HYDROGEOLOGY IN RIVER MANAGEMENT
RIO GRANDE VALLEY, NEW MEXICO

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INTRODUCTION

Problem

In addition to the legal, political, and socioeconomic aspects discussed elsewhere in this volume, river management also involves many technical considerations. Rivers seldom exist as hydraulically isolated phenomena, but are dominant features in larger, complex ground water/surface water systems. Effective administrators recognize and appreciate the significance of the geologic and hydrologic factors that control a river's behavior. Thus, efficacious management of the Rio Grande depends upon the administrators' capacity to conceptualize the ground water/surface water system, of which it is the dominant feature.

Purpose

We have three purposes in this paper. One is to call attention to some of the geologic, hydrologic, and hydrochemical concepts that have been advanced to explain ground water phenomena observed in the Rio Grande Valley. Another is to examine how these concepts fit into models of the system. The third is to discuss the implications of these conceptual models for management, especially in water-deficit or water-surplus years.

MODELS

Scientists and engineers use "models" to help themselves understand water-resource conditions. Models range from simple mental images, that can be expressed as "cartoons", to complex numerical simulations, that rely on advanced computer technology.

For discussion purposes we classify models as: (1) conceptual, (2) scale, (3) analog, (4) analytical, and (5) numerical. A conceptual model is a mental image. It is invoked through words and diagrams. A scale model is a small physical representation of reality. It may be a simple paper-mache replica of a basin or a small dynamic version built in a sandbox.

Analog models may be maps and cross sections that depict appropriate features of the basin: or they may simulate conditions in one physical/chemical domain using another physical/chemical domain with similar equations but different properties. (For example, hydrologists have simulated ground water flow which obeys Darcy's Law using the flow of electricity, which obeys Ohm's law.) An analytical model is an equation or set of equations that gives exact solutions, when appropriate values are substituted for specific parameters. An analytic model is usually expressed by a simple diagram, an equation, and a list of parameters; it produces a unique answer for each set of parameters used.

A numerical model makes use of equations that are solved by approximation methods. Usually these models require a grid, parameters for the grid, and a solution scheme. The user specifies the size of the grid and the basis of successive approximations. The most useful numerical models have been validated and calibrated. Usually validation means that the model reproduces an analytical solution. Calibration means that the model generates solutions that match data. However, even calibrated models may not be unique. Other validated/calibrated models, based on different assumptions, may give different answers.

Model types overlap, because they have some common features. They start with some expressed or implicit (but not necessarily the same) basic assumptions, they attempt to represent the salient features of an observed phenomenon, and they invoke logical responses to change.

Models have two uses. First, scientists and engineers use models to identify areas where more data may be needed. Second, they use models to predict the effects of changes in the system.

Models and data are intimately connected. The relation between models and data ranges from specific and direct to vague and dubious. Even though files contain years of records, the data they contain may be neither appropriate nor adequate, because scientists and engineers collect data for three different purposes:

(1) To quantify a system or art of a system they understand (e.g. the flow of water into and out of a reservoir),

(2) In the hope that the data will contribute to their understanding of the system, and

(3) To check a model's ability to predict.

A sound conceptual model can reduce the data required to create a useful numerical model.

Although a model may seem adequate, we should not assume that it is the only one that will serve. Other models may be just as adequate. Simple models may be easy to understand and use, but may not give acceptable results. Complex models may be capable of providing acceptable predictions, but the data they require may never be available. Even when models and data blend to give good predictions, political or economic factors may force managers to ignore them.

DATA SOURCES

Modelers need both geologic and hydrologic data. Models are only as good as the data used. The most effective models are those based on adequate geologic and hydrologic data.

Geologic data include the location, size, extent, and character of major structural features (folds, faults, basins, uplifts, and volcanic cauldrons), as well as the thickness, structure, extent, and lithology of major rock units. Raw data include outcrop observations, descriptions of samples, cuttings or core, and well logs. Interpretations of these data include geologic maps, subsurface (structure, depth, and thickness) maps, and cross sections.

