Salt/Gila Groundwater Analysis Project
Project Number WS90140004-S

DRAFT

Summary Report

Prepared for

Subregional Operating Group

March 2001

GREELEY AND HANSEN

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SUBREGIONAL OPERATING GROUP

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Project Number WS90140004-S

Summary Report

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Greeley and Hansen
March 2001

1. INTRODUCTION

The Subregional Operating Group (SROG) and the U.S. Army Corps of Engineers (Corps) initiated the Tres Rios Feasibility Study to evaluate the potential to develop a habitat restoration project in the Salt River and Gila River area downstream of the 91st Avenue Wastewater Treatment Plant (WWTP). SROG consists of the cities of Glendale, Mesa, Phoenix, Scottsdale and Tempe. These cities all own treatment capacity in the 91st Avenue WWTP. The City of Phoenix operates the 91st Avenue WWTP for SROG. The Tres Rios Steering Committee was the group responsible for the development of the Tres Rios Feasibility Study.

The 91st Avenue WWTP has the capacity to treat 163 million gallons per day (mgd) (617 million liters per day). However, the capacity is being expanded and will be 180 mgd (681 million liters per day) by late 2001. The 91st Avenue WWTP produces a high quality effluent and a portion is diverted for reuse as cooling water at the Palo Verde Nuclear Generating Station. The remainder of the effluent is discharged to the Salt River. A portion of the effluent is diverted from the river by the Buckeye Irrigation Company (BIC) for agricultural irrigation. The effluent that is not diverted continues to flow to the west.

The purposes of the Tres Rios Feasibility Study were:

- To develop a preferred alternative to facilitate implementation of a habitat restoration project and

- To provide information to be used in an Environmental Impact Statement (EIS) for the project.

The purpose of the Salt/Gila Groundwater Analysis Project was to provide the hydrologic information required to develop and assess the alternatives from the Tres Rios Feasibility Study. A computer model of the proposed Tres Rios area and surrounding area was developed as part of

the Salt/Gila Groundwater Analysis Project to assist in assessing the hydrologic impacts of the Tres Rios Habitat Restoration Alternatives.

This study report provides an overview of the physiography, topography, geology and existing hydrology of the Tres Rios area and surrounding areas. It also summarizes the water budget for the area and describes the development and results of the Salt/Gila hydrologic model that was created for this project. The following scenarios were modeled in the Salt/Gila hydrologic model:

- *Present Conditions Into The Future* – Discharge from the 91st Avenue WWTP continues unchanged into the future
- *Future Without Federal Action* – Discharge from the 91st Avenue WWTP to the Salt River is eliminated
- *Tres Rios Alternative 3.5* – Recommended alternative of the Tres Rios Steering Committee for habitat restoration along the Salt and Gila Rivers
- *Tres Rios Optimized Alternative 3.5* – Tres Rios Alternative 3.5 with the quantity of effluent discharged from the 91st Avenue WWTP optimized for what is needed for habitat restoration and to meet contractual obligations to the Buckeye Irrigation Company (BIC)

For each of the scenarios listed above, the Tres Rios hydrologic model was used to project the depth to groundwater into the future. The objectives of the groundwater model analyses were to project the groundwater table elevation in the Tres Rios area and in the channels of the Salt and Gila Rivers and to assess the relationships of the groundwater table elevations to riparian vegetation root zones

1.1 Location

The 91st Avenue WWTP is located adjacent to the Salt River on the east side of the alignment of 91st Avenue (**Figure 1-1**). The Salt River continues west past the 91st Avenue WWTP where it merges with the Gila River. The Agua Fria joins the Gila River downstream of the Salt River confluence (**Figure 1-1**).

The general Tres Rios area extends downstream from the 91st Avenue WWTP for approximately 7 miles (11.3 kilometers) to the BIC diversion (**Figure 1-1**). The name Tres Rios means three rivers in Spanish and refers to the location of the Salt, Gila and Agua Fria Rivers.

1.2 Project Purpose

The Salt/Gila Groundwater Analysis project was authorized by SROG to develop surface water and groundwater information for the Corps to use in the Tres Rios Habitat Restoration project Feasibility Study and EIS. Greeley and Hansen was selected by SROG to complete the Salt/Gila Groundwater Analysis. Water & Environmental Systems Technology, Inc. (W&EST) is a subconsultant to Greeley and Hansen on the project. W&EST developed and performed simulations using the Tres Rios hydrologic model. Background information was gathered and results were analyzed by Greeley and Hansen.

The primary purpose of the Salt/Gila Groundwater Analysis project was to develop a model that could simulate future surface water and groundwater conditions associated with the Tres Rios Habitat Restoration alternatives. This information was then used to assess the relationship of the projected groundwater table elevations to riparian vegetation root zones. The Corps of Engineers needed some of the hydrologic information collected and generated during this project prior to the completion of this report. This information was provided to the Corps to meet the Corps' needs.

1.3 Project Approach

The project team evaluated several groundwater models and recommended that the Modular Three-Dimensional Finite-Difference Groundwater Flow Model (MODFLOW) developed by the United States Geological Survey (USGS) be used to develop the model for the study. SROG approved this recommendation. MODFLOW was used to develop, calibrate and test the site-specific Tres Rios groundwater model. MODFLOW is used to organize the data, perform simulation calculations, and provide output of the analyses. The Tres Rios model was developed using the following steps:

- Establish the parameters for the model
- Develop a Tres Rios area water budget
- Collect the basic data required for model input
- Develop the Tres Rios hydrologic model
- Calibrate the model
- Conduct model sensitivity analyses
- Simulate conditions for the Tres Rios alternatives

The Tres Rios hydrologic model was used to project the impacts the Tres Rios alternatives would have on the groundwater, river and overbank areas. A goal was to develop the data to compare

the land surface elevations to the projected water table elevations. The calculated depth to water could then be compared to the maximum root zone depth of selected plant species to determine if there would be sufficient water available to maintain the plants. The water table depth data would also be used to assess if groundwater depth changes could impact the flow in the Salt and Gila Rivers. The Tres Rios hydrologic model was also used to optimize the preferred Tres Rios alternatives.

Soon after the initiation of the Salt/Gila Groundwater Analysis project, the approach and schedule required modification to meet the needs of the Corps. An analysis of two base Tres Rios alternatives, Present Without Project and Future Without Federal Actions, was needed to meet the Corps' F3 study milestone. The Corps Feasibility study process includes four formal technical review milestones. The first of these is the F3 milestone which is to define and analyze existing conditions. These base alternatives are described in detail in Section 6.

An initial Tres Rios Model was prepared to complete the Corps' F3 milestone. The second, more detailed model was prepared to simulate the Tres Rios habitat alternatives.

The primary difference between the initial model and the detailed model is the resolution. The initial model had cells that were larger in area than the cells in the detailed model. The larger size of each cell decreased the total number of cells in the initial model to cover the same area as the detailed model. The advantage of the initial model was that the data development and data input was reduced due to the reduced number of cells, thus the model could be developed in a shorter period of time

The use of the initial model allowed the two base conditions to be simulated and the results provided to the Corps to meet their project schedule. The results of the initial model was submitted in Greeley and Hansen's draft report "Task 5 Tres Rios Alternative Simulations Present Conditions and Future Without Federal Action Alternatives" (Task 5 report) (Greeley and Hansen, 1998b). This report was not part of the original scope of services for this project.

The advantage of the greater number of cells in the detailed model is that it increased the data set size and therefore the accuracy and resolution of the model. With the more detailed model, Tres Rios features could be defined at a finer scale allowing for a more specific evaluation of habitat modifications and project features.

2. REGIONAL SETTING

The initial tasks in development of the Tres Rios Model were to define the model area and to identify the regional physiographic conditions within the model area.

The concept of Tres Rios was proposed by the Corps in 1992 and since then, Tres Rios evolved into the present habitat restoration project. The Corps' Tres Rios study area begins at the 83rd Avenue alignment with the Salt River and extends west to the BIC diversion structure in the Gila River, a distance of about 8 miles (13 kilometers). The Corps' study area includes the lands to the north and south of the river channels that are within the 100-year floodplain, approximately 1-1/2 to 2 miles (2.4 to 3.2 kilometers) from the river banks to the north and to the south.

2.1 Tres Rios Model Area

The Tres Rios hydrologic model study area was divided into two parts: a focus study area and a much larger gross study area. Plate 1 of **Appendix A** shows both the focus study area and the gross study area used in the Tres Rios hydrologic model.

The Corps' Tres Rios study area was the focus area of the Tres Rios hydrologic model. However, groundwater model areas need to be much larger than the focus area to provide for an accurate interrelationship with the regional hydrogeologic conditions. The gross model area used is shown in Plate 1 of **Appendix A** and is defined by the following boundaries:

- East Boundary - 19th Avenue located 8 miles (12.9 kilometers) upstream from the east edge of the Corps Tres Rios study area at 83rd Avenue. Using the 19th Avenue alignment allowed incorporation of the discharges from the 23rd Avenue WWTP into the model matrix. The Salt/Gila Study east boundary corresponds to the east side of Range 2 East.

- West Boundary - 259th Avenue located 15 miles (24.2 kilometers) west of the west edge of Corps Tres Rios study area. The Salt/Gila Study west boundary corresponds to the west side of Range 3 West.

- North Boundary - McDowell Road alignment. The north boundary was located an average of 5 miles (8.0 kilometers) north of the river channels and corresponds to the north side of Township 1 North.

- South Boundary - Pecos Road alignment. This was located an average of 5 miles (8.0 kilometers) south of the river channels and corresponds to the south side of Township 1 South.

These boundaries define the gross area of investigation for the accumulation and analysis of model parameters. The gross model area is approximately 30 miles (48.3 kilometers) east-west and 12 miles (19.3 kilometers) north-south for a total area of approximately 360 square miles (932.4 kilometers^2).

The focus area used for the Tres Rios hydrologic model is much smaller than the gross area. The focus area used corresponds to the Corps' Tres Rios study area shown on **Figure 1-1** and in Plate 1 of **Appendix A**. The focus area is approximately 8 miles (13 kilometers) east-west and 2 miles (3.2 kilometers) north-south for a total area of approximately 16 square miles (41.5 kilometers^2).

The entire Tres Rios model area was divided into cells with 16 cells within each one square mile (259 hectare) area. Each cell is three cells deep. A simple base map of the Tres Rios Model grid was prepared for information collection as shown in Plate 1 of **Appendix A**. The three layer model grid has 118 cells in the east-west direction and 48 cells in the north-south direction for a total of 16,992 cells.

A Geographic Information System (GIS) base map was prepared using the Tres Rios Model cell pattern. This cell pattern map was used in conjunction with other maps, described in this report, for plotting model input parameter information.

2.2 Topography

The Tres Rios hydrologic model required detailed topographic information for the focus area and less detailed topography data for the remainder of the Tres Rios Model area. The Flood Control District of Maricopa County (FCDMC) provided 4-foot (1.22 meter) contour interval topographic maps for the Salt and Gila River channel areas and the adjacent overbank areas. The Tres Rios hydrologic model cell grid pattern was overlain on the FCDMC topographic maps. The average elevation of the land within each cell was calculated and recorded for input to the Tres Rios hydrologic model.

Topography from USGS quadrangle maps was used for the gross model area outside the focus Tres Rios Area. The USGS quadrangle maps have contour intervals of anywhere between 5 to 20-feet (1.5 to 6.1 meters). The Tres Rios Model cell grid was overlain on the quadrangle maps and the average ground surface elevation in each cell was calculated and input into the model.

Although the USGS topographic maps have less resolution than the FCDMC topographic maps, the USGS map data was of sufficient detail for lands outside of the focus area.

Topography delineated by elevation contour lines on the USGS quadrangle maps provided information about the Tres Rios Model area physiography. Mountain areas, river and wash channels, and valley floor areas were defined based on the topographic data.

2.3 Regional Geology

The regional geology of the Tres Rios Model area is summarized here in terms of the following three categories; physiography (i.e., geomorphology), bedrock geology and basin fill geology.

2.3.1 Physiography

The Tres Rios Model area is located within what is identified as the West Salt River structural basin of the Central Arizona Basin, in the Basin and Range Physiographic Province. The Basin and Range Physiographic Province is a large physiographic area in the Southwestern United States. Knowledge of the regional physiography was needed to define the regional geology for the Tres Rios Model. The Basin and Range Physiographic Province consists of large structural features called grabens and horsts, that are composed of blocks of crystalline, volcanic and sedimentary bedrock in Central Arizona. The grabens, which are downdropped blocks relative to the horsts, contain unconsolidated and semiconsolidated sediments and form the topographic valleys and corresponding depositional basins in the area. These depositional basins filled with unconsolidated sediments are referred to as alluvial basins. Rivers and washes eroded channels in the valley fill sedimentary materials. Mountain ranges exist in areas where horst blocks rise to higher elevations than the surface of the surrounding, otherwise continuous, unconsolidated sediments.

2.3.2 Bedrock Geology

Bedrock in the Tres Rios Model area occurs as mountains where the horst blocks are bedrock exposed at the surface and as the top of the graben basins which underlies the basin fill in the valleys. Bedrock geology was interpreted from information presented on the Maricopa County geologic map (Wilson, Moore, and Peirce, 1957). Bedrock defines the extent of the structural basin in the Tres Rios Model. Bedrock mountains in the Tres Rios Model area include South Mountain and Estrella Mountains south of the Salt and Gila Rivers and the White Tank Mountains in the northwest. The bedrock in the Tres Rios Model area is primarily Precambrian age granite gneiss and Cretaceous age granite. Granite is a coarse grained igneous rock unit and granite gneiss is a coarse grained metamorphic rock unit. The importance of identifying these rock types is because they are relatively impervious and non-porous and even if fractured,

usually do not store or transmit significant quantities of groundwater. Bedrock defines the vertical limits of the Tres Rios Model and several of the horizontal limits.

2.3.3 Basin Fill Geology

Basin fill in the West Salt River structural basin is the primary water-bearing sedimentary material in the Tres Rios Model area. The basin fill is unconsolidated sediments composed of clay, silt, sand and gravel. The geology of the basin fill has been characterized by several investigators. A comprehensive analysis of the basin fill in this area has been performed by Brown and Pool (1989). These investigators identified the following three basin fill units:

- Upper Unit
- Middle Unit
- Lower Unit

These three basin fill units are described in the following subsections. For more detailed information about the geology in the Tres Rios area, and for a description of how it was represented in the model, refer to the W&EST report in **Appendix A,** Section C.

2.3.3.1 Upper Unit

The Upper Unit of the basin fill is described as consisting of mostly unconsolidated gravel, sand and silt in stream channel, flood plain and alluvial fan (Brown and Pool, 1989). Caliche cementation occurs locally in alluvial fan deposits and stream terrace deposits. Caliche is a lime carbonate material that fills the pores in sedimentary materials and acts like cement to bind the sedimentary material together. Caliche can also form thick layers that have the same characteristics as limestone, which is hard, dense and impermeable. The Upper Unit ranges from zero to 400 feet in thickness. Published information and data compiled from 500 drillers' logs indicated that the Upper Unit needed to be divided into the following three smaller units for the Tres Rios Model: Upper Alluvium, Upper Clay and Lower Alluvium. For more detailed information on how the model layers were defined, refer to Section C of **Appendix A** which contains a complete copy of the W&EST summary report.

The Upper Alluvium portion of the Upper Unit consists of a heterogeneous mix of sand, gravel, silt and clay in layers that vary in thickness and areal extent throughout the area. The thickness of the Upper Alluvium was from drilling logs for each model cell and entered into the matrix.

Beneath the Upper Alluvium a thin clay layer was identified and named the Upper Clay for the purpose of this study. The Upper Clay was identified in wells along the Salt and Gila Rivers at a

depth of about 200 feet (61 meters) below the surface. The Upper Clay ranges in thickness from several feet to tens of feet (see **Appendix A**).

Beneath the Upper Clay is the Lower Alluvium that consists of many layers of sand, gravel, silt and clay. Drillers' logs indicate the Lower Alluvium has layers that have been cemented.

2.3.3.2 Middle Unit

In portions of the Tres Rios Model area, the material immediately underlying the Upper Unit is defined as the Middle Unit. The Middle Unit consists of layers of silt, clay, siltstone, silty sand and gravel. The finer grained sediments of silt and clay dominate the Middle Unit. These fine grained materials were interpreted to have been deposited under open to closed basin conditions in environments of deposition interpreted as playa, alluvial fan and fluvial. The Middle Unit can be up to 800 feet (244 meters) thick north of the Tres Rios area.

Toward the edges of the basin fill areas nearer to the mountains, the Middle Unit was not present. This was due to the historic geologic depositional environments. The Middle Unit was deposited in the central parts of the graben basin and not along the edges. Where the Middle Unit was not present, the Lower Unit was directly beneath the Upper Unit.

2.3.3.3 Lower Unit

The lower unit was described by (Brown and Pool, 1989) as consisting of silt, clay mudstone, gypsiferous, anhydrotic mudstone, gypsum, evaporites, sand and gravel. The Lower Unit was interpreted to have been deposited under closed basin conditions. Environments of deposition are interpreted to be playa, alluvial fan, fluvial and evaporitic. Thickness of the Lower Unit ranges from less than 1000 feet (305 meters) to greater than 10,000 feet (3,050 meters). A zone of massive halite occurs in the Lower Unit north of the Tres Rios Model area in the structurally deepest part of the West Salt River basin.

The Lower Unit was identified in drillers' logs in two stratigraphic positions. In locations where the Middle Unit was present, the Lower Unit occurred beneath the Middle Unit. Toward the edges of the basin fill areas nearer to the mountains, the Middle Unit was not present. Where the Middle Unit was not present, the Lower Unit was directly beneath the Upper Unit. Contacts between the layers in the Lower Unit were gradation, and in general materials were coarser near mountain flanks and finer-grained in the basin center.

2.3.3.4 River Sediments

In the Tres Rios Model area, the river sediments in the Salt River and Gila River channel consist primarily of coarse-grained sand to cobble size material. The surface materials grade to smaller sediments downstream within the Tres Rios Model study area. There is a limited amount of silt and clay materials in the river channels. The upstream river channel sections near 83rd Avenue have a very high percentage of cobbles that average 6 to 8 inches (15 to 20 centimeters) in diameter and these cobbles reduce in diameter to an average of 2 to 4 inches (5 to 10 centimeters) at the downstream edge of the model area near 259th Avenue. Mixed in-between the cobbles are coarse-grained sand sediments that form bars around the cobbles. The sand areas represent locations where the water velocity was slower than the main flow path and this lower energy environment was where the sand was deposited. The surface cobble layers provide an armor coating for the underlying river channel sedimentary materials. During low surface flow conditions, the flow in the river sorted the surface materials by removing some of the fine grained materials. The cobbles remained and protect the underlying sand materials from further erosion by the flows. When the surface cobble layer was removed during river channel field investigations conducted as a part of this study, sand was observed below the surface. During flood stages, the entire river bed can be subjected to erosion and deposition. Floods mix and redeposit river bed materials after which flows begin the sorting process over again.

During field investigations in the river channel, it was noted that in some locations there were very low water velocity conditions at some time in the past. These were identified by the presence of fine to medium grained sand. The low flow areas were close to the river banks where vegetation provided some protection from high velocity flows. There was some silt and clay sediments mixed with the fine sands. This was verified by the identification of cracks and curled sediments in the dry areas. These features indicate fine-grained materials.

The subsurface river bed materials were viewed in the sides of gravel mines. The materials were in layers that varied in thickness ranging from 1 to 5 feet (0.3 to 1.5 meters) thick. The individual layers were not continuous and could be seen to get thinner and thicker along the gravel mine walls. This is typical of river bed materials. The layers contained cobbles and sand however the proportion of each varied within the individual layers. Some had a greater percentage of cobbles and others were primarily sand.

2.4 Hydrogeology

The development of the Tres Rios Model required development of the regional hydrogeology as an initial step to defining the model parameters. The hydrogeology was divided into:

- Regional hydrogeology
- Bedrock hydrogeology
- Basin fill hydrogeology

2.4.1 Regional Hydrogeology

The regional hydrogeology is related to the regional physiography. The geologic materials that form the graben and horst blocks are composed of bedrock. In the Tres Rios Model area, the bedrock includes rock types such as igneous rocks (granite and basalt) and metamorphic rock (gneiss). These materials are generally consolidated and competent, with relatively low water storage and transmission characteristics and usually yield small quantities of water compared to the unconsolidated sediments in the basins. Bedrock does not form aquifer units and in fact forms a wall that prevents or restricts the flow of groundwater. It is the unconsolidated sediments in the grabens, referred to as basin fill, that form the primary water-bearing units in the Tres Rios Model area, and make up the principle aquifers. These sediments range in thickness from zero at the mountain flanks to 12,000 feet (3,700 m) in the deepest parts of the basins.

2.4.2 Bedrock Hydrogeology

Bedrock forms an impervious boundary to the movement of groundwater and defining the horizontal and vertical bedrock limits was essential to define the Tres Rios Model limits. Surface exposure of bedrock was interpreted using U.S. Geological Survey Quadrangle Maps. Subsurface depths to bedrock was interpreted from geologic logs prepared by drillers, published reports and also interpretations based on the existing information.

The depth to bedrock influences groundwater movement in the overlying basin fill by constraining the geometry of the basin fill. The depth of the downdropped bedrock graben controls the thickness of unconsolidated basin fill materials in the graben. The result is that a greater thickness of basin fill occurs where bedrock is deep, and relatively thin basin fill overlies shallow bedrock. In the Tres Rios Model area, shallow bedrock beneath the Gila River occurs just upstream of the confluence of the Salt River and Gila River between the Sierra Estrella and South Mountains. The basin fill is relatively thin in this area, and groundwater that moves from thicker upgradient basin fill areas enters the thinner basin fill in this area. In response to the diminishing volume of basin fill, groundwater levels rise to the surface, and the Gila River gains flow. This emerging groundwater results in gaining stream conditions and produces the surface flow in the Gila River, which is depleted of flow upstream of this area. This bedrock configuration and gaining stream groundwater condition was defined and entered into the Tres Rios Model data matrix.

2.4.3 Basin Fill Hydrogeology

The regional basin fill hydrogeology analyses followed the geologic descriptions and is based on the three units:

- Upper Unit
- Middle Unit
- Lower Unit

2.4.3.1 Upper Unit

Regionally following a trend from east to west along the Salt and Gila Rivers, the Upper Unit generally contains more than 80 percent sand and gravel. Hydraulic conductivity ranges from approximately 180 to 1700 feet/day (55 to 518 meters/day) in the Upper Unit. Groundwater exists in unconfined conditions in the Upper Unit.

The basin fill materials defined as the Upper Unit form the principal aquifer in the Phoenix area. In the Tres Rios Model area, the thickness of the upper unit ranges from 400 feet (122 meters) near the confluence of the Salt and Gila Rivers, to less than 100 feet (31 meters) thick south of the Gila River near Buckeye Hills. Although the unit is mostly to completely dewatered north of the Tres Rios Model area, it is presently saturated in the Tres Rios Model area.

2.4.3.2 Middle Unit

The basin fill materials defined as the Middle Unit range in thickness from over 500 feet (152 meter) near the confluence of the Salt and Gila Rivers to less than 200 feet (61 meters) along the flanks of the Sierra Estrella and Buckeye Hills. The middle unit hydraulic conductivity is estimated to range from 4 to 60 feet/day (1.2 to 18 meters). The unit was characterized as an unconfined to a leaky confined aquifer

The contact between the Middle and Lower units is gradational, and differentiation is based on a number of factors, including bedding frequency, color, geophysical resistivity, and presence of gypsum. The unit is indistinguishable from the underlying lower unit in some areas, indicating uninterrupted depositional processes.

2.4.3.3 Lower Unit

The Lower Unit was characterized as a leaky confined aquifer. Contacts between the units are gradational, and in general, materials are coarser near mountain flanks and finer-grained in the basin center. Hydraulic conductivity ranges from 6 to 14 feet/day (1.8 to 4.3 meters/day).

3. WATER BUDGET

An initial water budget was prepared as a part of the Tres Rios Model to identify and summarize the inflow sources and the outflows from the hydrologic system in the Tres Rios area. The water budget was presented in both the Task 5 Report (Greeley and Hansen, 1998b) and the Water Budget Analysis report in Appendix B. The following is a summary of the inflow and outflow information.

3.1 River Flows

Perennial river flows in the rivers in the Tres Rios Model area are diverted from the rivers upstream of the study area. The river flows in the Tres Rios Model area are a result of wastewater treatment plant discharges, agricultural drainage, stormwater runoff, groundwater inflow in gaining reaches and flood flow releases from upstream reservoirs.

The U.S. Geological Survey gages river flows. However, most of the gages from the east edge of the Tres Rios Model area to the 91st Avenue WWTP record zero flow for most of the time. Downstream of the 91st Avenue WWTP discharge, there is a USGS gauge that records flow in the Gila River at times when the Buckeye Irrigation Company (BIC) is not diverting all flow. See **Appendix B,** Section 2.1 for more detailed information.

3.2 Flood Flows

For the purposes of this study, flood flows are defined as releases from upstream storage reservoirs on the Salt, Gila and Agua Fria Rivers. These infrequent flood releases result in flows that range in quantity and duration and do not occur with dependable frequency.

3.3 Stormwater Regulated by the NPDES Program

There are limited stormwater flow data available. Most of the potential stormwater is conveyed via ungaged drains that are not regulated. Stormwater enters the Tres Rios Model area at concentrated points via storm drains or as sheet flow runoff.

3.4 Wastewater Treatment Plant Discharges

There are five wastewater treatment plants that discharge in or around the Tres Rios Model Area. Three of these, 23rd Avenue WWTP, 91st Avenue WWTP, and Tolleson WWTP, were included in the Tres Rios hydrologic model. The other two, Avondale WWTP and Goodyear WWTP, were not included in the Tres Rios hydrologic model because their discharges are intermittent and relatively small.

The most upstream of the WWTPs that were input to the Tres Rios hydrologic model is the 23rd Avenue WWTP which is owned by the City of Phoenix. The Roosevelt Irrigation District and Peterson Farms divert portions of the effluent from the 23rd Avenue WWTP. Flow that is not diverted for irrigation or reused within the 23rd Avenue WWTP is discharged to the Salt River at 35th Avenue.

The 91st Avenue WWTP also discharges flow to the Salt River. The cities of Glendale, Mesa, Phoenix, Scottsdale and Tempe own capacity of the 91st Avenue WWTP. A portion of effluent from the 91st Avenue WWTP is diverted to the Palo Verde Nuclear Power Plant where it is used as cooling water. Effluent that is not diverted by the Palo Verde Nuclear Power Plant is either reused at the plant or discharged to the Salt River downstream of 91st Avenue.

The City of Tolleson WWTP also discharges effluent in the Tres Rios study area. The City of Tolleson WWTP is located just west of 91st Avenue. The discharge from the Tolleson WWTP occurs at the same location as the 91st Avenue WWTP discharge. Discharge from the Tolleson WWTP is intermittent.

3.5 Agricultural Discharges

Water conservation regulations have resulted in decreased quantities of agricultural tail water discharges to the Salt and Gila Rivers. Very few of the agricultural drains are gaged and the total quantity and quality of the agricultural drainage water can not be verified. Salt River Project (SRP) discharges water to the Gila River to meet water rights requirements of the BIC. The discharge point is immediately upstream of the Agua Fria River junction with the Gila River. Ungaged SRP drains were identified, however, SRP reported no quantity information was available for these drains.

3.6 Dewatering Wells

The BIC operates 11 dewatering wells located in the western portion of the study area to lower the groundwater table as a part of the agricultural operations. These dewatering wells represent withdrawals from the groundwater hydrologic system and inflow to the surface water system. Data for these wells was included in the Tres Rios hydrologic model.

Data from the 91st Avenue WWTP dewatering wells were also included in the Tres Rios hydrologic model.

3.7 Groundwater in Gaining Stream Reaches

Groundwater contributes to flow in the Gila River in the gaining stream reaches. The quantity of groundwater that contributes to flow in the Gila River fluctuates seasonally and annually as the groundwater table fluctuates. Groundwater table fluctuations depend on the following factors:

- Flood flows and stormwater flows in the river channels
- Regional groundwater pumping during normal year irrigation seasons
- Additional groundwater pumping during drought year irrigation seasons

3.8 Minor Inflow Sources

There are several minor inflow sources to the Salt and Gila Rivers identified as NPDES permit discharges. These do not represent significant quantities of flow.

3.9 Irrigation Diversions

The BIC diverts flow from the Gila River immediately downstream of the junction of the Agua Fria River with the Gila River. The Gila River flow diverted by the BIC typically consists of a combination of SRP drainage, discharges from the 91st Avenue WWTP, discharges from the Tolleson WWTP and groundwater.

3.10 Riparian Vegetation Consumptive Use

Consumptive use by riparian vegetation was calculated for the Tres Rios Model. Detailed information required to calculate consumptive use included types of vegetation communities, evapotranspiration rates for types of vegetation and percent ground cover of each vegetation type. The following five land covers were identified and input to the Tres Rios Model:

- Desert
- Mountain
- River Floodplain
- Agricultural
- Municipal

Both land use data and detailed riparian habitat data were used to construct the evapotranspiration rate inputs for the Tres Rios hydrologic model. For more detailed information on how riparian vegetation evapotranspiration was accounted for in the Tres Rios hydrologic model, refer to Section G of the W&EST report in **Appendix A**.

3.11 Evaporation from Open Water

The evaporation rate in the Phoenix area averages 6 feet per year. Open water areas within the Tres Rios Model Area were identified and the associated evaporation losses were incorporated into the model.

3.12 Surface Water Infiltration

Surface Water infiltration occurs in the Salt and Gila Rivers in the losing stream reaches. The quantity and location of infiltration changes seasonally and annually, depending on local conditions. The projected infiltration capacity of each cell was input to the model and groundwater infiltration was accounted for as necessary.

4. ESTABLISH MODEL PARAMETERS

The output of the Tres Rios Model is the elevation of the groundwater table within each model cell. Calculation of the depth to groundwater required that the elevation of the ground surface be input into each cell. In addition, the following model parameters were researched or developed for the model: model layers, active and inactive cells, general head boundaries, aquifer parameters, current groundwater levels, river locations, well pumpage, natural recharge, land use, agricultural and municipal recharge and riparian vegetation evapotranspiration.

The Tres Rios Model parameters used in the initial model were detailed in the Task 5 Report (Greeley and Hansen, 1998b). The following is a summary of the model parameters used in the detailed model.

4.1 Model Layers

Hydrogeologic interpretations of the basin fill material identified the Upper Unit (consisting of the Upper Alluvium, Upper Clay, Lower Alluvium), the Middle Unit and the Lower Unit. Bedrock formed the boundary conditions. The Tres Rios Model was developed using three layers:

- Layer 1 – Upper Alluvium
- Layer 2 – Lower Alluvium
- Layer 3 – Middle Unit or Lower Unit depending on the subsurface stratigraphy in the cell.

The Upper Clay was not defined as a layer in the model, however, it was simulated by changing the conductance between Layer 1 and Layer 2. The clay retards the movement of groundwater and in MODFLOW this is simulated with a conductance value rather than a separate layer.

As was explained in Section 2.1, the Tres Rios Model contains 16 cells per square mile (259 hectares). Each cell is ¼ x ¼ mile (402 x 402 meters). A model configuration using six layers was evaluated but due to the size (area) of each cell relative to the thickness of the layers, a numerical instability occurred and therefore, three layers were used. This is explained in the W&EST report section titled *Model Framework* contained in **Appendix A.**

4.2 Active Cells

MODFLOW allows coding of cells as active cells and inactive cells. In the Tres Rios Model, cells were designated as active cells if they were overlying basin fill materials and contained groundwater. These cells were part of the regional aquifer system and were used as a part of the numeric simulations.

Cells were designated as inactive if the cell contained bedrock areas such as mountains or if the cell was overlying a thin section of basin fill materials that had been dewatered in the past. Inactive cells were not part of the regional aquifer system and were not active in the numeric simulations.

Locations of active cells and inactive cells are shown in Plate 1 of the W&EST report in **Appendix A.**

4.3 General Head Boundaries

In some areas, the limits of the Tres Rios Model were not defined by inactive model cells because bedrock mountains were not present. In these areas, the active model cells along the edges of the Tres Rios Model area were coded as having general head boundaries. The general head boundaries allow the model to be numerically connected to the aquifer outside of the model area for simulations.

4.4 Aquifer Parameters

The aquifer parameters developed for Layers 1 and 2 were based on the thickness of the layers and the hydraulic conductance. The thickness of Layer 1 and 2 in each cell was calculated based on information contained in drillers' logs. The thickness established the top and bottom elevation of Layer 1 and Layer 2. Published data was used for the initial hydraulic conductance of Layer 1 and Layer 2. The hydraulic conductance was adjusted during the Tres Rios Model calibration runs to reflect local conditions. The hydraulic conductance developed for the model was 800 feet per day (243.8 meters per day) for Layer 1 and 600 feet/day (182.9 m/day) for Layer 2.

The aquifer parameter established for Layer 3 was a transmissivity of 500 square feet per day (46.5 square meters per day). This value was not dependent on the thickness of Layer 3.

A storage coefficient of 0.0001 was used for all layers.

Vertical conductance between the layers was computed by MODFLOW during the model runs based on the layer thickness and the hydraulic conductivity. Vertical leakance values to define the conductance of the vertical interval between layers were calculated and input into the model matrix. The vertical leakance was adjusted as necessary during model calibration.

4.5 Groundwater Levels

Groundwater elevations were calculated based on the information contained in the USGS Ground-Water Site Inventory System (GWSI) database for Arizona. The USGS had records for decades of water level measurements. The information for the years 1986 and 1991 (the model calibration period) was sorted and water level contour maps developed. The water elevation for each active cell was input to the model. The data for year 1986 was used for the starting water level data for calibration runs and the data for 1991 was used to assess the model developed water levels.

4.6 Rivers

Portions of the Salt, Gila and Agua Fria Rivers are located within the Tres Rios Model area. USGS Quadrangle Maps and FCDMC topographic maps were used to define the location and geometry of the channels of the rivers. The active cells in the Tres Rios Model that contained the river channels were identified and the information related to the reach length, channel bottom elevation and location of the reach within the model were entered into the appropriate cells.

Flows gauged at USGS gaging stations were included in the calibration database. During the 1986 to 1991 period, flow was gaged in the Salt and Gila Rivers. No flow was gaged in the Agua Fria River during that period. River inflow data developed as a part of the water budget (Section 2, **Appendix B**) were incorporated into the model matrix.

Canal diversions from the rivers (such as the BIC diversion) and return flows to the river were also defined as Rivers in the model.

4.7 Well Pumpage

Well pumpage is a significant source of water supply for many of the water use entities in the Tres Rios hydrologic model area. Reporting of annual well pumpage has been mandatory for all major groundwater users since the mid 1980's. This information is collected and stored by the Arizona Department of Water Resources (ADWR) in the Registry of Ground-Water Rights (ROGR) electronic database, which contains most of the well pumpage information used in the Tres Rios hydrologic model. Well pumpage values for later years is generally more complete and accurate than for earlier years. Since the Gila River Indian Community (GRIC) does not report well pumpage to ADWR, pumpage for wells in the GRIC was projected. Well pumpage per model cell was computed as the total annual pumpage for all wells that correspond to a single model cell. Six data sets, one for each year in the six-year calibration period, were developed for input to the Tres Rios hydrologic model.

In addition to total annual pumpage by model cell, it was necessary to specify from which model layer(s) the wells were pumping. Only limited and incomplete information exists regarding well completions. In many cases, no information is available on screened casing intervals; in other cases, the screened casing interval is listed as the total well depth. A computer program was developed by W&EST to apportion pumpage to the model layers based on total well depth.

4.8 Natural Recharge

Natural recharge is the quantity of annual aquifer recharge attributed rainfall runoff from the bedrock mountains. This was calculated based on published information and the recharge was distributed among the active cells along the mountain fronts. Recharge associated with river flows was incorporated into the river channel active cells based on the periods of flood flow.

4.9 Land Use

Land uses were interpreted from air photographs. The Tres Rios Model included five different land uses; desert, mountain, river floodplains, agricultural, and municipal/urban.

4.10 Agricultural and Municipal Recharge

Land use data, water use entity data and water application data were used to compute the projected groundwater recharge for the model area from agricultural and municipal use. The agricultural and municipal recharge simulated in the model represents the amount of water applied to these lands that is projected to percolate through the soil back to the aquifer. In addition to application return flows, recharge to the aquifer also occurs due to leakage associated with the Roosevelt Irrigation District's (RID) Roosevelt Canal and Buckeye Irrigation

Company's canals. Annual average recharge was computed from these data sources to produce an array of recharge quantities by cell for input to the model.

Municipal/urban land accounts for 15 percent of the land use in the Tres Rios Model area. Municipal/urban land use does have a recharge component, however the individual land parcels are small and the recharge associated with these small parcels could not be quantified on a parcel by parcel basis. A recharge projection of 32 acre-feet (39.5 million liters) per model cell per year was assigned for municipal/urban land use cells.

4.11 Riparian Vegetation Evapotranspiration

Evapotranspiration is defined as the quantity of water used by the plant for growth and transpiration and evaporation from the area adjacent to the plant. Riparian areas within the Tres Rios Model area were identified based on published data. An evapotranspiration rate for each major vegetation type was assigned. The number of acres of each major vegetation type within a model cell were estimated. The riparian area vegetation within the Tres Rios Model focus area was very detailed, however, outside of the focus area the vegetation in the Salt, Gila, and Agua Fria channels was less defined. Cells coded as floodplain in the channels where the vegetation was not well defined was assigned a water use of 3.7 acre-feet (4.6 million liters) per year, which is an average rate for the potential mix of vegetation associations within the model cells coded as having riparian channel land use.

5. CALIBRATION AND SENSITIVITY ANALYSIS

After the model parameters were defined and entered into the model database, the Tres Rios Model was run through a series of calibration and sensitivity analyses. The calibration period started with 1986 and ended in 1991. The calibration was essential to verify that the simulated groundwater conditions during the calibration time period matched the water level contours prepared based on ADWR field measurements in wells. During the calibration period, model input parameters were adjusted to allow the numeric simulation to match the field data. As these parameters were adjusted, the response of the model to the parameter changes were observed as the sensitivity analysis. The sensitivity analysis was used to verify the amount of data output changes that would result from changes to the input parameters. This allowed small adjustments to be made to specific parameters to calibrate the model. The parameters that were adjusted included hydraulic conductivity, mountain-front recharge, agricultural return flows to both groundwater and to the Gila River, general head boundary conductance to increase or decrease groundwater inflow and outflow and vertical conductance between layers.

More information on the calibration and sensitivity analysis of the model is located in the Model Calibration section of **Appendix A.**

6. TRES RIOS ALTERNATIVES

Four scenarios were modeled in the detailed Tres Rios hydrologic model. They are:

- Present Conditions into the Future
- Future Without Federal Action
- Tres Rios Alternative 3.5
- Optimized Tres Rios Alternative 3.5 (Called Alternative 3.5A)

Characteristics of each modeled alternative are discussed in the following sections.

For each alternative, seasonality was taken into consideration and water table elevations were projected for four months per year. The months correspond to the end of each quarter of the year. Data is presented for the end of each quarter. The following months correspond to the end of each quarter:

- March = End of 1st Quarter
- June = End of 2nd Quarter
- September = End of 3rd Quarter
- December = End of 4th Quarter

Seasonality factors were applied to well pumpage and riparian evapotranspiration. Gila River inflow to the study area and discharge from the 91st Avenue WWTP were also varied on a seasonal basis.

6.1 Present Conditions Into The Future

The Present Conditions Into The Future alternative was used to assess the future groundwater conditions based on a projection of present conditions. The dataset used in the Tres Rios Model calibration was used for this alternative. The Present Conditions alternative does not include any riparian area changes to the Salt and Gila Rivers and does not include any changes in the discharge from the 91st Avenue WWTP. Deliveries to the BIC were maintained via the river channel.

This alternative provides a baseline for comparison of the other Tres Rios alternatives. Seasonality was incorporated into the model in order to simulate changing water needs on a quarterly basis for each year, as mentioned in the previous section.

The model was run for 20 years into the future, repeating the same quarterly seasonal values for each year. Modeled river flows and evapotranspiration totals were examined, and it was determined that the groundwater elevations, stream flows and evapotranspiration approached a long-term, constant condition within approximately 5 years, repeating the same seasonally-varying patterns of flows and evapotranspiration year after year. For this reason, a scenario run of 10 years was judged sufficient to represent a stabilized system.

Plates 3 through 6 in **Appendix A** present the final water levels and depth to water at the end of each quarter for the fifth year, at the time the heads had approached a long-term constant trend in the model simulation. The heads are highest at the end of the first quarter (March) as a result of relatively low total water demand throughout the winter months. Heads decline at the end of the second quarter (June), and reach their lowest at the end of the third quarter (September), reflecting high demands in the spring and summer months. Heads rise at the end of the fourth quarter (December), reflecting reduced demands in the fall. The pattern is repeated each year.

Table 6-1 summarizes the 91st Avenue WWTP discharges input for this scenario and the resulting modeled flow in the Gila River just upstream of the BIC Canal diversion.

6.2 Future Without Federal Action

The Future Without Federal Action Alternative consists of elimination of discharges to the Salt River from the 91st Avenue WWTP. The full contractual water supply to the BIC from the 91st Avenue WWTP (40,000 AF/yr, 49 x 10^6 m^3/yr) is assumed to be delivered via a pipeline. No modifications were made to the riparian habitat.

It was assumed that the BIC did not divert any flow from the Gila River. Historically, the BIC had a high water supply because they were able to divert much of the available flow from the Gila River and their irrigation efficiency was relatively low. Such a reduction in surface-water supply would required BIC to pump approximately 89,000 acre-feet per year (110 x 10^6 m^3/yr) from their wells in order to continue their historical water application rate. It was assumed that the BIC would not pursue such a high and costly well pumpage program and instead would increase their efficiency to 80 percent, resulting in a total pumpage increase of 20,000 acre-feet per year from their historical amount. The BIC dewatering wells were allowed to remain at their historical pumping rates.

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Table 6-1
Projected 91st Avenue WWTP Discharge to Salt River and Modeled River Flows - Present Conditions Into the Future

Greeley and Hansen
March 2001

Quarterly Average (Model Year 20)	*Projected 91st Avenue WWTP Discharge to Salt River (mgd)*	*Modeled Gila River Flow Just Upstream of BIC Canal (mgd)*
Jan-Mar	118	144
Apr-Jun	111	130
Jul-Sep	103	117
Oct-Dec	107	125

The Future Without Federal Action simulation was run for 20 years. The modeled conditions approached a long-term constant trend after the fifth year and modeled heads, river flows and ET patterns repeated each year thereafter. Plates 7 through 10 in **Appendix A** show the projected groundwater levels for the end of each quarter for the tenth year, when heads had approached long-term constant levels.

Table 6-2 shows the 91st Avenue WWTP discharges input for this scenario and the modeled Gila River flow just upstream of the BIC diversion. Section 8 discusses the differences between water table elevations projected for this scenario and water table elevations projected for the other scenarios.

6.3 Tres Rios Alternative 3.5

The Corps of Engineers developed five initial alternatives for the Tres Rios Habitat Restoration project. These alternatives incorporated flow regulation wetlands, overbank constructed wetlands, Saltcedar replacement with Cottonwood and Willow habitat and Saltcedar replacement with open water/marsh habitat, and cobble areas. The five alternatives contained different proportions of these features in different locations. The five alternatives were evaluated by the Corps and stakeholder groups for several months until the preferred alternative was selected. The preferred alternative was called Alternative 3.5 because it incorporated the features of the original Alternatives 3 and 4. The riparian habitat features in Alternative 3.5 are presented on **Figure 6-1**. The Corps' proposed modifications to riparian habitat include removal of selected saltcedar stands from the channels of the Salt and Gila Rivers and replacement with open water/marsh vegetation and riparian corridors. A regulated wetland adjacent to the 91st Avenue WWTP is planned to receive effluent from the treatment plant, which would then discharge into a linear over bank wetland, transferring water to the Gila River. Tres Rios Alternative 3.5 also includes pumpage at the 91st Avenue WWTP dewatering wells and discharging the water to habitat features on the south side of the Salt River.

The 91st Avenue WWTP is projected to release effluent directly to the Salt River in a quantity one half of the contracted amount to the BIC. The other half of BIC's allotment would reach the Gila River via the regulated and linear-overbank wetlands, and the open water/marsh habitat areas on the north side of the Gila River.

The model was run for ten years. Plates 11 through 14, present the quarterly results for the final year of this Tres Rios Alternative 3.5 simulation. **Table 6-3** shows the projected 91st Avenue WWTP discharges to the Salt River that were input to the Tres Rios hydrologic model in this

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Table 6-2
Projected 91st Avenue WWTP Discharge to Salt River and Modeled River Flows - Future Without Federal Action

Greeley and Hansen
March 2001

Quarterly Average (Model Year 20)	*Projected 91st Avenue WWTP Discharge to Salt River (mgd)*	*Modeled Gila River Flow Just Upstream of BIC Canal (mgd)*
Jan-Mar	0	28
Apr-Jun	0	22
Jul-Sep	0	19
Oct-Dec	0	22

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Table 6-3
Projected 91st Avenue WWTP Discharge to Salt River and Modeled River Flows - Tres Rios Alternative 3.5

Greeley and Hansen
March 2001

Quarterly Average (Model Year 10)	*Projected 91st Avenue WWTP Discharge to Salt River (mgd)*	*Modeled Gila River Flow Just Upstream of BIC Canal (mgd)*
Jan-Mar	21	56
Apr-Jun	49	75
Jul-Sep	49	69
Oct-Dec	21	47

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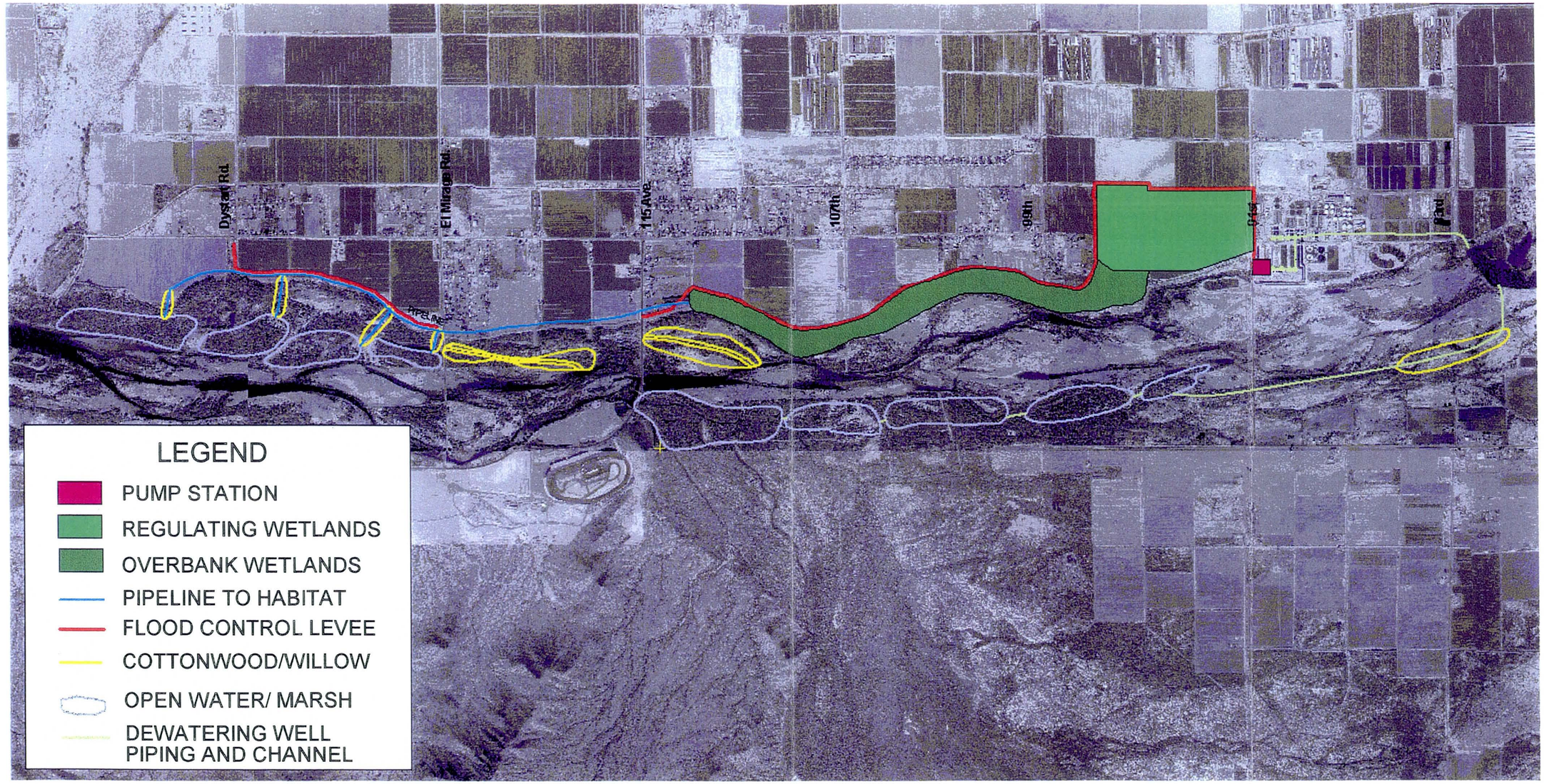
FIGURE 6-1



TRES RIOS ENVIRONMENTAL RESTORATION PROJECT
ALTERNATIVE 3.5

0.5 0 0.5 1 Miles

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MARCH 2001

scenario. **Table 6-3** also shows the modeled Gila River flow just upstream of the BIC diversion, under Tres Rios Alternative 3.5.

The results of this model simulation project that more flow would be in the Gila River just downstream of the modified habitat areas than is needed to satisfy the contractual obligation of the 91st Avenue WWTP to the BIC. This is in-part due to the fact that high infiltration in the habitat areas raise ground-water levels which increase the flow in the Gila River in the area. A second Alternative 3.5 simulation was performed to optimize the release of effluent from the 91st Avenue WWTP. This alternative was called Optimized Alternative 3.5 or Alternative 3.5A. A description of the simulation and results for this option are discussed in the following Section.

