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**Analysis of Flow and Water Use
Alternatives on Hydrologic
Conditions in the Riparian Corridor
of the Gila-Cliff Basin**

Prepared for:



New Mexico Interstate Stream Commission

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1.0 INTRODUCTION

S.S. Papadopoulos & Associates, Inc. (SSPA, 2010) developed riparian groundwater models for the Gila-Cliff Basin to support analyses of surface water-groundwater interactions along the Gila River, as part of work conducted for the Technical and Implementation Committees of the Southwest New Mexico Stakeholders Group, under the Arizona Water Settlement Act (AWSA). The riparian groundwater models extend from the confluence of the Gila River and Mogollon Creek to the Bird Site, just above the upper end of the Middle Box (Figure 1.1). The upper model (Reach 1) extends from above the confluence of Mogollon Creek to below Duck and Bear Creek; the lower model (Reach 2) model extends from above Duck and Bear Creek to the upper end of the Middle Box. The models are well-suited to examining groundwater-surface water interactions because they allow for a seasonally dependent river condition, wherein the position of the river channel and the depth of water in the river, both of which exert influence on groundwater conditions, can be changed over the course of a season to match the change in river flow. Surface water conditions are determined from supporting HEC-RAS model analyses.

In this study, the Reach 1 model is applied to assess hydrologic conditions associated with a set of alternate water diversion/water use scenarios. The objectives of this work are:

- to provide a general indication of changes in hydrologic conditions that may occur from modified diversions, increased irrigated agricultural acreage and increased riparian acreage, under a hypothetical set of scenarios; and,
- to provide an example of how the riparian groundwater models can be applied to alternative analysis and to demonstrate model capabilities.

The scenarios evaluated herein are not intended to cover a full range of potential conditions or alternatives, but should provide a sense of the type and magnitudes of changes that might be associated with modifications as noted. This information may prove useful in understanding impacts at a conceptual level, and, may be informative for scoping additional, more specific, alternative analyses.

The evaluations provided in this report are conducted independent of potential mitigation activities in order to isolate cause/effect relationships and facilitate understanding. For example,

in simulations with CUFA diversions, the water collected from the CUFA diversion is not applied in any fashion to mitigate impacts of the alternative CUFA diversion. More complex simulations may be conducted in a later phase, if desired, which use CUFA water for mitigation or improvement of river corridor conditions. Simulation results include changes in the depth to groundwater; and changes to stream gains (subsurface return flows) or losses (seepage) over multiple sub-reaches.

Beyond results of the target simulations, this report provides other supporting information including QA/QC of elevation datasets used in this and earlier work phases, analysis of a seepage investigation conducted in December 2010, analysis of CUFA diversion patterns for a range of water supply years and assessment of historical canal diversions to support inferences on the relationship between river flows and irrigation shortage conditions.

2.0 MODEL SET-UP ACTIVITIES

2.1 Review of Model Elevations

Elevation datasets used in the riparian groundwater models include field-surveyed river cross-sections and piezometers, HEC-RAS surface water elevation model results and a LiDAR (Light Detection and Ranging) digital terrain model. Brief metadata summaries for each dataset are included in Appendix A. Review of the accuracy of all elevation data sets used in the model development was undertaken as part of this project, due to differences in measured and simulated groundwater elevations noted at the end of the model calibration phase in preliminary model development (SSPA, June 2010). At that time, it was assumed that further model calibration might allow for closure of the differences; however, it was also decided to review the underlying data sets to rule out any systematic offsets associated with the survey data sets themselves.

Review of elevation datasets revealed a systematic offset in field-surveyed data in the northern reach of the Gila River valley, from the Gila River at Gila gage to approximately one mile below the TNC cross-section as compared to the LiDAR land surface elevations. The offset transferred to other intermediate work products used by contributing parties, and were ultimately reflected in the 2010 riparian groundwater model. To determine the source of the offset and enable its correction, the internal consistency of separate surveying events was examined. The LiDAR datasets were determined to be internally consistent and accurate; however, an error was found in some of the separately field-surveyed data including river cross-sections and piezometer elevations. Further review indicated that an adjustment to the field-surveyed data, based on the LiDAR data and control points, was needed to achieve consistency among elevations datasets used in the groundwater model. Details of this review and the resulting adjustment to surveyed elevations are provided in Appendix A.

Because the HEC-RAS surface water model incorporated unadjusted surveyed cross-section data, the earlier model results required adjustment for use in this project. Adjustments were applied to the HEC-RAS-based river bottom elevation and water surface elevations for each of the benchmark flow levels that are used in the groundwater model to identify river boundary conditions. The adjustment was applied separately to two sub-reaches, as described in Appendix A, based on the occurrence of two distinct offsets. These revisions result in reasonably

accurate and consistent elevations for present modeling purposes in the areas where surveyed cross-section data were collected. Uncertainty remains regarding local elevations in a number of sub-reaches where survey data could not be obtained in 2010 due to lack of landowner access. Additional channel cross-section surveying at uniform intervals throughout all modeled reaches is recommended to improve the overall accuracy and resolution of the models, depending on the degree of accuracy required for particular modeled scenarios.

2.2 Model Post-Processor and River Package Adaptations

To prepare for simulation of a Baseline Condition and various alternatives, modifications were made to pre-processor input-files and code to accommodate the number of stress periods selected for these simulations. Update included refinements to extract simulated daily water levels for the entire period of simulation, seepage and water-budget-summary processing of the additional stress periods, refined river sub-reach delineation, binary-file processing for multiple stress periods, generation of GIS import-compatible files, and various scripting and batch files to automate the production of hydrographs and seepage flux figures used for model run evaluation. Figure 2.1 shows the river sub-reaches identified for calculation of simulated sub-reach river seepage gains and losses. This figure also shows the location of model cells included in an additional River Package input file to set river boundary conditions for an additional low flow level of 30 cfs. The 30 cfs River Package supplements the previously developed River Packages (SSPA, 2010), and is discussed further in Section 3.

2.3 Data Analysis and Model Refinement

Modification of the 2010 Reach 1 Model was undertaken to adjust for the channel bed offset described above and to allow for consideration of additional data, including additional seepage runs conducted in December 2010 and an analysis of canal flow conditions. The winter/spring 2010 period remains the period utilized for model calibration. The December 2010 seepage run is considered representative of winter, low flow, pre-runoff conditions and provides a useful contrast to higher flow, irrigation season, conditions observed in May 2010. These data and analyses are briefly described below, followed by a summary of the model calibration.

2.3.1 Seepage Investigations, December 2010

A seepage investigation was conducted on December 13, 14 and 15 of 2010. For each of these three days, the daily mean flow at the Gila River near Gila gage (USGS 09430500) was 66 cfs, and all reported measurements are reported within the range of 65 to 67 cfs. The top-of-reach measurement for this seepage investigation, at the Gila River above Mogollon Creek, was 60 cfs. River and channel inflows/outflows were measured in this investigation by Luis Madrid at 25 locations, following USGS protocols of monitoring velocity at, typically, 20 or more sites across each measurement section and calculating discharge from velocity/area data. Repeat measurements were made at the beginning of each subsequent day over the 3-day event. Given the steady flow conditions and the experience of the hydrographer, the quality of this seepage investigation is considered to be excellent.

Appendix B contains summary tables providing data from this investigation and calculations of channel loss/gain. Table B-1 summarizes all of the reach loss/gain calculations including those relating to the May 2010 seepage investigations. Table B-1 updates and replaces Table 3.5 of the report, "Analyses of Surface Water-Groundwater Interactions along the Gila River, Gila-Cliff Basin" (SSPA, June 2010). Tables B-2 through B-4 provide loss/gain calculations for the December 2010 event, site names, section discharges and GPS-coordinates of the measurement sites.

The December 2010 seepage investigation depicts a very different hydrologic condition from that of May 2010. In May, the Gila River experienced a net channel gain from Mogollon Creek to the Highway 180 Bridge (roughly, the domain of Model Reach 1) of approximately 70 cubic feet per second (cfs). In December, a net gain of 22 cfs was observed. Conditions in May were characterized by top-of-reach flows of 224 cfs shortly after an extended high runoff period during March and April. Gains during this period likely reflect the return of water stored in the shallow groundwater environment during the preceding higher flow periods (bank storage). The May gain/loss calculations also may have been impacted by measurement sequencing and transient (declining) flow conditions, which may have resulted in over-estimation of gains. Despite the lower reliability of the May seepage investigation and potential for over-estimation of gains, the occurrence of net gains in amounts substantially greater than those of the December lower flow period is credible. As previously noted, the December event followed a stable, low

flow period. The net gain of 22 cfs observed during this period appears to be associated with subsurface returns of a portion of the diverted ditch flow, reported to be 49 cfs in total. In this period, given the occurrence of steady flows in weeks prior to the seepage investigation, no bank storage returns are occurring. These separate events under different hydrologic regimes provide information useful for the model calibration.

2.3.2 Canal Flow Conditions

Historical canal diversions were reviewed for the Upper Gila Ditch, the Ft. West Ditch and the Gila Farms Ditch to better understand diversion patterns under varying river flow conditions, and to support inferences regarding the occurrence of shortage conditions to irrigated lands. Figure 2.2 shows scatter plots of canal diversions during the years 2000 through 2005 and the corresponding flow at the Gila River at Gila gage for river flows below 200 cfs. Figure 2.3 shows the same scatter plots, but limits data to the months of June to September. Despite a high degree of scatter in the data, visual examination indicates that above a threshold range, diversions are independent of river flows; and, below the threshold, diversions are dependent and positively correlated to river flow. Not surprisingly, irrigation ditch diversions are reduced under low river flow conditions. These data are further discussed in Section 3.

2.3.3 Model Calibration

Using the adjusted elevations as noted above in Section 2.1 and Appendix A, and considering additional information relating to river, canal and other conditions, the Reach 1 model was re-calibrated. Available groundwater elevations were limited to the wells drilled on TNC property in May 2010. December 2010 seepage conditions were considered analogous to those corresponding to the first stress period of the model calibration (December 2009/early January 2010) and were considered in adjusting model parameters. May 2010 seepage conditions corresponded to the final stress period of the model calibration period and were also useful in evaluating model parameters. Appendix C-1 provides additional information on the 2010 simulation.

3.0 SIMULATION OF BASELINE CONDITION

The Gila-Cliff Riparian Groundwater Model (Reach 1 Model) was applied to assess changes in groundwater elevations and in river loss/gains associated with a set of alternate water diversion/water use scenarios. The objectives of this work were:

- to provide a general indication of changes in hydrologic conditions that may occur from modified diversions, increased irrigated agricultural acreage and increased riparian acreage, under a hypothetical set of scenarios; and,
- to provide an example of how the riparian groundwater models can be applied to alternative analysis and to demonstrate model capabilities.

Prior to simulating the alternatives, a Baseline Condition was identified to serve as a point of comparison for alternatives analysis. Because surface water-groundwater conditions are dynamic, responding to seasonal changes including river flows, irrigation demand, riparian evapotranspiration and subsurface inflow, a timeframe of one calendar year was selected to provide opportunity to simulate a wide range of conditions. The identification of the Baseline Condition is described below, followed by the simulation set-up, farm budget assumptions and model results.

3.1 Identification of Baseline Condition

A set of river conditions suitable for use in the Baseline Condition was selected based on examination of hydrographs from years available in the historical record. For this purpose, a suitable hydrograph would have several run-off events, a summer low flow period, and overall annual flow within an "average" range. Furthermore, because some of the alternatives to be analyzed involve the diversion of "CUFA" flows, that is, amounts identified according to the Consumptive Use and Forbearance Act, the corresponding quantity of "allowable" CUFA diversions was reviewed to ensure that the hydrograph of the Baseline year was associated with an "average" range of CUFA diversions.

Table 3.1 provides a list of annual yield and corresponding hypothetical CUFA diversions for the years 1936 to 2001, and the average and median values. From this information, the hydrographs for years falling close to the average or median values for both annual yield and CUFA diversions were reviewed for purposes of identifying an average-range

year with sufficient variety in the hydrograph to serve the intended purpose in this evaluation. The hydrograph for 1963, selected to represent a Baseline Condition in these analyses, is shown on Figure 3.1. Also shown on Figure 3.1 is a discretized hydrograph (step-function) that approximates the actual hydrograph using discrete flow levels for which detailed surface water modeling has previously been conducted, discussed below.

3.2 Baseline Condition Flows and Simulation Stress Periods

To represent the Gila River flow levels for the simulation period, the hydrograph from the Gila River gage (USGS Gage 09430500) located upstream of the Reach 1 model, was approximated with a step-function hydrograph (Figure 3.1). The step-function hydrograph is composed of seven discrete flow levels, each of which is associated with a different set of river conditions with respect to river stage and wetted channel. HEC-RAS surface water modeling was conducted by Tetra Tech in 2010 to characterize river depth and width for river flow levels of 75, 250, 500, 750, 1,000, and 3,000 cfs. One additional set of river conditions was developed for a low flow condition of 30 cfs by extrapolation. Inundation maps corresponding to each of the HEC-RAS modeled flow levels are provided in Appendix D.

The step-function shown on Figure 3.1 forms the basis for stress periods in the groundwater model simulations. For each change in the step function, a new stress period is initiated. The model input for river conditions is adjusted for each stress period: that is, the width and depth of the river are re-specified as appropriate for the new flow level. Table 3.2 summarizes for each model stress period the duration, dates, and the river flow levels used to set the river boundary condition.

3.3 Farm Budget Assumptions

The groundwater model represents farm processes through several mechanisms. These include infiltration of excess applied water through farm fields, implemented through the MODFLOW Recharge Package; and, canal seepage, implemented through the MODFLOW River Package. To develop model input for the simulations, information was reviewed including assumptions used for AZ v. CA water accounting and canal flow gage data. This section summarizes assumptions made regarding the farm budget. These assumptions may be modified

in subsequent work if additional information or data becomes available to the study team, or, as may be appropriate for other simulated conditions.

3.3.1 Shortage Conditions

On average, farm ditches divert at full supply when Gila gage flow exceeds a threshold range of about 50 to 60 cfs. “Full supply” is considered to be 20 cfs for Upper Gila and Ft. West Ditches and 10 cfs for Gila Farms Ditch (based on visual examination of river-ditch flow scatter plots, 2000 to 2005, June through September, Figure 2.3). When Gila gage is less than 50 cfs, decreased flow to ditches is observed. For the months June and July in the Baseline Condition (Figure 3.1) Gila River flow is approximately 30 cfs; this is assumed for purposes of the Baseline simulation to result in about a 25% reduction to “full supply” ditch flows, or, about 15 cfs for the upper two ditches and 7 cfs for the Gila Farms Ditch. The reduction in flow to ditches will not necessarily correlate exactly with a shortage in water for irrigation, but will require greater effort on part of ditch rider and irrigators to coordinate diversions and move water onto fields. On the other hand, delivery/efficiency challenges are not always readily overcome; for purposes of this evaluation, it will be assumed that water for crops is short by 25% in this condition and that other elements of the farm water budget are similarly reduced by 25%.

3.3.2 Canal Seepage

Water accounting for AZ v. CA assumes a value of 75% canal efficiency, that is, 25% of diverted water is lost to canal-associated -evapotranspiration and/or to canal seepage. Correspondingly, canal seepage was set as 25% of the assumed canal diversion amounts noted above for initial model simulations, that is, 5 cfs for the Upper Gila and the Ft. West Ditch and 2.5 cfs for the Gila Farms Ditch for all months with Gila River flow greater than 50 cfs. The amount of canal seepage was increased from the initial model assumptions during calibration to improve the consistency of the simulated river gains/losses with those observed in seepage runs (Appendix C-1) resulting in a simulated canal efficiency of 50%.

For the assumed shortage conditions occurring in the months of June and July, canals are assumed to run at 75% capacity of full-capacity amounts. The simulated canal efficiency under the shortage condition is maintained at 50%.

3.3.3 River Drying

The occurrence of localized river drying and its extent is not well documented, but may exist in very dry and low flow periods for some distance below the point where the upper two ditches are routed off the main river channel, perhaps on the order of a couple hundred feet to up to a quarter mile. In this simulation, a sub-reach of the river for a distance of one quarter mile below the Ft. West Ditch point of diversion (Figure 2.1) is assumed to be dry when Gila flows are at 30 cfs in June and July. This assumption should be re-visited in future simulations, particularly if documentation of actual conditions can be obtained.

3.3.4 Recharge from Applied Irrigation Water

Applying assumptions used for the AZ v. CA accounting, an on-farm efficiency of 55% and a seasonal crop consumptive irrigation requirement of 1.74 acre-feet per acre is assumed. Based on these assumptions, infiltration of excess applied irrigation water is assumed to be 1.4 acre-feet per acre during the irrigation season, under full supply conditions. During the shortage condition, this amount is reduced by the assumed shortage percentage. In actuality, greater irrigator efforts may stretch the available water and further reduce this infiltration. However, refinement of this assumption under shortage conditions is not attempted for this simulation. During the winter months, on-farm infiltration is assumed to occur on half of the lands: this is accomplished in the model by applying one-half the irrigation season rate to the identified irrigated acres. This reflects an assumption of winter irrigation of pasture lands on approximately one half of the irrigated lands within the valley: this assumption can be refined if necessary in future simulation evaluations.

3.3.5 Supplemental Groundwater Pumping

With a few exceptions, supplemental irrigation is not widely practiced as it is expensive to provide a power supply to pumps (personal communication, Tink Jackson, NMOSE Deming Office). Given the relatively small magnitude of supplemental groundwater pumping, that is, less than couple hundred acre-feet, supplemental groundwater pumping is not represented in the current simulations. However, there may be cases where the representation of supplemental pumping is important to the outcome of simulated alternatives. If so, additional work to specify locations and amounts of supplemental pumping will be needed.

3.4 Model Package Inputs for Baseline Condition Simulation

Input files for MODFLOW Packages were developed as described below for the simulation of the Baseline Condition. The abbreviations shown in parentheses correspond to the MODFLOW Package for a given model process:

- Spatial/temporal discretization (DIS): 25 stress periods are specified to correspond to the 25 steps identified in the step-function hydrograph (Figure 3.1).
- Seepage to/from the regional system (GHB): The regional system boundaries were adjusted to reflect the time discretization of the Baseline Condition.
- Riparian evapotranspiration (RIP): The stress period duration and timing were used to create monthly evapotranspiration-rate scaling factors and corresponding rates for each stress period. Scaling factors used in each stress period are summarized in Table 3.3.
- On-farm percolation (RCH): The winter rate was set at 0.5 times the summer rate. A new parameter was added to represent supply-limited conditions during June and July. A value of 0.75, or 75% of the irrigation-season rate of on-farm percolation, is used for the supply-limited conditions.
- River, tributaries and canals (RIV): One additional RIV Package was developed to represent a 30 cfs flow condition. The specifications for the Gila River for the 30 cfs flow condition include a dry reach from the Ft. West point of diversion for a distance of one-quarter mile. Specifications of river width/depth for the other flow levels are unchanged from the previously developed RIV Packages with the exception of the channel bed-stage elevation adjustments described in Section 2.1 and Appendix A.
- Seepage from tributary alluvium (WEL): A set of tributary-alluvium inflows were specified to correspond to stress periods defined by the Baseline Condition. Seasonal adjustments were made to subsurface inflow during model calibration. Details on the tributary-alluvium inflows corresponding to the various flow levels are provided in Appendix C.

3.5 Simulation Results for the Baseline Condition

Maps of depth-to-groundwater are shown on Figures 3.2 and 3.3, representing the end of the peak winter run-off and the end of a summer dry period. Figure 3.2 shows the depth-to-water at the end of Stress Period 5 (February 25), following a period of 15 days at a flow of 500 cfs; Figure 3.3 shows the depth-to-water at the end of Stress Period 12 (July 30), following a generally declining spring hydrograph and 58 days at a simulated flow of 30 cfs in June and July. Sub-reach river gains and losses are shown on Table 3.4 for the Baseline Condition.

This simulation assumes that irrigation water supply shortages occur in June and July, as discussed in Section 3.3.1, resulting in reduced canal diversions and unmet consumptive irrigation demand of 25% of the full-supply amounts. Including unsatisfied diversion demand for carriage and system operation, the irrigation system diversion deficit is 12.5 cfs (25% of the assumed 50 cfs full-supply total diversion amount). Over a two month period, this shortage is equivalent to 1,508 acre-feet.

4.0 SIMULATION OF ALTERNATIVES

4.1 Description of Alternatives

4.1.1 Scenario 1: CUFA Diversions

This scenario differs from the Baseline by the modification of the Baseline hydrograph to reflect hypothetical CUFA diversions. The amount of CUFA diversions corresponding to Baseline flows, and a corresponding step-function is shown on Figure 4.1. The flow levels for the steps comprising the step function were limited to incremental values such that the resulting CUFA-impacted Gila River flow levels could be matched to the suite of flow-dependent MODFLOW River Packages, thus achieving reasonable surface water boundary conditions on the groundwater model for the simulation. In creating the step-function, care was taken to preserve volumes of CUFA diversions within discrete time periods. Figure 4.2 shows the cumulative amount of daily CUFA diversions and the cumulative amount as approximated with the step-function. Figure 4.3 shows the resulting flow hydrograph for Scenario 1, the simulation of reduced flow due to CUFA diversions. The simulated reduction in river flow for the one-year simulation is 13.983 acre-feet, approximately 10% of the annual flow volume for the Baseline Condition. The disposition of the CUFA diversions is un-specified for this scenario but is assumed to result in no modeled impact other than as are associated with reduced flows in the simulated hydrograph. No changes to existing water or land uses were made.