The two major sources of geologic information in the state are the New Mexico Bureau of Mines and Mineral Resources and the New Mexico Geological Society. The bureau prepares and distributes separate lists for open-file and more formal report series. The New Mexico Geological Society also provides current lists of its publications. Both sources distribute material through the publications office of the bureau on the New Mexico Tech campus in

Socorro. The bureau is also a retail outlet for selected U.S. Geological Survey reports and maps.

Hydrologic data include climatological data, stream-flow and reservoir-capacity data, and ground-water data. Climatologic data are available for precipitation, snow pack, precipitation chemistry, air and ground temperature, evaporation, humidity, and wind. Stream-flow data include gaging-station records, results of seepage runs, as well as chemical and sediment loads. Ground-water data include records of existing wells, test holes, and piezometers; results of pumping tests; water-level-fluctuation histories; and chemical analyses of water.

Various government agencies routinely collect and, in some cases, publish water-resource data in New Mexico. State agencies include the New Mexico Bureau of Mines and Mineral Resources, New Mexico Environmental Improvement Division, and the New Mexico State Engineer Office. Federal agencies include the National Oceanographic and Atmospheric Administration, the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the U.S. Forest Service, the U.S. Geological Survey-Water Resources Division, the U.S. Bureau of Land Management, the U.S. Bureau of Reclamation, and the U.S. Soil Conservation Service. The New Mexico Water Resources Research Institute has published a directory of sources, which gives the kinds of information available from each agency (Harris 1986).

Some data compiled by these agencies may be easily searched and recovered by computer. For example, the U.S. Geological Survey has access to several national data-bases. The Bureau of Mines has put its well records and chemical analyses of water for DeBaca, Lea, Quay, and Union Counties, the San Juan Basin, Estancia Valley, and Nations Draw Area into computer files (Stone 1980). At present, these files contain only data published by the Bureau.

GENERAL SETTING OF THE RIO GRANDE VALLEY

The valley of the Rio Grande and its tributaries extends from the Colorado border on the north to the Texas border on the south (figure 1). Major tributaries include the Red River, Rio Pueblo de Taos, Rio Chama, Santa Fe River, Galisteo Creek, Jemez River, Rio Puerco, Rio Salado, and Costilla Creek. Along its path the Rio Grande drops 3,674 ft, entering at 7,410 ft at the Colorado border and exiting at 3,736 ft near El Paso (Smeltertown).

The valley traverses portions of two physiographic provinces (New Mexico Geological Society 1982). In the area north of Santa Fe County the river flows through the Southern Rocky Mountain Province. The rest of its course lies within the Basin and Range Province. Some western tributaries drain part of the Colorado Plateau province.

