# Riparian Groundwater Models for the Middle Rio Grande: ESA Collaborative Program FY07, Model Refinement

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# 1.0 INTRODUCTION

Eight high-resolution groundwater models of the near-river zone (riparian groundwater models) have been developed for the Middle Rio Grande from Cochiti Dam to Elephant Butte Reservoir, as part of a multi-year project with funding from the Middle Rio Grande Endangered Species Act Collaborative Program (ESA Collaborative Program) and the New Mexico Interstate Stream Commission (NMISC). This suite of models addresses the gap between the capabilities of other existing hydrologic models of the Middle Rio Grande system and the needs of water supply and water restoration planners to conduct detailed surface water/groundwater evaluations in the near-river zone of the Rio Grande. The models have been developed for specific reaches of the Middle Rio Grande (Figure 1.1) over a period of several years beginning in 2004.

This report describes refinements made to six of the riparian-zone groundwater models, those developed between 2004 and 2007 for the reaches from Cochiti to the northern boundary of Bosque del Apache[1]. Model refinements include updating to a more recent version of the surface water routing model used for specification of surface water boundary conditions, incorporating newly obtained channel elevation survey data for drains, and, additional model calibration using flow and water-level data from 2007 and 2008.

Section 2 of this report provides background on the development of the eight riparian groundwater models and the motivation for this model refinement project. Section 3 describes the additional data that were available to this project and Section 4 describes how the data were applied in the model refinements. Section 5 describes steady-state model simulations, and Section 6 describes the transient model simulations with a comparison of modeled results to observed conditions in 2007 and 2008. Section 7 provides summary and conclusions. Metadata is included in Appendix A; other supporting data are included in Appendices B through D.

This work was performed under Fiscal Year 2007 (FY07) funding from the ESA Collaborative Program and the New Mexico Interstate Stream Commission (NMISC). Principal investigators for this project were Deborah L. Hathaway of S.S. Papadopulos & Associates, Inc. (SSPA), and Nabil Shafike of the New Mexico Interstate Stream Commission. Work was

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[1] The Bosque del Apache and Ft. Craig models, recently completed as part of the FY07 funding, are not included in the model refinement as they already incorporate presently available data.

conducted by the principal investigators and SSPA staff, including Karen MacClune, Gil Barth, Elizabeth Jones and Dagmar Llewellyn.

## 2.0 DEVELOPMENT OF THE RIPARIAN GROUNDWATER MODELS

Numerous long-term projects have substantially improved the ability to understand and model hydrologic conditions along the Rio Grande, and many models have been developed as part of these studies. However, existing models did not provide the resolution needed to address some water supply and water restoration planning questions related to shallow, riparian groundwater conditions. In particular, a need was identified for models that would represent fine-scale surface-water/groundwater interactions under a variety of existing and proposed management conditions, and for assessment of how differences in antecedent or regional hydrologic conditions, channel structure or vegetation type might affect surface-water/groundwater interactions. The riparian groundwater models were developed with ESA Collaborative Program funding, augmented by NMISC and ACOE funding, to address this need. Potential model applications include the identification of flow levels that could help establish and maintain groundwater conditions for Southwest Willow Flycatcher (SWFL) habitat; or, assessment of the water supply needs, incremental depletions and sustainability of stream restoration projects under variable flow conditions that are being considered for improving Silvery Minnow habitat.

The high-resolution groundwater models of the near-river zone cover the Rio Grande corridor, riverside bosque, and drains. Hydrologic inflows and outflows in this area include river leakage, drain gains/losses, evaporative losses from open water and bare ground, evapotranspirative losses from the riparian forest, and the movement of water to or from the regional groundwater flow system. The riparian groundwater models provide a tool capable of examining the system under different flow regimes, such as low summer flows, spring runoff pulses, and average winter flows, and can be adapted to evaluate hydrologic questions related to river restoration.

Models developed to date include:

- ***Cochiti Reach***: Developed in 2007 with funding from the U.S. Army Corps of Engineers (ACOE) and the NMISC (SSPA and NMISC, 2007);
- ***Upper Albuquerque Reach***: Developed in 2004-2005 with funding from the ESA Collaborative Program FY03 and the NMISC (SSPA and NMISC, 2005);

- ***Lower Albuquerque Reach***: Developed in 2004-2005 with funding from the ESA Collaborative Program FY03 and the NMISC (SSPA and NMISC, 2005);
- ***Belen Reach***: Developed in 2004-2005 with funding from the ESA Collaborative Program FY03 and the NMISC (SSPA and NMISC, 2005);
- ***Bernardo Reach***: Developed in 2005-2006 with funding from the ESA Collaborative Program FY04 and the NMISC (SSPA and NMISC, 2006);
- ***Socorro Reach***: Developed in 2005-2006 with funding from the ESA Collaborative Program FY04 and the NMISC (SSPA and NMISC, 2006);
- ***Bosque del Apache Reach***: Developed in 2008 with funding from the ESA Collaborative Program FY07 and the NMISC (SSPA and NMISC, April 2008); and,
- ***Ft. Craig Reach:*** Developed in 2008 with funding from the ESA Collaborative Program FY07 and the NMISC (SSPA and NMISC, April 2008).

