Surface Water - Groundwater Interaction Represented in the Rio Grande Water Resources Planning Model

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ABSTRACT: The State of Colorado is in the process of developing the Colorado Decision Support System that includes a central database and GIS storage of water related data, plus models developed by river basins that can be used to answer water development and conservation questions. The Decision Support System developed for the Rio Grande Basin in Colorado requires modeling tools that accurately represent the interactions between surface water use and ground water pumping; agricultural diversions and ground water recharge; and consumptive use and river return flow timing. A surface water model was developed to simulate hydrologic conditions, water rights administration and accounting, and reservoir operations in the basin. The model includes all major reservoirs, diversions, pumping, transmountain imports and transmountain exports in the basin. In addition, it includes unique operational and administrative features that are critical to the administration of the river, such as groundwater use, the Closed Basin Project, and the Rio Grande Compact. The surface water model is capable of making comparative analyses for the assessment of historical and future water management policies.

KEY TERMS: surface water modeling; unit response functions.

INTRODUCTION

The Rio Grande Water Resources Planning Model (Rio Grande Model) was developed jointly by the State of Colorado Water Conservation Board and the Division of Water Resources as part of the Rio Grande Decision Support System (RGDSS). The objective was to develop a water allocation and accounting tool which represents 100 percent of the basin's consumptive use and would be capable of making comparative analyses for the assessment of historical and future water management policies.

BACKGROUND

The Rio Grande Basin in southern Colorado includes the Rio Grande, the Conejos River, the Closed Basin, and numerous other smaller tributaries, and comprises an area measuring approximately 7,700 square miles. The basin includes portions of 10 counties and and supplies an average annual flow (1950 – 1997) of approximately 416,000 acre-feet to the Colorado-New Mexico state line. The Basin is unique in that it includes a large sump area of approximately 2,940 square miles known as the Closed Basin. Many smaller streams and rivers flow into the Closed Basin from the northern perimeter of the Valley, although there is no natural outlet from this area. Deliveries at the New Mexico – Colorado stateline have been closely managed by the Division 3 Engineer since 1969 to ensure compliance with requirements of the Rio Grande Compact.

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The most significant water users in the basin include agriculture, municipal and wildlife areas. Agriculture is the largest water user, with hundreds of irrigation ditches diverting from the Rio Grande, Conejos River and other numerous tributary streams throughout the basin. Total irrigated area in the basin is estimated to be approximately 620,000 acres (Agro Engineering, 2000). Groundwater is an important component of the supply to most agricultural water users in the Valley. Agricultural pumping during recent years (1980 to present) has been estimated at roughly 500,000 acre-feet per year, or roughly 25 percent of total irrigation supply (LRCWE, 2000). Well water is extracted from both shallow (unconfined) and deep (confined) aquifers underlying the Valley floor. Many of the deeper wells have artesian flow. In addition to groundwater, several relatively large reservoirs provide water supply to a handful of ditches and irrigation companies. The eleven largest reservoirs comprise approximately 370,000 acre-feet of storage. Other, relatively minor, water uses in the Rio Grande basin include municipal uses, transbasin diversions and wildlife areas.

MODEL DEVELOPMENT

The Rio Grande Model was developed using StateMod, the State of Colorado's Stream Simulation Model, and can be operated on either a monthly or daily time step for calendar years 1950 to 1997. The model extends from headwaters around the perimeter of the San Luis Valley to the Colorado-New Mexico state line. It represents the entire Rio Grande drainage, including those tributaries that flow into the Closed Basin. The model attempts to simulate 100% of the basin's consumptive use by explicitly modeling all major structures and spatially aggregating minor structures. The model includes all major reservoirs, diversions, pumping, transmountain imports and transmountain exports in the basin. In addition, it includes unique operational and administrative features that are critical to the administration of the river, such as:

- Groundwater Use
- Closed Basin Project
- Rio Grande Compact
- Direct Flow Storage
- Reservoir Operations
- Soil Moisture Use

Development of the surface water model proceeded using a *data centered* approach which allows information to flow from a central database to StateMod input files using programs called Data Management Interfaces (DMI's). The data centered procedure is very efficient because it (1) allows new structures or information to be added quickly and efficiently once the central database is updated, (2) allows the user to focus on the system operation without being burdened with model input formats, (3) is self-documenting by automatically transferring the user-supplied commands file to a header on top of each output file, and (4) recognizes that official data stored in the database often needs enhancement before it can be used for modeling.