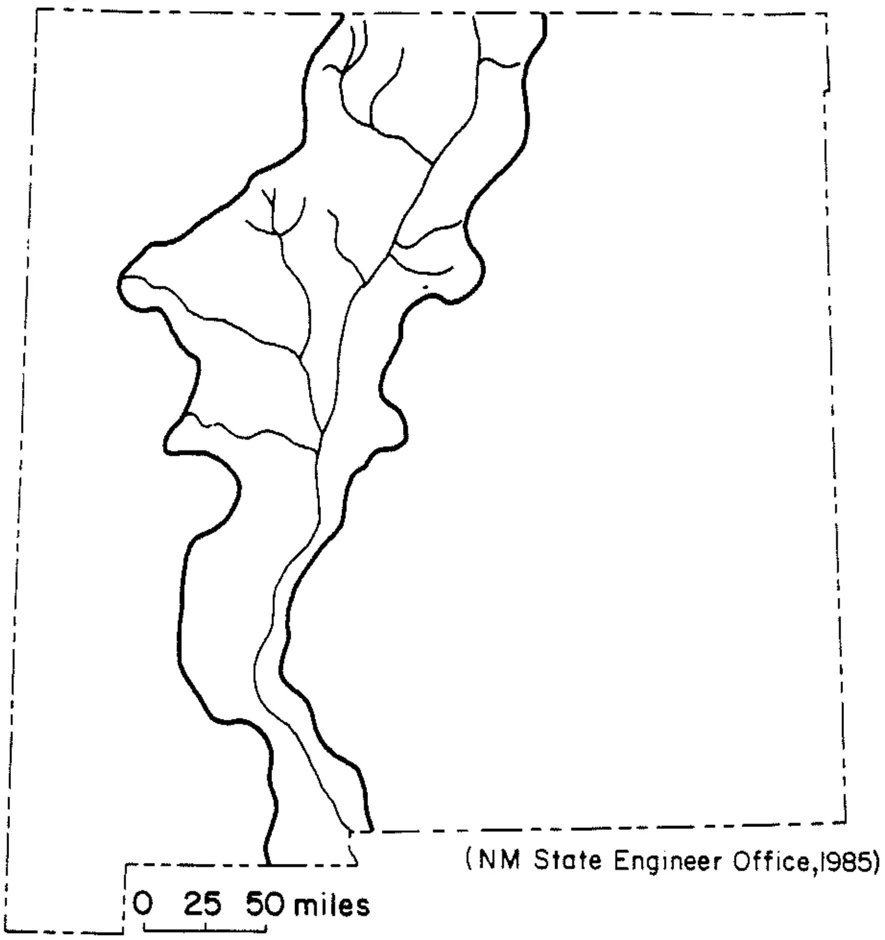


Figure 1. Location and extent of Rio Grande drainage.

GEOLOGIC CONCEPTS

Structure

The Rio Grande Valley occupies a structural depression known as the Rio Grande Rift or Trough. Geophysical investigations have shown that the valley consists of 13 basins separated by faults or bedrock highs (figure 2a). Crystalline and sedimentary rock units of Precambrian through Tertiary age crop out on both sides of the valley and alluvial and bolson deposits of Tertiary-Ouaternary age underlie the valley floor (figure 2b). Fault-bounded uplifts and basins as well as volcanic features ranging from simple cones to extensive cauldrons with long histories complete the geologic setting.

Stratigraphy

In the past, geologists distinguished separate rock units in the basin-margin uplifts, but paid little attention to sedimentary units of the valley fill. Outcrops in the uplifts are easy to see and convenient to map; whereas outcrops and deep wells in the valley fill are rare. The data disparity led geologists to portray and conceptualize the uplifts as stratigraphically complex, and to treat the valley fill as a homogeneous mass (figure 3a). However, by integrating available subsurface data and geomorphic models, geologists now recognize distinct lithologic units in the valley fill as well (figure 3b). The improved

