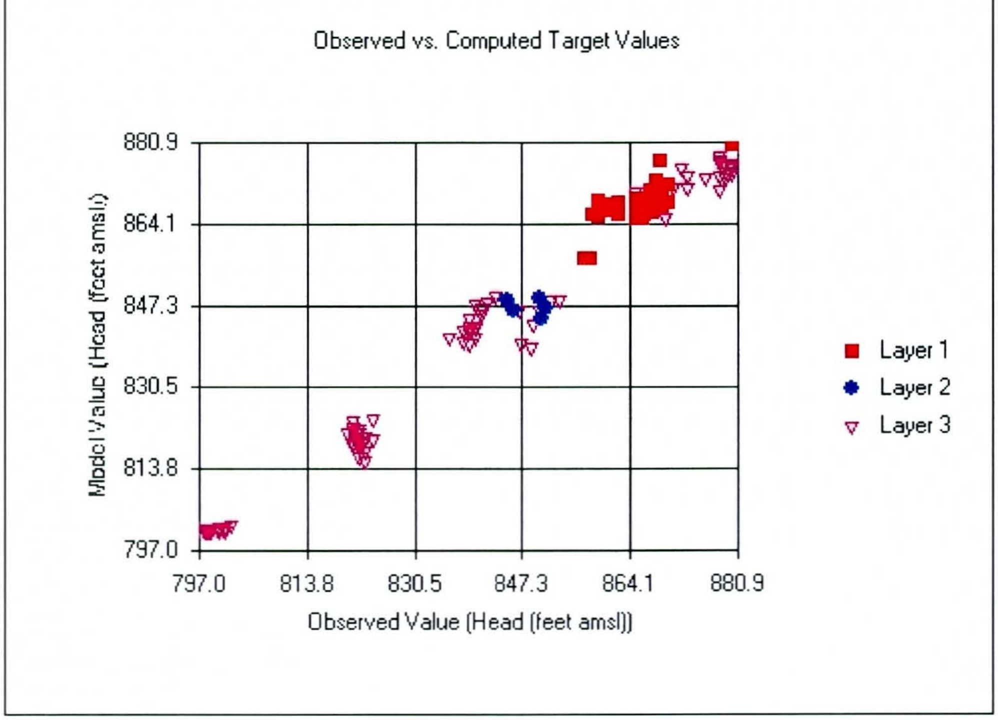

Figure 26. Comparison of Observed and Model Computed Heads

Sensitivity Analysis

A sensitivity analysis simulates the response of the calibrated groundwater flow model to changes in aquifer parameters or stresses. It's one method for evaluating the degree of uncertainty of data sets used in the model. Uncertainties include those associated with measuring aquifer parameters and defining boundary conditions, and stresses. Examples include applying point measured data such as heads or hydraulic conductivity to a larger area, the indirect measurement of recharge volumes and rates, or the assumptions used in defining boundaries. It can also be used to evaluate parameters for which limited data are available such as storage parameters or vertical conductivities.

The sensitivity analysis is designed to evaluate the effect of a single change in some parameter in the calibrated model on the model results, whether a mass balance error, a change in hydraulic gradients or the magnitude of change in heads. It provides a means of evaluating where additional data collection may result in more useful information to the model. For example, a model with little sensitivity to K, but a greater sensitivity to pumping volumes would benefit in better quantification of pumping volumes rather than additional aquifer tests.

The sensitivity analysis for the El Rio model was designed to evaluate model sensitivity to the changes in the following parameters:

- recharge
- specific yield and storage coefficient
- horizontal and vertical hydraulic conductivity

The sensitivity analysis for the El Rio model has limited utility because of the limited distribution of targets within the modeled area. However, the model appears to be most sensitive to changes in recharge, moderately sensitive to changes in hydraulic conductivity and least sensitive to changes in storage. Based on the problems with the initial head data, the model is also very sensitive to the initial heads.

Discussion and Conclusions

Development of the El Rio groundwater model began with the SRV regional model. Although calibrated by ADWR, the data in the SRV model for the area around the El Rio project did not match measured data. Changes made to the aquifer parameters and recharge resulted in a model that had a reasonable calibration within the modeled area. Model calculated hydraulic heads are similar to those measured with time, and the comparison of the 2001 contour map of measured heads with model calculated heads show similar shape and gradients.

The major problem with the calibration is the lack of data throughout much of the area, particularly near the river. Within the upper layer of the model, the aquifer of most concern to the El Rio project, there are only two wells with data covering the 1984 to 2003 period of the model, and these are located more than 4 miles from the river. So, although the model calibration is reasonable, the model data and results have a high degree of uncertainty.

REGIONAL MODEL SCENARIOS

Different scenarios were selected to evaluate the changes in depth to water near the Gila River as changes occur regionally in recharge and pumping. Scenarios simulated included a reduction in agricultural recharge, elimination of pumping in layer 1, increased pumping in layers 2 and 3, and a combination of decreased agricultural recharge and increased pumping in layers 2 and 3. The scenarios are described in Table 4.

Table 4. Regional Model Scenarios

Scenario	2003 Base Recharge	2003 Base Pumping	Agricultural Recharge Eliminated	Pumping in Layer 1 Eliminated	Increased Pumping in Layers 2 and 3	Recharge Eliminated north of Buckeye Canal
Scenario 1		X	X			
Scenario 2	X			X		
Scenario 3			X	X		
Scenario 4	X			X	X	
Scenario 5			X	X	X	
Scenario 6				X	X	X
Scenario 7				X		X
Scenario 8*			X	X	X	
	*Scenario 8 includes a 50 reduction in the constant flows across the model boundaries.					

Modifications to Calibrated Model

The calibrated base model was used to set up the model to evaluate potential scenarios. The simulation period, 10 years, is broken into 2 year stress periods. The following assumptions were made in developing the model:

- Pumping rates in 2003 apply.
- Ending heads in 2003 are the starting heads for the scenario model.
- Recharge distribution and rates from 2003 apply.

Although the starting data for the model scenarios are taken from data for 2003, the model results are not linked to actual time, but represent a hypothetical set of conditions within the area. The scenarios are designed to simulate possible changes in the aquifer over a ten year period.

The base model for the scenarios was run first with the constant heads used in the calibrated model. The constant heads were then converted to constant flow using the flow rates from the end of 2003 from the ElRioBase file. The model was run again and the two results compared to ensure that both were similar.

"Artificial targets" along the Gila River were added to the model to assist with evaluating the changes in the hydraulic heads near the river as assumptions changed and the calibration target wells were deleted.

Scenario 1: Reduction in Recharge

The first scenario assumes that irrigation recharge stops at the beginning of year 5. The only recharge in the model is from canals and standing water in the river. The assumption is that the irrigation canals continue to provide water to areas outside the model area. The average recharge rate in 2003 in the base model is 1.1739×10^7 cubic feet per day (cfd). The average recharge rate in Scenario 1 for years 1 through 4 is the same as the base rate, but in years 5 through 10 the rate is reduced to 3.1602×10^6 cfd, a 73 percent reduction in recharge. Pumping remains the same as in the base model.

Figure 27 shows the changes in hydraulic heads in the model area. Heads near the river are reduced by 20 to 70 feet. In areas where the thickness of the upper unit is less than 60 feet thick, heads are below the bottom of the upper unit.

Scenario 2: Layer 1 Pumping Eliminated

The second scenario assumes that all wells pumping from the shallow aquifer cease pumping at the beginning of year 5. Wells that pumped from all three layers were assumed to pump only from the lower two layers. The base pumping rate is 1.2590×10^7 cfd. The pumping eliminated from layer 1 is approximately 450,000 cfd. The pumping rate in year 5 is 8.0906×10^6 cfd, a 38 percent reduction in pumping. The recharge is the same as the base model.

Figure 28 shows the changes in hydraulic heads in the model area. Heads near the river rise 5 to 15 feet. The rise results in water flowing from the groundwater system to the river. Discharge from the groundwater to the river increases from 5.0593×10^6 cfd to 2.6128×10^7 cfd, an increase of 80 percent.

Scenario 3: Layer 1 Pumping Eliminated, Agricultural Recharge Eliminated

The third scenario assumes that all wells pumping from the shallow aquifer cease pumping at the beginning of year 5 (Scenario 2) and that irrigation recharge is eliminated (scenario 1), as well.

Figure 29 shows the changes in hydraulic heads in the model area. Heads near the river decline 15 to 25 feet.

Scenario 4: Layer 1 Pumping Eliminated, Wells Added to Layers 2 and 3

This scenario was designed evaluate what would happen to heads as pumping is converted from irrigation to residential supply, and users pump from the deeper layers. The total pumping rate from all three layers in 2003 was 1.2590×10^7 cfd. The pumping from layer 1 was 4.50×10^6 cfd; therefore nine hypothetical wells each pumping 500,000 cfd were added to layers 2 and 3 in year 5. The recharge remained the same as the base model.

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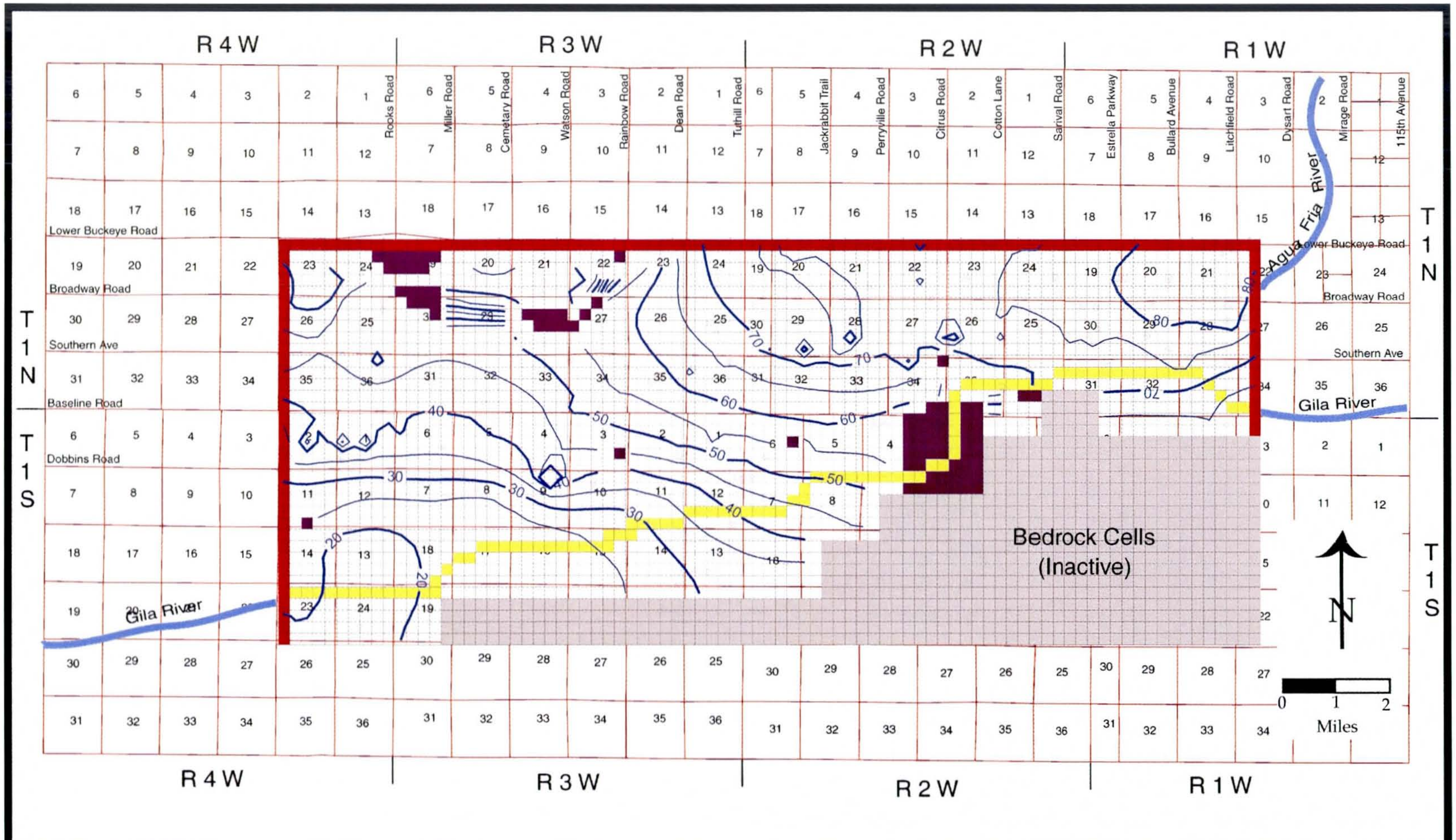

- River Nodes
- Boundary Nodes (Constant Flow)
- Dewatered Nodes
- Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

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Drawdown Scenario 1: Agricultural Recharge Eliminated

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RAB	7 Nov, 05	Figure 27	
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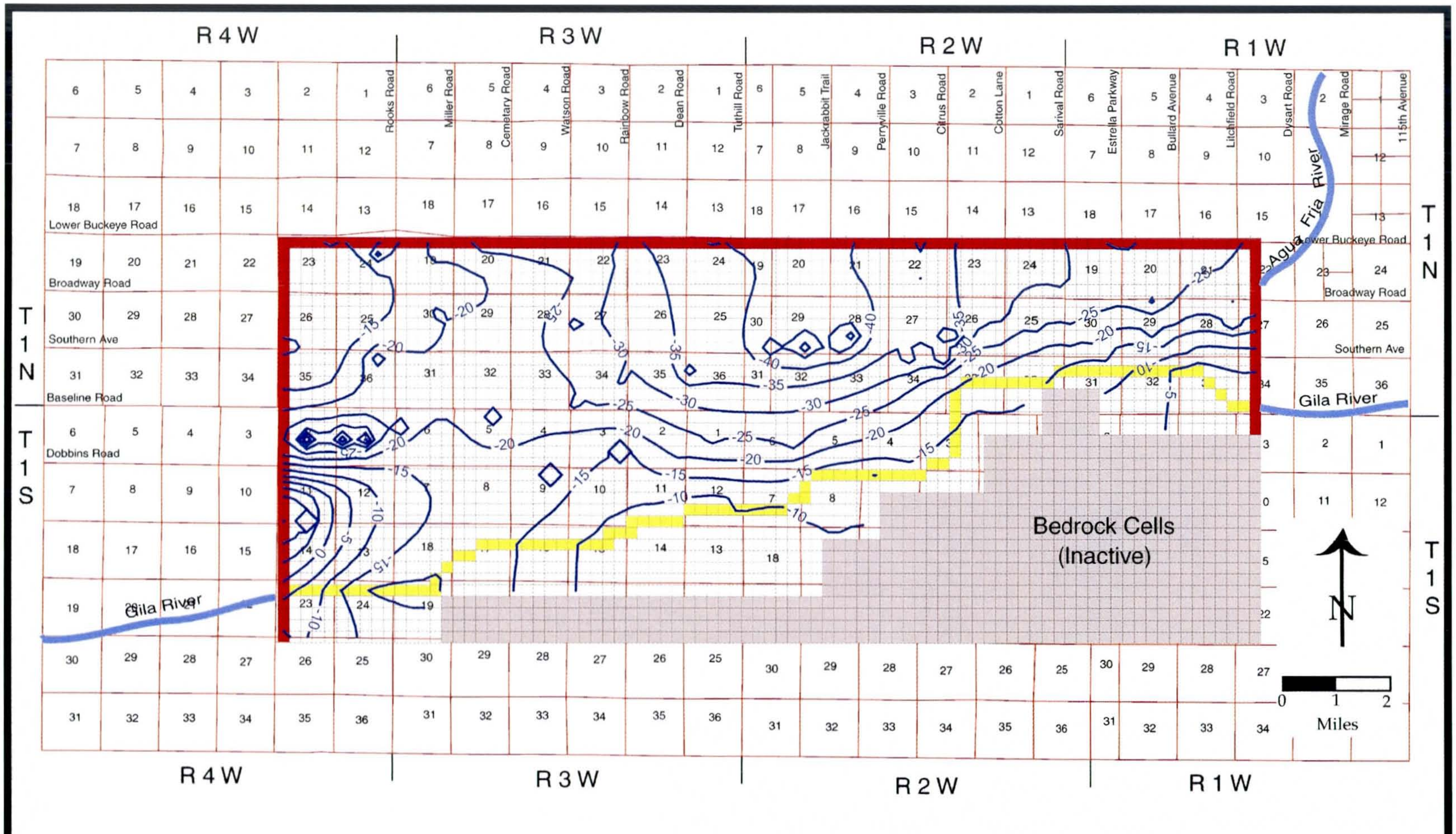

River Nodes

Boundary Nodes (Constant Flow)

Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

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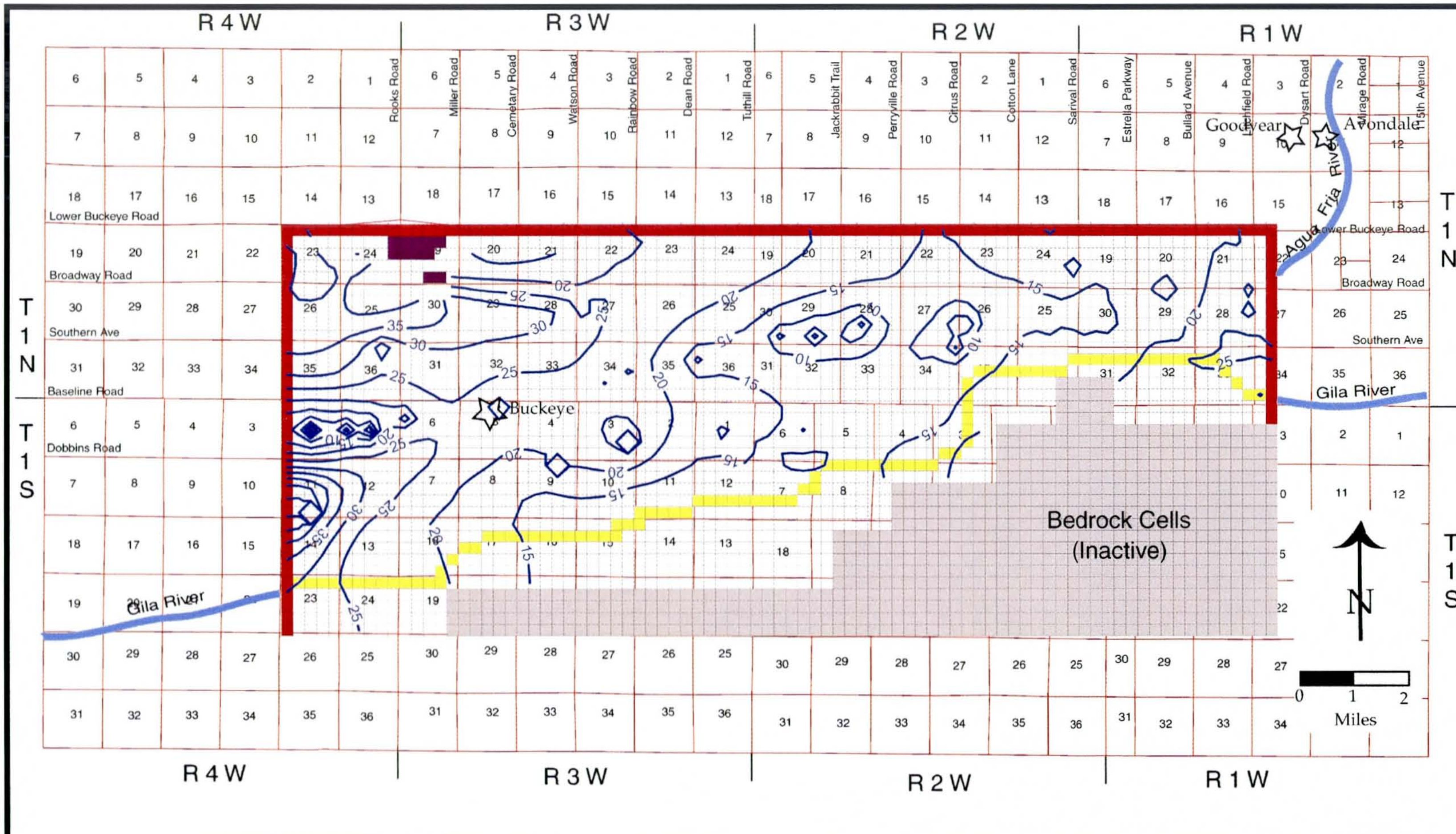
Drawdown

Scenario 2: Layer 1

Pumping Eliminated

DRAWN	DATE	DWG. NO.	REV. NO.
RAB	7 Nov, 05	Figure 28	
SCALE 1:160,000	W.O. NO.		