The Rio Grande Model was developed in three phases: Phase 1 Monthly Model, Phase 2 Daily Model and Phase 3 Refined Monthly and Daily Models. Within each phase three data sets were developed: Historical, Calculated, and Baseline. The *historical data set* was used to develop baseflows and calibrate parameters such as return flows and reservoir operations. Its results allow the modeled hydrology and reservoir operations to be compared to recorded streamflows and reservoir contents. The *calculated data set* uses the historical data set as its foundation, but it allows ditch systems and reservoirs to operate by demand. The demands are computed as a function of historic diversion practices and irrigated acreage, climate, cropping pattern, and efficiency estimates developed by the Consumptive Use contractor to the RGDSS project. The *baseline data set* builds upon the calculated data set by allowing reservoirs, structures, and operating rules that were constructed or have changed during the study period to operate in a consistent manner for the entire study period. This data set provides results which can be used directly for a "what if" analysis.

The Rio Grande Model consists of:

- Four-hundred and seven (407) key (explicit) diversion structures (representing roughly 90 percent of the basin's net absolute decreed surface water right amounts);
- Forty-six (46) aggregated irrigation structures representing the remaining irrigated lands that were not explicitly modeled;
- Twelve (12) key (explicit) reservoirs;
- Ten (10) aggregated reservoirs representing the remaining decreed storage not explicitly modeled;
- Sixty-nine (69) aggregated well structures representing the remaining approximately 90,000 acres of irrigated lands that are supplied by wells only and are not explicitly represented by key or aggregated surface diversion structures; and
- Twenty-eight (28) instream flow water rights.