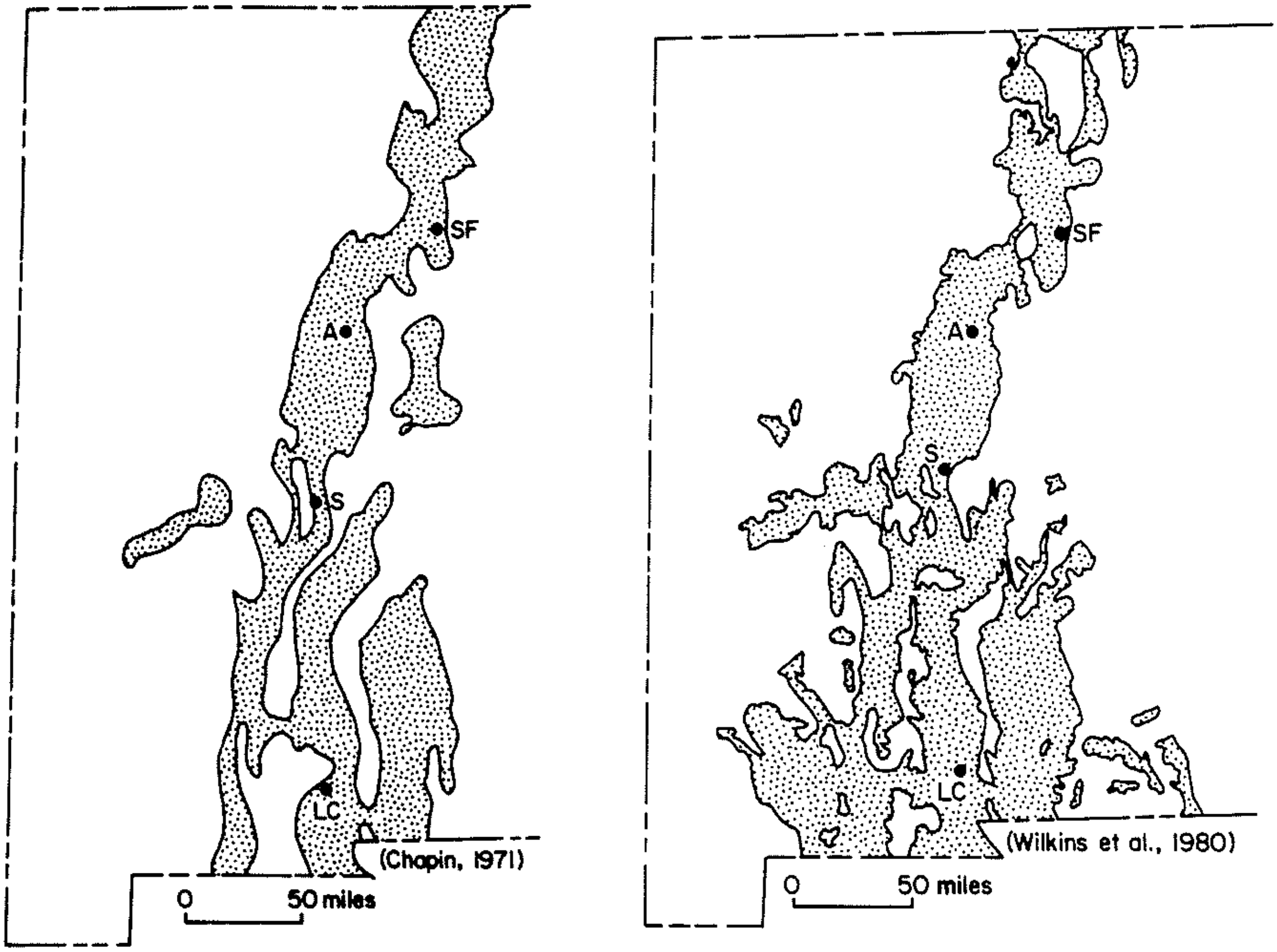
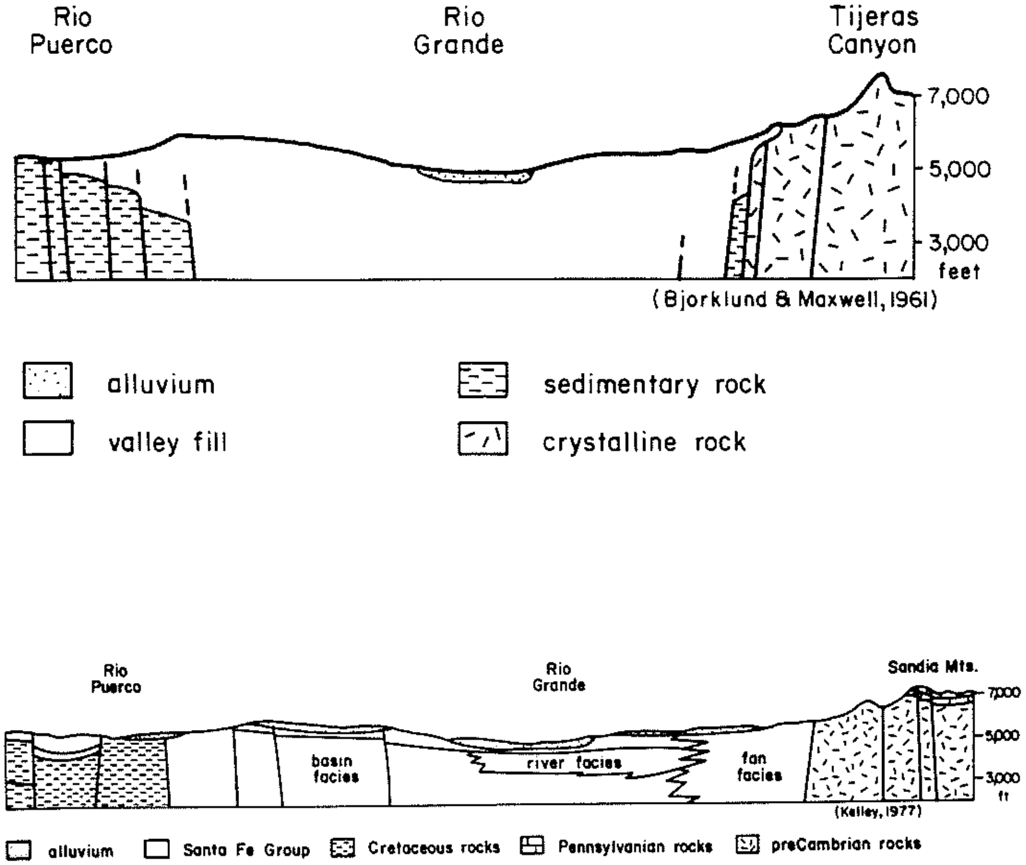