6.4 Tres Rios Optimized Alternative 3.5

In this alternative, the effluent released from the 91st Avenue WWTP into the Salt River and through the wetlands into the Gila River was reduced in the model to meet but not exceed the contractual amount of water available in the Gila River for delivery to the BIC. **Table 6-4** shows the 91st Avenue WWTP discharges used for this scenario. **Table 6-4** also shows the modeled flow in the Gila River just upstream of the BIC Canal diversion, for this scenario. As **Table 6-4** shows, no flow is discharged from the 91st Avenue WWTP to the river in the first and fourth quarters of the year and the discharge was reduced in the second and third quarters.

Plates 15-18 in **Appendix A** present the quarterly results for the final year of the ten-year model simulation Tres Rios Alternative 3.5A.

7. VEGETATION ROOT ZONES

Hydrological factors that are of key importance to riparian vegetation include availability of groundwater and surface water, magnitude and frequency of flood flows, and water quality. Availability of groundwater is addressed in this section. However, in order for a plant species to survive and proliferate, other criteria must also be met. A summary of these criteria and additional information are presented briefly in Section 8.

Simulation results from the Tres Rios hydrologic model contained the depth to groundwater along the Salt and Gila Rivers. These depths to groundwater can be used to project the relationship between groundwater depths and riparian vegetation root depths. A number of cross sections were developed to show how the projected water table elevations correspond to the root zones required to sustain plant growth. The groundwater elevations can then be compared to the maximum root depths to determine whether (based on depth to groundwater alone) plant species growth should be sustained.

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Table 6-4
Projected 91st Avenue WWTP Discharge to Salt River and Modeled River Flows - Tres Rios Optimized Alternative 3.5

Greeley and Hansen
March 2001

Quarterly Average (Model Year 10)	*Projected 91st Avenue WWTP Discharge to Salt River (mgd)*	*Modeled Gila River Flow Just Upstream of BIC Canal (mgd)*
Jan-Mar	0	35
Apr-Jun	25	50
Jul-Sep	29	49
Oct-Dec	0	26

Table 7-1 contains a summary of the maximum depths to groundwater from published literature, below which, plants cannot likely survive. That is, if the groundwater table is at a greater depth from the ground surface than the maximum root depth for growth, a given plant species will most likely not be able to survive or the quality of the stand will be compromised. **Table 7-1** shows maximum groundwater depths for both juvenile and mature species. Some plant species had conflicting maximum depths cited in the literature. In these cases, the species are listed at both or all depths in the table.

Table 7-2 contains a summary of the minimum groundwater depth for growth and the maximum groundwater depth for growth of willow, cottonwood, mesquite and saltcedar. These species were selected as key species by the Habitat Technical Committee as a part of the Tres Rios River Management Plan development.

In Section 8, a discussion of native riparian vegetation associated with the Tres Rios area is presented with a discussion of other factors important to plant growth.

In Section 9, the maximum depths to groundwater to sustain growth are compared to modeled groundwater depths using graphs for the four Tres Rios alternatives. The maximum depths to groundwater to sustain plant growth are shown in graphs as lines below the ground surface. Water table elevations are also shown on the same graph. This allows one to see where the groundwater table elevation is located in reference to the maximum plant root depths. If the groundwater table is above the maximum root depths, a mature plant should grow (juvenile plants may need supplemental watering) but if the maximum root depth is above the water table, the plant will not likely grow. The factors discussed in Section 8 are also important in sustaining plant growth.

8. RIPARIAN PLANT GROWTH AND SUSTAINABILITY

According to the Arizona Department of Water Resources (ADWR) *Riparian Protection Program Legislative Report*, from July 1994, the hydrologic factors that are of key importance to riparian vegetation include availability of groundwater and surface water, magnitude and frequency of flood flows, and water quality (ADWR, 1994). Geomorphic factors and soil factors also influence riparian vegetation, in part because they influence water availability and flood intensity. For example, floodplain soil texture influences soil moisture holding capacity and capillary water rise and stream bank soil substrate influences the extent of lateral water movement into stream banks.

Table 7-1
Maximum Groundwater Depth for Sustained Plant Growth

Greeley and Hansen
March 2001

Maximum Depth for Growth	*Age*	*Scientific Name*	*Common Name*
1.5 ft		Eleocharis montevidensis	sand spikerush
3 ft		Baccharis salicifolia	seepwillow
		Typha	cattail
6 ft	J M	Populus	Cottonwood
7 ft	J	Fraxinus velutina	velvet ash
	J	Morus microphylla	Texas mulberry
	J	Populus fremontii	Freemont cottonwood
	J	Salix gooddingii	Goodding's willow
9 ft		Baccharis salicifolia	mules fat
		Senecio longilobus	threadleaf groundsel
10 ft		Ambrosia psilostachya	Cuman ragweed
		Aster spinosus	aster
		Baccharis emoryi	Emory's baccharis
		Cynodon dactylon	Bermuda grass
	J	Salix gooddingii	Goodding's willow
11 ft	M	Fraxinus velutina	velvet ash
	M	Salix gooddingii	Goodding's willow
12 ft		Chrysothamnus nauseosus	heathgoldenrod
13 ft	J	Juglans major	Arizona walnut
14 ft	M	Acacia neovernicosa	viscid acacia
	M	Juglans major	Arizona walnut
17 ft	M	Populus fremontii	Freemont cottonwood
19 ft		Hymenoclea monogyra	singlewhorl burrobush
20 ft	J	Acacia greggii	catclaw acacia
		Atriplex	saltbrush
	J	Celtis reticulata	netleaf hackberry
		Lycium andersonii	Anderson's wolfberry
		Lycium pallidum	pale wolfberry
	J M	Prosopis julifbra	honey mesquite
		Sporobolus wrightii	giant sacaton
21 ft		Atriplex canescens	fourwing saltbush
22 ft	J	Prosopis velutina	velvet mesquite
	J	Rhus microphylla	littleleaf sumac
23 ft	M	Acacia greggii	catclaw acacia
		Anisacanthus thurberi	Thurbert's desert honeysuckle
	M	Celtis reticulata	netleaf hackberry
26 ft		Opuntia spinosior	walkingstick cactus
	M	prosopis velutina	velvet mesquite
		Ziziphus obtusifolia	lotebush
33 ft		Tamarix chinensis	saltcedar

J = juvenile typically < 5-10 years old
M = mature

Source = Wright, 1997 and Stromberg, 1996

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Table 7-2
Minimum and Maximum Groundwater Depths for Plant Growth

Greeley and Hansen
March 2001

Key Species	*Minimum GW Depth for Growth (ft)*	*Maximum GW Depth for Growth (ft)*
Willow	1	11
Cottonwood	2	17
Mesquite	3	26
Salt cedar	5	33

Source: Stromberg, 1996
Wright, 1997

Although physical components of the environment are the major determinants of riparian biotic communities, biological interactions also play a role. Biological factors such as pollination of flowers by insects, dispersal of seeds by animals, competition between plant species and the creation of a suitable habitat for one plant species by another plant species and others all influence the composition of riparian plan communities (ADWR, 1994).

8.1 Riparian Habitats

The following is a list that summarizes the functions and values of riparian vegetation in the Southwest (ADWR, 1994):

- Reduce flood flow velocity
- Enhance groundwater recharge
- Trap sediments
- Filter nutrients
- Stabilize stream banks
- Reduce soil erosion
- Provide habitat for riparian animals
- Provide habitat for fish and other aquatic organisms

The role of riparian systems in stabilizing sediment and stream banks is particularly important in arid setting, where inputs of sediment can be high and flood magnitude can be high relative to base flows. Riparian forests play a major role in removing eroded sediments from floodwaters and stabilizing them in the floodplain. Without riparian vegetation, rivers in arid regions undergo streambed scouring, channel widening, and carry increased sediment loads (ADWR, 1994).

Although riparian vegetation consumes both groundwater and surface water, these arid land systems perform water quantity, as well as water quality functions. For example, riparian vegetation can enhance groundwater recharge by slowing floodwaters and increasing water retention. Riparian vegetation can also modify flood flows by increasing lateral spread of floodwaters and decreasing downstream flow velocities (ADWR, 1994).

Stress and degradation can be detected by monitoring communities and ecosystems for changes in cover or biomass of the riparian stand, loss of biodiversity, or changes in species composition. A stressed community may show increased abundance of "keystone" species; or decreased abundance of indicator species that are very sensitive to ecosystem changes and that may serve

as early warning detectors of stress. Detection of stress requires investment of time and resources, but can be accomplished through a variety of techniques.

For many riparian species, in-channel flows serve as maintenance flows, while flood flows (out-of-bank flows) serve as regeneration flows. For other species, surface water is of direct importance to juvenile life stages, while groundwater is used by adults.

Studies in arid portions of California have shown that growth and canopy development of cottonwood trees increase significantly with annual streamflow volume, with flow volume in these studies serving as a surrogate indicator of water availability within the floodplain (Stromberg et. al., 1991).

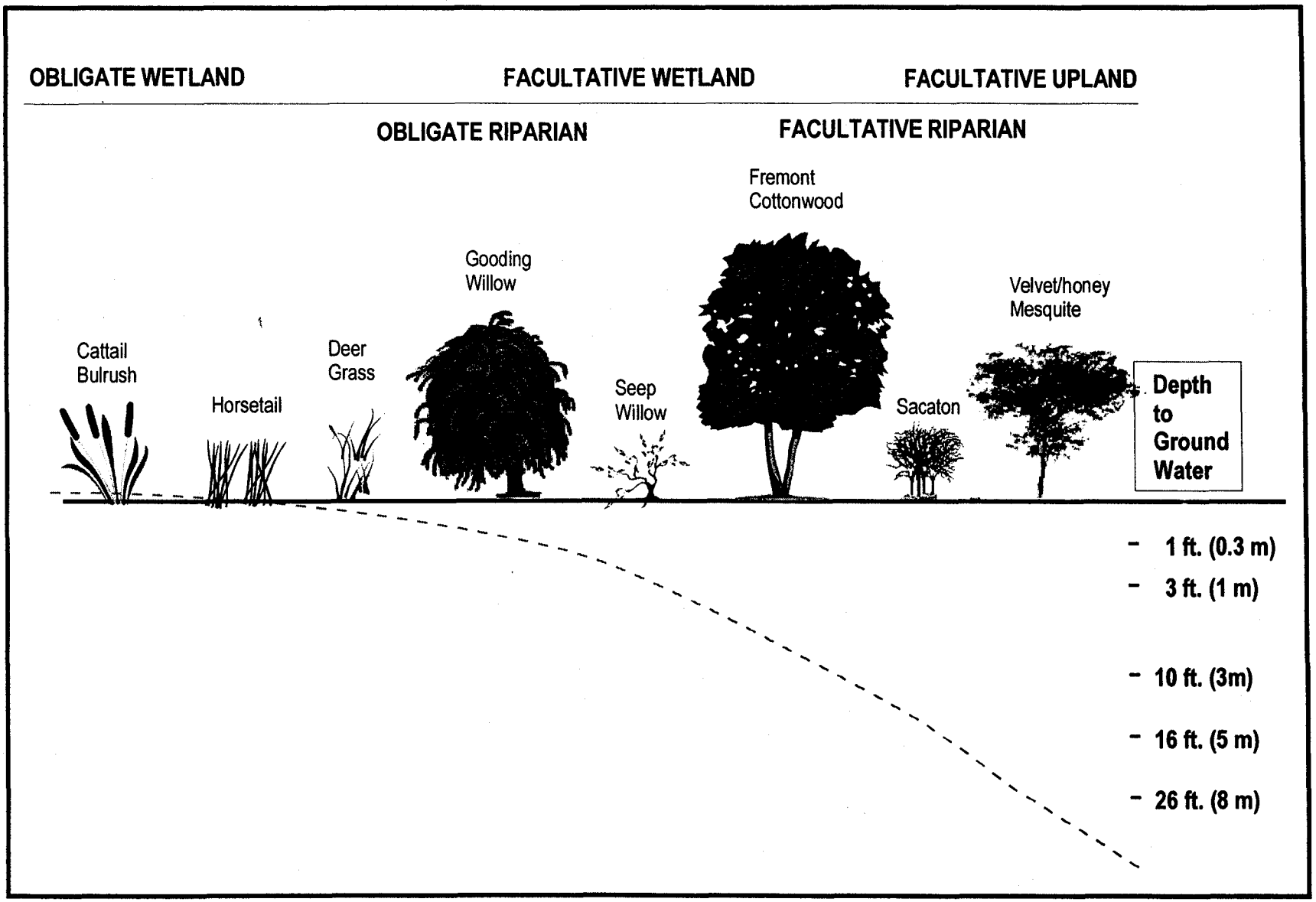
Riparian zone width, canopy, foliage area, woody stem basal area, and average canopy height all increased continuously with increasing surface flow (as noted in results from Stromberg [1993] and the Verde River Case Study).

Figure 8-1 shows the species change with increasing depth to groundwater in a Sonoran riparian ecosystem. As **Figure 8-1** shows, Goodding willow requires a more shallow groundwater table than cottonwood or mesquite.

Relationships with groundwater vary with age and life-stage of the riparian forest stand. Fremont cottonwood and Goodding willow, for example, are pioneer species that produce many tiny seeds, which germinate on saturated, unvegetated surface soil. Cottonwood seedlings have optimum growth and survival when the rate of water table decline below this surface level is less than 1 inch (3 cm) per day, which are characteristic rates of water table recession after winter or spring peak flows that stimulate cottonwood germination. One-year juveniles of both species have greatest survivorship on sites where the water table is between 2 to 3 feet (0.5 and 1 m) below the soil surface at summer's end, a zone in which seedling mortality is minimized both from drought and from late summer floods. Thus, although adult trees can tolerate deeper water tables, continued reproduction of the species requires short periods in spring in which water tables are very near the floodplain surface followed by a period in which water tables decline to a depth no greater than 3 feet (1 meter) by summer's end (ADWR, 1994).

8.2 Goodding Willow

Of all Sonoran riparian tree species, Goodding willow occupies the wettest habitats. It is the least tolerant of drought and most tolerant of saturated soils, and is classified as an obligate wetland species (United States, 1988). Groundwater and saturated soils and primary source of



SPECIES CHANGE WITH INCREASING DEPTH TO GROUNDWATER IN A SONORAN RIPARIAN ECOSYSTEM

NOTE: FIGURE REPRODUCED FROM ARIZONA DEPARTMENT OF WATER RESOURCES REPORT, *ARIZONA RIPARIAN PROTECTION PROGRAM LEGISLATIVE REPORT*, JULY 1994

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FIGURE 8-1

water for nature Goodding willow, based on isotope studies conducted with the Bill Williams and Colorado River floodplains (Busch et. al., 1992). Goodding willow typically grow at sites where the water table is less than about 10 feet (3 meters) below the floodplain surface which correspond to its maximum reported rooting depth (7 feet+, Zimmerman, 1969).

8.3 Fremont Cottonwood

Fremont cottonwood is often closely associated with Goodding willow, but is slightly more drought tolerant and can grow on sites that are slightly higher above the water table. There are conflicting reports regarding this issue, however. For example, Busch and his co-writers (1992) reported that Fremont cottonwood used saturated groundwater, while McQueen and Miller (1972) indicated that it used water from above the saturated zone.

Zimmerman (1969) noted that Fremont cottonwood grew at sites in Arizona where groundwater seasonally declined in summer to about 30-40 feet (9 to 13 m; Ash Creek); this may be a case where small "stringers" of Fremont cottonwood are supported by a combination of surface flow and seasonally high water tables. More recently, Fremont cottonwood has been reported from sites where groundwater was 16-20 feet (5 to 6 m) or 27 feet (8 m) below the floodplain surface, but in these cases the stand was either in poor condition with low vigor or consisted of only a few isolated trees. There are no reports of large, dense stands of Fremont cottonwood forests occurring on sites with water tables deeper than about 10 feet (3 m) below the surface, and this may be taken as a maximum depth for optimum Fremont cottonwood forest development. The optimum depth may vary with elevation. Freemont cottonwoods are relatively fast-growing trees. A study indicated that Fremont cottonwood establishes itself after winter or spring floods of magnitudes equal to or greater than the seven-year return flow (Stromberg et. al., 1991).

8.4 Mesquite

Across the groundwater continuum in Sonoran riparian ecosystems, Goodding willow and Freemont cottonwood give way to trees such as velvet mesquite, honey mesquite, cat-claw acacia (Acacia greggii), and netleaf hackberry (Celtis reticulata) that can either tap into deep groundwater or persist on capillary soil water (ADWR, 1994).

Mesquite forms bosques in areas where depth to groundwater ranges from about 7 to 50 feet (2 to 15 m) and is intolerant of very shallow water tables and saturated soils. The deep root system of mesquite is a primary reason for its prominence in riparian systems where groundwater is some distance below the surface. In well-developed bosques, roots of mesquite typically are within the upper 16 feet (5 m) of the soil surface, extending only into the unsaturated zone of soil moisture (capillary fringe) above the generally shallow phreatic zone. The capillary fringe can

extend for up to 8 feet (2.5 m) or more above the water table, particularly in fine textured soils with high moisture holding capacity, with which mesquite is commonly associated.

Mesquite also typically has an extensive network of shallow, lateral roots that absorb rainfall as well as surface moisture deposited during overbank floods.

Relationships with site hydrology also differ between juvenile and adult life stages for mesquite. Whereas mature bosques tend to occur on floodplains that are 10 feet or more above the water table, seedlings tend to establish on sites with shallower water tables. Along the Hassayampa River, for example, mature bosques were about 10 feet (3 m) above the water table, but mesquite seedlings had greatest survivorship on floodplain surfaces elevated 3 to 7 feet (1 to 2 m) above the water table. Mesquite seedlings arise from large seeds and can readily grow tap roots to the capillary zone from floodplains of this elevation.

8.5 The Necessity of Floods

Large winter floods are crucial to establishment of new cottonwood and willow. Seedlings experience greatest survival when floodwaters recede slowly during the growing season. Small differences in timing of spring floods can influence recruitment success of Freemont cottonwood vs. Goodding willow, because they have different "emergence phonologies". Both species disperse seeds and germinate over a relatively short period of time in spring and early summer. Goodding willow, however, disperses seeds somewhat later in the season than Fremont cottonwood. As a consequence, later spring floods favor willow by inundating floodplains during its germination period, while earlier floods favor cottonwood for the same reason. Zonation of these two species in the floodplain occurs for a similar reason, with Goodding willow occurring on floodplain terraces that are lower and closer to the stream than terraces supporting the earlier germinating Freemont cottonwoods.

Flood occurrences along many of Arizona's rivers are bimodal. Winter floods generally result from Pacific frontal storms, and cause widespread, regional flooding. Summer floods result from monsoon storms, and are typically more localized, more frequent, and or shorter duration. Some riparian species, particularly those of subtropical origin, are adapted to germinate during the hot summer periods with moisture provided by monsoon floods. Mesquite is an example of such a species. Although many mammals also play a role in its establishment by scarifying and dispersing seeds in fecal matter, summer floods also play a role in its establishment by abrading seeds, dispersing them to appropriate establishment sites in the floodplain, and moistening these optimal germination sites. Along the Hassayampa River mesquite seedlings were most abundant following late summer rains or floods of sufficient magnitude to inundate floodplain surfaces

elevated 3 to 7 feet (1 to 2 m) above the water table (Hughes, 1990). Late summer floods and rains also stimulate germination of many other riparian tree species, including desert willow.

Saltcedar and Goodding willow are inundation tolerant, whereas, cottonwood and mesquite are not. Altered seasonal flow patterns result in the replacement of native species by saltcedar or other non-native species.

When peak flows occur in summer or fall rather than spring, conditions in reaches downstream of dams favor the opportunistic saltcedar because it can germinate anytime during the growing season. Increased water salinities, altered sediment grain size, and lowered downstream water tables also favor saltcedar establishment. Once present, saltcedar excludes native species from its understory by pumping salt from groundwater to the surface soil and increasing fire frequency. Naturally timed floods, through a variety of mechanisms, including flushing of accumulated salts and recharge of water tables, can reduce the encroachment of exotic species and favor the abundance of native species to the natural, flood patterns of the Southwest.

It is recommended that seasonal and annual flow patterns closely track historical hydrograph information. That is, seasonal high flows should remain in the spring and late summer, or otherwise follow the natural seasonal flow pattern. The magnitude of the flood flow rate relative to the low flow rate should be consistent with the historical pattern if possible to optimize growth and sustainability of riparian species.

8.6 Water Quality

In the 1997 ADWR report *Arizona Riparian Protection Program Legislative Report*, it states that in Arizona, "water quantity issues often override water quality issues." The major water quality parameters of concern in Arizona were identified as salinity, alkalinity, nutrient and heavy metal content. **Table 8-1** shows the salinity tolerance range for selected riparian plant species.

Goodding willow and Fremont cottonwood have low salt tolerance. One study indicates that seed germination for both species is greatly reduced with salinities greater than 50 meq/l of NaCl (approximately 1,150 mg/L sodium and 1,770 mg/L chlorine). Seedlings tolerate no more than about 3,000 mg/L of total dissolved solids. An optimum salt concentration for both species is below 1,500 mg/L.

Most species of mesquite have fairly high salt tolerance. Honey mesquite germinates at salinities up to 300 meq/l of NaCl (approximately 6,900 mg/L sodium and 10,600 mg/L chlorine) and as

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Table 8-1
Salinity Tolerance Range (mg/L of TDS) for Selected Riparian Plant Species[1]

Greeley and Hansen
March 2001

Species	*Optimum Range*	*Maximum Tolerance*
Fremont cottonwood	0 – 1,500	3,000
Goodding willow	0 – 1,500	3,000
Arrowweed	0 – 6,000	18,000
Quailbush	0 – 18,000	60,000
Screwbean mesquite	1,500 – 36,000	36,000
Pickleweed	1,500 – 36,000	60,000
Honey mesquite	1,500 – 36,000	60,000
Saltcedar	1,500 – 36,000	95,000

(1) Table reproduced from ADWR report *AZ Riparian Protection Program Legislative Report*, July 1994.

adults can survive TDS levels of up to 60,000 mg/L. Screwbean mesquite has somewhat lower salt tolerance, and has much reduced seedling survivorship at greater than 36,000 mg/L TDS.

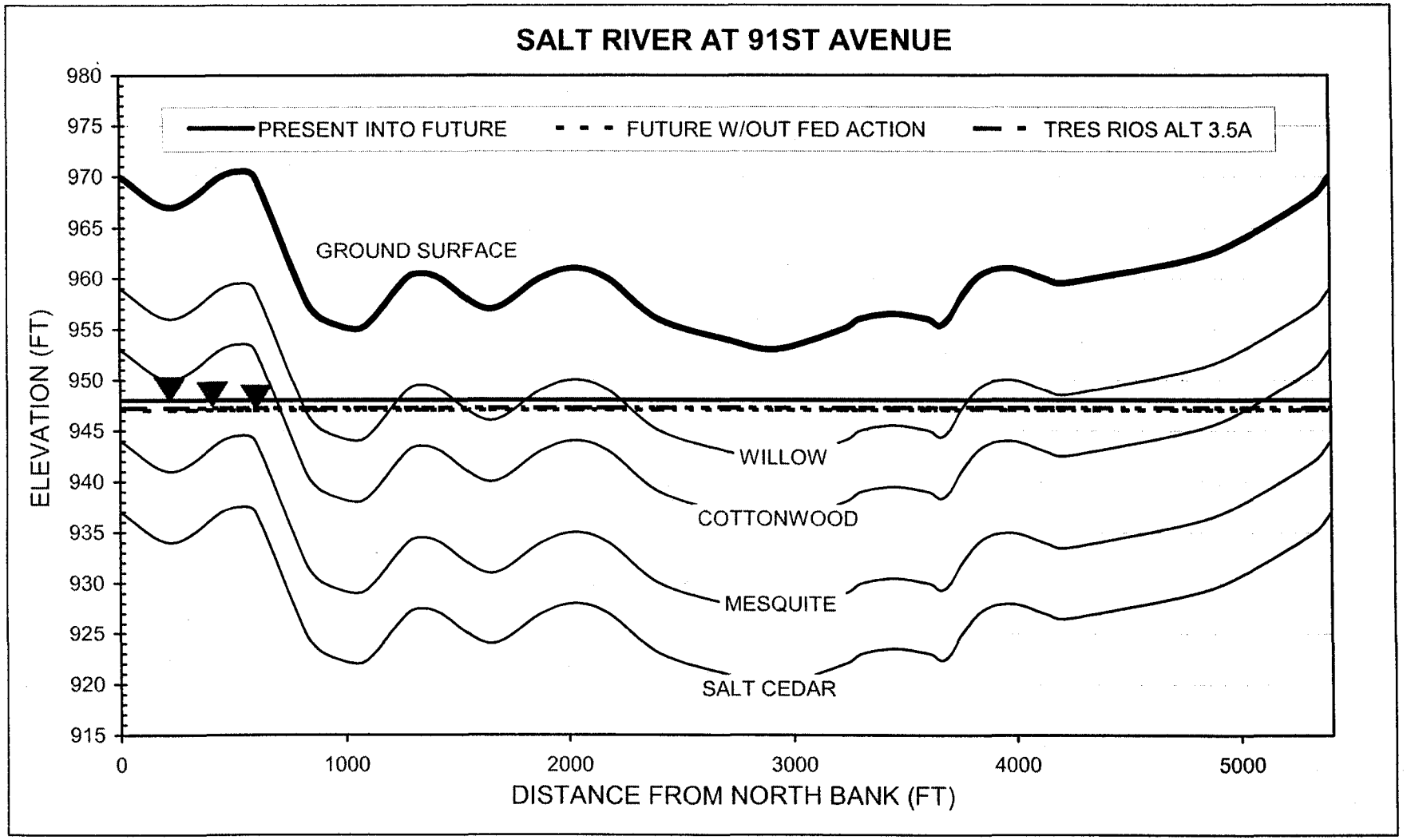
According to the ADWR, additional research is needed to determine the relationship of water quality parameters other than salinity (e.g., nutrients and heavy metals) to riparian vegetation and wildlife. It is recommended that monitoring wells be installed in floodplains that support valued riparian ecosystems and in regional aquifers that recharge the floodplain alluvium. Ideally, wells should be placed along a gradient away from the stream to the floodplain perimeter, and should be located within various vegetation types, particularly those most sensitive to groundwater change. Water tables should be monitored on a monthly basis, or at least biannually, including one reading in June, the driest month of the year. Declines in water tables below the norms or thresholds for each riparian type or indicator species can serve as a "red-flag" that signals a need to modify pumping, diversion, or other water uses (ADWR, 1994).

8.7 Bringing Back Riparian Vegetation

Riparian zones that have been stressed by dams and surface flow diversion can be restored by releasing surface flows that mimic historic hydrograph data, but recovery will be less complete if a river has been hydraulically disconnected from underlying groundwater. Generally, if a remnant riparian plant population still persists, the riparian ecosystem can recover naturally once the necessary physical conditions have been restored. Active restoration measures can hasten this natural recovery process. Ensuring that physical conditions and processes deviate as little as possible from historic "norms" can minimize ecosystem stress from hydrologic alterations.

9. ANALYSES

Figures 9-1 through **9-4** each show a cross section of the Salt River at 91st Avenue and the corresponding maximum depth to groundwater for the sustained growth of willow, cottonwood, mesquite and saltcedar. If the groundwater table is located above the maximum groundwater depth lines shown, growth of the given mature plant species should be sustained. However, if the groundwater table is located below the maximum depth lines shown, growth of the mature plant species will not be sustained. Based on a conversation with Julie Stromberg of Arizona State University, if the groundwater table drops below the maximum depth to groundwater for a given species for one or two quarters of the year but remains above the maximum depth for the remainder of the year, the species may survive but some attributes of the stand will be affected. Ms. Stromberg suggested that too deep a water table during part of the year may cause mortality of some plants and will likely affect the overall quality of the stand (Stromberg, n.d.).



PROJECTED GW TABLES IN MARCH[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-1

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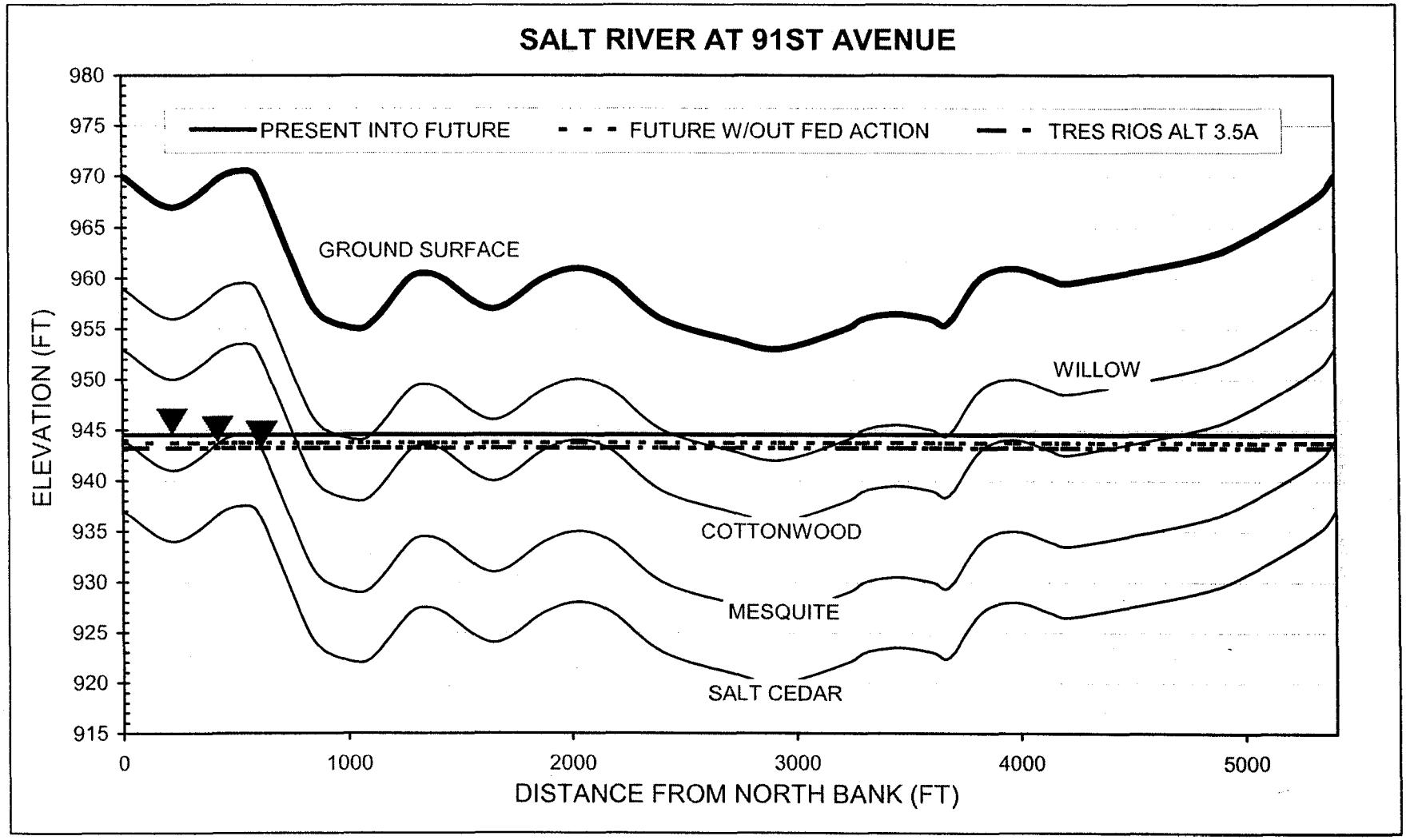

PROJECTED GW TABLES IN JUNE[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-2

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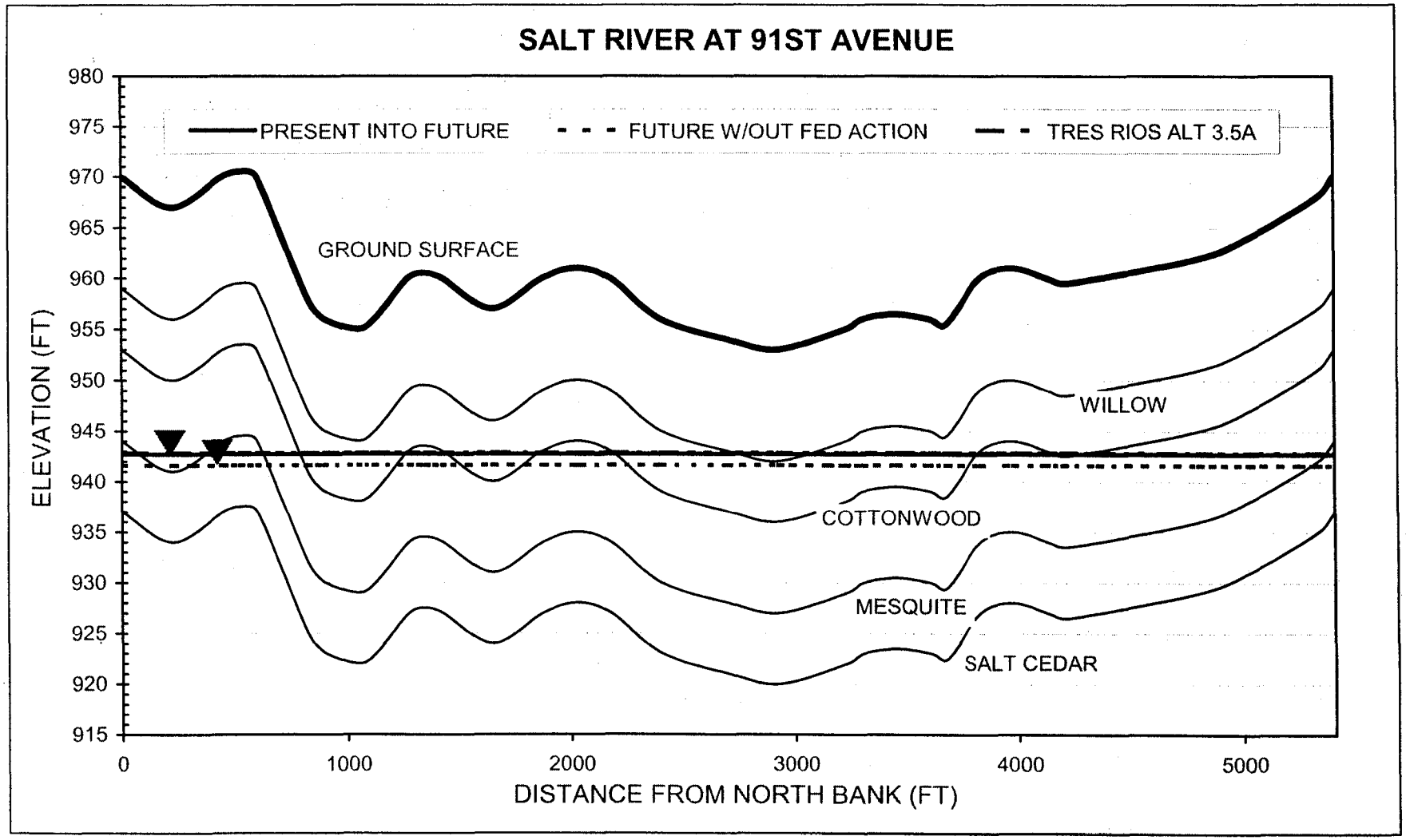

PROJECTED GW TABLES IN SEPTEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-3

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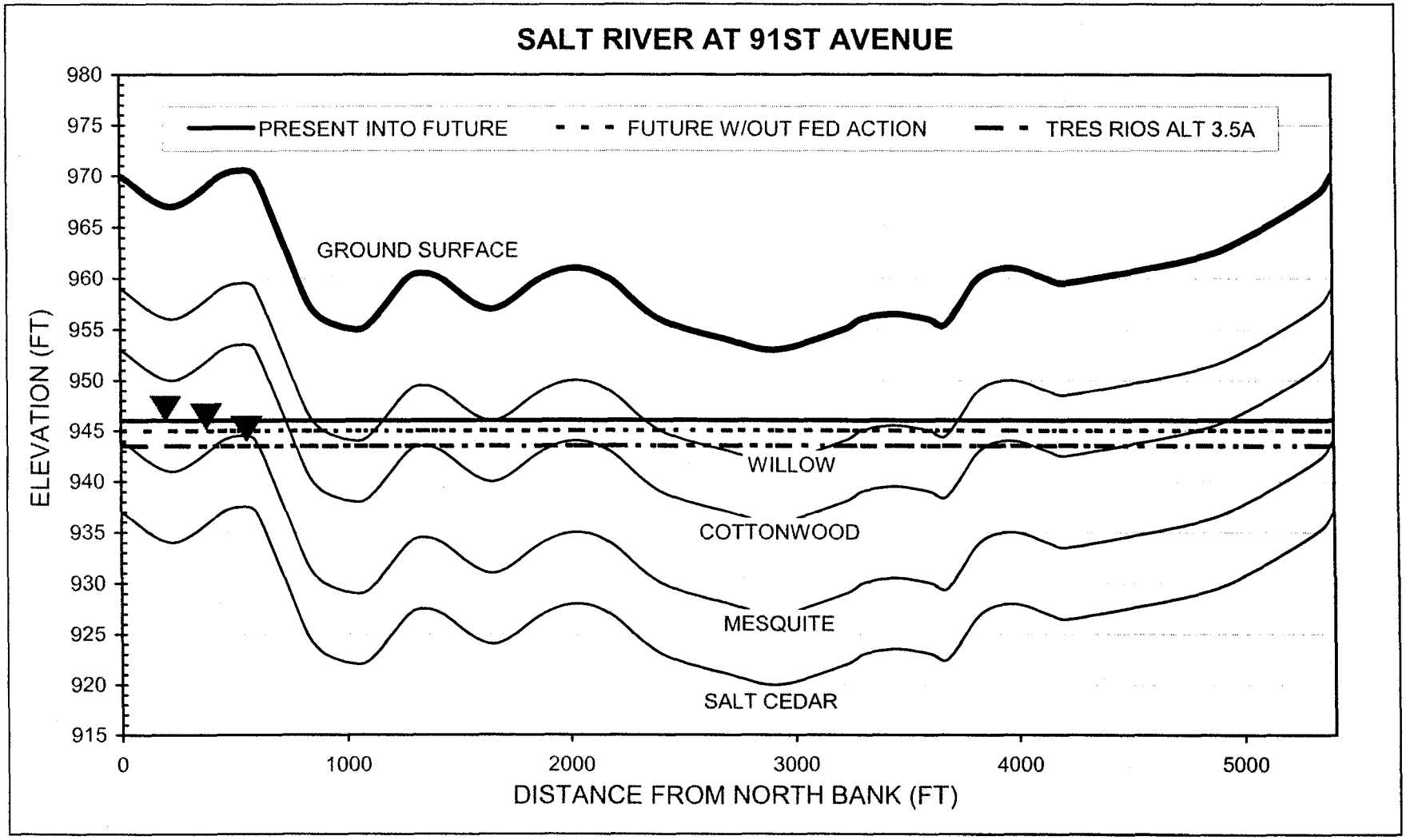

PROJECTED GW TABLES IN DECEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-4

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It is particularly important that the water table be above the threshold during the growing season (typically spring, early summer, and late summer). The depth to groundwater must be substantially less for seedling (i.e., juvenile plants) than for mature plants. Therefore, if a species is to reproduce and sustain itself, the depth to groundwater must be less than those listed in **Table 7-2** and shown in the Section 9 figures.

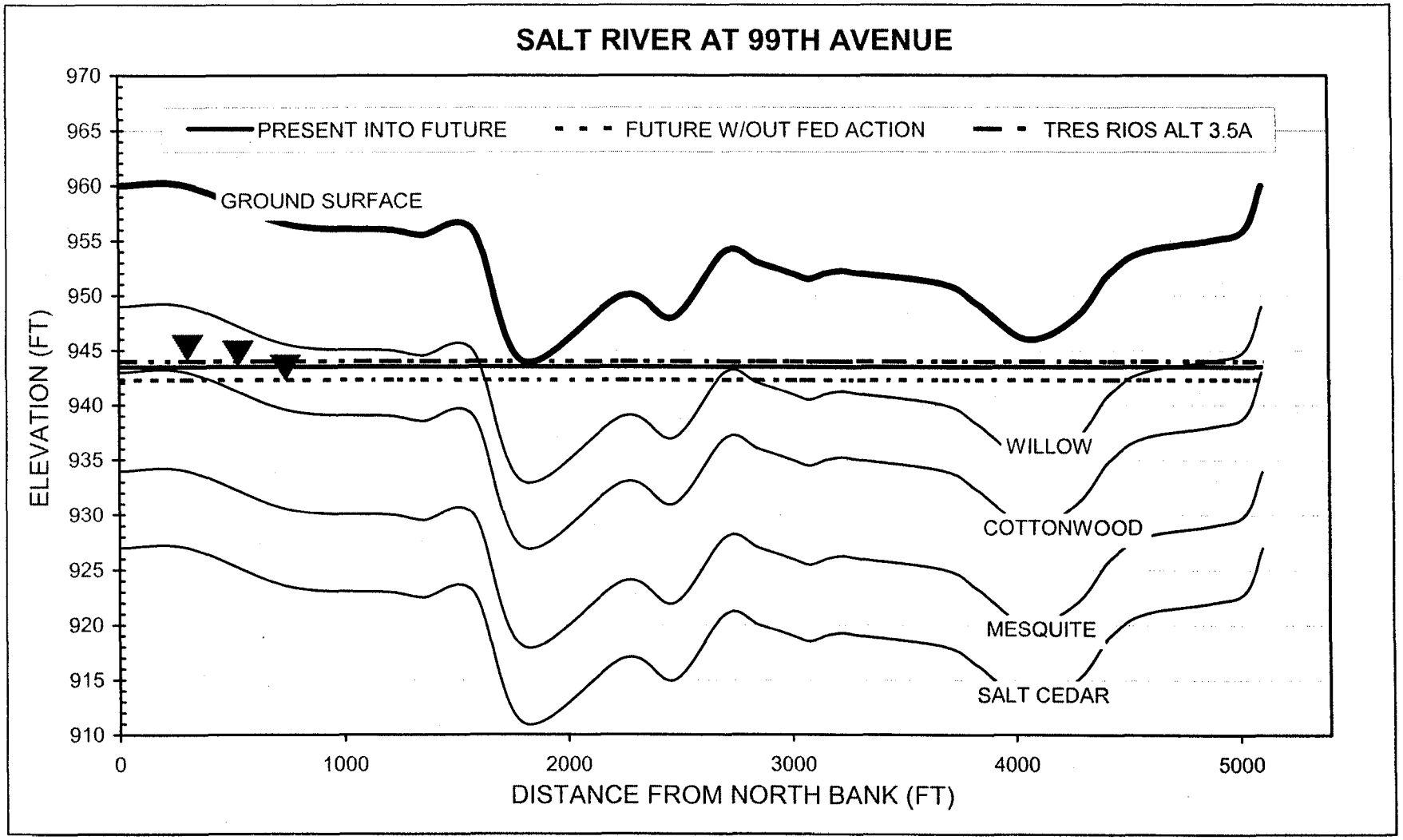
Projected groundwater table elevations for the following modeled alternatives are also shown on **Figures 9-1** through **9-4**:

- Present Conditions into the Future (existing 91st Avenue WWTP discharge and no habitat restoration)
- Future Without Federal Action (no 91st Avenue WWTP discharge to river and no BIC diversion)
- Optimized Tres Rios Alternative 3.5 (habitat restoration and optimized discharge from 91st Avenue WWTP)

Figure 9-1 shows the projected groundwater table elevations at 91st Avenue and the Salt River for the end of the first quarter of the year (March) once the model has reached a long term constant condition (after approximately the first five to ten years following the implementation of each alternative). **Figures 9-2, 9-3** and **9-4** show the projected groundwater table elevations for the end of the second quarter (June), third quarter (September) and fourth quarter (December), respectively.

Figure 9-1 shows that the groundwater table elevation is projected to be about one foot higher at 91st Avenue and the Salt River under the Present Into the Future scenario than under the Future Without Federal Action and the Tres Rios Alternative 3.5A. As the figures show, under all scenarios, mesquite and saltcedar growth can be sustained throughout the channel at 91st Avenue. Cottonwood growth can be sustained over most of the channel (other than the far north bank) and willow growth can be sustained in and around the main channel. As **Figures 9-1, 9-2, 9-3** and **9-4** show, the groundwater elevation is projected to vary by approximately 5 feet though the year. The lowest groundwater elevation occurs at the end of the third quarter (September). At the end of the third quarter, the groundwater drops below the maximum root zone for cottonwood and willow. Therefore, it is projected that healthy growth of cottonwood and willow cannot be sustained on either bank of the Salt River at 91st Avenue, without supplemental watering.