River Nodes

Boundary Nodes (Constant Flow)

Dewatered Nodes

25 Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

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Drawdown Scenario 3: Layer 1 Pumping and Agricultural Recharge Eliminated

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RAB	7 Nov, 05	Figure 29	
SCALE 1:160,000	W.O. NO.		

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Figure 30 shows the changes in hydraulic heads in the model area. Heads near the river decline in the western portion of the model in the area where the additional wells were placed and increase in the eastern part of the model.

Scenario 5: Increased Pumping and Agricultural Recharge Eliminated

Scenario 5 was designed to simulate the combination of no agricultural recharge (scenario 1), no pumping from layer 1 and increased pumping from layers 2 and 3 (scenario 4).

Figure 31 shows the changes in hydraulic heads in the model area. Heads near the river decline 25 to 55 feet. Several areas of the upper aquifer are dewatered as shown by the purple color on the figure.

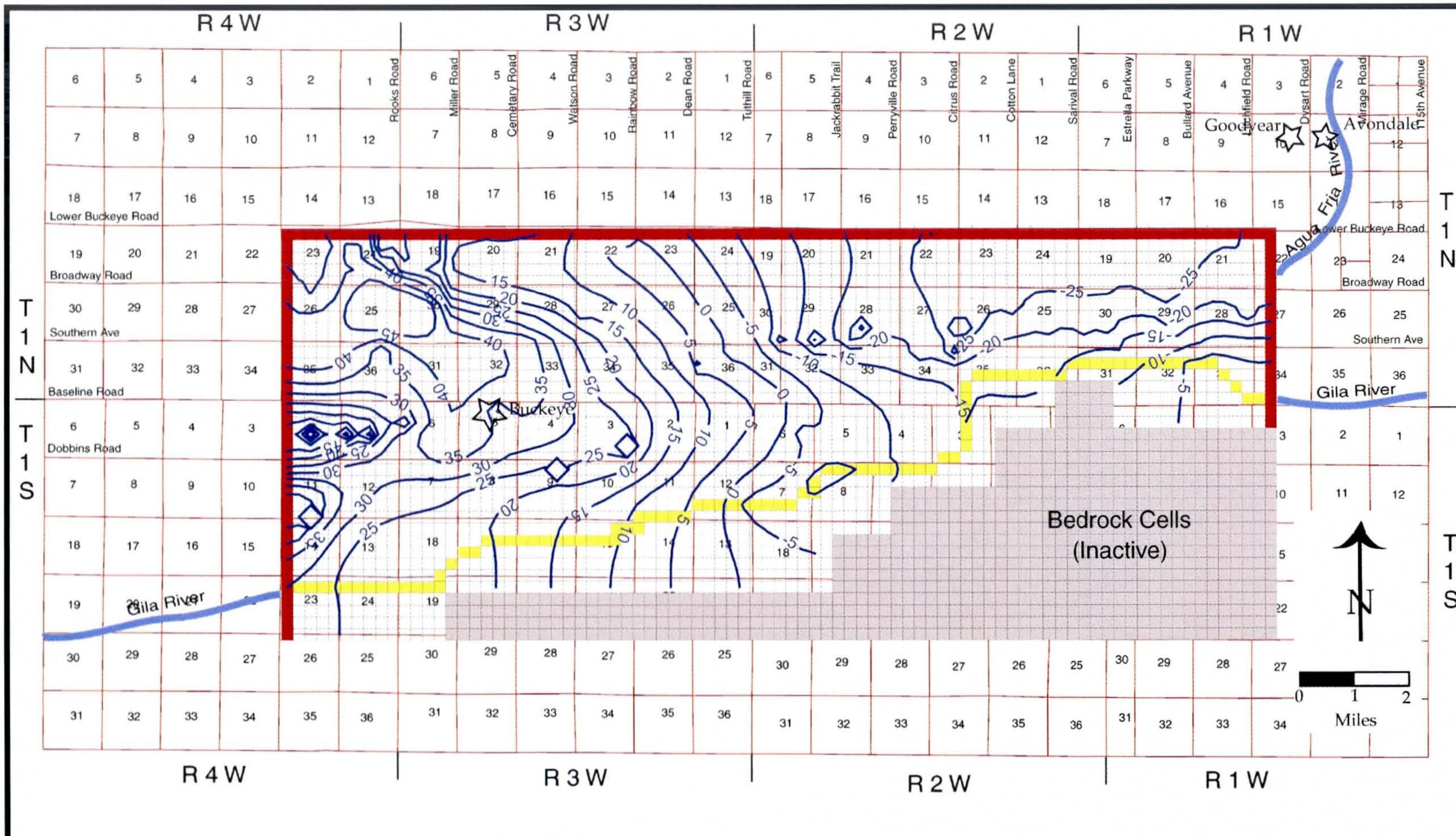
Scenario 6: Layer 1 Pumping Eliminated, Partial Agricultural Recharge, Increased Pumping

As with Scenario 4, this scenario was designed to evaluate the change in heads as pumping is converted from irrigation to residential supply, and users pump from the deeper layers. The pumping is the same as scenario 4, but recharge has been eliminated north of the Buckeye Canal (Figure 32). This is designed to simulate the change in land use, with an assumption that much of the irrigated land in the floodplain will remain under cultivation over the next 10 years. The average recharge rate, 0.71809 x 10^7 ft^3/day, is a 38 percent reduction in recharge from the base model.

Figure 33 shows the change in hydraulic heads in the model area. Heads near the river decline from 0 feet in the eastern portion of the project area, to 30 feet along the western edge.

Scenario 7: Layer 1 Pumping Eliminated, Partial Agricultural Recharge, No Increased Pumping

Scenario 7 was designed to simulate the combination of reduced agricultural recharge (scenario 6) and no pumping from layer 1. Pumping in layers 2 and 3 is similar to that in Scenario 3.



River Nodes

Boundary Nodes (Constant Flow)

Inactive Nodes (Bedrock Boundary)

Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

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Drawdown Scenario 4: Layer 1 Pumping Eliminated and Increased Pumping in Layers 2 and 3

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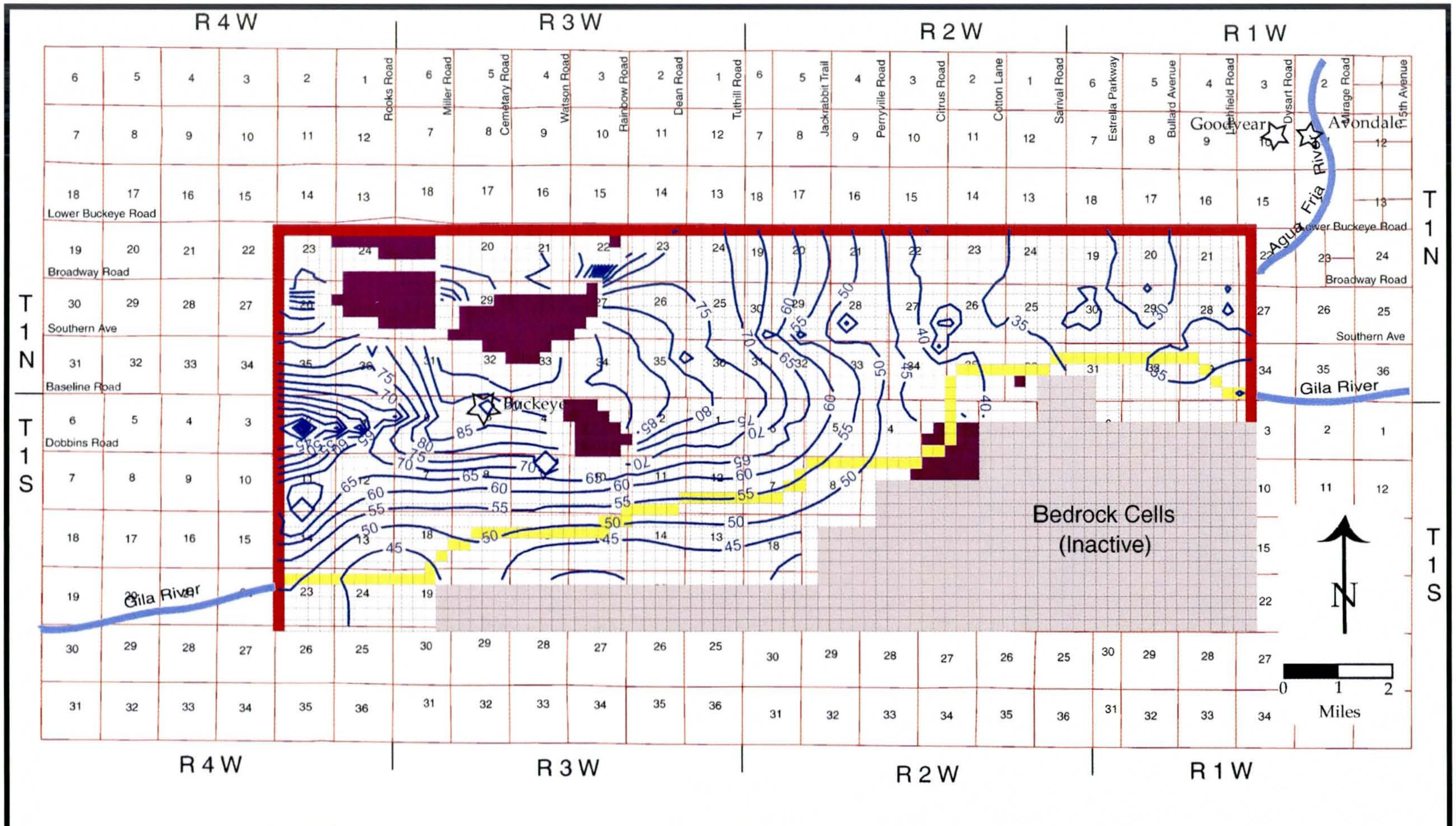
RAB	7 Nov, 05	Figure 30	
SCALE 1:160,000	W.O. NO.		



River Nodes

Boundary Nodes (Constant Flow)

Dewatered Nodes

Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

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Drawdown Scenario 5: Increased Pumping and Agricultural Recharge Eliminated

DRAWN	DATE	DWG. NO.	REV. NO.
RAB	7 Nov, 05	Figure 31	
SCALE: 1:160,000	W.O. NO.		

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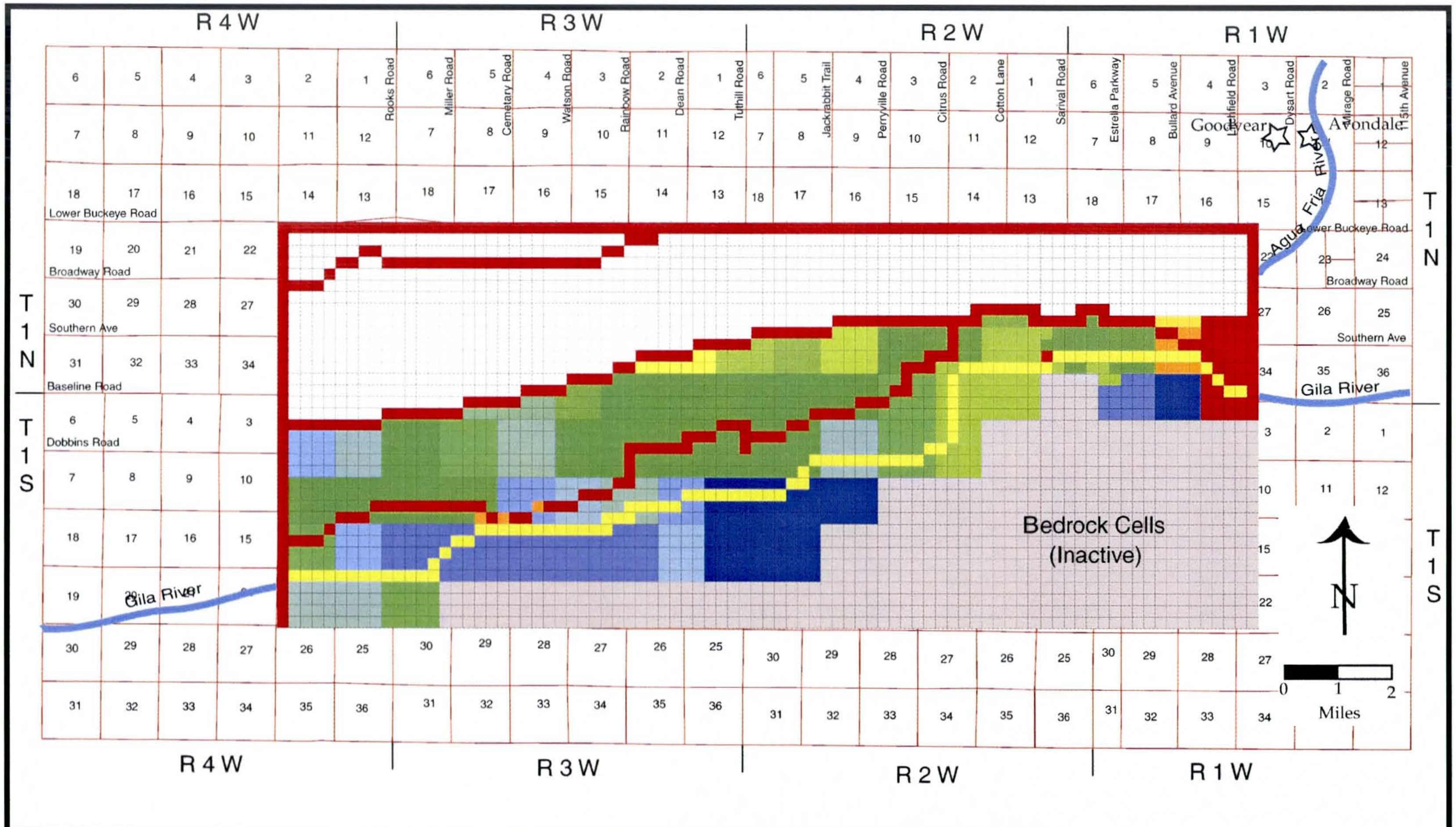

No Recharge

0.018 feet per day

6.4 x 10^{-5} feet per day

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Distribution of Decreased Recharge

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RAB	7 Nov, 05	Figure 32	
SCALE 1:160,000	W.O. NO.		

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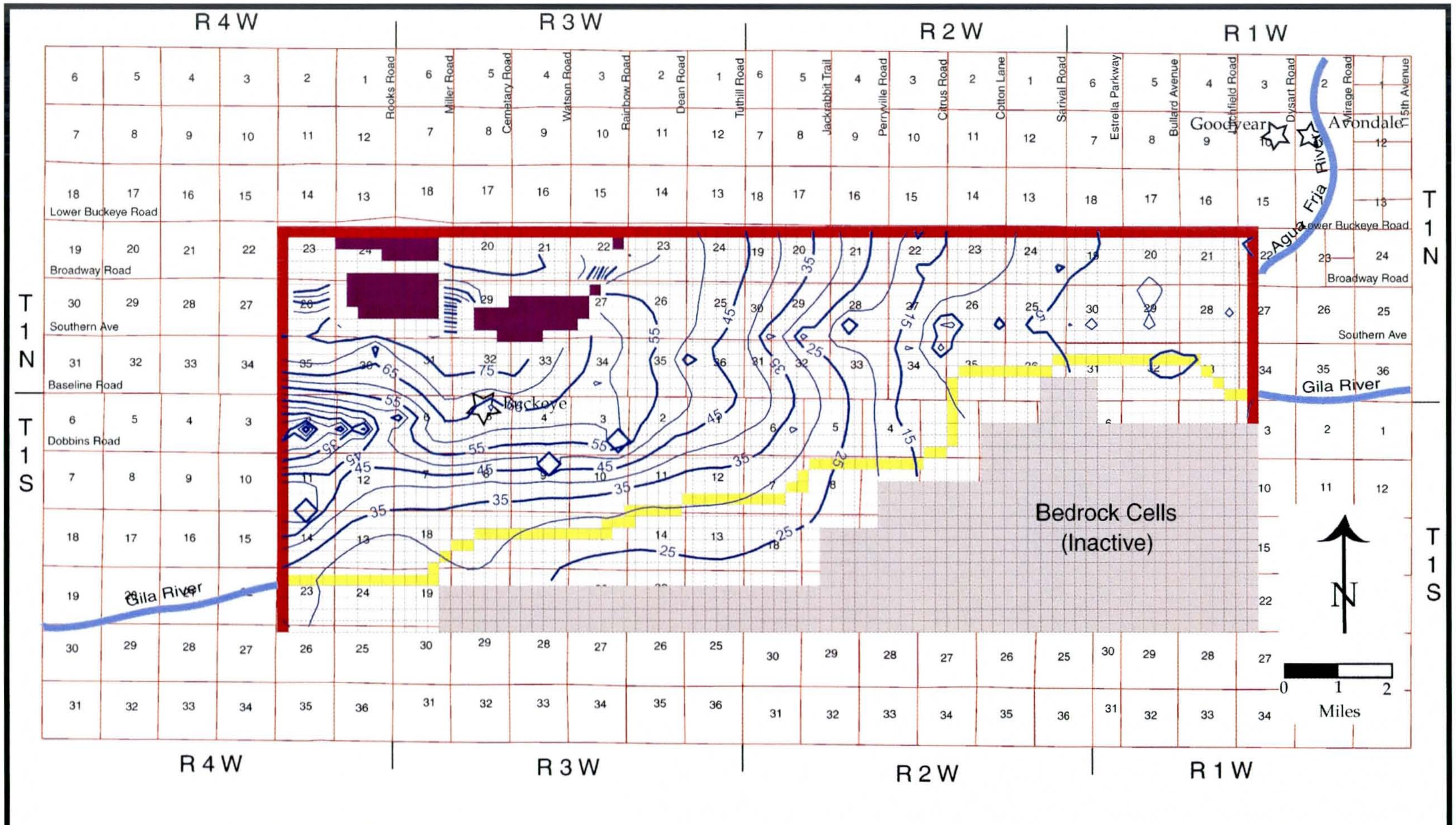

River Nodes

Boundary Nodes (Constant Flow)

Dewatered Nodes

Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

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Drawdown Scenario 6: Partial Recharge, Increased Pumping

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Figure 34 shows the changes in hydraulic heads in the model area. Heads near the river decline from 0 to 15 feet in the western third of the project area, but rise from 0 to 7 feet in the eastern two-thirds of the model area.