Figure 2. Distribution of basins within Rio Grande valley: a) based on structure, b) based on fill. Towns shown for reference include Santa Fe (SF), Albuquerque (A), Socorro (S), and Las Cruces (LC).



(Bjorklund & Maxwell, 1961)

(Kelley, 1977)

Figure 3. Geologic cross sections of the Rio Grande valley at Albuquerque: a) assuming valley fill is homogeneous, b) distinguishing various facies of the fill.

conceptualization of the geologic history and character of the fill leads to a revised conceptualization of the ground-water/river system.

HYDROLOGIC CONCEPTS

Groundwater Basins

The geologic concepts outlined above limit the ways in which one may conceptualize the hydrology. Dinwiddie (1967) characterized the Rio Grande valley as an impermeable "bath tub" filled with permeable material; whereas, Bryan (1937) recognized fault or bedrock boundaries between subbasins and characterized it as a chain of "bath tubs".

Study of the configuration of the water table or potentiometric surface reveals that the valley margins are not impermeable boundaries (Purtyman and Johansen 1974; Stone 1977). Although there are differences in the hydraulic properties of the uplifts and valley fill, they are hydraulically connected. Titus (1961) recognized this difference and described the "trough" in the water table associated with the central part of the Rio Grande Valley at Albuquerque as a lineal ground water drain and argued that it exists because the material in the valley center has a much higher average hydraulic conductivity than the rocks on either side.

Coons and Kelly (1984) recognized a trough or constriction between Taos and Espanola where volcanic rocks take the place of sediments. They suggested that the groundwater velocity in this trough is greater because the cross sectional area through which flow occurs has been decreased.

Water Budget

If an administrator knows the water budget of a basin, he can manage it more effectively. For maximum benefit, he must quantify both the ground water and surface water parts of the system. Available water-budget data are summarized in table 1 and are shown schematically in figure 4.

West and Broadhurst (1975) provided the estimates of runoff and evapotranspiration in water-use areas of the Rio Grande Basin. We estimated recharge using their basinwide precipitation value of 12 inches/yr and the empirical relationship (Summers 1981).

$$\frac{R}{P} \times 100 = i\ (p-j)/100$$

where R/P x 100 is recharge (R) expressed as a percent of precipitation (P), i is a terrain factor ranging from 0.5 to 1.5, and j is the precipitation that must be exceeded for recharge to occur (6 inches). Our minimum estimated recharge assumes i = 0.5; our maximum assumes i = 1.5.

Hydrologists can readily obtain precipitation records and stream-flow histories. But, recharge, evapotranspiration (ET), and ground water underflow must be

Table 1. Water-budget summary (in part from West and Broadhurst, 1975).

Parameter	Low Recharge Estimate (ac-ft x 106)	High Recharge Estimate (ac-ft x 106)
<u>Input</u>		
Precipitation	20.6	20.6
Total	20.6	Total 20.6
<u>Output</u>		
Runoff	0.7	0.7
Recharge		
discharge to Rio Grande	0.7	0.7
underflow	0.0	1.4
Evapotranspiration		
use areas	2.7	2.7
elsewhere	16.5	15.1
Total	20.6	Total 20.6