All eight riparian groundwater models were developed in MODFLOW 2000 (Harbaugh et al., 2000). The model grid consists of cells with sizes set at 250 feet in length and 125 feet in width, extending on both sides of the Rio Grande to include potential overbank and adjacent areas. The model domain is bounded by riverside drains where they are present, with the exception of the Cochiti model, which extends a greater distance laterally. The models are discretized vertically into four layers, with the top three layers representing the Rio Grande alluvium and the fourth layer representing the uppermost portion of the Santa Fe Group. The Rio Grande represents a flow-dependent boundary condition on the groundwater domain. The river width and depth under a variety of flow conditions are determined using the Middle Rio Grande FLO-2D Flood Routing Model (Riada Engineering, 2007). Regional groundwater conditions are identified using regional models (McAda and Barroll, 2002; Shafike, 2005). Evapotranspiration is modeled using seasonally variable rates for mapped plant functional groups. As initially developed, each model reflects best available data. All models can benefit from continuing refinement as new, reach-specific data is developed in upcoming years.

ESA Collaborative Program FY07 funding supported additional data collection and model refinement in several key areas:

- Seepage runs were conducted in several model reaches to further characterize river gains/losses;

- Piezometers were drilled and monitoring was initiated at several new locations; and,
- Drain and river bottom elevations were obtained at approximately one-mile increments along the river.

Additionally, the U.S. Geological Survey has continued to install and monitor wells placed in cross-sections within the Albuquerque and Belen reaches; the NMISC has continued to monitor water levels at well transects between San Acacia and Ft. Craig; and, the University of New Mexico has continued to collect water-level data at some of the observation wells associated with their field sites. These new data and recent updates to the FLO-2D Flood Routing Model provide opportunity to update and refine the riparian groundwater models.

# 3.0 INCOPORATION OF NEW INFORMATION INTO THE RIPARIAN MODELS

New information to support refinement of the riparian models has been compiled in the following areas:

- Channel elevation survey data;
- Gaged river flows;
- Groundwater elevations from piezometer sets and cross-sections;
- River gains/losses;
- Riparian vegetation water use characteristics.

These data are described in this section. Also discussed in this section is the updated FLO-2D flood routing model that is applied to determine the time-dependent river boundary condition. Details on model development that have not been modified during this refinement phase are provided in the respective initial project reports as identified in Section 1.1.

## 3.1 Surveyed Channel and Water Surface Elevations

A field survey of the Rio Grande and adjacent riverside drains between Albuquerque (beginning at the Alameda Bridge) and San Acacia was conducted in the fall of 2008. The motivating factor for the surveying project was to acquire drain bottom elevations, as these data were previously not available on the regional scale, and because drain elevations provide significant control on groundwater conditions in the riparian zone. The surveying project was scoped to also include other features along river transects, thus supporting correlation of surveyed drain elevation data with existing surveyed data for the river channel, and to provide other supplemental data. River and drain features were surveyed along transects spaced at approximately one-mile intervals. Surveyed features include river and drain invert elevations, water surface elevations and levee tops. A technical memorandum describing the surveying project and providing elevation data is included in Appendix B.

Figure 3.1 shows the locations of surveyed river transects and river invert (bottom) elevations at these locations. A comparison was made of the surveyed river bottoms, at approximately one mile intervals, with those obtained from the U.S. Bureau of Reclamation Aggradation/Degradation (Ag/Deg) lines surveyed in 2002[2], as reflected in interpolated values

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[2] The Ag/Deg lines are based on 2002 aerial photography, photo-interpreted by the USBR.

of minima previously assigned to model cells designated as containing river segments. Figure 3.2 shows the results of this comparison for each of the riparian models within the survey project study area, that is, for the Upper Albuquerque Model, the Lower Albuquerque Model, the Belen Model and the Bernardo Model. The comparison indicates reasonable correspondence between the two surveyed data sets. While small differences exist, these are not unexpected given natural channel variability and the “sampling” represented by survey projects conducted using different spatial intervals at different points in time. Most importantly, Figure 3.2 shows that overall, there appears to be no bias between the river survey projects in 2002 and 2008. Therefore, due to the higher resolution of 2002 Ag/Deg river survey intervals (every 500 feet), the river bottom elevations remain as previously specified from the 2002 Ag/Deg line elevations. With the exception of the Socorro model domain, few surveyed drain elevations were available prior to the recent survey project. Where applicable, drain elevations are specified using an interpolation process with the data obtained in this 2008 survey.

## 3.2 River and Drain Flows

River flows at selected gaging stations for the years 2007 and 2008 have been obtained from the U.S. Geological Survey NWIS website. The selected gages are those that provide the best approximation to flows at the top-of-reach location identified for FLO-2D simulations (which is used to develop the groundwater model boundary condition at the river). Table 3.1 identifies the top-of-reach for FLO-2D simulations used in each model, along with the selected gages. The selected gages are:

***Rio Grande at San Felipe***
Cochiti Model

***Rio Grande at Albuquerque***
Upper Albuquerque Model
Lower Albuquerque Model
Belen Model (minus diversions at Isleta Dam)
Bernardo Model (minus diversions at Isleta Dam)

***Rio Grande at San Acacia***
Socorro Model

Daily mean flows corresponding to these gage locations are provided in Appendix C for the years 2003 through October 2008. Other adjustments to gage flows to obtain representative top-of-reach flows may be desired in some cases. For example, the addition of Albuquerque wastewater inflow or drain inflows to the top-of-reach reference Belen or Bernardo flow may be important in the application of the models under low flow conditions. The reference inflows can be structured as desired by the user.

## 3.3 Groundwater Elevations

Groundwater data for use in model evaluation and calibration have been collected through several programs. Of interest to this study are the continued monitoring in 2007 and 2008 of existing wells and the monitoring of new wells providing data in new locations. Groundwater data collected within the near-river zone that may be suitable for model evaluation include data collected under the following programs:

- U.S. Geological Survey, monitoring well transects in the Albuquerque reaches -- transects have been constructed and sequentially brought online periodically since 2004;
- UNM Bosque ET towers and associated wells -- clusters of shallow wells variously monitored between 1999 and 2008 in Albuquerque, Belen and Bernardo reaches;
- NMISC/ACOE monitoring well transects and staff gages between San Acacia and Ft. Craig – generally, consistently monitored from 2003 to 2008;
- NMISC piezometers drilled under ESA FY07 Program in early 2008 – 4 new piezometer clusters.