This scenario is implemented by modifying the assignment of River Packages to affected time periods resulting in river conditions that reflect lowered stage and/or decreased wetted river channel during periods where river flow is reduced by the CUFA diversions. As summarized on Table 4.1, River Packages changes are as follows: from 250 cfs to 75 cfs during periods 2, 4, and 9 (from January 11 to 14, February 3 to 10 and March 31 to April 3); and, from 500 cfs to 250 cfs during periods 5 and 18 (from February 11 to 25 and August 26 to 27). For each of these periods, the width of the river and the depth of the river are modified to reflect the values obtained from the surface water modeling, thus obtaining a dynamic, flow-dependent, river boundary condition for the groundwater model.

4.1.2 Scenario 2: CUFA Diversions, Increased Irrigated Agriculture

Under this scenario, CUFA diversions are simulated as described for Scenario 1 and the resulting river flow ("CUFA Flow") is as shown in Figure 4.3. It is also assumed that irrigated agriculture increases by 30% when sufficient water is available for diversion. In order to structure this scenario, the additional demand represented by increased irrigation is examined in the context of the simulated flows for the scenario to identify stress periods wherein shortage may occur.

AZ v. CA accounting data provide estimates of monthly crop consumptive use, and diversion amounts necessary to satisfy crop consumptive use with a combined on-farm and canal efficiency factor of 0.41. For example, in 2007, with a full season consumptive irrigation requirement of 1.74 feet per year, the diversion required for 1,253 irrigated acres in the Gila-Cliff Valley is 5,313 acre-feet per year. With a 30% increase in irrigated acreage, the additional diversion requirement is 1,593 acre-feet per year (with an additional consumptive irrigation requirement of 654 acre-feet per year). Of more relevance to assessing potential shortage conditions are the diversion requirements in summer months. In 2007, diversion requirements for existing irrigated acreage in the months of May, June, July and August 2007 were 11.1, 19.4, 16.3 and 14.7 cfs, respectively for the combined Upper Gila, Ft. West and Gila Farms ditches using the efficiency factor noted above. But as a practical matter, and based on inspection of ditch diversion data and anecdotal information, it appears that it becomes more difficult to serve the existing irrigated lands when Gila River flow-falls below the range of 50 to 60 cfs in summer months and shortage conditions may occur even with river flows occurring well above the calculated monthly diversion requirements noted above.

It is assumed that no additional acreage can be irrigated in the months of June and July, as river flow in these months is simulated as 30 cfs, previously inferred to represent a 25% shortage condition (Section 3.3.1). The month of May is simulated at 75 cfs. Assuming 2007 as a reasonably representative year for purposes of estimating irrigation demand, the additional diversion requirement for May, beyond that of the existing condition, would be 30% of 11.1 cfs, or, 3.3 cfs. If a river flow condition of 60 cfs is suitable for serving the existing lands, as is suggested by the ditch diversion data (Figure 2.3), the simulated May flow of 75 cfs would be adequate for an additional diversion of 3.3 cfs. Furthermore, given that there is evidence of

tailwater return on the existing system and that a large amount of the canal diversions appear to serve carriage purposes, a significant increase in canal diversion may not be needed to serve the hypothetical additional irrigated lands if they are assumed to be located in and around existing irrigated acres. Rather, the additional consumptive use would simply decrease the tailwater or seepage returns of the existing ditch diversion amount, assuming ditches are running at full-supply levels. Other than June and July, previously discussed, no other simulated months exhibit lower river flows or higher irrigation demand than the month of May. Therefore, it is assumed that the Scenario 2 assumption of 30% increase in irrigated agriculture is satisfied for all months except the months of June and July.

This scenario is implemented by modifying the assignment of River Packages as described in Section 4.1.1 for Scenario 1 to handle changes in river width and stage associated with the decreased river flows associated with CUFA diversions. To represent the increased irrigation demand of a 30% increase in irrigated agriculture, it could be reasonably assumed that canal diversions remain the same, in that canal diversions as in the Baseline Condition include significant amounts of carriage water beyond the Baseline diversion demand, but that subsurface return flow is diminished in an amount equal to the additional consumptive irrigation requirement of 654 acre-feet per year. However, considering that additional incidental losses could occur, this amount is increased by an arbitrary value of 15%, to 752 acre-feet per year, or, 0.6 feet per acre over the irrigation season. This reduction is applied to the on-farm percolation represented in the Recharge Package for the stress periods falling within the irrigation season, excluding June and July for which surface water irrigation is supply-limited. In that this scenario is hypothetical, structured to look at isolated changes as opposed to presenting a “viable” alternative, a mechanism for providing water in the supply-limited months is not addressed here.

4.1.3 Scenario 3: CUFA Diversions, Increased Riparian Vegetation

Under this scenario, CUFA diversions are simulated as are described for Scenario 1 and the resulting river flow (“CUFA Flow”) is as shown in Figure 4.3. In addition, it assumed that the extent of riparian vegetation increases by 30% at unspecified locations.

This scenario is implemented by modifying the assignment of River Packages as described in Section 4.1.1 for Scenario 1 to handle changes in river width and stage associated

with the decreased river flows associated with CUFA diversions. To represent the increased riparian demand of 30%, the simulated rates of evapotranspiration are increased by 30%, as a proxy for increasing the riparian acreage by 30% with a similar spatial distribution as currently exists. Although this scenario will result in declines to groundwater elevations and corresponding increased channel losses and/or decreased channel gains, for purposes of illustrating impacts associated with a specific change, no mitigation activities are simulated.

4.2 Results

4.2.1 Scenario 1: CUFA Diversions

Maps of change in depth-to-groundwater from the Baseline Condition are shown on Figures 4.4 and 4.5, representing the end of the peak winter run-off and the end of a summer dry period. Figure 4.4 shows the groundwater level change at the end of Stress Period 5 (February 25), following a period of CUFA diversions of 11,600 acre-feet occurring largely during the period between February 3 to 25, with minor CUFA diversions also occurring January 11 to 14. Across most of the valley area, the winter groundwater elevation decreases by an amount of less than one half foot from the baseline levels shown on Figure 3.2. Decreases in groundwater elevation exceeding a half foot but generally less than one foot are shown towards the northern part of the modeled region. Figure 4.5 shows the change in groundwater levels at the end of the summer dry period from the Baseline Condition. Groundwater levels decrease by a maximum of 0.02 feet from the Baseline Condition at the end of Stress Period 12, that is, at the end of July. The simulated changes suggest that the occurrence of CUFA diversions of the magnitude reflected in this scenario are largely manifested shortly after their occurrence, and that there was negligible impact to the groundwater levels in the subsequent summer dry season.

Sub-reach river gains and losses¹ are shown on Table 4.1, including change from the Baseline Condition gains/losses. Overall river gains throughout the course of the year do not vary by more than a few percent between the Baseline Condition and Scenario 1; however, changes over the short term are noticeable. For example, in Stress Period 5, where the Baseline flow is reduced from 500 cfs to 250 cfs in the CUFA Scenario, river gains increase for the

¹ The gains/losses discussed in this report refer to seepage through the channel bed, apart from operational surface water diversions, tailwater or other surface water inflows or returns.

duration of the CUFA reduction. This occurs as a result of lower river stage during the lower flow period which favors a subsurface gradient towards the stream. On the other hand, without the CUFA diversion, a larger bank storage return is noted in the period immediately following the peak flow (Stress Period 6), which is dampened in the CUFA scenario. In the case of both the Baseline and the CUFA scenario, groundwater-surface water interactions are dominated by river gains, largely as a result of canal seepage, the percolation of applied irrigation water, and additional contributions of tributary and regional subsurface flow.

Under this scenario, there are no additional shortages in meeting crop demand beyond those that would occur under the Baseline Scenario because no CUFA-based flow reductions occurred during periods approximated at or below the flow level of 75 cfs. Shortage conditions are not expected when river flow levels are above a threshold range of about 50 to 60 cfs.

4.2.2 Scenario 2: CUFA Diversions, Increased Irrigated Agriculture

Maps of change in depth-to-groundwater from the Baseline Condition are shown on Figures 4.6 and 4.7, representing the end of the peak winter run-off and the end of a summer dry period. In addition to reflecting the impacts of CUFA diversions as simulated in Scenario 1, these results also include the impacts of increased consumptive use associated with the increase in irrigated agriculture which are simulated for all irrigation-season months except June and July, when surface water supplies are inadequate to support the additional irrigation demand. Similar to the results shown for Scenario 1, Figure 4.6 shows the groundwater level change at the end of Stress Period 5 (February 25), following a period of CUFA diversions of 11,600 acre-feet occurring largely during the period between February 3 to 25, with minor CUFA diversions also occurring January 11 to 14. Changes at this point in time are no different than those of Scenario 1, as increased irrigated agriculture does not impact the winter period. Figure 4.7 shows the change in groundwater levels at the end of the summer dry period from the Baseline Condition. Changes occur in varying but small amounts with a maximum decrease in groundwater level of less than 0.1 foot from the Baseline Condition. However, it should be recalled that no mechanism was provided for addressing shortage to irrigated agriculture in the months of June and July under this scenario. If groundwater pumping were implemented to address the shortage conditions, additional groundwater declines would be observed.

Sub-reach river gains and losses are shown on Table 4.2 for this scenario, including change from the Baseline Condition gains/losses. Largely, the differences are associated with short-term timing and overall net gains are similar to those for the Baseline Condition. However, an overall reduction occurs from the net gains seen in Scenario 1, on the order of the increased consumptive and incidental water use of the hypothetical additional irrigated acreage, which is simulated as approximately 540 acre-feet, excluding the supply-limited months of June and July.

The shortage in June and July would represent unmet demand for 25% of the existing acreage, or 313 acres, and for the hypothetical additional 30%, or 375 acres. The shortage for the existing acreage, discussed in Section 3.3.1, includes deficit ditch diversions for carriage and system operation in addition to crop irrigation requirements; the combined deficit is assumed to be 12.5 cfs (25% of a 50 cfs total diversion requirement), or, approximately 1,508 acre-feet over the two month period. In addition to this shortage, a CIR-based shortage is assumed for the additional 375 acres irrigated under Scenario 2. For the months of June and July under this scenario, the additional CIR-based shortage is estimated at 259 acre-feet, using monthly CIR of 0.38 and 0.31, respectively (from 2007 monthly accounting), or, 298 acre-feet, including the assumed incidental losses associated with the additional irrigated acreage. The total shortage, including that of the existing acreage and the hypothetical additional acreage, is estimated at 1,806 acre-feet over the two-month period, or, 15 cfs.

4.2.3 Scenario 3: CUFA Diversions, Increased Riparian Vegetation

Maps of change in depth-to-groundwater from the Baseline Condition are shown on Figures 4.8 and 4.9, representing the end of the peak winter run-off and the end of a summer dry period. Similar to the results shown for Scenario 1 and 2, Figure 4.8 shows the groundwater level change at the end of Stress Period 5 (February 25), following a period of CUFA diversions of 11,600 acre-feet occurring largely during the period between February 3 to 25, with minor CUFA diversions also occurring January 11 to 14. Changes at this point in time are no different than those of Scenario 1, as increased riparian vegetation does not impact the winter period. Figure 4.9 shows the change in groundwater levels at the end of the summer dry period as compared to the Baseline Condition. In addition to reflecting the impacts of CUFA diversions as simulated in Scenario 1, these results include the impacts of a 30% increase riparian vegetation demand. Decreases in the groundwater elevations are subtle.

typically less than 0.1 foot, but range up to 0.2 feet in some locations at the end of July (Stress Period 12).

Sub-reach river gains and losses are shown on Table 4.3 for this scenario, as a change from the Baseline Condition gains/losses. The most apparent differences are those associated with short-term timing, as were noted above with respect to Scenario 1. Beyond those impacts, the overall net river gain in this scenario is reduced by the additional consumptive use of riparian vegetation, approximately 950 acre-feet per year, with greatest differences occurring in the summer months when the evapotranspiration rates are highest. These changes can be seen in differences in gains from the Baseline Condition between Scenario 1 and 3 (comparing the Scenario – Baseline column in Tables 4.1 and 4.3) which are on the order of a couple cubic per second in the May through September timeframe.

5.0 DISCUSSION

The riparian groundwater model used for the illustrative scenarios described in this report is a high-resolution, three-dimensional groundwater flow model that incorporates flow-dependent river boundary conditions based on output from a HEC-RAS surface water models. The handling of the river boundary in the groundwater model allows for calculation of river seepage losses/gains through various model sub-reaches. These surface water-groundwater exchanges are dynamic, varying spatially and temporally according to water use patterns and river flow conditions. The groundwater model includes a very detailed representation of riparian vegetation areas, irrigated crop areas and major canals. The model calibration was revisited as part of this study and several model refinements were made based on information acquired since the initial model development in 2010. Simulation results for a set of alternative scenarios include changes in the depth to groundwater; and changes in river gains/losses.

The model accuracy is considered to be reasonably good for developing a general understanding of hydrologic conditions and the impacts of changes in river flows or land and water use. However, the model accuracy can be improved by continuing to incorporate data and field observations as they become available. Additional data is particularly important if the quantification of localized impacts is needed, for example, changes in groundwater elevations in the vicinity of a drought-sensitive wetland. Beyond refinement for improving local accuracy, linking the riparian groundwater model to the regional groundwater model and refining the latter may be important to some scenarios, for example, evaluation of change in land or water use beyond the riparian/irrigated area.

Specific field activities that are recommended to support continued improvement and application of the model include:

- River seepage investigations: Continue to conduct seepage runs both in the irrigation and non-irrigation seasons. Minor changes to measurement points can be recommended at this stage, based on the information gathered from the application of the models and to support analysis of specific sensitive local areas.
- Canal seepage and tailwater investigations: Existing data leave some uncertainty in the disposition of canal diversions throughout the irrigated areas and in the overall farm water budget, in general. A set of canal seepage runs conducted during the summer and during the winter would be useful for better understanding

the magnitude and spatial variation of canal seepage: this information is important for improving the understanding and quantification of river gains/losses at the sub-reach level. Additionally, careful documentation of locations and patterns of operational and tailwater returns to the river from the canals will support improvements in the accuracy of the model at the sub-reach or localized scale.

- Groundwater elevations: The model accuracy can be improved by continuing to collect groundwater elevation data at the TNC cross-section, and by supplementing these data by drilling and equipping similar piezometers elsewhere within the modeled area. Similarly, groundwater elevation monitoring at piezometer transects in other reaches should be continued.
- Channel thalweg surveying: Significant gaps remain in the acquisition of land-based survey data of channel conditions. While the 2010 LiDAR survey provided excellent coverage of non-channel areas, because LiDAR does not provide elevations of the channel bottom below the water surface, the LiDAR data must be supplemented by surveyed channel thalweg or cross-section data. Due to lack of landowner access, only a limited number of cross-sections were surveyed in 2010. Obtaining surveyed thalweg elevations at relatively fine intervals, i.e., every 500 feet, throughout the entire model reach would greatly enhance the accuracy of the existing model on a local scale.
- IIEC-RAS modeling: The IIEC-RAS models provide a good indication of channel depth and width for a range of flow levels. Accuracy can be improved by obtaining additional survey data, as discussed above. Additionally, the accuracy of low flow conditions and the groundwater-river boundary can be improved by additional IIEC-RAS simulations in the low flow range that incorporate river loss assumptions that are being developed through the combination of field investigation and groundwater simulation.

The scenarios described in this report provide a general indication of the hydrologic impacts that would be associated with the changes simulated, using an annual hydrograph (Baseline Condition) patterned from a year in the historical record that is within an average range for annual flow volume and slightly above average in terms of the associated, hypothetical, CUFA diversions. To evaluate other changes or sets of changes, perhaps coupled with mitigation strategies, similar simulations can be structured and compared against the Baseline Condition as developed for this analysis. In some cases, it may be of interest to make a comparison using a very wet or a very dry year as a baseline; to that end, other years from the historical record can be selected and simulated as alternate baselines.

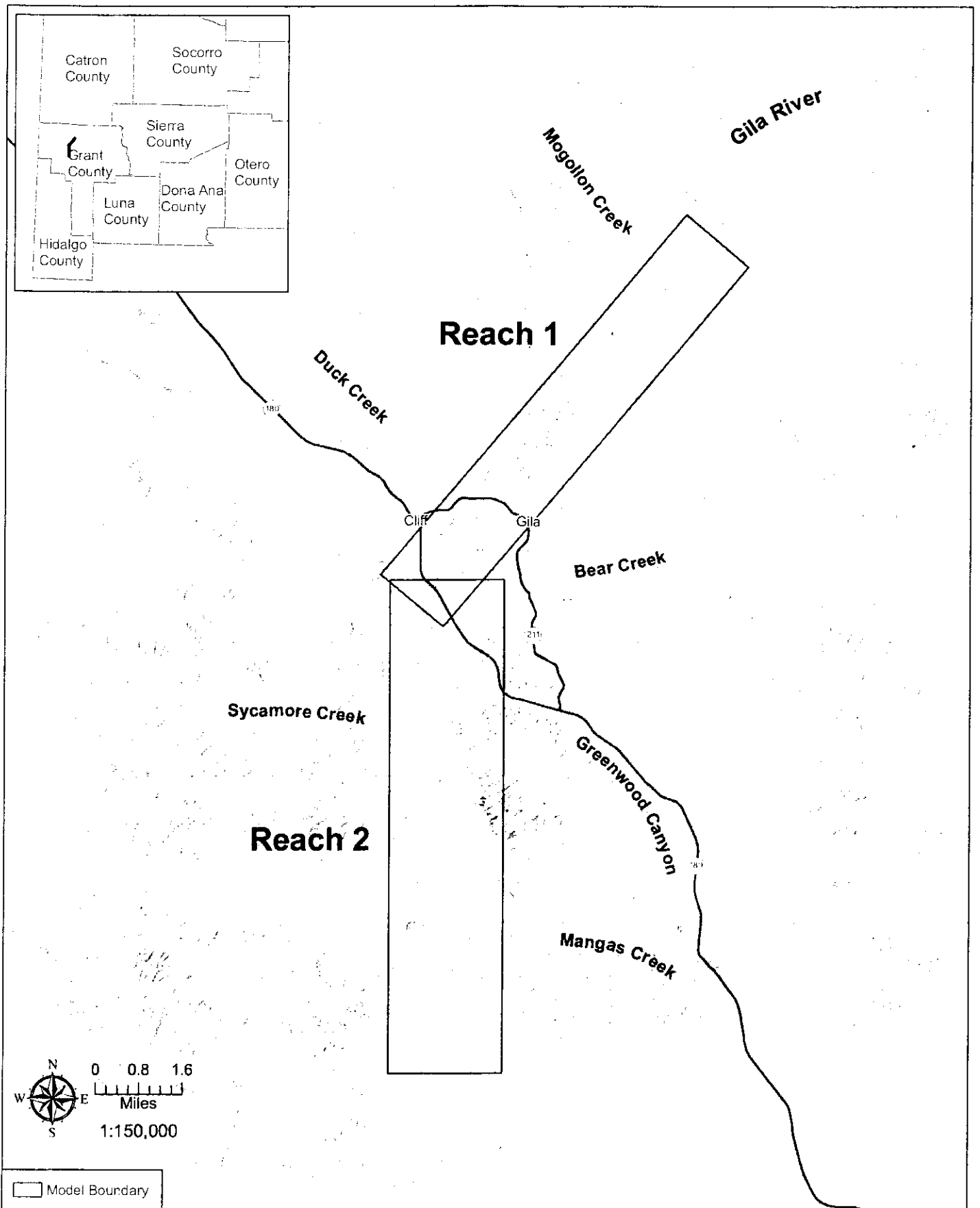
The scenarios presented are not intended to cover a full range of potential conditions or alternatives, but provide a sense of the type and magnitudes of changes that might be associated

with the featured modifications. These analyses are informative for understanding impacts at a conceptual level, and, for scoping additional, more specific, alternative analyses.

6.0 REFERENCES

- S.S. Papadopulos & Associates, Inc., 2010. *Analyses of Surface Water-Groundwater Interactions along the Gila River, Gila-Cliff Basin*. Report prepared for the New Mexico Interstate Stream Commission.