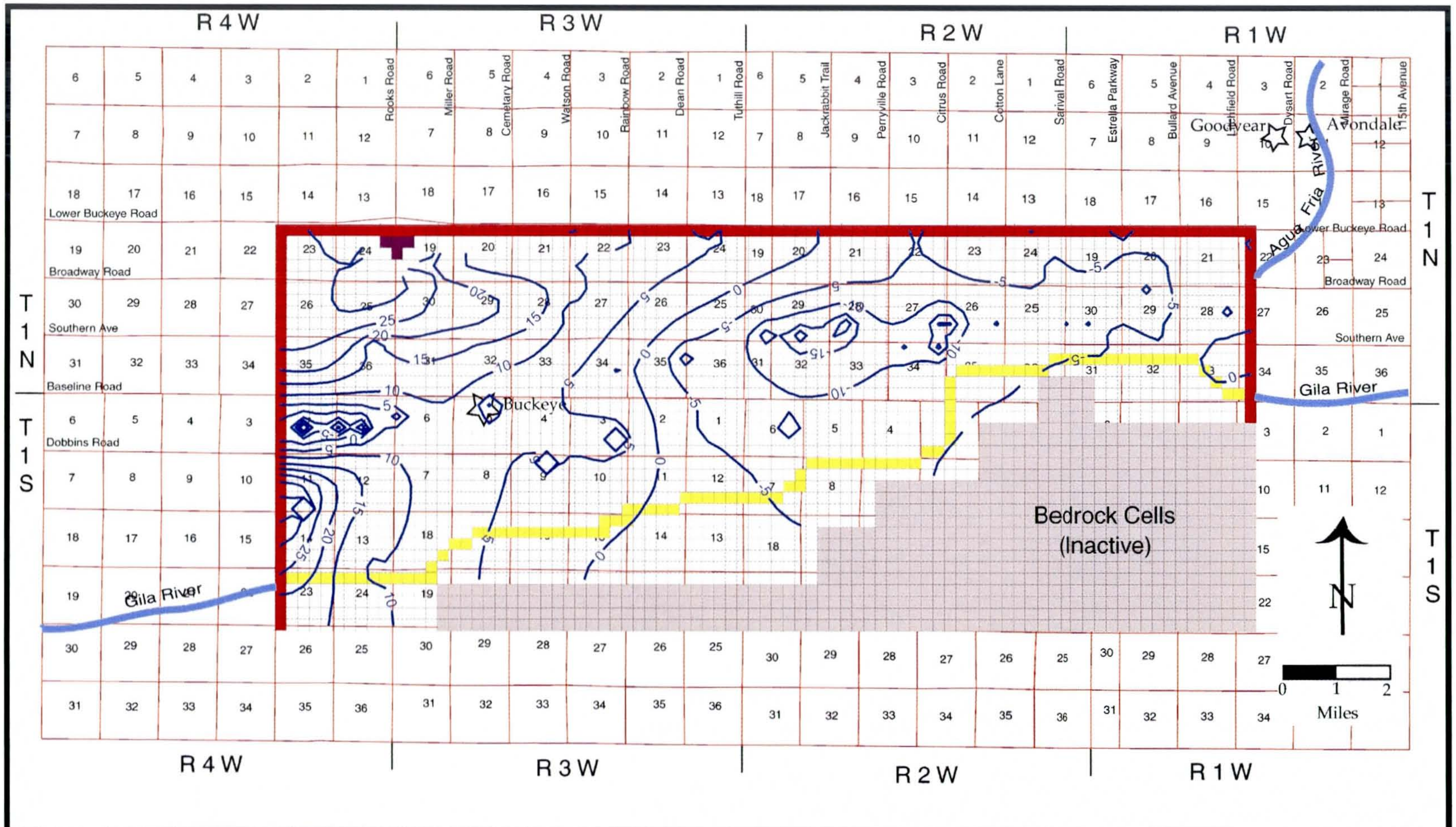
Scenario 8: Layer 1 Pumping Eliminated, Agricultural Recharge Eliminated, Increased Pumping Layers 2 and 3, Boundary Flows Reduced

Scenario 8 was designed to evaluate the impact of changes in the constant flows along the western, eastern and northern model boundaries on heads near the river. This scenario uses the combination of hypothetical conditions from scenario 5 – pumping eliminated in layer 1, agricultural recharge eliminated and increased pumping from layers 2 and 3 beginning in year 5, plus a 50 percent reduction in the boundary flows from the beginning of the model simulation. The heads for this scenario are shown in Figure 35.

Figure 36 shows a comparison of heads in a hypothetical well located in node 25, 29 near the river. The calculated heads are for the base model and for scenario 5, with and without reduced boundary flows. The difference in heads after the 10 year simulation period for scenario 5 is 5 feet, a change of 12 percent.

Discussion and Conclusions

The urbanization of the west Salt River Valley will impact the groundwater system in the El Rio project area. Changes in the locations of pumping wells, the depth at which pumping occurs, and the locations and rates of recharge, impact the groundwater levels near the river. In 2005 the majority of pumping in the model area is for agriculture, dewatering and municipal water supply. The dewatering wells generally pump from the upper unit while the irrigation and municipal wells may pump from all three units. Pumping wells are scattered throughout the area. Recharge occurs from the infiltration of applied irrigation water and from the canals. The three basic variables then are depth and location of pumping and recharge rate. Scenario 1 shows the greatest impact on heads near the river. Eliminating the agricultural recharge but maintaining the



River Nodes

Boundary Nodes (Constant Flow)

Dewatered Nodes

Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

EL RIO

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Drawdown Scenario 7: Partial Recharge No Increased Pumping

DRAWN	DATE	DWG. NO.	REV. NO.
RAB	7 Nov, 05	Figure 34	
SCALE 1:160,000	W.O. NO.		

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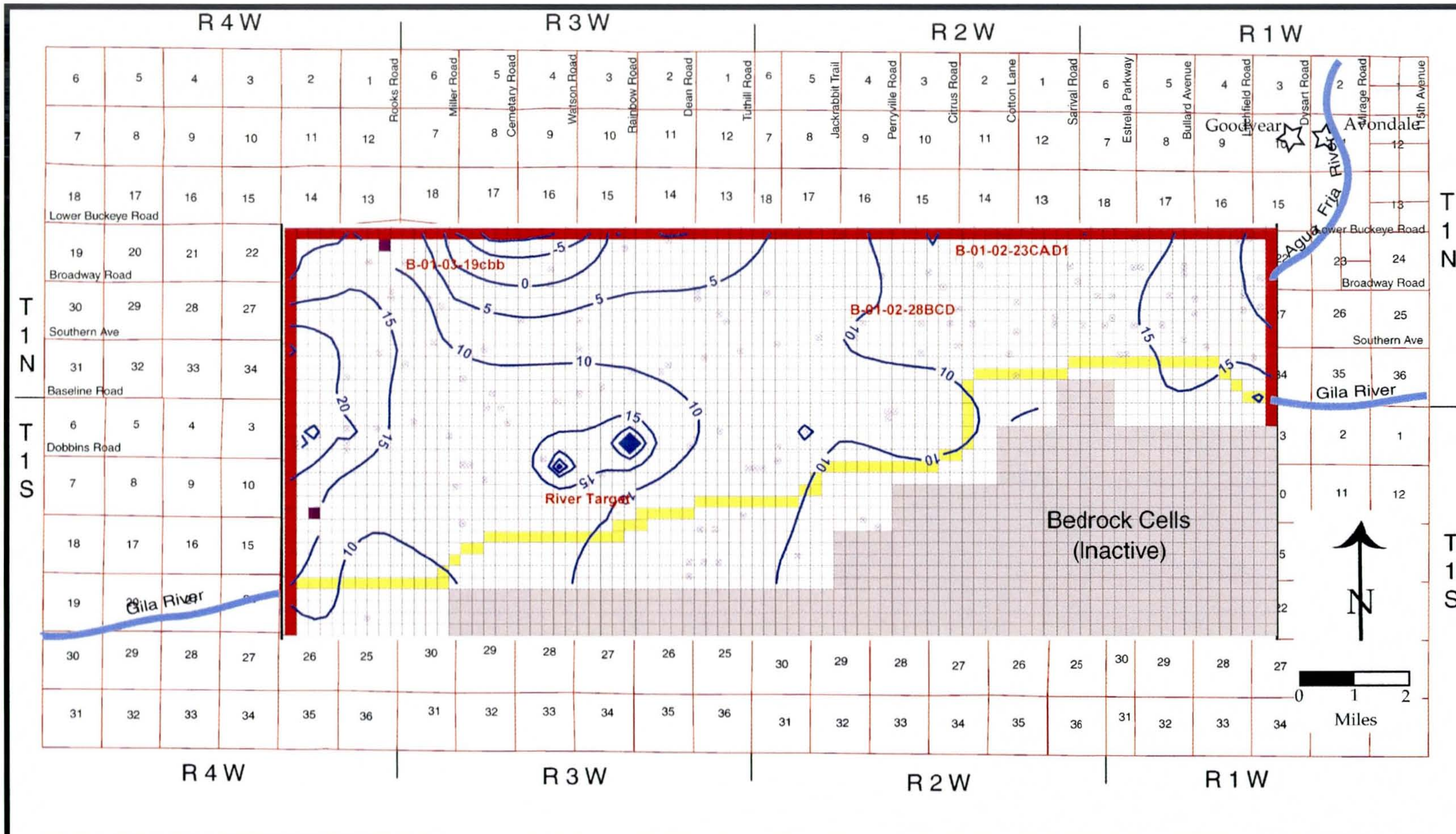

■ River Nodes

■ Boundary Nodes (Constant Flow)

■ Dewatered Nodes

Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

El Rio

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Drawdown Scenario 8: Agricultural Recharge Eliminated, Increased Pumping Layers 2 and 3

DRAWN	DATE	DWG. NO.	REV. NO.
RAB	17 Dec. 05	Figure 35	
SCALE 1:160,000	W.O. NO.		

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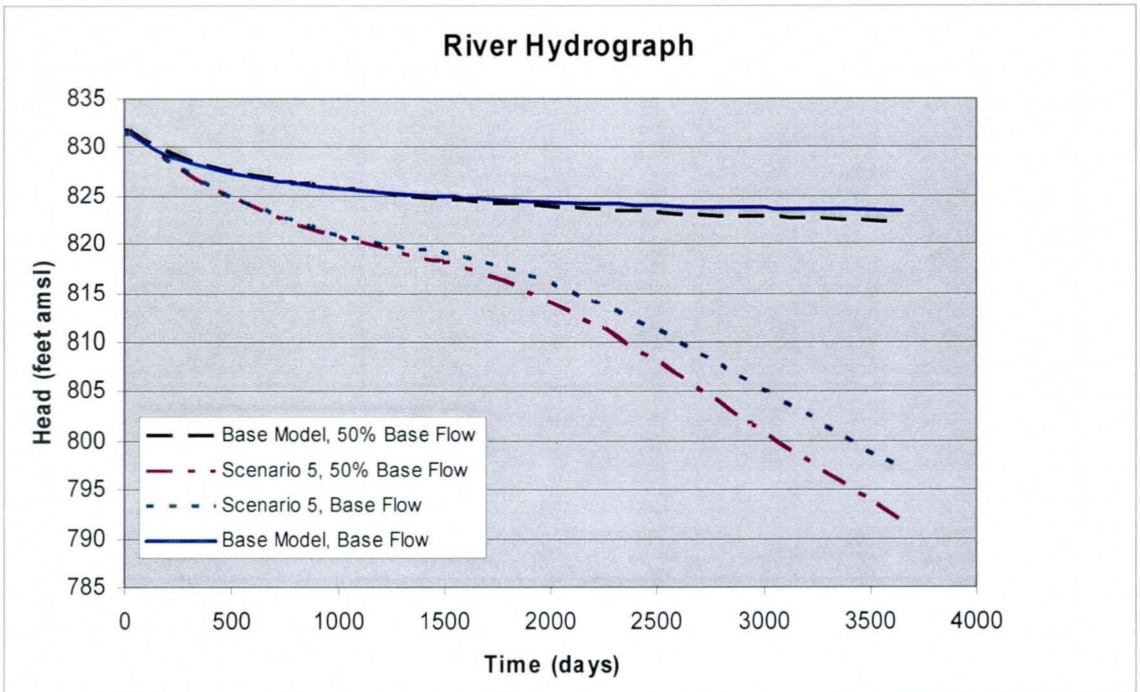
Figure 36. Comparison of Heads with Reduction in Boundary Flows



current pumping rates in all three layers results in the greatest decrease in heads near the river, particularly in the eastern portion of the model area where heads decrease by 70 feet. Scenario 2, with no pumping in the upper unit shows the opposite affect, water levels along the river rise from 10 to 20 feet. Neither scenario is likely to happen. It is likely that recharge to and pumping from the upper aquifer, although reduced will continue.

The most likely scenario will be similar to the seventh scenario which has reduced agricultural recharge, no pumping in the upper layer, and increased pumping from layers 2 and 3. This scenario shows that heads would decline as much as 15 feet in the western edge of the project area, but heads in the majority of the central portion of the area rise from 0 to 7 feet.

Based on the results of the eight scenarios, the reduction in recharge as agricultural land is retired, coupled with the decrease in pumping in the upper layer and the possible increase in pumping from the lower layers could result in declines in head beneath the river of as much as 20 feet.

DETAILED MODEL

The detailed model is a subset of the El Rio base model (Figure 37). The aquifer and river parameters in the base model, with a grid spacing of 1,056 feet, are averaged for every model node. The detailed model, with a grid spacing of 528 feet, also has aquifer and river parameters averaged over the node, but as more site specific information becomes available, more detailed information can be obtained for the area of concern.

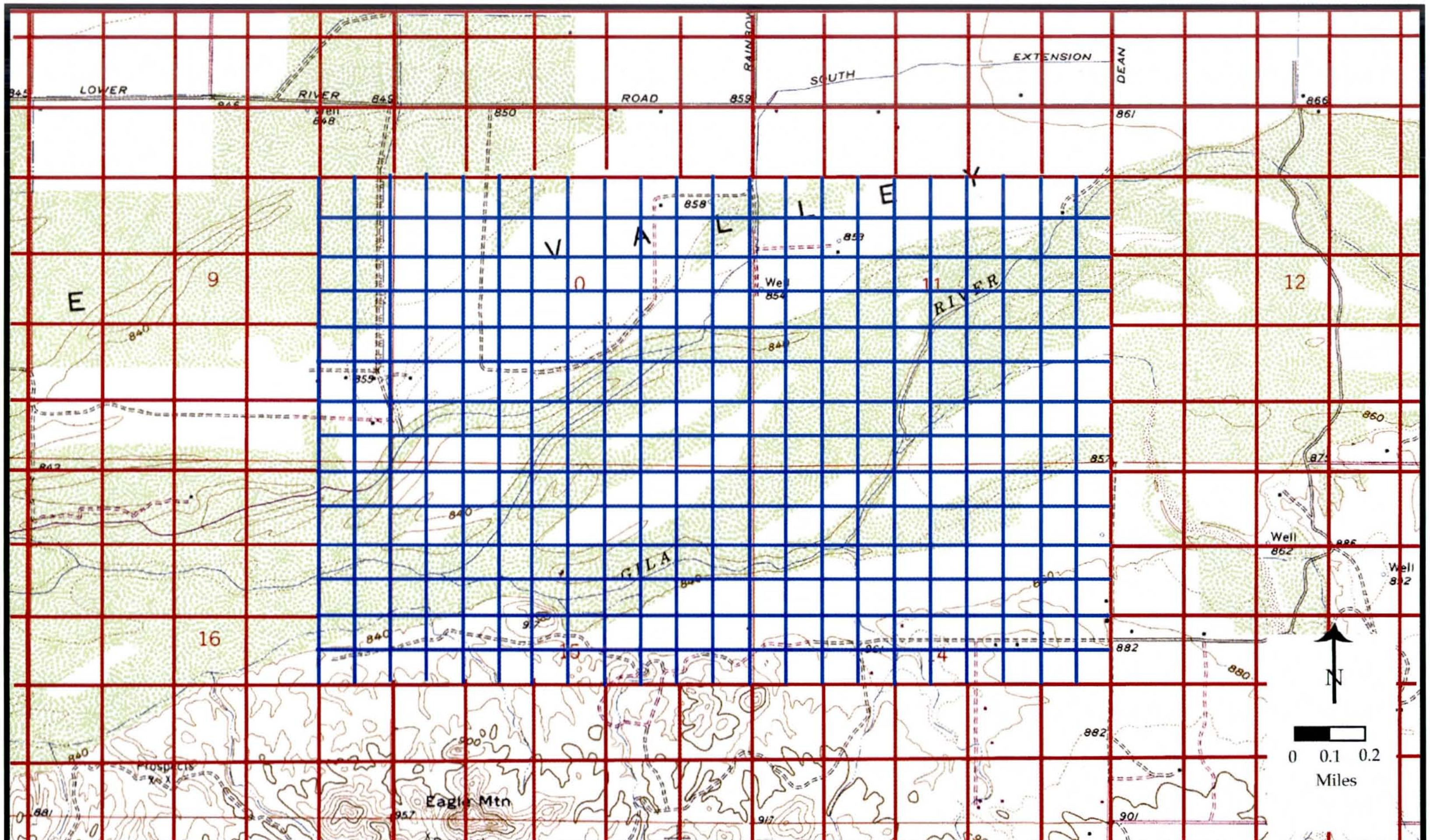
Location

The area selected by the District for the detailed model is the area between Watson and Dean Roads within the project area. The detailed model area is 1.4 miles wide and 2 miles long and is centered on the Gila River.

Changes to the Calibrated Model

Land surface elevations in the detailed model area are available from the channel cross sections surveyed along the Gila River for the surface flow modeling. Changing the surface elevations to an average for the smaller grid spacing allowed a better definition of the river channel within the detailed model area. Where the base model had one node for the entire river, the detailed model now shows several distinct channels (Figure 37). Although the channels locations do not appear to match those on the topographic map base, the channels correspond to the more recent data from the cross sections.

Aquifer parameters, pumping distribution and recharge distribution remained the same as in the base model.



Primary Model Node (0.2 miles)

Detailed Model Node (0.1 miles)

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Detailed Model Grid

DRAWN	DATE	DWG. NO.	REV. NO.
RAB	14 Nov. 05	Figure 37	
SCALE 1:24,000	W.O. NO.		