Hydrographs of groundwater elevations at these wells are provided in Appendix D, along with tables of well identification and attribute information. The locations of the wells (or transects/clusters) monitored in 2007 or 2008 and selected for use in evaluating simulated model results are shown for the respective model reaches on Figures 3.3 through 3.8, with additional detail provided in Appendix D (Figures D.2 through D.9).

## 3.4 Riparian Vegetation Evapotranspiration and Open Water Evaporation

### 3.4.1 Background

Riparian vegetation communities and open water areas in the study reach remain unchanged from the original models. Riparian communities and open water areas were identified based on available URGWOPS (USBR 2004) and IKONOS (Strech and Matthews, 2001) GIS vegetation classification coverages.

For both riparian vegetation Evapotranspiration (ET) and open water evaporation, the ET rates and ET rate with depth curves developed for the Bosque del Apache and Fort Craig modeling effort were used in the riparian model refinement. For vegetation, five unique curves were used to represent the vegetation classes used, with maximum annual ET rates ranging from 3.8 feet per year for native cottonwood to 4.2 feet per year for cottonwood with a dense understory of non-native plants to 3.6 feet per year for salt cedar to 6.0 feet per year for marsh. *Bare Land, Unknown Vegetation*, and non-in-channel *Open Water* are all represented by an ET rate curve which rises from 0 to 1 foot per year when the groundwater level is between 1 foot and a half foot in depth, and then rises to 5 feet per year, representative of open water, when the water table surface is between a half foot deep and land surface. Open water evaporation rates are based on daily pan evaporation measurements taken by the USBR at Elephant Butte Dam during 2004, 2005 and 2006, corrected by a factor of 0.7 to account for increased heating and evaporative losses from the pan as compared to an open water surface.

### 3.4.2 Development of Temporally Varying MODFLOW RIP Package

Riparian evapotranspiration and open water evaporation rates in the Middle Rio Grande region vary not only by plant type and depth to groundwater, but also by season. Seasonal variability can equal or exceed variability due to differences in plant type or depth to groundwater. To allow for temporally varying simulation of evapotranspiration using the RIP Package (Maddock and Baird, 2004), a set of 12 monthly RIP packages were prepared for each model.

For each of the monthly packages, the percentage plant coverage within each cell by each plant sub-group was varied as a function of time within the growing season. For vegetation, a hypothetical curve describing the variation of evapotranspiration with time was developed based on monthly ET rates averaged over 5 years for salt cedar, cottonwood and Russian olive (2000-2004 UNM data, Sevilleta LTER website). The average monthly ET rate, as a percentage of total annual evapotranspiration, for each of the five vegetation categories, and the hypothetical curve extracted from them are shown in Figure 3.9. The average monthly ET rates were used to calculate monthly evapotranspiration weighting factors, and the weighting factor used to scale percentage plant sub-group coverage for each vegetation sub-group within each active model cell. The same weighting factors were used for each of the vegetation categories. Weighting factors ranged from 0 to 2.4, reflecting the winter periods (October to April) with no transpiration, and the very high evapotranspiration rates during June and July. The percentage coverage of each cell by each plant sub-group was left unchanged when the average monthly ET rate was equal to 1/12th (8.33%) of the annual ET rate. As a result, from October to April, when the hypothetical curve monthly ET rates are less than 8.33% of the annual ET rate, percent coverage was scaled down; from May through September, when the hypothetical curve monthly ET rates are greater than 8.33% of the annual ET rate, percent coverage was scaled up.

For open water, the same methodology as described above was used to implement the open water evaporation curve shown in Figure 3.10. For open water, weighting factors ranged from 0.37 to 1.77, reflecting low evaporation rates in winter and high evaporation rates in summer.

### 3.5 River Seepage

River seepage is characterized through field investigation involving sequential flow measurements in the river under specific flow conditions, from which reach gains and losses can be calculated using a mass balance procedure. These field investigations, termed “seepage runs” have been conducted along different reaches during different seasons by the NMISC in several mobilizations since 2001 (SSPA 2001, 2002, 2004b). Additional river seepage runs have been conducted in 2007 and 2008, funded by the ESA Collaborative Program FY07 activities and the NMISC (SSPA 2007, 2008). The latter seepage runs correspond to river reaches included in the Upper Albuquerque, Lower Albuquerque and Belen models. The estimated seepage rates derived from the seepage runs conducted between 2001 and 2008 and relevant to this model refinement phase are summarized on Table 3.2.

River seepage rates developed in field seepage runs provide useful information for evaluating the reasonableness of simulated flows with the models. However, unless a model simulation is configured to precisely match the conditions at the time of field seepage investigations, close simulation of the field-based seepage is not targeted as a direct simulation outcome. For example, river seepage is influenced not only by river flow levels, but also by drain elevations, seasonal plant ET demand and antecedent conditions. These factors in the context of model simulation are further discussed in Sections 5 and 6.

### 3.6 River and Overbank Boundary Conditions from FLO-2D

In January 2008 Riada Engineering, Inc. released a revised version of the *FLO-2D Flood Routing Model for the Middle Rio Grande from Cochiti Dam to Elephant Butte Reservoir*. This revised FLO-2D model uses a 250-foot grid system, and has undergone significant recalibration. In the present study, the revised FLO-2D model was used to update river boundary conditions for the riparian groundwater models for flows of 100, 500, 1,000, 2,000, 3,000, 5,000, 7,000, and 10,000 cfs. Flows were initiated in the FLO-2D model at Cochiti Dam, Angostura, Isleta, and San Acacia, for a total of 32 model runs (8 flow conditions at each of 4 flow initiation locations). FLO-2D runs with flows initiated at the downstream locations were made to allow closer match to gaged hydrographs measured or calculated at these downstream locations. Table 3.1 provides information of which FLO-2D initiation point was used for each groundwater model.