Figures



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Figure 1.1. Location of Riparian Groundwater Models, Reach 1 and Reach 2

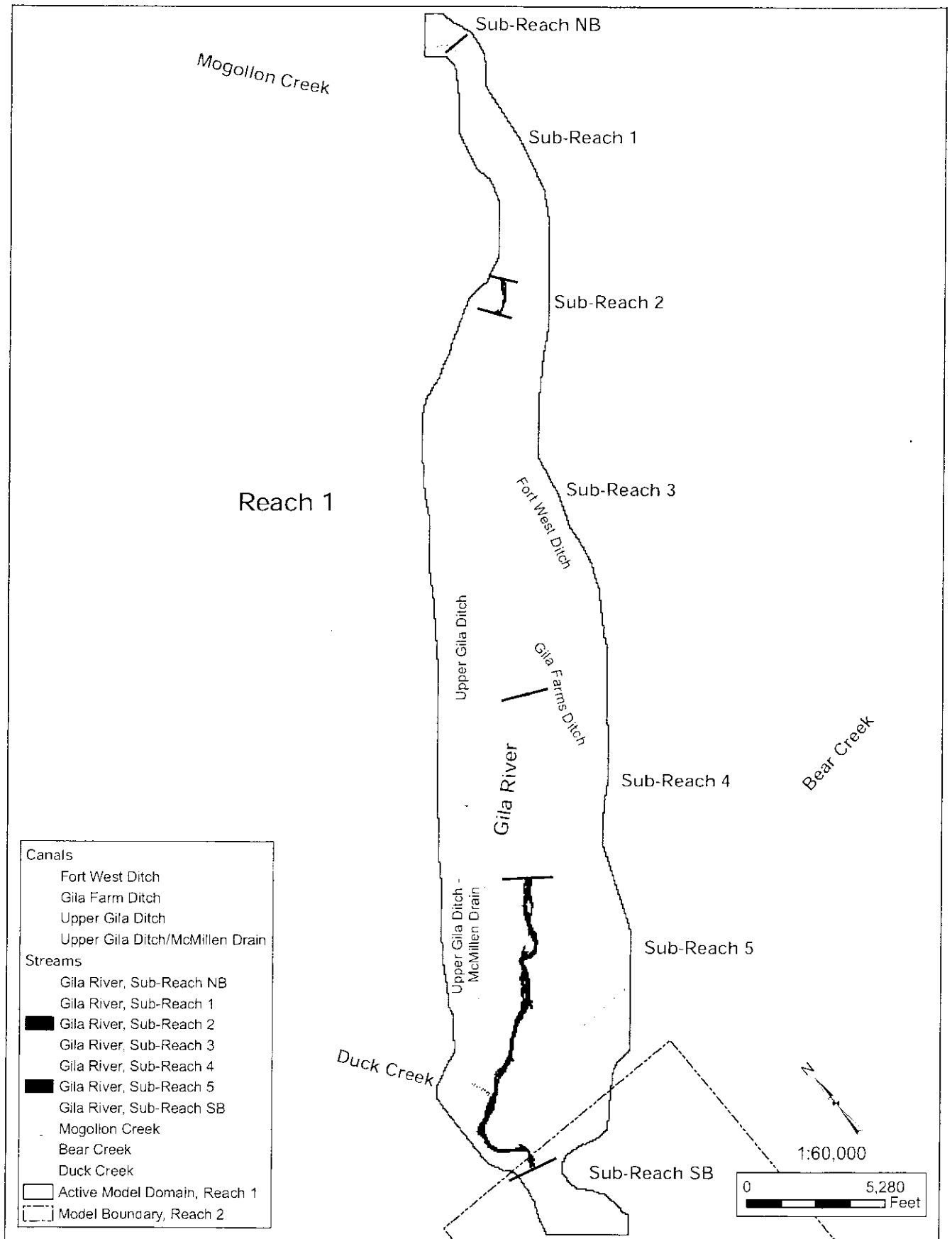


Figure 1.2 Gila River Sub-Reaches, Reach 1

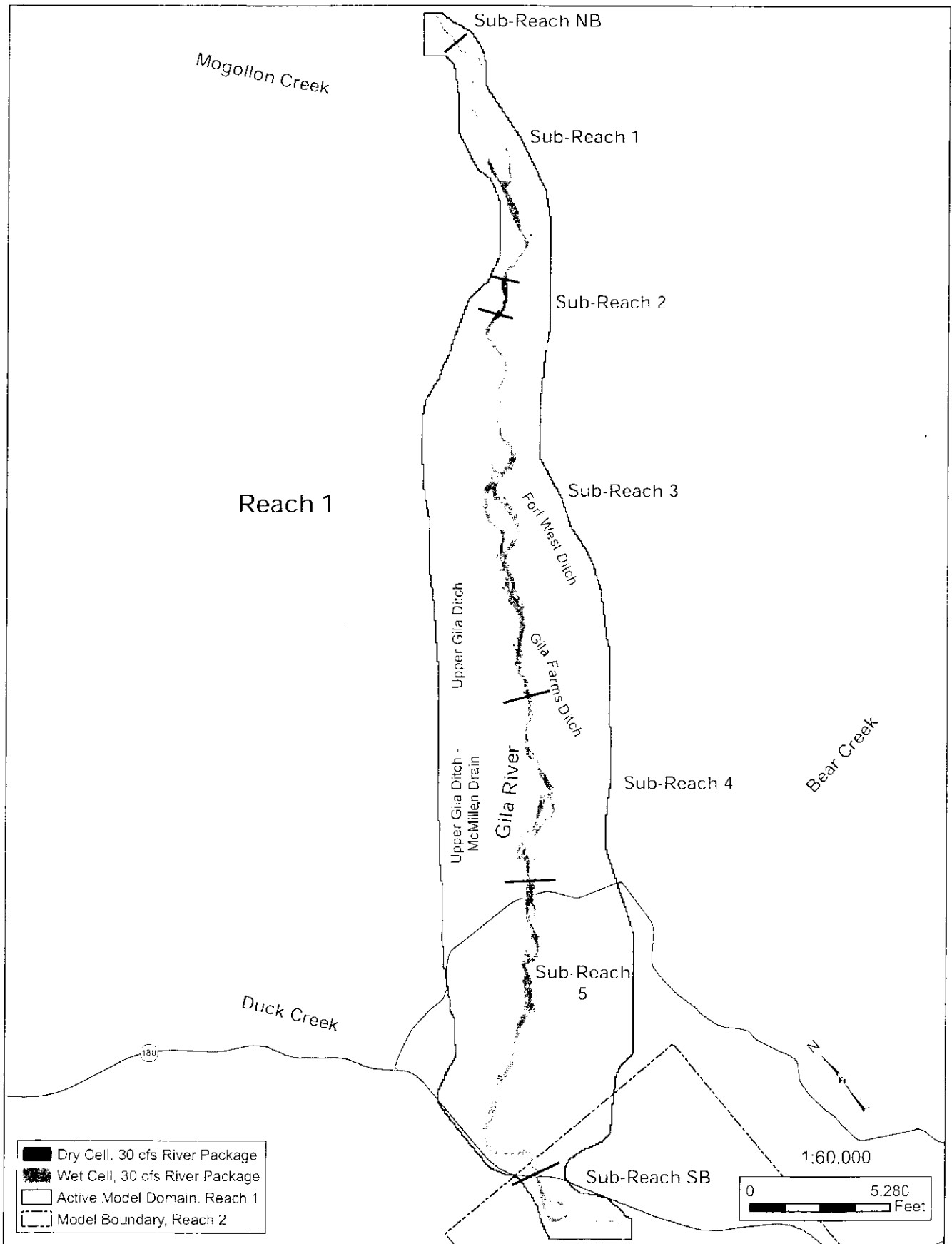


Figure 2.1 River Sub-Reaches for Simulated Seepage Calculations

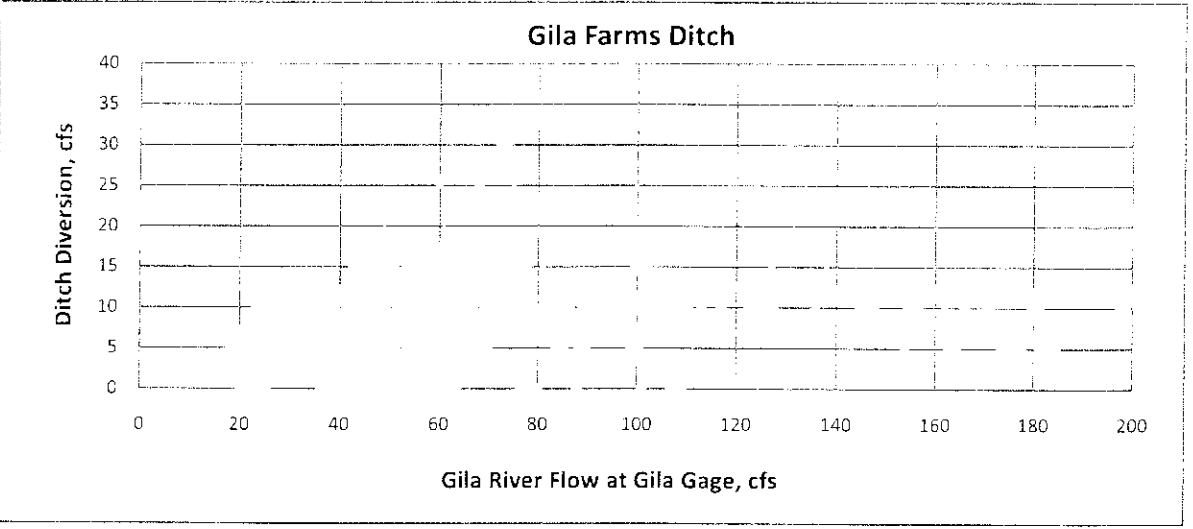
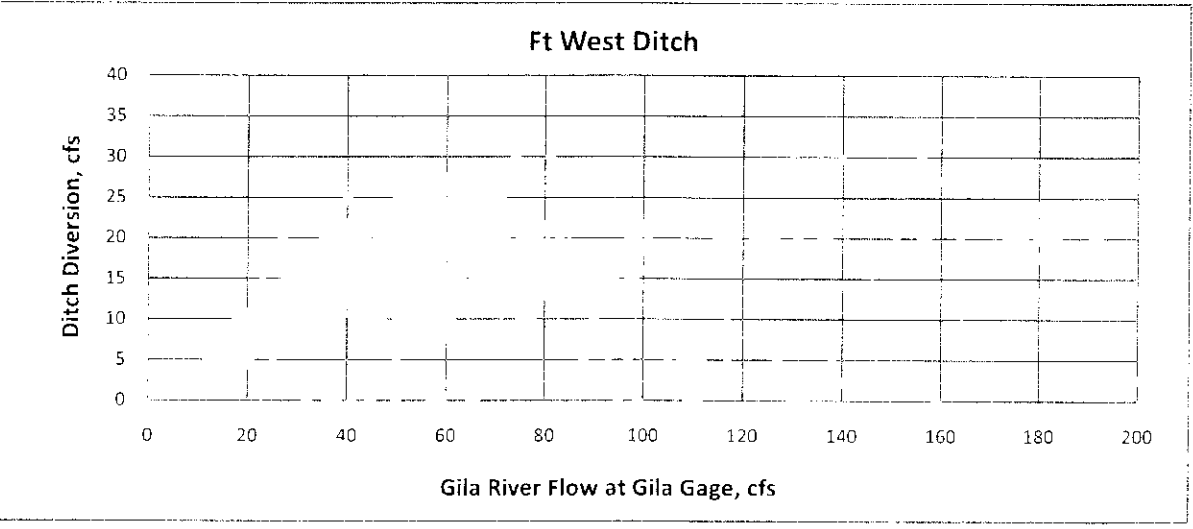
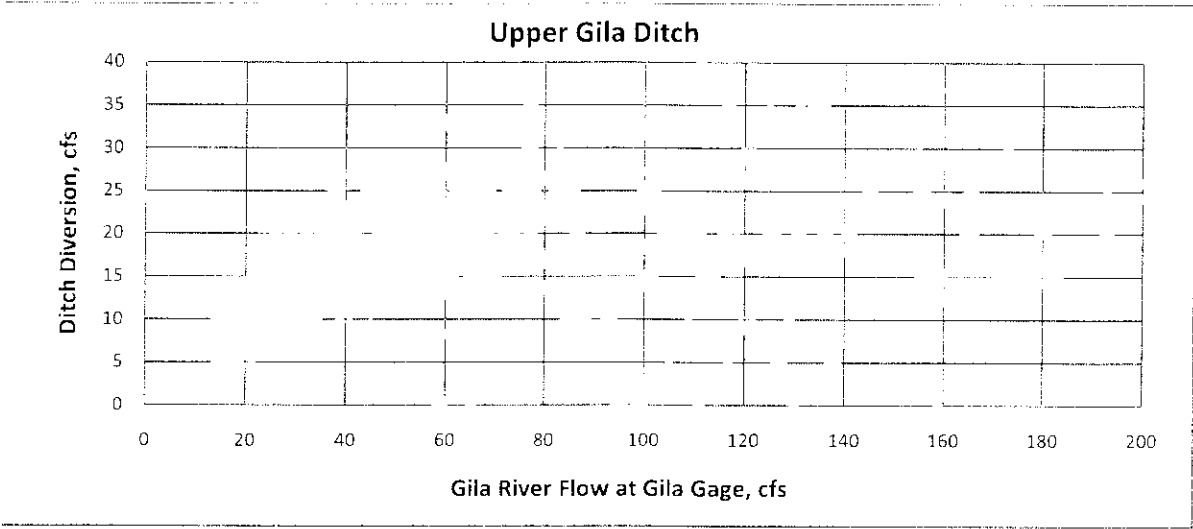


Figure 2.2. Ditch Diversions during Periods of Gila River Flow less than 200 cfs, 2000 to 2005, All Months

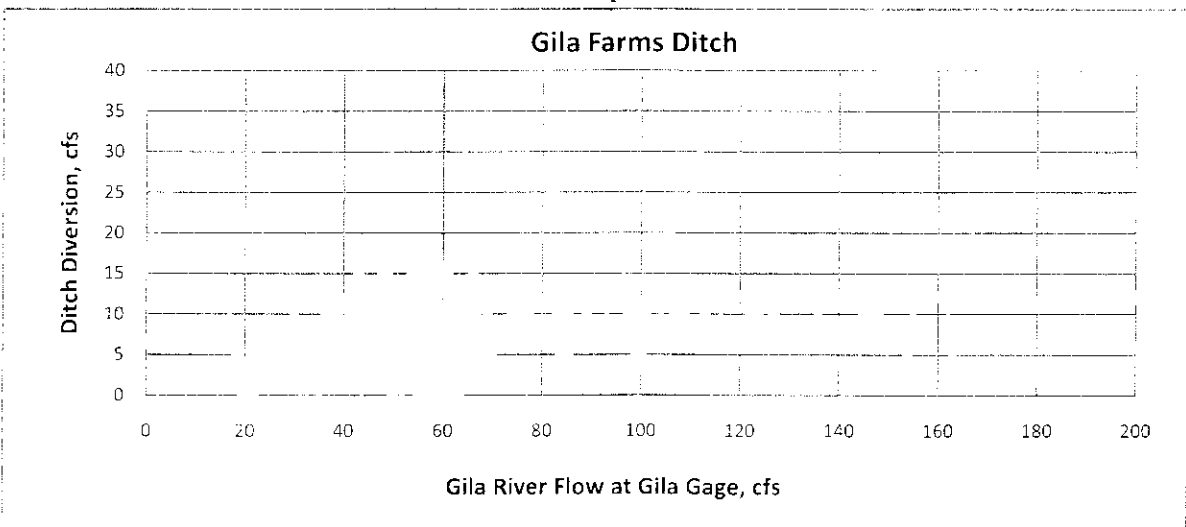
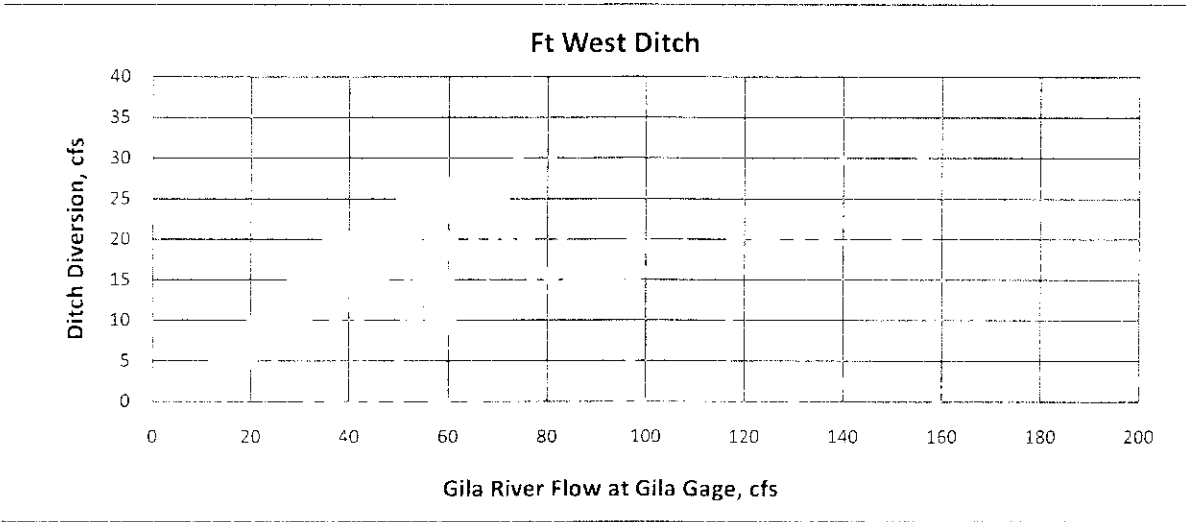
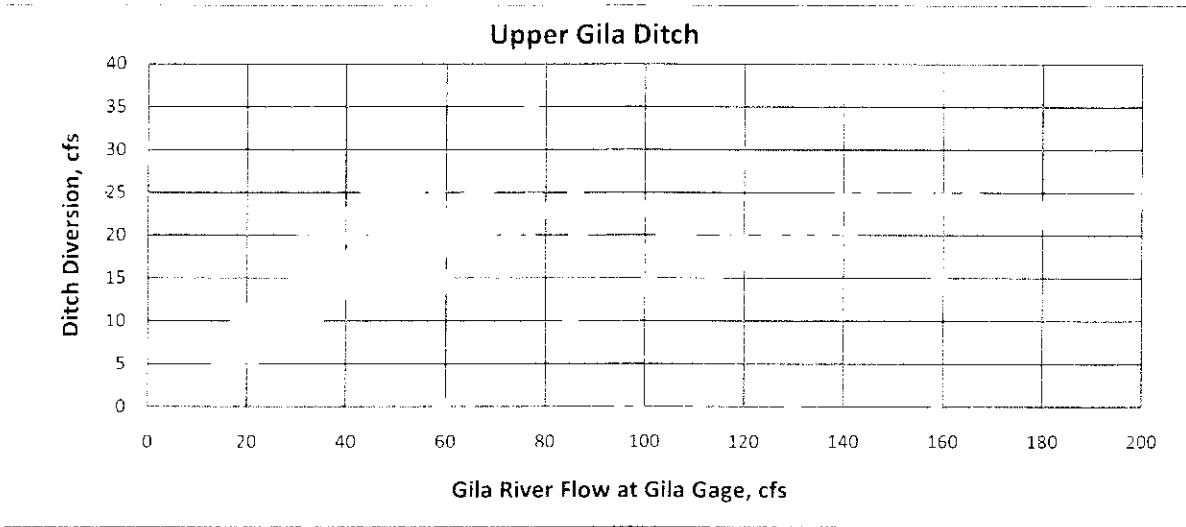
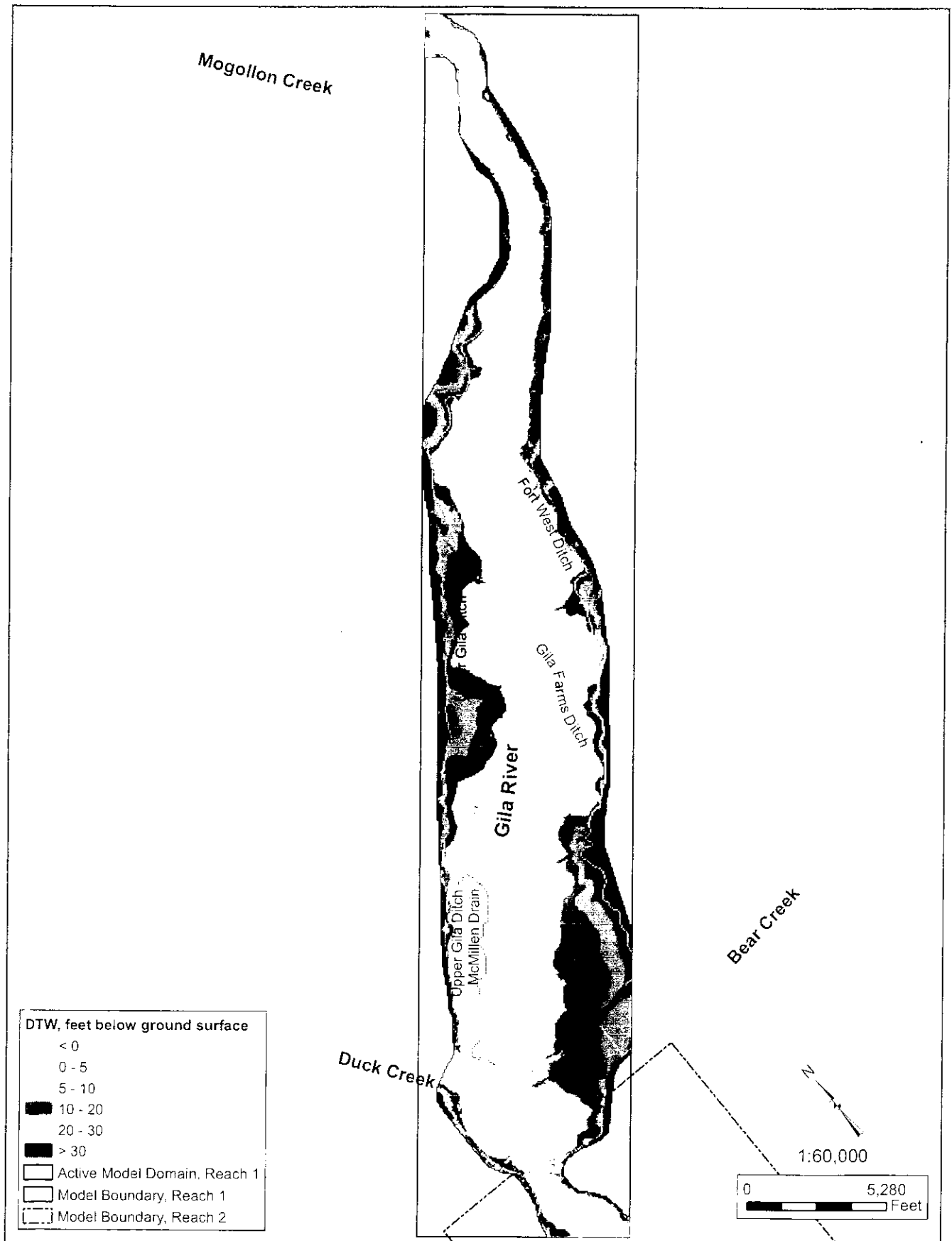


Figure 2.3. Ditch Diversions during Periods of Gila River Flow less than 200 cfs, 2000 to 2005, June to September.