Scenario 1: Reduced Recharge, Layer 1 Pumping Eliminated, No Increased Pumping in Layers 2 and 3

The first detailed scenario evaluated the changes in hydraulic head along the river as recharge is eliminated north of the Buckeye Canal in year 5. It assumes that the only pumping is from Layers 2 and 3 and that pumping rates remain similar to those in 2003.

Heads along the river in the detailed model area rise 2.5 feet on the eastern edge of the model and decline 2.5 feet along the northwestern edge (Figure 38).

Scenario 2: Reduced Recharge, Layer 1 Pumping Eliminated, Increased Pumping in Layers 2 and 3

The second detailed scenario evaluated the changes in hydraulic head along the river as recharge is eliminated north of the Buckeye Canal and pumping increases from layers 2 and 3 in year 5.

Within the detailed model area hydraulic heads decline 15 to 40 feet, (Figure 39).

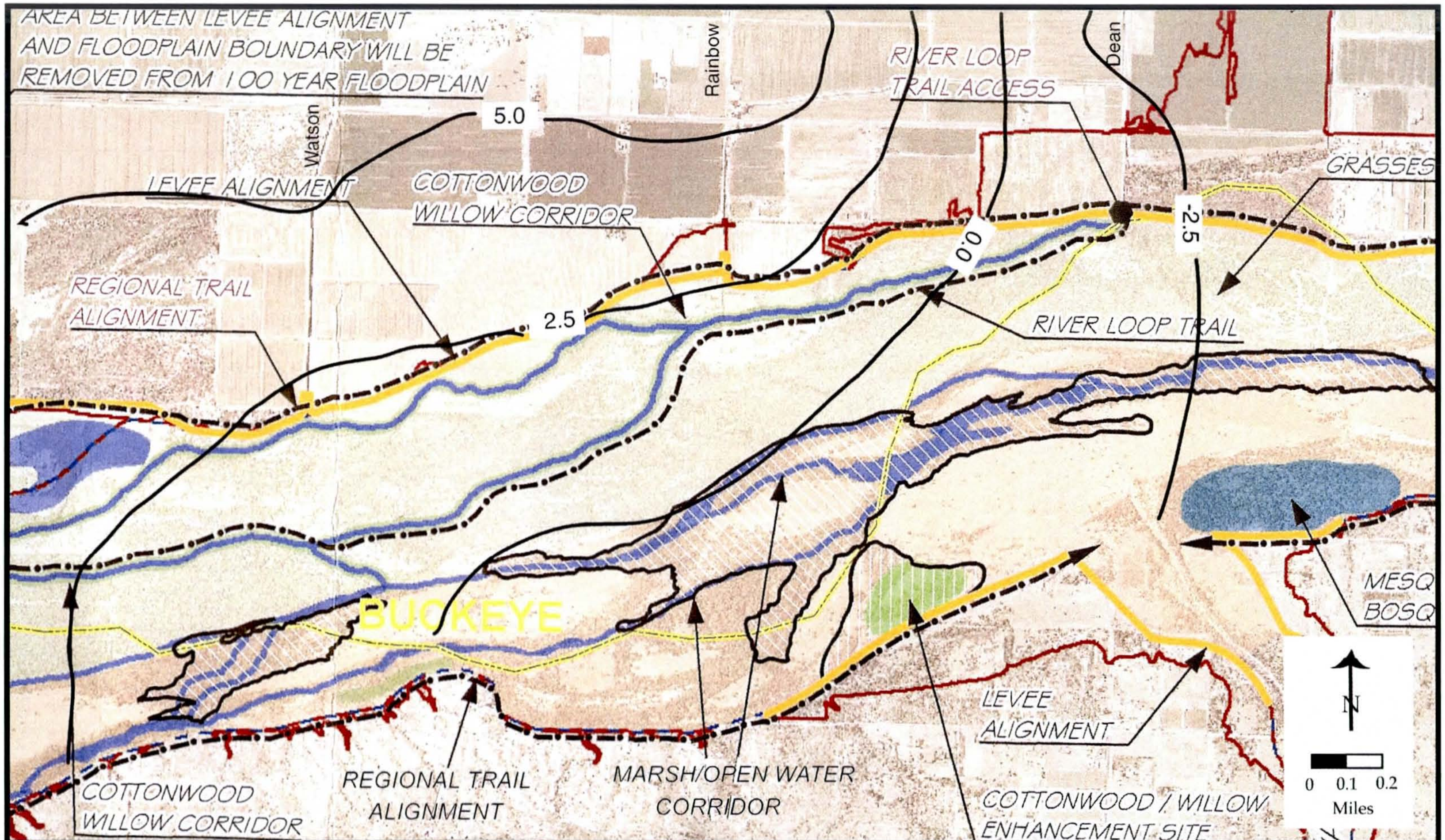
Scenario 3: Increased Pumping, Reduction in Recharge, Increased Recharge along River

The third scenario is the same as Scenario 2, but includes additional recharge along the river to reduce the drawdown beneath the river. The recharge was added at point locations to provide an example of the impact of recharge on the drawdowns beginning in year 5.

Within the detailed model area, the decline in heads is reduced by half as compared to Scenario 2 (Figure 40). However, because the three layers are interconnected near the river, 600,000 AFY are needed before the declines in heads are cut in half.

Discussion, Recommendations and Conclusions

The detailed model provides a reasonable method of evaluating changes within the groundwater system along the Gila River between Watson and Dean Roads. It simulates changes in head that are similar to those calculated by the larger scale base model. The model was run with two scenarios that show the changes in head as pumping is increased in the deeper layers. An



2.5 Contour showing Reduction in Head (feet), after ten years

Contour Interval = 2.5 feet

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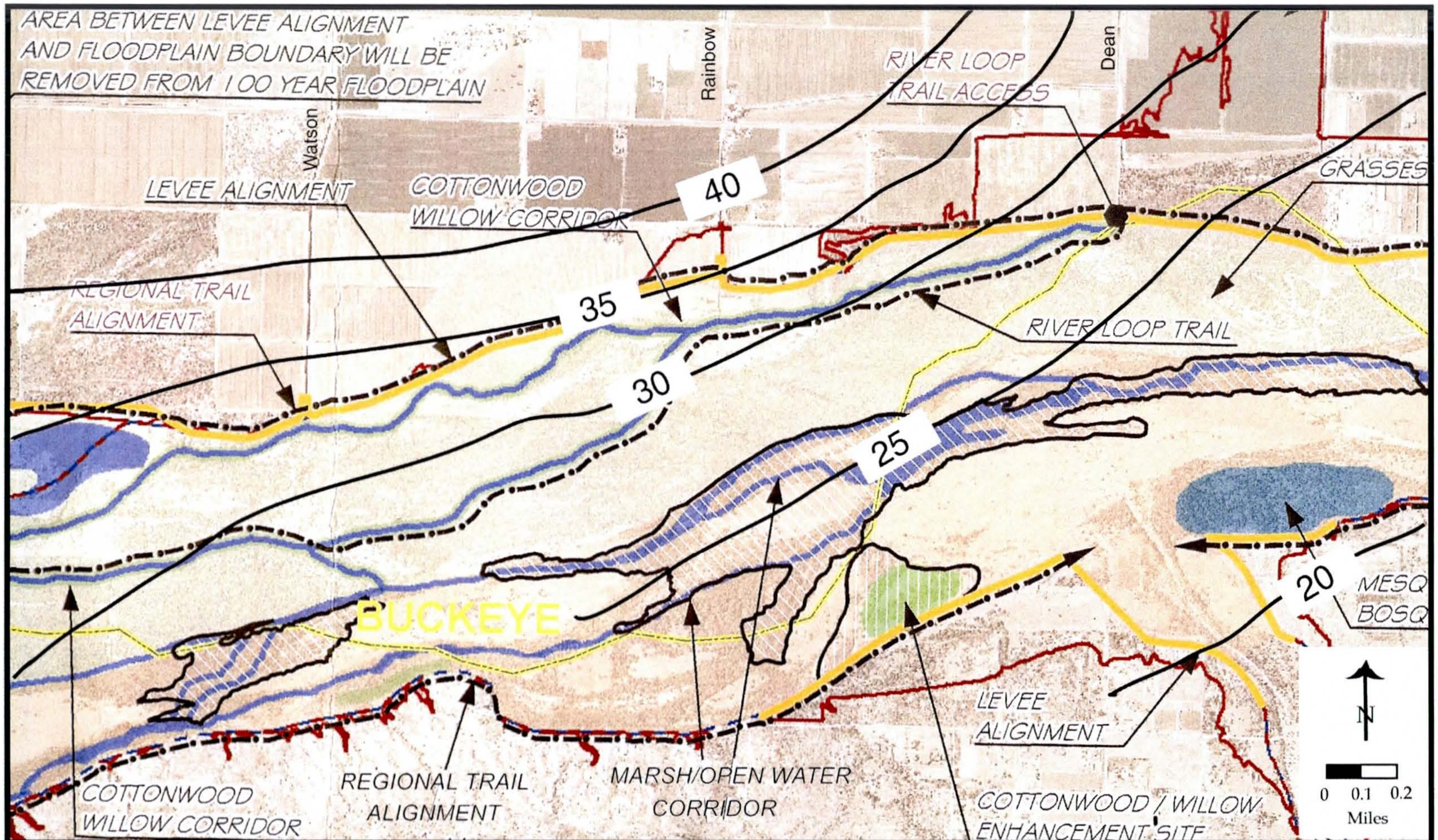
Drawdown Scenario 1: Reduced Recharge, Layer 1 pumping eliminated No Increased Pumping in Layers 2 and 3

DRAWN	DATE	DWG. NO.	REV. NO.
RAB	14 Nov. 05	Figure 38	
SCALE 1:24,000	W.O. NO.		



2.5 Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

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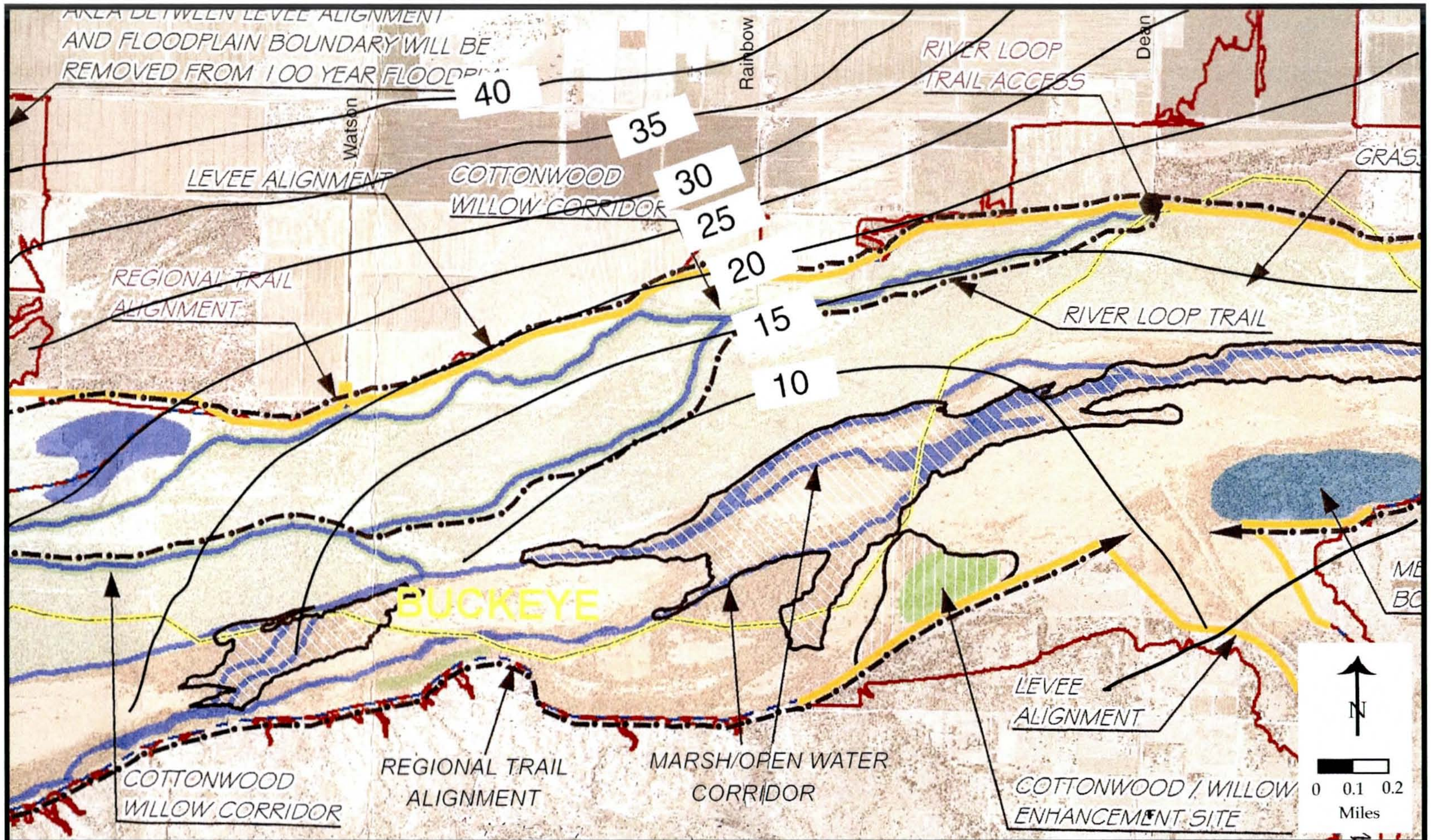
**Drawdown
Detailed Scenario 2:
Partial Recharge
Increased Pumping**

DRAWN	DATE	DWG. NO.	REV. NO.
RAB	14 Nov. 05	Figure 39	
SCALE 1:24,000	W.O. NO.		



2.5 Contour showing Reduction in Head (feet), after ten years

Contour Interval = 5 feet

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Detailed Scenario 3: Partial Recharge, Increased Pumping and Recharge Wells

DRAWN	DATE	DWG. NO.	REV. NO.
RAB	14 Nov. 05	Figure 40	
SCALE 1:24,000	W.O. NO.		

increase in pumping of 4.5 x 10^6 cfd (37,700 acre-feet per year) in layers 2 and 3 causes a reduction in heads near the river of 20 to 40 feet. This decline can be reduced by adding recharge along the river channel or through recharge wells. An example of the application of additional recharge is shown in Scenario 3. This scenario assumes that water is recharged directly to the groundwater aquifer. Because of the interconnection of the aquifers near the river, 600,000 AF per year are required to cut the declines in head near the river in half as compared to Scenario 2. This is an unrealistic approach. It would be more efficient and require less water if the water is applied directly to the plants.

If pumping in the deeper layers is not increased, heads within the detailed model area remain relatively stable with a range of change from 2.5 feet of decline to 2.5 feet of rise.

The scenarios show that the area near the river is sensitive to changes in the distribution of pumping and recharge and the degree of interconnection between the three hydrologic units. The assumptions made for the aquifer parameters are reasonable, but the model can only provide relative comparison of possible changes in head until better, site specific information is available. The model should be updated with site specific data as it becomes available, and model scenarios revised as changes in groundwater use occur within the area.

The scenarios show that heads near the river may rise or decline depending on the changes that are occurring in the El Rio area. The magnitude of changes are such that riparian and wetland vegetation could be stressed as depths to water fall below or rise above rooting depths. One means of mitigating the effects of the changes in groundwater is to develop a tiered contingency plan that can be implemented as changes occur. Proactive management of the project should begin with selecting wells in which groundwater heads can be monitored. Wells should be selected in the regional aquifer to provide both early warning of changes but should also be monitored in areas of critical vegetation within the project. The wells cannot be pumped and construction information needs to be available to ensure that the wells are completed in the shallow sediments. One possible category of wells that should be examined for use are the dewatering wells currently used by BWCCD. It is unlikely that suitable wells will be found within the El Rio project area, so shallow wells may need to be installed as part of the project. A preliminary recommendation is that at least one well be selected for monitoring in the regional aquifer and that three wells be installed within the project area. Wells can be equipped with recorders and telemetry equipment so that data can be downloaded remotely.

Heads could be monitored on a monthly basis with the plan providing levels which trigger a specific action. For example, a five-foot decline in heads in the regional well for more than three months might trigger weekly monitoring of the project wells. Declines of one-foot for more than three weeks in a project well located in a wetlands area could trigger the implementation of a water augmentation system designed to mitigate the effects of the groundwater declines on the vegetation.

The plan should identify the vegetation most susceptible to changes in groundwater and the triggering events that stress the vegetation. The triggering events, such as different depths-to-water and the lengths of time needed before the vegetation is stressed or dies, should be set based on the vegetation monitored by the specific well. For example, a marsh or wetland community may be most susceptible at changes of a foot or more over a few weeks, while a cottonwood/willow community may not show stress until depths-to-water are greater than 10 feet over a several month period.

DATA RELIABILITY

The data used in this evaluation of the hydrology of the El Rio project area provide a reasonable snapshot of conditions within the area during average precipitation (early 2000s) and drought conditions (early 1960s). The interpretation of the data is influenced by the accuracy of the data in representing the actual conditions in the aquifer. The accuracy of the data can be influenced by errors when measuring the water levels, errors in estimating land surface elevations and/or locations of the wells, errors caused by measuring water levels in pumping wells, errors created when entering the data into the electronic data base and errors introduced during the extrapolation of the data.

DATA MEASUREMENT ERRORS

Different field personnel measured the water level data over many years. In the 1960s the data would have been collected using chalk and a steel tape, while it is likely data from the 1990s were measured using a water level indicator that emits a sound when the water is sensed. Both methods require that the field person determine when the water surface is encountered, and then measure a length of tape or wire to determine the actual depth to water. Mistakes can occur in determining the starting measurement at the top of the well casing, in determining the length of tape below the water surface and in subtracting the two.

LAND SURFACE AND LOCATION ERRORS

Many of the wells have never been surveyed. The well locations and top of casing elevations are estimated using a USGS topographic map. The wells are located to the quarter, quarter, quarter section. This places the well anywhere within a 10 acre parcel (within a square that is 660 feet on a side). The land surface elevation for the well may be estimated from the topographic map, as well. In this area the topographic maps have a contour interval of 10 feet, which provides a margin of error in the elevation of plus or minus 5 feet.

PUMPING WELLS

Water levels are generally measured in January and February to minimize the effect of pumping on groundwater elevations. The water level database does not contain information on nearby pumping wells, or when the well being measured was last pumped. Water levels in pumping wells are not representative of water levels in the surrounding aquifer because of the inefficiencies in moving water into the well. Water levels within a well also do not recover to those of the surrounding aquifer immediately when a pump is shut down. If a water level measurement is collected before the water level has stabilized in the well, the water level measurement may provide a point measurement that is not representative of the aquifer.

TRANSCRIPTION ERRORS

Water level measurements are first recorded on a field data sheet or in a field notebook. They may be stored in paper files and eventually transcribed to an electronic database. Errors can occur at any stage of the data transfer process.

EXTRAPOLATION OF THE DATA

The water level measurements are point measurements within an aquifer. There are standardized methods for interpreting the data and creating a water table map, but all of the methods assume that the data are representative of the water levels in the aquifer. Although the hydrologic units are interconnected in the area surrounding the Gila River, this is not true for areas away from the channel where clays in the MAU limit vertical movement between the layers. Wells in the area away from the River may be screened in just the UAU or the MAU, or they may be screened across both the UAU and MAU. The aquifer of interest for the El Rio project is the shallow UAU; so composite water levels for wells screened across the two units may not be representative of the shallow UAU. Screened intervals aren't available for all wells so determining which unit they represent isn't always possible.