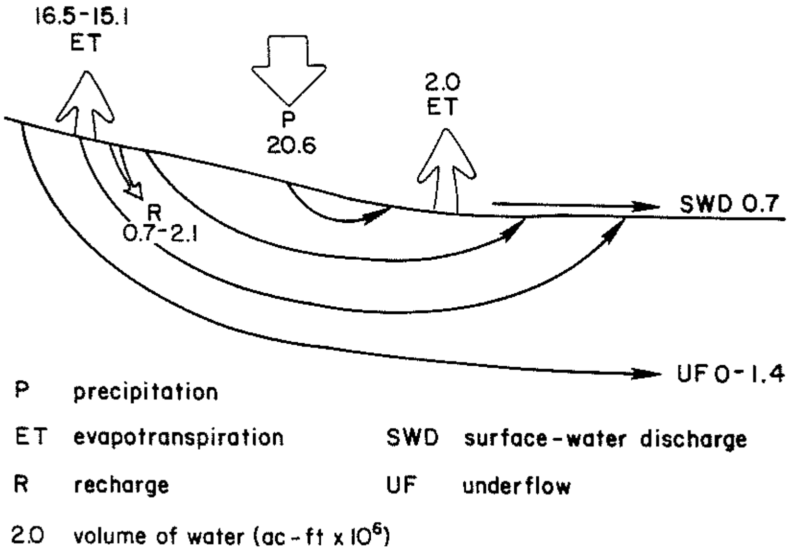


Figure 4. Schematic diagram of the water budget for the Rio Grande valley based on data in Table 1.

estimated. ET estimates from irrigated areas are probably pretty good, because agronomists have studied water use by crops extensively. But estimates of ET elsewhere in the basin and recharge are difficult to defend. ET is usually assumed to be the difference between precipitation and other water-budget parameters. Hydrologists have made only a few measurements of recharge (Phillips et al. 1984; Stone 1984a, b), and ideas about the validity and representativeness of these measurements vary. We know recharge occurs through direct infiltration and percolation of precipitation and through seepage along mountain-front streams. The volume of water that becomes recharge is moot.

We also know that not all ground water discharges to the river or to wells in New Mexico. Some moves to Texas as ground water underflow.

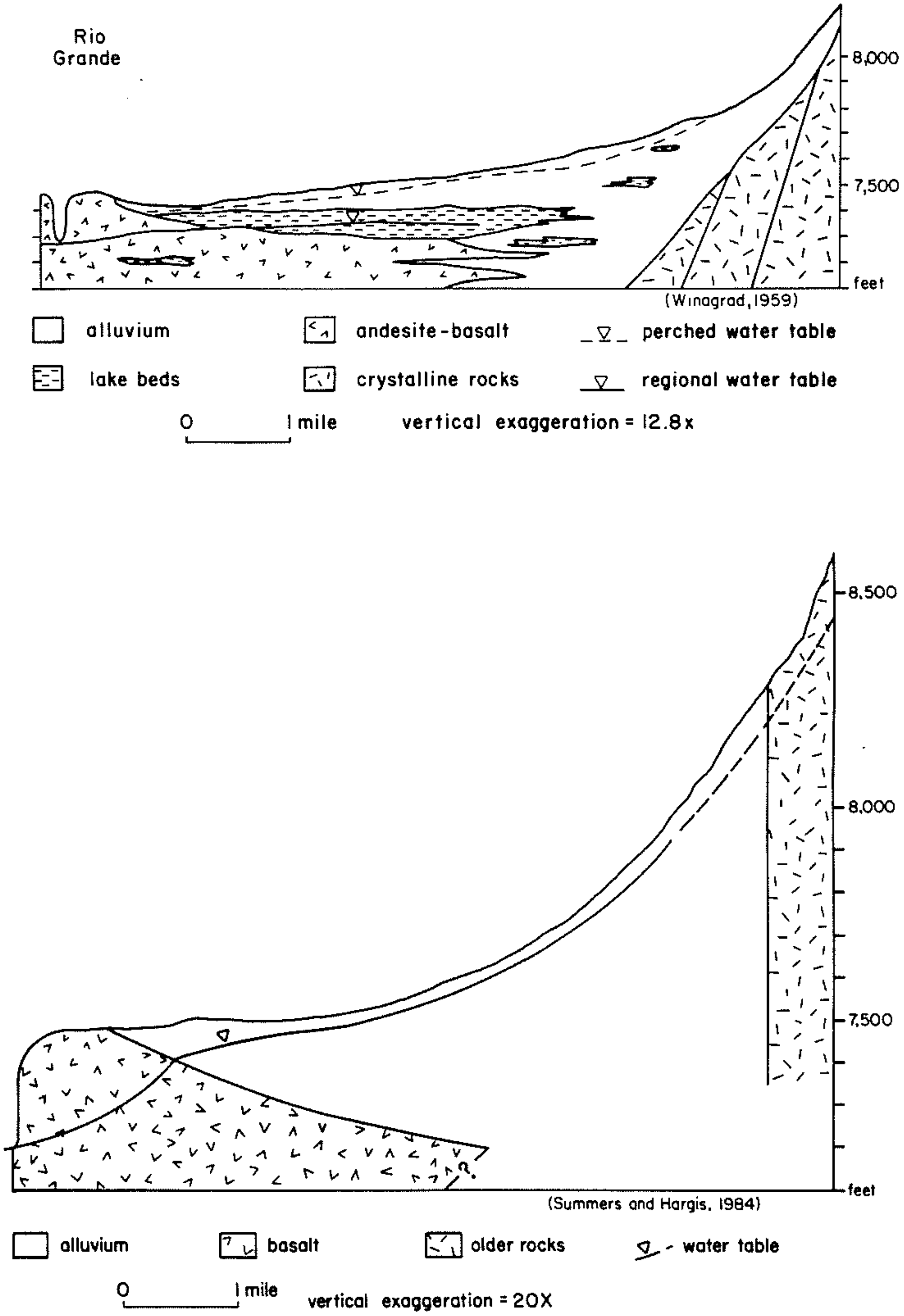
In some places within the Rio Grande trough in New Mexico the river is a gaining stream; in others it is a losing stream, that is, the Rio Grande gains water from the ground water part of the system in some reaches and gives water up to the ground water reservoir in others. Thus, the distinction between surface water and ground water becomes blurred. Wilson et al. (1981) found, for example, that in the Rincon/Mesilla valleys, both gaining and losing reaches occur. Tributary streams crossing the mountain front lose water to the ground-water reservoir. Heath