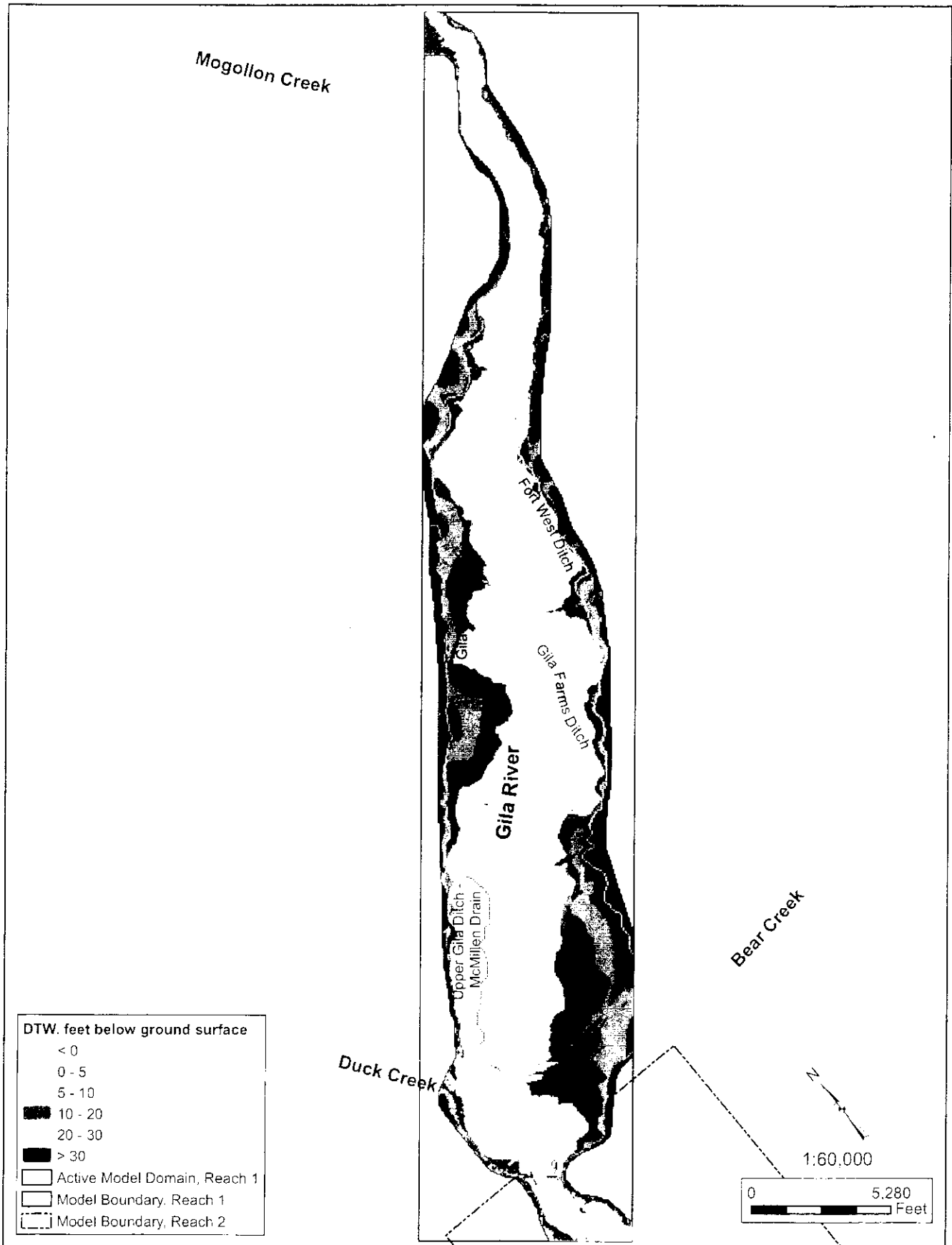


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Figure 3.2. Depth to Groundwater, Post-Winter Run-off, Baseline Condition

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Figure 3.3. Depth to Groundwater, Summer Dry Period, Baseline Condition

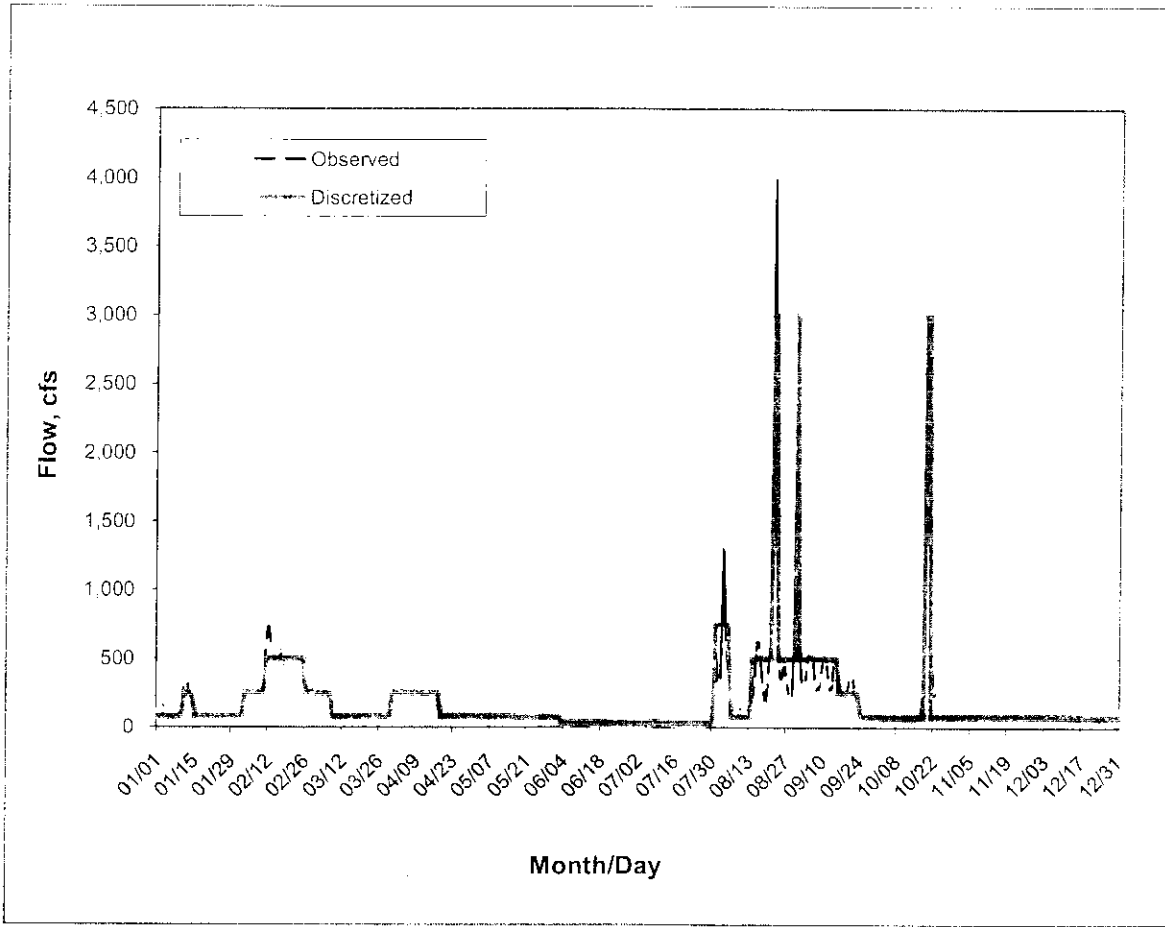


Figure 3.1. Discretized Gila River Hydrograph for Baseline Condition

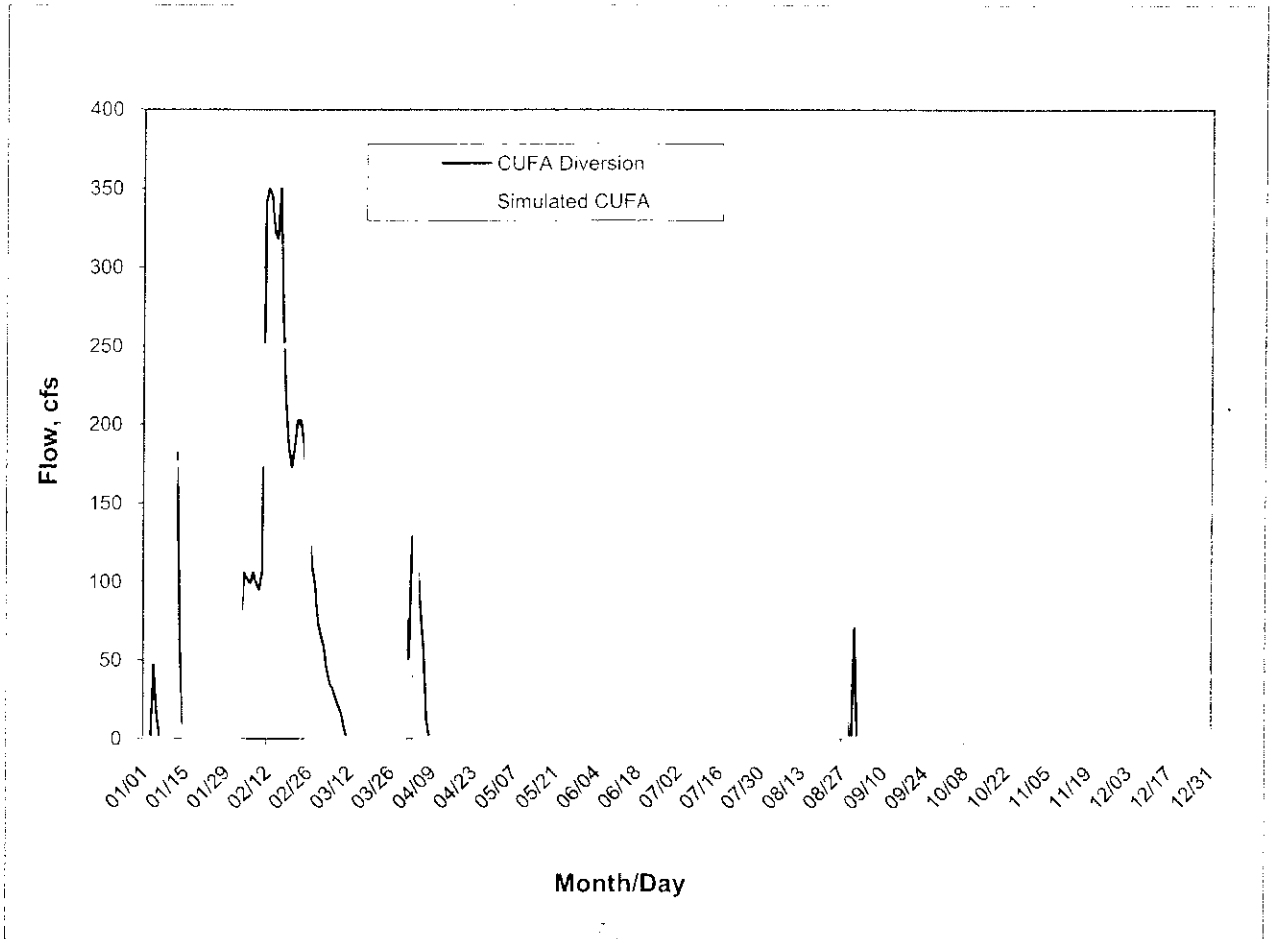


Figure 4.1. CUFA Diversion and Adjusted Step-Function Approximation

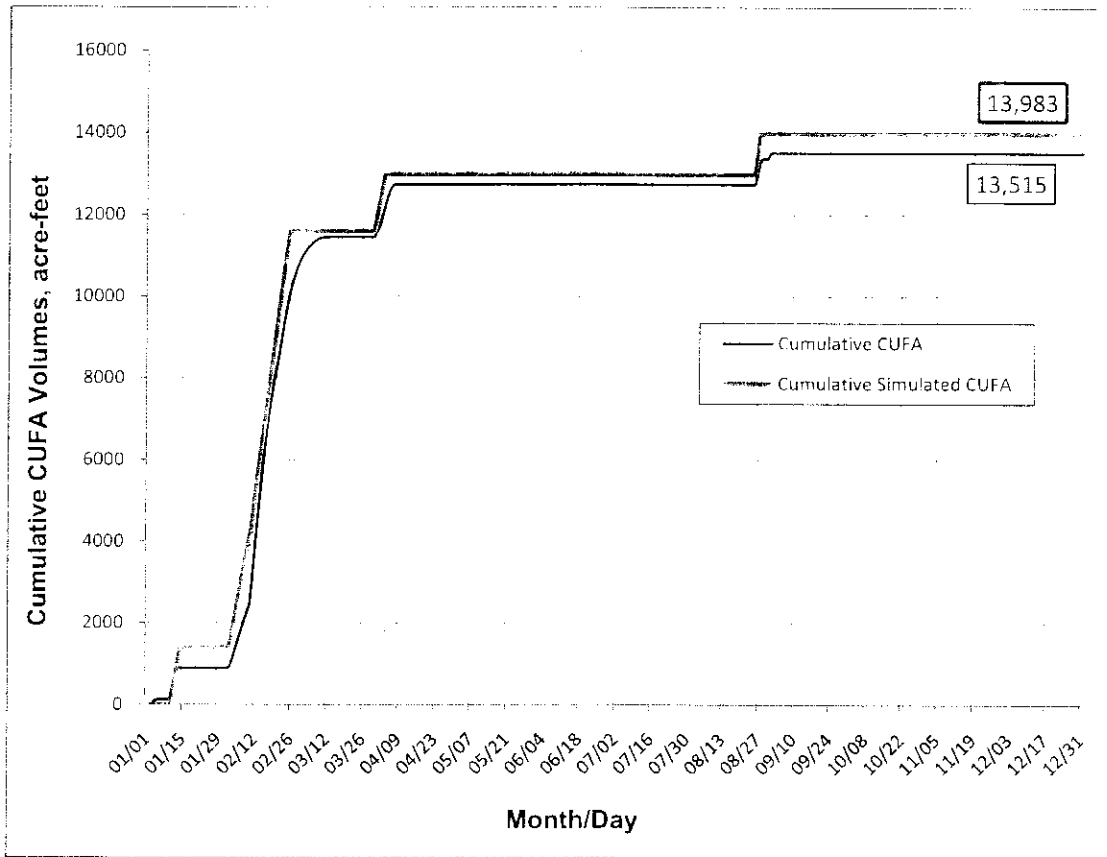


Figure 4.2. Cumulative CUFA and Simulated CUFA

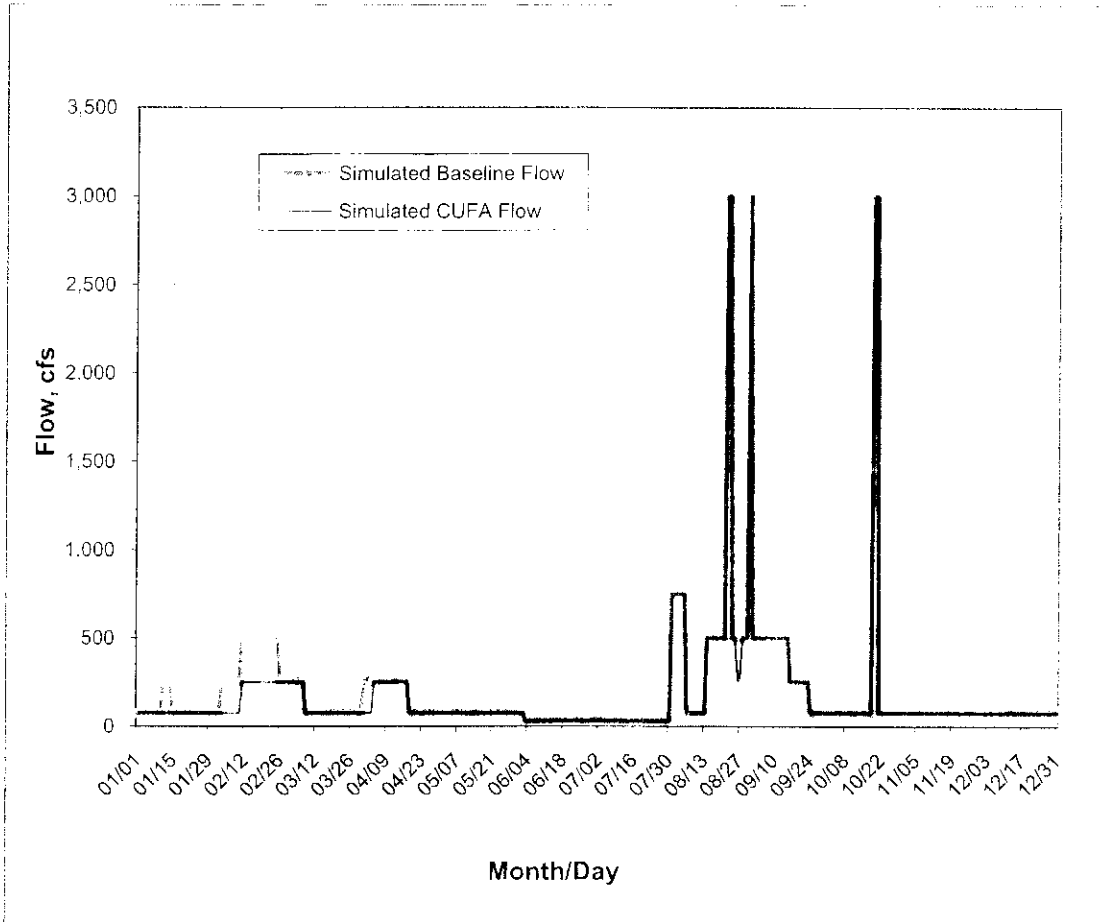
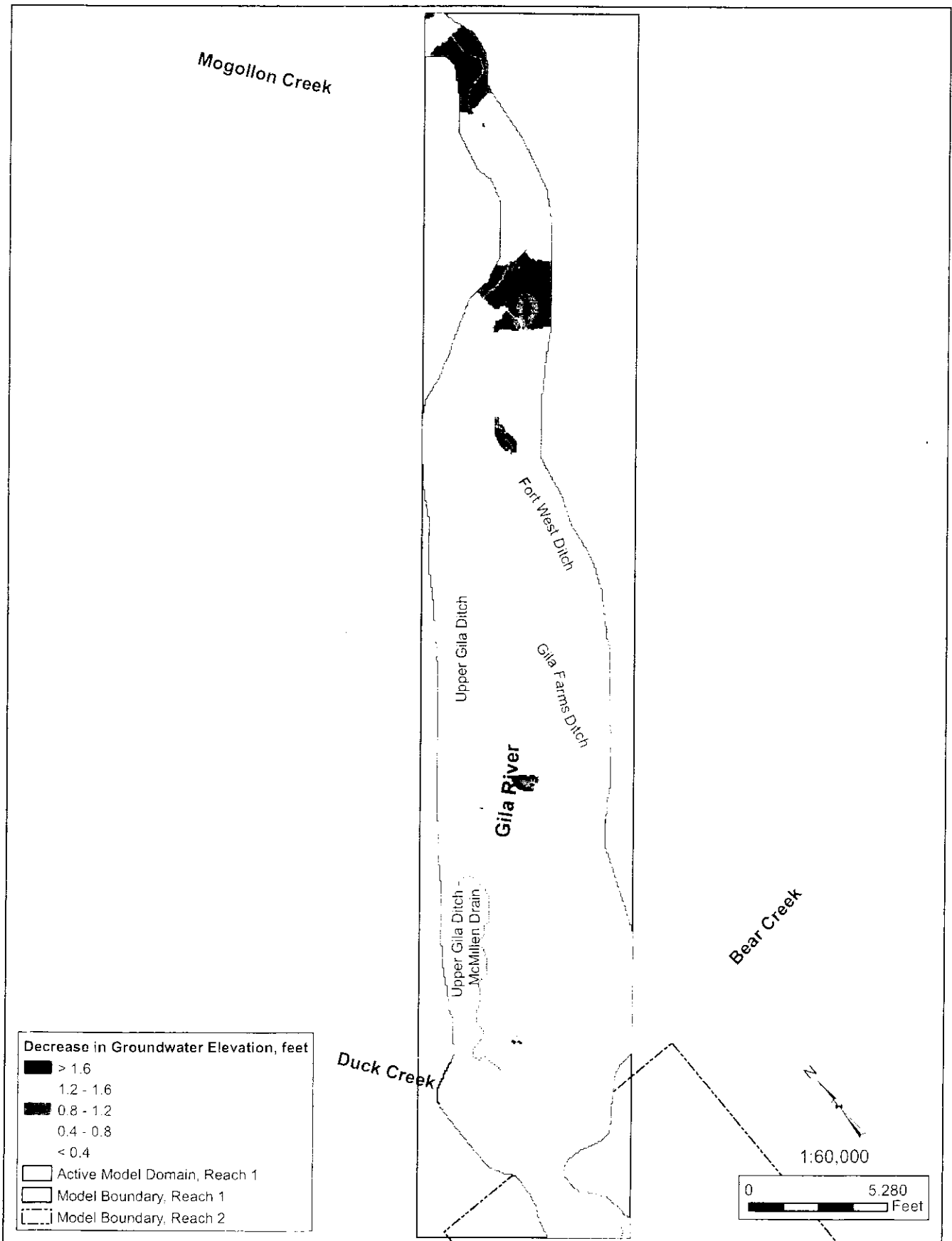
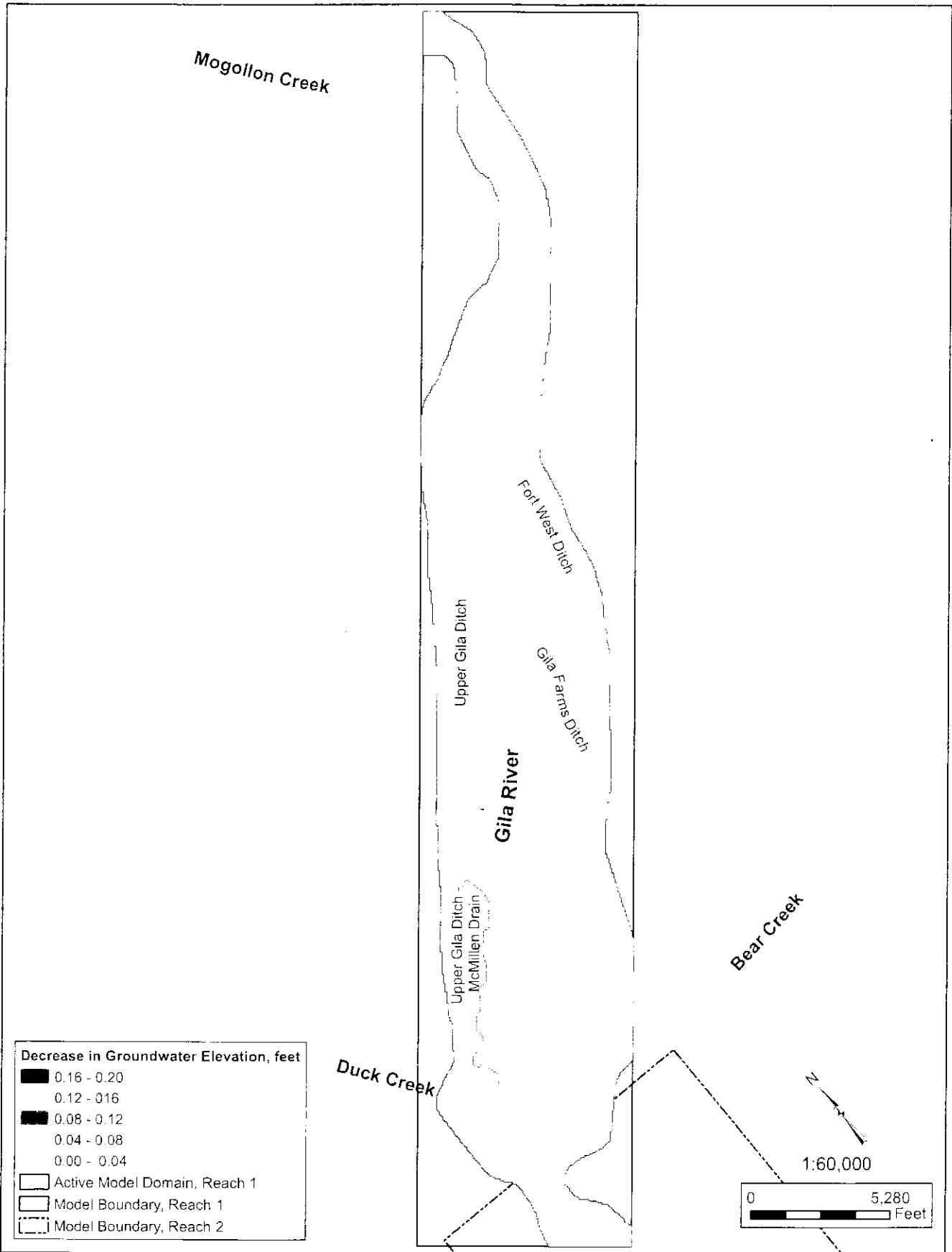