Figures 9-5 through **9-8** show the ground surface elevation and projected groundwater elevations at 99th Avenue and the Salt River. The groundwater elevation is projected to be higher under



PROJECTED GW TABLES IN MARCH[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-5

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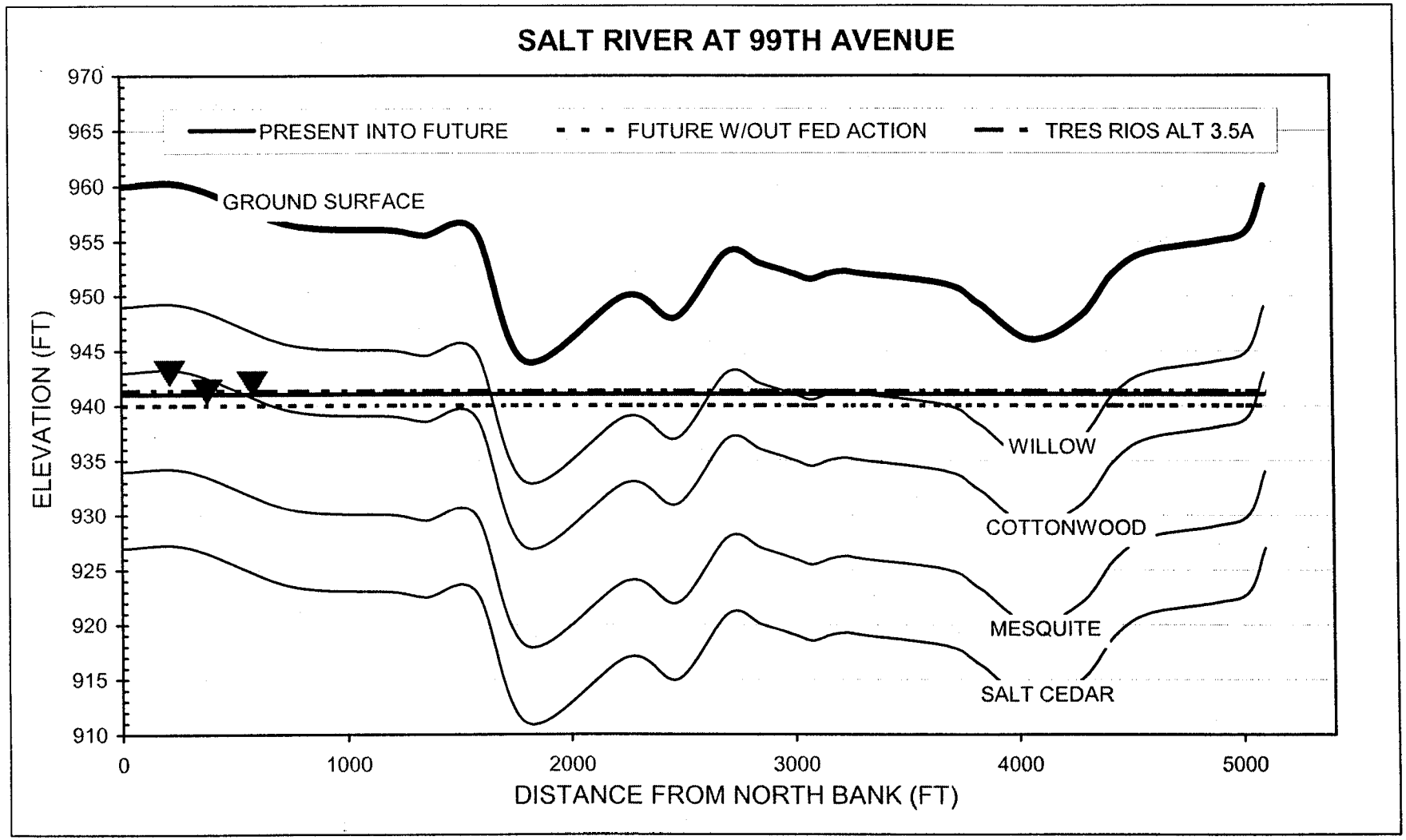

PROJECTED GW TABLES IN JUNE[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-6

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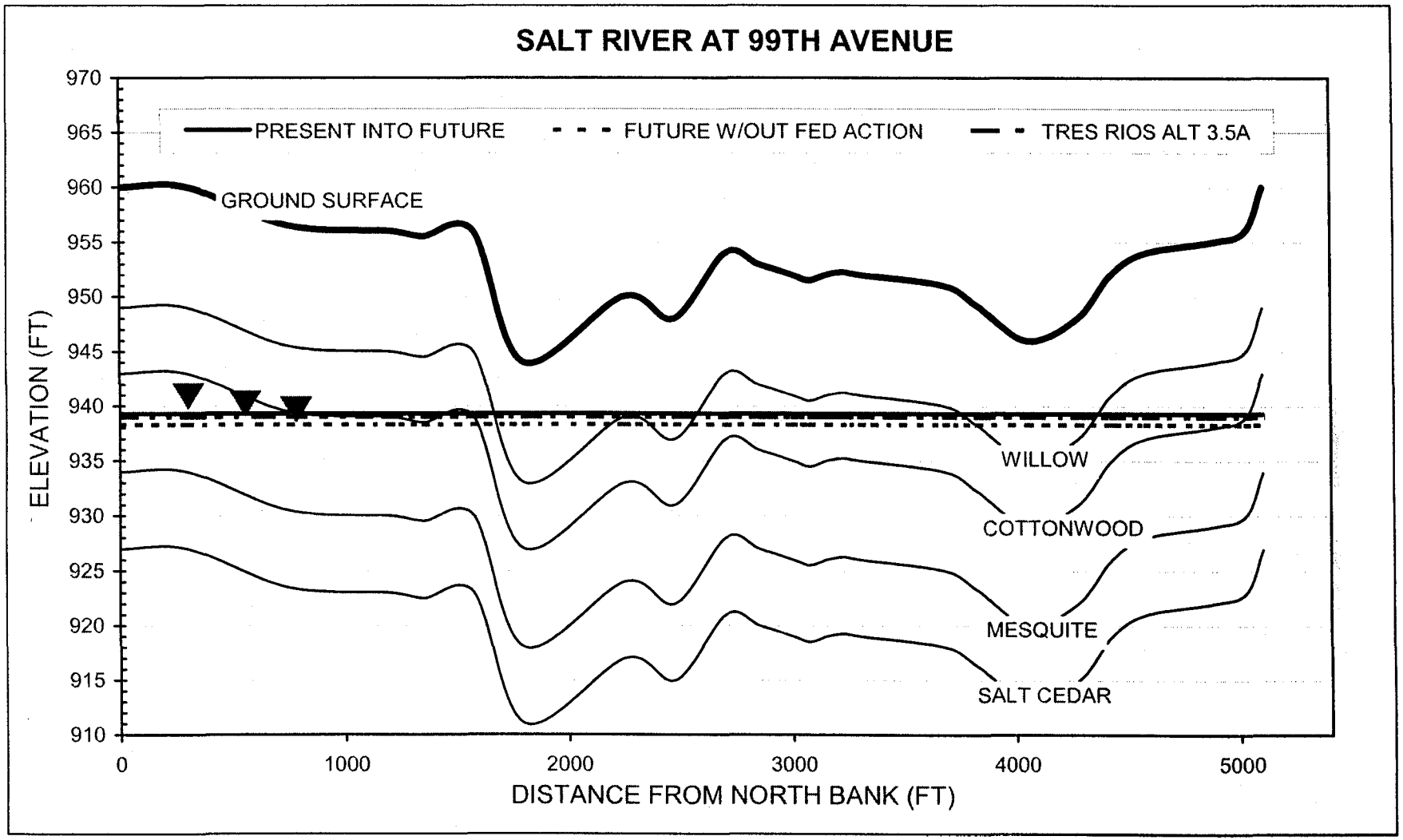

PROJECTED GW TABLES IN SEPTEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-7

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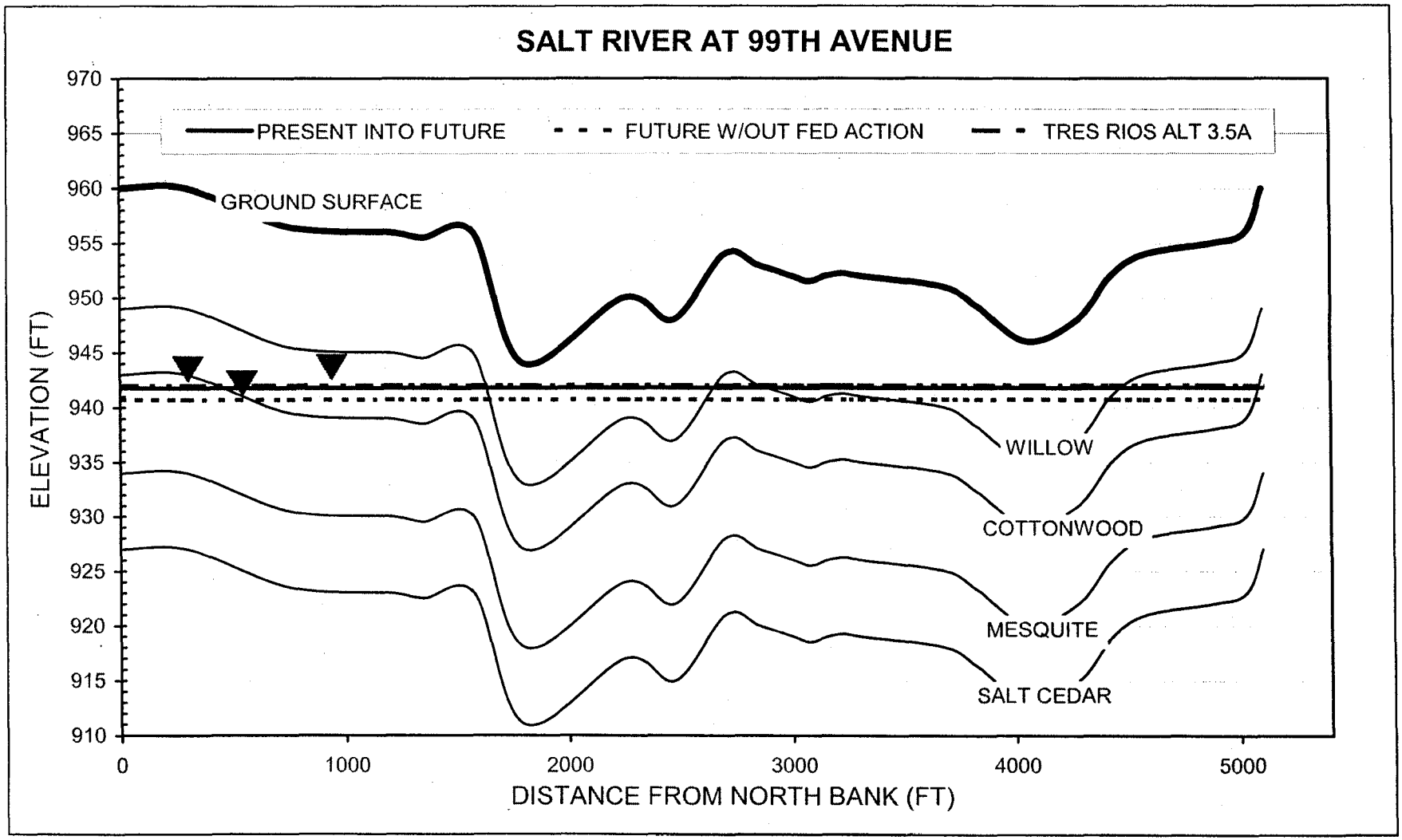

PROJECTED GW TABLES IN DECEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-8

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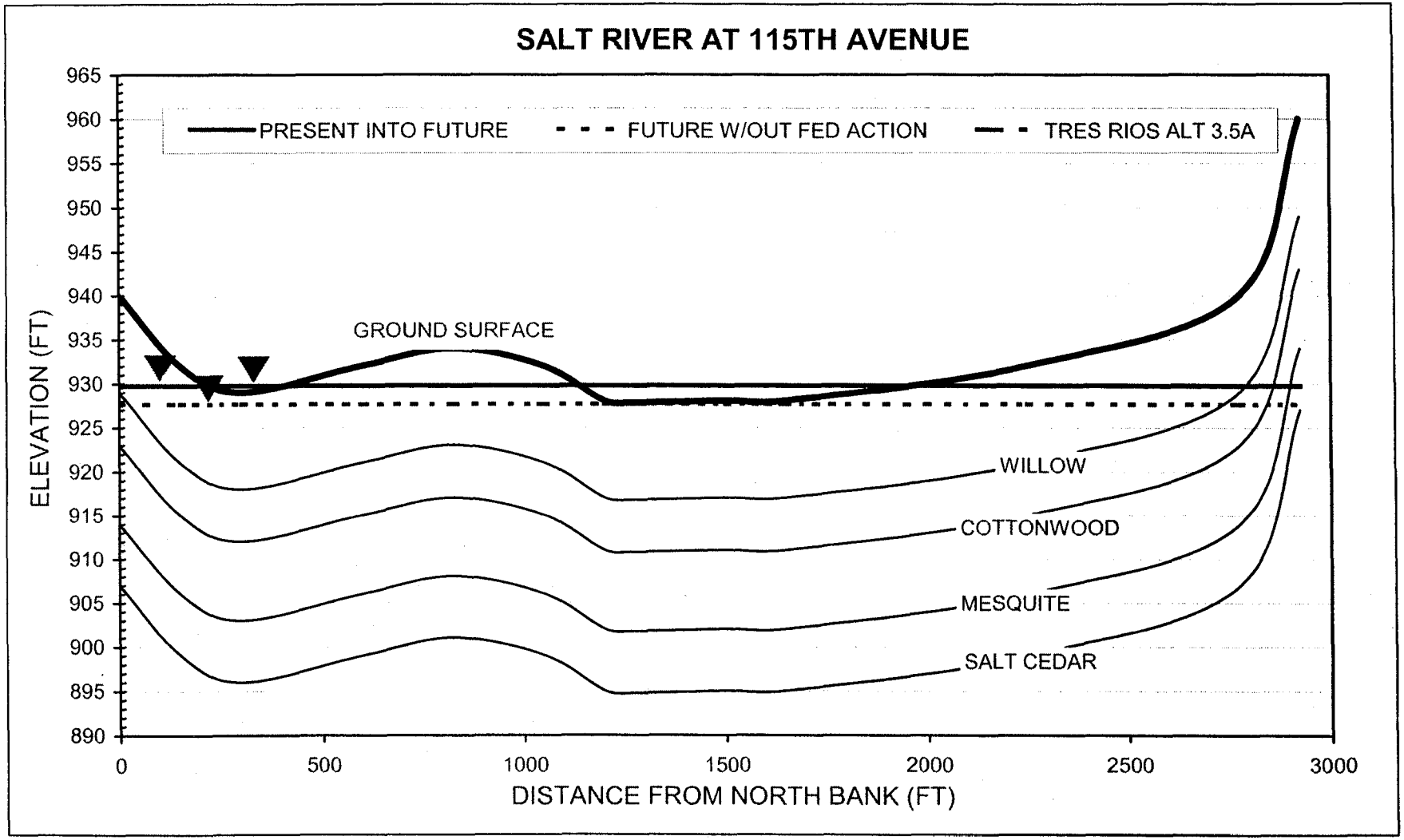
Optimized Alternative 3.5 scenario than Present Conditions Into The Future or Future Without Federal Action. The groundwater elevation is projected to vary by approximately 5 feet through the year. At the end of the third quarter (September) when the groundwater elevation is projected to be the lowest, mesquite and saltcedar can grow across the river bank, cottonwood can grow in the channel and along the south bank, but willows growth cannot be sustained on either bank.

Figures 9-9 through **9-12** show the ground surface elevation and the projected groundwater elevations at 115th Avenue and the Gila River for each modeled alternative once a long term constant condition has been achieved. The groundwater elevation is projected to vary by approximately 3 feet between March and September. Under each alternative, it is projected that willow, cottonwood, mesquite and saltcedar growth can be sustained at 115th Avenue and the Gila River (except at the far south bank). Lush riparian vegetation should survive well at 115th Avenue because of the high groundwater table.

Figures 9-13 through **9-16** show the ground surface elevation and projected groundwater elevations at the Gila River at El Mirage Road once a long term constant condition has been achieved. For the end of the first quarter of the year (March) the groundwater elevation under the Present Into The Future scenario is approximately 2.5 feet higher than under Tres Rios Alternative 3.5A and 3.5 feet higher than under the Future Without Federal Action scenario. The groundwater elevation is projected to vary by approximately 3.5 feet at the Gila River at El Mirage Road through the year. As **Figure 9-15** shows, when the groundwater elevation is projected to be at its lowest (end of the third quarter = September) growth of willows can not be sustained, while cottonwood, mesquite and saltcedar growth should be sustained over most of the channel over the year.

Figures 9-17 through **9-20** show the ground surface elevation and projected groundwater elevation at the Gila River and Dysart Road. The groundwater elevation is projected to vary by approximately 5 feet through the year at this location. When the groundwater elevation is at its lowest (**Figure 9-19**), growth of healthy willow cannot be sustained over most of the channel without supplemental watering, healthy cottonwood growth cannot be sustained on the far banks without supplemental watering, but healthy growth of mesquite should be sustained over the entire channel without supplemental watering.

Figures 9-21 through **9-24** show the ground surface elevation and projected groundwater elevation at the Gila River and Litchfield Road for the three modeled scenarios: Present Into the Future, Future Without Federal Action and Tres Rios Alternative 3.5A. It is projected that the



PROJECTED GW TABLES IN MARCH[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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SALT-GILA GROUNDWATER ANALYSIS
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FIGURE 9-9

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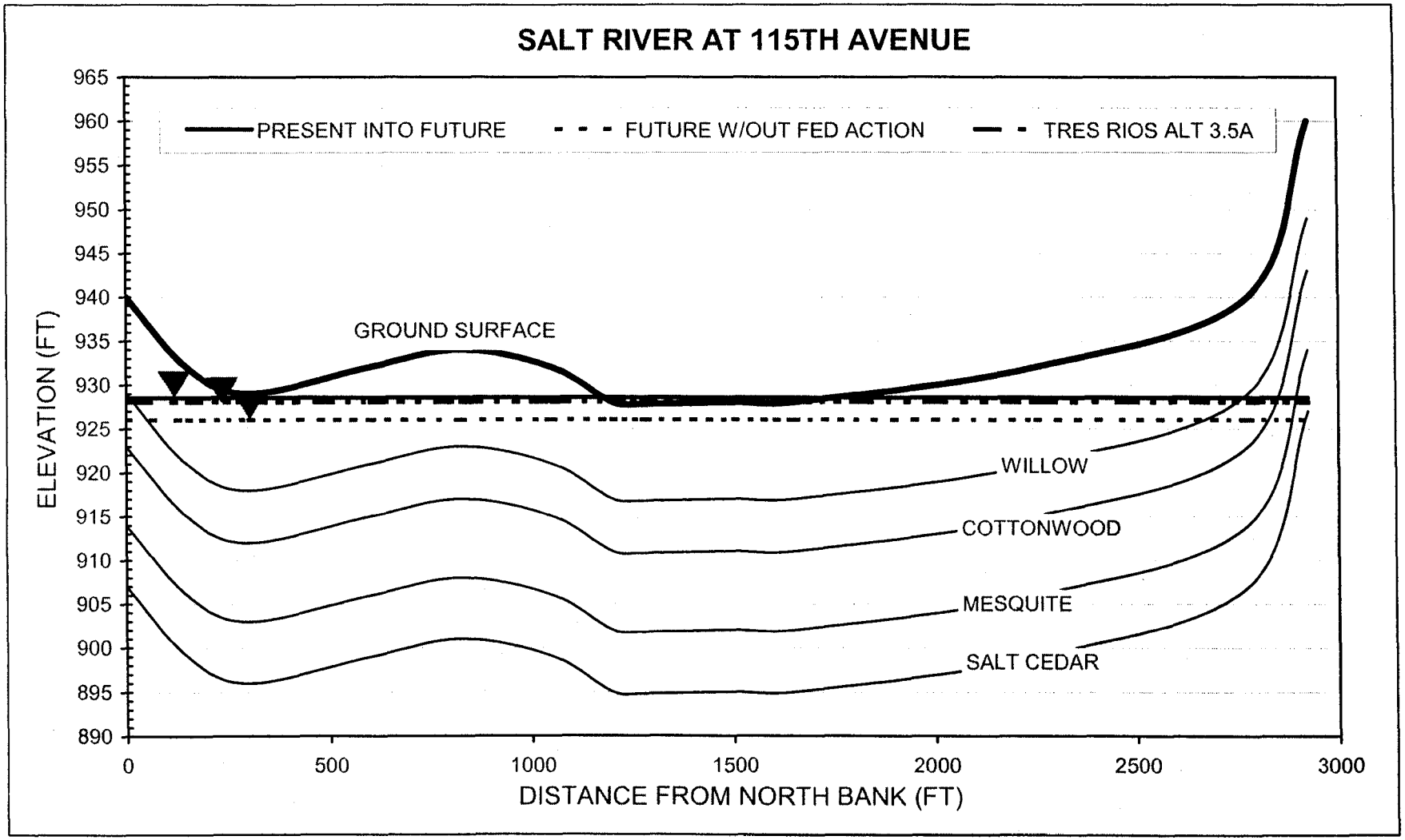

PROJECTED GW TABLES IN JUNE[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-10

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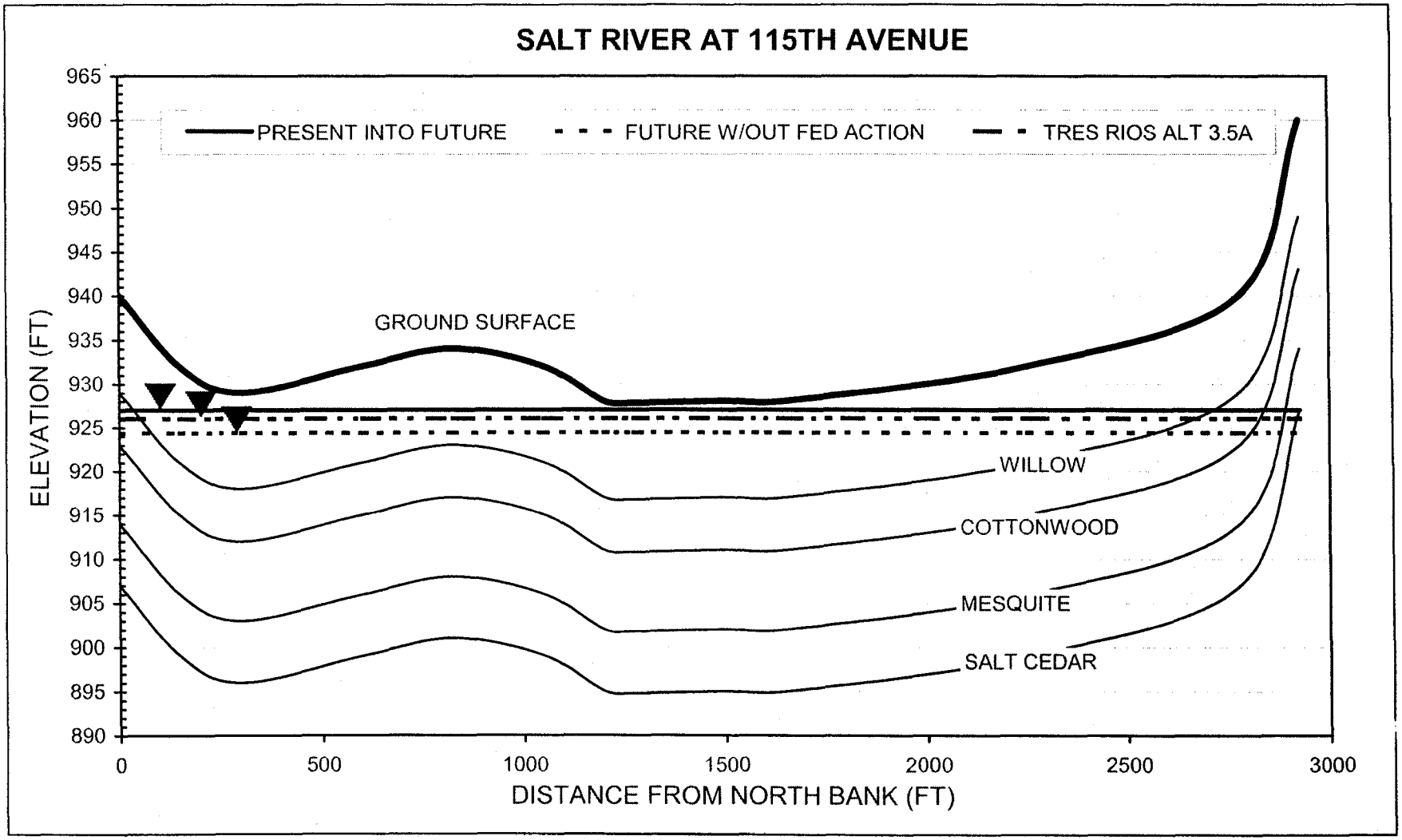

PROJECTED GW TABLES IN SEPTEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-11

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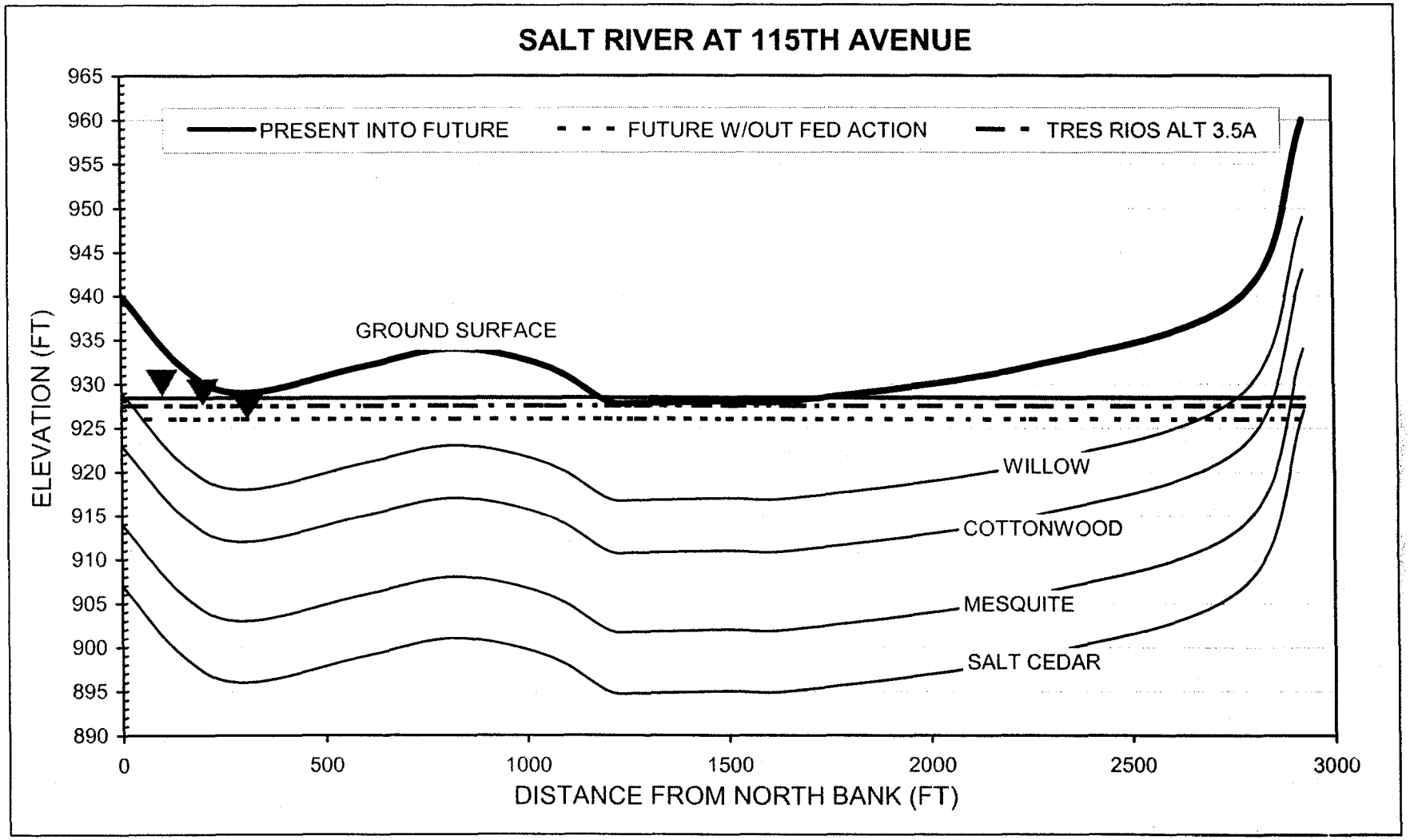

PROJECTED GW TABLES IN DECEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-12

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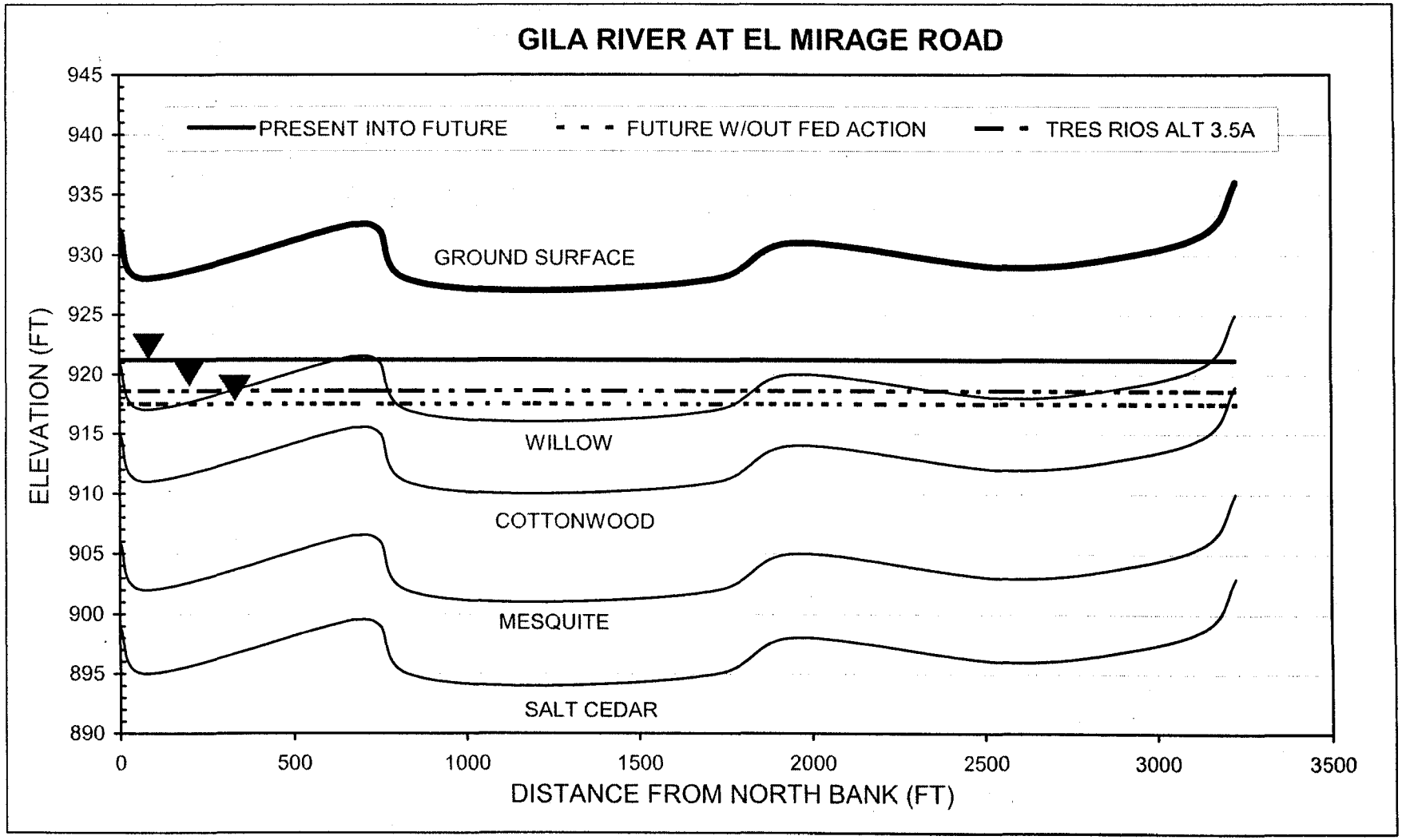

PROJECTED GW TABLES IN MARCH[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-13

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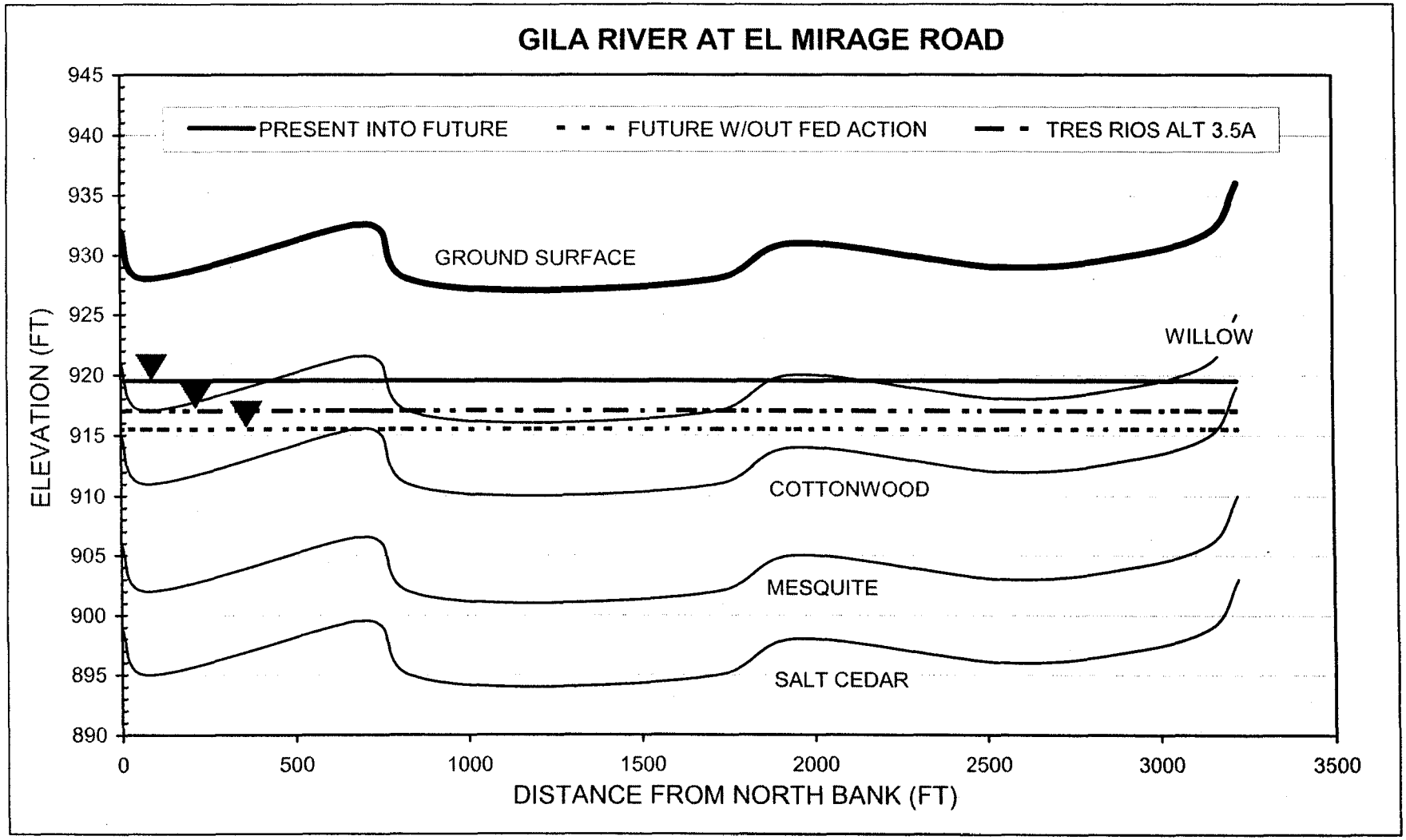

PROJECTED GW TABLES IN JUNE[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-14

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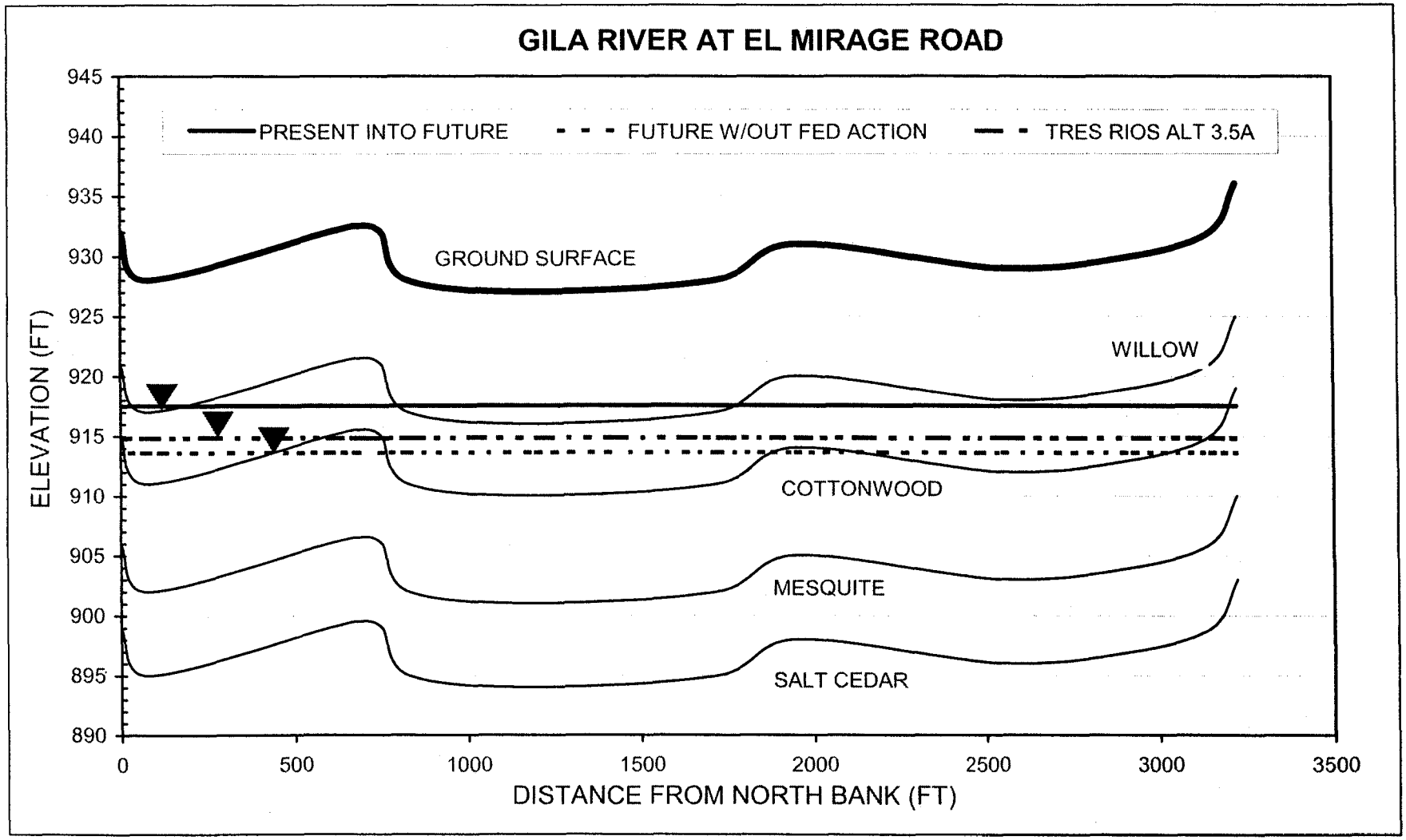

PROJECTED GW TABLES IN SEPTEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-15

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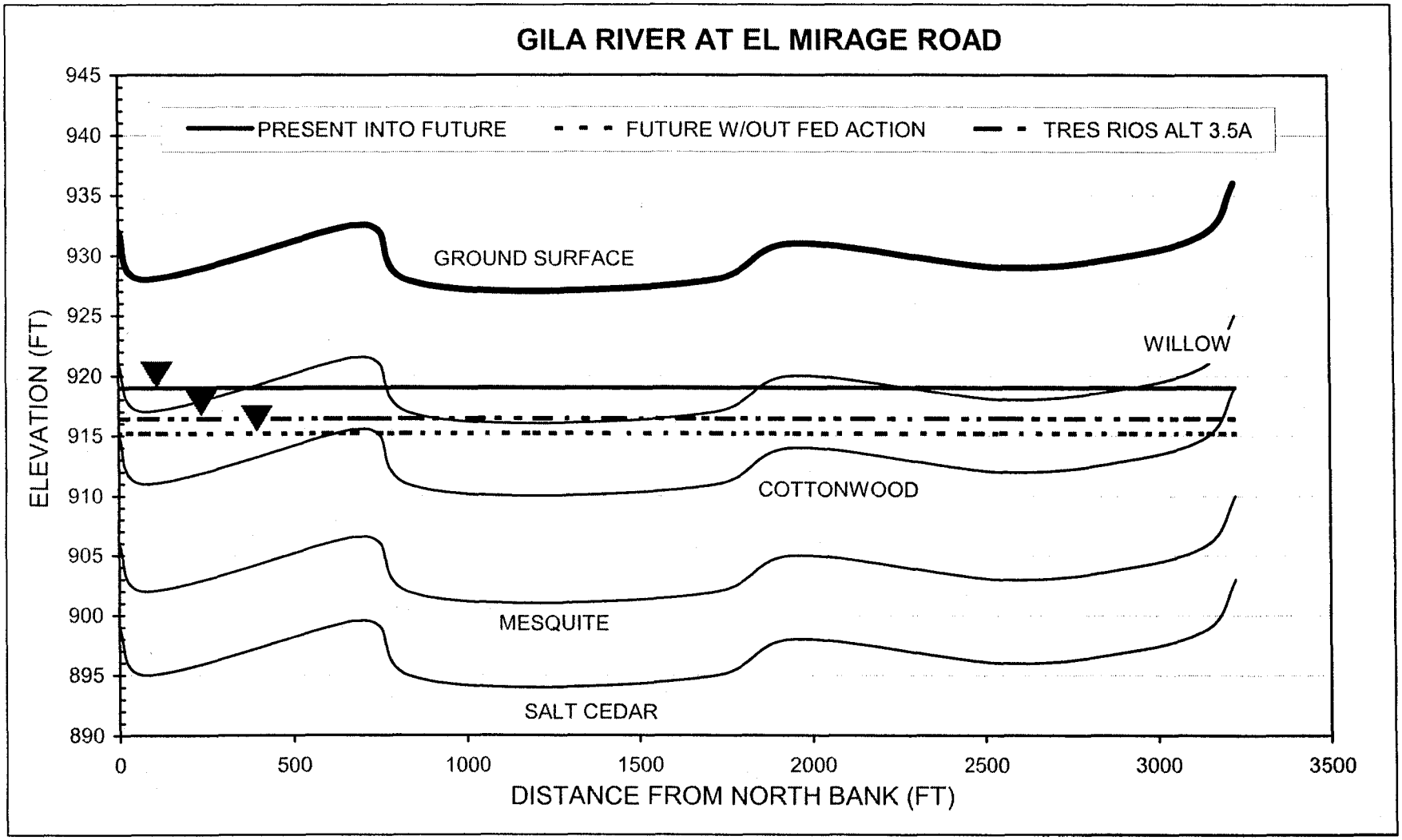

PROJECTED GW TABLES IN DECEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-16

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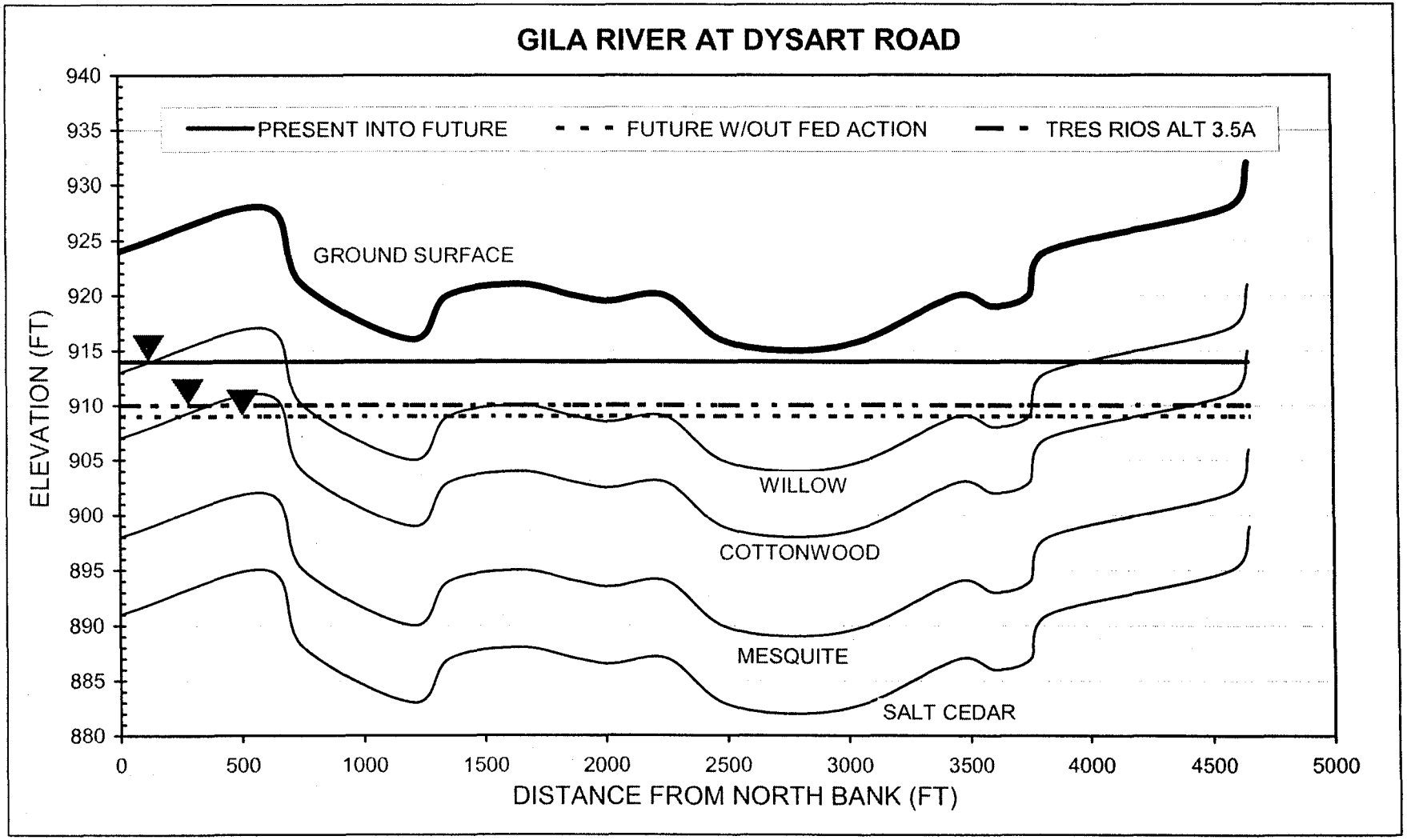

PROJECTED GW TABLES IN MARCH[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-17

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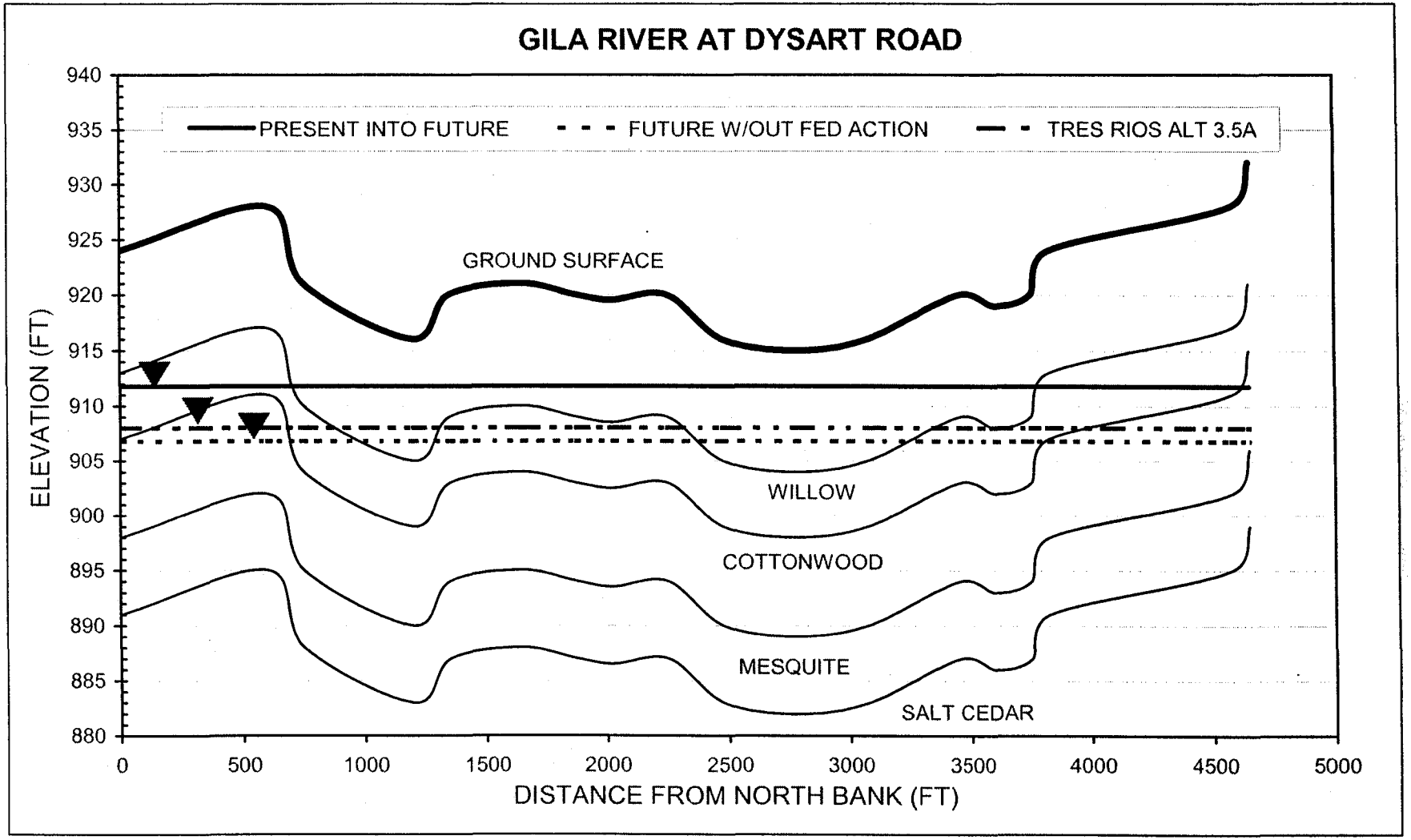

PROJECTED GW TABLES IN JUNE[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-18

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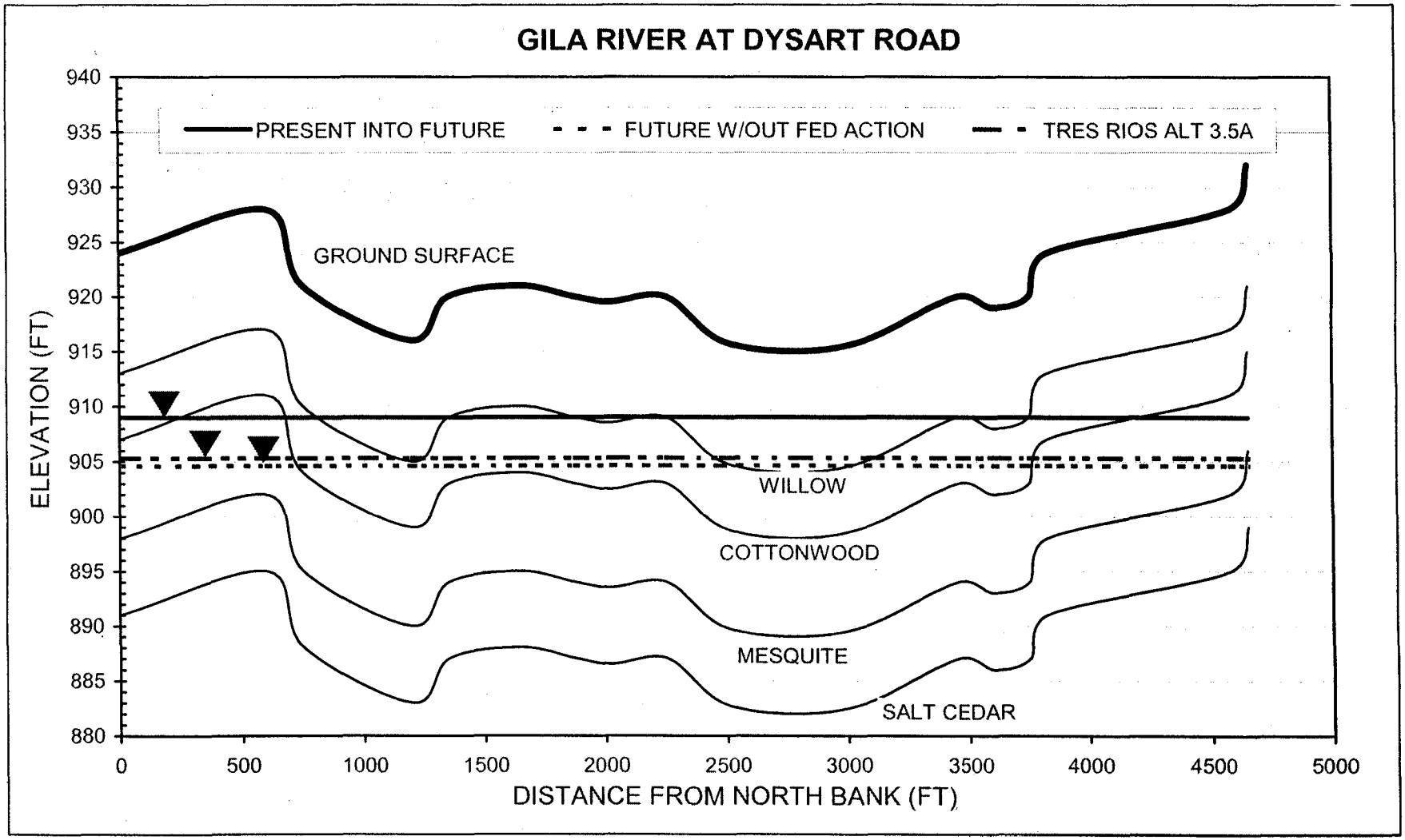

PROJECTED GW TABLES IN SEPTEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-19