(1983) concluded that average seepage rates along a 48-mile reach of the Rio Puerco, where it flows over valley fill, average approximately 5 cfs in the winter and 10 cfs in the summer. Water diverted to acequias from streams in northern New Mexico lose as much as 5 percent of their water per mile (Lee Wilson, Personal communication 1984).

Flow nets and Discharge

Conceptualization of flow nets and discharge depend on both availability of data and interpretation of those data. Different interpretations have been made from essentially the same data (figure 5; Winograd 1959; Summers and Hargis 1984; Winograd 1985).

Figure 6 shows the flow paths in a cross section from the San Andres Mountains to the Rio Grande obtained by a numerical model (Bedinger et al. 1984). It shows that although the ground water circulates to depths of more than 2,000 m (6,000 ft), most of the flow occurs above 1,000 m and must have its origin at the mountain front. The model also shows that discharge occurs to a zone that is perhaps as wide as 200 m. Because the conditions imposed on the model allow no other solution, and because it is two dimensional, the model cannot show underflow and must show that all ground water in the plane of the section discharges to the river.



(Winagrad,1959)

(Summers and Hargis, 1984)

Figure 5. Cross sections showing different interpretations of the hydrogeology of Sunshine Valley: a) with a perched and regional water table, b) with just a regional water table.