Figure 4.3. Simulated Baseline and CUFA River Flow



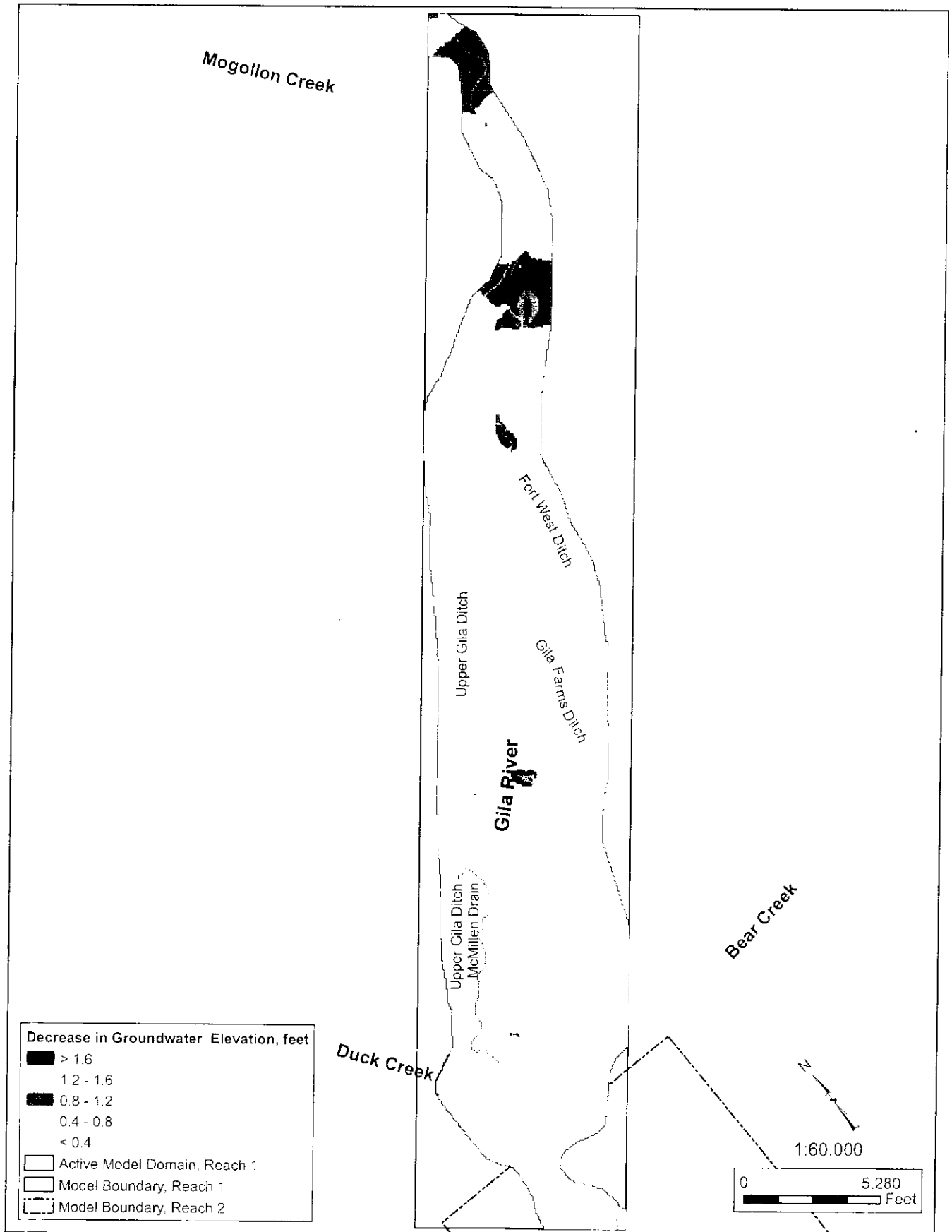
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Figure 4.4. Decrease in Groundwater Elevations, Post-Winter Run-off, Scenario 1



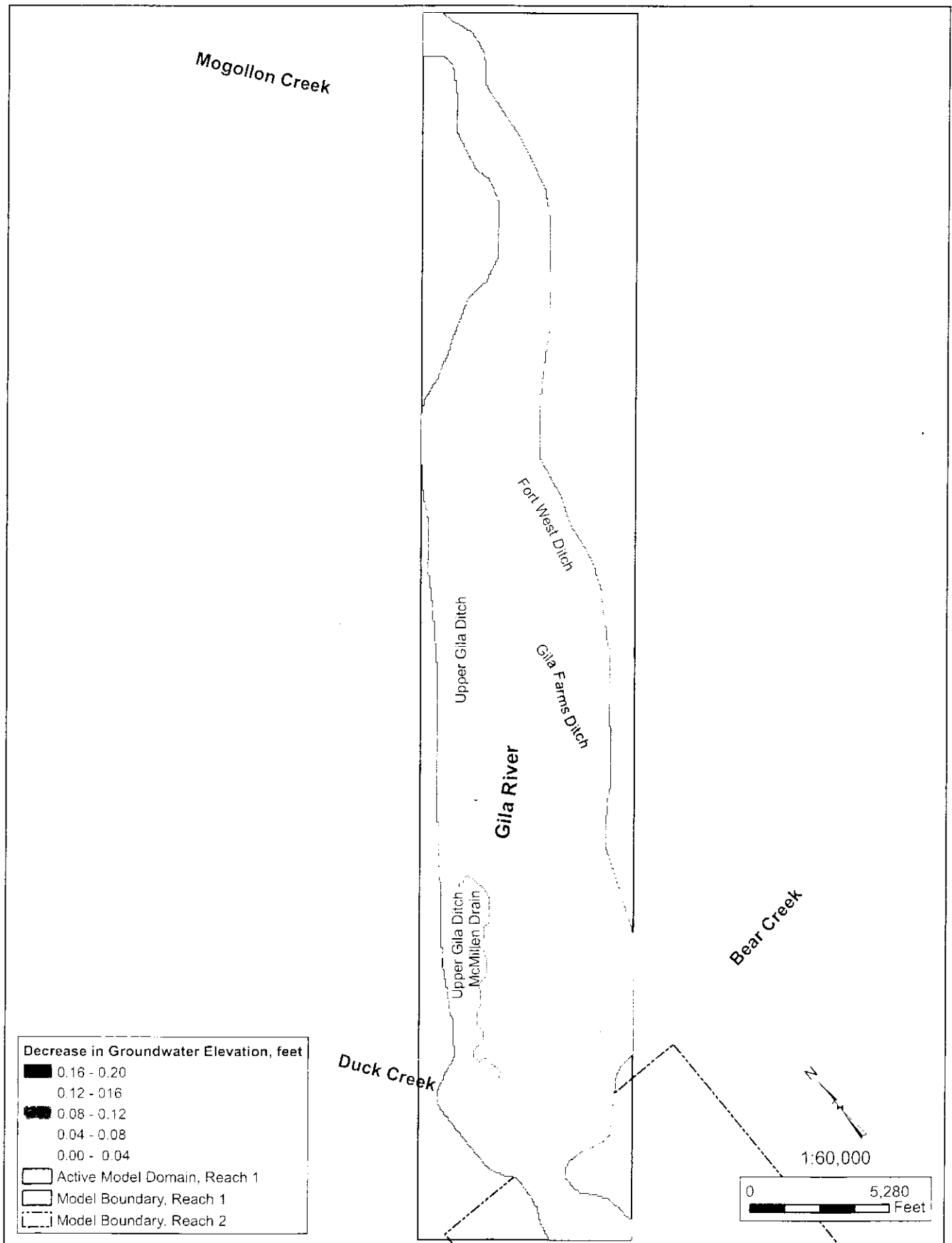
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Figure 4.5. Decrease in Groundwater Elevations, Summer Dry Period, Scenario 1



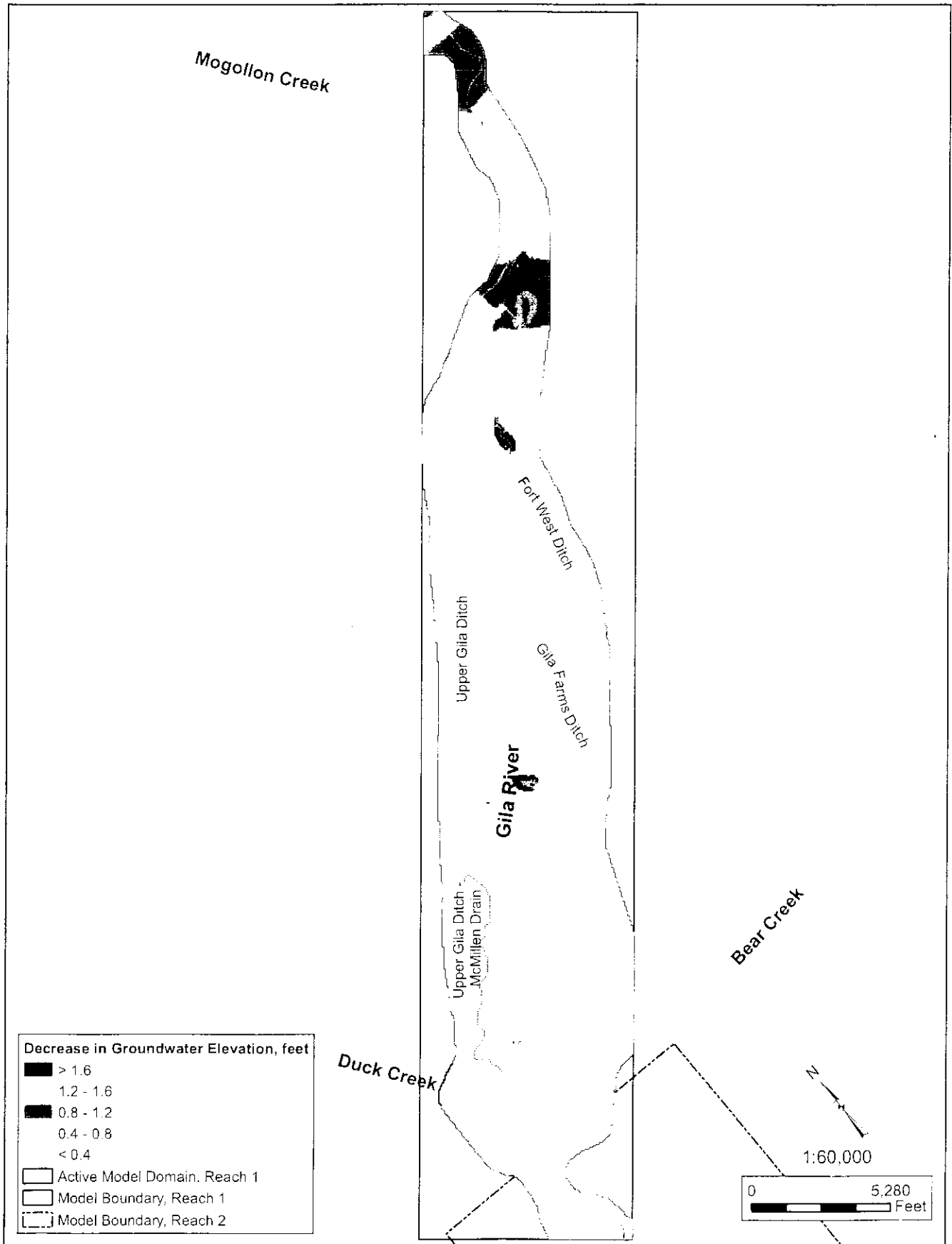
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Figure 4.6. Decrease in Groundwater Elevations, Post-Winter Run-off, Scenario 2



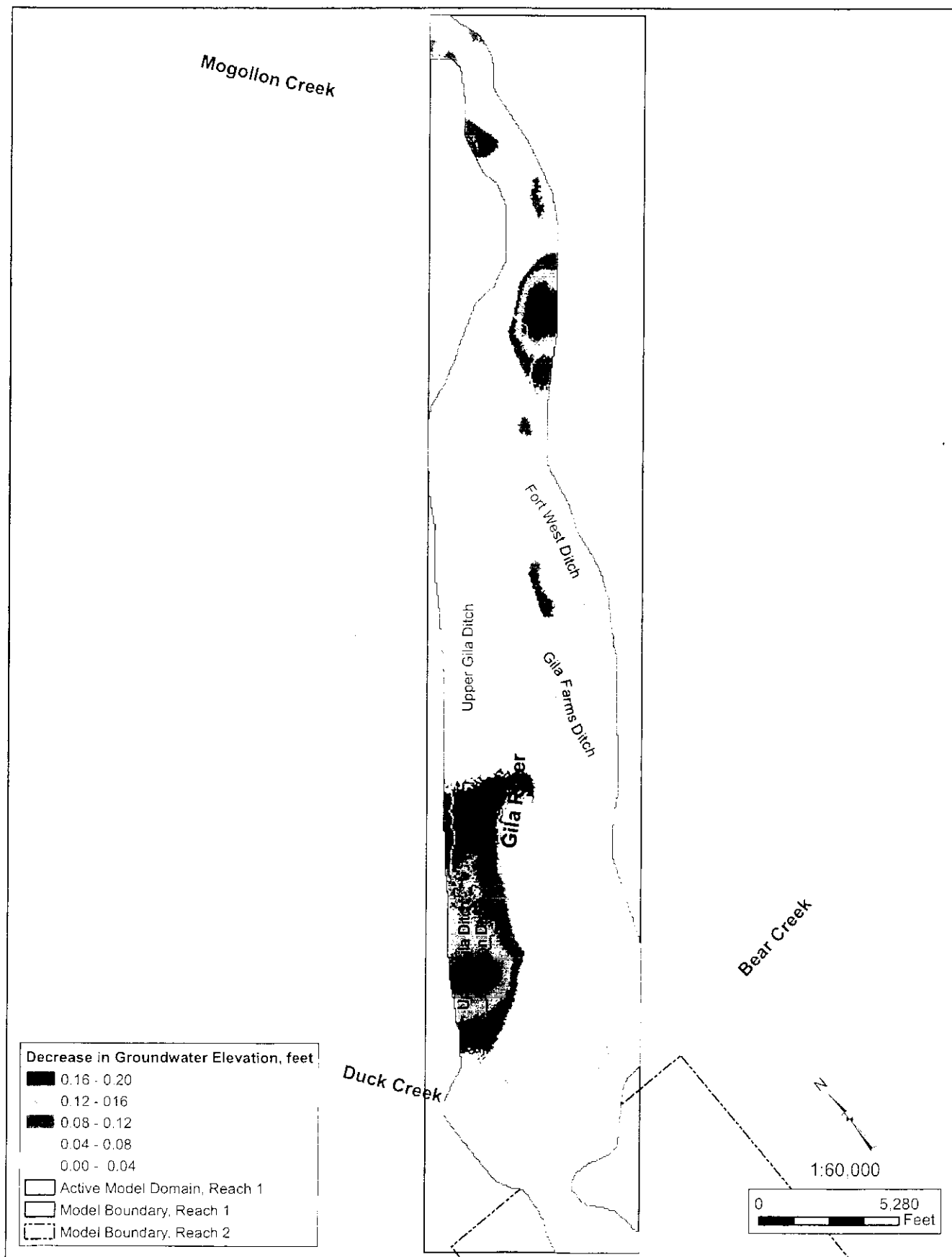
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Figure 4.7. Decrease in Groundwater Elevations, Summer Dry Period, Scenario 2



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Figure 4.8. Decrease in Groundwater Elevations, Post-Winter Run-off, Scenario 3



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Figure 4.9. Decrease in Groundwater Elevations, Summer Dry Period, Scenario 3

Tables

**Table 3.1
Annual Gila River Flow and Hypothetical CUFA Diversions**

Year	Gila River Flow, acre-feet	CUFA Diversion, acre-feet
1936	14,507	0
1937	180,984	44,569
1938	71,032	4,005
1939	70,003	0
1940	134,221	8,120
1941	382,048	63,660
1942	100,629	6,821
1943	57,021	1,803
1944	54,180	2,473
1945	89,776	8,567
1946	52,048	0
1947	40,782	0
1948	69,408	0
1949	255,138	48,551
1950	34,138	0
1951	35,800	0
1952	184,988	36,411
1953	39,882	0
1954	76,558	5,986
1955	73,087	8,007
1956	25,585	0
1957	105,991	11,691
1958	260,019	29,347
1959	92,444	10,830
1960	143,649	30,319
1961	98,430	7,418
1962	202,889	22,899
1963	138,551	13,515
1964	67,016	1,860
1965	228,627	12,133
1966	203,498	0
1967	157,144	8,346
1968	311,062	3,658
1969	64,657	962
1970	56,053	169
1971	98,170	8,273

Year	Gila River Flow, acre-feet	CUFA Diversion, acre-feet
1972	234,415	21,410
1973	337,523	50,303
1974	48,601	996
1975	150,329	33,828
1976	66,670	5,447
1977	50,390	0
1978	361,301	18,609
1979	338,467	135
1980	212,511	996
1981	59,314	36
1982	105,029	16,253
1983	607,285	54,508
1984	193,402	10,195
1985	305,022	6,377
1986	141,832	24,095
1987	174,016	5,587
1988	198,252	8,700
1989	56,981	1,295
1990	73,751	5,839
1991	303,130	7,164
1992	328,768	5,558
1993	572,680	10,824
1994	157,335	17,925
1995	206,043	17,328
1996	81,487	8,604
1997	102,417	24,331
1998	150,123	20,489
1999	107,038	16,869
2000	178,381	7,073
2001	85,765	10,957
Average	155,428	12,305
Median	106,514	7,713