FLO-2D output files were processed according to the methods applied in the Bosque del Apache and Fort Craig modeling effort (SSPA and NMISC, 2008b). River channel delineation and river bottom elevation remain unchanged from previous models. In-channel water depths were extracted from the FLO-2D output files and applied directly to the riparian model in-channel cells. FLO-2D overbank depths were superimposed on the riparian models, percentage of each riparian model cell covered by overbank flooding was recorded, and for the flooded portion, an average water depth was calculated.

Bed conductance for in-channel cells was calculated using the following equation:

$$C = \frac{L * W * \left({}^{TopWidth}\!\big/_{MaxTopWidth}\right) * K_v}{M} \qquad \text{Equation 3.1}$$

where:

$C$ is river bed conductance (ft$^2$ /day);
$L$ is length of river within the given cell (set equal to the length of the cell, 250 ft);
$W$ is width of river within the given cell (set equal to the width of the cell, 125 ft);

*TopWidth* is the top width of the river channel under the given flow conditions (FLO-2D output);
*MaxTopWidth* is the maximum width of the river channel (FLO-2D Top Width from the 10,000 cfs flow scenario);
$K_v$ is river bed vertical hydraulic conductivity (initially set at 1 ft/day);
$M$ is river bed thickness (initially set at 1 ft).

Overbank flows were found in FLO-2D model simulations for flows of 2,000 cfs and greater; the flow at which overbank flooding first occurs varied by model. Riparian model overbank cell conductance was scaled by the percentage of the cell flooded. Conductance was calculated using the following equation:

$$C = \frac{L * W * K_v}{M} * \frac{PerCov}{100} \qquad \text{Equation 3.2}$$

where:

$C$ is the flooded model cell conductance (ft$^2$ /day);
$L$ is length cell, 250 ft;
$W$ is width of cell, 125 ft;
$K_v$ is the floodplain surface vertical hydraulic conductivity (initially set at 1 ft/day);
*PerCov* is the percentage of the riparian cell covered by flooded FLO-2D cells;
$M$ is the presumed bed thickness (initially set at 1 ft).

# 4.0 REFINEMENT OF RIPARIAN MODEL INPUT AND STRUCTURE

## 4.1 Summary of Refinements to Model Input and Structure

Refinements relating to riparian model input and structure were made in four primary areas:

- *RIV packages* – For all six of the riparian models revised as part of this work, RIV packages for all flow conditions were rebuilt using results from the January 2008 FLO-2D model, which is based on a 250 foot by 250 foot grid cell (Section 3.6). For all six models, FLO-2D results were reviewed to establish at what flow levels overbank flooding first occurs. RIV packages were then constructed, incorporating both in-channel and overbank flows, for each flow level;
- *Riverside drains* – For all but the Cochiti model, where drains were already represented in the STR package, drains were re-specified into STR packages. With this package, the flow and stage within drains are explicitly simulated based on assumed channel geometry, hydraulic parameters and drain bottom elevations. The drains represented as segments in the STR package are shown on Figures 3.3 to 3.8 and identified on Table 3.3.
- *Drain bottom elevations* – For the Upper Albuquerque, Lower Albuquerque, Belen, and Bernardo models, drain bottom elevations and drain slopes were revised using the new 2008 survey data;
- *RIP packages* – For all six of the models, ET rates in the RIP packages were adjusted to account for new consumptive use data and monthly RIP packages were prepared.
- *LPF packages* – Aquifer and channel hydraulic parameters were adjusted after evaluation of model results where improvement in the match of simulated to observed conditions could be achieved through modification of channel bed conductances and aquifer hydraulic conductivity. Changes to the specification of aquifer channel hydraulic parameters are further described in Section 5.0.

Specific changes applied to each model are described below.

## 4.2 Cochiti Reach

RIV and RIP packages were revised as described above (Section 4.1). RIV packages were built using FLO-2D model results initiated with flows at Cochiti Dam. No changes were made to the existing STR package. Drain segments are shown on Figure 3.3.

## 4.3 Upper Albuquerque Reach

RIV and RIP packages were revised as described in Section 4.1. RIV packages were built using FLO-2D model results initiated with flows at Angostura Dam. Riverside drains were moved from the RIV package to the STR package. Drains were subdivided into segments as shown on Figure 3.4. Surveyed drain elevations obtained in 2008 (Appendix B) were used in assigning drain bottoms for the model area south of Alameda Bridge. North of this point, existing data and interpolations were used. Drain slopes were calculated between new survey data points, or cell-by-cell in areas lacking new survey data. In the latter case, slopes were calculated using drain bottom elevations in adjacent upstream and downstream cells divided by the drain length between elevation locations. Negative slopes were set to 0.0001. Results were reviewed and slopes in approximately 15 cells were set equal to adjacent average slopes to avoid unrealistic pooling of water.

### 4.4 Lower Albuquerque Reach

RIV and RIP packages were revised as described in Section 4.1. RIV packages were built using FLO-2D model results initiated with flows at Angostura Dam. Riverside drains were moved from the RIV package to the STR package. Drains were subdivided into segments as shown on Figure 3.5. Surveyed drain elevations obtained in 2008 (Appendix B) were used in assigning drain bottoms for this model. Drain slopes were calculated for drain lengths between sequential surveyed data points and assigned to model cells accordingly.