SHALLOW BEDROCK

There are several areas of shallow bedrock in the El Rio Project area. Fractured zones within the bedrock can transmit substantial quantities of water to wells, but the water is not necessarily connected to the water table in the alluvial aquifer. The bedrock water levels may occur at an elevation higher than the regional water table, and may be incorrectly interpreted to be a major source of recharge to the alluvium because of the steep gradients. However, the limited storage capacity of the fractured bedrock limits the volume of water that can be provided to the alluvium on a continuous basis.

APPLICABLE REGULATIONS (ADWR, 1993)

Although the District has the right to modify the river channel to mitigate damage from flood events, that right may not extend to impounding water for the purposes of creating recreational lakes. To understand the effect of Arizona water law on the El Rio project, it is important to recognize that separate and distinct regulations govern surface water and percolating groundwater. Effluent is not comprehensively regulated under either of these doctrines. But, water quality laws enacted by the State and federal governments substantially affect how water can be used and managed.

RIGHTS TO SURFACE WATERS OF THE STATE

Except for Colorado River water, rights to use surface water in Arizona are subject to the doctrine of prior appropriation. Based on the tenet "first-in-time, first-in-right", appropriated water in Arizona must be beneficially used and its use must be appurtenant to the land.

In 1953, the Arizona Supreme Court ruled that percolating groundwater was to be excluded from the doctrine of prior appropriation, while surface water was subject to the doctrine. Surface water is defined to mean waters of all sources, flowing in streams, canyons, ravines or other natural channels, or in definite underground channels, whether perennial or intermittent, flood, waste or surplus water, and of lakes, ponds and springs on the surface. The process of appropriation and registration of surface water diversion has been in place since before statehood. The issue of when hydrologically connected waters are separated into the legally divided "surface waters" and "percolating groundwater" is currently the subject of litigation before the Arizona Supreme Court.

TYPES OF SURFACE WATER RIGHTS

Water users have established rights to use surface water under a number of different statutes. A water user can hold a pre-1919 surface water right based on an appropriated and continuous use started prior to statehood. These rights had to be registered with the State prior to June 30, 1979 to remain valid. After 1919, a water right could be established by an application for a permit to appropriate under State code. Stock ponds with a capacity of less than 15 acre-feet have had to have a permit since 1977. Those ponds in existence before 1977 could be recognized as having valid rights prior to 1977 if a claim for the pond was made prior to June 30, 1979.

Anyone who files an application for permit to appropriate may be granted the permit if the appropriation does not conflict with vested rights, is not a menace to public safety or against the interests and welfare of the public. After approval of a permit the permit holder has two years to begin construction of diversion works and five years to complete the construction unless additional time is justified and allowed by the ADWR. The permit to appropriate must be perfected before the ADWR may issue a certificate of water right. All permits and certificates are for specific uses at specific places. Each certificate is endorsed with the priority date and extent and purpose of the right. The right must be beneficially used or it may be subject to abandonment and forfeiture.

Beneficial use generally means using water for domestic, municipal, irrigation, stock watering, electric power generation, recreation, wildlife including fish, artificial groundwater recharge, and mining uses. The water right becomes attached and appurtenant to the land on which it is beneficially used.

Other permits are associated with certificates of appropriation. Reservoir permits may be applied for to store water that may be beneficially used by certificate holder. Underground storage and recovery permits may also be obtained to store and use water pursuant to certificates.

In the past, water had to be diverted and put to beneficial use off stream. However, the ADWR now recognizes "in-stream" uses principally for wildlife including fish and recreation. Several permits to appropriate in-stream water rights have been issued. The location and use of these rights are contained in the planning area chapters. Water can now also be diverted and used for general recharge of the groundwater aquifers. Such water remains public water and can be captured by groundwater right holders. It is these in-stream use permits that would most closely meet the needs of the District in developing the El Rio alternatives.

RECOMMENDATIONS AND CONCLUSIONS

The complexity of the groundwater-surface water interaction within the El Rio area, coupled with the probable changes in recharge and pumping with time, make it difficult to determine whether the depths to water in the range needed for the riparian vegetation will be available long term. Despite the lack of precision, some conclusions can be reached regarding the groundwater system in the El Rio area.

Shallow groundwater levels and flowing streams, uncharacteristic of other parts of the Gila River drainage, are common in El Rio's environs, as are riparian vegetation and habitat. Here, the area's history of geologic upheaval coupled with human intervention in the normal course of surface water movement have combined to create a riparian area where groundwater that may have flowed hundreds of feet below the surface in other parts of the basin is forced to the surface and reappears as stream flow through much of this reach.

The area demonstrates the effects that slow urbanization of agricultural lands can have on the underlying aquifer system. Water use patterns will be modified as agricultural fields are converted to subdivided lots. With the loss of this imported water, most water use in the area will come from the local aquifer to satisfy municipal and subdivision. Effluent from these sources will be transported to treatment facilities outside the El Rio area and, from there, possibly routed to other uses. This pumping will reduce heads in the area possibly increasing flow from El Rio toward the west. During future drought periods, this could result in decreased water levels in the west of the study area where none have been observed in the past.

Water levels in the El Rio area will be aided by in-channel recharge projects planned for the Agua Fria River. A large portion of the water entering the stream channel alluvium along the Agua Fria and Salt River Systems will, in all likelihood, reemerge as rejected recharge in the El Rio area, sustaining water levels near their current elevations.

Over the last several years whenever large, multi-objective projects were planned, the concept of recharging the groundwater system has usually been part of those plans. El Rio was no exception. Original expectations were that some form of groundwater recharge could be coupled with the recreational amenities developed as part of the project. After evaluating the aquifer system in the El Rio area, however, it became apparent that a recharge project with the objective of storing large quantities of groundwater for future use is infeasible under conditions in 2005.

The primary requirement for a groundwater storage project is that sufficient unsaturated alluvium be available to constitute a storage reservoir for the recharged water. In the El Rio area, water levels are so near the land surface that there is simply no place to put recharged water. In addition, the surface flow currently evident in the Gila River is rejected recharge from upstream sources. Adding additional recharge water to this area would, in all likelihood, simply increase the streamflow through the project.

This should not be construed, however, to indicate that the future El Rio programs would not have a recharge component. It may simply be that recharge will not be undertaken with the objective of storing water for future use. Instead, should water levels drop during periods of prolonged drought, artificial recharge of the riparian aquifer might be undertaken to sustain local water levels within the root zone of riparian plant communities.

Although available research indicates that the area may be entering a 30-year drought period, the magnitude of drawdowns seen in the 1960s may not be repeated during this drought cycle because of the decrease in agricultural pumping in the area and the potential recharge to this system coupled from both the WWTP and the aquifer storage and recovery projects. These should maintain El Rio groundwater levels at or near current elevations. Once specific sites have been selected for development, more site specific data should be collected to validate these conclusions.

The groundwater flow model for the El Rio area shows the impact of changes in recharge and pumping in the immediate El Rio area on groundwater levels beneath the river. The scenarios were designed to evaluate reasonable combinations of changes in pumping and recharge to determine maximum and probable impacts on groundwater levels.

If all agricultural recharge is eliminated as irrigated acreage is converted to urban uses, water levels near the river could decline 20 to 70 feet. Assuming that the change in land use results in the installation of municipal wells that tap deeper sediments and the abandonment of wells tapping shallower sediments, heads near the river could decline 0 to 30 feet in the western half of the model area and rise of 0 to 15 feet in the eastern half of the model area. The combination of the two situations, the elimination of agricultural recharge and increased municipal pumping could result in water level declines of 25 to 55 feet near the river.

The changes in pumping and recharge will occur over a period of time, not immediately as simulated in the model. An intermediate scenario, where recharge north of the Buckeye Canal is eliminated but pumping from deeper sediments isn't increased, results in declines in heads near the river of 0 to 15 feet in the western third of the project area but rises in heads of 0 to 7 feet in the eastern two-thirds of the model area.

The possible changes in groundwater levels beneath the river indicate that it is possible that a time will come when the groundwater levels are below the rooting depths of the riparian and wetland vegetation within the El Rio area. A contingency plan for implementation of mitigation measures such as limited irrigation or increased flows in surface streams near critical habitat needs to be developed. The plan should identify locations to monitor groundwater heads with time and use the changes in heads to trigger response strategies to mitigate impact of groundwater changes on the river habitat.

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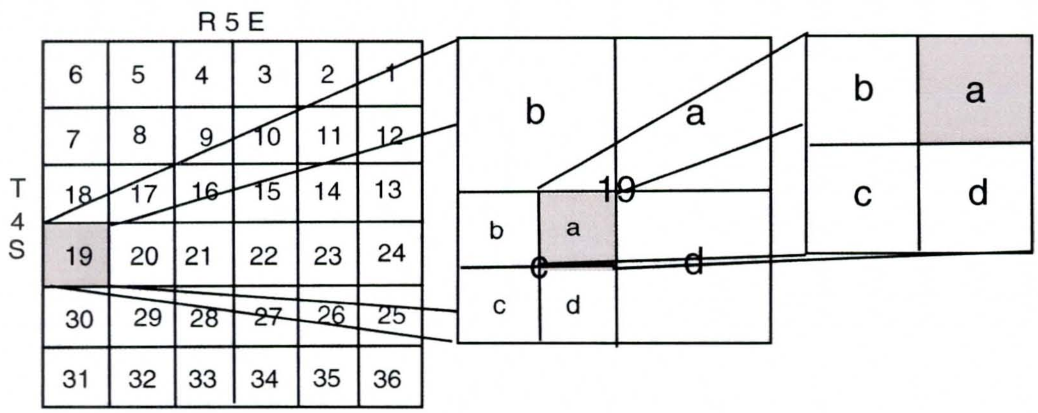
APPENDIX A

USGS Cadastral Numbering

Quadrant D, Township 04 South, Range 05 East, Section 19, Quarter Section c, Quarter Section a, Quarter Section a



The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in "A" quadrant, that north and west in "B" quadrant, that south and west in "C" quadrant, and that south and east in "D" quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-4-5) l9caa designates the well as being in the NE ¼, NE ¼, SW ¼, Sec. 19, T 4 S, R 5 E. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

APPENDIX B

ADWR 55 Database Information

(Provided on CD)

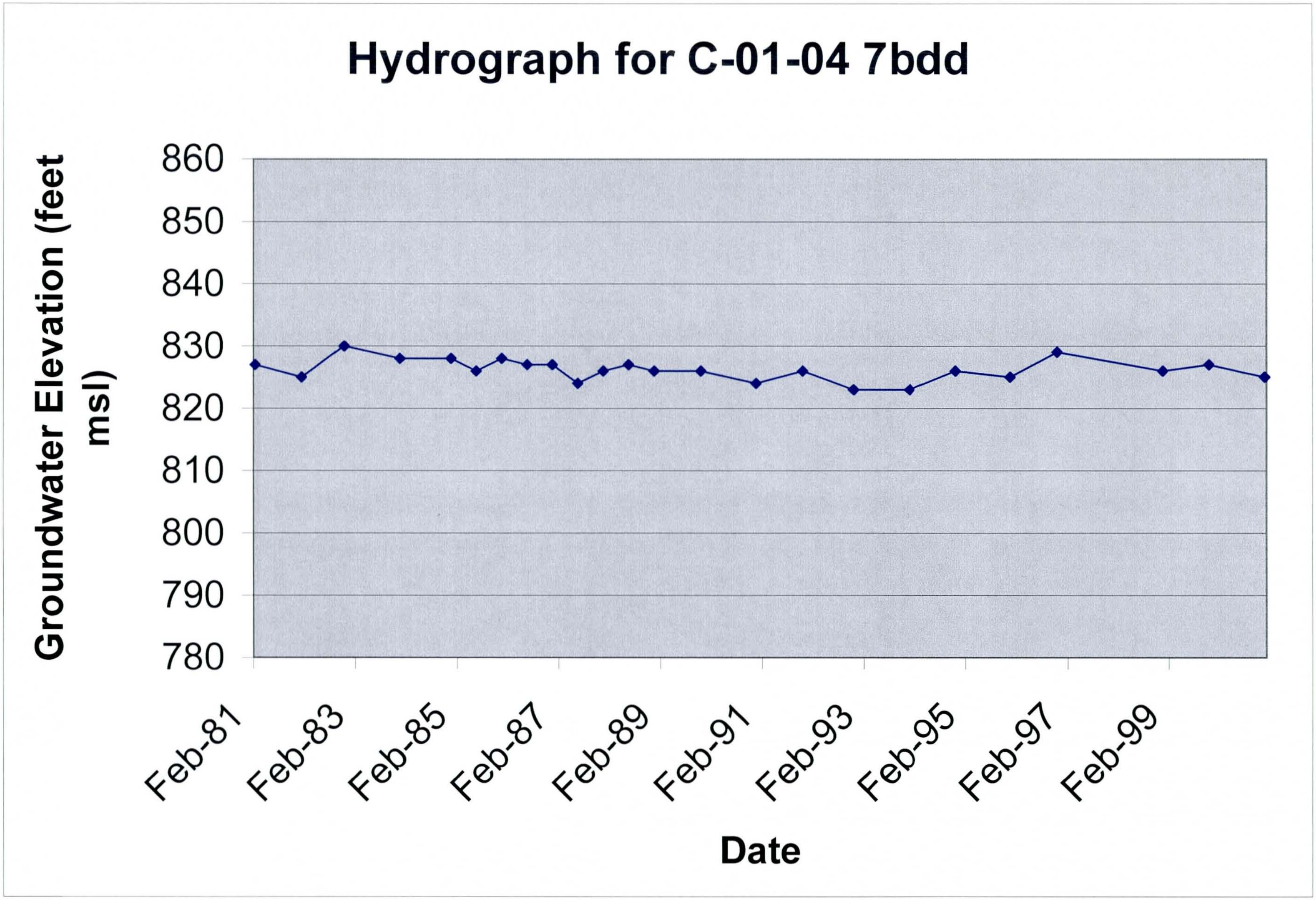
APPENDIX C

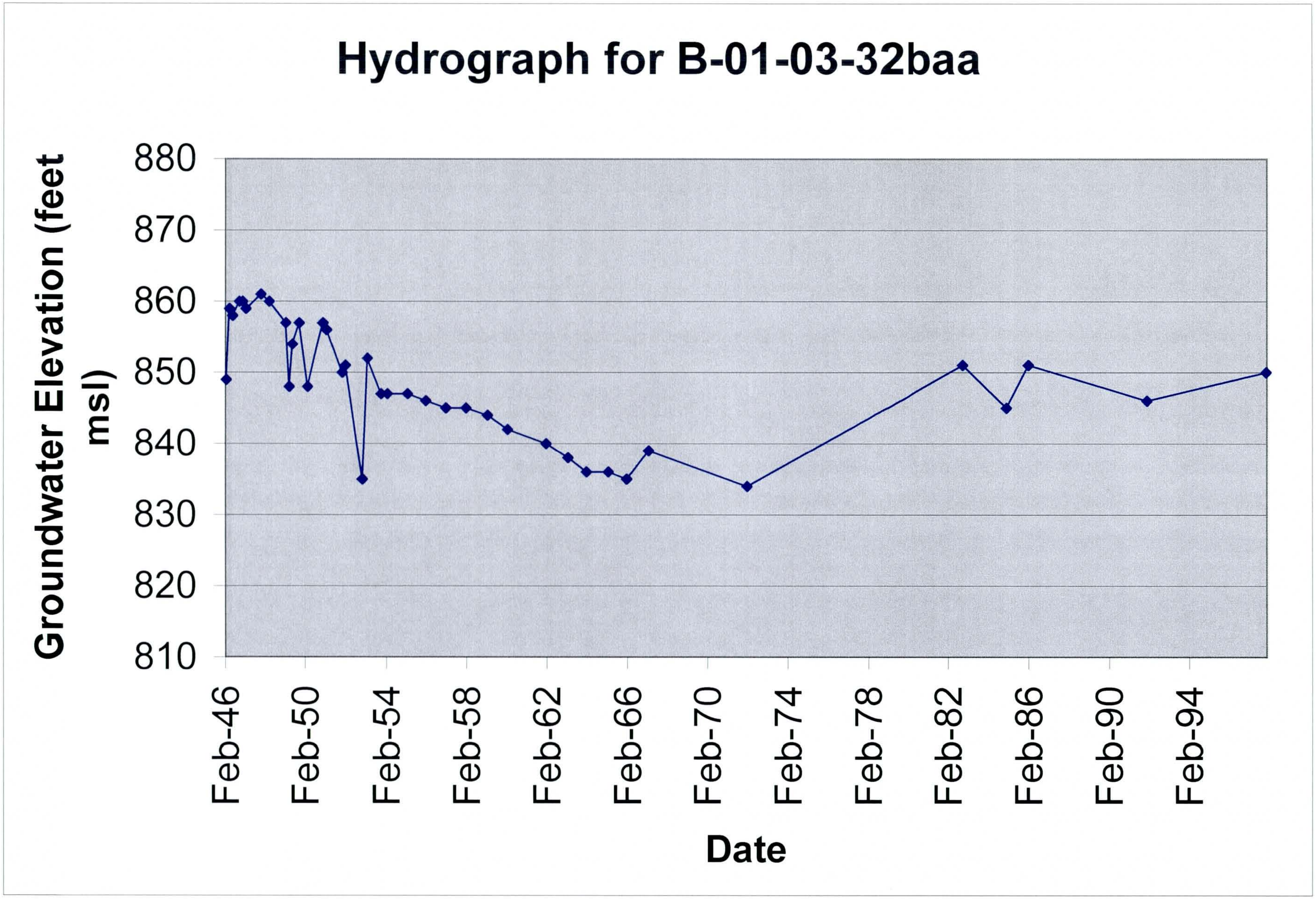
Groundwater Elevations

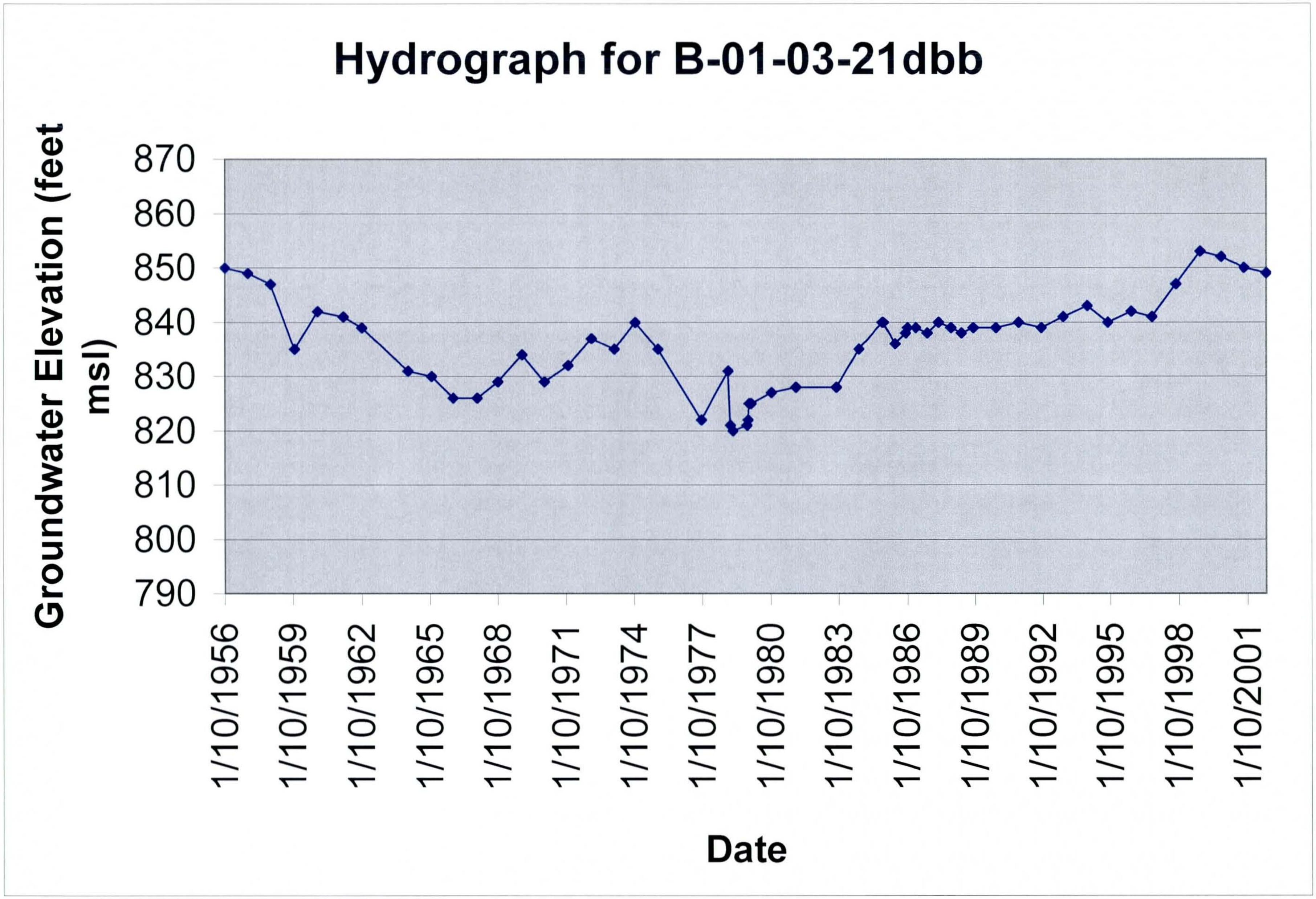
(Provided on CD)