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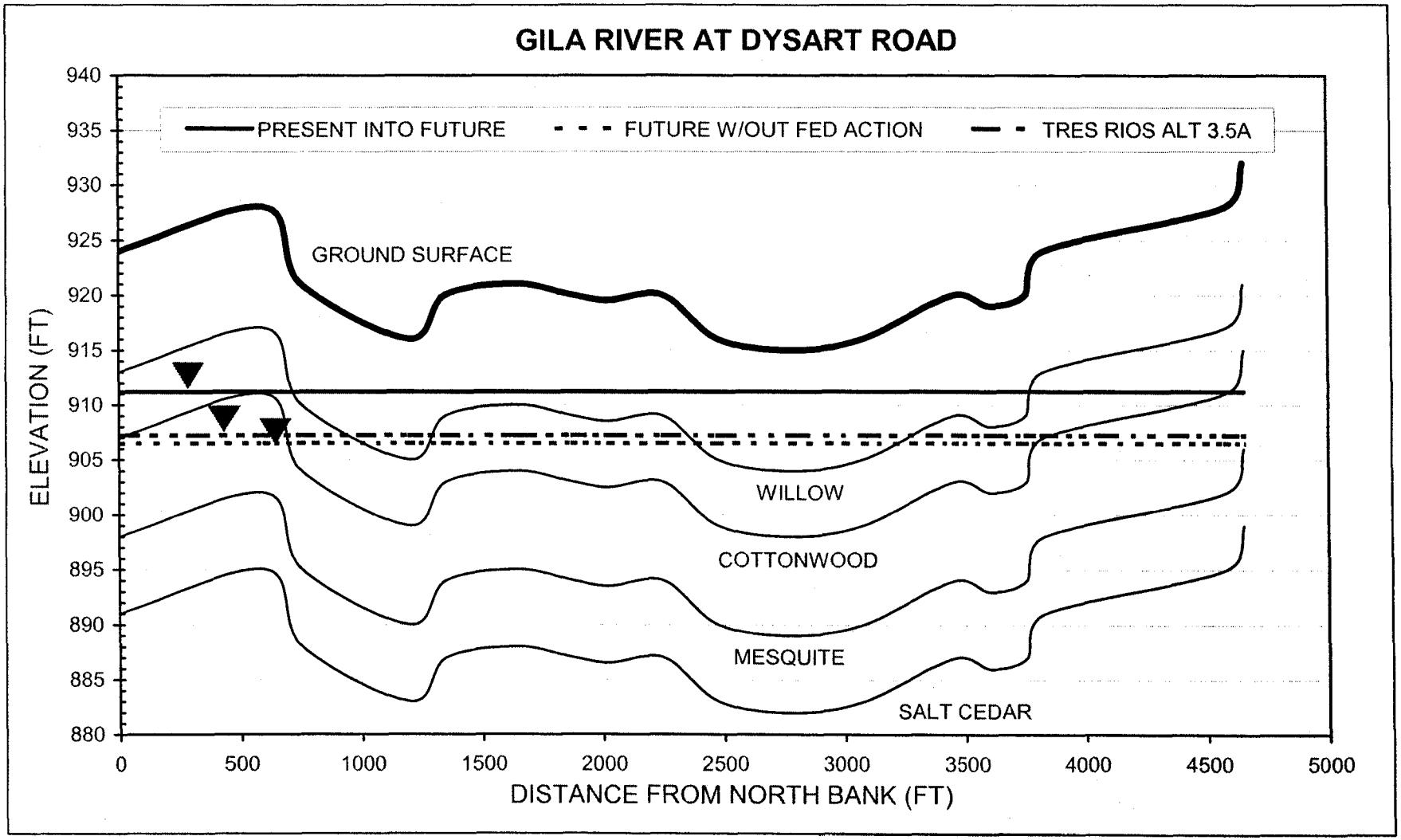

PROJECTED GW TABLES IN DECEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-20

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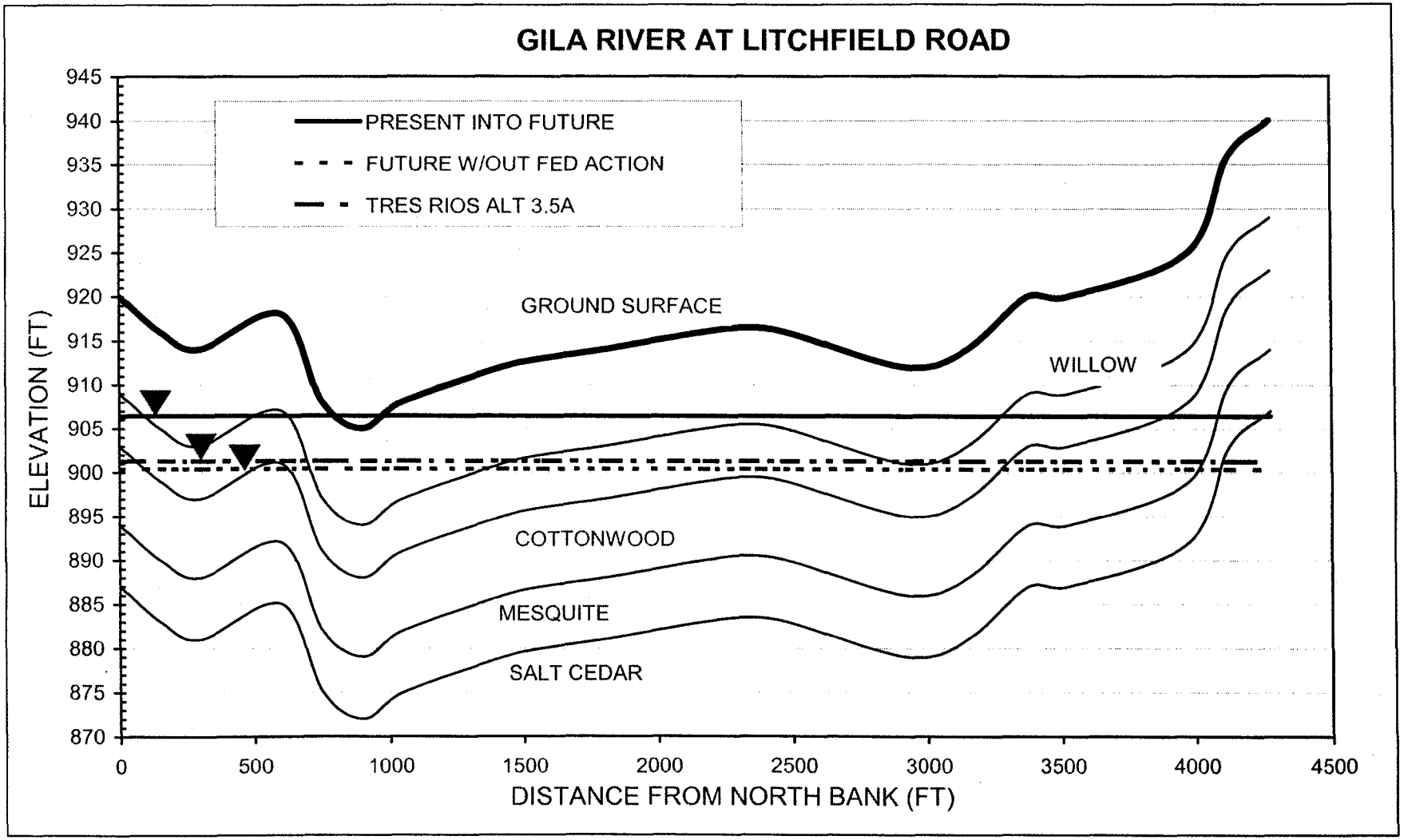

PROJECTED GW TABLES IN MARCH[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-21

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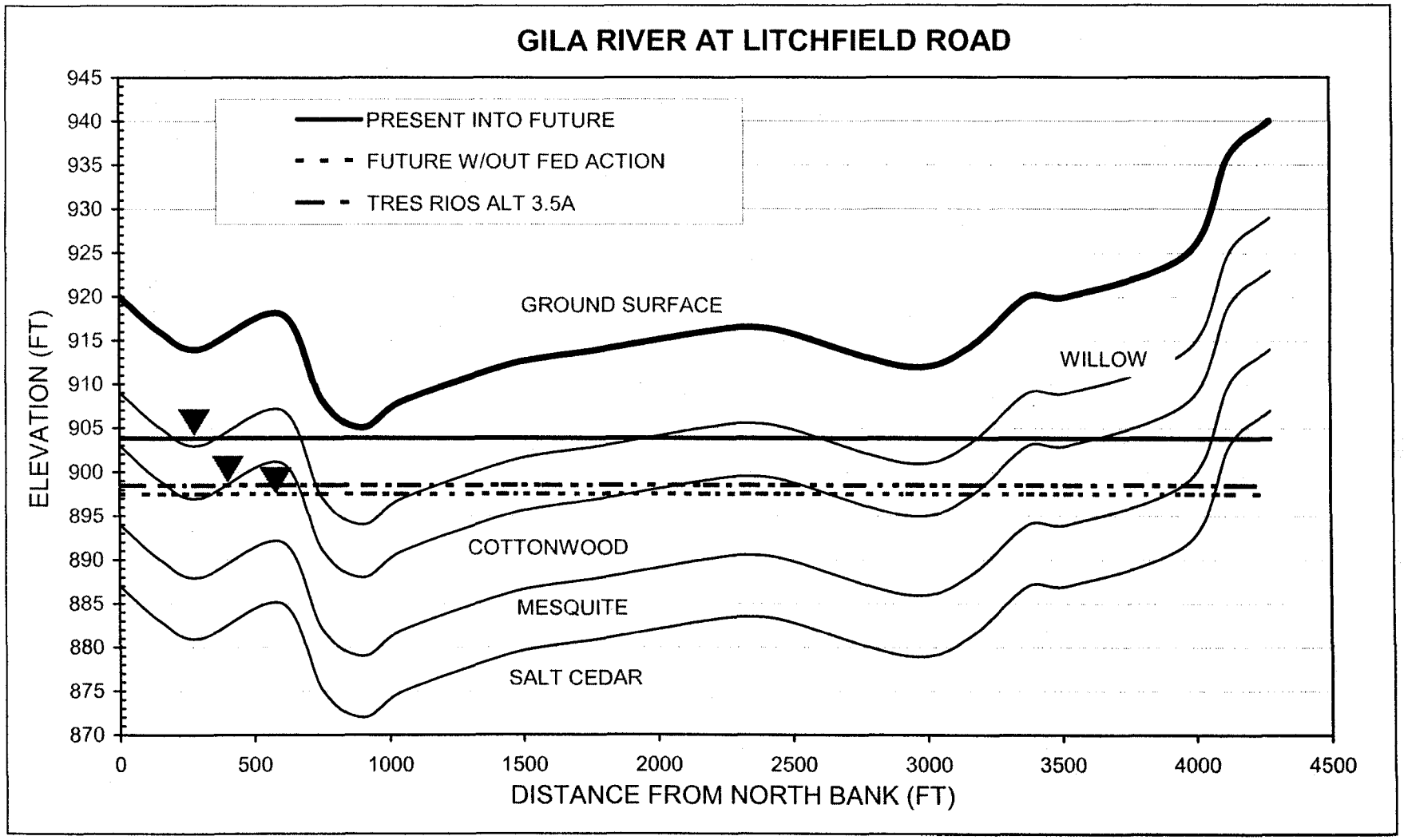

PROJECTED GW TABLES IN JUNE[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-22

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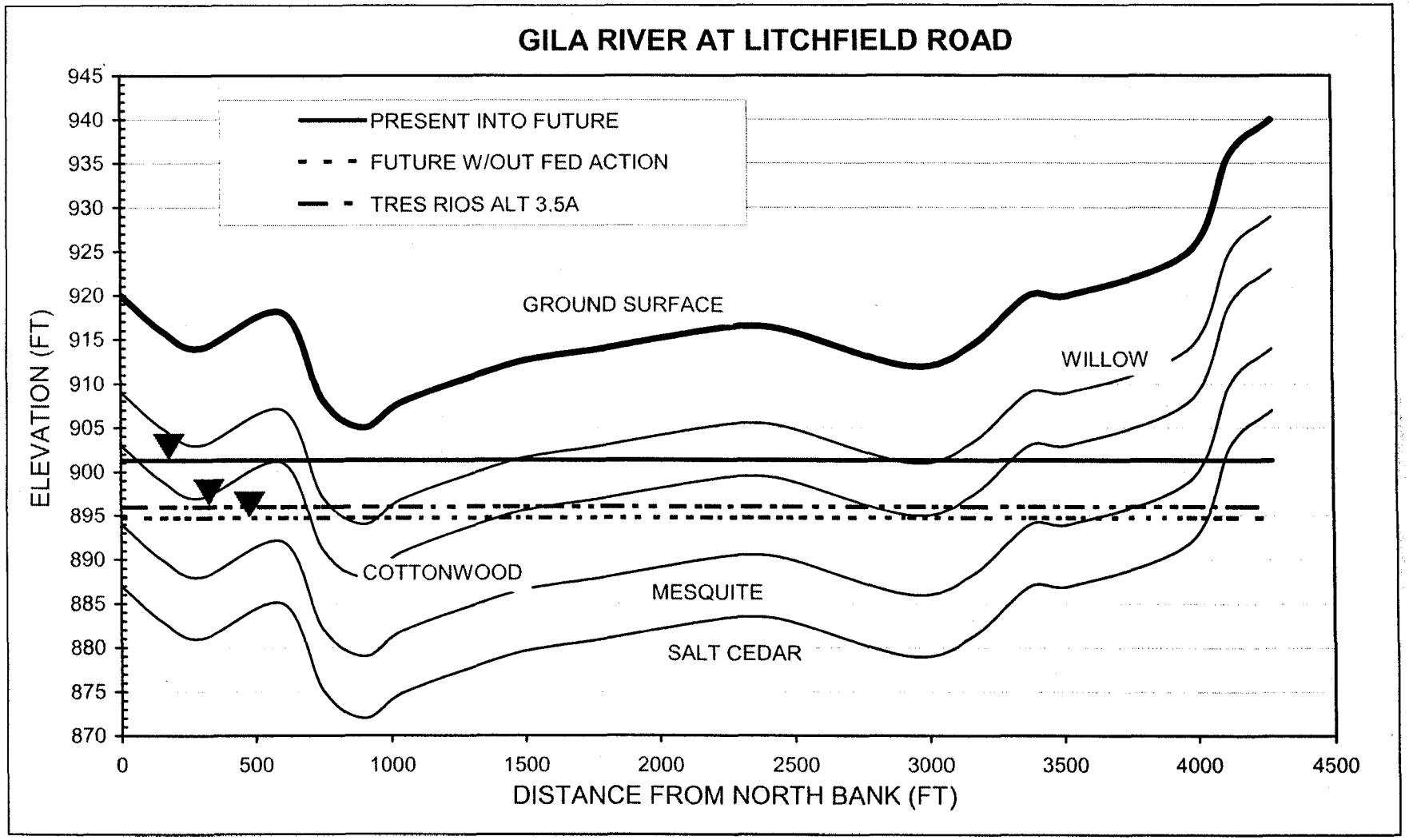

PROJECTED GW TABLES IN SEPTEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-23

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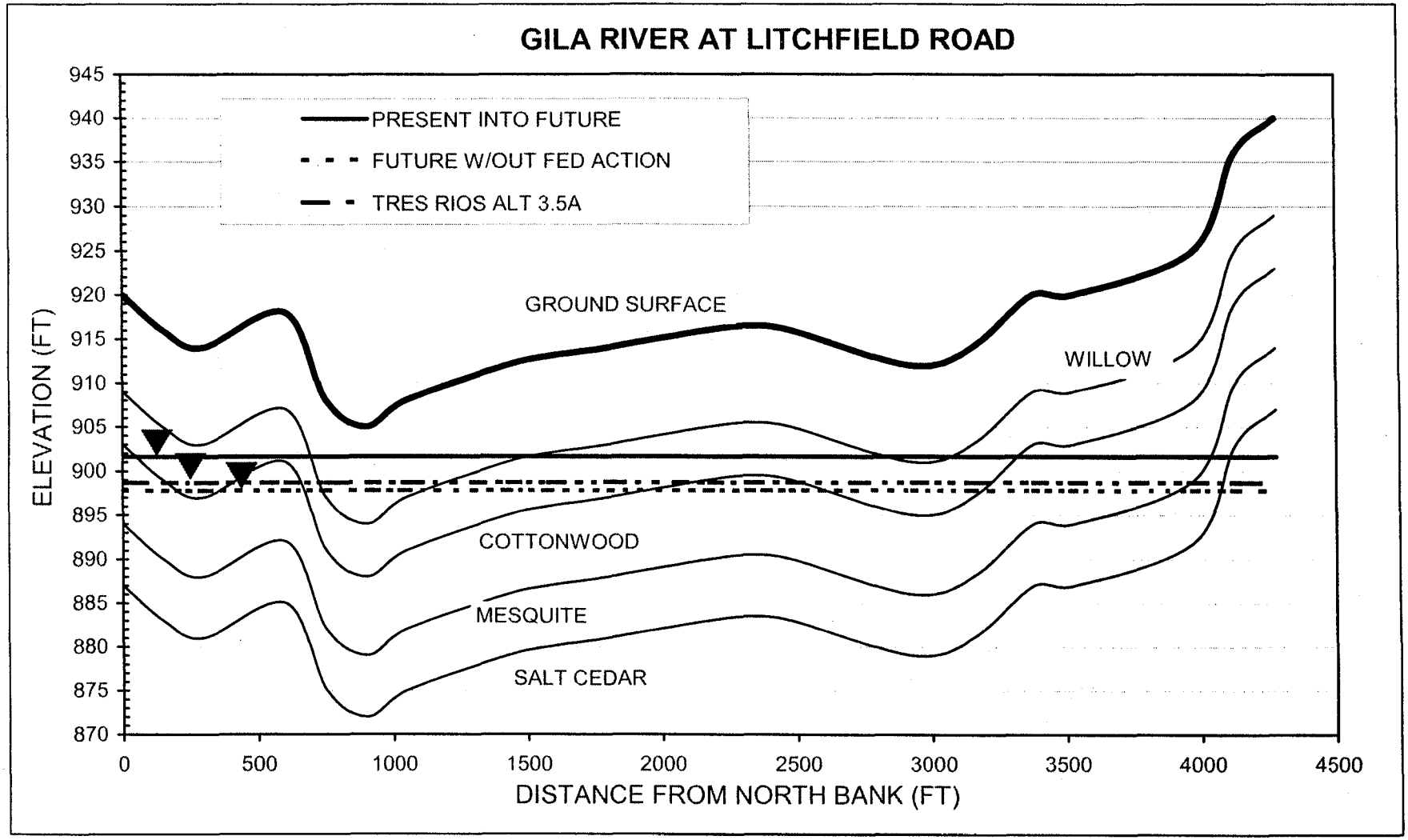

PROJECTED GW TABLES IN DECEMBER[1] AND MAXIMUM GW DEPTHS FOR SUSTAINED GROWTH

[1] GW ELEVATIONS PROJECTED FOR STABILIZED SYSTEM

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FIGURE 9-24

4263\SumRpt\LITCHFIELD

groundwater elevation will vary by approximately 5 feet over the year at the Gila River and Litchfield Road. It is projected when the groundwater is at its lowest **(Figure 9-23)** growth of willow and cottonwood cannot be sustained under Tres Rios Alternative 3.5A over most of the river channel, while growth of mesquite can be sustained.

For a healthy, sustainable riparian forest, it is important that high flow "floods" be simulated periodically in the spring, early summer, and late summer if seeds are to be dispersed and germinated, and the long-term growth native riparian species be maintained.

As discussed in Section 8, these floods are important in dispersing seeds, allowing seeds to germinate and temporarily raising the water table to promote growth of seedlings.

10. CONCLUSIONS

The Salt/Gila groundwater model was developed using drillers logs and historical groundwater level measurements. Once developed the model was calibrated and a sensitivity analysis performed. Four alternatives were input to the model and groundwater surface elevations were projected for each alternative. The four scenario's modeled were:

- *Present Conditions Into The Future* – Continued discharge from the 91st Avenue WWTP into the future

- *Future Without Federal Action* – Zero discharge from the 91st Avenue WWTP

- *Tres Rios Alternative 3.5* – Recommended alternative of the Tres Rios Steering Committee for a habitat restoration project along the Salt and Gila Rivers

- *Tres Rios Optimized Alternative 3.5 (Alternative 3.5A)* - Tres Rios Alternative 3.5 with the quantity of effluent discharged from the 91st Avenue WWTP optimized for what is needed for habitat restoration and to meet contractual obligations to the Buckeye Irrigation Company (BIC)

For each alternative groundwater elevations were projected for four quarters per year to account for seasonal elevation changes in the groundwater table. Groundwater table elevations were projected for March, June, September and December for each alternative.

The key hydrologic factors important to the survival and proliferation of riparian vegetation include availability of groundwater and surface water, magnitude and frequency of flood flows, and water quality.

In this study, the projected depths to groundwater calculated from the Tres Rios hydrologic model were compared to root zones required for the key native riparian species of Goodding willow, Fremont cottonwood, and Honey mesquite. It was then possible to project where stands of these riparian species should grow well in the Tres Rios area, based only on availability of groundwater. It should be noted however, that adequate water quality and flood flows with appropriate timing/duration are necessary factors for proliferation and sustainability of a native riparian habitat.

The following are conclusions from the results of the groundwater model analyses:

- In general groundwater table elevations are highest in March and lowest in September. Groundwater table elevations cycle through the year in a similar manner under each modeled scenario

- Under the Future Without Federal Action scenario, groundwater elevations during each quarter are several feet lower than under the Present Conditions Into the Future scenario; this difference in groundwater elevation is approximately 6 to 7 feet in the west end of the Tres Rios Study Area and less than one foot at the east end of the Tres Rios Area

- Under Tres Rios Alternative 3.5, the groundwater elevations average about 1 foot higher in each quarter than in the Future Without Federal Action scenario, but about 1.5 feet lower in each quarter than the Present Conditions into the Future scenario. The greatest head differences are in the western part of the Tres Rios Area.

- Under original Tres Rios Alternative 3.5, more flow is in the Gila River just downstream of the modified habitat areas than is needed to satisfy the contractual obligation of the 91st Avenue WWTP to the BIC. High infiltration in the habitat areas raises ground-water levels, which increase the flow in the Gila River in this area.

- Modeled groundwater elevations are only about 0.3 feet lower under scenario 3.5A than in the original scenario 3.5, with the largest head differences in the western portion of the Tres Rios Study Area.

- Based on projections of maximum depths to groundwater for the sustained growth of willow, cottonwood, mesquite and saltcedar, it is projected that under the proposed Tres Rios Alternative 3.5, mature willow growth cannot be sustained over most of the Tres Rios areas based on depth to groundwater alone. Rather, surface water must be provided if willow growth is to be sustained. However, willows should be able to grow between 115th Avenue and El Mirage Road without supplemental irrigation.

- Mature cottonwood growth should be sustained for all alternatives along the river except at the extreme high points along the north and south banks based on the projected groundwater elevation.

- Mature mesquite can grow over the entire Tres Rios area for all alternatives based on depth to groundwater.

- Seasonal irrigation or flood flows of willow, cottonwood and mesquite may be necessary to sustain growth during the juvenile stages. If such irrigation is not repeated each year, the species will not reproduce and contribute to long-term sustainability of natural riparian species.

- In general, the model results show that with optimization of the effluent discharge and proper habitat management, a corridor of native riparian vegetation along the Salt and Gila Rivers can be sustained.

- As with any groundwater model, uncertainty exists due to the non-homogeneous nature of the subsurface, therefore, test plots may be needed to observe growth patterns prior to implementation of the full scale project.

- In order to maintain a healthy riparian forest, it is important that high flow "floods" be simulated periodically to disperse seeds, allow seeds to germinate and temporarily raise the water table to promote growth of seedlings.

- ADWR recommends that monitoring wells be installed in floodplains that support valued riparian ecosystems. Water tables should be measured biannually, at a minimum. Declines in water tables below the norm or thresholds for each riparian type or indicator species can serve as a "red-flag" that signals a need to modify pumping, diversion, or other water uses.

- Increased water salinities, altered sediment grain size, and lowered downstream water tables favor the opportunistic non-native saltcedar. Once present, saltcedar excludes native species by pumping salt from groundwater to the surface soil.

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APPENDIX A

Tres Rios Hydrologic Model Development and Applications Report

Salt/Gila Groundwater Analysis Project
Project Number WS90140004-S

TRES RIOS HYDROLOGIC MODEL DEVELOPMENT AND APPLICATIONS REPORT

prepared for
Greeley and Hansen
Phoenix, Arizona

Water & Environmental Systems Technology, Inc.
2914 West 29th Avenue
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Catherine Kraeger-Rovey, PhD, PE, CCE
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CERTIFIED CONSULTING ENGINEER 180 COLORADO
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June 2000

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TRES RIOS HYDROLOGIC MODEL REPORT

Water & Environmental Systems Technology, Inc.
June, 2000

INTRODUCTION

The Tres Rios model was developed to be used in conjunction with the Tres Rios Habitat Restoration Feasibility Study of the U. S. Army Corps of Engineers (Corps). The purpose of the Corps study is to determine ways to restore the ecosystem of the Salt, Gila and Agua Fria Rivers where they join west of Phoenix, Arizona to enhance wildlife habitat in addition to controlling floods on the rivers. The Tres Rios area defined by the Corps begins at 83rd Avenue and continues downstream for approximately seven miles past the junction of the Gila River and the Agua Fria River to the Buckeye Irrigation Company diversion structure. The area includes the land in the river channel and a portion of the land on the north bank. This area is defined as the Tres Rios Study Area.

The Tres Rios model was developed to examine the baseflow regime of the Salt River and Gila River through the Tres Rios Study Area and assess the potential water needs of the Corps' proposed habitat design. Currently, baseflow in the Salt River within the Tres Rios Study Area is maintained primarily by releases into the Salt River from the 91st Avenue Waste-Water Treatment Plant (WWTP), and in the Gila River by both the Salt River flow and gaining stream conditions resulting from shallow groundwater. The Tres Rios hydrologic model was calibrated to baseline conditions and was then used to assess the projected impacts that implementation of the Corps' preferred alternative for Tres Rios could have on the hydrologic regime downstream from the 91st Avenue WWTP. The baseflow regime includes both surface water and groundwater.

The numerical model described in this report was developed for the purpose of analyzing the hydrologic responses of the Tres Rios riparian zone to proposed Tres Rios alternatives. The responses modeled include both surface water and groundwater. The habitat restoration alternative plans include such components as diurnal wetlands, habitat wetlands, open water areas, salt cedar replacement areas, and wetland areas re-vegetated with native plant species. The evapotranspiration from these redesigned areas differs from present rates, and may result in decreased stream flows and/or groundwater levels. If groundwater levels decline below the root

zone of the desired plant species, the newly created habitat areas may be at risk. The model is used to assess the responses of groundwater levels and stream flows to water consumption in the re-designed habitat areas, to quantify water requirements for sustaining the ecosystem, and to test the effectiveness of alternative plans for providing an adequate water supply to maintain stream flows, water levels, and the health of the riparian plant communities in the Tres Rios Study Area.

COMPUTER MODEL

The type of model selected for this analysis is a numerical, three-dimensional, finite-difference model. This type of model represents the aquifer as a series of grid cells or blocks, each representing a specific area and thickness of aquifer material. The model simulates flow of water through the domain using a system of mathematical formulas that describes movement of water through rocks and soil, pumping from wells, recharge from the surface, evapotranspiration by vegetation, flows in rivers and canals, and seepage between the aquifer and adjacent streams.

The mathematical formulas making up the model are organized into a computer code along with commands that read in data and produce numerical results. Model results are presented in the form of water levels and flow rates throughout the model domain. The code used in this application is the Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, or MODFLOW, which was developed by McDonald and Harbaugh of the U.S. Geological Survey (McDonald and Harbaugh, 1988). This code was selected for this project because it has been extensively used and accepted within the groundwater profession, has been accepted by the legal profession, and has been widely used in litigation. Water & Environmental Systems Technology, Inc. (W&EST) has made a number of modifications to the basic MODFLOW code to better suit it to this particular application.

In this hydrologic model, all water level data, including both input data and model results, are presented as elevations in feet relative to mean sea level. The term used for all water level elevations in the model is "head". This includes water levels in wells, modeled aquifer heads, and both measured and modeled water levels in the river segments.

The purpose of the model was to assess the impacts of proposed Tres Rios Alternatives on the Salt and Gila Rivers. Before that could be done, however, the model had to be calibrated. The calibration process consists of modeling historical uses over a given time span and comparing the

modeled heads and river flows with measured heads and flows. To achieve a good match, parameters that may be variable within the model (such as aquifer hydraulic conductivity or specific yield) can be adjusted. When measured and modeled values are similar, the model is considered calibrated and can be used to predict future conditions with a higher degree of confidence.

Appendix B provides an overview of mathematical groundwater models, a description of MODFLOW and modifications to MODFLOW made by W&EST.

MODEL FRAMEWORK

A. Tres Rios Model Area

The Tres Rios Study Area is located west of Phoenix, Arizona within the Central Arizona Basin and includes an area from the confluence of the Salt and Gila Rivers to the confluence of the Gila and Agua Fria Rivers (USACE, June 1999). The approximate location of the Tres Rios Study Area extends from the 83rd Ave. alignment of the Salt River westward downstream to the Buckeye Irrigation Company (BIC) diversion structure on the Gila River and generally encompasses the channel and adjacent overbank areas on the north bank of the Salt and Gila Rivers in this area (Greeley and Hansen, May 1998).

The Tres Rios model area was defined larger than the Tres Rios Study Area in order to have boundaries sufficiently distant to ensure that potential groundwater and surface water impacts outside of the Tres Rios Study Area are identified and considered for the study. The Tres Rios model area encompasses Township 1 North and Township 1 South, and Range 2 East through Range 3 West. Corresponding street alignments include 19th Avenue to the east, Rooks Road to the west, the McDowell Road alignment to the north and the Pecos Road alignment to the south (Plate 1). Minor mis-alignments in township and section lines have negligible impacts on model results; therefore the model grids were all considered perfect squares one-quarter mile on each side.

The southern boundary of the Tres Rios model grid system extends beyond the margin of the alluvial aquifer at the northern end of the Sierra Estrella Mountains. The Precambrian rocks which compose the mountain range are considered to be essentially impervious, thus providing a

physical boundary to the alluvial aquifer and to groundwater movement. These mountain cells are represented in the model as a mathematical boundary consisting of inactive grid cells. On the north, east, and west sides of the area of interest, physical boundaries are also present, but at considerable distances beyond the Tres Rios Study Area. Rather than extend the model boundaries out to natural boundaries on the north, east, and west, which would have resulted in a very large, data-intensive model, the model boundaries were set at the above-mentioned limits, with appropriate boundary conditions assigned to simulate flows across the boundaries and head changes responding to influences beyond the model domain. These boundaries are located at sufficient distances from the Tres Rios Study Area that impacts of any boundary effects on model results in the Tres Rios Study Area are negligible.

B. Tres Rios Model Geometry

The Tres Rios model grid system is based on quarter-quarter sections (40-acre areas) within the model area, to provide small model cells along the Salt and Gila Rivers. However, due to initial land surveys, there are some townships and sections in the model domain that are not square. In these cases the sections and corresponding quarter-quarter sections are represented as square in the Tres Rios model. To facilitate the representation of the Tres Rios Study Area in the model, minor mis-alignments in the surveyed township and section lines were not incorporated in the model grid alignment.

Each model cell has dimensions of 1320 feet by 1320 feet, and sixteen 40-acre cells comprise one section (640 acres). Exceptions occur in Township 1 North, Range 2 West and Township 1 South, Range 1 West where sections in their western quadrants have dimensions of approximately one mile by one-half mile, the shorter dimension in the east-west direction. These dimensions were established as a part of the original land survey. These sections were divided into eight cells, two in the east-west direction and four in the north-south direction (Plate 1). The three-layer model grid has 118 cells in the east-west direction and 48 cells in the north-south direction, a total of 16,992 cells.

C. Model Layers

1. Hydrogeology

More than 500 drillers' well logs were examined to determine the hydrogeology of the Tres Rios model area. The average well depth was 400 feet, though many wells did extend to more than 700 feet in depth. The materials typically encountered by wells throughout the model area as reported on the well logs are interbedded gravels, sands, silts and clays to a depth of approximately 400 feet, with a somewhat continuous thin clay layer (up to 40 feet, but typically about 10 feet in thickness) encountered at approximately 200 feet depth. Below 400 feet depth, a thick sequence of clay (up to hundreds of feet thick) was encountered in many wells in the model area. These clay layers did not occur or were not reported for every well. The primary reason for the absence of these two features on many well logs was that the wells were not drilled deep enough to penetrate the clay layers. However, some well log lithologic descriptions were not detailed enough or were of such a nature that the descriptions were of limited use. In some locations the geology was such that the clay layers were not present.

The depths to these clay layers as determined from the well logs were collated, averaged and organized by the locations of the wells. The depths of major geologic stratigraphic units for all wells occurring in the same section were averaged for that section, then plotted to produce structure contour maps. The geological materials were differentiated by this method into an upper alluvium, an upper clay, a lower alluvium, and a lower clay or interbedded material layer (Figure 1).

The upper alluvium consists of a heterogeneous mix of sand, gravel, silt and some clay. The distribution and relative abundance of these materials from well to well does not occur with regularity or predictability. However, this is typical of alluvial formations in the Central Arizona Basin. Individual layers of sediment vary in thickness and areal extent due to the nature of the depositional environment of alluvium. The numerous layers are consolidated into a single geologic unit. In this study this unit is referred to as the upper alluvium. In general, sands and gravels are the most abundant sediments reported in the well logs.

Beneath the upper alluvium is the upper clay layer. This geologic unit represents a depositional environment change and is a geologic unit that is more regional than the individual layers in the

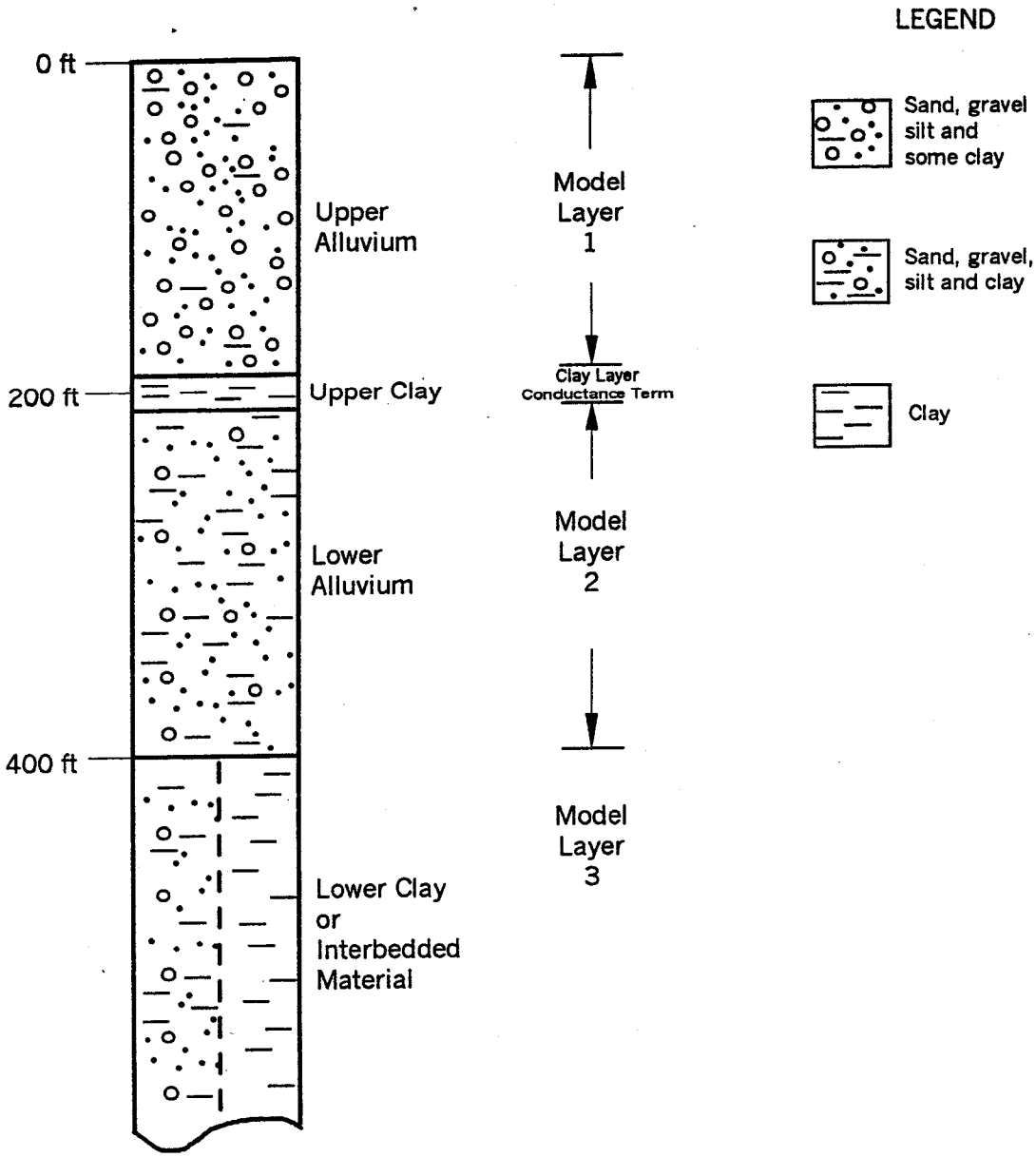

Figure 1. Generalized Stratigraphic Section of the Tres Rios Model Area and Representation of Model Layers (not to scale)

upper alluvium. The upper clay layer occurs approximately 200 feet below the surface in wells near and along the Salt and Gila Rivers in the model area. The clay layer ranges in thickness from several feet to many tens of feet.

Beneath the upper clay layer is the lower alluvium, which contains many layers of sand, gravel, silt and clay in most places. The individual layers are too small to use as a unit, so just as with the upper alluvium the layers are consolidated into one unit for geologic interpretations. Much of the material in the lower alluvium layer was reported to be cemented. However, the degree of cementation was not quantified in the drillers' logs except in general terms, such as hard cemented, or well cemented. The amount of clay in this alluvial material was reported to be greater than that in the upper alluvium.

Beneath the lower alluvium is either the underlying lower clay or the interbedded gravels, sands, silts, and clays. The underlying lower clay was best observed in wells in the center of the model area. Wells in the western portion of the model area, west of the Agua Fria River, generally did not penetrate a massive clay layer but instead penetrated interbedded gravels, sands, silts and clays beneath the lower alluvium.

The drillers' well logs and an overall interpretation of the geographic characteristics of the model area indicate a desert basin river environment. The discontinuous nature of the upper 400 feet of material encountered by the wells indicates an environment of deposition that is indicative of an open basin environment. These materials are characteristic of both low and high energy stream deposits and associated alluvial geomorphological processes. The relatively continuous clay layer encountered at the 200 foot depth indicates a depositional environment different from stream and alluvial processes. The thick clay encountered beneath the 400 foot level is indicative of a closed basin, low energy depositional environment.

2. Model Representation of Stratigraphy

The four hydrogeologic units identified in the model area were represented by three separate layers in the Tres Rios model. The upper and lower alluvial materials are represented as layers 1 and 2, respectively. The upper clay between the upper and lower alluvial materials is simulated by a very low vertical conductance between model layers 1 and 2. Vertical conductance is similar to hydraulic conductivity. Hydraulic conductivity is a measure of the ease with which water moves

horizontally through a geologic unit; vertical conductance is the ease with which water moves vertically from one unit to the unit above or below it. In areas where the upper clay is not present, the vertical conductance term is higher to represent the increased vertical flow between the adjacent layers 1 and 2. The lower clay or interbedded material is represented by layer 3 of the model (Figure 1).

Initially, the possibility of developing a six-layer model with three, very thin upper layers to simulate movement of near-surface groundwater was considered. This was not advisable, because multiple, thin layers require additional data and cause the model to be less numerically stable. Numerical instability occurs when the ratio of water flowing to and from a grid cell to the volume of water stored within the grid cell exceeds about ten percent. This is generally a problem when grid cells are too thin. The matrix solution produces estimates of head that oscillate, rather than approaching a solution. Also, the additional layers do not improve the accuracy of the model, because there are insufficient data for vertical hydraulic conductivity and evapotranspiration rate as a function of depth to justify this level of refinement. Evapotranspiration as a function of depth is adequately simulated using the existing linear function in the upper layer of the current model. Should additional information on evapotranspiration with depth be obtained, the linear function in the model can be readily replaced with a curvilinear or step function as appropriate. A more detailed explanation of the operation of the numerical model is presented in Appendix B.

Layer 1 in the Tres Rios model simulates the upper alluvium encountered in wells in the model area. Parameters used to define the layer are elevation of the layer top (water table) and elevation of the layer bottom, hydraulic conductivity and specific yield of the layer. The saturated thickness of the layer varies based on the water level, allowing the transmissivity to vary.

Layer 2 in the Tres Rios model simulates the lower alluvium encountered by wells in the model area and is separated from the upper alluvium by the upper clay. Layer 2 is represented by elevations for the top and bottom of the layer, hydraulic conductivity and storage coefficient of the layer.

Layer 3 is the lowermost layer and represents the lower clay or interbedded material beneath layer 2. This model layer is simulated as having constant transmissivity, since for the time period modeled, water levels do not decline below the top of the deep clay or interbedded material.

D. Time Period

It was necessary to choose a time period during which minimal or no releases occurred from Granite Reef Dam to the Salt River to ensure that the calibration period would be simulating the low baseflow condition. It was also desirable to select a time period in which adequate well pumping and water level information were available. No releases at Granite Reef Dam in excess of 10,000 cfs were reported in the time period between June 01, 1985 and December 22, 1991 (Greeley and Hansen, April 1998). Also, well water level measurement and well pumpage data are available for this time period. The time period January 01, 1986 through December 31, 1991 was chosen for the model calibration period.

MODEL DATA SOURCES

The following is a discussion of the types of data required to develop the Tres Rios model. Lithologic information from drillers' logs was compiled and mapped to obtain data for aquifer geometry, layering and hydraulic characteristics. Water level measurements from wells were contoured and digitized to develop aquifer heads and boundary conditions. Well locations and pumpage rates were used to develop an array (by model grid cell) of pumping rates for the model runs. Agricultural and municipal entity locations were used to assign a land use type to each active model grid cell. The land use information was then used to develop data arrays, by grid cell, for water application appropriate to each land use. Water use information, where available, was used to appropriately distribute water application rates throughout the model. Recharge characteristics were used to develop irrigation efficiencies, which were then used to develop recharge arrays for the model. Canal locations, leakance rates and diversion amounts were used to develop additions to the recharge array from canal leakage. River locations and channel geometries were used to develop information used by the river package to compute stream depth, losses or gains, and flow rates through the model. River flow data were used to develop stream inflows at the upstream end of the rivers flowing into the model, and other stream gaging records were used in calibration, to verify that modeled flows reasonably matched gaged flows. Riparian habitat distribution and evapotranspiration amount were used to develop data arrays of the potential evapotranspiration rate in each grid cell where riparian habitat occurs.

Data previously compiled by Greeley and Hansen (April 1998 and May 1998) include a tabulation of flood flows in the Salt River, evapotranspiration rates for phreatophytes, and contracted

delivery amounts from the 91st Avenue WWTP to Buckeye Irrigation Company (BIC). Detailed mapping of riparian vegetation in the Tres Rios Study Area was performed by CH2M Hill (CH2M Hill, n.d.). The United States Geological Survey (USGS) Ground-Water Site Inventory (GWSI) database contains selected water level measurements for many wells in the Tres Rios model area for the time period of the model (USGS, n.d. a). Gila River flows were obtained from USGS surface gaging station records. The United States Bureau of Reclamation Central Arizona Project report contains maps displaying locations of water use entities in the Central Arizona Basin (USBR, 1976). USGS 7.5 minute topographic quadrangle sheets provided selected surface elevation data for the model area. The Flood Control District of Maricopa County (FCDMC) constructed detailed maps of topography and river channel locations along the Salt and Gila River floodplains in the vicinity of the Tres Rios Study Area (FCDMC, n.d.). The Arizona Department of Water Resources (ADWR) Registry of Ground-Water Rights (ROGR) database contains annual well pumpage for most wells in the state of Arizona since the mid 1980s (ADWR, n.d.).

Greeley and Hansen provided data for the Tres Rios model during the development phase of the project. Data for the Tres Rios model that were acquired by Greeley and Hansen include drillers' well logs, USGS GWSI and ADWR ROGR datasets, and information regarding water use for the model area. Greeley and Hansen also constructed land use and surface elevation data arrays for input into the Tres Rios model. These data sets were provided to W&EST in electronic format.

MODEL DEVELOPMENT

Model development involves data collection and integration into the discrete model cells of the numerical groundwater flow model. The complexity of the development of the Tres Rios hydrologic model can be demonstrated using the magnitude of the data input. There are 16,992 cells in the model, of which approximately sixty percent are active and require input data. The model has three aquifer layers and two low-permeability zones separating the model layers. Each aquifer cell requires input of an average of nine values of information from the data sets to define the hydraulic properties and geometry of the cells, for a total of over 90,000 data values. In addition, arrays of "stresses", such as pumping, recharge, and stream inflows must be input to the model at the beginning of each stress period. (A stress period is a span of time during which the "stresses" on the model, such as stream inflow, total pumping, or total recharge, do not change substantially, and can therefore be considered to be constant.) If a model run is made for ten stress periods, an additional 300,000 data values must be read into the model. This means the

total number of data values incorporated into the Tres Rios hydrologic model for a typical run of ten stress periods is approximately 400,000. The validity of the data sets was then tested through the processes of calibration (history-matching modeled results with actual hydrologic information) and sensitivity analyses (testing the impact on results of varying each type of data over a reasonable range of uncertainty). Model inputs were developed to represent the baseflow condition of the Salt and Gila Rivers. In addition to selecting a time period without flood flow releases from Granite Reef Dam or flood flows in the Salt River, direct precipitation, minor tributary flows to the rivers and tailwater outside of BIC were not included in the simulation.

Multiple data sets are required as part of the model setup. For the grid cells representing the aquifer, these data sets include aquifer geometry (top and bottom elevations of all but the bottom layer of the model), aquifer properties (hydraulic conductivity for the upper layers, transmissivity for the bottom layer, and storativity for all layers), pumping, recharge, maximum evapotranspiration rates, and initial heads.

To develop each data set for aquifer geometry and properties (which do not change through time), and initial heads, the available data for each parameter must be mapped and contoured so that a single value can be interpolated for each individual active cell in the entire model. In some cases this can be done using contouring software; otherwise it is done manually. A data array is also required for each layer to identify which grid cells are active or inactive.

In addition, an array of data for stream geometry and hydraulic properties must be prepared. River data required for the model include channel bed elevation, width, gradient, streambed conductance and Manning roughness coefficient, as well as stream inflows and diversions. Each stream reach is defined as that portion of the channel located in an individual grid cell. The model is set up in this manner so that seepage between the stream and aquifer can be computed for each grid cell in which a section of stream is located. River inflows and canal diversions were modified for the model scenario runs as appropriate.

Pumping, recharge and maximum evapotranspiration rates are also read into arrays whose locations correspond to the grid cells in which they occur. As these parameters change through time, a new array of values is required for each stress period. Each of these stress period data sets was modified for the model scenario runs as appropriate.

The following sections describe the data sources and methodologies used to develop input data sets for the Tres Rios hydrologic model.

A. Land Use

Land use data were used to develop a number of data sets for the Tres Rios model. Greeley and Hansen digitized land use by model cell for the Tres Rios model area (Greeley and Hansen, n.d.). These data were provided as an integer code that indicates the predominant land use in the model cell. The five types of land use are desert, mountain, river floodplain, agricultural and municipal. Greeley and Hansen further sub-divided the land use into sub-classifications which, though not used in construction of data sets for the current model, could provide information for use in water quality analyses. The alluvial aquifer occurs in areas coded as river floodplain, agricultural, and municipal land uses.

Cells coded as mountains correspond to the White Tank Mountains, the Sierra Estrella, and the South Mountains. Areas coded as desert are generally located on the flanks of the mountains in the model area. Land use within the Tres Rios Study Area is river floodplain, and the majority of non-mountain land use in the area immediately surrounding the Tres Rios Study Area and in the remainder of the Tres Rios model area is agricultural. Five miles away from the eastern boundary of the Tres Rios Study Area in the northeast corner of the model area (T. 1 N., R. 2 E.), the land use is mostly municipal. Municipal land use in the Tres Rios model accounts for only approximately 15 percent of the developed land use in the active model areas.

B. Active Cell Locations

The boundaries of the Tres Rios model area encompass portions of the Salt, Gila and Agua Fria River valleys and developed lands in the adjacent valleys, as well as surrounding mountains. The area associated with Waterman Wash (Rainbow Valley) in the southwestern portion of the model area was coded as inactive because it is not part of the area of interest. Model cells specified as mountain land were also made inactive, because the mountains are not part of the alluvial aquifer. Areas coded as desert land that overlie relatively thin alluvium along the mountain flanks were also made inactive in the model because they do not contain alluvial ground water. Based on analysis of historical water levels, additional cells were changed to inactive from original active status, mainly along the flank of the White Tank Mountains in the northwestern corner of the

model area due to the lack of stored groundwater. Therefore, the Tres Rios model simulates only the alluvial aquifer and associated river valleys and adjacent developed lands.

C. Water Levels

The USGS GWSI database includes water level measurements spanning more than a century in the Phoenix area of Arizona and was utilized to develop maps of groundwater levels in the Tres Rios model area. Data in the GWSI database include well location, owner and water level information, and water quality and well completion information. The number and locations of available water level measurements differ yearly (USGS, n.d.a).

Water level data for the years 1986 and 1991 were used to develop water level maps for model calibration. The water level measurements were sorted chronologically and maps were constructed for periods judged to have sufficient data points to be meaningful. Data points taken from wells known to be pumping or where data were clearly anomalous, were discarded. Anomalous readings are generally due to drawdown resulting from pumping of the well; however, some of the anomalies are likely to be measurement or typographical errors.

Water levels from December, 1985 through January, 1986 were used to estimate starting heads for the model calibration. River channel bed elevations were used in the Tres Rios Study Area and along the Gila River as additional water level data points because measured water levels were sparse and the rivers appear to be hydraulically connected to the water table at these locations. Water level measurements on the northwestern flank of the South Mountains also were sparse in the 1986 GWSI database, so several 1991 water level measurements were used to augment the 1986 GWSI data.

Measured water levels from November and December, 1991 were used as target heads for the end of the calibration run. However, because the modeled stresses represented average annual data, the modeled heads do not exactly match the measured heads. This is because the water levels in the wells fluctuate in response to seasonal groundwater pumping, recharge and stream flow. The water levels are typically highest during spring, decline during summer, and are their lowest in the fall. The water levels recover during fall and winter.

D. Rivers

The Gila, Salt and Agua Fria Rivers traverse the model area, with the Tres Rios Study Area focused on the confluence of the three rivers. The locations of the three rivers as represented in the Tres Rios model are shown on Plate 1. The geometry of each reach and river inflows and outflows were required to construct model input data sets. Only the Salt and Gila Rivers have flow in the model area during the six-year calibration period.

1. River Locations and Geometries

River location and channel characteristic data were manually compiled from detailed topographic maps constructed by the Flood Control District of Maricopa County (FCDMC, n.d.) of the Salt and Gila Rivers from approximately 27th Avenue downstream to about Miller Road. These maps were used to locate the main channels of the Salt, Gila and Agua Fria Rivers in the Tres Rios Study Area. They were also used to develop parameters of the river geometry for each river reach including reach length, stream bottom elevation, and the location of the reach within the model. For those reaches of the Salt, Gila, and Agua Fria Rivers outside of the FCDMC detailed topographic maps, USGS 7.5 minute topographic quadrangle maps were used to define the river locations and geometries for the model. Appendix C presents the modeled river inputs by cell for the Tres Rios Study Area.