### 4.5 Belen Reach

RIV and RIP packages were revised as described in Section 4.1. RIV packages were built using FLO-2D model results initiated with flows at Isleta Dam. Riverside drains were moved from the RIV package to the STR package. Drains were subdivided into segments as shown on Figure 3.6. Surveyed drain elevations obtained in 2008 (Appendix B) were used in assigning drain bottoms for this model. Drain slopes were calculated for drain lengths between sequential surveyed data points and assigned to model cells accordingly.

### 4.6 Bernardo Reach

RIV and RIP packages were revised as described in Section 4.1. RIV packages were built using FLO-2D model results initiated with flows at Isleta Dam. Riverside drains were moved from the RIV package to the STR package. Drains were subdivided into segments as shown on Figure 3.7. Surveyed drain elevations obtained in 2008 (Appendix B) were used in assigning drain bottoms for this model.  Drain slopes were calculated for drain lengths between sequential surveyed data points and assigned to model cells accordingly.

## 4.7 Socorro Reach

RIV and RIP packages were revised as described in Section 4.1.  RIV packages were built using FLO-2D model results initiated with flows at San Acacia Dam.  The Low Flow Conveyance Channel (LFCC) was moved from the RIV package to the STR package.  The LFCC is represented by one segment, as shown on Figure 3.8.  No change was made to the existing LFCC bottom elevations.  LFCC slopes were calculated using LFCC bottom elevations in adjacent upstream and downstream cells and the LFCC length between elevation locations. Negative slopes were set to 0.0001; resulting slopes were then smoothed using a moving-average.

## 5.0 STEADY-STATE SIMULATIONS

### 5.1 Method

A series of steady-state simulations were conducted using river boundary conditions corresponding to flows of 100, 500, 1,500, 2,000, 3,000, 5,000, 7,000 and 10,000 cfs. The following results were reviewed:

- Net river seepage (from in-channel and flooded overbank cells);
- Net gains in drains;
- Groundwater elevations and depth below river bottom; and,
- Vertical head differences.

### 5.2 Parameter Adjustment

While no historical or existing condition is strictly comparable to the results of the steady-state simulations, the results can be used in a general sense to evaluate the reasonableness of the models. Initial model simulations employed channel conductances and hydraulic conductivity distributions from previous model versions, but with the model input and structure refinements discussed in Section 4.0. Review of the results and comparison with a broad range of river seepage run observations suggested that simulated river seepage losses and drain accretions were low. For example, in the 500 or 1,000 cfs steady-state simulations for the Albuquerque reaches, river losses were simulated in the range of 3 to 4 cfs per mile. Inspection of seepage run observations suggested that losses for these flow levels tend to fall within a range of 4 to 8 cfs over these model reaches. Similarly, the losses in the Socorro model appeared to fall on the low end of a reasonable range of losses expected based on seepage run investigations.

A series of sensitivity analyses were made to assess the impact of channel conductance and Layer One hydraulic conductivity on river losses and drain accretions. The vertical hydraulic conductivity assigned to the channel bed, and used in computing the channel conductance, was varied from the initial value of 1 foot per day to values of 2, 5, 10, 20 and 50 feet per day. The lower values had limited impact. Ultimately, a combination of an increase in the vertical hydraulic conductivity for the channel bed to 10 feet per day and an increase in the hydraulic conductivity of Layer One by a factor up to two, depending on model[3], was selected.

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[3] The resulting horizontal conductivity for layer 1 was 60 feet per day for the Socorro model and 80 feet per day for the Cochiti, Upper Albuquerque, Lower Albuquerque, Belen and Bernardo models.

These changes resulted in seepage losses/gains in the Albuquerque (Upper and Lower) and Socorro model reaches that were generally within the mid-range of observed values. Seepage loss data for other model reaches was less definitive; nevertheless, these changes were extended to all model reaches. Net seepage from river and overbank areas, and to drains, from simulations with the adjusted parameter values is tabulated in Table 5.1 for each of the steady-state simulations for the various flow-dependent river boundary conditions. Table 5.2 shows the simulated rate of inflow for specific drains under the steady-state simulation with river flows maintained at 500 cfs. These rates of inflow represent those under a hypothetical condition wherein river and regional groundwater boundary conditions, as well as evapotranspiration, are held constant at approximate average values. While no actual condition corresponds to this simulation, the results are useful for evaluating general spatial trends and comparing the simulated seepage conditions in different model reaches.

### 5.3 Discussion of Results

The Cochiti reach exhibits generally low seepage losses from the river and enhanced accretions to the drains, due to the generally higher water table conditions in this reach, particularly in the upper reaches close to Cochiti Lake. Under steady-state river flow conditions of 1,000 cfs, on average, the simulated river losses and drain accretions are 0.7 cfs and 3.9 cfs per mile, respectively. The magnitude of both river losses and drain accretions increases with increasing river flow levels. All drains gain, at rates varying between 2.8 and 4.1 cfs per mile under the 500 cfs steady-state condition (Table 5.2). The Santa Fe River as it approaches the Rio Grande (Cochiti Segment 7) is simulated as losing about 2.5 cfs per mile. Field investigation of seepage from the Rio Grande, from the Santa Fe River, or to drains has not been conducted in this reach and comparisons of simulated to observed values have not been developed.