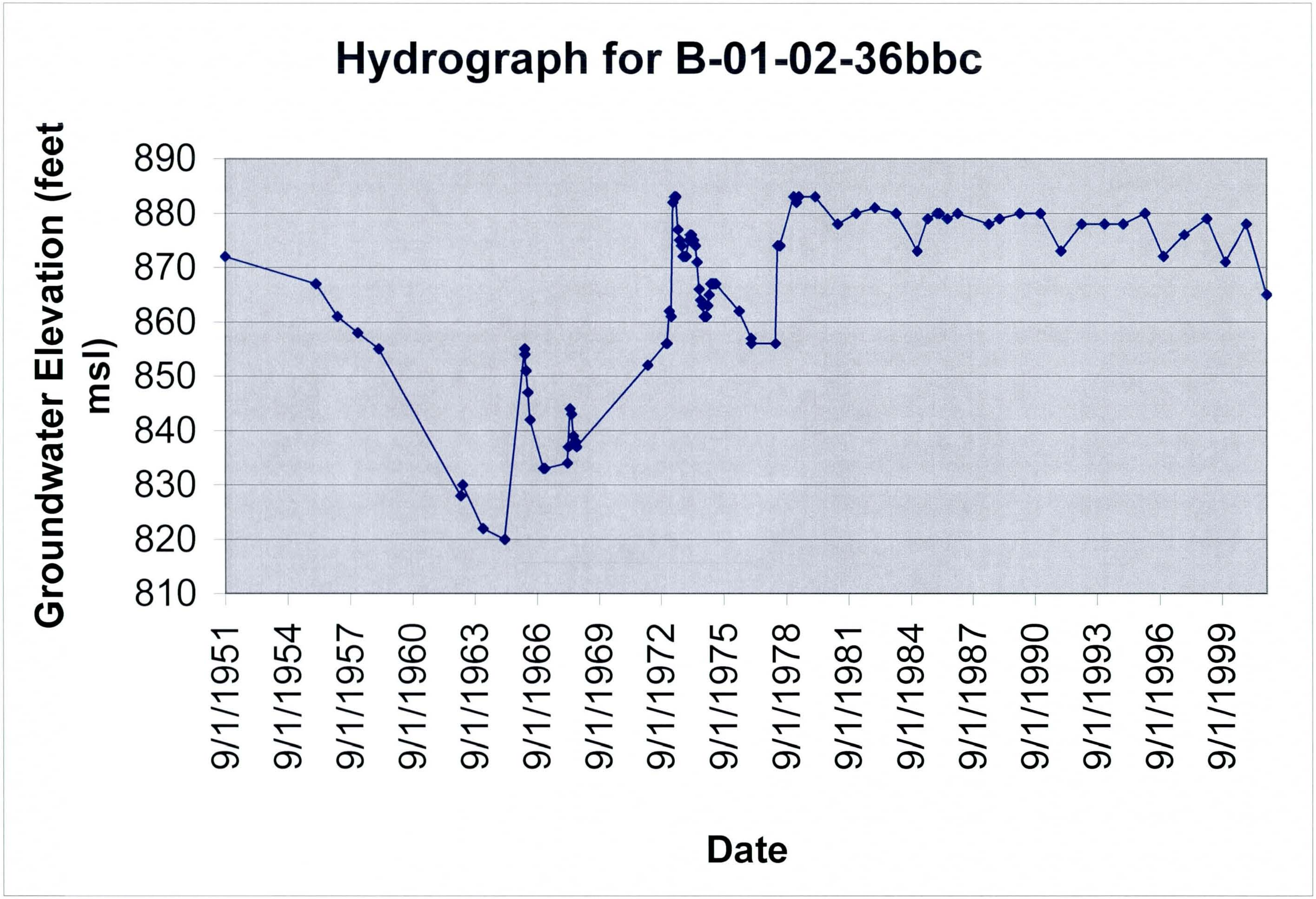
APPENDIX D

Groundwater Hydrographs

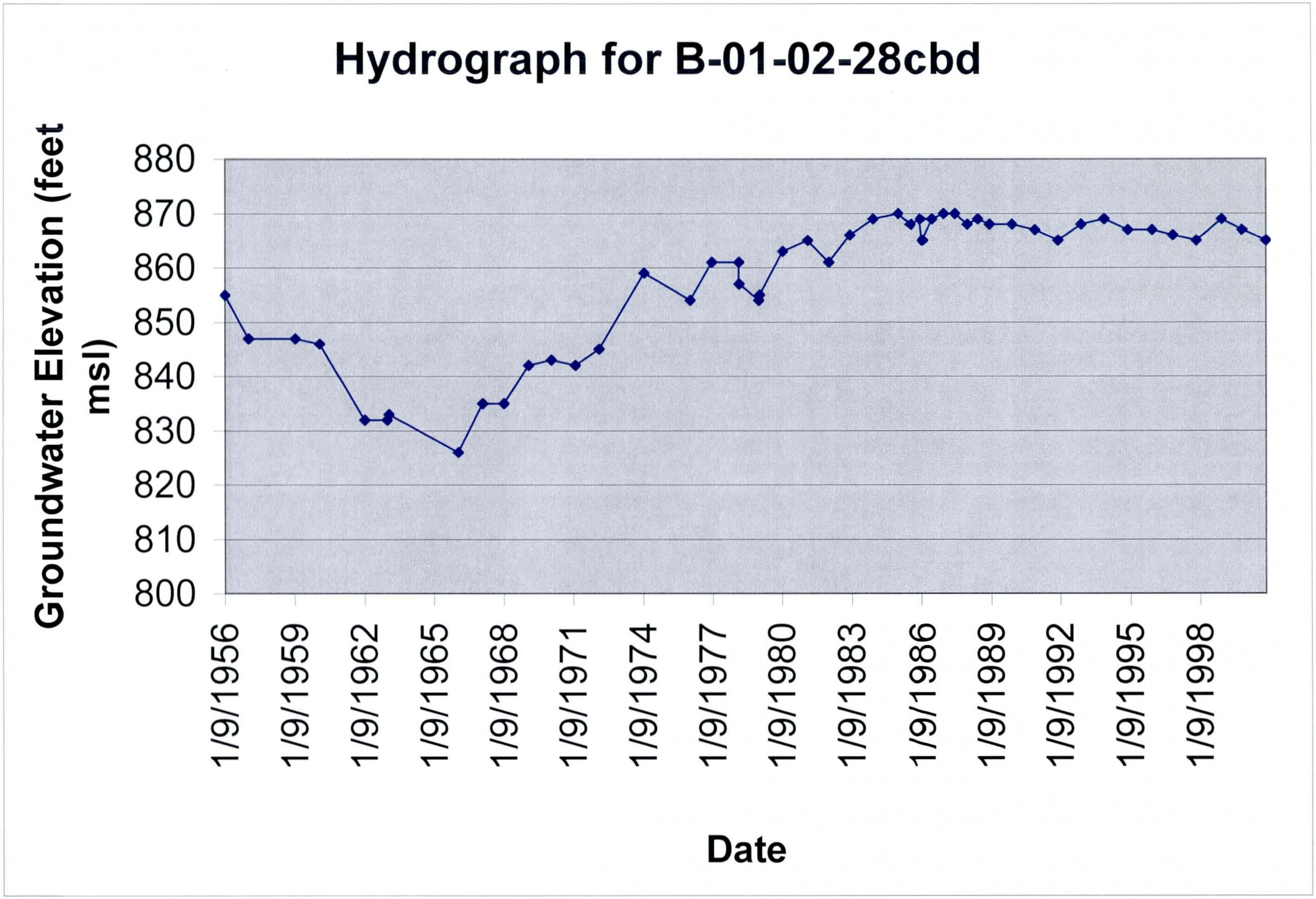

Hydrograph for C-01-04 7bdd
Groundwater Elevation (feet msl)
860
850
840
830
820
810
800
790
780
Feb-81
Feb-83
Feb-85
Feb-87
Feb-89
Feb-91
Feb-93
Feb-95
Feb-97
Feb-99
Date

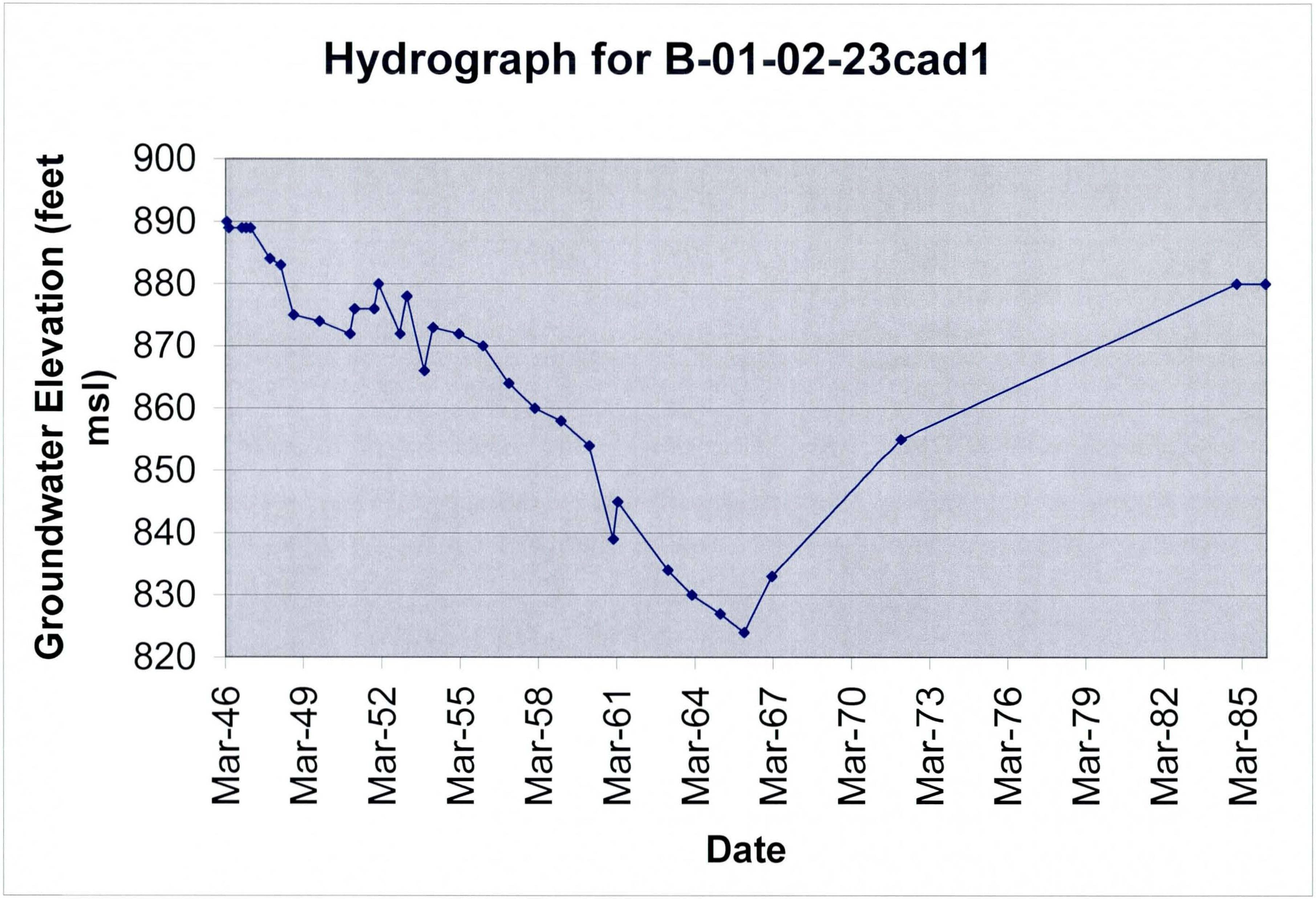

Hydrograph for B-01-03-32baa
Groundwater Elevation (feet msl)
880
870
860
850
840
830
820
810
Feb-46
Feb-50
Feb-54
Feb-58
Feb-62
Feb-66
Feb-70
Feb-74
Feb-78
Feb-82
Feb-86
Feb-90
Feb-94
Date

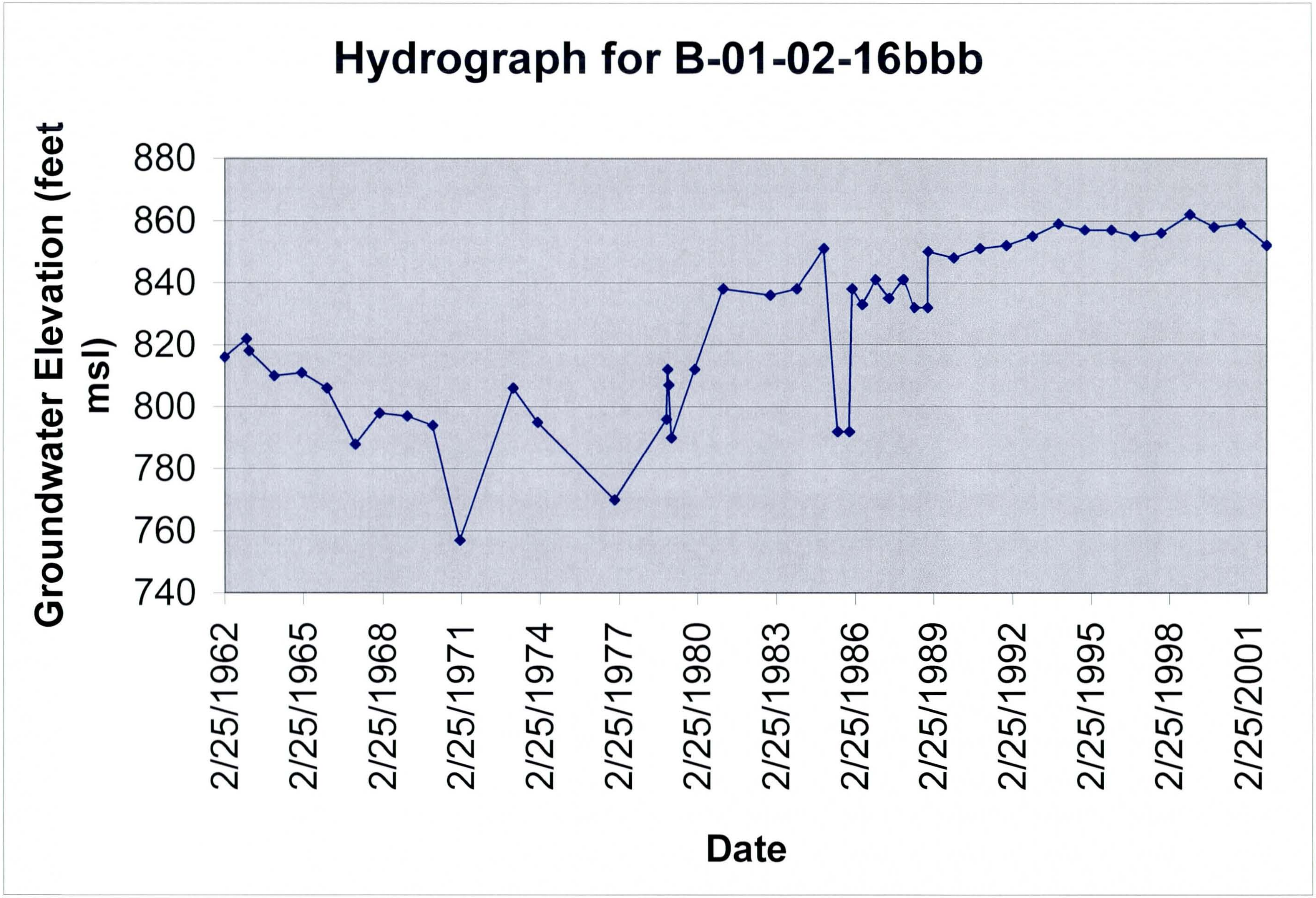

Hydrograph for B-01-03-21dbb
Groundwater Elevation (feet msl)
870
860
850
840
830
820
810
800
790
1/10/1956
1/10/1959
1/10/1962
1/10/1965
1/10/1968
1/10/1971
1/10/1974
1/10/1977
1/10/1980
1/10/1983
1/10/1986
1/10/1989
1/10/1992
1/10/1995
1/10/1998
1/10/2001
Date