Table 3.2
Step-Function River Flow Levels for the Baseline and CUFA Simulations

Stress Period	Duration, days	Start Date	End Date	Baseline Flow Level, cfs	CUFA Flow Level, cfs
1	10	Jan-1	Jan-10	75	75
2	4	Jan-11	Jan-14	250	75
3	19	Jan-15	Feb-2	75	75
4	8	Feb-3	Feb-10	250	75
5	15	Feb-11	Feb-25	500	250
6	10	Feb-26	Mar-7	250	250
7	15	Mar-8	Mar-22	75	75
8	8	Mar-23	Mar-30	75	75
9	4	Mar-31	Apr-3	250	75
10	14	Apr-4	Apr-17	250	250
11	46	Apr-18	Jun-2	75	75
12	58	Jun-3	Jul-30	30	30
13	6	Jul-31	Aug-5	750	750
14	8	Aug-6	Aug-13	75	75
15	8	Aug-14	Aug-21	500	500
16	2	Aug-22	Aug-23	3,000	3,000
17	2	Aug-24	Aug-25	500	500
18	2	Aug-26	Aug-27	500	250
19	3	Aug-28	Aug-30	500	500
20	1	Aug-31	Aug-31	3,000	3,000
21	15	Sep-1	Sep-15	500	500
22	8	Sep-16	Sep-23	250	250
23	25	Sep-24	Oct-18	75	75
24	2	Oct-19	Oct-20	3,000	3,000
25	72	Oct-21	Dec-31	75	75

Note: Step-function flow levels correspond to the River Package input files used to identify river boundary conditions for the groundwater model

**Table 3.3
Riparian Evapotranspiration Scaling Factors**

Stress Period	Duration, days	Start Date	End Date	Baseline Flow Level, cfs	Weighted ET Scaling Factor⁽¹⁾
1	10	Jan-11	Jan-10	75	0.00
2	4	Jan-11	Jan-14	250	0.00
3	19	Jan-15	Feb-2	75	0.00
4	8	Feb-3	Feb-10	250	0.00
5	15	Feb-11	Feb-25	500	0.00
6	10	Feb-26	Mar-7	250	0.21
7	15	Mar-8	Mar-22	75	0.30
8	8	Mar-23	Mar-30	75	0.30
9	4	Mar-31	Apr-3	250	0.53
10	14	Apr-4	Apr-17	250	0.60
11	46	Apr-18	Jun-2	75	1.28
12	58	Jun-3	Jul-30	30	2.40
13	6	Jul-31	Aug-5	750	2.20
14	8	Aug-6	Aug-13	75	2.16
15	8	Aug-14	Aug-21	500	2.16
16	2	Aug-22	Aug-23	3,000	2.16
17	2	Aug-24	Aug-25	500	2.16
18	2	Aug-26	Aug-27	500	2.16
19	3	Aug-28	Aug-30	500	2.16
20	1	Aug-31	Aug-31	3,000	2.16
21	15	Sep-1	Sep-15	500	1.68
22	8	Sep-16	Sep-23	250	1.68
23	25	Sep-24	Oct-18	75	0.99
24	2	Oct-19	Oct-20	3,000	0.72
25	72	Oct-21	Dec-31	75	0.21

(1) Factor by which each plant functional group's annual average evapotranspiration rate is adjusted for each stress period

Table 3.4
Simulated River Gains/Losses for Baseline Condition

Stress Period	Start Date	End Date	River Gain (-), Loss (+), cfs
1	Jan-1	Jan-10	-29.4
2	Jan-11	Jan-14	1.4
3	Jan-15	Feb-2	-34.5
4	Feb-3	Feb-10	-7.1
5	Feb-11	Feb-25	-9.3
6	Feb-26	Mar-7	-39.0
7	Mar-8	Mar-22	-41.7
8	Mar-23	Mar-30	-33.4
9	Mar-31	Apr-3	-0.6
10	Apr-4	Apr-17	-25.8
11	Apr-18	Jun-2	-30.9
12	Jun-3	Jul-30	-21.9
13	Jul-31	Aug-5	66.8
14	Aug-6	Aug-13	-44.2
15	Aug-14	Aug-21	12.3
16	Aug-22	Aug-23	173.5
17	Aug-24	Aug-25	-136.7
18	Aug-26	Aug-27	-22.3
19	Aug-28	Aug-30	-24.9
20	Aug-31	Aug-31	279.4
21	Sep-1	Sep-15	-43.2
22	Sep-16	Sep-23	-40.7
23	Sep-24	Oct-18	-38.4
24	Oct-19	Oct-20	244.6
25	Oct-21	Dec-31	-38.3

Table 4.1
Change in River Gains/Losses for Scenario 1
CUFA Diversions

Stress Period	Start Date	End Date	Baseline Flow Level, cfs	CUFA Diversion, cfs	Baseline River Gain (-)/Loss (+), cfs	Scenario River Gain (-)/Loss (+), cfs	Gain/Loss Difference, (Scenario-Baseline) (+) indicates lower gain or higher loss, cfs
1	Jan-1	Jan-10	75	0	-29.4	-29.4	0.0
2	Jan-11	Jan-14	250	175	1.4	-29.6	-31.0
3	Jan-15	Feb-2	75	0	-34.5	-29.7	4.9
4	Feb-3	Feb-10	250	175	-7.1	-29.9	-22.7
5	Feb-11	Feb-25	500	250	-9.3	-19.9	-10.6
6	Feb-26	Mar-7	250	0	-39.0	-27.9	11.1
7	Mar-8	Mar-22	75	0	-41.7	-39.5	2.1
8	Mar-23	Mar-30	75	0	-33.4	-32.2	1.2
9	Mar-31	Apr-3	250	175	-0.6	-31.2	-30.6
10	Apr-4	Apr-17	250	0	-25.8	-18.7	7.0
11	Apr-18	Jun-2	75	0	-30.9	-30.4	0.5
12	Jun-3	Jul-30	30	0	-21.9	-21.8	0.1
13	Jul-31	Aug-5	750	0	66.8	66.9	0.1
14	Aug-6	Aug-13	75	0	-44.2	-44.1	0.0
15	Aug-14	Aug-21	500	0	12.3	12.4	0.0
16	Aug-22	Aug-23	3,000	0	173.5	173.5	0.0
17	Aug-24	Aug-25	500	0	-136.7	-136.6	0.0
18	Aug-26	Aug-27	500	250	-22.3	-66.7	-44.3
19	Aug-28	Aug-30	500	0	-24.9	-7.9	17.1
20	Aug-31	Aug-31	3,000	0	279.4	283.3	4.0
21	Sep-1	Sep-15	500	0	-43.2	-42.8	0.4
22	Sep-16	Sep-23	250	0	-40.7	-40.6	0.2
23	Sep-24	Oct-18	75	0	-38.4	-38.4	0.1
24	Oct-19	Oct-20	3,000	0	244.6	244.7	0.1
25	Oct-21	Dec-31	75	0	-38.3	-38.3	0.0

Table 4.2
Change in River Gains/Losses for Scenario 2,
CUFA Diversions and Increased Irrigated Agriculture

Stress Period	Start Date	End Date	Baseline Flow Level, cfs	CUFA Diversion, cfs	Baseline River Gain (-), Loss (+), cfs	Scenario River Gain (-)/Loss (+), cfs	Gain/Loss Difference (Scenario-Baseline) (+) indicates lower gain or higher loss, cfs
1	Jan-1	Jan-10	75	0	-29.4	-29.4	0.0
2	Jan-11	Jan-14	250	175	1.4	-29.6	-31.0
3	Jan-15	Feb-2	75	0	-34.5	-29.7	4.9
4	Feb-3	Feb-10	250	175	-7.1	-29.9	-22.7
5	Feb-11	Feb-25	500	250	-9.3	-19.9	-10.6
6	Feb-26	Mar-7	250	0	-39.0	-27.9	11.1
7	Mar-8	Mar-22	75	0	-41.7	-39.5	2.1
8	Mar-23	Mar-30	75	0	-33.4	-31.9	1.6
9	Mar-31	Apr-3	250	175	-0.6	-30.6	-30.0
10	Apr-4	Apr-17	250	0	-25.8	-17.7	8.1
11	Apr-18	Jun-2	75	0	-30.9	-28.9	2.0
12	Jun-3	Jul-30	30	0	-21.9	-21.3	0.6
13	Jul-31	Aug-5	750	0	66.8	67.5	0.7
14	Aug-6	Aug-13	75	0	-44.2	-43.3	0.8
15	Aug-14	Aug-21	500	0	12.3	13.6	1.3
16	Aug-22	Aug-23	3,000	0	173.5	175.3	1.8
17	Aug-24	Aug-25	500	0	-136.7	-135.5	1.2
18	Aug-26	Aug-27	500	250	-22.3	-65.5	-43.2
19	Aug-28	Aug-30	500	0	-24.9	-6.4	18.5
20	Aug-31	Aug-31	3,000	0	279.4	285.6	6.2
21	Sep-1	Sep-15	500	0	-43.2	-41.3	1.9
22	Sep-16	Sep-23	250	0	-40.7	-39.1	1.7
23	Sep-24	Oct-18	75	0	-38.4	-36.7	1.7
24	Oct-19	Oct-20	3,000	0	244.6	247.6	3.0
25	Oct-21	Dec-31	75	0	-38.3	-37.9	0.5

Table 4.3
Change in River Gains/Losses for Scenario 3,
CUFA Diversions and Increased Riparian Vegetation

Stress Period	Start Date	End Date	Baseline Flow Level, cfs	CUFA Diversion, cfs	Baseline River Gain (-), Loss (+), cfs	Scenario River Gain (-)/Loss (+), cfs	Gain/Loss Difference (Scenario-Baseline) (+) indicates lower gain or higher loss, cfs
1	Jan-1	Jan-10	75	0	-29.4	-29.4	0.0
2	Jan-11	Jan-14	250	175	1.4	-29.6	-31.0
3	Jan-15	Feb-2	75	0	-34.5	-29.7	4.9
4	Feb-3	Feb-10	250	175	-7.1	-29.9	-22.7
5	Feb-11	Feb-25	500	250	-9.3	-19.9	-10.6
6	Feb-26	Mar-7	250	0	-39.0	-27.7	11.3
7	Mar-8	Mar-22	75	0	-41.7	-39.2	2.5
8	Mar-23	Mar-30	75	0	-33.4	-31.9	1.6
9	Mar-31	Apr-3	250	175	-0.6	-30.7	-30.1
10	Apr-4	Apr-17	250	0	-25.8	-18.0	7.8
11	Apr-18	Jun-2	75	0	-30.9	-28.9	2.0
12	Jun-3	Jul-30	30	0	-21.9	-19.0	2.9
13	Jul-31	Aug-5	750	0	66.8	70.7	3.8
14	Aug-6	Aug-13	75	0	-44.2	-41.5	2.6
15	Aug-14	Aug-21	500	0	12.3	15.7	3.4
16	Aug-22	Aug-23	3,000	0	173.5	178.1	4.5
17	Aug-24	Aug-25	500	0	-136.7	-133.9	2.7
18	Aug-26	Aug-27	500	250	-22.3	-64.2	-41.8
19	Aug-28	Aug-30	500	0	-24.9	-4.7	20.3
20	Aug-31	Aug-31	3,000	0	279.4	288.4	9.0
21	Sep-1	Sep-15	500	0	-43.2	-40.3	2.9
22	Sep-16	Sep-23	250	0	-40.7	-38.4	2.3
23	Sep-24	Oct-18	75	0	-38.4	-36.9	1.5
24	Oct-19	Oct-20	3,000	0	244.6	247.1	2.5
25	Oct-21	Dec-31	75	0	-38.3	-37.9	0.4

Appendix A

APPENDIX A SUMMARY OF ELEVATION DATASETS

Elevation datasets used in the riparian groundwater models include:

- Land surface elevations
 - 1/2-foot Light Detection and Ranging (LiDAR) raster and
 - 30-meter National Elevation Data (NED) raster
- Field surveyed elevations
 - Points along river transects and
 - Piezometer well locations, ground elevations and water level measurement datums
- HEC-RAS surface water model results
 - Minimum river channel exported from HEC-RAS model
 - Water surface elevation determined from HEC-RAS model results for a suite of flow conditions
- Measured groundwater levels at the piezometer transects and
- General Head Boundary (GHB) conditions calculated from the Transboundary Aquifer Study regional model.

Metadata for each dataset are included below. The *Supplemental Information* section of each metadata summary indicates how these data were used in the riparian groundwater model.

A review of elevations revealed overall correlation of datums except for a section of field surveyed data in the northern area of Reach 1. The review process consisted of comparing elevations with respect to a network of 16 ground control points established before and during LiDAR data acquisition. Comparison of the processed LiDAR raster data with the ground control network reported a root mean square error of 0.11 feet. Because of the low error sample rate and continuous coverage in the valley, the LiDAR raster was assumed to be accurate and used as the base ground elevation. All other datasets were compared to the LiDAR raster.

Surveyed ground surface elevations were compared to bare-earth LiDAR elevations and in general, the datasets correlate with the exception of two distinct areas between Gila River at Gila gage to approximately one mile below the TNC cross-section. The cause of the surveyed elevation deviation was believed, and later confirmed by Tetra Tech, to be a base station setup and/or loop-closure miscalculation or omission.

The field survey data were initially incorporated by Tetra Tech into the HEC-RAS surface water model without correcting for the errors, causing the elevations to be shifted lower in the surface water model; however, calculated surface water hydraulics were not affected and would remain the same except in transition areas. To correct for the offset of HEC-RAS elevations used in the groundwater model, an adjustment was applied to the HEC-RAS river bottom elevation and HEC-RAS water surface elevation model results for each flow scenario. Figure A-1 shows the areas where adjustments were applied to the groundwater model inputs. The adjustments, +9.5 feet and +0.6 feet over two distinct sub-reaches were calculated as the average difference

between field surveyed ground elevations and corresponding LiDAR elevations at specific surveyed points within each of the two sub-reaches.

The river bottom elevation and water surface elevations for all flow scenarios were shifted +9.5 feet from the upper end (northern extent) of the groundwater model to HEC-RAS stationline 33767.64 and +0.6 feet from HEC-RAS stationline 31988.39 to 28856.2. In the transition areas from stationline 33767.64 to 32602.28 and from 28856.2 to 28549, the adjustments were linearly interpolated to smooth water elevations.

Dataset: Light Detection and Ranging (LiDAR) Bare Earth Ground Elevations

Provider: Merrick & Company, 2450 S. Peoria Street, Aurora, CO 80014 303-353-3903

Date Acquired: 3/26/2010 - 4/5/2010, *Date Produced:* 4/29/2010

Date Received: 4/30/2010

Reported Horizontal Datum: New Mexico State Plane, West Zone (feet) NAD83

Reported Vertical Datum: NAVD88, Geoid 03

Vertical Accuracy: Reported Median Control Error -0.06ft, 0.11 RMSE of Z for sample

Supplemental Information: Used in to determine average groundwater model cell elevation.

Equipment Used: A Leica ALS50-II LiDAR sensor was used to obtain the LiDAR dataset. Breaklines were collected. A 0.3ft RMSE of Z accuracy was achieved and verified by comparing 15 ground control points. A 0.4ft contour interval was achieved and a 0.5ft resolution raster was delivered.

Data was provided via CDROM (ESRI Grid file named "dtm")

Dataset: National Elevation Dataset

Provider: Mussetter Engineering Inc/Tetra Tech

Date Acquired: Unknown

Date Received: 5/18/2009

Reported Horizontal Datum: Geographic Decimal Degrees, NAD83

Reported Vertical Datum: Not reported

Vertical Accuracy: Not reported

Supplemental Information: Where LiDAR was not available (near the outer boundaries of the active model domain), standard USGS NEDs were supplemented.

GIS data was provided by Matt Iman, MEI via FTP (ESRI Grid file named "ned_23482646")

Dataset: Surveyed Cross-Sections and Piezometers

Provider: Tetra Tech, 6121 Indian School Rd NE, Ste 205, Albuquerque, NM 87110 (505) 881-3188

Date Produced: Data was acquired during two field survey events in June 2009 and May 2010. After surveys were completed, elevations were adjusted from a local, relative datum (ellipsoid height) to an established orthometric datum (NGVD88). Details on the field surveys and the vertical adjustment are described below.

- 1) Initial field investigations were performed 6/4/2009 to 6/20/2009. Tetra Tech installed piezometers and surveyed elevations at three transects:
 - a. Fred McCulley Ranch Upstream (FM-1);
 - b. Fred McCulley Ranch Downstream (FM-2); and
 - c. Lee Ranch near Virden Bridge (VL).

During the 2009 survey, a local area network was established and only relative elevations (ellipsoid heights) were captured; no established orthometric heights were obtained. Horizontal locations and vertical elevations were surveyed at the piezometer gauge transducer, piezometer top of casing, piezometer ground surface elevation and along the cross-section of the river at each transect.

Data provided via email (Text files named "LeeRanchXS.CSV", "McCauleyRanchXS.CSV" and "Piezometer_PNEZD.csv")

- 2) Additional field investigations were performed 5/2/2010 to 5/5/2010. Tetra Tech installed piezometers at two transects:
 - a. The Nature Conservancy (TNC); and
 - b. Bird (B).

In addition to installing and locating the piezometers, topographic data was collected at 23 transects along the Gila River from the Gila Gage at Gila above Mogollon Creek to Ira Canyon. During the 2010 survey, an established NGS vertical control point was found along Highway 180 between Bill Evans Rd and Iron Bridge Rd allowing the survey elevations to be rectified as Orthometric heights.

Data provided via email (MS Excel file named "Gila_DataCollection_0510.xls")

- 3) Following the May 2010 surveys, elevations collected in June 2009 were vertically adjusted to approximate the established NGVD88 datum. The adjustment, +80.46 feet, was calculated as the distance between the relative datum (ellipsoid height) to the orthometric height (NGVD88) at the discovered NGS vertical control point. All piezometer elevations, cross-sections and corresponding water surface elevations at the FM-1, FM-2 and VL transects were adjusted +80.46, regardless of distance from the NGS vertical control point.

Data provided via email (MS Excel files named "XSData.xls" and "Piezometer_PNEZD.xls")

Date Received: Final delivery 6/18/2010

Dataset: Surveyed Cross-Sections and Piezometers continued

Reported Horizontal Datum: New Mexico State Plane, West Zone (feet) NAD83

Reported Vertical Datum: Final delivery adjusted to NAVD88

Vertical Accuracy: reported accuracies for GPS system utilized are 1 cm \pm 1 ppm horizontally and 2 cm \pm 2 ppm vertically when conducting an RTK survey. Static survey accuracies are 5 mm \pm 1 ppm horizontally and 5 mm \pm 2 ppm vertically. A combination Static \pm RTK survey were conducted since no control points were located within reasonable distance of survey areas.

Supplemental Information: Surveyed cross-sections were used in the HEC-RAS surface water model inputs. Minimum river channel bottom elevations and surface water elevations were exported from HEC-RAS and used in the groundwater model.

Equipment used: Ranch Trimble 4800 Survey Grade GPS Base, Trimble 4800 Survey Grade GPS Rover, and Trimble R8 Model 2 GNSS Rover were used to obtain surveyed cross-sections. Channel features were surveyed and classified for each point elevation.

Dataset: HEC-RAS Surface Water Model Results

Provider: Tetra Tech, 130 Ski Hill Road, Ste 130, PO Box 1659, Breckenridge, CO 80424 (970) 453-6394

Date Received: 5/25/2010 5/26/2010

Reported Horizontal Datum: New Mexico State Plane, West Zone (feet) NAD83HARN

Reported Vertical Datum: N/A

Vertical Accuracy: N/A

Supplemental Information: File contains (1) HEC-RAS river stationline (2) minimum channel elevation at each stationline (3) water surface elevation at each stationline and (4) velocity, top width and Froude number assumed for 75cfs, 250cfs, 750cfs, 1,000cfs and 3,000cfs flow scenarios.

Data was provided via email (MS Excel file named "Gila_RAS_Output.xls")

Dataset: Piezometer Groundwater Levels

Provider: New Mexico Interstate Stream Commission via Ellen Soles, contractor

Date Received: 6/2/2010

Reported Horizontal Datum: Not Applicable

Reported Vertical Datum: Not reported

Vertical Accuracy: Not reported

Supplemental Information: Observed groundwater levels were compared to simulated groundwater levels.

Note from Ellen Soles: Levellogger's altitude erroneously set to 6000 ft. rather than correct 4600 ft. Per Solinst manual 3.4.4 p. 56, the Levellogger automatically calculated barometric offset as $31.17 - (6000/826) = 23.906$. Correct barometric offset would have been calculated as $31.17 - (4600/826) = 25.60$ (variance = 1.69 feet). However in this case the Barologger was also erroneously set to 6000 feet. Average variance between the Lichty Barologger and FM1 Barologger (correctly set for elevation) was calculated over a 3 day period as 1.62. Therefore the adjustment for altitude here was calculated as $1.62 - 1.69$ feet, or -0.07 ft.

Water level data was provided by Ellen Soles via email (Excel file named "Lichty-ISC-transducers.xls")

Dataset: Transboundary Aquifer Study Water Level Contours for SWNM project

Provider: NM Water Resources Research Institute, Stucky Hall, Espina and Stewart, Las Cruces, NM, 88003 (505) 646-4337

Date Acquired: 2/1/1999

Date Received: 10/1/2009

Reported Horizontal Datum: UTM Zone 13N, NAD27, Meters

Reported Vertical Datum: No information provided in metadata

Vertical Accuracy: No information provided in metadata. Most likely a mix of vertical datums with variable accuracy.