2. Salt River Inflow

The model calibration period (calendar years 1986 through 1991) was selected to represent a time period without significant flood flow releases from Granite Reef Dam into the Salt River (Greeley and Hansen, April 1998). During this time period the only significant river inflows are 91st Avenue WWTP effluent. Minor sources of inflow including ungaged tributary and storm runoff, direct precipitation and miscellaneous tailwater were not represented in the model because the quantities are difficult to measure or estimate (Greeley and Hansen, April 1998). They are not significant values to the model because the purpose of the model is to analyze baseflow conditions. Therefore, the only inflows to the Salt River in the area of the Tres Rios model area are effluent releases from the 23rd Avenue and 91st Avenue WWTPs. The total annual effluent from these facilities (COP, 1996a and 1996b) for the model time period are presented in Table 1.

Table 1. River Flow Data Used in Tres Rios Model

YEAR	23RD Avenue WWTP Effluent Release (acre-feet)	91ST Avenue WWTP Effluent Release (acre-feet)	Gila R. gaged flow near Laveen, AZ (acre-feet)	Gila R. gaged flow near Buckeye, AZ[1] (acre-feet)
1986	30,702	131,809	43	
1987	35,992	125,726	64	
1988	37,315	103,332	67	
1989	27,664	153,303	23	
1990	26,229	126,776	1,746	89,490
1991	32,753	97,443	794	86,824

[1] No records prior to December 1989

3. Gila River Inflow

The Gila River flows into the model area through the Gila River Indian Community. Surface flow measurements of the Gila River near Laveen, Arizona (USGS, n.d. b) provided the values of simulated Gila River inflow (Table 1). The measuring station is approximately two miles downstream of the southern model boundary and the flow in the Gila River at the gaging station is considered to approximate the flow at the model boundary. As with the Salt River, minor sources of river inflow were not simulated in the model.

4. Gila River Outflow

Stream gaging records for 1990 and 1991 exist for a gaging station on the Gila River at State Highway 85 near Buckeye (USGS, n.d. b), which is located approximately one mile west of the western model boundary. The reliability of the measurements (Table 1) is unknown and the values are considered questionable (Turek, July 1999 and BIC, 1999) but are the only measured river outflows from the model area.

5. Canal Diversions

The only canal diversion from river flow within the model area is the Buckeye Canal diversion from the Gila River approximately one-half mile downstream of the confluence with the Agua Fria River. The BIC has a contract to receive 30,000 acre-feet of effluent annually from the 91st Avenue WWTP during the model calibration period, (Greeley and Hansen, May 1998) but has historically diverted much of the flow in the Gila River (BIC, 1999). These diversions for the years 1986 through 1991 averaged approximately five times the contracted diversion amount (Table 2).

Table 2. Annual Buckeye Canal Diversion from the Gila River, 1986 - 1991

YEAR	BIC Canal Diversion from the Gila River (acre-feet)
1986	158,294
1987	157,133
1988	148,131
1989	170,488
1990	148,412
1991	131,443

6. Return Flows

Three sources of return flow to the Gila River were identified in the western Tres Rios model area. These return flows are all associated with the BIC. The Southern Extension of the Buckeye Canal wastes water into the Gila River, and water pumped from dewatering wells in the western half of the irrigation district is allowed to return to the Gila River. Application of water on the BIC agricultural lands has historically exceeded the crop demands and some of the applied water is projected to return via canal wasteways to the Gila River.

The first source of return flow is a portion of the water that is diverted into the Buckeye Canal, enters the Southern Extension canal, and is wasted back into the Gila River approximately 10 miles downstream of the Buckeye Canal diversion. This amount is approximately 7,900 acre-feet per year (BIC, 1999). The second source of return flow is water pumped from the three BIC

dewatering wells located near the western end of the model area which flows back as waste to the Gila River. This amount is approximately 5,400 acre-feet annually (BIC, 1999). The third source of return flow is excess water from over-application of surface water and groundwater on BIC agricultural lands. This water is considered to augment the Gila River as tailwater return flow through canal wasteways near the western end of the Tres Rios model. Approximately 16,000 acre-feet per year are projected to return along the length of the Gila River adjacent to the BIC lands in the western Tres Rios model area based on application amounts, irrigated acreage and projected irrigation efficiency.

E. Agricultural and Municipal Recharge

Land use data, water use entity data and water application data were used to compute the projected groundwater recharge for the model area from agricultural and municipal use. The agricultural and municipal recharge simulated in the model represents the amount of water applied to these lands that is projected to percolate through the soil back to the aquifer. In addition to application return flows, recharge to the aquifer also occurs due to leakance associated with the Roosevelt Irrigation District's (RID) Roosevelt Canal and Buckeye Irrigation Company's canals. Annual average recharge was computed from these data sources to produce an array of recharge by cell for input to the model.

1. Water Use Entities

Identification of water use entities in the Tres Rios hydrologic model area was necessary to allow simulation of different water uses in agricultural areas. Four water use entities were defined: Salt River Project (SRP), RID, the GRIC and the BIC. The locations and boundaries of these entities were determined from maps of water use districts in the Central Arizona Basin (USBR, 1976). The maps were overlain with the model cell grid and the water use entities were manually digitized into an integer code for each active model cell.

2. Water Application and On-Land Recharge

Water application in the Phoenix Active Management Area (AMA), which includes the areas covered by the Tres Rios hydrologic model, averaged 5.74 acre-feet per acre in 1988 for agricultural lands (Greeley and Hansen, July 1998). Projecting that approximately 15 percent of

the applied water recharges the aquifer, recharge on land is approximately 0.86 acre-foot per acre. Each acre is not 100 percent irrigated. A portion is used for roads and canals. The total area of each acre was reduced by eight percent to account for non-irrigated portions. These values were used to compute on-land recharge by model cell of 32 acre-feet for each of the water use entities except the BIC, which has historically had much higher on-land application than the neighboring water use entities because of the availability of extra water from the Gila River.

The BIC historically has diverted much of the flow available in the Gila River. The 91st Avenue WWTP has a contract to provide 30,000 acre-feet per year annually to BIC, and the SRP is contracted to deliver 1.1 percent of the natural flow diverted at Granite Reef Dam on the Salt River. The sum of these contract deliveries averaged approximately 50,000 acre-feet annually for the time period of the model. A portion of the water diverted from the Gila River is released back to the river further downstream via the South Extension canal.

Approximately one half (the eastern half) of the BIC acreage lies within the Tres Rios model. Wells pump in the BIC lands to supply water for agricultural uses to augment the Buckeye Canal diversions from the Gila River. The pumped and diverted water is applied to the agricultural lands, and a portion of the applied water infiltrates the ground to recharge the underlying aquifer. In addition to water supply wells, numerous dewatering wells pump in the western portion of BIC. Only three of these wells are located within the model area, and the water from the dewatering wells is returned to the Gila River.

The historical annual amounts of water used by the BIC (BIC, 1999) for the model time period are summarized in the following table:

Table 3. Historical Annual Water Supply of the Buckeye Irrigation Company, 1986 - 1991

YEAR	SRP Delivery (acre-feet)	Gila River Diversion (acre-feet)	Pumped (acre-feet)	Total Supply (acre-feet)
1986	22,595	158,294	23,477	204,366
1987	24,767	157,133	27,358	209,258
1988	23,086	148,131	31,616	202,833
1989	19,876	170,488	23,664	214,028
1990	13,015	148,412	31,413	192,840
1991	18,974	131,443	34,536	184,953

The sum of the SRP delivery, Gila River diversions and well pumpage equals the total water application on BIC agricultural lands. Assuming BIC crop consumptive use is similar to surrounding agricultural lands, BIC efficiency is approximately 45 percent. Therefore, 55 percent of the applied water is in excess of the demand and is projected to either recharge the aquifer or return as waste to the Gila River. Since only one-half of the BIC is in the model area, after accounting for canal losses (discussed in the following section), approximately 46,000 acre-feet per year of excess application occurs in the Tres Rios hydrologic model. Of this amount about 65 percent is projected to recharge the aquifer and computes to 92 acre-feet per cell. The remaining 35 percent is projected to return to the Gila River as tailwater.

Determination of water application on municipal lands is much more complex than on agricultural lands. Municipal lands account for approximately 15 percent of the land use in the Tres Rios model area. Detailed analysis of municipal water use was considered to be outside the scope of the present study. Therefore, for simplification, and because these areas are relatively distant from the Tres Rios Study Area, the modeled on-land recharge for municipal lands was estimated to be 32 acre-feet per model cell.

3. Canal Leakance

In addition to on-land recharge from agricultural and municipal water use, leakance from the Buckeye, South Extension, Roosevelt and Grand Canals recharges the model areas. The Grand Canal is located in the northeastern model area and conveys water from the Salt River to recipients in the SRP. The Roosevelt Canal conveys water pumped from the aquifer east of the

Agua Fria River to the RID. Values of canal leakance per wetted perimeter (Turek, June 1999) were used to compute recharge to the aquifer for model cells in which canals occur. The leakance values used are 0.05 cubic feet per day (cfd) for lined canals and 0.50 cfd for unlined canals. The canal leakance, where applicable, and the on-land recharge were summed to produce recharge per model cell.

F. Well Pumpage

Well pumpage is a significant source of water supply for many of the water use entites in the Tres Rios hydrologic model area. Reporting of annual well pumpage has been mandatory for all major groundwater users since the mid 1980s. This information is collected and stored by the ADWR in the ROGR electronic database (ADWR, n.d.), which contains most of the well pumpage information used in the Tres Rios hydrologic model. Well pumpage values for later years is generally more complete and accurate than for earlier years. Since the Gila River Indian Community does not report well pumpage to ADWR, pumpage for wells in the GRIC was projected. Well pumpage per model cell was computed as the total annual pumpage for all wells that corresponded to a single model cell. Six data sets, one for each year in the six-year calibration period, were developed for input into the Tres Rios hydrologic model.

In addition to total annual pumpage by model cell, it was necessary to specify from which model layer(s) the wells were pumping. Only limited and incomplete information exists regarding well completions. In many cases, no information is available on screened casing intervals; in other cases, the screened casing interval is listed as the total well depth. A computer program was developed by W&EST to apportion pumpage to the model layers based on total well depth. The approximate average total depth of wells in each model cell was tabulated during the analysis of the model area hydrogeology. If the total well depth was equal to or less than the depth to the bottom of layer 1, all of the pumpage was allocated to layer 1. If the bottom of the well was determined to be within layer 2, the pumpage was weighted by the amount of penetration of layers 1 and 2 as well as the hydraulic conductivies of the two layers. Likewise, if the well's total depth extended into layer 3, the pumpage was weighted by the amount of penetration into all three layers and by the layers' hydraulic conductivites. These computations provided the well pumping inputs to the model.

1. Registry of Ground-Water Rights (ROGR) Pumpage

Pumpage for the Tres Rios hydrologic model was extracted from the ADWR Registry of Ground-water Rights database. The total annual pumpage was determined from the ROGR database for each model cell by Greeley and Hansen. The total annual ROGR pumpage for the Tres Rios hydrologic model area for the calibration period is presented in the following table:

Table 4. Total Annual ROGR Pumpage

YEAR	Total ROGR Pumpage (acre-feet)
1986	200,820
1987	191,208
1988	215,254
1989	222,345
1990	218,660
1991	200,724

2. Gila River Indian Community (GRIC) Pumpage

The GRIC does not report pumpage to the ADWR and the ROGR database contains incomplete data on pumpage for the GRIC area. However, wells are pumped in the GRIC southeast of the Tres Rios Study Area. Locations of GRIC wells in the model area were determined from available drillers' well logs to identify the model cells in which to include GRIC pumpage. Fifteen GRIC pumping cells, each containing a single well, were identified in the model.

Once the GRIC wells were identified in the model area, it was then necessary to ascertain the pumpage associated with the wells. Unfortunately, it was not possible to determine a pumping rate for each well. The methodology used to develop the well pumpage model inputs was to divide the total computed demand on the GRIC agricultural lands in the Tres Rios model area (approximately 42,000 acre-feet) by the number of GRIC wells (15), with the assumption that the wells serve the adjacent lands.

3. Buckeye Irrigation Company Dewatering Well Pumpage

Because of water-logging problems in western BIC lands, 10 dewatering wells are pumped to lower the water table. Three of these wells are located in the far western portion of the model area (BIC, 1999). The water from these wells is allowed to flow back to the Gila River as waste water. The total annual pumpage from these wells is included in the ROGR database.

G. Riparian Vegetation Evapotranspiration

Riparian vegetation evapotranspiration (ET) is the consumption of groundwater by plants in near-surface water table conditions and occurs in the model area along specific areas of the floodplains of the Salt and Gila Rivers. Both land use data and detailed riparian habitat data were used to construct the ET rate inputs for the Tres Rios hydrologic model. The ET rates represent an average annual maximum rate for the model calibration period. The numerical groundwater model computes the ET amount based on the calculated water level for those cells with associated ET during the simulation. An extinction depth value constrains the ET to a specific depth below land surface.

The ET extinction depth assigned to the cells is twenty feet below the ET surface. The extinction depth represents the maximum groundwater depth from which riparian vegetation can draw water (Greeley and Hansen, May 1998). The ET surface is modeled as the average land surface along the river floodplain outside of the Tres Rios Study Area where ET is generally minimal. Within the Tres Rios Study Area the use of the average topography as the ET surface resulted in insufficient modeled ET because the average land surface was higher than the river bottoms and lowlands in which the riparian vegetation occurred, and this elevation difference reduced the modeled ET considerably. The ET surface was changed within the Tres Rios Study Area to reflect the 1991 modeled heads, allowing all of the ET to be modeled.

1. Riparian Habitat

Detailed riparian vegetation mapping was performed by CH2M Hill for the area along the Salt and Gila Rivers floodplains between 67th Avenue and the Buckeye Canal intake in the vicinity of the Tres Rios Study Area (CH2M Hill, n.d.). Vegetation associations differentiated on the maps include salt cedar, cottonwood-willow/salt cedar, quailbush-saltbush, and marsh. Open water and

cobble areas were also identified. The model grid was overlain on the detailed riparian habitat maps and the approximate percentage of each vegetation association and channel type was manually ~~projected and~~ tabulated by model cell. This procedure also allowed computation of vegetation association acreage by model cell as well as total acreage for the Tres Rios Study Area.

Greeley and Hansen (April 1998) computed approximately 7,340 acre-feet of average annual evapotranspiration associated with the 2,454 acres of vegetation in the vicinity of the Tres Rios Study Area. Average annual evaporation associated with the approximately 440 acres of open water in this area was computed to be about 2,640 acre-feet per year.

2. Evapotranspiration Rates

For the Tres Rios hydrologic model, evapotranspiration rates by cell in the Tres Rios Study Area were computed using the average maximum ET rates for the vegetation and river channel types identified by model cell. Within the Tres Rios Study Area, average ET rate was computed as the weighted average maximum ET rate of the vegetation associations and/or channel types in the model. This was done by multiplying the average maximum ET rate for each vegetation association and channel type (Greeley and Hansen, May 1998) by the percentage of that association and type occurring in the cell.

Detailed vegetation data were absent outside of the Tres Rios model area along the Salt, Gila and Agua Fria Rivers. Therefore, cells with land use coded as river floodplain were assigned an ET rate of 3.7 feet per year, which is an average rate for the potential mix of vegetation associations within the model cells coded as having riparian channel land use.

H. Natural Recharge

Based on literature values and previous work, W&EST projected that an annual average of approximately 1,200 acre feet of mountain front recharge occurs within the Tres Rios hydrologic model area. This recharge occurs along the northern flank of the Sierra Estrella, the northwestern flank of the South Mountains, and along the southeast flank of the White Tank Mountains. The recharge was manually distributed according to the elevation of each mountain range, and the number of grid cells bordering each mountain flank. These recharge values were assigned to the

first two or three rows of active cells adjacent to the inactive mountain cells in each area. The mountain front recharge values were added to irrigation and canal seepage recharge values and placed into the single recharge array for the model.

I. General Head Boundaries

Since the Tres Rios Study Area is not bounded by nearby natural barriers to groundwater flow, it was necessary to construct the Tres Rios model with general head boundaries along much of the model's perimeter. The alluvial aquifer extends beyond the western, northern, eastern and southeastern model boundaries. The general head boundaries allow connection between the active border model cells to the alluvial aquifer outside of the model area so that changing water levels at the perimeter of the model cause the movement of groundwater into or out of the model domain.

General head boundary inputs by model cell were constructed from model layer thicknesses and hydraulic conductivities, and from model starting heads. A general head boundary was connected to each active perimeter model cell. The model layer parameters for the active edge cell were used to compute the conductance of the associated general head boundary, and the starting head for that cell was assigned as the general head boundary head value.

J. Aquifer Parameters

Model layer top and bottom elevations were determined from well log data. Because the model does not simulate the upper clay layer between layers 1 and 2 as a separate layer, and because the clay is much thinner than layers 1 and 2, for simplicity the bottom of layer 1 was assumed to be equal to the top of layer 2. Since layer 2 directly overlies layer 3, the bottom of layer two is equal to the top of layer 3. Locations of wells with layer depth information were plotted in the model area, and the program SURFER was used to interpolate values for each model cell. The depths to tops and bottoms were converted to elevation data by subtracting the depths from the average land surface for each cell.

Brown and Pool (1989) state that the range of hydraulic conductivities for their upper alluvial unit (the 400 feet of alluvium overlying the lower clay) is 180 to 1700 feet per day. This interval corresponds to Tres Rios hydrologic model layers 1 and 2. Because the upper portion of this

zone is more pervious than the average for the entire zone, model layer 1 was assigned hydraulic conductivity values somewhat higher than those in layer 2.

During calibration these values of hydraulic conductivity were adjusted in an effort to more closely match measured heads and stream flows in the western portion of the model domain. The layer 1 hydraulic conductivities were varied from a low of 300 to a high of 1600 feet per day, and the layer 2 values were varied between 100 and 1200 feet per day. Neither the heads nor the stream flows were very sensitive to the hydraulic conductivity variations. The highest values produced the best results, but it was judged that 1600 and 1200 feet per day for model layers 1 and 2, respectively, were too high. The final values used were 800 feet per day for model layer 1 and 600 feet per day for model layer 2; these values produced reasonable modeled heads and stream flows, and fell in the middle of the range cited by Brown and Pool. Constant values were used for each layer because the model was not sensitive enough to hydraulic conductivity to warrant varying it over the model domain.

Model layer 3 was modeled as a layer of constant transmissivity without a thickness associated with it. The transmissivity valued used for the layer was 500 square feet per day.

Vertical conductance between model layers incorportates both layer thickness and vertical hydraulic conductivity and is computed by the model code during model runs. A value, the vertical leakance, is the conductance of the vertical interval between two model layers divided by the cell area, and is the necessary model input. Vertical leakance values for the confining layers separating two aquifer layers are typically 1 to 3 orders of magnitude lower than the hydraulic conductivities of the aquifers. Values of 0.001 were initially input to the model. These values were re-computed by the computer program during adjustments to hydraulic conductivity to achieve calibration.

The following table summarizes the aquifer parameters used in the Tres Rios hydrologic model:

Table 5. Aquifer Parameters Used in Tres Rios Hydrologic Model

LAYER	Hydraulic Conductivity (feet/day)	Transmissivity (feet^2/day)	Specific Yield (percent)	Storage Coefficient
1	800	—	15	.0001
2	600	—	10	.0001
3	—	500	—	.0001

MODEL CALIBRATION

The purpose of the model is to study baseflow conditions along the Gila River. The calibration encompassed the calendar years 1986 through 1991 because the river flows were very low during this time period. The January 1986 mapped heads were used as starting heads for the simulation. Six stress periods were used, with each stress period equal to one year and simulating the average conditions for that year. Modeled heads and Gila River outflows were compared with measured heads and measured Gila River flows at the Buckeye gage to determine the quality of the calibration. The total modeled evapotranspiration in the Tres Rios Study Area was also compared with estimates from Greeley and Hansen (Greeley and Hansen, April 1998).

Some parameters were adjusted during the calibration process to achieve the best matches between modeled and measured data. As these parameters were adjusted, the response of the model to the parameter changes were observed as a sensitivity analysis. Parameters that were adjusted included hydraulic conductivity, mountain-front recharge, agricultural return flows to both groundwater and to the Gila River, general head boundary conductance to increase or decrease groundwater inflow and outflow, and vertical conductance between layers.

Plate 2 shows the 1991 modeled heads in the Tres Rios Study Area; individual data points are measured water levels from November and December, 1991, at the end of the model calibration period. Overall, the modeled heads appear smoother than the measured heads; not all measured heads fit exactly onto the map of modeled heads. However, the general trends and gradients are similar. The reason for the minor discrepancies is that the modeled stresses represent average annual data, and pumping depths for individual wells are unknown. Also, the model is a three-

layer system, whereas the real world is much more complex. However, the model represents the physical system with sufficient accuracy to make future projections.

Because the model was designed to examine baseflows, and therefore omitted precipitation and tributary runoff, the modeled surface water outflow was less than the measured outflow at the Buckeye Gage on the Gila River. The water budget for the calibrated model is presented in Appendix D.

MODEL ANALYSES AND RESULTS

The calibrated Tres Rios hydrologic model was used to make predictive runs to determine the impact of potential future water use changes on the riparian vegetation in the Tres Rios Study Area. The model was also used to analyze proposed habitat changes (alternatives) in the Tres Rios Study Area and their water requirements. These scenarios are discussed in detail in the Corps Draft F-4 documentation (USACE, June 1999).

A. Present Conditions into the Future

The calibrated model was used to assess the impacts of continuing the present conditions into the future on the Tres Rios Study Area. This is identified as the Present Conditions into the Future Scenario. This alternative provided a baseline of comparison for the Tres Rios alternatives. Seasonality was incorporated into the model in order to simulate changing water needs on a quarterly basis for each year simulated.

The historical values (1986 through 1991) that were used to construct the inputs for the calibration run were averaged for the six-year period to produce average annual values. A seasonality factor was applied for each quarter year to the average annual values of well pumpage and riparian evapotranspiration. The seasonality factor for the riparian evapotranspiration was determined from phreatophyte consumptive use curves (Culler and others, 1982), and the seasonality factor for the well pumpage was based on consumptive use curves for agricultural crops (USDA, 1982). Seasonal average values for Gila River inflow to the model and for the 91st Avenue WWTP effluent flow to the Salt River were computed from monthly and daily historical data. The inputs were used to simulate the hydrologic system for many years to assess the water levels and river flows if current conditions were to continue into the future.

The model was run for 20 years into the future, repeating the same quarterly seasonal values for each year. Modeled river flows and evapotranspiration totals were examined, and it was determined that the modeled heads, stream flows and evapotranspiration approached a long-term, constant condition within approximately 5 years, repeating the same seasonally-varying patterns of flows and evapotranspiration year after year. For this reason, a scenario run of 10 years is sufficient.

Plates 3 through 6 present the final water levels and depth to water at the end of each quarter for the fifth year, at the time heads had approached a long-term constant trend in the model simulation. Appendix E presents a tabulation of these depth to water values for individual cells in the Tres Rios Study Area. Table 6 presents the 91st Avenue WWTP effluent discharge to the Salt River, the surface water flow in the Gila River just upstream of the BIC canal, and the total evapotranspiration in the Tres Rios Study Area for each quarter of the year at the end of the model simulation, when conditions had approached long-term constant conditions.

Table 6. Model Results for Present Conditions into Future, Model Year 20

Quarter (Model Year 20)	91st Avenue WWTP Discharge to Salt River (acre-feet)	Gila R. Flow Just Upstream of BIC Canal (acre-feet)	Tres Rios Study Area ET (acre-feet)	91st Avenue WWTP Discharge to Salt River (MGD)[1]	Gila R. Flow Just Upstream of BIC Canal (MGD)
1st	33,126	40,341	1,380	118	144
2nd	31,222	36,437	5,116	111	130
3rd	28,823	32,810	6,286	103	117
4th	29,895	35,140	2,918	107	125
Ann. Tot:	123,065	144,727	15,628	110	129

[1] million gallons per day

Plates 3 through 6 show that the modeled heads (and therefore the depth to the water table) cycle throughout the year. The heads are highest at the end of the first quarter (March) as a result of relatively low total water demand throughout the winter months. Heads decline at the end of the second quarter, and reach their lowest at the end of the third quarter (September), reflecting high

demands in the spring and summer months. Heads rise at the end of the fourth quarter, reflecting reduced demands in the fall. This pattern is repeated each year.

Table 6 shows that the surface flow in the Gila River just upstream from the BIC Canal cycles throughout the year, also. The flow is highest after the first quarter when the heads are highest. The flow is reduced in the second and third quarters and then rises again at the end of the fourth quarter.

B. Future Without Federal Action

The Future Without Federal Action simulation was performed to assess the impact on the hydrologic system in the Tres Rios Study Area of the elimination of all 91st Avenue WWTP discharges to the Salt River. The contracted amount of effluent the BIC receives from the 91st Avenue WWTP is assumed to increase to the maximum future contract amount of 40,000 acre-feet per year (Greeley and Hansen, April 1998). It was further assumed that the BIC did not divert any flow from the Gila River and received their contracted amount via a piped conveyance. Historically, the BIC had a high water supply because they were able to divert much of the available flow from the Gila River, and their irrigation efficiency was relatively low. Such a reduction in surface-water supply would require the BIC to pump approximately 89,000 acre-feet per year from their wells in order to continue their historical water application rate. It was assumed that the BIC would not pursue such a high and costly well pumpage program and instead would increase their efficiency to 80 percent. This assumption requires that the BIC increase their pumpage by only 20,000 acre-feet from the historical amount. Concurrent with this, on-land recharge in the BIC was decreased by 80 percent and the assumption was made that no agricultural return flow would reach the Gila River with the increased irrigation efficiencies. Also, canal leakance was assumed to be 33 percent less than the historical value due to reduced conveyance volumes, and the South Extension Canal was assumed to waste approximately 50 percent less water to the Gila River. The BIC dewatering wells, however, were allowed to remain at their historical pumping rates. Other than changing BIC water use and recharges and the 91st Avenue WWTP effluent discharge to the Salt River, all other inputs to the model remain the same.

The model simulation was run for 20 years. Figure 2 shows the modeled quarterly evapotranspiration volumes for all twenty stress periods. The modeled conditions approached a

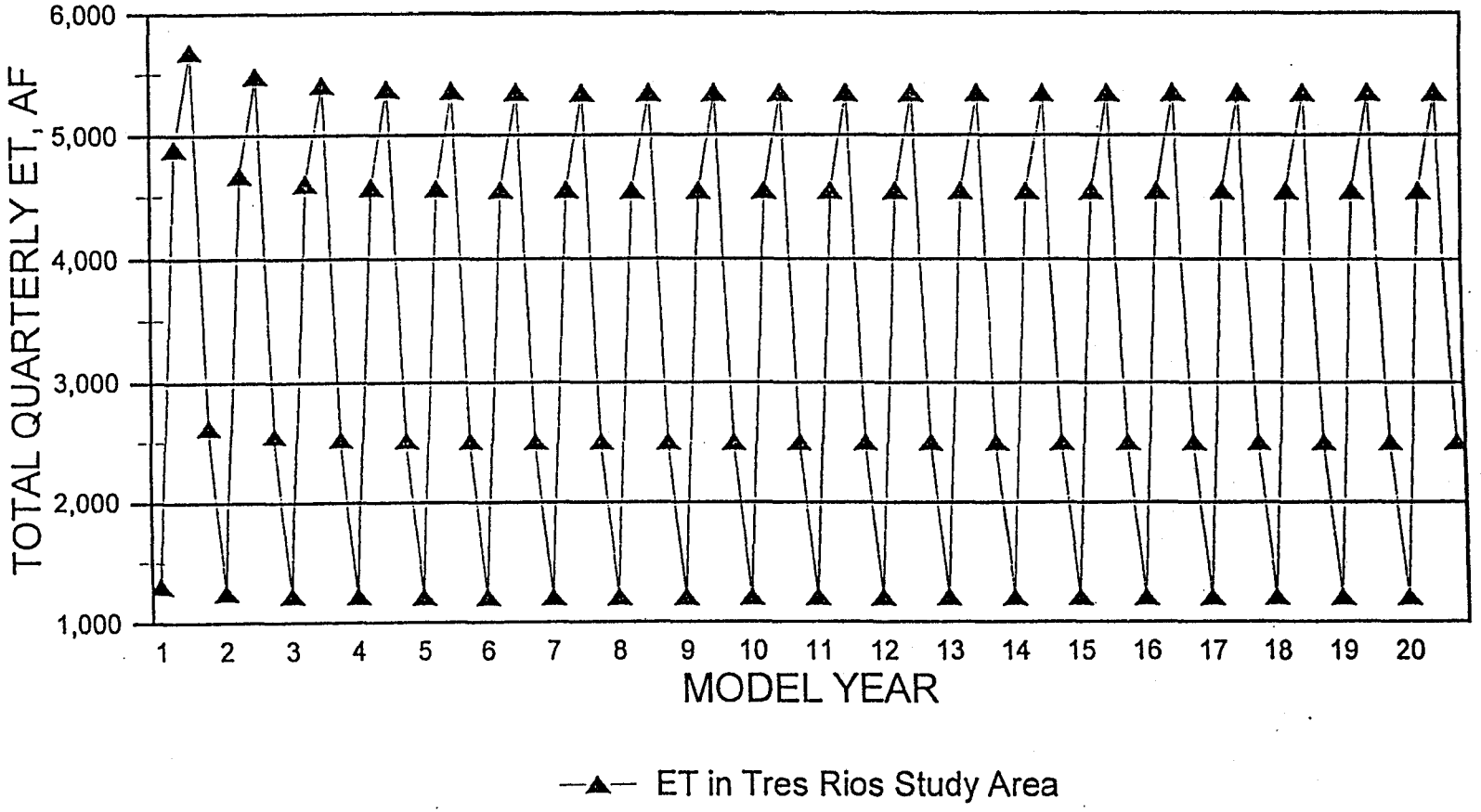

Figure 2. Future Without Federal Action Scenario, Quarterly ET Rates for 20-Year Model Period

long-term constant trend after the fifth year and modeled heads, river flows and ET patterns repeated each year thereafter. The reason that the model stabilizes within five years is that the riparian plants adjust their evapotranspiration rates to equal the reduced amount of water available for consumption. This stable level of evapotranspiration is approximately 85 percent of maximum potential evapotranspiration. Plates 7 through 10 present the modeled water levels for the end of each quarter for the tenth year, when heads had approached long-term constant levels. Appendix E presents a tabulation of depth to water for individual cells, and Table 7 presents the volumes of flow in the Tres Rios Study Area for the final year of model simulation:

Table 7. Model Results for Future Without Federal Action, Model Year 20

Quarter (Model Year 20)	91st Avenue WWTP Discharge to Salt River (acre-feet)	Gila R. Flow Just Upstream of BIC Canal (acre-feet)	Tres Rios Study Area ET (acre-feet)	91st Avenue WWTP Discharge to Salt River (MGD)	Gila R. Flow Just Upstream of BIC Canal (MGD)
1st	0	7,903	1,208	0	28
2nd	0	6,299	4,549	0	22
3rd	0	5,352	5,350	0	19
4th	0	6,183	2,505	0	22
Ann. Tot:	0	27,375	13,613	0	23

Plates 7 through 10 show that the modeled heads cycle throughout the year in a manner very similar to the cycle seen in the simulation of Present Conditions into the Future; however, the heads for each quarter are several feet lower. In the Future without Federal Action scenario the heads range from 6 to 7 feet lower at the west end of the Tres Rio Study Area to less than one foot lower at the east end of the Tres Rios Study Area than in the Present Conditions into the Future scenario. The average head difference is about 2.4 feet in each of the four quarters.

Table 7 shows that the modeled Gila River flows are much less in the Future without Federal Action scenario than in the Present Conditions into the Future scenario. However, this could be expected because discharge from the 91st Avenue WWTP was eliminated and the only major source contributing flow to the river is groundwater. The river flows cycle throughout the year in the same pattern as was seen in the Present Conditions into the Future scenario, but the Future

without Federal Action average modeled flow is only 18 percent of the modeled flow from the Present Conditions into the Future scenario.

The modeled evapotranspiration in the Tres Rios Study Area is less in the Future without Federal Action scenario than in the Present Conditions into the Future scenario, but the ET decrease is much less than the modeled decrease in the river flows. The modeled annual ET in the Future without Federal Action scenario is 87 percent of the annual ET in the baseline scenario (13,613 acre-feet per year in this scenario as compared with 15,628 acre-feet per year in the Present Conditions into the Future scenario).

C. Future With Federal Action

The Corps investigated several potential habitat modifications and water use alternatives for the Tres Rios Study Area. Modifications explored by the Corps include reduced effluent discharge from the 91st Avenue WWTP into the Salt River, and construction of wetlands and other habitat changes along the floodplains of the Salt and Gila Rivers. Alternative 3.5 was selected by the Corps as the preferred alternative and was simulated with the Tres Rios model. Details of the current, projected and contracted 91st Avenue WWTP effluent discharges, riparian vegetation evapotranspiration, habitat leakance rates, and distributions of the proposed modified habitats are presented in the Corps Draft F4 Document (USACE, June 1999).

1. Alternative 3.5

The Corps' proposed modifications to riparian habitat include removal of selected salt cedar stands from the channels of the Salt and Gila Rivers and replacement with open water/marsh vegetation and riparian corridors. A regulated wetland adjacent to the 91st Avenue WWTP is planned to receive effluent from the treatment plant, which would then discharge into a linear overbank wetland, transferring water to the Gila River. Plate 11 shows the locations of these proposed habitat modifications. Dewatering wells located at the 91st Avenue WWTP plant are projected to pump water to supply modified habitat on the south side of the Salt River. The 91st Avenue WWTP is projected to release effluent to the Salt River in a quantity one half of the contracted amount to the BIC, with the remainder reaching the Gila River via the regulated and linear-overbank wetlands, and the open water/marsh habitat areas on the north side of the Gila River.

The Tres Rios model run, Future Without Federal Action, was modified to simulate the Alternative 3.5. The consumptive use and recharge of the modified habitat areas were computed to define the required pumpage to be assigned to the 91st Avenue WWTP dewatering wells, in addition to the approximate discharge from the 91st Avenue WWTP into the regulated and linear-overbank wetlands to allow one half of the contracted amount deliverable to BIC (40,000 acre-feet per year) to be discharged into the Gila River at the downstream end of the modified habitat areas. The modified habitat area infiltration was added to the model recharge input array.

The model was run for ten years and Plates 11 through 14, Table 8 and Appendix E present the quarterly results for the final year of this simulation.

Table 8. Model Results for Alternative 3.5, Model Year 10

Quarter (Model Year 10)	91st Avenue WWTP Discharge to Salt River (acre-feet)	Gila R. Flow Just Upstream of BIC Canal (acre-feet)	Tres Rios Study Area ET (acre-feet)	91st Avenue WWTP Discharge to Salt River (MGD)	Gila R. Flow Just Upstream of BIC Canal (MGD)
1st	6,012	15,772	1,760	21	56
2nd	13,866	20,989	6,700	49	75
3rd	13,618	19,214	7,944	49	69
4th	5,865	13,201	3,741	21	47
Ann. Tot:	39,361	69,176	20,145	35	62

Plates 11 through 14 show that the modeled heads in the Alternative 3.5 scenario cycle throughout the year in the same manner as the two previous simulations. The heads in this scenario average about 1 foot higher in each quarter than in the Future without Federal Action scenario, but about 1.5 feet lower in each quarter than the Present Conditions into the Future scenario. The greatest head differences are in the western part of the Tres Rios Study Area.

Table 8 shows that this scenario has caused Gila River flows to increase from the previous scenario, Future Without Federal Action, by 2.70 times; however the average modeled flows are still only 48 percent of those modeled in the Present Conditions into the Future scenario. The maximum flow in the Gila River just upstream of the BIC Canal occurs in the second and third

quarters, rather than the first and fourth quarters. This is caused by changes in recharge and in the modified habitat areas' evapotranspiration rates and infiltration characteristics.

The modeled evapotranspiration in the Tres Rios Study Area increased from the Future Without Federal Action scenario because of the increased flow in the Gila River. The annual ET is about 1.5 times the annual ET modeled in the Future Without Federal Action scenario.

The results from this model simulation indicate that more flow is in the Gila River just downstream of the modified habitat areas than is needed to satisfy the contractual obligation of the 91st Avenue WWTP to the BIC. High infiltration in the habitat areas raised ground-water levels which increased the flow in the Gila River in this area. Therefore, a second Alternative 3.5 simulation was performed to optimize the release of effluent from the 91st Avenue WWTP, and the simulation and its results are discussed in the following section.

2. Optimized Alternative 3.5

The amount of effluent released from the 91st Avenue WWTP into the Salt River and through the wetlands into the Gila River was reduced in the model to meet but not exceed the contractual amount of water available in the Gila River for delivery to the BIC. Because the Gila River just downstream of the modified habitat areas had sufficient flow in the original Alternative 3.5 simulation, no discharge was necessary in the first and fourth quarters of the year. The discharge was reduced in the second and third quarters.

Plates 15 through 18, Table 9 and Appendix E present the quarterly results for the final year of the ten-year model simulation:

Table 9. Model Results for Optimized Alternative 3.5, Model Year 10

Quarter (Model Year 10)	91st Avenue WWTP Discharge to Salt River (acre-feet)	Gila R. Flow Just Upstream of BIC Canal (acre-feet)	Tres Rios Study Area ET (acre-feet)	91st Avenue WWTP Discharge to Salt River (MGD)	Gila R. Flow Just Upstream of BIC Canal (MGD)
1st	0	9,760	1,737	0	35
2nd	6,933	13,882	6,612	25	50
3rd	8,159	13,625	7,827	29	49
4th	0	7,402	3,679	0	26
Ann. Tot:	15,092	44,668	19,854	13	40

By reducing the effluent recharge from the 91st Avenue WWTP to the minimum necessary to meet the BIC contractual demands, modeled heads and river flows are decreased, but the modeled ET is very nearly equal to the total modeled in the original Alternative 3.5. Plates 15 through 18 show that modeled heads are only about 0.3 feet lower in this scenario than they were in the original Alternative 3.5 scenario, with the largest head differences in the western portion of the Tres Rios Study Area.

The modeled river flows just upstream from the BIC Canal are reduced by about 24,500 acre-feet per year from those modeled in the original Alternative 3.5. This value is nearly identical to the decrease in the effluent discharge from the 91st Avenue WWTP. As in the original Alternative 3.5 scenario, the greatest river flows are in the second and third quarters of the year.

The annual modeled evapotranspiration is only about one percent less in this scenario than in the original Alternative 3.5 scenario. This simulation shows that optimization of the effluent discharge along with proper habitat management should maintain the riparian corridor.

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APPENDIX A

PLATES

TRES RIOS MODEL AREA BASE MAP

Tres Rios Study Area

River Channel Alignment in Model

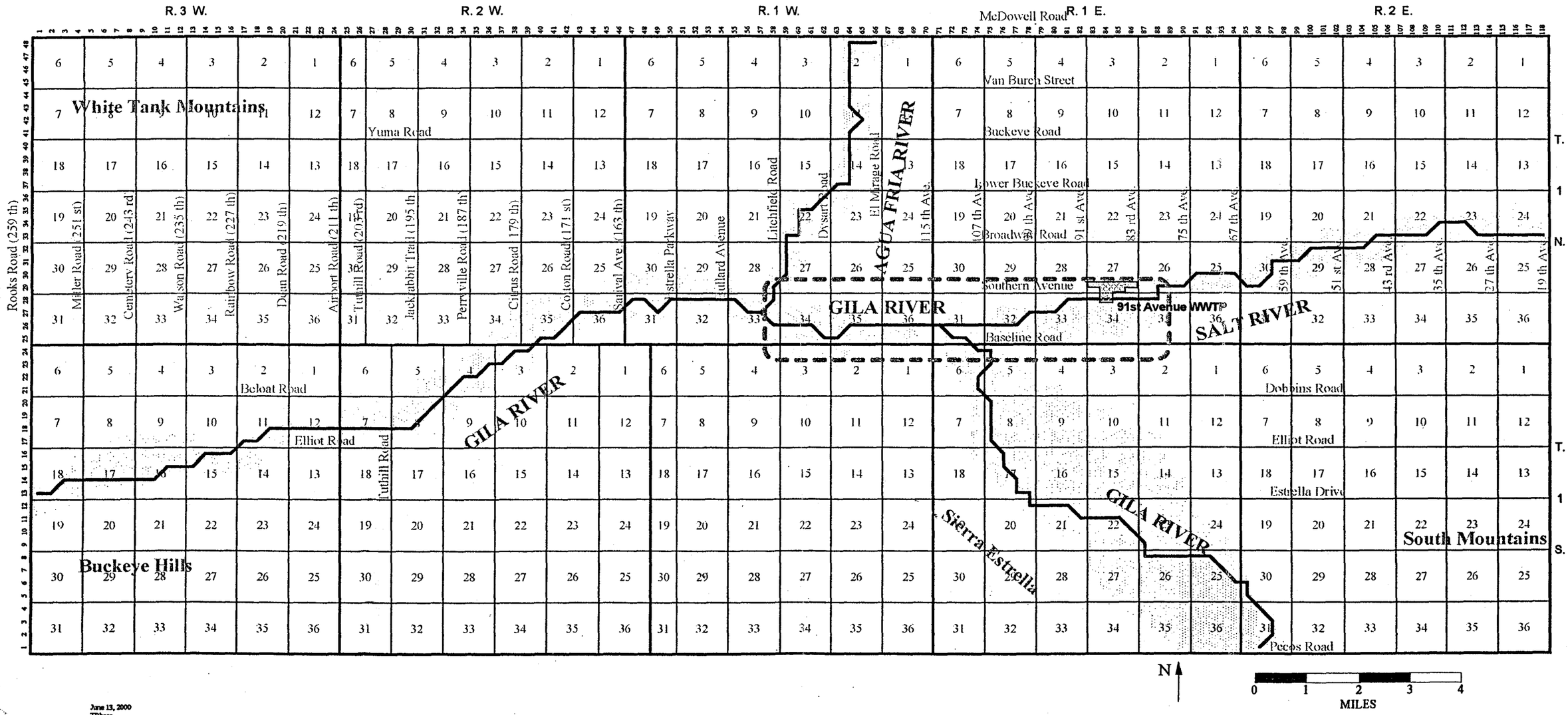
Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

Bedrock Areas (Inactive Cells)

Plate 1

Tres Rios Model Area



June 13, 2000
TRbase

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

902 — 1991 Measured Heads (elevation above sea level)

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

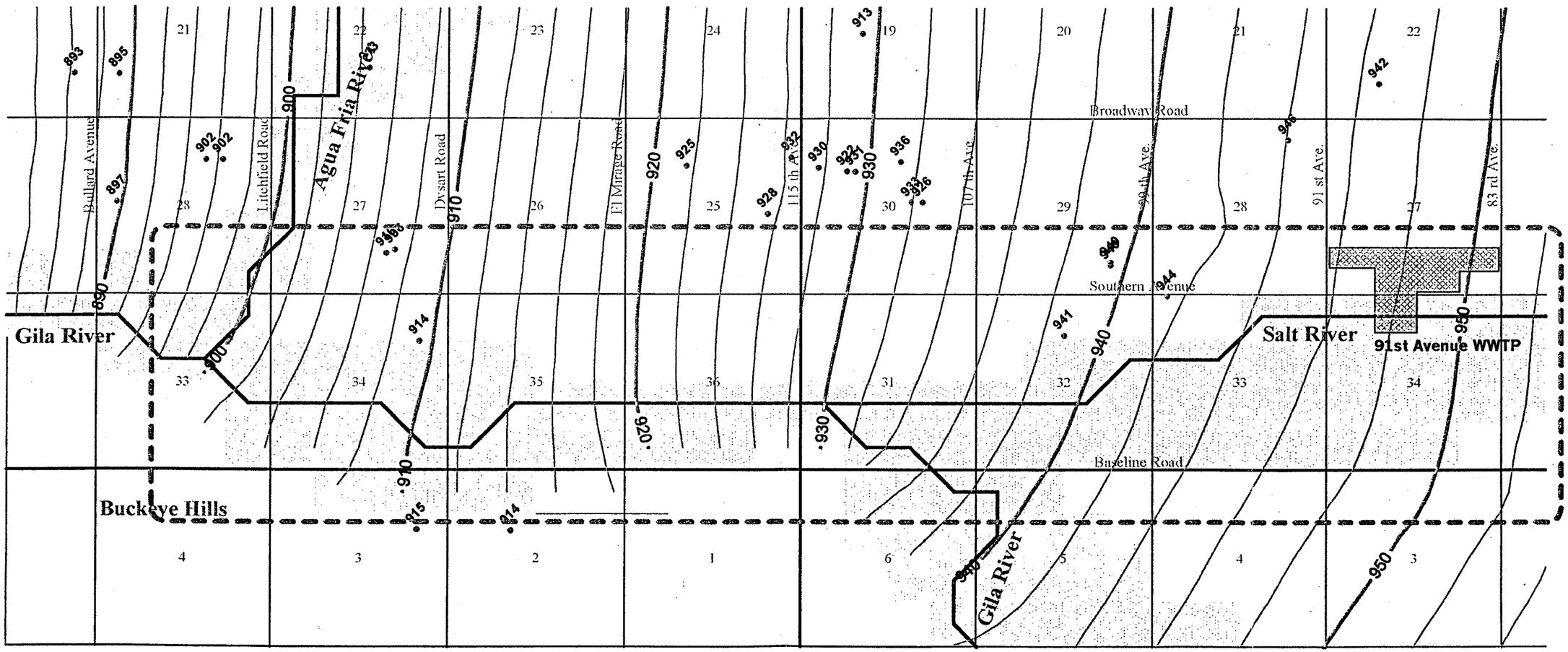
River Floodplain (Active Cells)

Bedrock Areas (Inactive Cells)

Plate 2

Modeled Groundwater Elevations

End of Calibration Period Dec., 1991



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
TR20SP6.SRF

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

• 10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

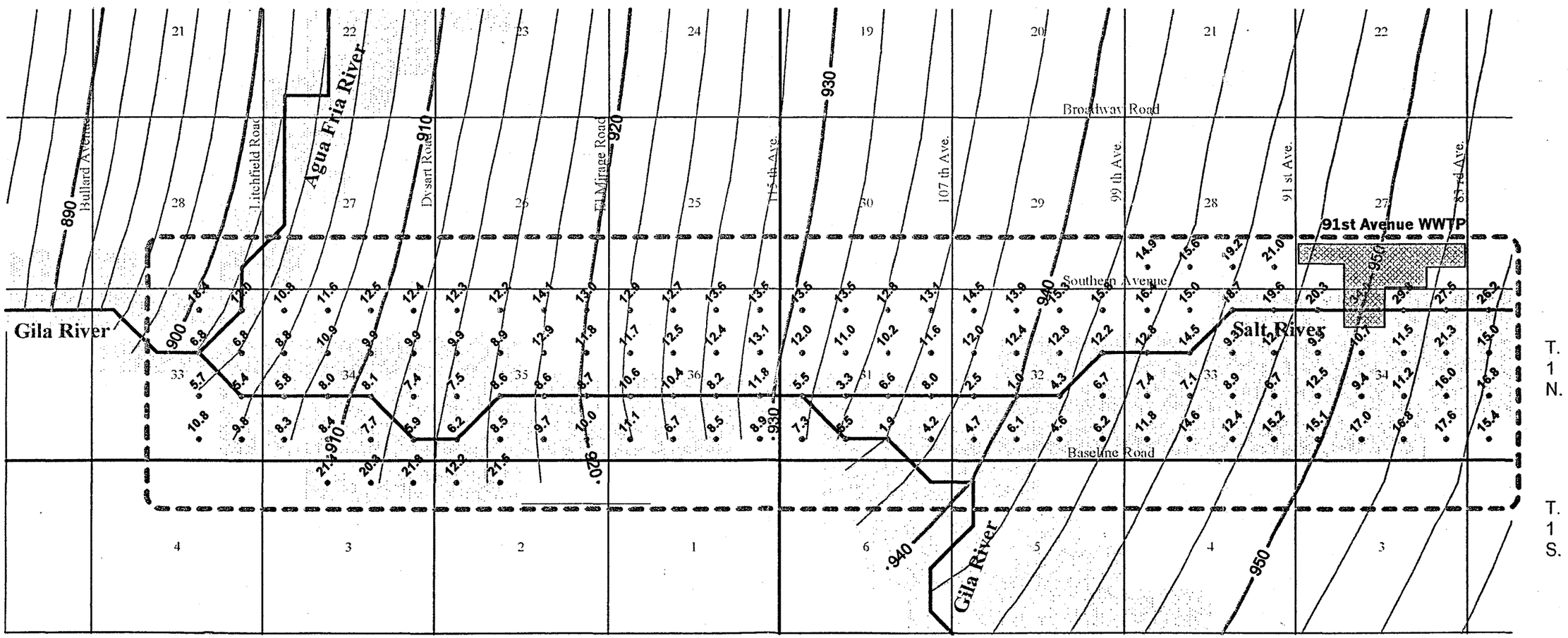
Bedrock Areas (Inactive Cells)