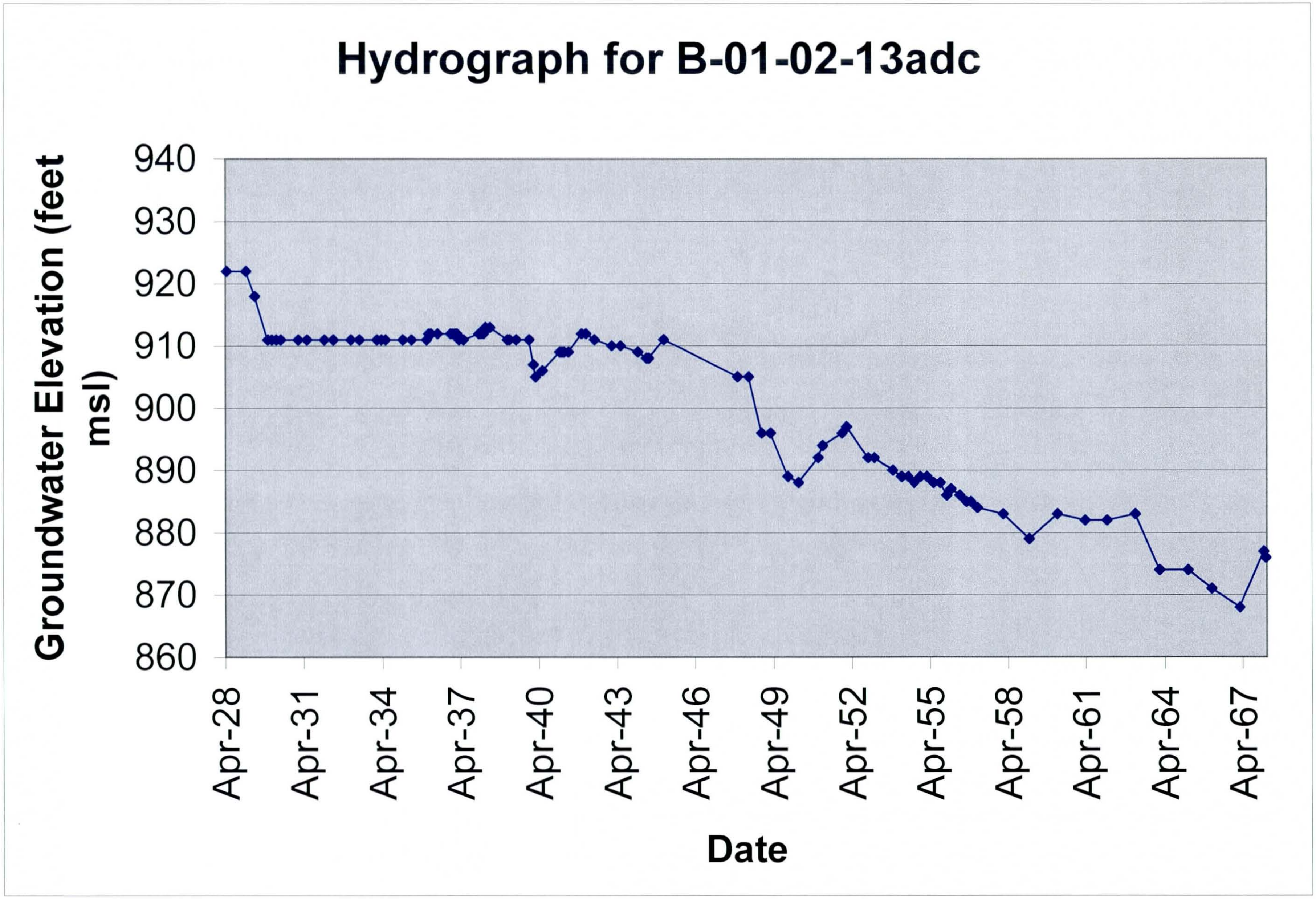


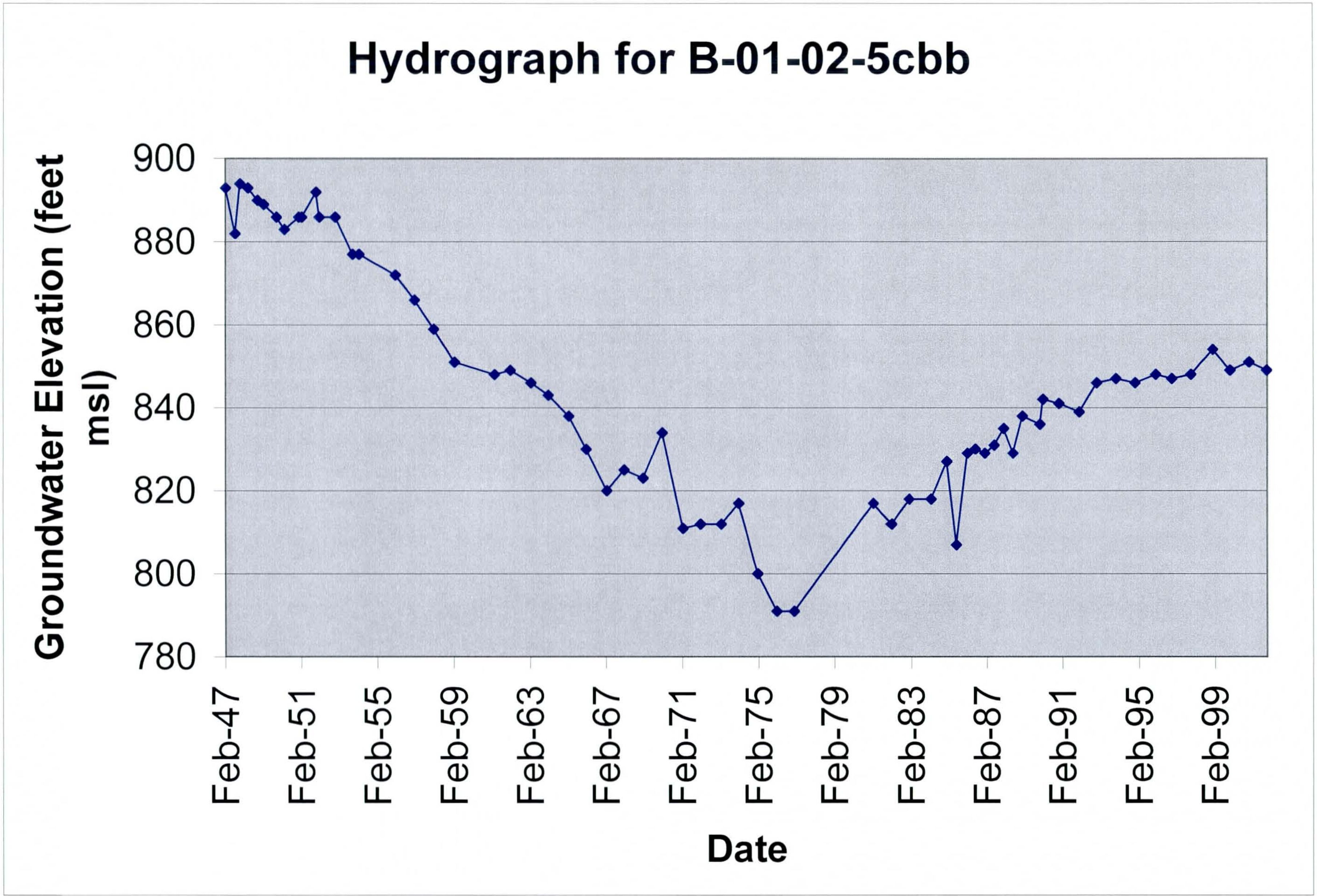
Hydrograph for B-01-02-36bbc
Groundwater Elevation (feet msl)
890
880
870
860
850
840
830
820
810
9/1/1951
9/1/1954
9/1/1957
9/1/1960
9/1/1963
9/1/1966
9/1/1969
9/1/1972
9/1/1975
9/1/1978
9/1/1981
9/1/1984
9/1/1987
9/1/1990
9/1/1993
9/1/1996
9/1/1999
Date


Hydrograph for B-01-02-28cbd
Groundwater Elevation (feet msl)
880
870
860
850
840
830
820
810
800
1/9/1956
1/9/1959
1/9/1962
1/9/1965
1/9/1968
1/9/1971
1/9/1974
1/9/1977
1/9/1980
1/9/1983
1/9/1986
1/9/1989
1/9/1992
1/9/1995
1/9/1998
Date

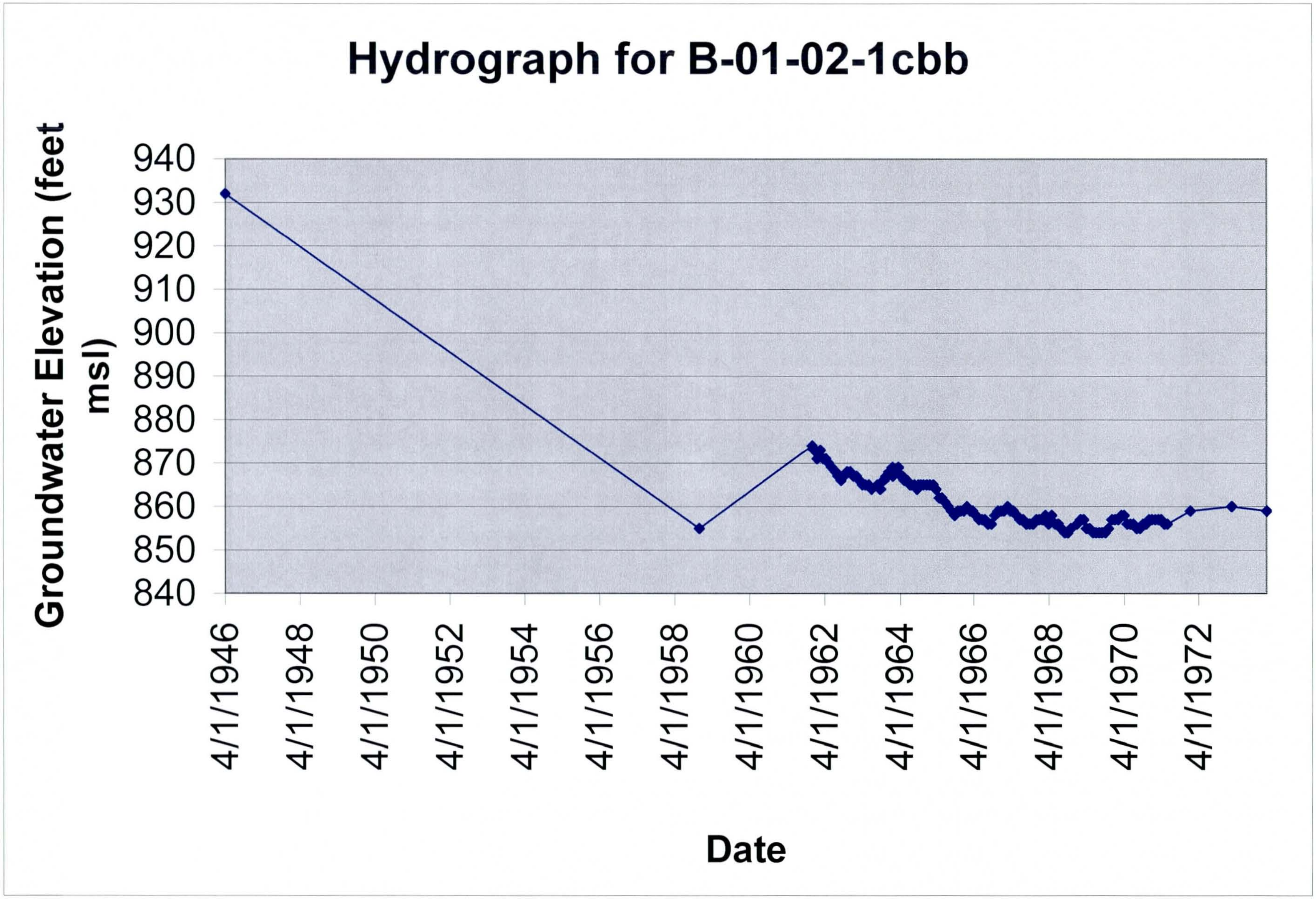

Hydrograph for B-01-02-23cad1
Groundwater Elevation (feet msl)
900
890
880
870
860
850
840
830
820
Mar-46
Mar-49
Mar-52
Mar-55
Mar-58
Mar-61
Mar-64
Mar-67
Mar-70
Mar-73
Mar-76
Mar-79
Mar-82
Mar-85
Date

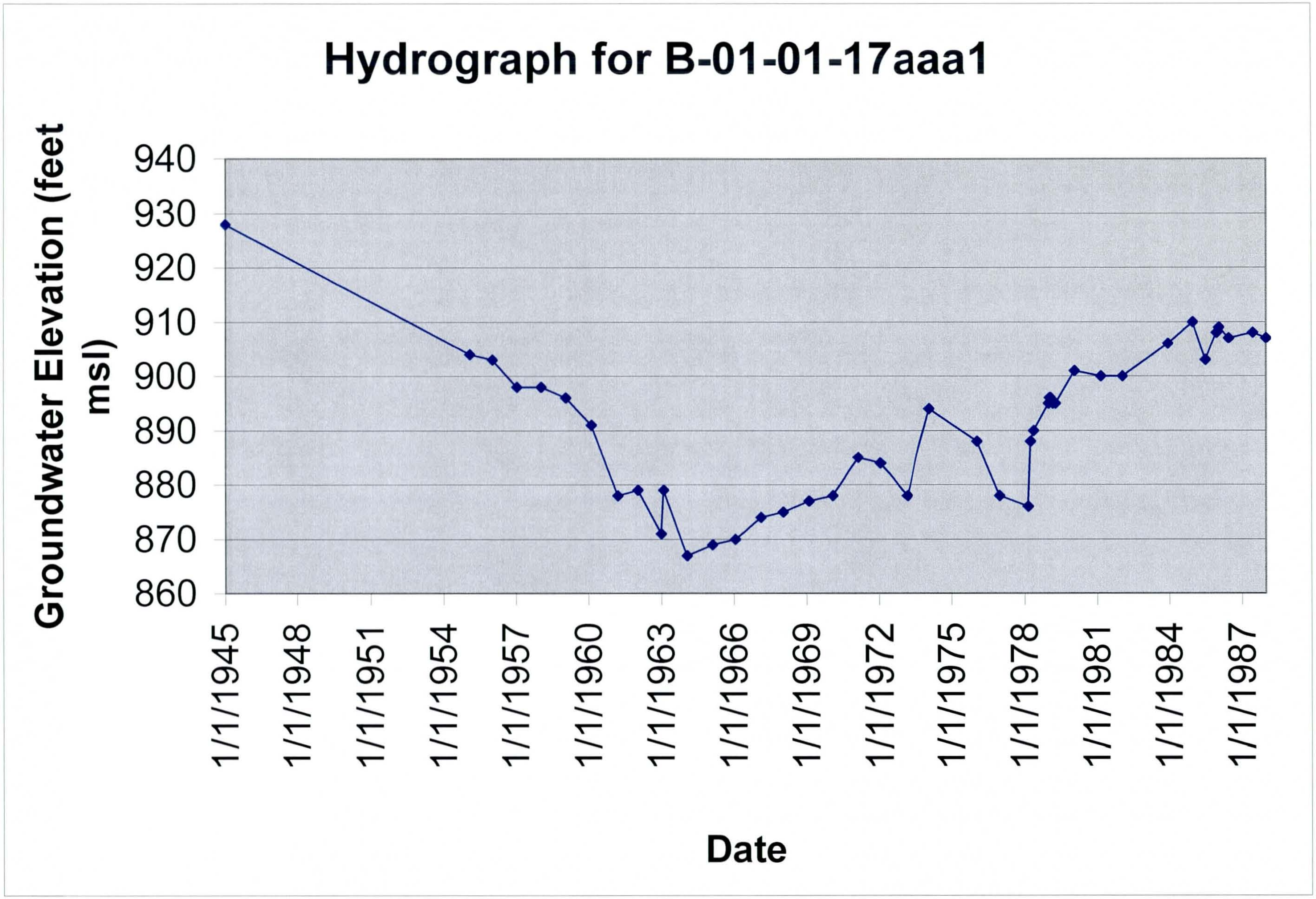

Hydrograph for B-01-02-16bbb
Groundwater Elevation (feet msl)
880
860
840
820
800
780
760
740
2/25/1962
2/25/1965
2/25/1968
2/25/1971
2/25/1974
2/25/1977
2/25/1980
2/25/1983
2/25/1986
2/25/1989
2/25/1992
2/25/1995
2/25/1998
2/25/2001
Date

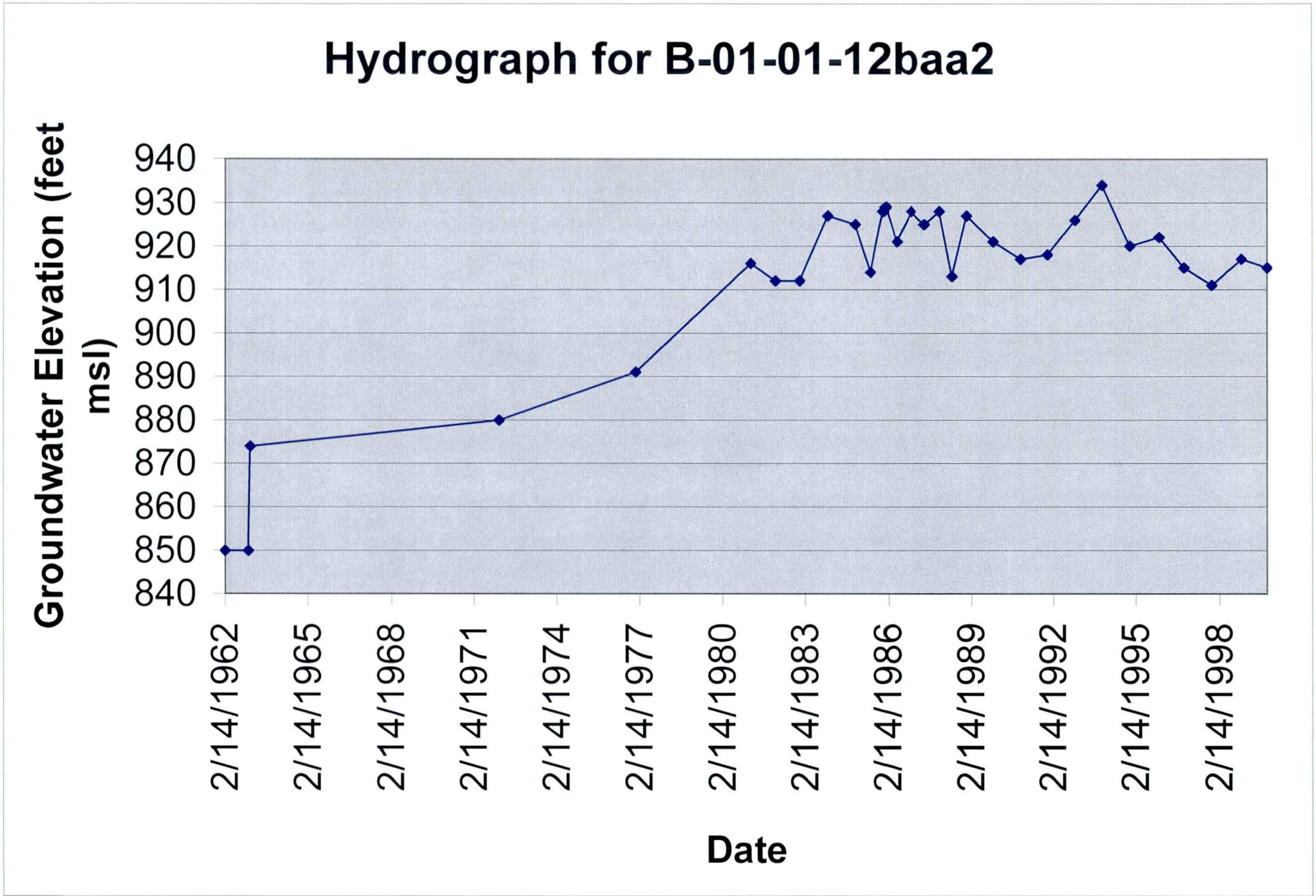

Hydrograph for B-01-02-13adc
Groundwater Elevation (feet msl)
940
930
920
910
900
890
880
870
860
Apr-28
Apr-31
Apr-34
Apr-37
Apr-40
Apr-43
Apr-46
Apr-49
Apr-52
Apr-55
Apr-58
Apr-61
Apr-64
Apr-67
Date