Supplemental Information: The Transboundary Aquifer Study Groundwater Levels were used to estimate the General Head Boundary (GHB) for the groundwater model. The GHB was set equal to 1425m in elevation at a distance from the center of the GHB model cell to the centerline of the 1425m contour interval from the WRRRI Transboundary Aquifer Study.

“CON(FT)” attribute contains contour interval in feet. “CONTOUR” attribute contains contour interval in meters.

Data was provided via CDROM (ESRI Grid file named “wrrri_contour arc”) Native file format in Arc/Info export (contour.e00)

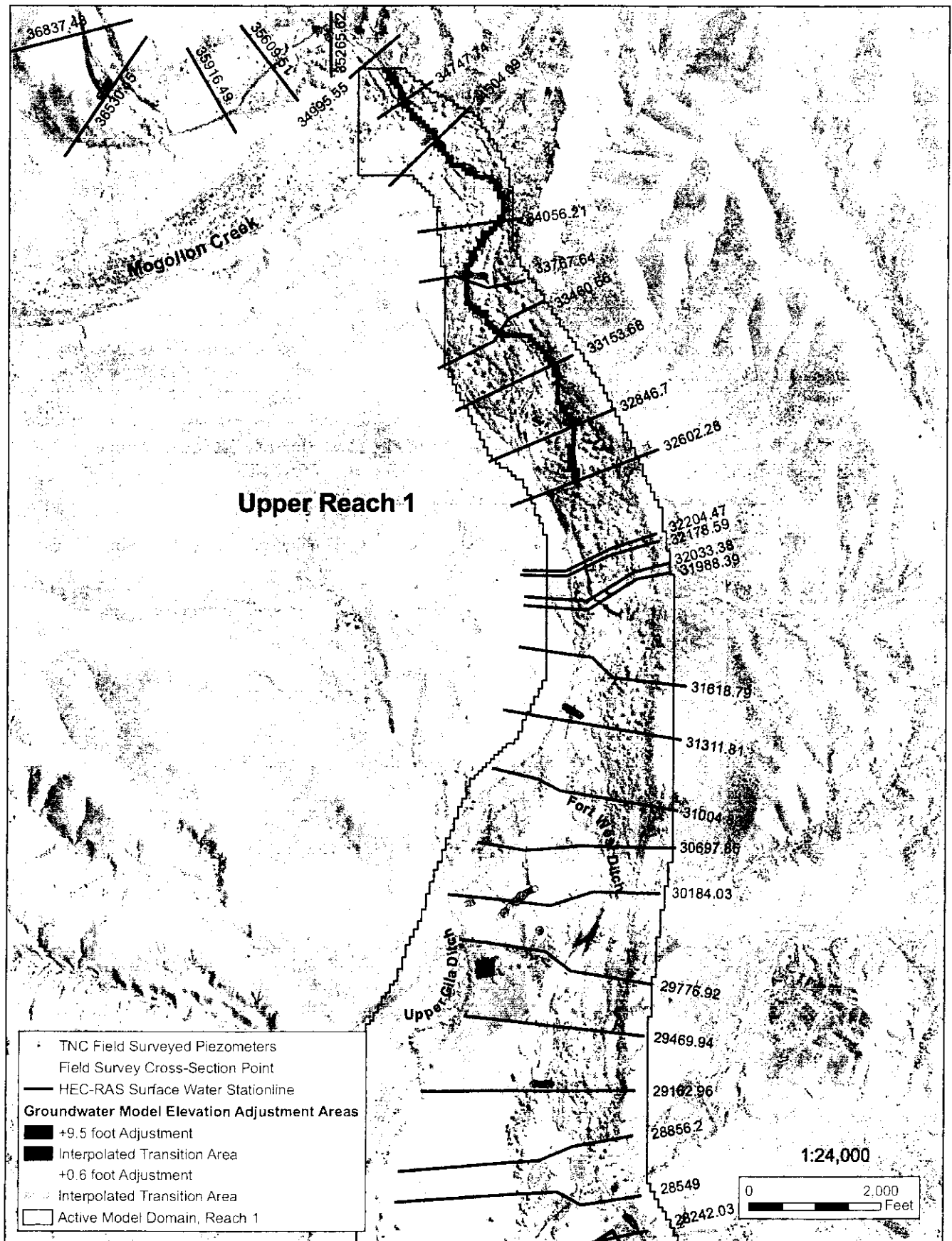


Figure A-1 Elevation Adjustment Extents in the Groundwater Model

Appendix B

Table B-3
Discharge at Measurement Sites
Gila River Seepage Run, December 13-16, 2010

Day One 12-15-2010

Site #	Discharge in CFS	Remarks
1	59.9	
2	No Flow	
3	58.3	
9430815	18.4	Out flow from Gila River to Upper Gila Ditch
9430820	17.4	Out flow from Gila River to Fort West Ditch
4	11.5	
9430825	13.8	Out flow from Gila River to Gila Farms Ditch
5	18.4	
6	28.9	

Day Two 12-14-2010

Site #	Discharge in CFS	Remarks
6	32.6	(Second measurement at site 6)
8	0.62	Return flow from Upper Gila Ditch to Gila River
10	3.23	Return flow from Gila Farms Ditch to Gila River
7	39.5	
11	39.8	
9	1.07	Return flow from Fort West Ditch to Gila River
12	59.5	
13	43.6	
14	58.2	
20	No Flow	Out flow from Gila River to Bill Evans Canal
21	0.16	Return flow from Bill Evans Canal to Gila River
15	63.7	
16	3.28	Inflow from Mangas Creek Abv Mouth near Cliff, NM
17	64	

Day Three 12-15-2010

Site #	Discharge in CFS	Remarks
17	67.6	(Second measurement at site 17)
18	69.5	
19	74.4	
22	75.1	

Table B-2
Calculated Stream Loss/Gain
Gila River Seepage Run, December 13-16, 2010

Field ID	Map ID	13-Dec-10	Main Channel Flow, cfs	Inflow, cfs	Outflow, cfs	Gain (-) or Loss (+), cfs
#1	A	Gila River abv Mogollon Creek near Gila	59.9			
#2	B	Mogollon Creek at Mouth near Gila		0.0		
#3	C	Gila River blw Mogollon Creek near Gila	58.3			
		REACH A TO C				1.6
9430815	V	Upper Gila Ditch near Gila			18.4	
9430820	W	Fort West Ditch near Gila			17.4	
#4	D	Gila River blw Upper Gila Ditch (and Ft West Ditch) near Gila	11.5			
		REACH C to D				11.0
		REACH A TO D				12.6
9430825	X	Gila Farms Ditch near Gila			13.8	
#5	E	Gila River blw Gila Farms Ditch near Gila	18.4			
		REACH D TO E				-20.7
#6	F	Gila River abv Highway 211 Bridge @ Gila	28.9			
		REACH E TO F				-10.5
		14-Dec-10				
#6	F	Gila River abv Highway 211 Bridge @ Gila	32.6			
#7	G	Gila River blw Highway 211 Bridge near Gila (at Bear Creek inflow: Bear Creek not flowing)	39.5			
		REACH F TO G				-6.9
#8	H	Upper Gila Ditch return @ Gila (not at river channel)		0.6		
#10	J	Gila Farms Ditch return near Gila (not at river channel)		3.2		
#11	K	Gila River upstream of US 180 Bridge near Cliff	39.8			
		REACH F TO K (assuming ditch returns do not return as surface flow to river)				-7.2
		REACH F TO K (assuming ditch returns do return as surface flow to river)				-3.4
#9	I	Fort West Ditch return near Gila (at river)		1.1		
#12	L	Gila River blw US 180 Bridge near Gila	59.5			
		REACH K TO L				-18.6
		McCauley Diversion (assumed)			0.0	
#13	M	Gila River near Cliff	43.6			
		REACH L TO M				15.9
#20	T	Outflow from Gila River to Bill Evans Canal			0.0	
#21	U	Return flow from Bill Evans Canal to Gila River		0.2		
#14	N	Gila River near Bill Evans Lake	58.2			

Table B-2, continued
 Calculated Stream Loss/Gain
 Gila River Seepage Run, December 13-16, 2010

Field ID	Map ID	13-Dec-10	Main Channel Flow, cfs	Inflow, cfs	Outflow, cfs	Gain (-) or Loss (+), cfs
#15	O	Gila River abv Mangas Creek near Cliff	63.7			
		REACH M TO O				-19.9
#16	P	Mangas Creek abv Mouth near Cliff		3.3		
#17	Q	Gila River blw Mangas Creek near Cliff	64.0			
		REACH O TO Q				3.0
		15-Dec-10				
#17	Q	Gila River blw Mangas Creek near Cliff	67.6			
#18	R	Gila River at BLM Area	69.5			
#19	S	Gila River Upstream of Bird Area	74.4			
		REACH Q TO S				-6.8
		REACH O TO S				-3.8
#22	Y	Gila River abv Gila River Middle Box	65.8			
		REACH S TO Y				8.6

Note: Measurements listed in downstream order

**Table B-1
Summary of Seepage Investigations**

Event	Reach Description	Reach, by Map ID	Measurement Date	Reach distance, miles	Gain (-)/ Loss (+), cfs		Gain (-)/ Loss (+), cfs/mile
1	Gila River at Gila Gage to below Ft. West Ditch	0 to 4	5/10/2010	4.4	-14.9	gain	-3.4
1	Below Iron Bridge to above Bill Evans Diversion	5 to 6	5/11/2010	3.6	-15.6	gain	-4.3
1	Upstream Bill Evans Diversion to downstream Bill Evans Diversion	6 to 8	5/12/2010	2.1	-7 **	gain	-3.3
1	Downstream Bill Evans Diversion to Bird Area	8 to 10	5/12/2010	4.2	-16.9	gain	-4.0
2	Above Mogollon Creek to below Upper Gila (and Ft. West) Ditch diversions	A to D	5/15/2010	2.1	17.2	loss	8.2
2	Below Upper Gila Ditch to below Gila Farms Ditch	D to E	5/15/2010	3.4	-31.2	gain	-9.2
2	Below Gila Farms Ditch to above Hwy 211	E to F	5/15/2010	1.5	-21	gain	-14.0
2	Above Hwy 211 to At Hwy 180	F to K	5/16/2010	2.6	-35.3 (-53)***	gain	-13.6 (-20.4)
2	Above Hwy 180 to below Hwy 180	K to L	5/16/2010	3.2	-3.5	gain	-1.1
2	Below Hwy 180 to Gila near Cliff (near Sycamore Ck)	L to M	5/16/2010	3.6	16****	loss	4.4
2	Gila near Cliff (near Sycamore Ck) to Gila at Bill Evans	M to N	5/16/2010	1.0	-4.5	gain	-4.5
2	Gila at Bill Evans to above Mangas Creek	N-O	5/17/2010	2.1	-1.9	gain	-0.9
2	Above Mangas Creek to upstream of Bird Area	O-S	5/17/2010	1.7	-4.3	gain	-2.5
3	Above Mogollon Creek to below Upper Gila (and Ft. West) Ditch diversions	A to D	12/13/2010	2.1	12.6	loss	6.0
3	Below Upper Gila Ditch to below Gila Farms Ditch	D to E	12/13/2010	3.4	-20.7	gain	-0.7
3	Below Gila Farms Ditch to above Hwy 211	E to F	12/13/2010	2.5	-10.5	gain	-4.2
3	Above Hwy 211 to Bear Creek inflow (no inflow recorded)	F to K	12/14/2010	2.6	-3.4(-7.2)***	gain	1.3(-2.8)
3	Above Hwy 180 to below Hwy 180	K to L	12/14/2010	3.2	-18.6	gain	-5.8

**Table B-1, continued
Summary of Seepage Investigations**

Event	Reach Description	Reach, by Map ID	Measurement Date	Reach distance, miles	Gain (-)/ Loss (+), cfs		Gain (-)/ Loss (+), cfs/mile
3	Below Hwy 180 to Gila (near Sycamore Ck)	L to M	12/14/2010	3.6	15.9	loss	4.4
3	Gila near Cliff (near Sycamore Ck) to above Mangas Creek	M to O	12/14/2010	3.1	-19.9	gain	-6.4
3	Above Mangas Creek to upstream of Bird Area	O to S	12/14/2010		-3.8	gain	
3	Upstream of Bird Area to Middle Box	S to Y	12/15/2010	2.5	8.6	loss	3.4

* Map ID's refer to Figures 3.8 and 3.9. SSPA June 2010 report

** Bill Evans Net Flow (Diversion and Return) estimated as a net 20 cfs inflow based on May 15-17 observations

*** Value assumes that ditch tailwater measured distant from river reaches river within reach in same amount as measured: value in parentheses assumes tailwater percolates and direct surface water inflow is zero

**** Assuming no diversion to McCauley Ranch

Values in *italics* adjusted from Table 3.5. SSPA June 2010 report. due to additional information on location of measurement points.

Table B-4
GPS Readings for Measurement Sites
Gila River Seepage Run, December 13-16, 2010

#1	33.02.38N	108.31.46W
#2	33.02.37N	108.31.48W
#3	33.02.11N	108.31.58W
#4	33.01.17N	108.32.33W
#5	32.59.07N	108.34.18W
#6	32.58.13N	108.35.10W
#7	32.57.23N	108.36.05W
#8	32.58.10N	108.35.35W
#9	32.56.41N	108.36.15W
#10	32.57.19N	108.35.18W
#11	32.56.45N	108.36.26W
#12	32.54.47N	108.35.26W
#13	32.54.12N	108.35.51W
#14	32.53.24N	108.35.42W
#15	32.51.48N	108.35.26W
#16	32.51.46N	108.35.25W
#17	32.51.23N	108.35.27W
#18	32.50.47N	108.35.37W
#19	32.50.35N	108.35.52W
#20	32.53.43N	108.35.45W
#21	32.52.38N	108.35.22W
#22	32.49.09N	108.36.07W
9430815	33.01.18N	108.32.34W
9430820	33.00.56N	108.32.37W
9430825	32.59.01N	108.34.14W

Appendix C

APPENDIX C-1 MODEL CALIBRATION

After incorporating several revisions the 2010 simulation (SSPA, 2010) calibration was updated providing the best match between simulated results and available observations. Revisions to the 2010 simulation focused on incorporating corrections to the survey information, both in terms of the river bottom elevation, and estimates of river stage. In addition, corrections were applied to the piezometer observations to account for surveying corrections.

Parameter adjustments for calibration of the 2010 simulation were constrained by a limited amount of information: water levels from several piezometers, and seepage-run results. The piezometers are located in a single transect and have a limited number of observations coinciding with the final stress period of the simulation. As a result, the observations do not provide insight to the water level response to changes in river flow, providing essentially just one observation per piezometer. Simulated water levels during the period of observation were all within two feet of the observed values. Given the issues such as corrections to survey information, the limited amount of observations and the limited number of cross sections that were available to construct and simulate the surface water conditions, this size of residual is quite reasonable.

The observed water levels were also used to provide information on the gradient moving away from the river. For example, the average observed water-level difference between TNC1S and TNC2 was 0.3 feet, and from TNC2 to TNC3 was 1.0 feet. Simulated water-level differences for that period are 0.3 and 0.7, between TNC1S/TNC2 and TNC2/TNC3, respectively, indicating that the model does a relatively good job of representing the hydraulics of water moving from the river. Additional data in the form of a more extensive time series, and additional locations would allow the model calibration to proceed further, and improve these results. This information would also give insight to the uncertainty of the observed gradient, and how it changes with changes in river flows.

Seepage evaluations from May and December of 2010 provided some information for constraining calibration. However, as discussed in the main report, the receding limb of the spring hydrograph raised the question of bank storage having a significant influence on the measured May seepages. Based on the steady conditions, the December measurements appear to provide a better indication of seepage, and these values were used to guide model parameter adjustments. Model calibration targeted the overall seepage from sub-reach 1 – 5 and the simulated values provided a reasonable match to the observed. Some variability within specific subreaches was not as well matched, however, there was no information such as measurements of canal losses to guide model adjustments and match the more localized observations of sub-reach losses.

With the collection of additional data from the existing piezometers, installation and monitoring of new piezometers, measurements of canal seepage and carefully executed Gila-River seepage measurements, it will be possible to begin the process of performing more localized adjustments within the model. Such adjustments will help to improve the match between the observed and simulated values, and improve the model's local predictive capabilities, e.g., evaluating scenario impacts on a more detailed level.

APPENDIX C-2 BASELINE AND ALTERNATIVE-CONDITION REFINEMENTS

Baseline

General changes to the 2010 simulation (SSP&A, 2010) required to create the Baseline simulations are provided in Section 3.4 of the report. This section provides some additional details.

The 30 cfs RIV package is based on the footprint and stage from the 75 cfs package, with the following modifications.

1. Values of STAGE for the 30 cfs condition were generated by subtracting 50% of each row's median depth from the 75 cfs STAGE values in that row.
2. Depths associated with the 30 cfs STAGE were computed by subtracting RBOT from STAGE. Eleven cells, having depths less than zero, were flagged for adjustment.
3. The 30cfs cells with depth less than zero were adjusted by replacing the STAGE calculated in step 1 with the value of STAGE from the nearest adjacent RIV cell.
4. To represent the dry stretch in sub-reach 2, any STAGE values in rows 169 – 190 were adjusted to equal the RBOT value.

Other changes incorporated include specification of time-varying components for the tributary alluvium, handled through the WEL package. Parameter values for the tributary inflow were set proportional to the Gila River flows, and adjusted across all flows as part of the calibration process in order to better represent groundwater variations. Canal conductances were also specified as time varying components, but their adjustment was limited to representing the decreased seepage during supply limited periods.

Scenario 1

The Baseline simulation required only a minor modification to create Scenario 1. This consisted of modifying the parameter calls in the RIV package so that the reduced flows, associated with CUFA diversions, were used at the appropriate stress periods, as discussed in the report.

Scenario 2

Modifications to the Baseline simulation to create scenario 2 consisted of those implemented for Scenario 1 and reducing the on-farm-percolation (OFP) parameter value in the RCH package from 1.0, representing a percolation rate of 1.4 feet/season, to 0.5714, representing a rate of 0.8 feet/season for the non-supply-limited stress periods.

Scenario 3

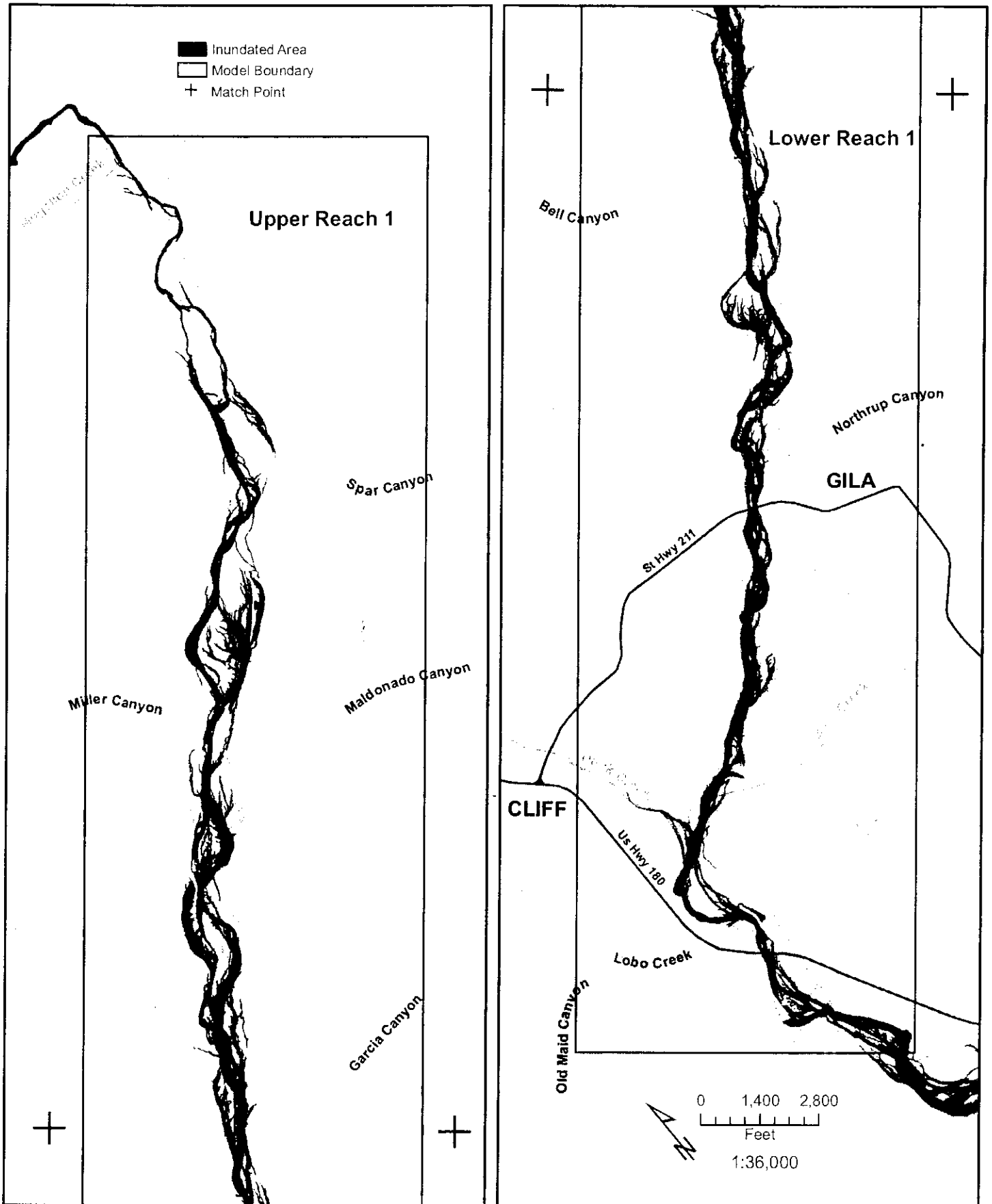
Modifications to the Baseline simulation to create scenario 3 consisted of those implemented for Scenario 1 and increasing the fCOV terms in the RIP input package to represent a 30% increase in fractional coverage. This modification was performed by incorporating an additional multiplication factor into the RIP-package preprocessor.