Plate 3

Present Conditions Into Future

Modeled Groundwater Elevations and Depths

End of First Quarter, Year 5



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
TR23Mar5

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

• 10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

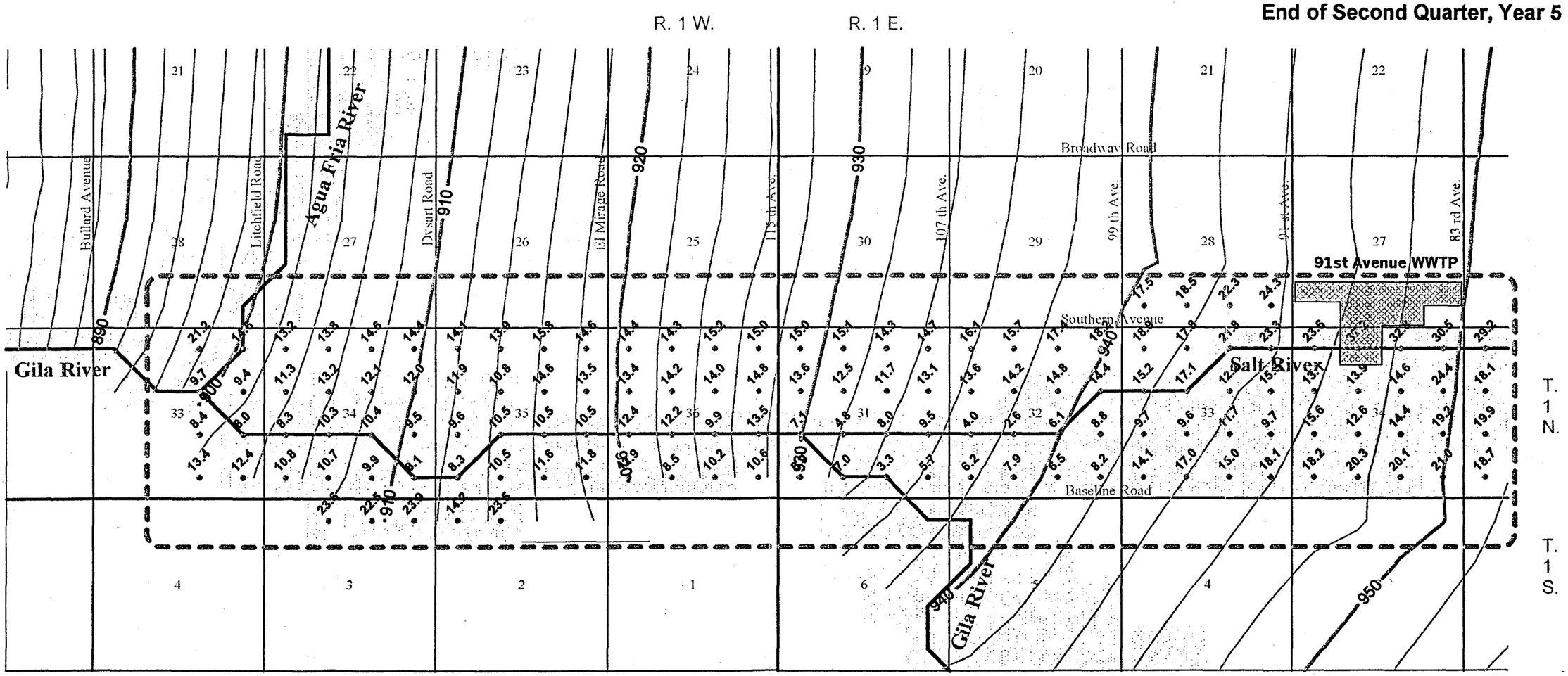
Bedrock Areas (Inactive Cells)

Plate 4

Present Conditions Into Future

Modeled Groundwater Elevations and Depths

End of Second Quarter, Year 5



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
TR23Jun5

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

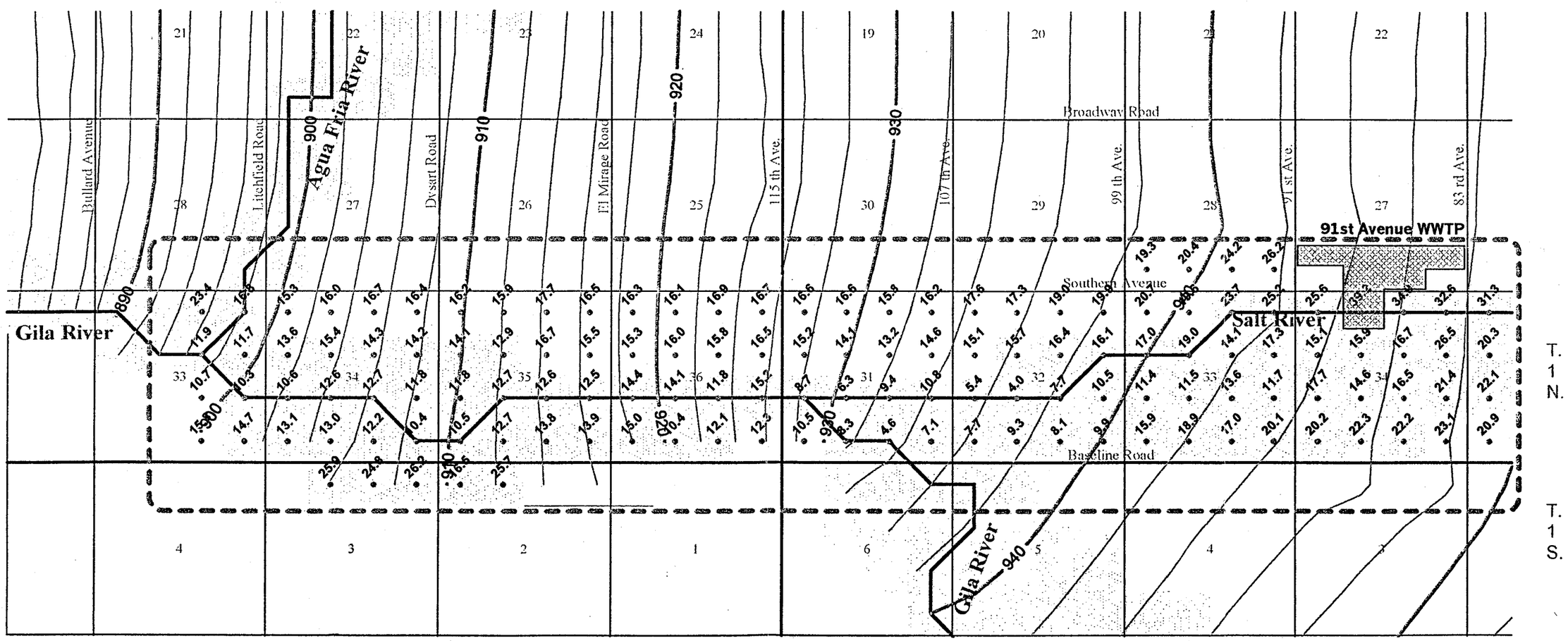
- • 10.8 Depth from land surface to top of modeled water table, feet
- Tres Rios Study Area
- River Channel Alignment in Model
- Alluvial Aquifer (Active Cells)
- River Floodplain (Active Cells)
- Bedrock Areas (Inactive Cells)

Plate 5

Present Conditions Into Future

Modeled Groundwater Elevations and Depths

End of Third Quarter, Year 5



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
TR23Sep5

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

• 10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

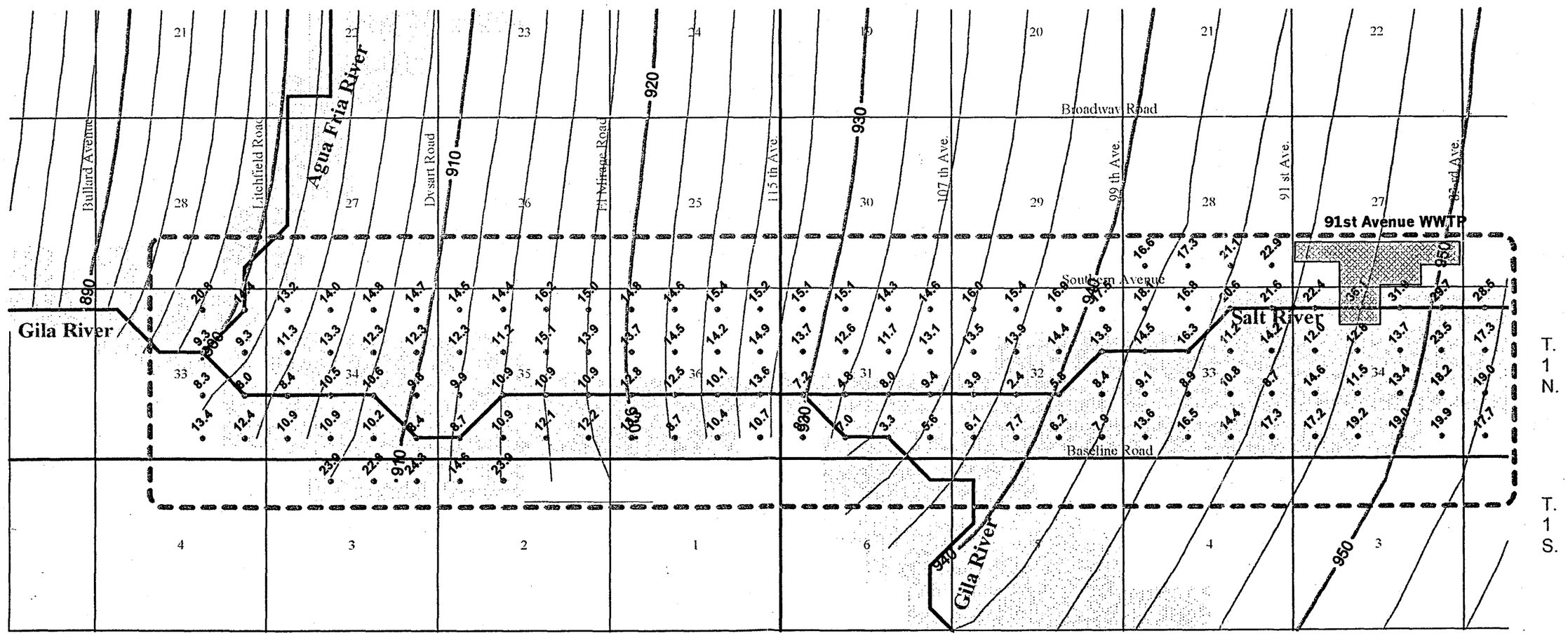
Bedrock Areas (Inactive Cells)

Plate 6

Present Conditions Into Future

Modeled Groundwater Elevations and Depths

End of Fourth Quarter, Year 5



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
TR23Dec5

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

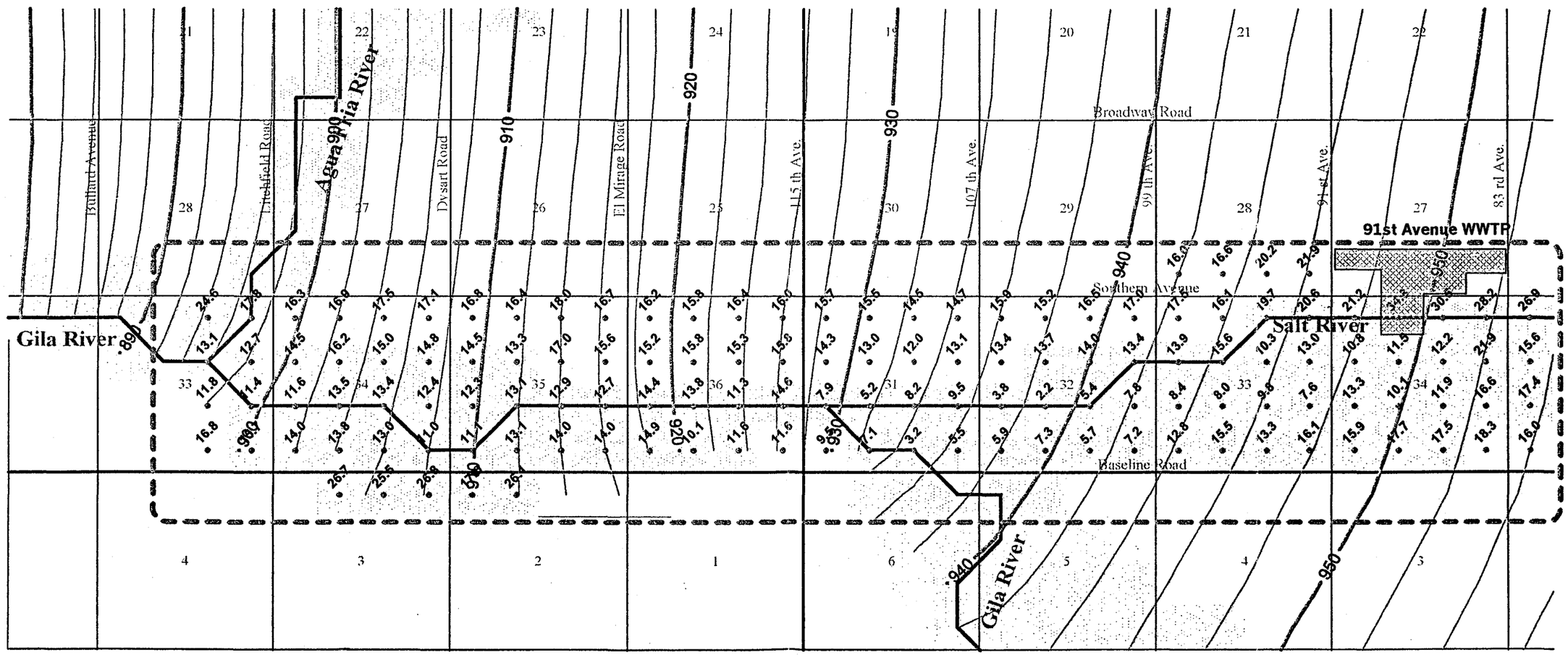
- • 10.8 — Depth from land surface to top of modeled water table, feet
- Tres Rios Study Area
- River Channel Alignment in Model
- Alluvial Aquifer (Active Cells)
- River Floodplain (Active Cells)
- Bedrock Areas (Inactive Cells)

Plate 7

Future Without Federal Action

Modeled Groundwater Elevations and Depths

End of First Quarter, Year 10



June 13, 2000
T25Mar10

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

• 10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

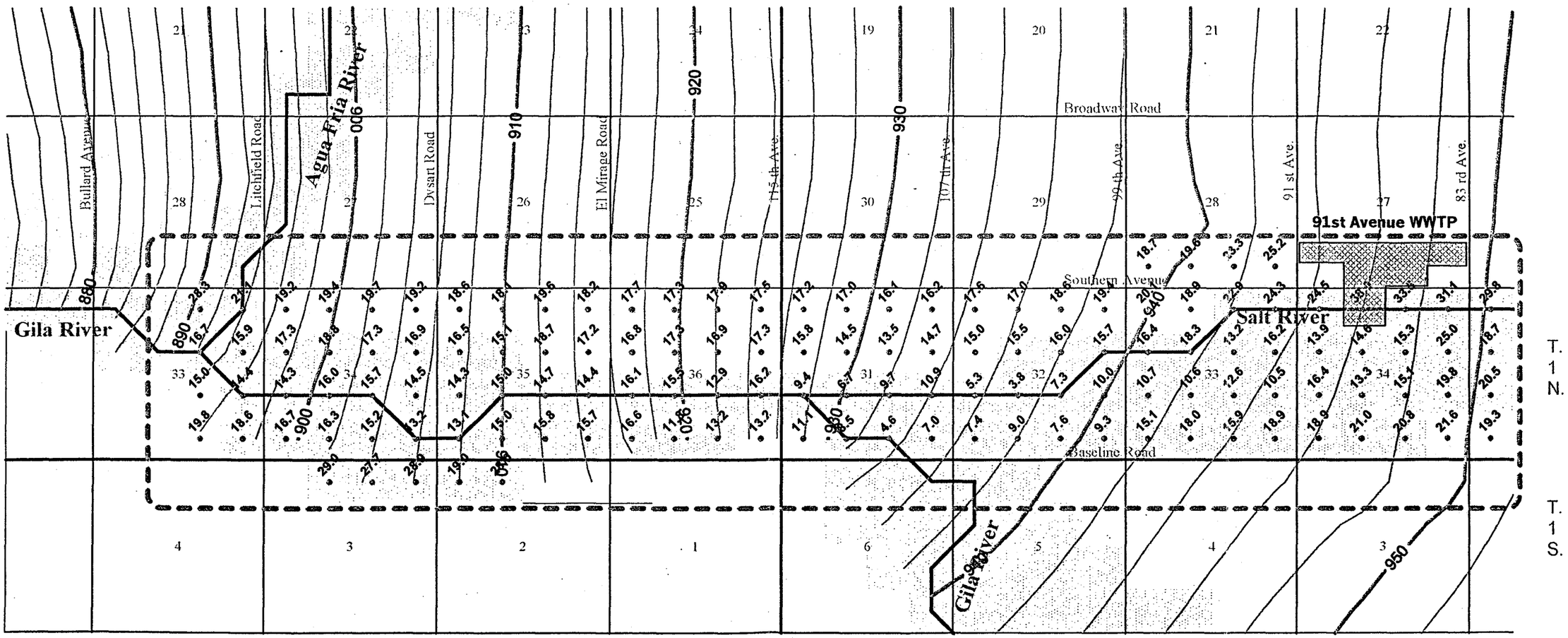
Bedrock Areas (Inactive Cells)

Plate 8

Future Without Federal Action

Modeled Groundwater Elevations and Depths

End of Second Quarter, Year 10



June. 13, 2000
T25Jun10

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

• 10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

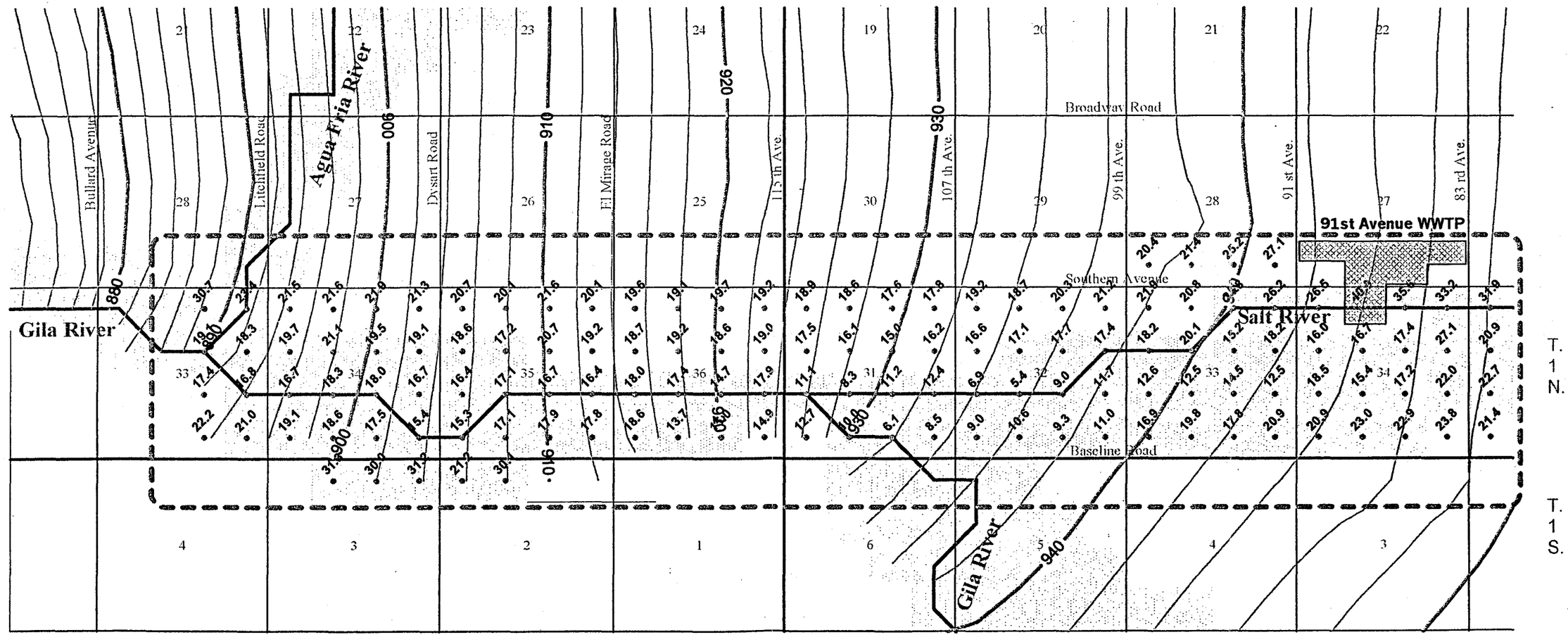
Bedrock Areas (Inactive Cells)

Plate 9

Future Without Federal Action

Modeled Groundwater Elevations and Depths

End of Third Quarter, Year 10



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T25Sep10

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

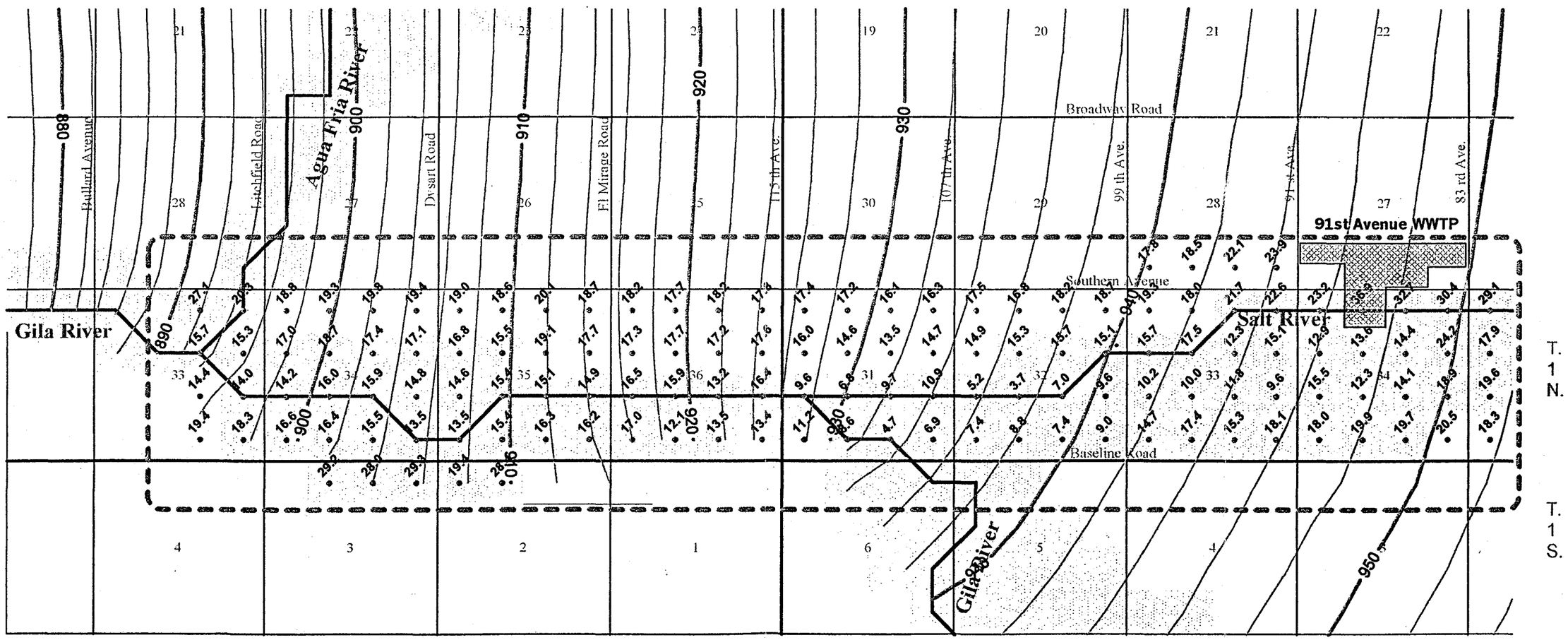
- 10.8 — Depth from land surface to top of modeled water table, feet
- Tres Rios Study Area
- River Channel Alignment in Model
- Alluvial Aquifer (Active Cells)
- River Floodplain (Active Cells)
- Bedrock Areas (Inactive Cells)

Plate 10

Future Without Federal Action

Modeled Groundwater Elevations and Depths

End of Fourth Quarter, Year 10



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T25Dec10

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

Bedrock Areas (Inactive Cells)

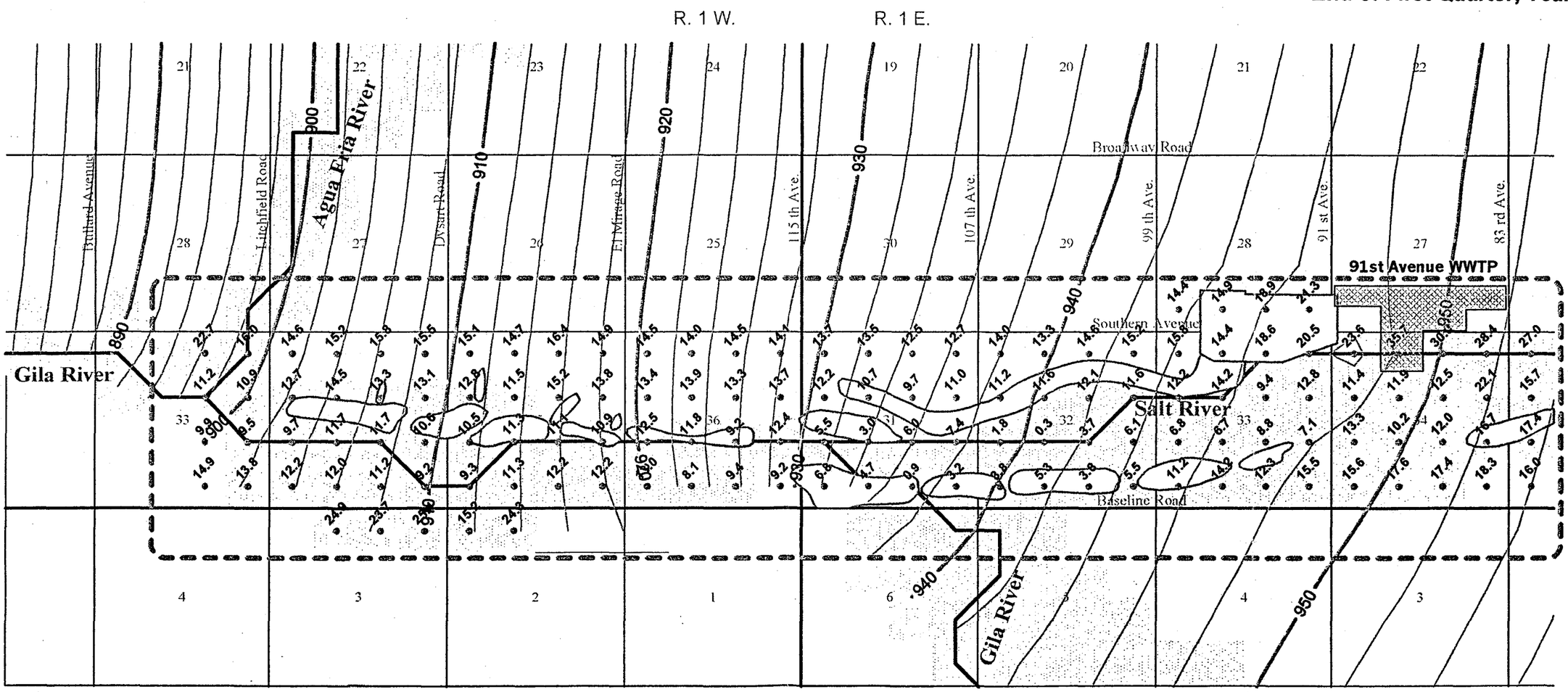
Proposed Alternative 3.5 Tres Rios Habitat Modification

Plate 11

Future With Federal Action Alternative 3.5

Modeled Groundwater Elevations and Depths

End of First Quarter, Year 10



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T35BMa10

Water and Environmental Systems Technology, Inc.

Plate 12

ENLARGEMENT OF TRES RIOS STUDY AREA

• 10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

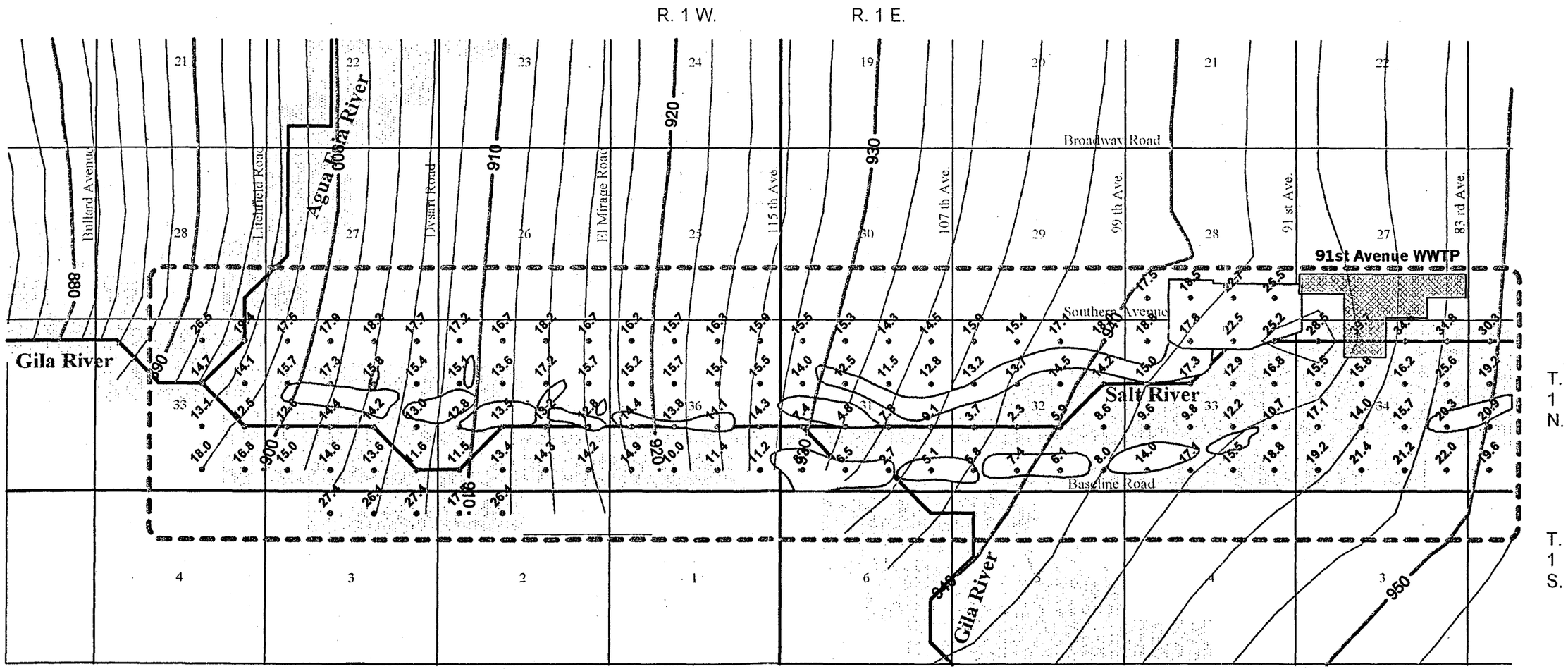
Bedrock Areas (Inactive Cells)

Proposed Alternative 3.5 Tres Rios Habitat Modification

Future With Federal Action Alternative 3.5

Modeled Groundwater Elevations and Depths

End of Second Quarter, Year 10



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T35BJu10

Water and Environmental Systems Technology, Inc.

Plate 13

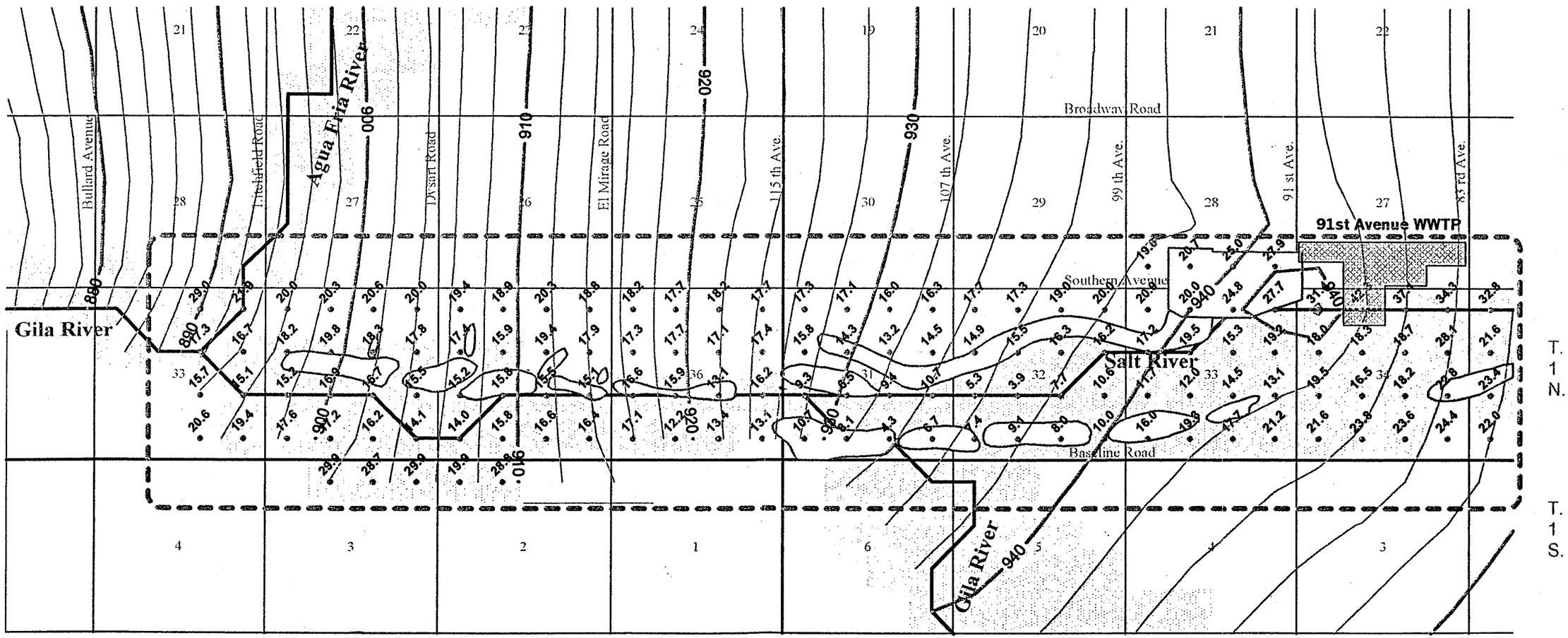
ENLARGEMENT OF TRES RIOS STUDY AREA

- • 10.8 Depth from land surface to top of modeled water table, feet
- Tres Rios Study Area
- River Channel Alignment in Model
- Alluvial Aquifer (Active Cells)
- River Floodplain (Active Cells)
- Bedrock Areas (Inactive Cells)
- Proposed Alternative 3.5 Tres Rios Habitat Modification

Future With Federal Action Alternative 3.5

Modeled Groundwater Elevations and Depths

End of Third Quarter, Year 10



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T35BSe10

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Plate 14

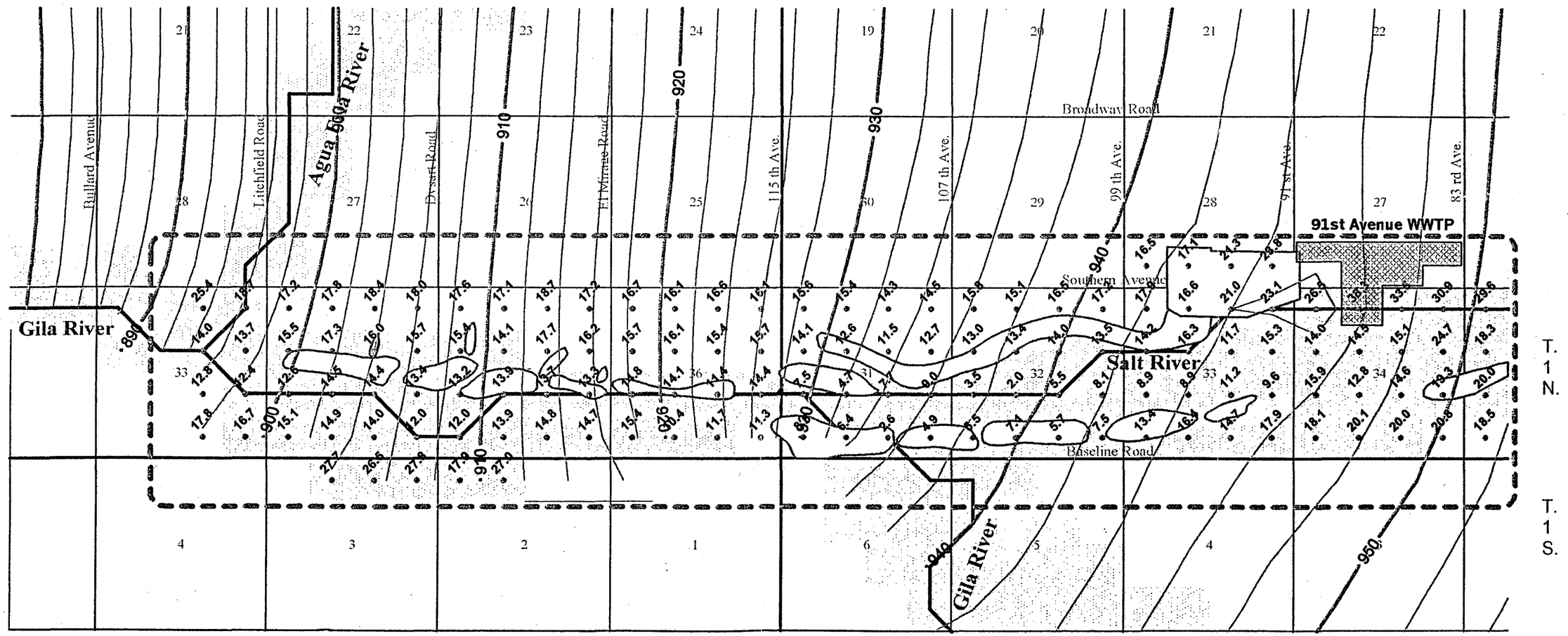
ENLARGEMENT OF TRES RIOS STUDY AREA

Future With Federal Action Alternative 3.5

Modeled Groundwater Elevations and Depths

End of Fourth Quarter, Year 10

- 10.8 — Depth from land surface to top of modeled water table, feet
- Tres Rios Study Area
- River Channel Alignment in Model
- Alluvial Aquifer (Active Cells)
- River Floodplain (Active Cells)
- Bedrock Areas (Inactive Cells)
- Proposed Alternative 3.5 Tres Rios Habitat Modification



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T35BDe10

Water and Environmental Systems Technology, Inc.

Plate 15

ENLARGEMENT OF TRES RIOS STUDY AREA

• 10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

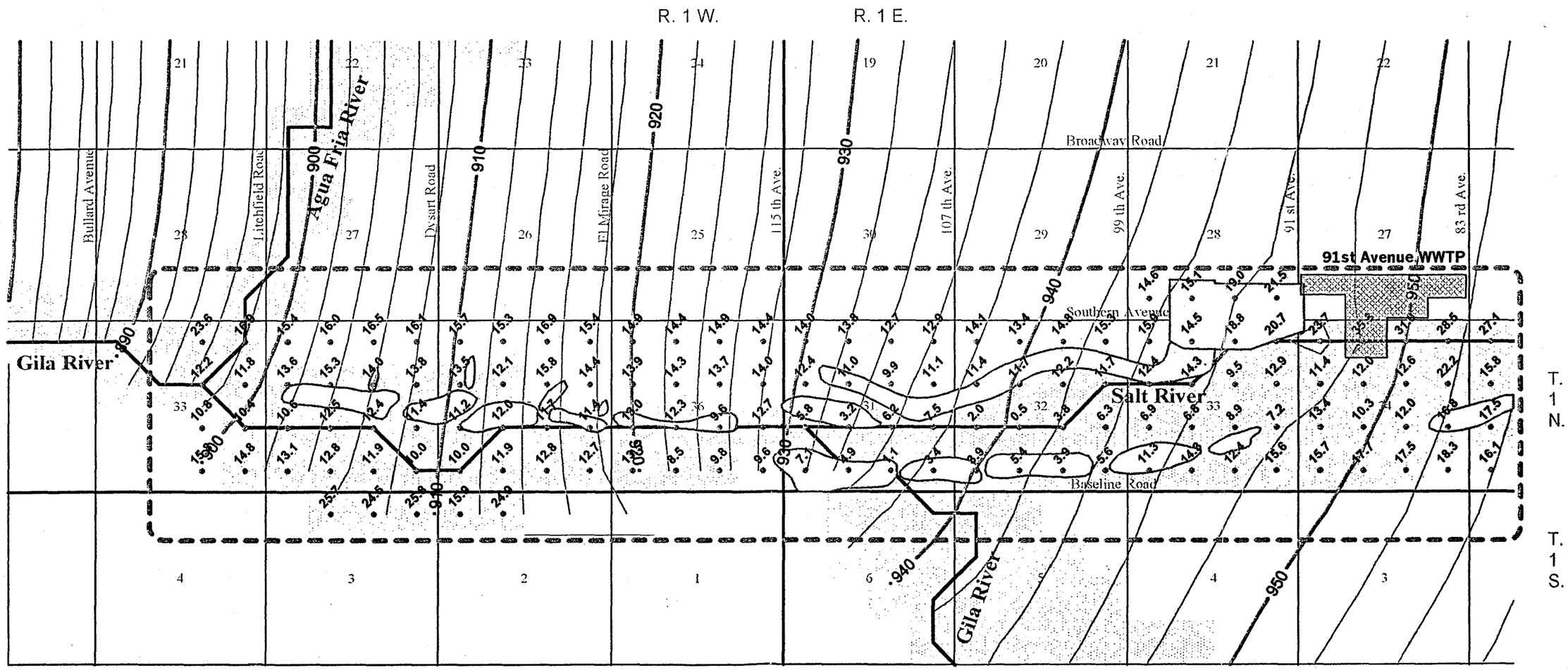
Bedrock Areas (Inactive Cells)

Proposed Alternative 3.5 Tres Rios Habitat Modification

Future With Federal Action
Optimized Alternative 3.5

Modeled Groundwater Elevations and Depths

End of First Quarter, Year 10



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T35DMA10

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

• 10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

Bedrock Areas (Inactive Cells)

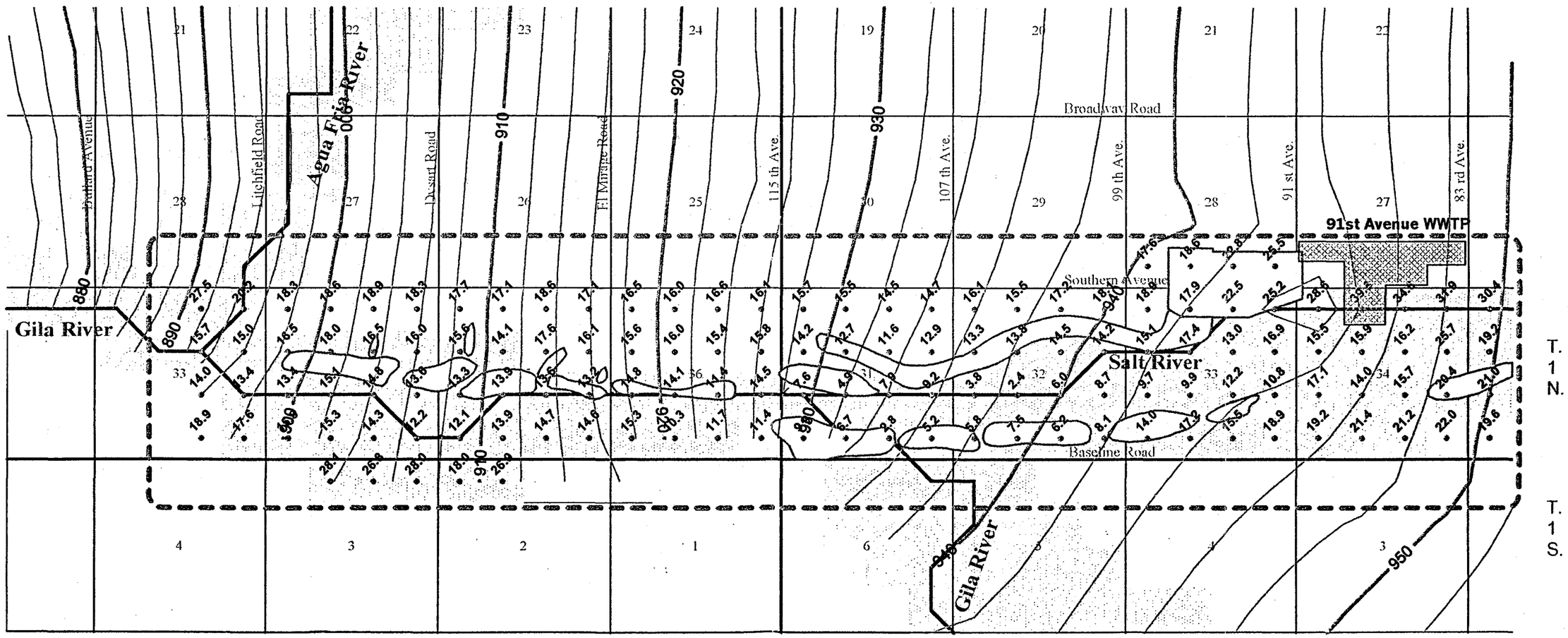
Proposed Alternative 3.5 Tres Rios Habitat Modification

Plate 16

Future With Federal Action
Optimized Alternative 3.5

Modeled Groundwater Elevations and Depths

End of Second Quarter, Year 10



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T35DJu10

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

• 10.8 Depth from land surface to top of modeled water table, feet

Tres Rios Study Area

River Channel Alignment in Model

Alluvial Aquifer (Active Cells)

River Floodplain (Active Cells)

Bedrock Areas (Inactive Cells)

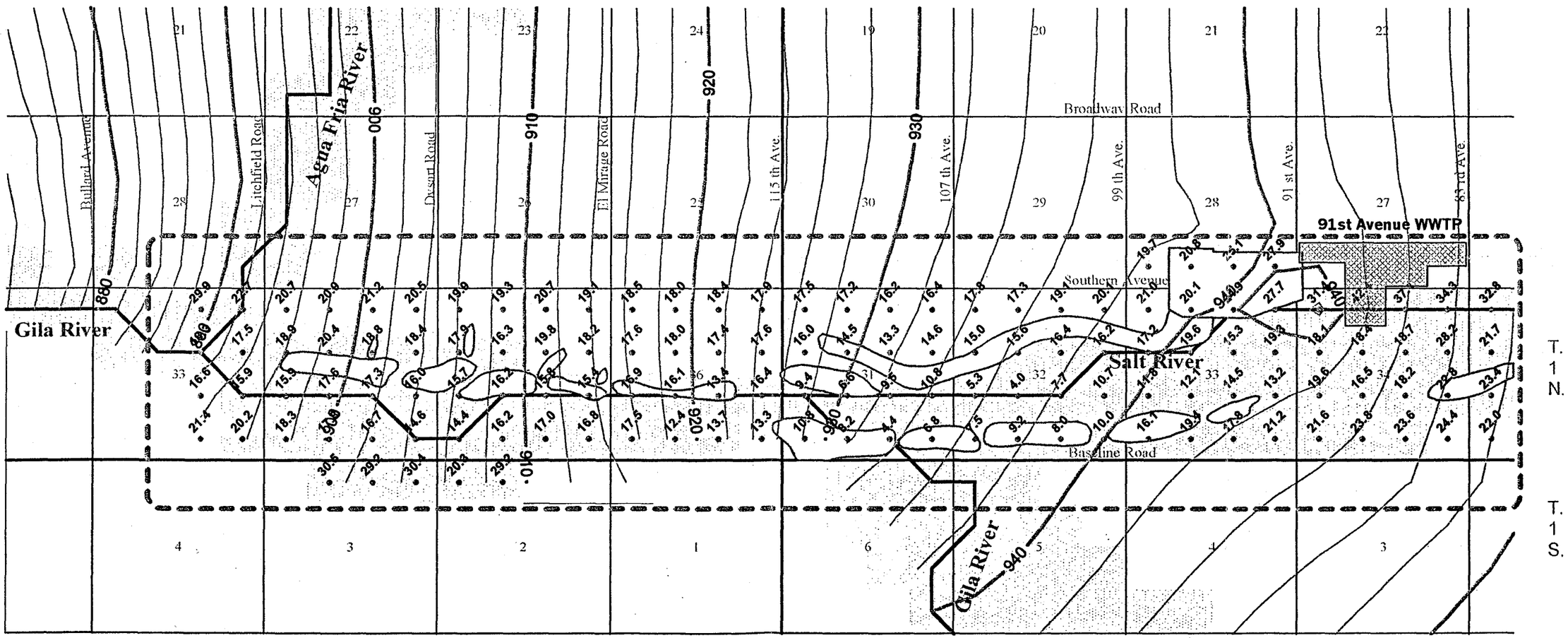
Proposed Alternative 3.5 Tres Rios Habitat Modification

Plate 17

Future With Federal Action Optimized Alternative 3.5

Modeled Groundwater Elevations and Depths

End of Third Quarter, Year 10



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T35DSe10

Water and Environmental Systems Technology, Inc.

ENLARGEMENT OF TRES RIOS STUDY AREA

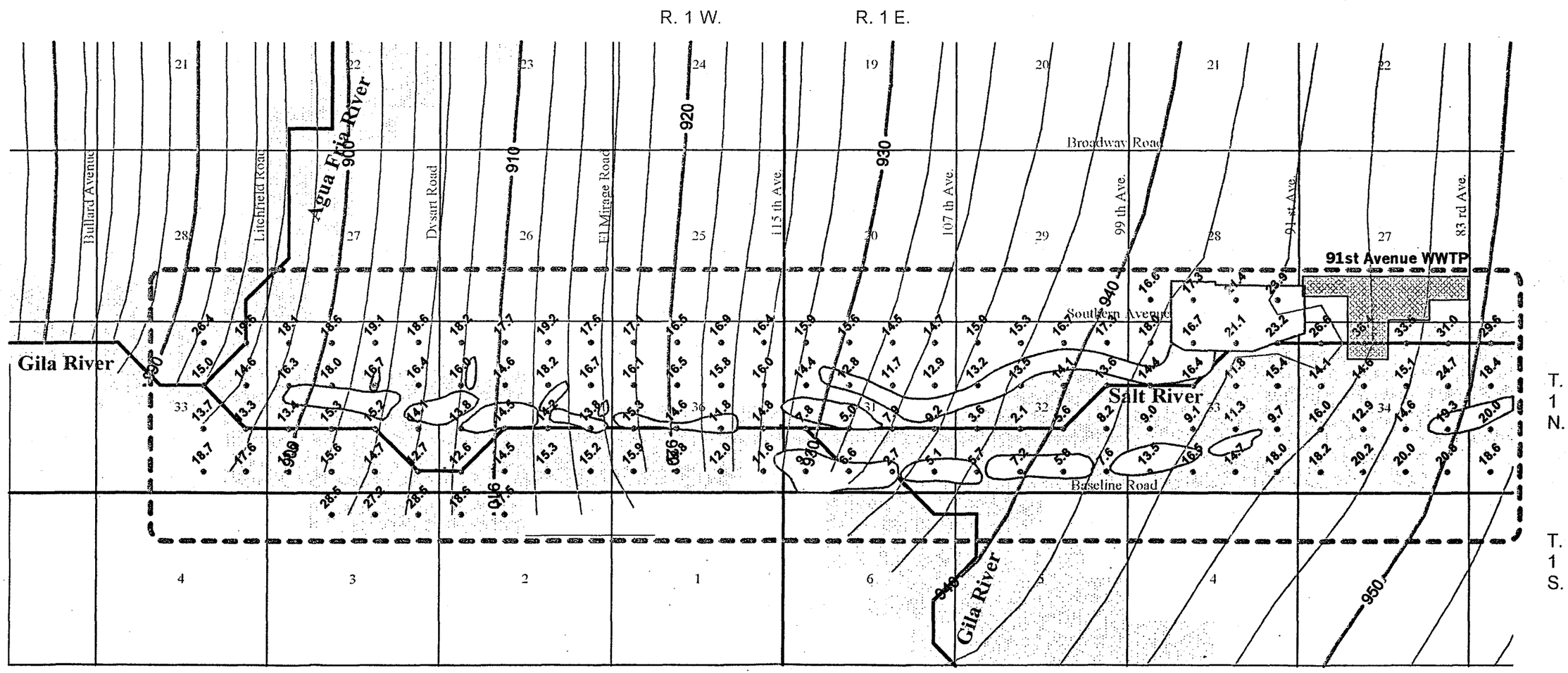
- 10.8 — Depth from land surface to top of modeled water table, feet
- Tres Rios Study Area
- River Channel Alignment in Model
- Alluvial Aquifer (Active Cells)
- River Floodplain (Active Cells)
- Bedrock Areas (Inactive Cells)
- Proposed Alternative 3.5 Tres Rios Habitat Modification

Plate 18

Future With Federal Action Optimized Alternative 3.5

Modeled Groundwater Elevations and Depths

End of Fourth Quarter, Year 10



Scale in Miles

0 1 2 3 4

Contour Interval = 2 feet

June 13, 2000
T35DDe10

Water and Environmental Systems Technology, Inc.