In the Upper Albuquerque reach, at a steady-state flow of 500 cfs, simulated river losses and drain accretions are 5.1 and 2.6 cfs per mile respectively. In the Lower Albuquerque reach, at a steady-state flow of 500 cfs, simulated river losses and drain accretions are 4.9 and 1.6 cfs per mile, respectively. The simulated river losses fall within the range observed during several field seepage investigations (Table 3.2). Notably, the seepage losses are greater in the lower part of the Upper Albuquerque reach (Alameda to Central) than in the upper part (Angostura to Alameda), both as observed in the field and as simulated. Drain accretions are reduced in the lower part of the Upper Albuquerque model and in the Lower Albuquerque model (Table 5.2) to values generally less than 2.5 cfs per mile, in part due to suppressed regional groundwater levels, as represented in the boundary groundwater levels (GHB Package) on the models. In both models, the magnitude of simulated river losses and drain accretions increases with increasing river flow levels.

In the Belen reach, at a steady-state flow of 500 cfs, simulated river losses and drain accretions are 4.1 and 1.9 cfs per mile, respectively, with river seepage losses higher in the upper part, Isleta to Tome, than in the lower part, Tome to the county line. The simulated losses appear reasonable in the context of available observations (Table 3.2). In the Bernardo reach, at a steady-state flow of 500 cfs, simulated river losses and drain accretions are 0.06 and 0.33 cfs per mile, respectively. The Bernardo reach exhibits an interesting change in simulated conditions in the vicinity of Highway 60. In the upper part of the reach, the river experiences seepage losses (16.41 cfs over rows 1-198 of the model domain); but, in the lower part of the reach, the river gains (14.9 cfs over rows 199-450 of the model domain). This change is also reflected in simulated Layer One groundwater elevations, which show a transition from a losing to a gaining condition. The simulated function of drains is variable in this model reach. The Lower San Juan Riverside Drain on the east side of the river gains water in most of its upper half, whereas it tends to lose water in its lower reach, below Highway 60. Similar function is seen with the Lower Sabinal Riverside Drain on the west side of the river. In areas where drains are losing rather than gaining, the drain appears to be situated above the elevation of the adjacent river bottom. Additionally, near the bottom of the model reach, the river’s gaining conditions may also be attributed to a vertical upward gradient from deep to shallow model layers. This condition reflects the presence of a geologic constriction in the basin at San Acacia, and the movement of deeper groundwater towards the Rio Grande.

In the Socorro reach, at a steady-state flow of 500 cfs, simulated river losses and LFCC gains are 5.2 and 4.9 cfs per mile, respectively. Observed river losses in this reach have been quantified over several field investigations, with losses from the river between San Acacia and Highway 380 averaging about 150 cfs over this 27 mile reach, or, about 5.6 cfs per mile. Observed LFCC gains were in the range of 4 to 6.6 cfs per mile between San Acacia and the North Boundary of the Bosque del Apache as calculated from several seepage runs conducted in

2000 (Table 3.2). While the simulated steady-state conditions are not a replicate of the conditions during the field investigations, nevertheless, they are expected to be in the general range of those observed given the nature of the simulated conditions. The general correspondence between the simulated and observed conditions suggests that the model is reasonably well parameterized in this reach, at least on a broad scale.

# 6.0 TRANSIENT SIMULATIONS

## 6.1 Transient Periods Evaluated, 2007 and 2008

Spring run-off pulses occurred in both 2007 and 2008. The pulse in 2008 was greater in magnitude and longer in duration (Appendix C), representing an ideal period for evaluation of the models' ability to represent transient conditions. At the Rio Grande at San Felipe, flows reached 2,000 cfs for several days in March of 2008, and maintained generally above 3,000 cfs throughout April. In May, flow increased to 4,000 cfs; with a late May spike to 6,000 cfs and another spike in June, after which flows steadily ramped down to about 1,000 in mid-July. In 2007, a flow peak, just above 3,500 cfs, occurred in May.

Based on available monitoring well and stream gage data, one time period was selected for transient simulation for each model reach. These are:

***2007 Spring Pulse***: Lower Albuquerque and Bernardo models;
***2008 Spring Pulse***: Cochiti, Upper Albuquerque, Belen and Socorro models.

For each of these years, flows at selected gages are aggregated into step-function hydrographs for use in transient modeling of seasonal groundwater changes (Figure 6.1a-f). Table 6.1 provides a summary of the monitoring wells that provide groundwater elevation observations for comparison to simulated values in these transient simulations. Table 6.2 provides details on the stress periods, including number of days, dates, and flows, for each of the modeled transient runs. Table 6.3 provides modeled net flux rates at the end of each stress period. The methods and results for transient simulation of each model reach are discussed below.

For all simulations described herein, the general head boundary conditions representing regional groundwater conditions are held constant throughout the course of the simulation. There may be some applications of the model where variation in these conditions is desired, for example, where a strong seasonal signal beyond those modeled with the riparian model are impacting head conditions at the boundary of the model. Incorporation of a transient boundary condition would involve significant additional effort to the model setup, but might be considered depending on modeling objectives.

### 6.2 Cochiti Model

The transient simulation for the Cochiti model extends from January through August 2008 and employs 13 stress periods with river conditions derived from flow levels between 1,000 and 7,000 cfs. The stress periods range from 2 to 58 days in length. Simulated and observed water level responses at the NMISC Pena Blanca piezometer cluster are shown on Figure 6.2. The locations of the piezometer clusters are shown on Figure 3.3. In general, the simulated changes in water level are a good match to the observed changes considering the approximation involved in the step-function hydrograph used to develop the river boundary condition (Figure 6.1a). While the simulated change is relatively good, the comparison indicates an offset in absolute elevations of about 2 feet, with the simulated water levels higher than the observed water levels. This offset may reflect inaccuracy in the river or drain elevations, for which recent survey data were unavailable. If elevation control in these areas can be obtained, the model can be improved to achieve a better match to absolute elevations.