Post Processing Refinements

Extraction of simulated equivalents to observed values, and simulated values for the entire simulation period, required modifications to some of the model control files. Modifications are summarized below.

- Dummy observations were added to the PEST control file to specify simulated-value times and locations for processing.
- Processing instructions were incorporated into the instruction file (.INS) to guide the extraction of water levels from the post-processed simulation results.
- Batch files were created to control other utilities, e.g.,
 - Extraction of simulated water levels (MOD2OBS)
 - Combining simulated and observed values (HDSIMVOBS) and macros to load values into a TECPLOT layout file and generate plots
 - Seepage control/instruction files to extract seepages for each stress period for the refined set of river sub-reaches (RDLSTFLX)
 - Processing with R to generate plots of simulated seepage.
- The water-budget processor (mbal), controlling batch file, and associated spreadsheet were modified to handle the 25 stress-period baseline simulation and the Gila River sub-reach refinement.
- The binary water-level file post processor (PPMF2KH) was modified to accept multiple stress-period specification and GIS-compatible files and a simple controlling batch file created (RUNppmf2kh.bat).

Appendix D

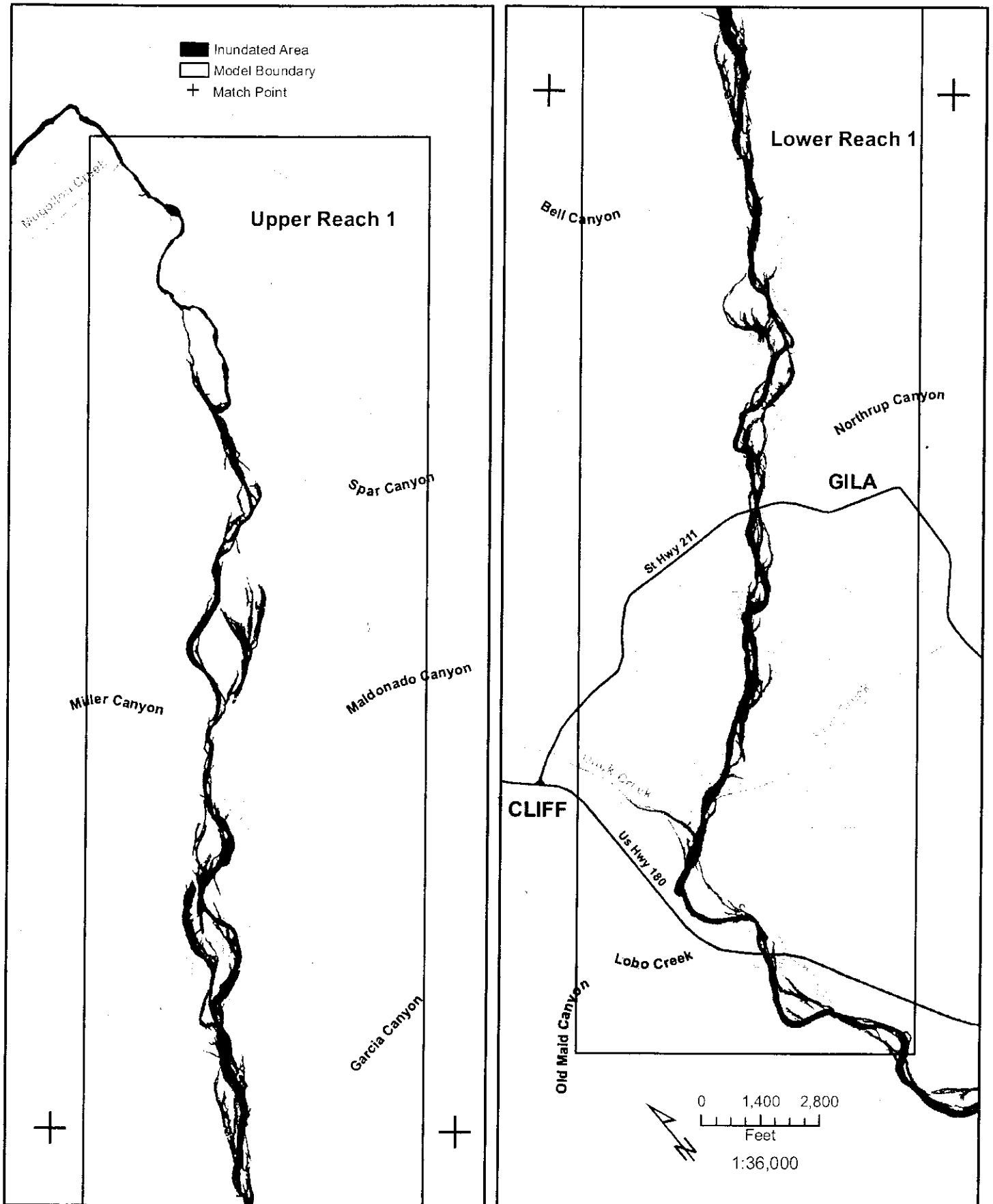


S.S. PAPADOPULOS & ASSOCIATES, INC.

Inundated Channel and Overbank Areas at 3,000 cfs, Gila Model Reach 1

0666

NMISC

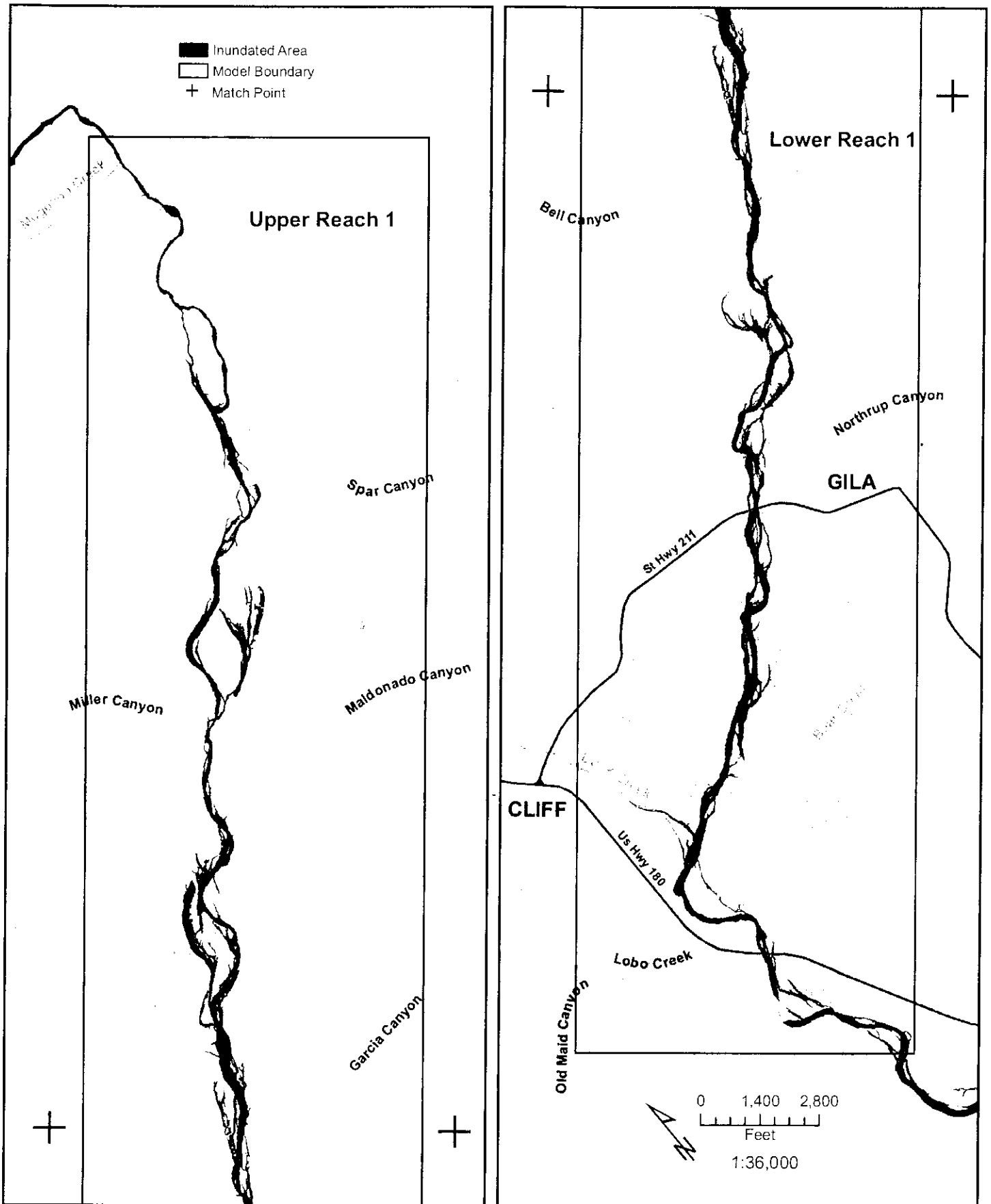


S.S. PAPADOPULOS & ASSOCIATES, INC.

Inundated Channel and Overbank Areas at 1,000 cfs, Gila Model Reach 1

0667

NM/SC

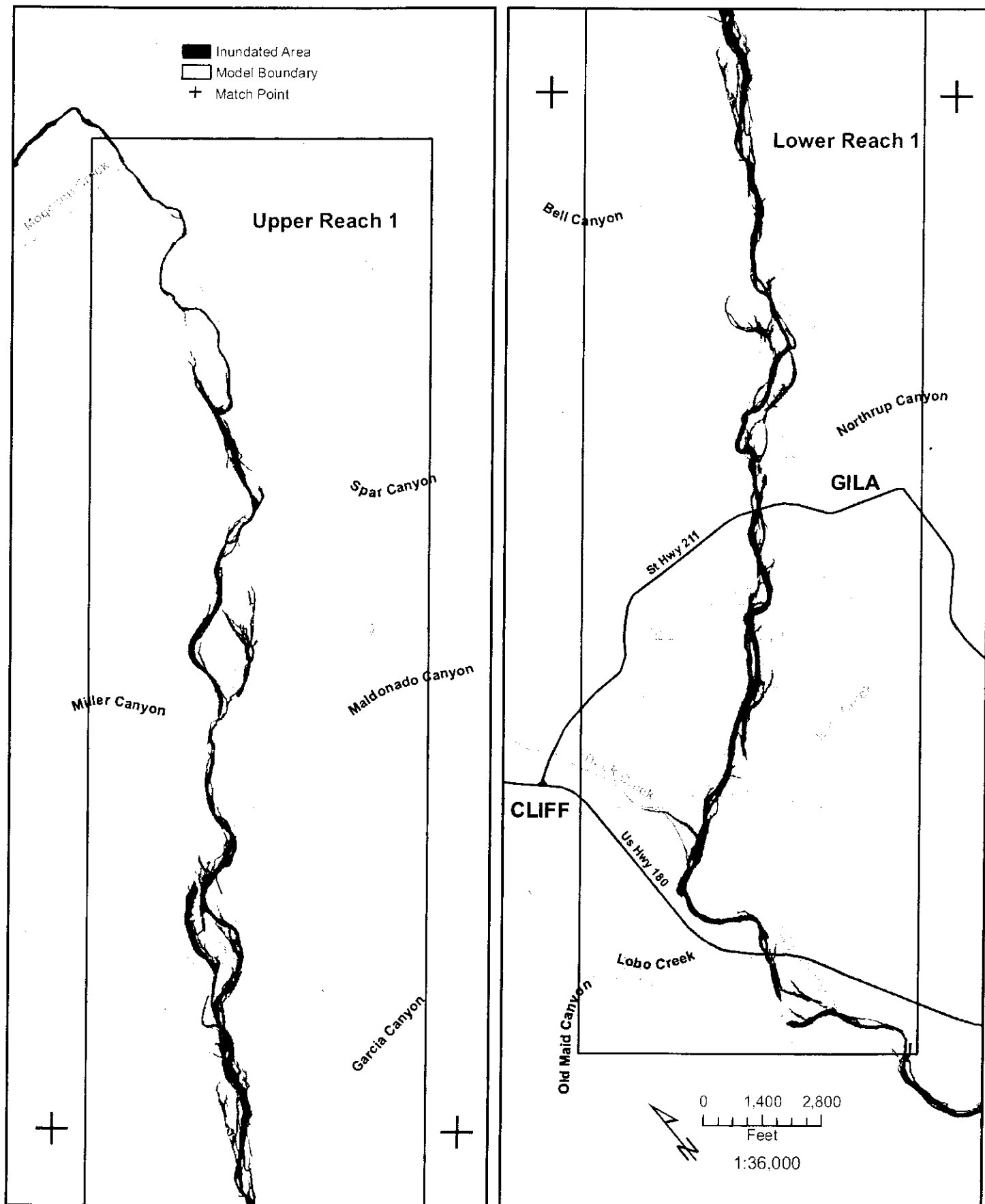


S.S. PAPADOPULOS & ASSOCIATES, INC.

Inundated Channel and Overbank Areas at 750 cfs, Gila Model Reach 1

0668

NMISC

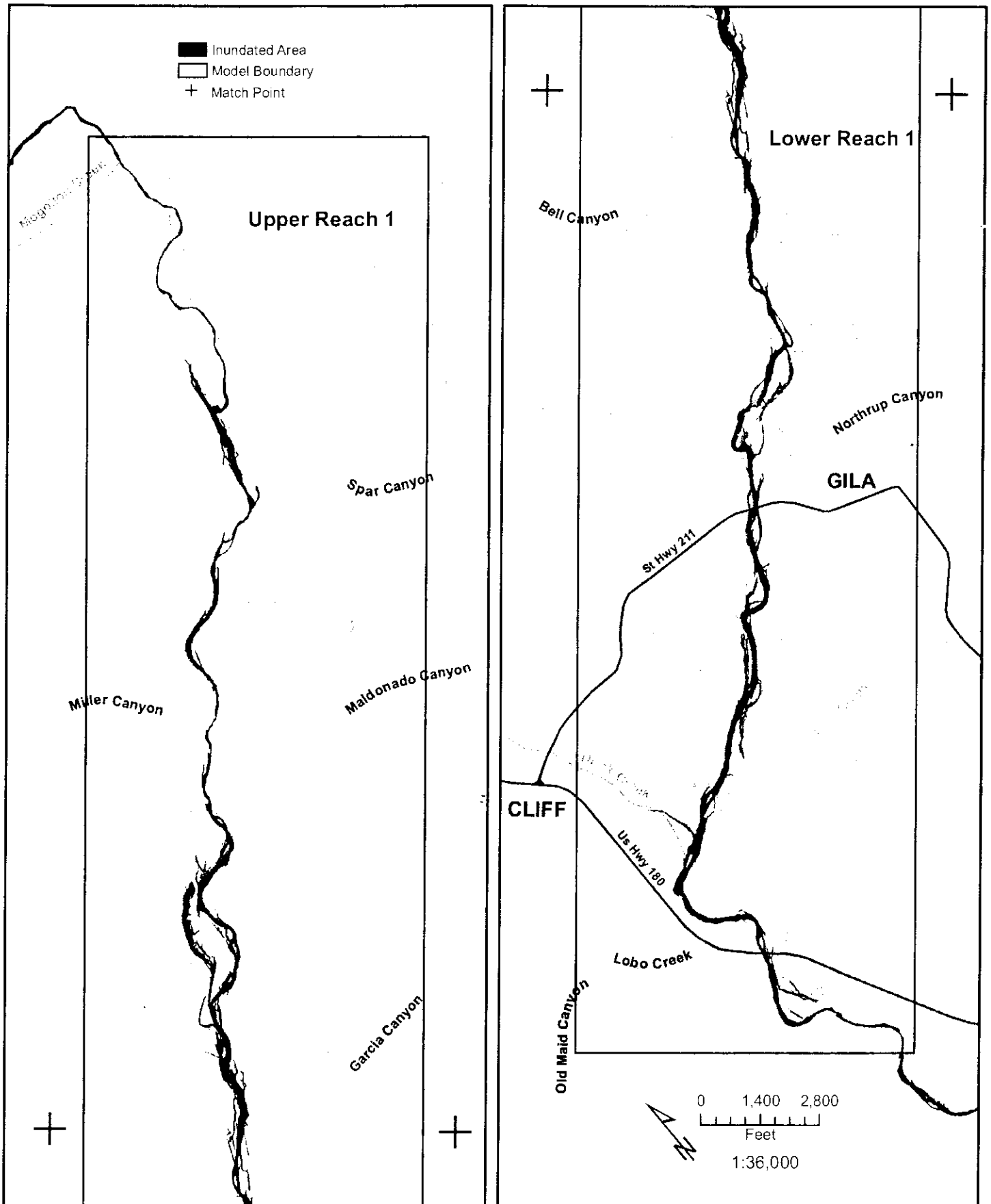


S.S. PAPANOPULOS & ASSOCIATES, INC.

Inundated Channel and Overbank Areas at 500 cfs, Gila Model Reach 1

0669

NMISC

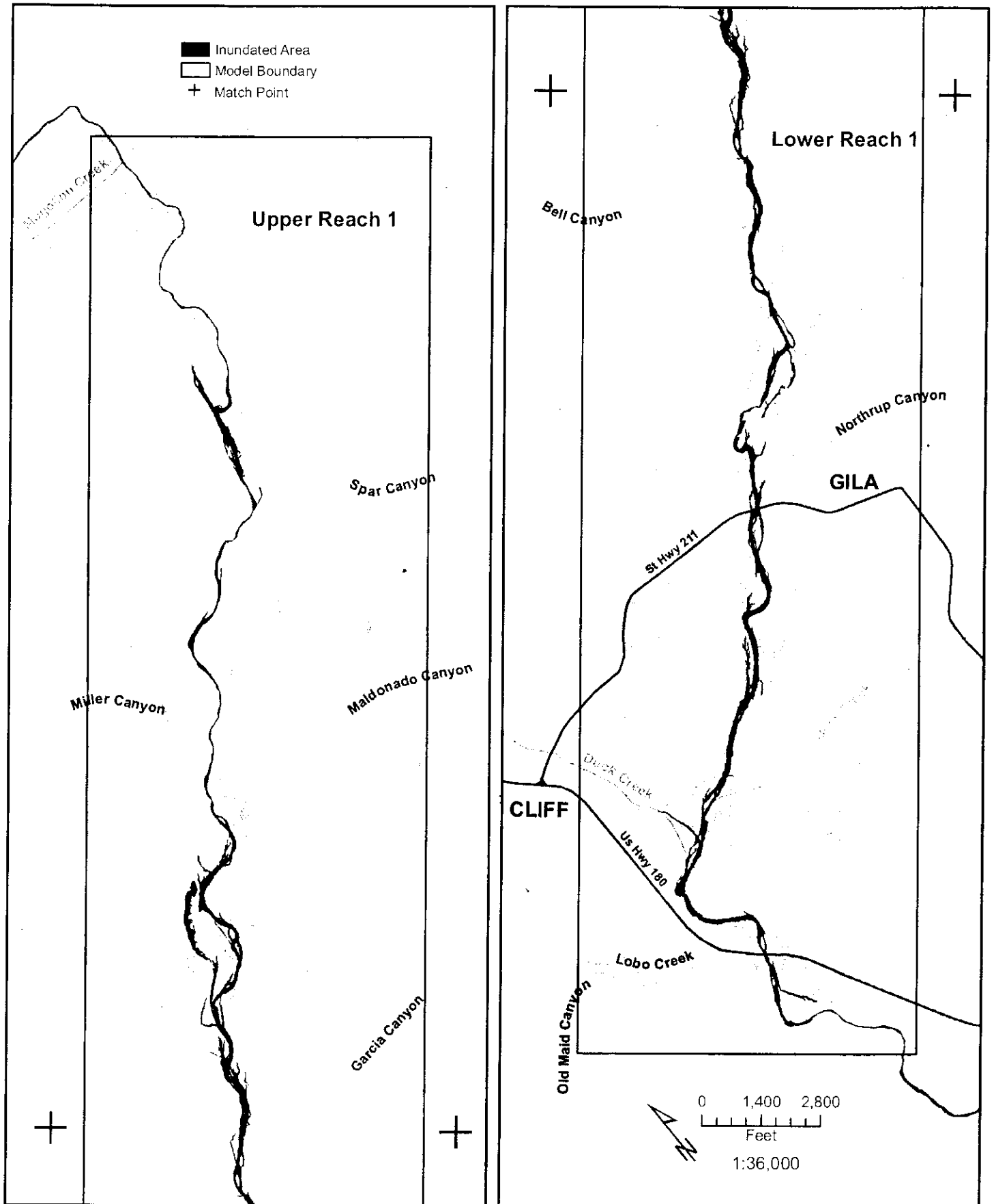


S.S. PAPANOPULOS & ASSOCIATES, INC.

Inundated Channel and Overbank Areas at 250 cfs, Gila Model Reach 1

0670

NMISC



S.S. PAPADOPULOS & ASSOCIATES, INC.

Inundated Channel and Overbank Areas at 75 cfs, Gila Model Reach 1

0671

NMISC