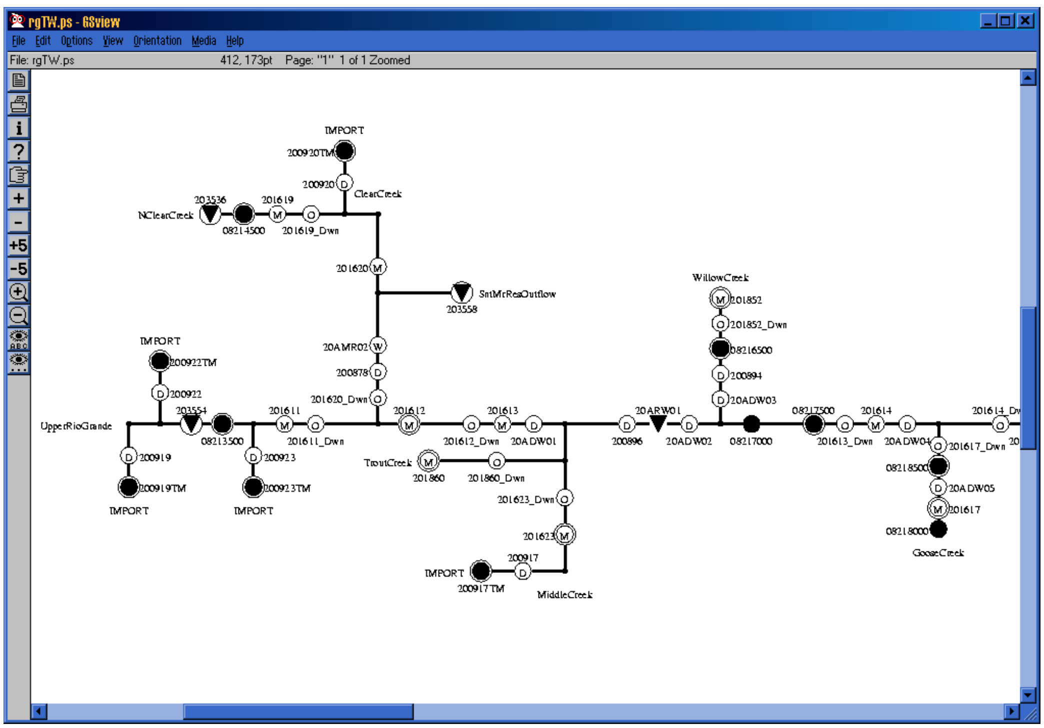

Figure 1 A portion of the Network Diagram for the Rio Grande Surface Water Model

SURFACE WATER – GROUNDWATER INTERACTION

The location and timing of stream return flows and depletions are dependent, in part, upon the nature of the hydrogeologic connection between the stream and the groundwater aquifers. The distance from the stream of the recharge or pumping, the aquifer's geometry and hydraulic characteristics (conductivity, specific yield, etc.), the stream bed geometry and conductance, and existence of phreatophytes all affect return flow and depletion patterns. As part of RGDSS, the San Luis Valley groundwater flow model was used to develop Unit Response Functions (URFs) to represent the stream-aquifer interaction. Unique URFs were defined for each combination of aquifer layer (unconfined and confined), spatially defined URF zones, and stream reaches in the basin. URFs then became the patterns used in the Surface Water model, which assumes the stream-aquifer interaction behaves as a linear system.

Spatially defined URF zones are shown in **Figure 2**. For convenience, these zones were initially delineated based on location of surface stream gages, and later refined based on known physical properties of the groundwater aquifers. Ninety-three URF zones were defined for the initial URF development, including 18 "river" zones that are adjacent to larger rivers and streams in the San Luis Valley. URFs are incorporated into the Surface Water model via the *delay* input file.

The Rio Grande Model also requires input concerning the location of return flows or depletions. This input occurs via three location files: the *return flow location* file contains (location of return flows from surface water diversions); the *well return location* file (location of return flows from well pumping); and the *well depletion location* file (location of depletions from well pumping). Note that the effects of pumping and/or return flows from one area may be "felt" by several different river reaches, and each of these river reaches will have a different URF that defines the temporal pattern of the effect.

Figure 2 Spatially defined Unit Response Function (URF) zones.

The **makertn** StateMod utility was created to automate the process of preparing the return flow and depletion input files for the Surface Water Model. **Makertn** combines the location information for irrigated lands with the return flow and depletion information for the URF zones (**Figure 3**). This involves use of GIS coverages which contain maps of irrigated parcels and associations of these parcels with surface diversion structures. The GIS databases also contain the spatial definition of URF zones in the basin being modeled. The GIS is then used to relate each irrigated parcel to an URF zone. This task was automated via an ArcInfo Avenue script file.

Note that URFs define unique relationships (depletion or accretion) between groundwater activity in the URF zones and a discrete number of river reaches. **Makertn** uses a URF and a "river reach to node" database to define which StateMod nodes that recharge and/or pumping in each URF zone and each aquifer layer affects.

The information from the GIS and URF databases is processed in an Access™ database and exported to text input files for **makertn** to use. **Makertn** reads these files, integrates the irrigated parcel and URF information, and then prepares the StateMod input files as output. The **makertn** command file defines the input and output file names and locations. Default values for some key return flow and depletion parameters can be specified in the command file as well. Additionally, the user can place commands in the **makertn** command file to replace the calculated surface and groundwater return flows or depletions with a new set specified by the user.