### 6.3 Upper Albuquerque Model

The transient simulation for the Upper Albuquerque model extends from January through August 15, 2008 and employs 12 stress periods with river conditions derived from flow levels between 500 and 5,000 cfs. The stress periods range from 4 to 57 days in length. Simulated and observed water level responses at the NMISC Paseo piezometer cluster (Figure 3.4) are shown on Figure 6.3. The observed water elevations at these piezometers are very well-matched by the simulated values throughout the season. The initial simulated water elevations are slightly high, but this is explained by the first step of the step-function hydrograph (Figure 6.1b), which is similarly slightly high.

### 6.4 Lower Albuquerque Model

The transient simulation for the Lower Albuquerque model extends from the end of February 2007 through August 15, 2007 and employs 12 stress periods with river conditions derived from flow levels between 500 and 5,000 cfs. The stress periods range from 5 to 55 days in length. Simulated and observed water level responses at wells along three USGS well transects are shown on Figure 6.4. The transects are located at Barelas Bridge, Rio Bravo Bridge and I-25 Bridge (Figure 3.5). As with the Upper Albuquerque model, the initial simulated water elevations are slightly high, but this is explained by the first step of the step-function hydrograph (Figure 6.1c), which is similarly slightly high.

Beyond the first stress period, the water level changes at the wells along the Barelas Bridge transect are reasonably well matched, however there is a offset in absolute elevation values ranging from about a half a foot to two feet. An inquiry was made to the USGS regarding the accuracy of the surveyed land elevations at the wells when some ambiguity was identified in the data sets. It was learned that the USGS suspects that some reference elevations and/or spatial coordinates may not be correct, and for this reason, an audit is being conducted by the USGS to review the data. Similarly, at the Rio Bravo and I-25 transects, there is an offset between the simulated and observed water level elevations. Furthermore, at the I-25 transect, the simulated change in water levels is dampened as compared to the observed changes. Additional attention to this area is warranted once the USGS water level and survey audit is complete.

### 6.5 Belen Model

The transient simulation for the Belen model extends from June 2007 through August 2008 and employs 13 stress periods with river conditions derived from flow levels between 0 and 5,000 cfs. The stress periods for the portion of the simulation occurring in 2008 range from 6 to 58 days in length. Several months in 2007 were also simulated due to the nature of those conditions and their potential impact on the initial condition in 2008. In particular, a long, dry period was simulated in the fall of 2007. Simulated and observed water level at the two recently drilled NMISC piezometer clusters in Los Lunas and Belen are shown on Figure 6.5. The piezometer clusters are located as shown on Figure 3.6. The match of simulated to observed values is generally reasonable, although there is a slight high offset at Los Lunas and a low offset at Belen. Furthermore, there is a difference in the timing of the peaks, which suggests that inferences made regarding ungaged inflow conditions below Isleta may be subject to some error.

Elevations of the wells, river and drains have been recently surveyed and accuracy in surveyed elevations is understood to be good. On the other hand, with drain survey control points only at one mile intervals, resolution might explain an offset on the order of one foot. Local conditions not reflected into the model could also be a factor in the simulated water elevation offsets. The occurrence of such offsets in spite of the past and present level of effort in developing the models simply underscores the need for enhanced and site-specific data to improve model results for application to specific locations.

### 6.6 Bernardo Model

The transient simulation for the Bernardo model extends from June 2007 through August 2008 and employs 11 stress periods with river conditions derived from flow levels between 0 and 3,000 cfs (Figure 6.1e). The stress periods range from 10 to 44 days in length. Only two well clusters are available within this model reach, and these are wells developed as part of the UNM Bosque ET research at La Joya and Sevilleta (Figure 3.7). A comparison of observed to simulated water levels is shown on Figure 6.6 for one well from each of the clusters. Accurate surveyed measuring point elevations are not available for the wells, therefore, only change in water level is shown.

Some differences between simulated and observed conditions are notable, including, high simulated declines in the post-spring recession period. This difference is attributed to the modeled step-function hydrograph, which trails to zero rather than maintaining an intermittent, slight flow level. The model values illustrate the high sensitivity of groundwater elevations to periods of river drying; in this case, the modeled scenario was drier than that which actually occurred. Additionally, there is some imprecision in the step-function hydrograph, and perhaps in the underlying flow assumptions below Isleta, that probably accounts for the lack of close tracking of the high and low points on the well hydrographs.

### 6.7 Socorro Model

The transient simulation for the Socorro model extends from June 2007 through August 2008 and employs 16 stress periods with river conditions derived from flow levels between 100 and 5,000 cfs (Figure 6.1f). The stress periods for the portion of the simulation occurring in 2008 range from 4 to 35 days in length. Several months in 2007 were also simulated due to the nature of those conditions and their potential impact on the initial condition in 2008. In particular, a long period of very low flow was simulated in the summer and fall of 2007. Simulated and observed water levels at four NMISC well transects are shown on Figure 6.6. The transects are located at San Acacia, Escondida, Brown Arroyo and Highway 380 (Figure 3.8).

With one exception, discussed further below, the observed and simulated groundwater elevations compare reasonably well, although at some transects, in some periods of time, offsets of a foot or two are evident. In general, these offsets represent opportunities for further fine-tuning of the models to localized conditions, for example, conductances could be modified to increase or decrease river losses in certain sub-reaches.