APPENDIX B

DISCUSSION OF FINITE DIFFERENCE COMPUTER MODEL

DISCUSSION OF FINITE DIFFERENCE COMPUTER MODEL

MATHEMATICAL GROUND-WATER FLOW MODELS

A model is a representation of a given subject. Physical models are usually miniaturized versions of the original, or prototype, that look like the original, such as a ship in a bottle. A working physical model of a hydrologic system must not only look like the original, but also perform like the original, i.e. the flow rates of streams, ground-water movement, gradients, and distribution of water must be miniaturized versions of the original. A physical model of a hydrologic system is often constructed using a "sand box", filled with materials that resemble the make-up and geometry of an aquifer, contoured to fit the geologic and topographic features of the original, and representing the water-related activities by adding and removing appropriately miniaturized quantities of water at the correct times and locations.

Because of the size of the Tres Rios model domain, a physical, "sand box" model is infeasible. Even at a scale of only 1:100, a sand box model would cover approximately 23 acres. Detection of changes in stream flow or ground-water levels in this scaled-down model would be extremely difficult and subject to substantial error, because of the limitations of a "sand box" to accurately represent the real system and also because of the limitations on accuracy of currently available devices for measuring water levels, flow rates in streams and other hydrologic phenomena.

The first numerical models of hydrologic systems were developed over fifty years ago. Numerical models represent the physical system with a set of mathematical expressions that describes the dynamics of the system. Although a mathematical model does not physically resemble the real system, the mathematical expressions accurately describe how water moves through the system and how water levels and flows respond to "stresses" such as pumping ground water, diverting water into canals from the river, irrigating fields, and using water in municipal areas.

Mathematical models have many advantages over physical models. They do not require the construction of a physical replica covering several hundred acres and made of large amounts of earth materials, do not require physical instrumentation, and do not require additional construction to change details, such as a new interpretation of the permeability of a zone in the aquifer. Whereas the physical model requires removing and replacing earth materials to

accommodate such a change, the mathematical model requires only the change in some numerical values in the model data set. Mathematical models are orders of magnitude less expensive to develop and operate than physical models, and are much more flexible. At the present time, numerical models are by far the most powerful and economical tool available for evaluating hydrologic systems.

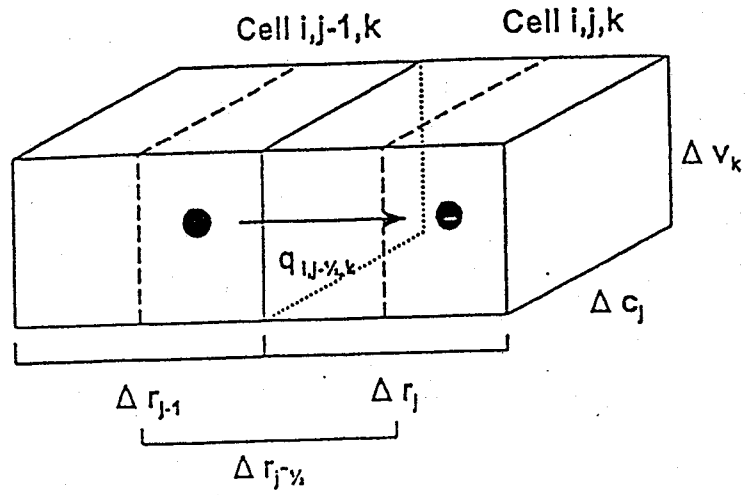
DESCRIPTION OF FINITE DIFFERENCE MODELS

A finite-difference model is a mathematical model that represents the model domain as a set of interfacing grid blocks or cells. Each grid cell represents, on average, the properties and hydrologic conditions present within the boundaries of the cell. Within each cell, properties and conditions are uniform, but they can and do vary from cell to cell to represent the variability present in the continuous and non-uniform real system. Variability occurs not only in lateral dimensions, but also vertically. Many aquifers, including the alluvial aquifer present in the Tres Rios model domain, consist of distinct geologic layers. The mathematical model is accordingly layered to represent the distinct properties and conditions present in each of these layers.

Each cell is assigned a set of parameter values that represents the average conditions for the zone encompassed within the boundaries of the cell. The parameters used in the model include hydraulic conductivity, specific yield for unconfined aquifer conditions, storativity for confined aquifer conditions, and aquifer top and bottom elevations. The top and bottom elevations of each cell correspond to the average top and bottom elevations of that portion of the geologic layer represented by the cell. In addition to these intrinsic geologic properties and aquifer geometry delineations, each cell is assigned a value for the initial head or water level that represents the average for the cell.

The model operates by solving equations for flow between each cell and the cells adjacent to it. In a three-dimensional model there are six adjacent cells for each model cell (above, below, right, left, front and back), except for those cells on the top, bottom, or perimeters of the model. Figure 1 is an illustration of the flow equation that is solved between two adjacent cells.

In a transient model run, "stresses" are applied to the model, and the changed heads that result in response to the stresses are the solution. Stresses can include pumping from wells, seepage to or



$$q_{i,j-½,k} = KR_{i,j-½,k}^{\Delta ci-\Delta vk} \frac{(h_{i,j-½,k} - h_{i,j,k})}{\Delta r_{j-½}}$$

Where:

$h_{i,j,k}$ = head at node i,j,k and $h_{i,j-1,k}$ = head at node i,j-1,k

$q_{i,j-½,k}$ = volumetric fluid discharge through the face between cells i,j,k and i,j-1,k (L^3/t)

$KR_{i,j-½,k}$ = hydraulic conductivity along the row between nodes i,j,k and i,j-1,k (L/t)

$^{\Delta ci-\Delta vk}$ = area of the cell faces normal to the row direction

$\Delta r_{j-½}$ = distance between nodes i,j,k and i,j-1,k (L)

Source: McDonald and Harbaugh, 1988

Figure 1. Flow Equation Solved Between Two Adjacent Cells

from a stream, extraction of water from the aquifer by evapotranspiration, drains, or any other withdrawals, and addition of water to the aquifer through recharge. A stress period in the model is defined as a period during which stresses remain sufficiently unchanged so that they can be considered constant. Stress periods can vary in length, and are generally selected on the basis of variations in existing stream flow, pumping and other water use data. Ideally, none of these parameter values should change drastically during a stress period.

MODFLOW COMPUTER CODE

The U.S. Geological Survey MODFLOW program is a finite-difference code developed by McDonald and Harbaugh (1988) for a broad range of uses within the ground-water profession. Prior to the development of MODFLOW, most mathematical models were tailor-made for each specific application. MODFLOW was designed with a set of "packages", any combination of which could be selected as appropriate for the problem at hand. The basic configuration of the model and the solver for the matrix of ground-water flow equations are standard programs that have been widely used and accepted. Each of the packages added to MODFLOW has been set up to model the effects of various stresses, including seepage between the aquifer and the river, pumping, recharge, evapotranspiration, and general head boundaries (GHB's). A drain package is also available, but this has not been used in the Tres Rios model to date. Each of the packages is briefly described below.

The river package developed by Prudic (1989) was used to simulate seepage between the aquifer and a flowing stream under pre-development hydrologic conditions Each river reach in the model is a section encompassed within the boundaries of one grid cell. Each reach is assigned parameter values describing the geometry and hydraulic properties of that section of the river, including mean bed elevation, width, initial depth and flow rate, length, streambed conductance and Manning roughness coefficient. At the beginning of each stress period river flows entering the model domain are read into the data set. As flow moves through each reach, the depth of flow in the stream is computed using the Manning formula. The water level in the stream is then compared with the water level in the adjacent aquifer grid cell to determine whether seepage is occurring into or out of the stream. The seepage rate is computed, and that value is added to or subtracted from the flow into the reach to determine the outflow into the next reach downstream. This process is repeated until seepage and flow rates have been computed for all stream reaches in

the model. The seepage to or from every stream reach is added into the ground-water flow equation, so that the aquifer response to this stress can be computed.

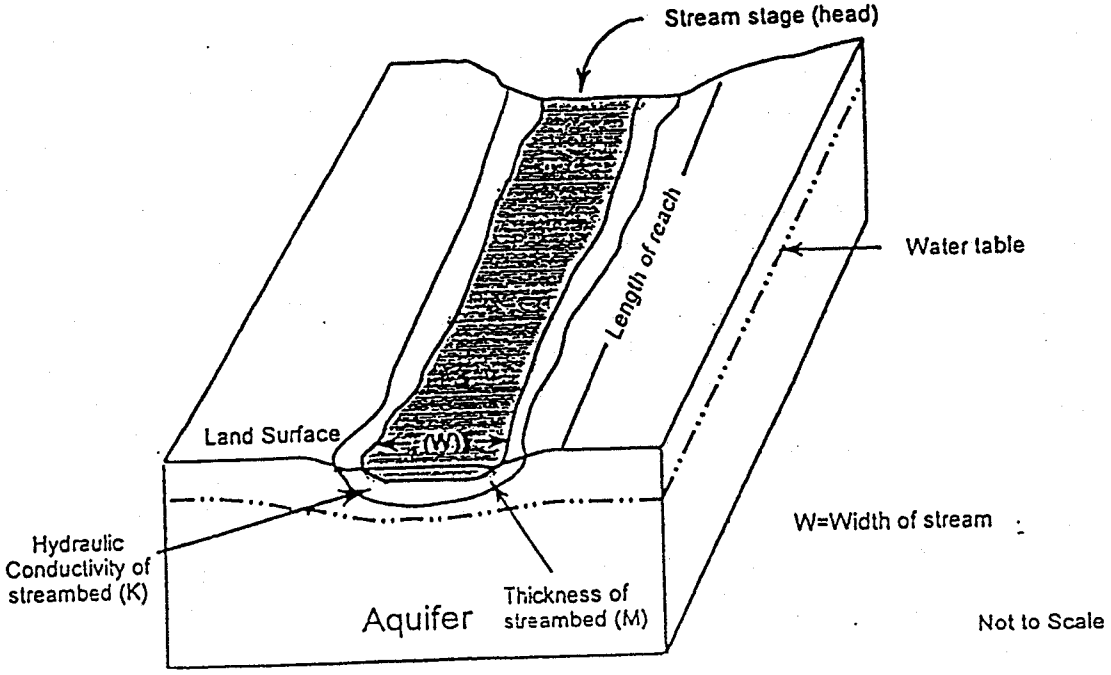
The original version of MODFLOW contained a river package that did not account for mass balance in the stream, and therefore could not accommodate the possibility of variable head in the river, including the possible dry-up of the stream. Several more realistic river packages have been developed since then. Figure 2 is a schematic diagram taken from Prudic (1989) showing the operation of the most widely-used river package for MODFLOW.

Canal diversions can be handled in two ways. Canals can be included as part of the stream package, or canal diversions can simply be subtracted from stream flow at the appropriate locations within the model. The second method of handling canal diversions was selected, because canal seepage is not well-documented in the Tres Rios Model domain and is considered to be a small fraction of total recharge from waters distributed through the canals. Much of this water is used for agricultural or municipal irrigation. Recharge from irrigation is generally distributed in areas where canal seepage also occurs. Therefore, canal seepage was distributed along with recharge from irrigation.

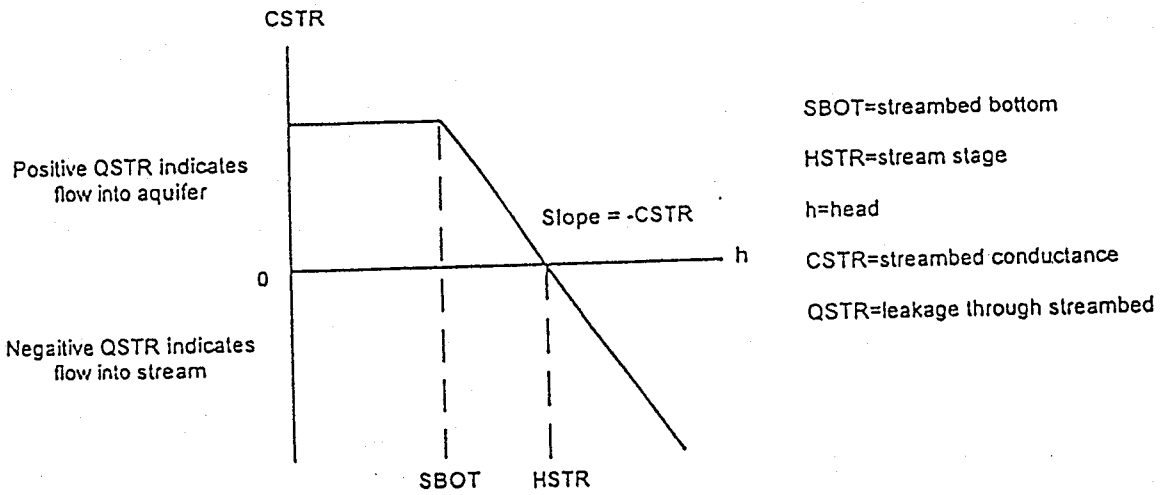
Evapotranspiration (ET) was modeled with a package that computes evapotranspiration from designated model cells in which phreatophytic vegetation is located. ET can range from some designated maximum rate to a minimum of zero. The variation in ET occurs over a range of water levels from a designated maximum rate at the ET surface to a minimum rate of zero at the extinction depth. Figure 3 is a schematic diagram of the operation of the MODFLOW ET package. This linear function can be replaced with a curvilinear formula or a step function if adequate ET data with depth below ground surface becomes available.

The well package simulates pumping from the aquifer by extracting a specified quantity of water from grid cells representing areas where pumping occurs. Wells can be pumped from any layer of the model, so that deep wells completed in lower zones of the aquifer can be correctly simulated.

The recharge package is very similar to the well package. Water is added to specified model grid cells at the appropriate times and locations for simulating historical conditions or to simulate future scenarios.



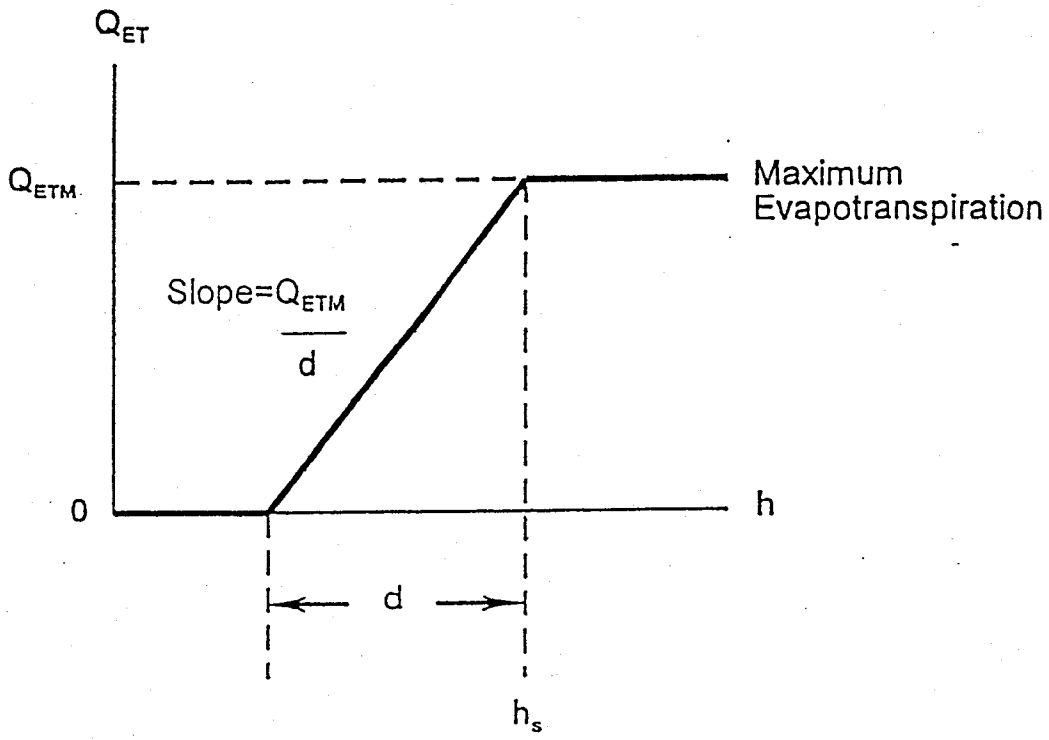
$$\text{Conductance of streambed (CSTR)} = \frac{KLW}{M}$$



Leakage (QSTR) through a streambed into an aquifer as a function of head (h), in a model cell. Slope is dependent on streambed conductance (CSTR).

Source: Prudic, 1989

Figure 2. Schematic Diagram of the Operation of the Prudic Stream Flow Package



Plot of volumetric evapotranspiration (Q_{ET}) as a function of head (h) in a cell where d is the cutoff depth and h_s is the ET surface elevation.

Source: McDonald and Harbaugh, 1988

Figure 3. Schematic Diagram of the Operation of the MODFLOW Evapotranspiration Package

General head boundaries (GHBs) are used to compute inflows to and outflows from the model in areas around the perimeter of the model where geologic barrier boundaries are not present. A general head boundary functions much like an additional model grid cell located beyond the model boundary. Heads in the GHB can vary through time, to simulate the impact on areas within the model of stresses beyond its boundaries, such as pumping in an adjacent valley, for example.

MODIFICATIONS TO MODFLOW BY W&EST

Although the MODFLOW code is relatively flexible, several changes were needed to correctly simulate flow conditions in the Central Arizona Basin. The changes W&EST made to MODFLOW for this purpose are described in the following paragraphs.

The current stream package of MODFLOW allows seepage from the stream to occur only if the grid cell in which it is located is active. If the cell goes dry, it becomes inactive and seepage from the stream no longer occurs. This is not a realistic representation of conditions in the TresRios Model domain, where significant ground-water declines have occurred, even in the vicinity of stream channels. Stream reaches should continue to leak at a maximum rate, no matter how low the water table drops below the streambed. To alleviate this problem, W&EST modified the code so that a stream reach would continue to leak and the seepage would go to the uppermost active cell beneath it, thus bypassing the dry cell and preventing the code from discontinuing the seepage altogether.

A second modification to the stream package changed the program logic to better represent canal diversions. In the original Prudic (1989) stream package, a specified canal diversion actually occurred only if stream flow equaled or exceeded the canal demand. This is not representative of management practices throughout much of the western United States. Instead, if a canal demand exceeds stream flow, the usual practice is to divert whatever is available in the stream. W&EST changed the code to allow canal diversions equal to the total flow at the diversion point whenever canal demands exceeded stream flow.

Another unusual problem caused by the large head decline in parts of the Central Arizona Basin is wells going out of service. Like the stream segment, a well ceases to pump in the present version of MODFLOW if the grid cell in which it is located goes dry. In reality, such wells are generally

deepened or replaced. W&EST modified the code to relocate the well in a dry cell to the next deeper cell, so that it continues to pump. In addition, W&EST made code changes to allow pumping to return to the upper layer if the cell re-wets. This is particularly useful for modeling future scenarios in which pumping may be discontinued in parts of the Tres Rios model domain, but not in other areas, or if a recharge plan is implemented.

W&EST also created several post-processing programs to select output from MODFLOW runs and convert this information into a format for presentation in a GIS format. This allows the information to be examined visually and interpreted efficiently.

APPENDIX C

MODELED RIVER PARAMETERS

FOR THE TRES RIOS STUDY AREA

Table 1. Model River Inputs, Tres Rios Study Area

River	Model Row	Model Column	Bottom Elevation (feet)	Riverbed Conductance (ft2/day)	Manning Coefficient	River Slope	Bottom Width (feet)
Agua Fria	21	58	910	34,848	0.05	0.001	60
Salt	21	81	949	44,352	0.05	0.002	60
Salt	21	82	952	38,016	0.05	0.004	60
Salt	21	83	959	31,680	0.05	0.001	60
Salt	21	84	960	31,680	0.05	0.001	60
Salt	21	85	960	31,680	0.05	0.002	60
Salt	21	86	962	34,848	0.05	0.001	60
Salt	21	87	956	31,680	0.05	0.001	60
Agua Fria	22	57	909	19,008	0.05	0.001	60
Gila	22	57	905	47,520	0.05	0.001	60
Salt	22	78	942	34,848	0.05	0.001	60
Salt	22	79	943	31,680	0.05	0.001	60
Salt	22	80	944	34,848	0.05	0.003	60
Gila	23	58	906	38,016	0.05	0.001	60
Gila	23	59	907	38,016	0.05	0.002	60
Gila	23	60	910	38,016	0.05	0.003	60
Gila	23	61	914	34,848	0.05	0.002	60
Gila	23	64	919	34,848	0.05	0.002	60
Gila	23	65	922	34,848	0.05	0.002	60
Gila	23	66	925	31,680	0.05	0.002	60
Gila	23	67	927	31,680	0.05	0.001	60
Gila	23	68	928	31,680	0.05	0.002	60
Gila	23	69	930	31,680	0.05	0.002	60
Gila	23	70	932	38,016	0.05	0.001	60
Gila	23	71	933	31,680	0.05	0.001	60
Salt	23	72	933	31,680	0.05	0.001	60
Salt	23	73	934	34,848	0.05	0.001	60
Salt	23	74	934	38,016	0.05	0.001	60
Salt	23	75	935	31,680	0.05	0.001	60
Salt	23	76	936	38,016	0.05	0.002	60
Salt	23	77	939	31,680	0.05	0.002	60
Gila	24	62	917	31,680	0.05	0.001	60
Gila	24	63	918	31,680	0.05	0.001	60
Gila	24	72	930	44,352	0.05	0.001	60
Gila	24	73	932	44,352	0.05	0.002	60

APPENDIX D

CALIBRATED TRES RIOS MODEL WATER BUDGET

Appendix D

Tres Rios Model Calibration

Water Budget, 1991 (Model Year 6)

Acre-Feet Per Year

Modeled Inflows	
Surface Water Inflows	
Salt River	0
Gila River	794
23rd Ave. WWTP	32,775
91st Ave. WWTP	97,510
Agricultural Return Flows	29,368
Ground Water Inflows	
General Head Boundaries	271,320
Recharge	129,270
Storage	2,483
Total Inflows	563,520

Modeled Outflows	
Surface Water Outflows	
Gila River	38,422
BIC Diversion	131,443
Ground Water Outflows	
General Head Boundaries	122,150
Wells	242,130
ET	38,342
Storage	3,116
Total Outflows	575,603

APPENDIX E

SCENARIO MODEL RESULTS

FOR THE TRES RIOS STUDY AREA

Table 1. Modeled Depth to Water, Present Conditions into Future, Tres Rios Study Area

Model Row	Model Column	Depth to Water at End of Quarter (feet) Quarter 1	Quarter 2	Quarter 3	Quarter 4
20	79	14.9	17.5	19.3	16.6
20	80	15.6	18.5	20.4	17.3
20	81	19.2	22.3	24.2	21.1
20	82	21.0	24.3	26.2	22.9
21	57	18.4	21.2	23.4	20.8
21	58	12.0	14.6	16.8	14.4
21	59	10.8	13.2	15.3	13.2
21	60	11.6	13.8	16.0	14.0
21	61	12.5	14.6	16.7	14.8
21	62	12.4	14.4	16.4	14.7
21	63	12.3	14.1	16.2	14.5
21	64	12.2	13.9	15.9	14.4
21	65	14.1	15.8	17.7	16.2
21	66	13.0	14.6	16.5	15.0
21	67	12.9	14.4	16.3	14.8
21	68	12.7	14.3	16.1	14.6
21	69	13.6	15.2	16.9	15.4
21	70	13.5	15.0	16.7	15.2
21	71	13.5	15.0	16.6	15.1
21	72	13.5	15.1	16.6	15.1
21	73	12.8	14.3	15.8	14.3
21	74	13.1	14.7	16.2	14.6
21	75	14.5	16.1	17.6	16.0
21	76	13.9	15.7	17.3	15.4
21	77	15.3	17.4	19.0	16.9
21	78	15.8	18.2	19.9	17.5
21	79	16.4	18.9	20.7	18.1
21	80	15.0	17.8	19.6	16.8
21	81	18.7	21.8	23.7	20.6
21	82	19.6	23.3	25.2	21.6
21	83	20.3	23.6	25.6	22.4
21	84	34.0	37.2	39.2	36.1
21	85	29.8	32.8	34.9	31.9
21	86	27.5	30.5	32.6	29.7
21	87	26.2	29.2	31.3	28.5
22	57	6.8	9.7	11.9	9.3
22	58	6.8	9.4	11.7	9.3
22	59	8.8	11.3	13.6	11.3
22	60	10.9	13.2	15.4	13.3
22	61	9.9	12.1	14.3	12.3
22	62	9.9	12.0	14.2	12.3
22	63	9.9	11.9	14.1	12.3
22	64	8.9	10.8	12.9	11.2
22	65	12.9	14.6	16.7	15.1
22	66	11.8	13.5	15.5	13.9
22	67	11.7	13.4	15.3	13.7
22	68	12.5	14.2	16.0	14.5
22	69	12.4	14.0	15.8	14.2
22	70	13.1	14.8	16.5	14.9
22	71	12.0	13.6	15.2	13.7
22	72	11.0	12.5	14.1	12.6
22	73	10.2	11.7	13.2	11.7
22	74	11.6	13.1	14.6	13.1
22	75	12.0	13.6	15.1	13.5
22	76	12.4	14.2	15.7	13.9
22	77	12.8	14.8	16.4	14.4
22	78	12.2	14.4	16.1	13.8
22	79	12.8	15.2	17.0	14.5
22	80	14.5	17.1	19.0	16.3
22	81	9.3	12.2	14.1	11.2
22	82	12.1	15.3	17.3	14.2
22	83	9.9	13.1	15.1	12.0
22	84	10.7	13.9	15.9	12.8
22	85	11.5	14.6	16.7	13.7
22	86	21.3	24.4	26.5	23.5
22	87	15.0	18.1	20.3	17.3
23	57	5.7	8.4	10.7	8.3
23	58	5.4	8.0	10.3	8.0
23	59	5.8	8.3	10.6	8.4
23	60	8.0	10.3	12.6	10.5
23	61	8.1	10.4	12.7	10.6
23	62	7.4	9.5	11.8	9.8
23	63	7.5	9.6	11.8	9.9
23	64	8.6	10.5	12.7	10.9
23	65	8.6	10.5	12.6	10.9
23	66	8.7	10.5	12.5	10.9
23	67	10.6	12.4	14.4	12.8
23	68	10.4	12.2	14.1	12.5
23	69	8.2	9.9	11.8	10.1
23	70	11.8	13.5	15.2	13.6
23	71	5.5	7.1	8.7	7.2
23	72	3.3	4.8	6.3	4.8
23	73	6.6	8.0	9.4	8.0
23	74	8.0	9.5	10.8	9.4
23	75	2.5	4.0	5.4	3.9
23	76	1.0	2.6	4.0	2.4
23	77	4.3	6.1	7.7	5.8
23	78	6.7	8.8	10.5	8.4
23	79	7.4	9.7	11.4	9.1
23	80	7.1	9.6	11.5	8.9
23	81	8.9	11.7	13.6	10.8
23	82	6.7	9.7	11.7	8.7
23	83	12.5	15.6	17.7	14.6
23	84	9.4	12.6	14.6	11.5
23	85	11.2	14.4	16.5	13.4
23	86	16.0	19.2	21.4	18.2
23	87	16.8	19.9	22.1	19.0
24	57	10.8	13.4	15.8	13.4
24	58	9.8	12.4	14.7	12.4
24	59	8.3	10.8	13.1	10.9
24	60	8.4	10.7	13.0	10.9
24	61	7.7	9.9	12.2	10.2
24	62	5.9	8.1	10.4	8.4
24	63	6.2	8.3	10.5	8.7
24	64	8.5	10.5	12.7	10.9
24	65	9.7	11.6	13.8	12.1
24	66	10.0	11.8	13.9	12.2
24	67	11.1	12.9	15.0	13.3
24	68	6.7	8.5	10.4	8.7
24	69	8.5	10.2	12.1	10.4
24	70	8.9	10.6	12.3	10.7
24	71	7.3	8.9	10.5	9.0
24	72	5.5	7.0	8.3	7.0
24	73	1.9	3.3	4.6	3.3
24	74	4.2	5.7	7.1	5.6
24	75	4.7	6.2	7.7	6.1
24	76	6.1	7.9	9.3	7.7
24	77	4.6	6.5	8.1	6.2
24	78	6.2	8.2	9.9	7.9
24	79	11.8	14.1	15.9	13.6
24	80	14.6	17.0	18.9	16.5
24	81	12.4	15.0	17.0	14.4
24	82	15.2	18.1	20.1	17.3
24	83	15.1	18.2	20.2	17.2
24	84	17.0	20.3	22.3	19.2
24	85	16.8	20.1	22.2	19.0
24	86	17.6	21.0	23.1	19.9
24	87	15.4	18.7	20.9	17.7
25	60	21.4	23.6	25.9	23.9
25	61	20.3	22.5	24.8	22.8
25	62	21.8	23.9	26.2	24.3
25	63	12.2	14.2	16.5	14.6
25	64	21.5	23.5	25.7	23.9

Table 2. Modeled Depth to Water, Future Without Federal Action, Tres Rios Study Area

Model Row	Model Column	Depth to Water at End of Quarter (feet) Quarter 1	Quarter 2	Quarter 3	Quarter 4
20	79	16.0	18.7	20.4	17.8
20	80	16.6	19.6	21.4	18.5
20	81	20.2	23.3	25.2	22.1
20	82	21.9	25.2	27.1	23.9
21	57	24.6	28.3	30.7	27.1
21	58	17.8	21.1	23.4	20.3
21	59	16.3	19.2	21.5	18.8
21	60	16.9	19.4	21.6	19.3
21	61	17.5	19.7	21.9	19.8
21	62	17.1	19.2	21.3	19.4
21	63	16.8	18.6	20.7	19.0
21	64	16.4	18.1	20.1	18.6
21	65	18.0	19.6	21.6	20.1
21	66	16.7	18.2	20.1	18.7
21	67	16.2	17.7	19.6	18.2
21	68	15.8	17.3	19.1	17.7
21	69	16.4	17.9	19.7	18.2
21	70	16.0	17.5	19.2	17.8
21	71	15.7	17.2	18.9	17.4
21	72	15.5	17.0	18.6	17.2
21	73	14.5	16.1	17.6	16.1
21	74	14.7	16.2	17.8	16.3
21	75	15.9	17.6	19.2	17.5
21	76	15.2	17.0	18.7	16.8
21	77	16.5	18.6	20.3	18.2
21	78	17.0	19.4	21.2	18.7
21	79	17.5	20.1	21.9	19.3
21	80	16.1	18.9	20.8	18.0
21	81	19.7	22.9	24.8	21.7
21	82	20.6	24.3	26.2	22.6
21	83	21.2	24.5	26.5	23.2
21	84	34.8	38.0	40.0	36.9
21	85	30.5	33.5	35.6	32.7
21	86	28.2	31.1	33.2	30.4
21	87	26.9	29.8	31.9	29.1
22	57	13.1	16.7	19.1	15.7
22	58	12.7	15.9	18.3	15.3
22	59	14.5	17.3	19.7	17.0
22	60	16.2	18.8	21.1	18.7
22	61	15.0	17.3	19.5	17.4
22	62	14.8	16.9	19.1	17.1
22	63	14.5	16.5	18.6	16.8
22	64	13.3	15.1	17.2	15.5
22	65	17.0	18.7	20.7	19.1
22	66	15.6	17.2	19.2	17.7
22	67	15.2	16.8	18.7	17.3
22	68	15.8	17.3	19.2	17.7
22	69	15.3	16.9	18.6	17.2
22	70	15.8	17.3	19.0	17.6
22	71	14.3	15.8	17.5	16.0
22	72	13.0	14.5	16.1	14.6
22	73	12.0	13.5	15.0	13.5
22	74	13.1	14.7	16.2	14.7
22	75	13.4	15.0	16.6	14.9
22	76	13.7	15.5	17.1	15.3
22	77	14.0	16.0	17.7	15.7
22	78	13.4	15.7	17.4	15.1
22	79	13.9	16.4	18.2	15.7
22	80	15.6	18.3	20.1	17.5
22	81	10.3	13.2	15.2	12.3
22	82	13.0	16.2	18.2	15.1
22	83	10.8	13.9	16.0	12.9
22	84	11.5	14.6	16.7	13.6
22	85	12.2	15.3	17.4	14.4
22	86	21.9	25.0	27.1	24.2
22	87	15.6	18.7	20.9	17.9
23	57	11.8	15.0	17.4	14.4
23	58	11.4	14.4	16.8	14.0
23	59	11.6	14.3	16.7	14.2
23	60	13.5	16.0	18.3	16.0
23	61	13.4	15.7	18.0	15.9
23	62	12.4	14.5	16.7	14.8
23	63	12.3	14.3	16.4	14.6
23	64	13.1	15.0	17.1	15.4
23	65	12.9	14.7	16.7	15.1
23	66	12.7	14.4	16.4	14.9
23	67	14.4	16.1	18.0	16.5
23	68	13.8	15.5	17.4	15.9
23	69	11.3	12.9	14.7	13.2
23	70	14.6	16.2	17.9	16.4
23	71	7.9	9.4	11.1	9.6
23	72	5.2	6.7	8.3	6.8
23	73	8.2	9.7	11.2	9.7
23	74	9.5	10.9	12.4	10.9
23	75	3.8	5.3	6.9	5.2
23	76	2.2	3.8	5.4	3.7
23	77	5.4	7.3	9.0	7.0
23	78	7.8	10.0	11.7	9.6
23	79	8.4	10.7	12.6	10.2
23	80	8.0	10.6	12.5	10.0
23	81	9.8	12.6	14.5	11.8
23	82	7.6	10.5	12.5	9.6
23	83	13.3	16.4	18.5	15.5
23	84	10.1	13.3	15.4	12.3
23	85	11.9	15.1	17.2	14.1
23	86	16.6	19.8	22.0	18.9
23	87	17.4	20.5	22.7	19.6
24	57	16.8	19.8	22.2	19.4
24	58	15.7	18.6	21.0	18.3
24	59	14.0	16.7	19.1	16.6
24	60	13.8	16.3	18.6	16.4
24	61	13.0	15.2	17.5	15.5
24	62	11.0	13.2	15.4	13.5
24	63	11.1	13.1	15.3	13.5
24	64	13.1	15.0	17.1	15.4
24	65	14.0	15.8	17.9	16.3
24	66	14.0	15.7	17.8	16.2
24	67	14.9	16.6	18.6	17.0
24	68	10.1	11.8	13.7	12.1
24	69	11.6	13.2	15.0	13.5
24	70	11.6	13.2	14.9	13.4
24	71	9.5	11.1	12.7	11.2
24	72	7.1	8.5	10.0	8.6
24	73	3.2	4.6	6.1	4.7
24	74	5.5	7.0	8.5	6.9
24	75	5.9	7.4	9.0	7.4
24	76	7.3	9.0	10.6	8.8
24	77	5.7	7.6	9.3	7.4
24	78	7.2	9.3	11.0	9.0
24	79	12.8	15.1	16.9	14.7
24	80	15.5	18.0	19.8	17.4
24	81	13.3	15.9	17.8	15.3
24	82	16.1	18.9	20.9	18.1
24	83	15.9	18.9	20.9	18.0
24	84	17.7	21.0	23.0	19.9
24	85	17.5	20.8	22.9	19.7
24	86	18.3	21.6	23.8	20.5
24	87	16.0	19.3	21.4	18.3
25	60	26.7	29.0	31.3	29.2
25	61	25.5	27.7	30.0	28.0
25	62	26.8	28.9	31.2	29.3
25	63	17.0	19.0	21.2	19.4
25	64	26.1	28.0	30.1	28.4

Table 3. Modeled Depth to Water, Alternative 3.5, Tres Rios Study Area

Model Row	Model Column	Depth to Water at End of Quarter (feet) Quarter 1	Quarter 2	Quarter 3	Quarter 4
20	79	14.4	17.5	19.6	16.5
20	80	14.9	18.5	20.7	17.1
20	81	18.9	22.7	25.0	21.3
20	82	21.3	25.5	27.9	23.8
21	57	22.7	26.5	29.0	25.4
21	58	16.0	19.4	21.9	18.7
21	59	14.6	17.5	20.0	17.2
21	60	15.2	17.9	20.3	17.8
21	61	15.8	18.2	20.6	18.4
21	62	15.5	17.7	20.0	18.0
21	63	15.1	17.2	19.4	17.6
21	64	14.7	16.7	18.9	17.1
21	65	16.4	18.2	20.3	18.7
21	66	14.9	16.7	18.8	17.2
21	67	14.5	16.2	18.2	16.7
21	68	14.0	15.7	17.7	16.1
21	69	14.5	16.3	18.2	16.6
21	70	14.1	15.9	17.7	16.1
21	71	13.7	15.5	17.3	15.6
21	72	13.5	15.3	17.1	15.4
21	73	12.5	14.3	16.0	14.3
21	74	12.7	14.5	16.3	14.5
21	75	14.0	15.9	17.7	15.8
21	76	13.3	15.4	17.3	15.1
21	77	14.6	17.1	19.0	16.5
21	78	15.2	18.0	20.0	17.2
21	79	15.8	18.8	20.9	17.9
21	80	14.4	17.8	20.0	16.6
21	81	18.6	22.5	24.8	21.0
21	82	20.5	25.2	27.7	23.1
21	83	23.6	28.5	31.4	26.5
21	84	35.7	39.7	42.3	38.3
21	85	30.9	34.6	37.1	33.5
21	86	28.4	31.8	34.3	30.9
21	87	27.0	30.3	32.8	29.6
22	57	11.2	14.7	17.3	14.0
22	58	10.9	14.1	16.7	13.7
22	59	12.7	15.7	18.2	15.5
22	60	14.5	17.3	19.8	17.3
22	61	13.3	15.8	18.3	16.0
22	62	13.1	15.4	17.8	15.7
22	63	12.8	15.1	17.4	15.4
22	64	11.5	13.6	15.9	14.1
22	65	15.2	17.2	19.4	17.7
22	66	13.8	15.7	17.9	16.2
22	67	13.4	15.2	17.3	15.7
22	68	13.9	15.7	17.7	16.1
22	69	13.3	15.1	17.1	15.4
22	70	13.7	15.5	17.4	15.7
22	71	12.2	14.0	15.8	14.1
22	72	10.7	12.5	14.3	12.6
22	73	9.7	11.5	13.2	11.5
22	74	11.0	12.8	14.5	12.7
22	75	11.2	13.2	14.9	13.0
22	76	11.6	13.7	15.5	13.4
22	77	12.1	14.5	16.3	14.0
22	78	11.6	14.2	16.2	13.5
22	79	12.2	15.0	17.2	14.2
22	80	14.2	17.3	19.5	16.3
22	81	9.4	12.9	15.3	11.7
22	82	12.8	16.8	19.2	15.3
22	83	11.4	15.5	18.0	14.0
22	84	11.9	15.8	18.3	14.5
22	85	12.5	16.2	18.7	15.1
22	86	22.1	25.6	28.1	24.7
22	87	15.7	19.2	21.6	18.3
23	57	9.9	13.1	15.7	12.8
23	58	9.5	12.5	15.1	12.4
23	59	9.7	12.6	15.2	12.6
23	60	11.7	14.4	16.9	14.5
23	61	11.7	14.2	16.7	14.4
23	62	10.6	13.0	15.5	13.4
23	63	10.5	12.8	15.2	13.2
23	64	11.3	13.5	15.8	13.9
23	65	11.1	13.2	15.5	13.7
23	66	10.9	12.8	15.1	13.3
23	67	12.5	14.4	16.6	14.8
23	68	11.8	13.8	15.9	14.1
23	69	9.2	11.1	13.1	11.4
23	70	12.4	14.3	16.2	14.4
23	71	5.5	7.4	9.3	7.5
23	72	3.0	4.8	6.5	4.7
23	73	6.0	7.8	9.4	7.7
23	74	7.4	9.1	10.7	9.0
23	75	1.8	3.7	5.3	3.5
23	76	0.3	2.3	3.9	2.0
23	77	3.7	5.9	7.7	5.5
23	78	6.1	8.6	10.6	8.1
23	79	6.8	9.6	11.7	8.9
23	80	6.7	9.8	12.0	8.9
23	81	8.8	12.2	14.5	11.2
23	82	7.1	10.7	13.1	9.6
23	83	13.3	17.1	19.5	15.9
23	84	10.2	14.0	16.5	12.8
23	85	12.0	15.7	18.2	14.6
23	86	16.7	20.3	22.8	19.3
23	87	17.4	20.9	23.4	20.0
24	57	14.9	18.0	20.6	17.8
24	58	13.8	16.8	19.4	16.7
24	59	12.2	15.0	17.6	15.1
24	60	12.0	14.6	17.2	14.9
24	61	11.2	13.6	16.2	14.0
24	62	9.2	11.6	14.1	12.0
24	63	9.3	11.5	14.0	12.0
24	64	11.3	13.4	15.8	13.9
24	65	12.2	14.3	16.6	14.8
24	66	12.2	14.2	16.4	14.7
24	67	13.0	14.9	17.1	15.4
24	68	8.1	10.0	12.2	10.4
24	69	9.4	11.4	13.4	11.7
24	70	9.2	11.2	13.1	11.3
24	71	6.8	8.8	10.7	8.8
24	72	4.7	6.5	8.1	6.4
24	73	0.9	2.7	4.3	2.6
24	74	3.2	5.1	6.7	4.9
24	75	3.8	5.8	7.4	5.5
24	76	5.3	7.4	9.1	7.1
24	77	3.8	6.1	8.0	5.7
24	78	5.5	8.0	10.0	7.5
24	79	11.2	14.0	16.0	13.4
24	80	14.2	17.1	19.3	16.4
24	81	12.3	15.5	17.7	14.7
24	82	15.5	18.8	21.2	17.9
24	83	15.6	19.2	21.6	18.1
24	84	17.6	21.4	23.8	20.1
24	85	17.4	21.2	23.6	20.0
24	86	18.3	22.0	24.4	20.8
24	87	16.0	19.6	22.0	18.5
25	60	24.9	27.4	29.9	27.7
25	61	23.7	26.1	28.7	26.5
25	62	25.1	27.4	29.9	27.8
25	63	15.2	17.5	19.9	17.9
25	64	24.3	26.4	28.8	27.0

Table 4. Modeled Depth to Water, Optimized Alternative 3.5, Tres Rios Study Area

Model Row	Model Column	Depth to Water at End of Quarter (feet) Quarter 1	Quarter 2	Quarter 3	Quarter 4
20	79	14.6	17.6	19.7	16.6
20	80	15.1	18.6	20.8	17.3
20	81	19.0	22.8	25.1	21.4
20	82	21.5	25.5	27.9	23.9
21	57	23.6	27.5	29.9	26.4
21	58	16.9	20.2	22.7	19.6
21	59	15.4	18.3	20.7	18.1
21	60	16.0	18.6	20.9	18.6
21	61	16.5	18.9	21.2	19.1
21	62	16.1	18.3	20.5	18.6
21	63	15.7	17.7	19.9	18.2
21	64	15.3	17.1	19.3	17.7
21	65	16.9	18.6	20.7	19.2
21	66	15.4	17.1	19.1	17.6
21	67	14.9	16.5	18.5	17.1
21	68	14.4	16.0	18.0	16.5
21	69	14.9	16.6	18.4	16.9
21	70	14.4	16.1	17.9	16.4
21	71	14.0	15.7	17.5	15.9
21	72	13.8	15.5	17.2	15.6
21	73	12.7	14.5	16.2	14.5
21	74	12.9	14.7	16.4	14.7
21	75	14.1	16.1	17.8	15.9
21	76	13.4	15.5	17.3	15.3
21	77	14.8	17.2	19.1	16.7
21	78	15.3	18.1	20.1	17.3
21	79	15.9	18.9	21.0	18.0
21	80	14.5	17.9	20.1	16.7
21	81	18.8	22.5	24.9	21.1
21	82	20.7	25.2	27.7	23.2
21	83	23.7	28.6	31.4	26.6
21	84	35.8	39.8	42.4	38.4
21	85	31.0	34.6	37.1	33.5
21	86	28.5	31.9	34.3	31.0
21	87	27.1	30.4	32.8	29.6
22	57	12.2	15.7	18.3	15.0
22	58	11.8	15.0	17.5	14.6
22	59	13.6	16.5	18.9	16.3
22	60	15.3	18.0	20.4	18.0
22	61	14.0	16.5	18.8	16.7
22	62	13.8	16.0	18.4	16.4
22	63	13.5	15.6	17.9	16.0
22	64	12.1	14.1	16.3	14.6
22	65	15.8	17.6	19.8	18.2
22	66	14.4	16.1	18.2	16.7
22	67	13.9	15.6	17.6	16.1
22	68	14.3	16.0	18.0	16.5
22	69	13.7	15.4	17.4	15.8
22	70	14.0	15.8	17.6	16.0
22	71	12.4	14.2	16.0	14.4
22	72	11.0	12.7	14.5	12.8
22	73	9.9	11.6	13.3	11.7
22	74	11.1	12.9	14.6	12.9
22	75	11.4	13.3	15.0	13.2
22	76	11.7	13.8	15.6	13.5
22	77	12.2	14.5	16.4	14.1
22	78	11.7	14.2	16.2	13.6
22	79	12.4	15.1	17.2	14.4
22	80	14.3	17.4	19.6	16.4
22	81	9.5	13.0	15.3	11.8
22	82	12.9	16.9	19.3	15.4
22	83	11.4	15.5	18.1	14.1
22	84	12.0	15.9	18.4	14.6
22	85	12.6	16.2	18.7	15.1
22	86	22.2	25.7	28.2	24.7
22	87	15.8	19.2	21.7	18.4
23	57	10.8	14.0	16.6	13.7
23	58	10.4	13.4	15.9	13.3
23	59	10.6	13.4	15.9	13.4
23	60	12.5	15.1	17.6	15.3
23	61	12.4	14.8	17.3	15.2
23	62	11.4	13.6	16.0	14.1
23	63	11.2	13.3	15.7	13.8
23	64	12.0	13.9	16.2	14.5
23	65	11.7	13.6	15.8	14.2
23	66	11.4	13.2	15.4	13.8
23	67	13.0	14.8	16.9	15.3
23	68	12.3	14.1	16.1	14.6
23	69	9.6	11.4	13.4	11.8
23	70	12.7	14.5	16.4	14.8
23	71	5.8	7.6	9.4	7.8
23	72	3.2	4.9	6.6	5.0
23	73	6.2	7.9	9.5	7.9
23	74	7.5	9.2	10.8	9.2
23	75	2.0	3.8	5.3	3.6
23	76	0.5	2.4	4.0	2.1
23	77	3.8	6.0	7.7	5.6
23	78	6.3	8.7	10.7	8.2
23	79	6.9	9.7	11.8	9.0
23	80	6.8	9.9	12.1	9.1
23	81	8.9	12.2	14.5	11.3
23	82	7.2	10.8	13.2	9.7
23	83	13.4	17.1	19.6	16.0
23	84	10.3	14.0	16.5	12.9
23	85	12.0	15.7	18.2	14.6
23	86	16.8	20.4	22.8	19.3
23	87	17.5	21.0	23.4	20.0
24	57	15.8	18.9	21.4	18.7
24	58	14.8	17.6	20.2	17.6
24	59	13.1	15.8	18.3	15.9
24	60	12.8	15.3	17.8	15.6
24	61	11.9	14.3	16.7	14.7
24	62	10.0	12.2	14.6	12.7
24	63	10.0	12.1	14.4	12.6
24	64	11.9	13.9	16.2	14.5
24	65	12.8	14.7	17.0	15.3
24	66	12.7	14.6	16.8	15.2
24	67	13.5	15.3	17.5	15.9
24	68	8.5	10.3	12.4	10.8
24	69	9.8	11.7	13.7	12.0
24	70	9.6	11.4	13.3	11.6
24	71	7.1	9.0	10.8	9.1
24	72	4.9	6.7	8.2	6.6
24	73	1.1	2.8	4.4	2.7
24	74	3.4	5.2	6.8	5.1
24	75	3.9	5.8	7.5	5.7
24	76	5.4	7.5	9.2	7.2
24	77	3.9	6.2	8.0	5.8
24	78	5.6	8.1	10.0	7.6
24	79	11.3	14.0	16.1	13.5
24	80	14.3	17.2	19.4	16.5
24	81	12.4	15.5	17.8	14.7
24	82	15.6	18.9	21.2	18.0
24	83	15.7	19.2	21.6	18.2
24	84	17.7	21.4	23.8	20.2
24	85	17.5	21.2	23.6	20.0
24	86	18.3	22.0	24.4	20.8
24	87	16.1	19.6	22.0	18.6
25	60	25.7	28.1	30.5	28.5
25	61	24.5	26.8	29.2	27.2
25	62	25.8	28.0	30.4	28.5
25	63	15.9	18.0	20.3	18.6
25	64	24.9	26.9	29.2	27.5

APPENDIX B

Task 2 – Water Budget Analyses and Development
Salt and Gila River Technical Memorandum

Tres Rios, Arizona Feasibility Study
Salt/Gila Groundwater Analysis
Index No. S-961342

Task 2 - Water Budget Analyses and Development Salt and Gila River Technical Memorandum

DRAFT

Prepared for
Subregional Operating Group
and
U.S. Army Corps. of Engineers

April 1998

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TRES RIOS, ARIZONA FEASIBILITY STUDY

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Task 2 - Water Budget Analyses and Development Salt and Gila River Technical Memorandum

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1. INTRODUCTION

The City of Phoenix and the U.S. Army Corps of Engineers (COE) have initiated the Tres Rios, Arizona Feasibility Study of the Tres Rios area consisting of that portion of the Salt River and Gila River extending from 83rd Avenue which is just upstream from the 91st Avenue Wastewater Treatment Plant (WWTP) to a downstream point at the Agua Fria River. The City of Phoenix is the local sponsor for the COE study representing the multi-city Subregional Operating Group (SROG) who own capacity in the 91st Avenue WWTP. SROG includes the cities of Glendale, Mesa, Phoenix, Scottsdale and Tempe. The purposes of the COE project is to study the feasibility of implementing habitat restoration, environmental enhancement and a wide range of associated issues. A key task in the COE Feasibility Study is completion of the Salt/Gila Groundwater Analysis. Information developed as a part of the Groundwater Analysis will provide the foundation for water supply, water quality, habitat, vegetation management and endangered species analyses in the Feasibility Study.