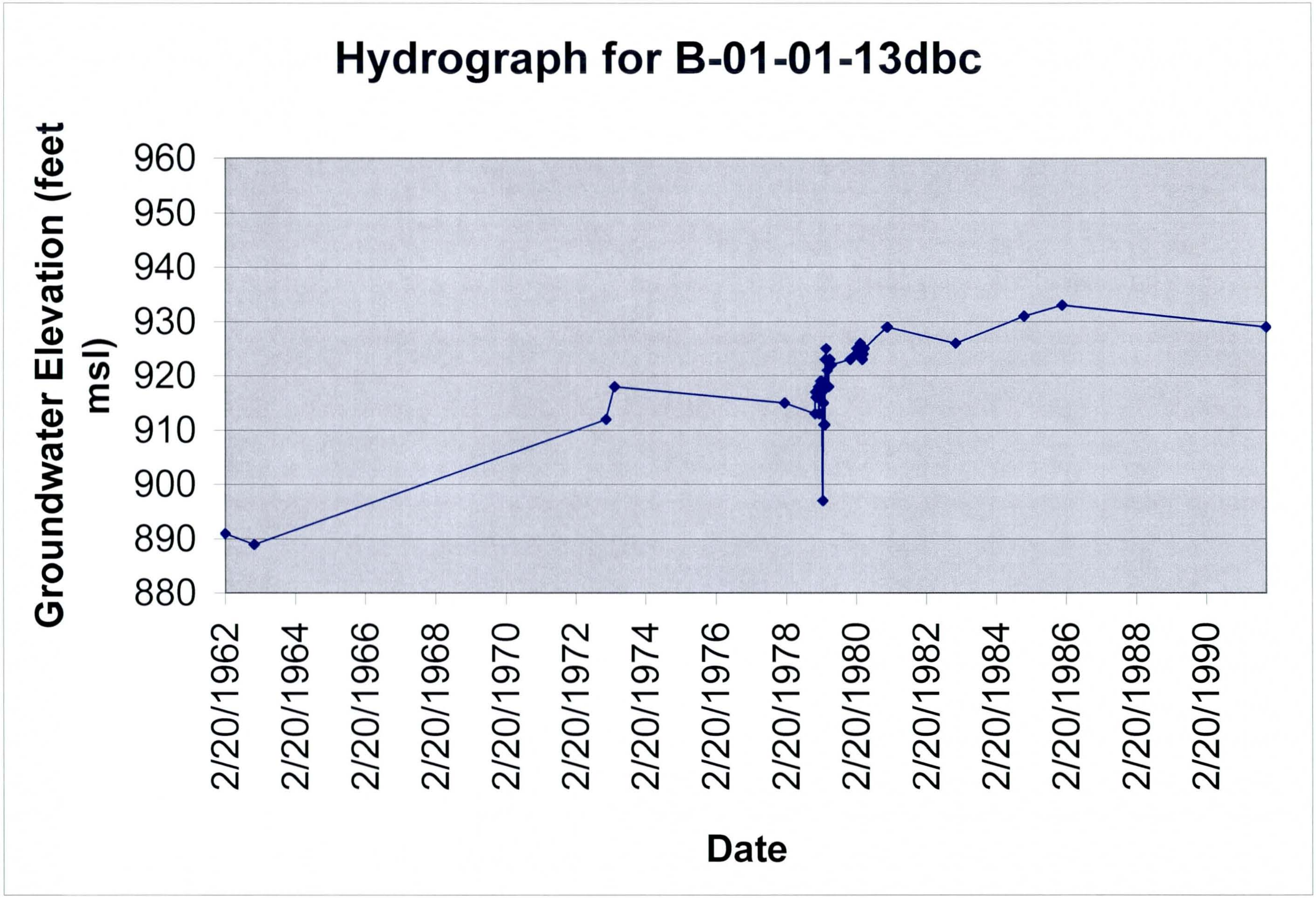


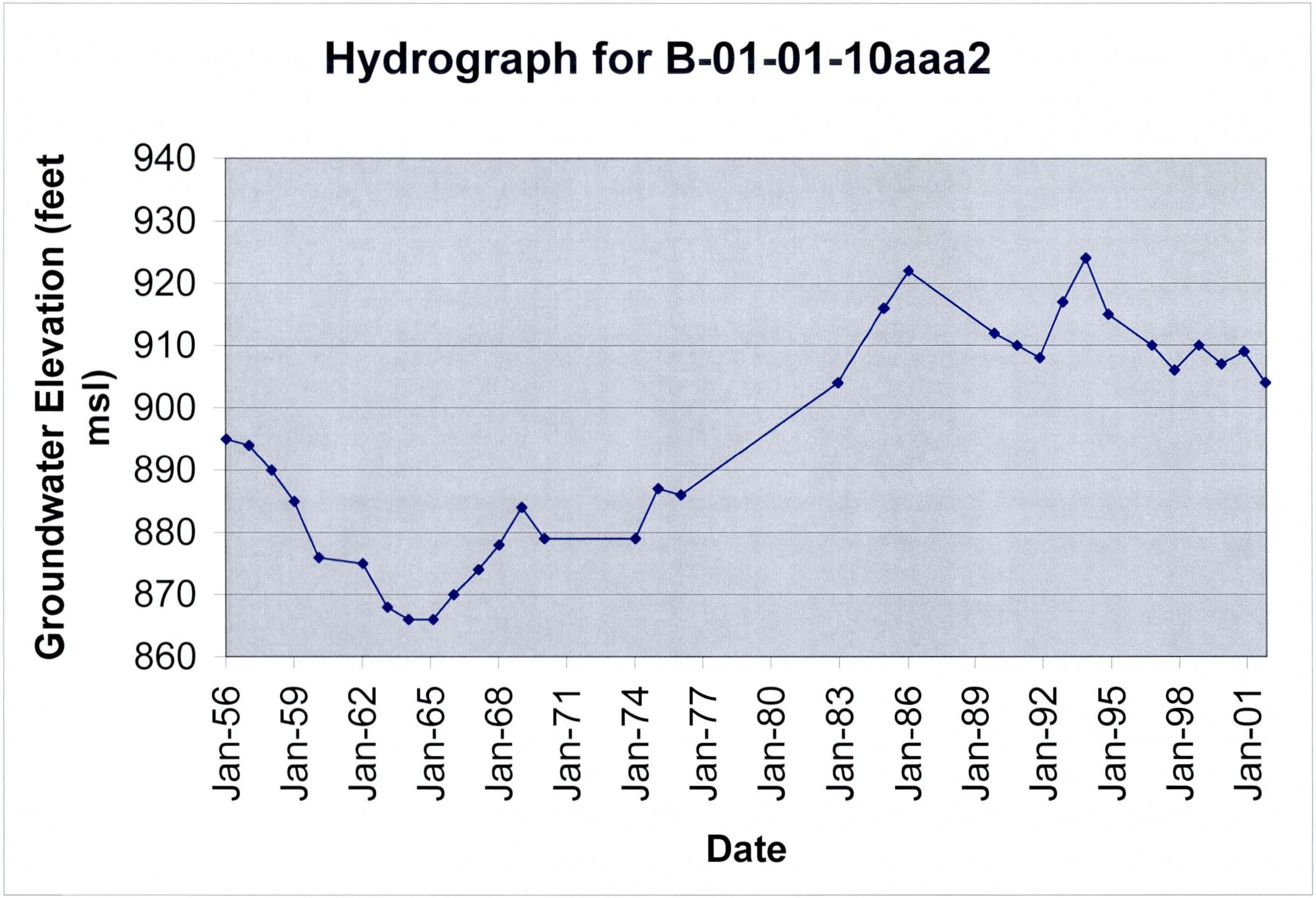
Hydrograph for B-01-02-5cbb
Groundwater Elevation (feet msl)
900
880
860
840
820
800
780
Feb-47
Feb-51
Feb-55
Feb-59
Feb-63
Feb-67
Feb-71
Feb-75
Feb-79
Feb-83
Feb-87
Feb-91
Feb-95
Feb-99
Date


Hydrograph for B-01-02-1cbb
Groundwater Elevation (feet msl)
940
930
920
910
900
890
880
870
860
850
840
4/1/1946
4/1/1948
4/1/1950
4/1/1952
4/1/1954
4/1/1956
4/1/1958
4/1/1960
4/1/1962
4/1/1964
4/1/1966
4/1/1968
4/1/1970
4/1/1972
Date

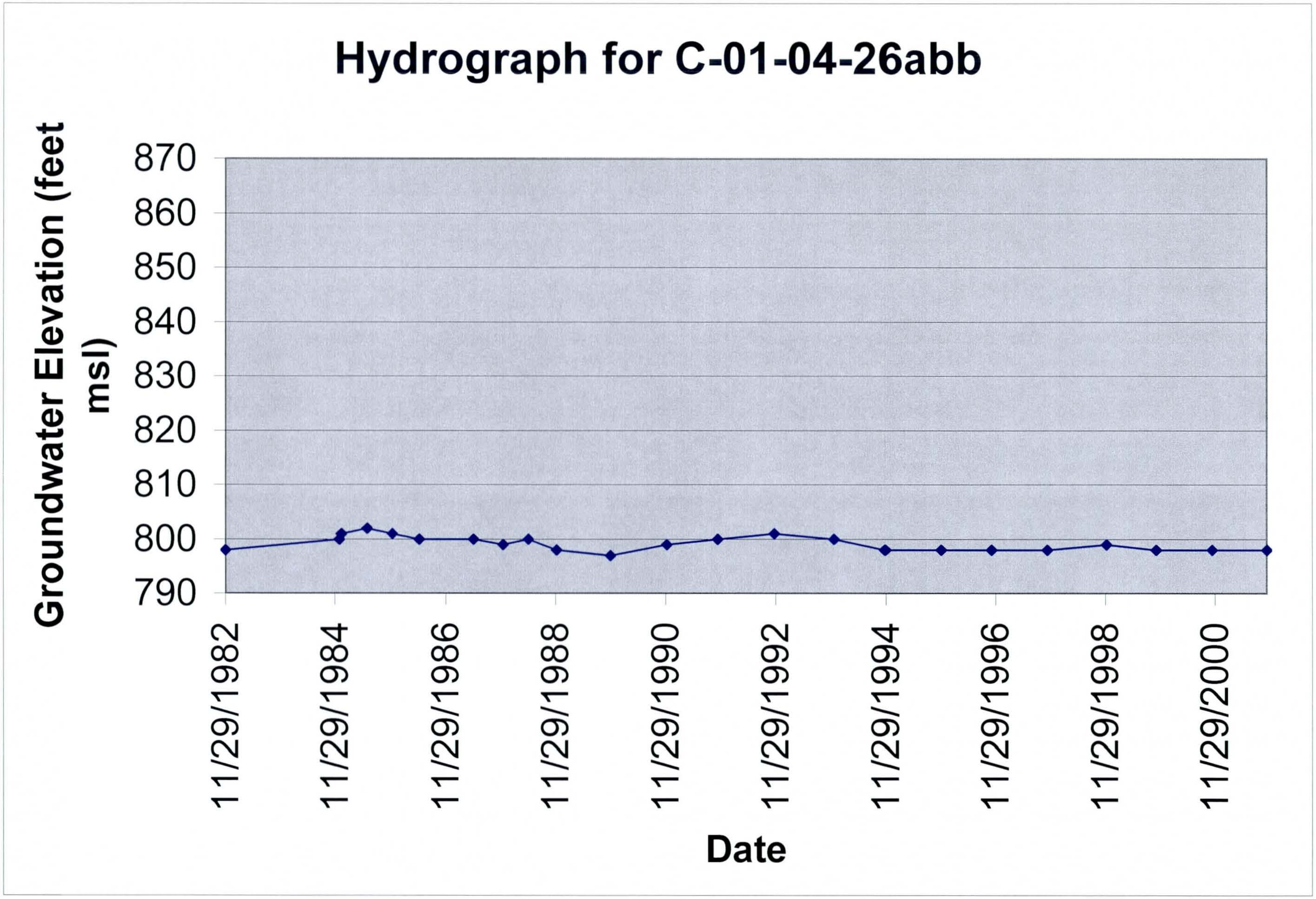

Hydrograph for B-01-01-17aaa1
Groundwater Elevation (feet msl)
940
930
920
910
900
890
880
870
860
1/1/1945
1/1/1948
1/1/1951
1/1/1954
1/1/1957
1/1/1960
1/1/1963
1/1/1966
1/1/1969
1/1/1972
1/1/1975
1/1/1978
1/1/1981
1/1/1984
1/1/1987
Date


Hydrograph for B-01-01-12baa2
Groundwater Elevation (feet msl)
940
930
920
910
900
890
880
870
860
850
840
2/14/1962
2/14/1965
2/14/1968
2/14/1971
2/14/1974
2/14/1977
2/14/1980
2/14/1983
2/14/1986
2/14/1989
2/14/1992
2/14/1995
2/14/1998
Date

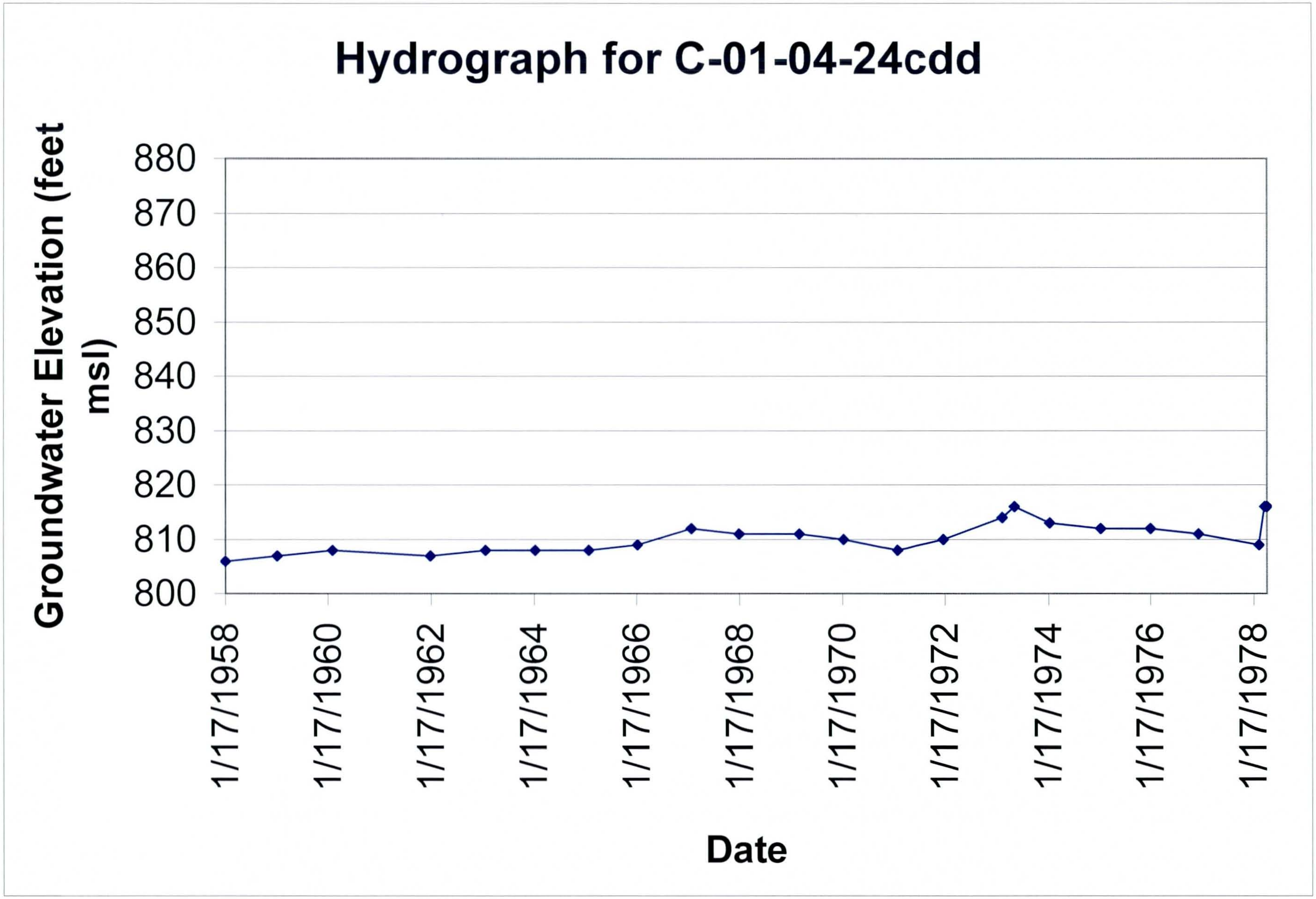

Hydrograph for B-01-01-13dbc
Groundwater Elevation (feet msl)
960
950
940
930
920
910
900
890
880
2/20/1962
2/20/1964
2/20/1966
2/20/1968
2/20/1970
2/20/1972
2/20/1974
2/20/1976
2/20/1978
2/20/1980
2/20/1982
2/20/1984
2/20/1986
2/20/1988
2/20/1990
Date



Hydrograph for B-01-01-10aaa2
Groundwater Elevation (feet msl)
940
930
920
910
900
890
880
870
860
Jan-56
Jan-59
Jan-62
Jan-65
Jan-68
Jan-71
Jan-74
Jan-77
Jan-80
Jan-83
Jan-86
Jan-89
Jan-92
Jan-95
Jan-98
Jan-01
Date



Hydrograph for C-01-04-26abb
Groundwater Elevation (feet msl)
870
860
850
840
830
820
810
800
790
11/29/1982
11/29/1984
11/29/1986
11/29/1988
11/29/1990
11/29/1992
11/29/1994
11/29/1996
11/29/1998
11/29/2000
Date



Hydrograph for C-01-04-24cdd
Groundwater Elevation (feet msl)
880
870
860
850
840
830
820
810
800
1/17/1958
1/17/1960
1/17/1962
1/17/1964
1/17/1966
1/17/1968
1/17/1970
1/17/1972
1/17/1974
1/17/1976
1/17/1978
Date

APPENDIX E

Groundwater Model Input and Output

(Provided on CD)

APPENDICES

B, C & E

(Provided on CD)