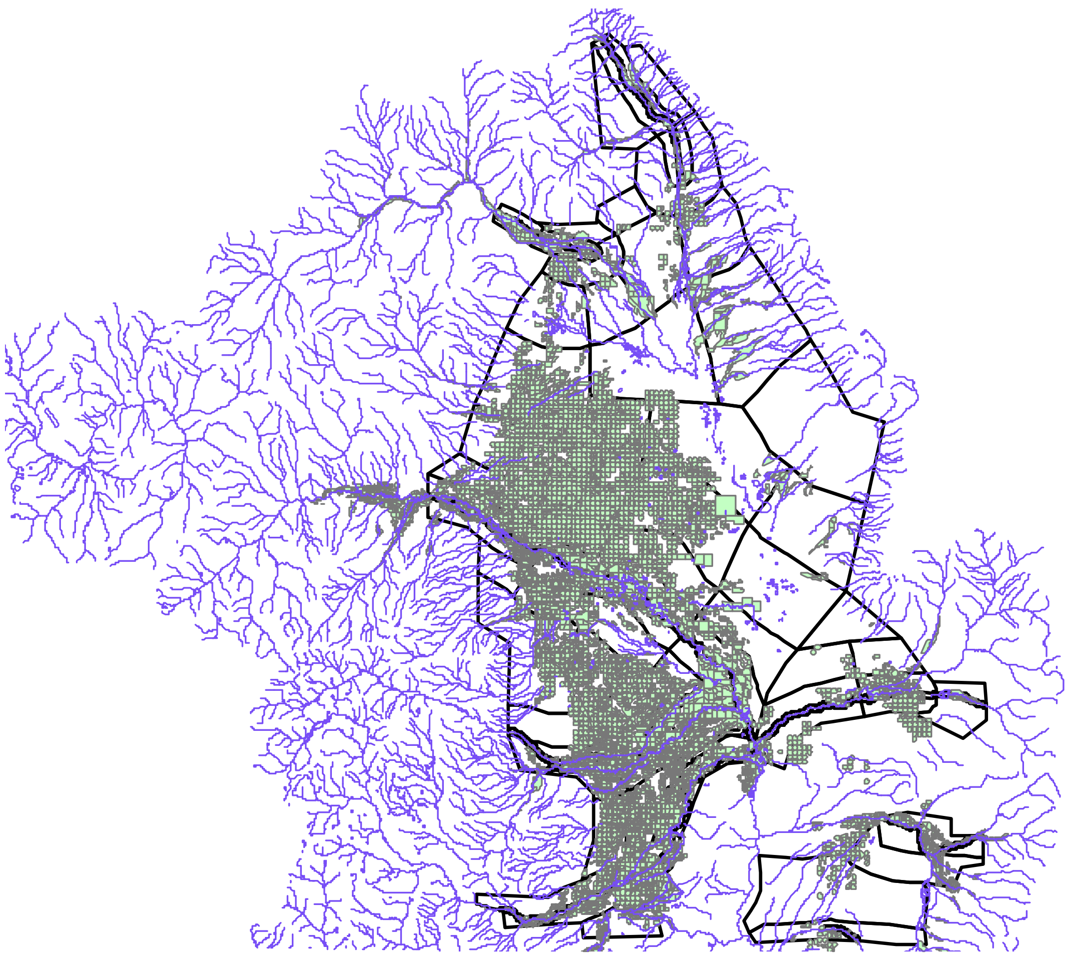

Figure 3 URF zones superimposed on irrigated lands.

For a model such as the Rio Grande that represents a large geographic area and many different water users, the spatial relationships between parcels of irrigated lands, URF zones, river reaches, groundwater wells and aquifer layers can be very complex. Use of GIS and the utility **makertn** make the processing of these complex relationships quicker and makes it feasible to incorporate the information into a surface water model. Additional information concerning the Rio Grande Surface Water Model, StateMod, modeling return flows and well depletions, and **makertn** can be found at the State of Colorado Decision Support System (CDSS) Web site (http://cdss.state.co.us).

SURFACE WATER MODEL RESULTS

Key results of the Rio Grande Surface Water Modeling effort are as follows:

1) Using StateMod, a water resources planning model has been developed that can make comparative analyses of historical and future water management policies in the Rio Grande basin. The model attempts to represent 100% of the basin's surface and ground water use.
2) The model represents surface water and groundwater interaction using Unit Response Functions (URFs). The URFs assumes that the stream-aquifer interaction behaves as a linear system.
3) URFs are developed using the San Luis Valley Groundwater Model, and URF assignments in the Surface Water Model are made using the utility **makertn**.
4) The surface water model has been calibrated for a study period extending from calendar years 1950 to 1997.
5) The calibration in the Historic scenario is considered excellent, based on a comparison of historical to simulated streamflows, reservoir contents, and diversions.
   - Diversions deviate, on average, 1.6 percent from their historical diversions.
   - Pumping deviates, on average, less than 1 percent from their historical estimate.
   - Simulated reservoir end-of-month contents are representative of historical operations.
   - Rio Grande Compact operations are consistent with historic operations.
6) The calibration in the Calculated scenario is considered good, based on a comparison of historical to simulated streamflows, reservoir contents, and diversions.
7) A baseline data set has been prepared which, unlike the calibration data set, assumes all existing water resources systems were on-line and operational for calendar years 1950 to 1997. This baseline set is appropriate for evaluating various “what if” scenarios over a long hydrologic time period containing dry, average, and wet hydrologic cycles.
8) Development of the Rio Grande Surface Water Model will continue. As development of the Groundwater Model continues, URFs will be updated, and the Surface Water Model re-calibrated.

REFERENCES

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