Task 2 in the Salt/Gila Groundwater Analysis is the development of a water budget for the project. This Technical Memorandum focuses on the inflow sources and diversions from the Salt River and Gila River within the COE study area and also within the Salt/Gila groundwater model area. The groundwater model area is larger than the COE study area, extending from 19th Avenue in the east downstream to 259th Avenue in the west.

2. SYSTEM INFLOW SOURCES

The following categories of sources were identified as contributing flow to the Salt and Gila Rivers within the groundwater model area. There were:

- Stream Flows
- Flood Flows
- Stormwater (NPDES)
- Wastewater Treatment Plant Discharges (NPDES)

- Agricultural Discharges
- Dewatering Wells
- Groundwater (Gaining Stream)
- Minor Sources of Inflow

The water budget inflow analysis identified specific sources of water inflow within each category and the location where the source entered the Salt and Gila Rivers. The analysis of sources also included a projection of the quantity of water related to the source, daily and seasonal flow characteristics, and if the source represents a dependable, continuous flow or if it s ephemeral dependent on precipitation runoff.

2.1 Stream Flow

Stream flow in the Salt/Gila groundwater model area is the result of all the inflow sources that enter the area. The Salt/Gila groundwater area does not contain the traditional perennial stream flow because all perennial surface flow is diverted upstream and only reaches the Salt/Gila groundwater area during flood flow releases. The individual sources of inflow are discussed in following sections of this Technical Memorandum.

Stream flow is measured by the U.S. Geological Survey (USGS) at gaging stations and the gages relevant to the Salt/Gila groundwater model area are presented in **Table 2-1**. USGS gage data is from EarthInfo CD Rom with records from 1920 to July 1996 and in USGS annual stream flow publications. Stream flow is measured daily and for some stations, such as the Salt River below Stewart Mountain Dam, this is a very large database so **Table 2-1** is a summary. Most of the gage records for gages upstream of Tres Rios show zero (0) flow for the majority of the time. The exceptions are the Salt River below Stewart Mountain Dam and Verde River near Scottsdale because these two stations are upstream from Granite Reef Dam where the flow is diverted into canals. The Gila River at Estrella Park near Goodyear, Arizona gage does record flow in the Gila River for most of the year, but this is a result of 91st Avenue WWTP discharges and groundwater inflow.

The Gila River upstream of the junction with the Salt River contains surface water, however, this flow is the result of groundwater and local storm water runoff. Surface water flow in the Gila River is diverted for irrigation about 80 miles upstream at the Ashurst-Hayden Dam near Florence. The Gila River channel is dry from Ashurst-Hayden to the area upstream of the junction with the Salt River

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Table 2-1
Streamflow Gages

Greeley and Hansen
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Description	Gage #	Period of Record	Drainage Area (sq mi)	Maximum Flow (cfs)	Maximum Discharge Date	Comment
Salt River below Stewart Mountain Dam	09502000	3/30 to present	6,232	75,200	02/15/80	
Verde River near Scottsdale	09511300	2/61 to present	6,615	127,000	01/08/93	
Salt River at Priest Drive near Phoenix, AZ	09512165	12/93-9/94	13077 est.	300,000	2/1891	No flow during period of record; maximum flow is outside period of record. Drainage Area Estimated
Salt River at 24th Street at Phoenix, AZ	09512190	82-92	ND	35,700	10/03/84	
Salt River Tributary at South Mountain Park	09512200	1/61 to present	1.75	1,210	08/15/90	
Gila River near Laveen, AZ	09479500	1/40-9/46; 12/47 to present	20,615	41,600	01/20/93	
Santa Cruz River near Laveen, AZ	09489000	1/40-9/46; 12/47 to present	8,581	33,000	10/04/83	
Agua Fria River at El Mirage	09513650	10/62-4/79; 10/80-9/93	1,628	58,400	12/19/78	
New River near Glendale, AZ	09513910	61-63; 2/64-10/70; 71-79; 4/90 to present	324	19,800	12/19/67	
Gila River at Estrella Park near Goodyear, AZ	09514100	8/92 to present	45,585	162,000	01/09/93	

at a point near the junction of the Gila River and the Santa Cruz River. The local bedrock geology narrows the channel both in horizontal and vertical directions forcing the groundwater to the surface which results in a surface flow.

2.2 Flood Flows

Flood flows occur when inflow to the reservoirs exceeds the storage capacity and water is released. Flood flows can enter the Salt/Gila groundwater model area due to releases from reservoirs on the Salt River, Verde River, Gila River, and Agua Fria River. Flood flows are usually not the result of an individual storm event as are stormwater runoff and some stream flows. The data in **Table 2-1** shows an estimated flood flow of 300,000 cubic feet per second (cfs) in the Salt River upstream of the Tres Rios area.

The major source of flood flows in the Salt/Gila groundwater model area is a result of releases of water from the Salt River and Verde River reservoirs. These flows are measured daily at Granite Reef Dam, and records provided by Salt River Project (SRP) for the period from November 1912 through December 1995 were analyzed to compile **Table 2-2**. Minor flood flow releases are not included in the table because they infiltrate prior to reaching the Salt/Gila groundwater model area. The flows are presented as average daily flow in cfs, not peak discharge releases.

The data in **Table 2-2** shows there were numerous flood flows from 1914 to 1941. This was the period of dam construction on the Salt and Verde Rivers to store water for times of shortage. The reservoirs created by the dams helped to reduce flood flows. During the period from 1941 to 1965 and from 1966 to 1973, there were no flood flow releases. Since 1973, there have been several releases including the major floods of 1978.

These data demonstrate that flood flows:

- Vary in duration and volume
- Are very infrequent
- May not constitute a dependable water supply for groundwater recharge or for habitat restoration use in the Tres Rios area

2.3 Stormwater (NPDES)

Stormwater flows occur in direct response to precipitation runoff. Most stormwater runoff in the Salt/Gila groundwater model area is not measured or gaged. The runoff is sheet flow across the land

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Table 2-2
Salt River Flood Flows
Salt River Releases at Granite Reef Dam
Flow Events with 10,000 cfs Discharge
Period of Record November 1912 through December 1995

Greeley and Hansen
April 1998

Period of Flow Start Date	Period of Flow End Date	Flow Event Max. Avg. Daily Flow (cfs)
02/07/14	07/02/14	15,800
01/29/15	08/18/15	18,700
01/15/16	05/15/16	79,100
09/08/16	02/04/17	21,100
04/17/17	05/15/17	23,400
03/07/18	03/26/18	28,400
11/25/19	12/14/19	46,200
01/04/20	04/25/20	87,800
12/26/21	01/09/22	24,100
02/08/22	02/18/22	10,000
03/16/22	04/10/22	18,000
09/18/23	09/22/23	24,100
12/26/23	01/08/24	42,800
03/31/26	04/16/26	28,800
02/14/27	03/19/27	49,800
09/12/27	09/20/27	16,200
04/04/29	04/19/29	17,200
02/12/31	02/20/31	22,900
02/09/32	03/29/32	48,700
02/06/37	03/25/37	36,891
02/28/39	03/17/38	58,739
02/05/41	05/25/41	32,206
12/21/65	01/12/66	64,000
02/20/73	06/05/73	22,273
02/28/78	04/11/78	95,800
12/16/78	04/19/79	110,000
01/29/80	06/03/80	137,725
02/02/83	06/17/83	30,000
09/27/83	10/24/83	39,878
12/24/83	01/24/84	11,200
12/21/84	06/01/85	25,604
12/22/91	06/21/92	12,898
08/21/92	09/08/92	13,615
12/28/92	06/04/93	99,396
01/20/95	05/02/95	53,316

Salt River Project Information based on average daily flow releases at Granite Reef Dam

or is gathered in ditches that drain to the river channels. The U.S. Environmental Protection Agency (EPA) has a NPDES stormwater quality monitoring program required for cities with a population larger than 100,000. There are three of these NPDES monitor sites within the Salt/Gila groundwater model area and the data is presented in **Table 2-3**.

These three sites are in the Salt River and were compared with the information to verify if the flow was stormwater or flood flows. The data for the Salt River at 27th Avenue are storm flow measurements. The storm flows measured at the Salt River at the 35th Avenue site are not related to flood flows. The February 17, 1995 flow at the 51st Avenue Bridge is probably a flood flow, but the other two measurements are stormwater flows.

The stormwater data shows that storm flows are small quantity and short duration events. The largest event measured was at the Salt River at 35th Avenue and this was equal to a total of 51.5 acre-feet. These flows will not have a significant impact on the Salt/Gila groundwater model and do not constitute a dependable water supply for Tres Rios habitat restoration.

2.4 Wastewater Treatment Plant Discharges

Wastewater treatment plant discharges are monitored by EPA NPDES permits. There are WWTPs within the Salt/Gila groundwater model area and two of these are within the Tres Rios, Arizona Feasibility Study area: 91st Avenue WWTP and City of Tolleson WWTP. The summary of WWTP information is presented in **Table 2-4**. These data show the largest volume of WWTP discharges are from the 23rd Avenue WWTP, 91st Avenue WWTP and City of Tolleson WWTP. Discharges from the Goodyear WWTP and Buckeye WWTP flow into irrigation canals. The Goodyear Estrella WWTP discharges to Corgett Wash and the flow infiltrates before it can reach the Gila River. The Avondale WWTP discharges to the Agua Fria just upstream from the junction with the Gila River but it is only 1,684 AF/yr.

2.4.1 23rd Avenue WWTP

The City of Phoenix operates the 23rd Avenue WWTP. This facility is at the east edge of the Salt/Gila groundwater model area. **Table 2-4** shows this facility has three NPDES permit discharge points to the Salt River. Reclaimed water produced by this WWTP is reused by the Roosevelt Irrigation District (RID) for agricultural irrigation. When the RID is taking the reclaimed water, there is no flow discharged to the Salt River. During the winter, the reclaimed water is discharged to the Salt River. The discharge usually percolates into the river bed before it reaches the Tres Rios, Arizona Feasibility Study area at 83rd Avenue. When the hydrologic conditions permit, the flow from

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Table 2-3
NPDES Stormwater Monitoring Sites

Greeley and Hansen
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Description	Drainage Area (ac)	Date	Instantaneous Discharge (cfs)	Storm uration (min)	Preceding Dry Days	Total Storm Runoff (ft^3)	Comment
Salt River at 27th Avenue	45	12/10/91	3	660	11	ND	
		12/18/91	1.2	720	7	ND	
		03/02/92	1.8	1,056	18	ND	
		03/08/92	0.63	780	1	ND	
		07/11/92	2	198	4	ND	
		08/22/92	2.3	126	14	ND	
		12/08/92	2.7	402	41	ND	
		11/13/93	0.71	336	2	ND	
		02/07/94	0.33	414	83	ND	
		03/25/94	0.96	168	6	ND	
		10/15/94	1.3	132	22	ND	
		12/05/94	0.5	1,134	49	ND	
		01/04/95	0.5	846	5	ND	
		11/01/95	8.1	132	53	ND	
		02/01/96	0.71	804	8	ND	
		02/25/96	1.3	84	24	ND	
		03/14/96	0.71	978	16	ND	
		07/06/96	7.1	50	114	ND	
		07/09/96	7.1	108	2	ND	
		07/25/96	2.7	90	10	ND	

Table 2-3
NPDES Stormwater Monitoring Sites
(Continued)

Description	Drainage Area (ac)	Date	Instantaneous Discharge (cfs)	Storm uration (min)	Preceding Dry Days	Total Storm Runoff (ft^3)	Comment
Salt River at 35th Avenue	1363.2	01/03/92	ND	ND	ND	ND	Flow not measured, quality sample taken
		02/06/92	ND	ND	ND	ND	Flow not measured, quality sample taken
		03/26/92	ND	ND	ND	ND	Flow not measured, quality sample taken
		08/22/92	ND	ND	ND	ND	Flow not measured, quality sample taken
		12/05/94	16.7	720	ND	ND	
		01/04/95	27.17	600	18	ND	
		03/11/95	3.96	334	11	51,000	
		08/14/95	7.09	394	156	68,800	
		08/19/95	2.66	670	5	34,300	
		09/07/95	9.36	212	18	64,600	
		09/28/95	136.51	252	18	611,000	
		11/01/95	86.18	196	33	ND	
		03/13/96	3.39	366	16	41,320	
		07/07/96	38.6	270	116	128,000	
		07/15/96	1.6	405	7	ND	
		07/25/96	361.49	149	10	2,243,110	
		09/11/96	13.6	510	10	129,000	
51st Avenue Bridge	ND	01/07/95	675	ND	ND	ND	Flood Flow Period[1]
		01/30/95	140	ND	ND	ND	Flood Flow Period[1]
		02/17/95	19,500	ND	ND	ND	Flood Flow Period[1]

[1] During flood flow period, quantity sampled included stormwater flows and releases from Granite Reef Dam

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Table 2-4
WWTP Discharges

Greeley and Hansen
April 1998

Description	NPDES #	Permit Discharge Flow Rate (mgd)	Average Flow Rate (cfs)	(mgd)	(af/yr)	Dates Averaged	Discharges Into	Comment
23rd Avenue WWTP, City of Phoenix, Outfall 001	100578	63	33.25	21.45	24084	1/95-8/97	Roosevelt Irrigation District (RID)	Discharge here when demand exists
23rd Avenue WWTP, City of Phoenix, Outfall 002	100578	63	34.9	22.5	25263	1/95-8/97	Salt River at 35th Ave.	Discharge here when not to RID
23rd Avenue WWTP, City of Phoenix, Outfall 003	100578	63	15.5	10	11201	1/95-8/97	Peterson Farms	10 mdg consistently
City of Tolleson WWTP	100339	N/A	8.96	5.78	6490	1,3,5-10/94; 1,2,4-6,8,9,11,12/95; 3,5,7,8,9/96; 1-4/97	Salt River	Discharge to river is intermittant
91st Avenue WWTP, City of Phoenix	100579	153.75	151.8	97.9	109922	6/92-7/97	Salt River	
City of Avondale WWTP	100573	3.5	2.32	1.5	1684	1,8-9,12/94; 1-12/95;	Agua Fria River	
City of Goodyear WWTP	101324	N/A	1.94	1.24	1392	1-12/94; 1,4,6-12/95; 9/96	Buckeye Irrigation Company	As of 4-97 they use 100% SAT recharge; no discharge
Estrella WWTP, City of Goodyear	102424	0.2	0	0	0	--	Corgett Wash-tributary to Gila River	No discharge most of the time
Town of Buckeye WWTP	100574	0.6	0.46	0.30	337	1-3/91; 4-6/92; 7-9/93; 10-12/94; 4-6/95; 1-3/96	Arlington Canal	Canal discharges to Gila River upstream of Gillespie

23rd Avenue WWTP can reach the Tres Rios area. This occurs during periods when large storm flows or flood flows have saturated the river bed. **Table 2-5** presents the average discharges by month from the 23rd Avenue WWTP.

2.4.2 91st Avenue WWTP

The current capacity of the 91st Avenue WWTP is 153 million gallons per day (mgd). A portion of the reclaimed water is delivered to the Palo Verde Nuclear Power Plant via the Arizona Nuclear Power Project (ANPP) pipeline. The quantity of reclaimed water taken by ANPP varies seasonally and hourly based on the demand for electricity. Reclaimed water discharged from the 91st Avenue WWTP is released into the Salt River via an effluent channel. These discharges are the primary water source maintaining flow in the effluent dependent portion of the Salt and Gila Rivers. This discharge is in the center of the Salt/Gila groundwater model area and on the east edge of the Tres Rios, Arizona Feasibility Study area.

The 91st Avenue WWTP has an average daily capacity of 153 mgd which is equal to a quantity of 172,000 AF/yr. SROG is planning an expansion that will increase the capacity by 17.5 mgd, however, this capacity will be needed in the winter, not the summer. The winter period is viewed as a 4-month period.

The 91st Avenue WWTP reclaimed water production is not a constant rate. It varies monthly and hourly. **Table 2-6** presents the annual reclaimed water production for the existing plant plus the planned expansion. The greatest discharge variation occurs within each day following the diurnal pattern. The daily discharge variations differ between summer and winter. There are days in the summer when the inflow to the WWTP is low but the ANPP demand is great. ANPP can divert all the reclaimed water and there is no discharge. The SROG Cities entered into a contract on April 23, 1973 with the Arizona Public Service Company (APS) and Salt River Project Agricultural Improvement and Power District (SRP) to provide reclaimed water for the construction and operation of ANPP Units. Paragraph 5.20 of the contract defines the Units as "... each of the respective complete systems of ANPP for generating electricity, including without limitation the nuclear steam supply system and its containment or any other complete steam supply systems, the turbine generator, all auxiliary structures, system facilities and equipment necessary or useful in the operation of the Unit." The contract consists of four options of 35,000 AF/yr each, which correspond to ANPP Units 1-4. This is an annual contract total of 140,000 AF/yr. ANPP currently has three operating reactor units and has notified the Cities for each of these units that it is exercising the option of 35,000 AF/yr for a total of 105,000 AF/yr. ANPP rights to reclaimed water extend to 40

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Table 2-5
23rd Avenue WWTP Discharge

Greeley and Hansen
April 1998

Month	Average Effluent Flow mgd	Average RID Demand mgd	Average Salt River Discharge mgd
January	53.49	37.23	16.26
February	51.64	39.72	11.92
March	53.59	43.69	9.90
April	55.86	44.15	11.71
May	58.47	47.81	10.66
June	58.08	30.61	27.47
July	58.99	38.33	20.66
August	58.84	37.52	21.32
September	59.67	19.02	40.65
October	57.94	0.00	57.94
November	56.29	0.00	56.29
December	54.65	0.00	54.65

1996 Data

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Table 2-6
91st Avenue WWTP Reclaimed Water Projection

Greeley and Hansen
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Month	Current Plant mgd	Planned Expansion mgd	Total Flow mgd	Total Flow AF/mo
January	157.10	17.50	174.60	16,610.7
February	157.20	17.50	174.70	15,011.8
March	155.60	0.00	155.60	14,803.1
April	150.50	0.00	150.50	13,856.0
May	145.30	0.00	145.30	13,823.2
June	146.80	0.00	146.80	13,965.9
July	148.30	0.00	148.30	14,108.6
August	157.40	0.00	157.40	14,974.3
September	159.00	0.00	159.00	15,126.5
October	153.70	0.00	153.70	14,622.3
November	156.90	17.50	174.40	16,591.6
December	153.80	17.50	171.30	16,296.7
		Total Acre-Feet		179,790.8

years after the last ANPP Unit has been placed in operation, but in no event later than the year 2040, unless the parties agree to an extension. Based on information received from APS, Unit 3 went on line in 1987, therefore, assuming that no additional units will be constructed, the contract should expire in 2027.

Historic diversion data records can be used to project the average daily ANPP diversions, however, it is essential to incorporate operation criteria into future diversion projections. In the past, the ANPP used the Palo Verde Nuclear Power Plant as more of a peak demand facility rather than as a base demand facility, but recently the operation has changed and it is now used as a base demand facility. This change increased the use of reclaimed water.

Table 2-7 is a compilation of historic reclaimed water use by the ANPP. These data are used to develop the design parameters to be incorporated into discharge alternative development. The average annual ANPP diversion used is 60,000 AF/yr to reflect historic maximum monthly average day flow projections under the current power plant operating criteria.

The daily flow pattern for the 91st Avenue WWTP is presented in **Table 2-8** for an average winter day (March 27, 1997) and for a summer day with a zero discharge period (May 25, 1997). These daily diurnal flow data show how the range of discharge on each day compares to the daily average. These daily flow variations should be incorporated into habitat restoration alternative development.

The City of Phoenix entered into contract on June 1, 1971 with the Buckeye Irrigation Company (BIC) to provide 30,000 AF/yr of reclaimed water for a period of forty years. On August 19, 1994 the SROG Cities and BIC signed an agreement to extend the contract. When the original contract expires in the year 2011, the new agreement will be in effect, which consists of a series of five-year options which gives the BIC the right to purchase a specific amount of reclaimed water per calendar year for the option period subject to a minimum of 20,000 AF/yr and a maximum of 40,000 AF/yr. The total annual amount for which BIC exercises an option will be allocated on a monthly basis as follows under the new contract:

- September through March — 5 percent each month
- April and May — 10 percent each month
- June through August — 15 percent each month

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Table 2-7
ANPP Reclaimed Water Diversions

Greeley and Hansen
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Month	Diversion, mgd
January	47.2
February	50.6
March	42.7
April	38.7
May	41.8
June	66.6
July	65.5
August	63.0
September	56.6
October	60.4
November	53.6
December	51.5

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Table 2-8
91st Avenue WWTP Daily Diurnal Discharge Variations

Greeley and Hansen
April 1998

Hour	Winter March 27, 1997		Summer May 25, 1997	
	Discharge mg	Flow mgd	Discharge mg	Flow mgd
0	5.65	135.60	3.38	81.12
1	5.78	138.72	2.99	71.76
2	5.60	134.40	2.64	63.36
3	5.36	128.64	2.28	54.72
4	4.94	118.56	1.90	45.60
5	4.38	105.12	1.35	32.40
6	3.69	88.56	0.77	18.48
7	3.07	73.68	0.41	9.84
8	2.59	62.16	0.22	5.28
9	2.36	56.64	0.00	0.00
10	2.28	54.72	0.00	0.00
11	2.66	63.84	0.00	0.00
Noon	3.61	86.64	0.11	2.64
1	5.21	125.04	1.65	39.60
2	5.84	140.16	3.45	82.80
3	5.90	141.60	3.99	95.76
4	6.11	146.64	3.96	95.04
5	6.24	149.76	4.00	96.00
6	6.06	145.44	4.10	98.40
7	5.87	140.88	3.91	93.84
8	5.69	136.56	3.64	87.36
9	5.50	132.00	3.61	86.64
10	5.46	131.04	3.41	81.84
11	5.65	135.60	3.27	78.48

BIC is required by contract to use the water for agricultural irrigation purposes only on lands provided with BIC water and may not sell, transfer, deliver, or exchange the reclaimed water for any other purpose. BIC diversions are summarized in Section 3.1.

The contract extension agreement with BIC expires on December 31, 2030 or the expiration date of the SROG Cities contract with ANPP, whichever occurs first. As mentioned earlier, assuming that no additional ANPP units will be constructed, the ANPP and BIC contracts should expire in 2027.

SROG is required to deliver the reclaimed water to BIC by making the water available in a natural channel in the Salt River west of 91st Avenue. BIC is responsible for the transportation and delivery of the reclaimed water to the headgate of the Buckeye Canal located on the Salt-Gila River west of the Agua Fria River. There are provisions in the contract extension allowing for delivery of the reclaimed water at a mutually agreeable delivery point upstream from the headgate of, or at the Buckeye Canal. The reclaimed water may also be delivered through the existing turnout structure in the ANPP pipeline and discharged to the Buckeye Canal at a point just east of the extension of Sarival Avenue.

2.4.3 City of Tolleson WWTP

The City of Tolleson operates a WWTP with capacity of 17.4 mgd and treats an average of 11 mgd. The majority of the effluent is delivered to the ANPP for reuse at Palo Verde, but just as with the 91st Avenue WWTP, the ANPP demand varies. Effluent that is not taken by ANPP is discharged to the Salt River via the 91st Avenue WWTP effluent channel at a point just downstream from the 91st Avenue street alignment. The effluent discharge can vary from 11 mgd to zero depending on ANPP demands. The City of Tolleson reported that WWTP discharge to the river has averaged 3 to 4 mgd for 3 to 4 hours per day.

2.5 Agricultural Discharges

There are two types of agricultural discharges in the Salt/Gila groundwater model area: tailwater and downstream irrigation rights releases.

2.5.1 Tailwater

Tailwater is a term used to describe surplus irrigation water that is applied to fields but is not used by the crops. Tailwater drains from the fields into drainage laterals and is eventually discharged to the Salt and Gila Rivers. Tailwater occurs when fields are irrigated and thus is a seasonal water source. Residents of the Holly Acres area and St. Johns Irrigation District have reported the quality

of the tailwater is poor, but the quantity has been decreasing. Irrigation water use conservation has been mandated by the State. Increased irrigation water efficiency has greatly reduced tailwater quantities. Residents of Holly Acres have identified the tailwater discharge points, but these are ungaged. Salt River Project (SRP) gaged tailwater discharges are presented in **Table 2-9**. SRP has several ungaged tailwater discharge canals to the Salt River located at 35th Avenue, 59th Avenue, 67th Avenue, 75th Avenue, 83rd Avenue, 91st Avenue and 99th Avenue.

2.5.2 Downstream Irrigation Rights Releases

SRP discharges irrigation water to the Gila River to meet the water rights of the BIC. The SRP discharge point is just east of the Litchfield Road alignment. SRP water commingles with the reclaimed water discharged from the 91st Avenue WWTP. The commingled water flows past the junction with the Agua Fria and is diverted by the BIC. The SRP discharge is located on the west (downstream) limit of the Tres Rios area. SRP must deliver 1.1 percent of the natural flow diverted at Granite Reef Dam to meet BIC water rights. SRP released 21, 073 AF in 1995 and 24,224 AF in 1996 to meet BIC rights. SRP provided information on agricultural discharges and this is also summarized in **Table 2-9**.

BIC diverts flow from the Gila River and as described in Section 2.4.2, the BIC can divert all of the flow. The BIC has two turnouts in their diversion canal that allows them to return flow to the Gila River. The BIC reported that they do not use these two turnouts to return flow to the Gila River. Water diverted by the BIC that is not used by them for irrigation is either discharged to the Hassayampa River from the end of the BIC irrigation system or diverted to the Arlington Canal Company irrigation system. Both the Hassayampa River release point and the Arlington Canal Company are downstream from the Salt/Gila groundwater model area.

A third source of agricultural water in the Salt/Gila groundwater model area will be from lands in the Gila River Indian Community (GRIC). GRIC is considering expanding their irrigation system to bring new lands under cultivation using Central Arizona Project water (CAP). The GRIC is negotiating to receive 500,000 AF/yr of CAP water as a part of an Indian Water Rights Claims Settlement. The CAP water would be used throughout the entire GRIC area. This includes a large amount of land that is a part of the San Carlos Project near Coolidge and some of the lands that could be supplied water via the SRP system. Currently there are 1,080 acres of land in District 7 that are irrigated using SRP water. A Programic Environmental Impact Statement (EIS) was prepared for the GRIC project. CAP water used on the San Carlos Project lands within the GRIC will have no significant impact on the Salt/Gila groundwater model. Excess irrigation water that percolates into the ground will flow

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Table 2-9
SRP Agricultural Discharges

Greeley and Hansen
April 1998

Description	Year	Total Flow (ac-ft)	Year	Total Flow (ac-ft)	Comment
Laveen Drain into Deadhorse Ditch	1995	3280	1996	2179	
Maricopa Drain off Lateral 14 on Western Canal	1995	3255	1996	3020	
Lennox Drain into Buckeye Irrigation Co. feeder	1995	21073	1996	24224	Discharge is to Gila which flows into Buckeye Feeder canal

south from the GRIC area into a groundwater depression near Maricopa-Stanfield caused by historic mining of groundwater for irrigation. The EIS identified District 7 of the GRIC as an area with shallow groundwater and where the additional irrigation could result in water logging. District 7 is located in the area of the Gila River and Salt River junction and extends south along the Gila River. The EIS stated drain tiles will be needed to reduce water logging. The EIS did not quantify the quantity of CAP water that would be used in District 7, the amount or quality of drainage water or the disposal method, only that it would be addressed in a future management study.

This GRIC drainage could impact the quality of surface water used for habitat restoration. The GRIC drainage water is not expected to impact the water table in the groundwater because the flow in the Gila River should be in the gaining stream reach.

While the EIS did not quantify the drainage water quantity an allowance will be made in the Salt/Gila groundwater model for this water inflow. The irrigation drainage from the GRIC will be used as a quantity equal to the two SRP irrigation drainage discharges. This is equal to an average of 5,850 AF/yr.

2.6 Dewatering Wells

The BIC operates 10 dewatering wells to lower the groundwater table in the southern portion of the BIC area near the Gila River. The BIC dewatering wells represent both an inflow to the surface water and an outflow source from groundwater. The modeling will accommodate the dewatering wells in both categories. The BIC dewatering wells were included in this report as a system inflow source because it was recognized that a large number of the potential users of the water budget information will focus on surface water impacts.

Only two of these wells are within the Salt/Gila groundwater model area. These wells operate continuously and discharge to the Gila River. Well 55-619833 has a discharge rate of 1233 gpm and is located in Township 1 South Range 3 West in Section 7. Well 55-619834 has a yield of 1527 gpm and is located in Township 1 South Range 3 West in Section 4. These wells pump continuously. The discharge from Well 55-619833 is equal to 1,988.8 AF/yr and the discharge from Well 55-619834 is equal to 2,463.1 AF/yr.

2.7 Groundwater

The focus of the Salt/Gila groundwater model is to define where groundwater conditions result in the infiltration of surface water and where groundwater contributes to the surface water. The alignment

of 115th Avenue is the approximate location where the groundwater transition occurs. Upstream from 115th Avenue, the Salt River and portion of the Gila River are losing streams because surface flow infiltrates into the ground. The Gila River downstream from 115th Avenue and flow in the Gila River upstream from the junction with the Salt River are projected to be gaining streams sections because the groundwater table intersects the surface and groundwater contributes to the surface flow.

The surface flow in the Gila River at the junction with the Salt River originates upstream of the junction due to groundwater inflow. The inflow starts downstream of the Gila River gage listed in **Table 2-1** as Gila River near Laveen. Stream inflow contribution from groundwater quantification and defining both the gaining and losing stream reaches are goals of the Salt/Gila groundwater model and will be calculated in the future.

2.8 Minor Sources of Inflow

There are several minor sources of inflow to the Salt/Gila groundwater model area related to industrial NPDES permits. These are summarized in **Table 2-10**. This data shows four NPDES permits discharge to the BIC canal and only one to the Salt River.

3. SYSTEM OUTFLOW SOURCES

The following categories of sources were identified as diversions from the Salt River and Gila River within the groundwater model area. These were:

- Irrigation Diversion
- Riparian Consumptive Use
- Evaporation (Open Water Areas)
- Groundwater Infiltration

3.1 Irrigation Diversions

The majority of the Salt/Gila Groundwater Study area is supplied irrigation water by Salt River Project. The irrigation supply is derived from wells and surface water diverted from the Salt River at Granite Reef Dam which is many miles upstream from the Tres Rios Study area. The only irrigation diversions within the groundwater model area are those made by the BIC. A portion of the BIC flow is delivered to the Arlington Canal Company, which is located downstream from the BIC, however, the Arlington Canal Company is outside of the Salt/Gila Groundwater Model Study area.

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Table 2-10
Minor Sources of Inflow

Greeley and Hansen
April 1998

Description	NPDES #	Permit Discharge Flow Rate (mgd)	Average Flow Rate (cfs)	Average Flow Rate (mgd)	Average Flow Rate (af/yr)	Dates Averaged	Discharges Into	Comment
Western Cotton Services Corp. (aka Anderson Clayton)	100953	1.6	2.48	1.6	1797	when operating		Seasonal operation; discharges occur between Oct.-Apr.
Lockheed Martin Discharge 001	101570	0.25*	0.056	0.036	40.76	1-12/95; 1-12/96; 1,2,4,5/97	Irrigation ditch - tributary to B.I.C. Canal into Hassayampa into Gila	Non-contact cooling water
Lockheed Martin Discharge 002	101570	1*	0.11	0.071	79.8	1-12/95; 1-12/96; 1,2,4/97	Irrigation ditch - tributary to B.I.C. Canal into Hassayampa into Gila	Metal treatment rinse water
Lockheed Martin Discharge 003	101570	0.065*	0.034	0.022	24.7	1-12/95; 1-12/96; 1,2,4,5/97	Irrigation ditch - tributary to B.I.C. Canal into Hassayampa into Gila	Domestic wastewater and photo rinse
Lockheed Martin Discharge 004	101570	N/A	0	0	0		Irrigation ditch - tributary to B.I.C. Canal into Hassayampa into Gila	Rainwater only; no limit on discharge volume, concentration Std. only

The BIC diverts surface flow from the Gila River just west of the Agua Fria River. The contract and diversion quantities were presented in Section 2.4.2. The BIC often diverts all of the water in the Gila River. A review of the daily flow records for the U.S. Geological Survey gage at the Estrella Parkway Bridge located 2 miles downstream of the BIC diversion shows no flow for many days. When effluent is discharged from the 91st Avenue WWTP, downstream water users with valid water rights can divert the effluent. The result is that flow downstream of the BIC diversion is groundwater in the gaining stream section that will re-establish the flow supplemented by agricultural drainage discharge. This zero flow condition should be included in the habitat restoration analyses.

The USGS measures the flow in the BIC canal at Gage 09514000 and the BIC stated this flow is the diversion from the Gila River. The USGS reported the flow was gaged from 1951 to 1971 and again in water year 1997 that began on October 1996 and extended to September 1997. The gage data shows 10 of the 12 month maximum flow was recorded in water year 1997 and this corresponds with background information obtained from other sources that the BIC diversions have increased in the past few years. **Table 3-1** presents the BIC diversions, the historic data was reported for the period of 1953 to 1971 and water year 1997. The recent data is the water year 1997 gaged diversion. These data show the recent diversions are more than three times the historic diversions. These data also show the diversion greatly exceeds the contracted 91st Avenue WWTP discharge of 40,000 AF/yr plus the SRP irrigation discharge listed in Section 2.5.2 of about 23,000 AF/yr.

3.2 Riparian Consumptive Use

Riparian area consumptive use can be calculated at two levels of detail. The baseline ecological study provides detailed information on the portion of the Salt and Gila Rivers extending from 67th Avenue downstream to the BIC Canal turnout. Information obtained from Arizona Game and Fish Department characterizes the riparian habitat in more general terms throughout the remainder of the Salt/Gila Groundwater Study area.

The riparian vegetation in the Salt and Gila Rivers was inventoried as a part of the Baseline Ecological Characterization Study (1997). This study also called the ETI study inventoried the habitat types and acres of habitat types in the river reach from 67th Avenue on the Salt River downstream to the BIC diversion on the Gila River. The ETI study inventoried 4,263 acres within their study area and identified the vegetation communities, open water areas, and cobble (bare riverbed). The ETI data is presented on **Table 3-2** and includes the subdivision of vegetation communities based on habitat types and the acres included in each of the vegetation and other areas.

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Table 3-1
Historic Diversions by the Buckeye Irrigation Company from October 1953 through September 1997

Greeley and Hansen
April 1998

Month	Historic Average Acre-Feet	Recent Diversions (Acre-Feet)
January	2,354.8	10,950.0
February	2,360.2	11,290.0
March	3,234.0	13,710.0
April	2,856.0	10,190.0
May	2,422.4	11,240.0
June	2,850.1	10,540.0
July	4,273.1	10,630.0
August	5,705.7	12,490.0
September	3,915.1	12,320.0
October	2,195.0	6,672.0
November	1,838.6	5,780.0
December	2,508.5	10,600.0
Total	36,513.5	126,412.0

Transpiration rates associated with the vegetation communites listed on **Table 3-2** are presented on **Table 3-3**. The transpiration values include the range and the average values. The range is required because under optimal conditions the vegetation will be the most vigorous and can use the maximum amount of water. When the vegetation is stressed, water use decreases to the minimum to sustain plant life.

The consumptive use by the vegetation was calculated using the information on **Tables 3-2** and **3-3**. The vegetation areas were evaluated on aerial photographs to estimate the percent groundwater density in each vegetation community structural type. The calculated water use by the vegetation shown on **Table 3-4** is 7,337.8 AF/yr.

There are areas of open water throughout the Tres Rios study area. The projected evaporation rate in the Phoenix area is 6 feet per year. The ETI study projected 440 acres of open water within the study area extending from 85th Avenue to the BIC canal diversion. This equals an evaporation rate of 2,640 AF/yr.

The riparian habitat in the river section of the entire Salt/Gila groundwater model area was calculated from the GIS riparian area maps prepared for the Middle Gila River Watershed Management Study by Greeley and Hansen. This GIS data includes the Tres Rios area but does not have the same detail as the ETI study because the GIS data was delivered from a State map prepared by Arizona Game and Fish Department. The regional vegetation is summarized as follows:

Habitat Type	*Acres*
Tamarisk (Salt Cedar)	7,711
Cottonwood/Willow	50
Mesquite	340

The Arizona Game and Fish data did not include areas of cobble and open water. The GIS area listed as vegetation that corresponded with the ETI area indicated there were 2,599 acres of vegetation as compared to the 2,454 acres in the ETI study. The data on **Table 3-2** shows vegetation accounted for 57.93 percent of the total area in the ETI study, cobble was 31.68 percent, and open water was 10.39 percent. When the Arizona Game and Fish GIS data is adjusted to account for the cobble and open water the totals are:

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Table 3-2
Land Cover in ETI Study Area

Greeley and Hansen
April 1998

Habitat Type	Structural Type	Acres	Percent of Total
Cottonwood-Willow	II	22	0.52%
Cottonwood-Willow	III	220	5.19%
Cottonwood-Willow	IV	268	6.33%
Salt Cedar	II	10	0.24%
Salt Cedar	III	400	9.44%
Salt Cedar	IV	628	14.83%
Salt Cedar	V	262	6.19%
Salt Cedar	VI	90	2.12%
Marsh		16	0.38%
Honey Mesquite	IV	125	2.95%
Honey Mesquite	V	30	0.71%
Quailbush-Saltbush		220	5.19%
Desert		157	3.71%
Desert Wash (Xeric-riparian)		6	0.14%
Cobble		1,342	31.68%
Open Water		440	10.39%
Total		4,236	100.00%

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Table 3-3
Vegetation Evapotranspiration Values

Greeley and Hansen
April 1998

Vegetation Type	Evapotranspiration Range Ft/Yr	Evapotranspiration Average Ft/Yr
Cottonwood Willow	4.1-8.5	6.3
Salt Cedar	3-9.2	6.1
Honey Mesquite	1.6	1.6
Marsh	7.5-16	11.7
Quailbush-Saltbush	3.2	3.2
Desert	2	2
Desert Wash (Xericriparian)	2	2

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Table 3-4
Vegetation Consumptive Use

Greeley and Hansen
April 1998

Habitat Type	Structural Type	Percent Ground Cover	Acres	Average Evapotranspiration Af/Ac/Yr	Calculated Consumptive Use Af/Yr
Cottonwood-Willow	II	90%	22	6.3	124.7
Cottonwood-Willow	III	70%	220	6.3	970.2
Cottonwood-Willow	IV	50%	268	6.3	844.2
Salt Cedar	II	90%	10	6.1	54.9
Salt Cedar	III	90%	400	6.1	2,196.0
Salt Cedar	IV	50%	628	6.1	1,915.4
Salt Cedar	V	30%	262	6.1	479.5
Salt Cedar	VI	10%	90	6.1	54.9
Marsh		100%	16	11.7	187.2
Honey Mesquite	IV	50%	125	1.6	100.0
Honey Mesquite	V	30%	30	1.6	14.4
Quailbush-Saltbush		10%	220	3.2	70.4
Desert		100%	157	2	314.0
Desert Wash (Xericriparian)		100%	6	2	12.0
Total			2,454		7,337.8

- Vegetation 2,599 acres
- Cobble 1,421 acres
- Open Water 466 acres

  Total 4,486 acres

The riparian vegetation in the entire Salt/Gila Groundwater model area totals 8,101 acres. When this is adjusted using the ETI data proportions the totals are:

- Vegetation 8,101 acres
- Cobble 4,430 acres
- Open Water 1,453 acres

  Total 13,984 acres

The next step is to calculate the consumptive use of the vegetation in the Salt/Gila groundwater model area. The information on **Table 3-4** shows an average water us of 2.99 AF/Acre when vegetation density is included in the calculations. The water demand associated with the 8,101 acres of vegetation is 24,222 AF/yr.

3.3 Groundwater Infiltration

The water table upstream from 115th Avenue is at a sufficient depth to permit surface water to infiltrate into the ground and recharge the water table. This area is identified as a losing stream reach because the surface flow is lost to groundwater. Downstream from 115th Avenue the Salt River is a gaining stream because the groundwater flow augments the surface flow. Groundwater infiltration is impacted by several factors including the permeability of the riverbed material, the quantity of flow available, the period of time flow is available, and the saturation of the riverbed materials. Quantification of groundwater infiltration is a goal of the Salt/Gila groundwater model. The quantity will be determined as a part of modeling efforts and will be available in the future.

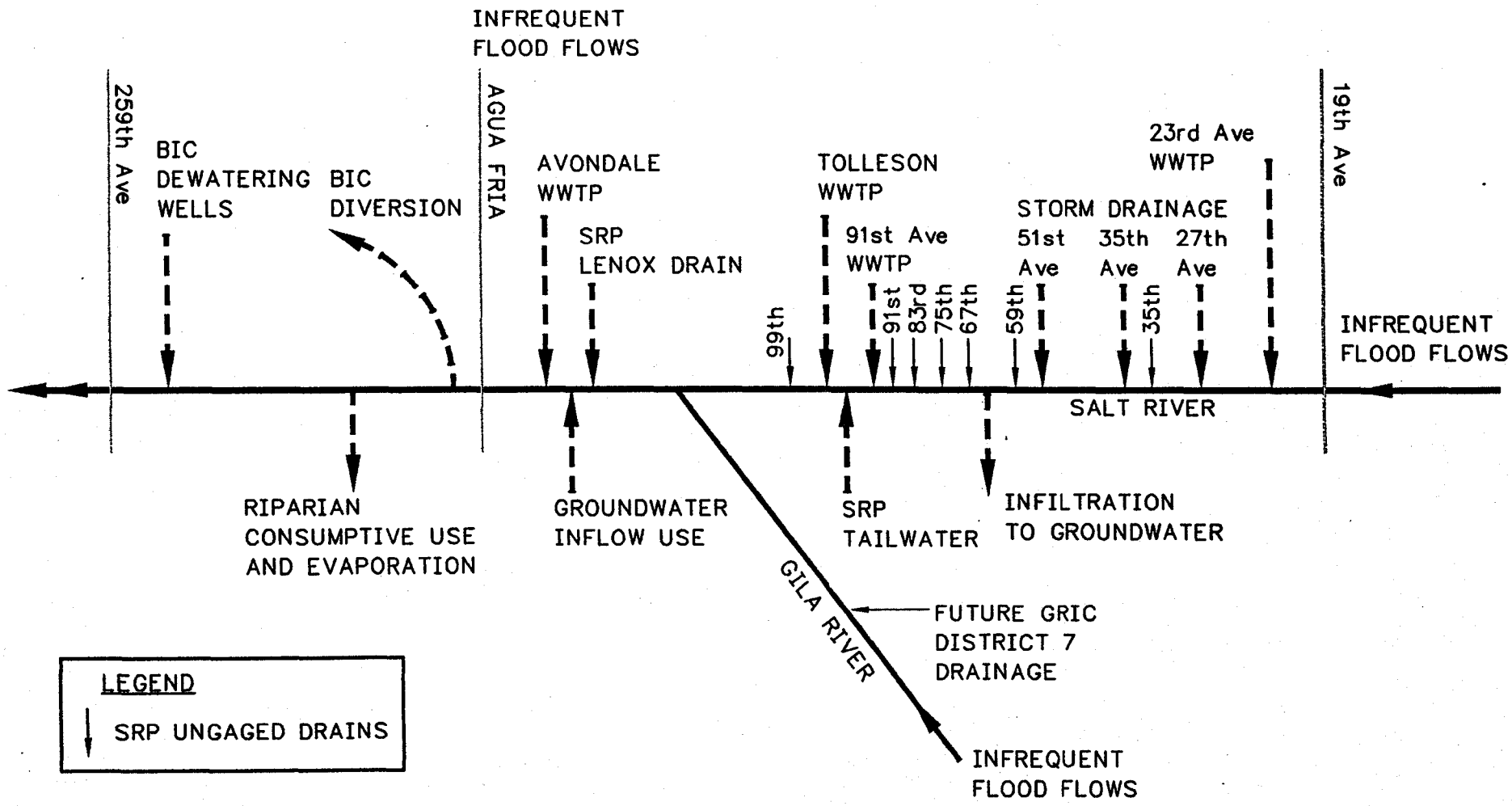
4. WATER BUDGET SUMMARY

Figure 4-1 is a schematic diagram to present the inflow sources and diversions from the Salt and Gila Rivers.

5. SALT/GILA GROUNDWATER MODEL WATER BUDGET

The water budget for the groundwater model summarizes all of the information presented in Sections 2 and 3 plus must include regional additions and depletions to the hydrologic system. The initial water budget prepared for the groundwater model is summarized on **Figure 5-1**.

FILE: R:\4264\FIG4-1 SCALE: 1:1 03/31, 1998 at 08:23 - CADD-001 *13_c4*



SCHEMATIC WATER BUDGET DIAGRAM

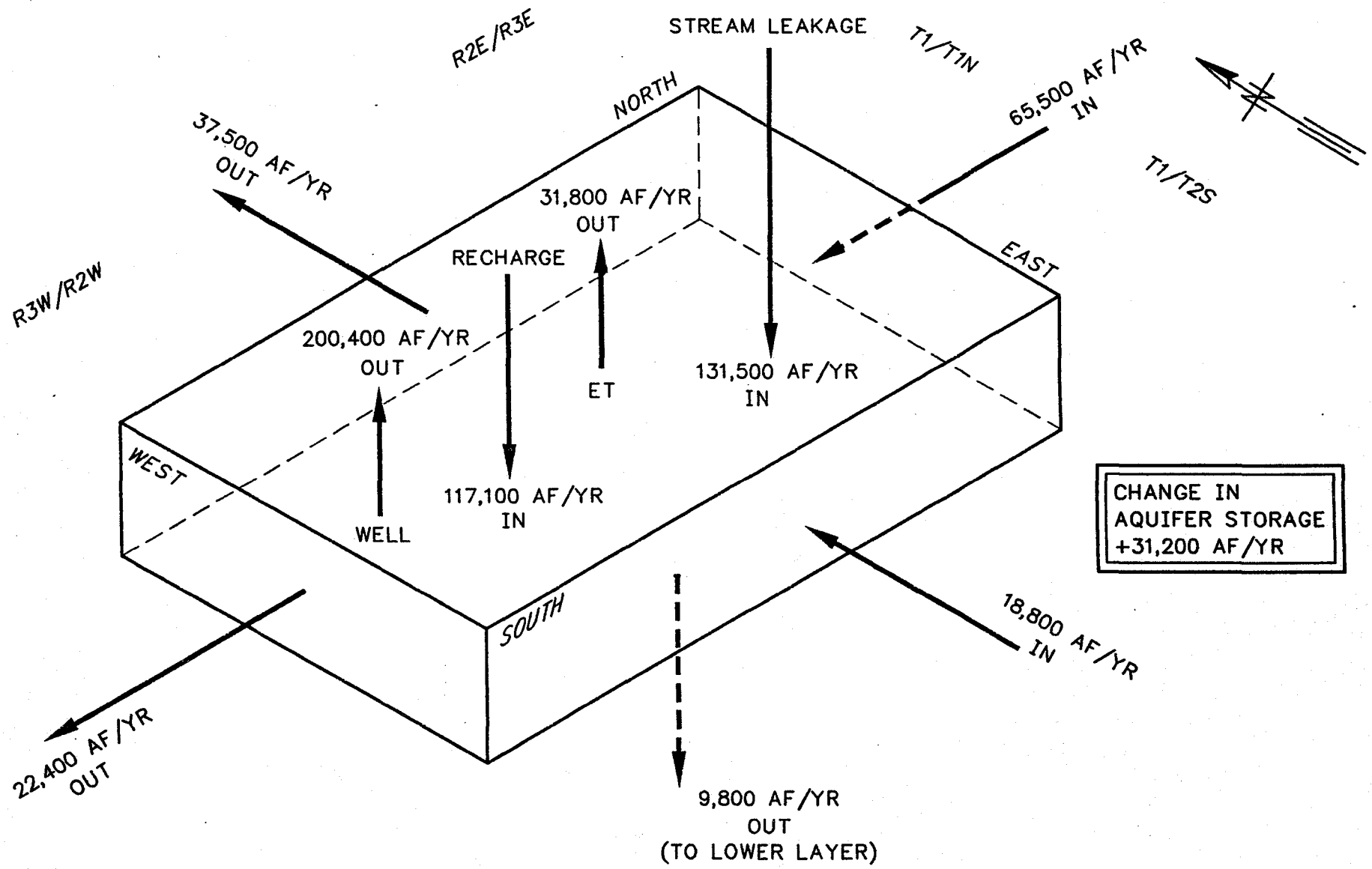
RIVER WATER BUDGET

GREELEY AND HANSEN

MARCH 1998

FIGURE 4-1

FILE: R:\4264\FIG5-1 SCALE: 1:1 03/10, 1998 at 08:27 - CADD-001 *13_c4*



SALT/GILA GROUNDWATER MODEL WATER BUDGET

GREELEY AND HANSEN

MARCH 1998

FIGURE 5-1