There is one significant deviation in observed and simulated groundwater elevations during the very low flow period of summer/fall 2007 at the Brown Arroyo and Highway 380 transects. This is attributed to the underestimation of river seepage in the FLO-2D model, which provides the basis for the river boundary conditions on the groundwater model. This is evidenced, for example, in the hydrographs for Brown Arroyo E01B and E01C (Figure 6.7 i, j), where observed values show a water elevation drop of over 5 feet between August and November of 2007 with flows at San Acacia generally fluctuating in the range of 50 to 250 cfs. Given that the Rio Grande through this reach typically loses on average 5 cfs per mile, the flow at Brown Arroyo and at Highway 380, 20 and 26 miles respectively, below San Acacia, would be very low and/or experience some drying in this reach with low flows at San Acacia. Yet, in the FLO-2D model with an inflow at San Acacia of 100 cfs, flow throughout this reach is maintained, as evidenced by the calculated depths to water reflected in the FLO-2D output at the bottom of the reach. Until the simulation of seepage in the FLO-2D model is corrected, the simulated groundwater elevations in the Socorro reach will not be realistic at low flows.

# 7.0 SUMMARY AND RECOMMENDATIONS

The six updated riparian groundwater models discussed in this report, along with the recently completed Bosque del Apache and Fort Craig models (SSPA and NMISC, 2008), provide a suite of eight models for simulation of river corridor conditions under changing river, drain, vegetation, and regional groundwater conditions. These models can be used to support restoration activities such as: site selection and assessment, feasibility studies, project design, and project monitoring, operations, and maintenance; they can be used by water managers to support quantification of depletions, seepage loss, and return flow under various hypothetical conditions such as alternative water conveyance conditions or river operations scenarios.

All models presently incorporate best available data at a regional scale. However, the models vary in the amount and quality of available data at the local scale used in their development and calibration, and, in their expected accuracy. Recommendations for appropriate use and future improvements are provided below.

## 7.1 Cochiti Model

This model can be improved substantially with the acquisition and incorporation of surveyed drain elevations and additional river elevation data. Additional monitoring wells and field seepage investigation would aid in model refinement. To date, efforts to obtain this type of data have been unsuccessful due to lack of access agreements. Nevertheless, broad trends can be evaluated at a qualitative level in this reach with the existing model.

## 7.2 Upper Albuquerque Model

This model can be further evaluated and calibrated in coming years with the new NMISC piezometers, in conjunction with the existing USGS Montano Bridge piezometers if maintained by the respective agencies. For the present work, contemporaneous data from both locations were unavailable. However, in future years, assuming that data collection programs are maintained, these data may serve to further refine the models. Continued, periodic, field seepage investigations will also prove useful, especially if coordinated with the measurement of drain stage. At present, the model is reasonably well-developed, and should be useful for general analyses. Site-specific analyses would be well-served by the collection of high-resolution drain and river bottom elevation data.

### 7.3 Lower Albuquerque Model

This model is relatively well developed. However, some additional site-specific and higher resolution drain and river elevation data will be important for any site-specific applications. Continued, periodic, field seepage investigations will also prove useful, especially if coordinated with the measurement of drain stage. Additional model calibration may be warranted after completion of the USGS audit of survey data for their well transects.

### 7.4 Belen Model

This model would benefit from better definition of river inflow at Isleta, as well as additional monitoring wells, and periodic field investigation of seepage. Regardless, the model is useful for evaluating general trends. Site-specific application will require additional site-specific data to improve accuracy.

### 7.5 Bernardo Model

As with the Belen model, the Bernardo model would benefit from better definition of river inflow at Isleta, as well as additional monitoring wells, and periodic field investigation of seepage. Regardless, the model is useful for evaluating general trends. Site-specific application will require additional site-specific data to improve accuracy.

### 7.6 Socorro Model

The Socorro model has benefited from a robust program of groundwater monitoring and field seepage evaluations. However, simulation of groundwater conditions under low river flow (i.e., especially less than 300 cfs) will not be accurate until FLO-2D is updated to better incorporate the observed river seepage conditions. Continued groundwater monitoring will be important to future model evaluation and updates. As with the other models, site-specific application will benefit from additional site-specific data, including higher resolution LFCC and river bottom elevation data.

### 7.7 Bosque del Apache Model

The Bosque del Apache model wasn’t addressed in the current refinement phase because it was completed in early 2008, and additional data is not available for refinement. The Bosque del Apache model can be applied on a broad scale to address general questions related to surface water/groundwater interactions in this reach. However, additional refinement and/or calibration are recommended prior to applying the model on a sub-annual scale or to localized or site-specific management questions. Key data of interest for this model include higher-resolution land surface elevation data, higher-resolution data on LFCC bed elevations, and LFCC water surface data corresponding to specific river flow conditions. Continued monitoring of the NMISC piezometers is recommended, as these data are invaluable in assessing groundwater conditions in changing river environments.

### 7.8 Fort Craig Model

The Fort Craig model wasn't addressed in the current refinement phase because it was completed in early 2008, and additional data is not available for refinement. The Fort Craig model is not yet calibrated, and, until better land surface elevation data are available, it can not be fully calibrated. Subtle adjustments can be made to improve the fit between simulated and observed data, but as a predictive tool the model will remain limited. At its current stage of development, the Fort Craig model can be applied on a broad scale to address general questions related to river and LFCC gains and losses. However, it should not be used for detailed analysis without further refinement. Key data of interest for this model include higher-resolution land surface elevation data, higher-resolution data on LFCC bed elevations, and LFCC water surface data corresponding to specific river flow conditions. Continued monitoring of the NMISC piezometers is recommended, as these data are invaluable in assessing groundwater conditions in changing river environments.

### 7.9 Summary

The model refinement project has resulted in improved model representations, particularly for those model reaches that experienced the bulk of additional data improvements. The models are suitable for screening-level evaluation of questions related to surface water/groundwater interactions that may arise in relation to river restoration activities. While detailed evaluation of specific sites will still require the incorporation of site-specific data collected in areas of greatest interest, the work accomplished in this effort will expedite the future application of the models to water management and river restoration questions.

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