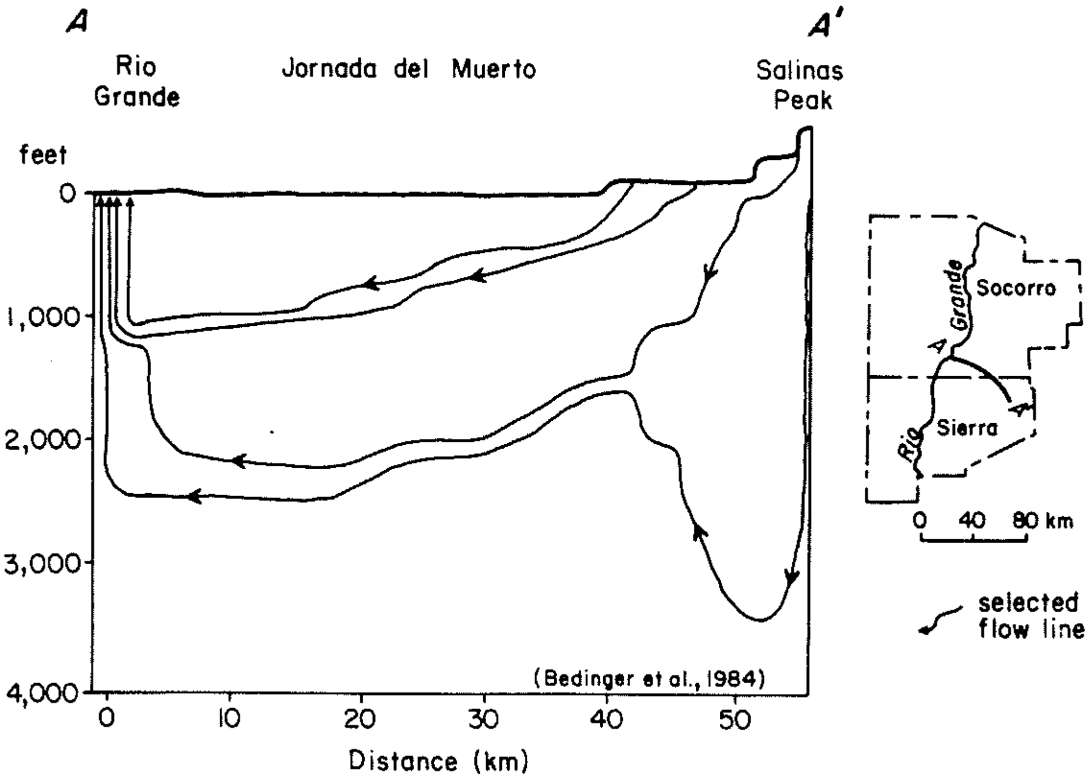


Figure 6. Cross section of a portion of the Rio Grande valley showing flow lines as generated by a two-dimensional, vertical model.

Pumping Wells Near the River

The predicted effect of pumping wells on the river depends upon the model one uses. One analytical method (Glover and Balmer 1954) that engineers have used for years to predict pumping effects assumes that the river and the well fully penetrate the ground water reservoir and that initially the water table is flat, therefore excluding recharge. This model predicts that eventually 100 percent of the water pumped comes from the river. Other methods, that assume the river only partially penetrates the reservoir and allow for recharge, show that less than 10 percent of the water discharged by well comes from the river (Emery 1966; Wright 1958). In Albuquerque, the city's south valley wells and the drains installed by the Middle Rio Grande Conservancy District to prevent water logging of irrigated land have created a situation where the river is a recharge source. As a consequence, the ground water for approximately 1/4 mi on either side of the river is in fact river water that has moved into the ground (Dennis McQuillan, EID, personal communication Oct. 2, 1986).

HYDROCHEMICAL CONCEPTS

Salinity Layers

One prevailing water-chemistry concept is that more or less continuous layers of differing salinity exist within the valley fill. Kelly (1974) applied this concept to the entire Rio Grande basin in the United States. In his model, fresh ground water lies at or very near the water table. Beneath the fresh water are layers of increasingly higher salinity, ranging from slightly saline to brine (figure 7).

Other hydrogeologists (Bushman 19G3, Cliett 1969, and McQuillan 1984) working in the valley have noted and employed a slightly different layered model. In this case, they reason that shallowest water is of poorer quality than somewhat deeper water, because irrigation return flow, evapotranspiration, and pollution from septic-tank effluent increase the salinity of the shallow ground water.

Fresh Water Tongues

Hiss and others (1975) showed that the chemical characteristics of ground water in the northern part of the Albuquerque/Belen Basin could be correlated with those of probable source areas on both sides of the basin.

Work in the Socorro area has produced more specific conceptual hydrochemical models. Stone and Foster (1977) and Stone (1984c) found that ground water along the western margin of the Rio Grande valley was much fresher than that underlying the valley proper because of leakage of fresh ground water from an elevated side basin through the mountain front. This fresh water occurs in tongues associated with the more conductive fracture zones in the mountain (figure 8a). Such tongues no doubt occur in other

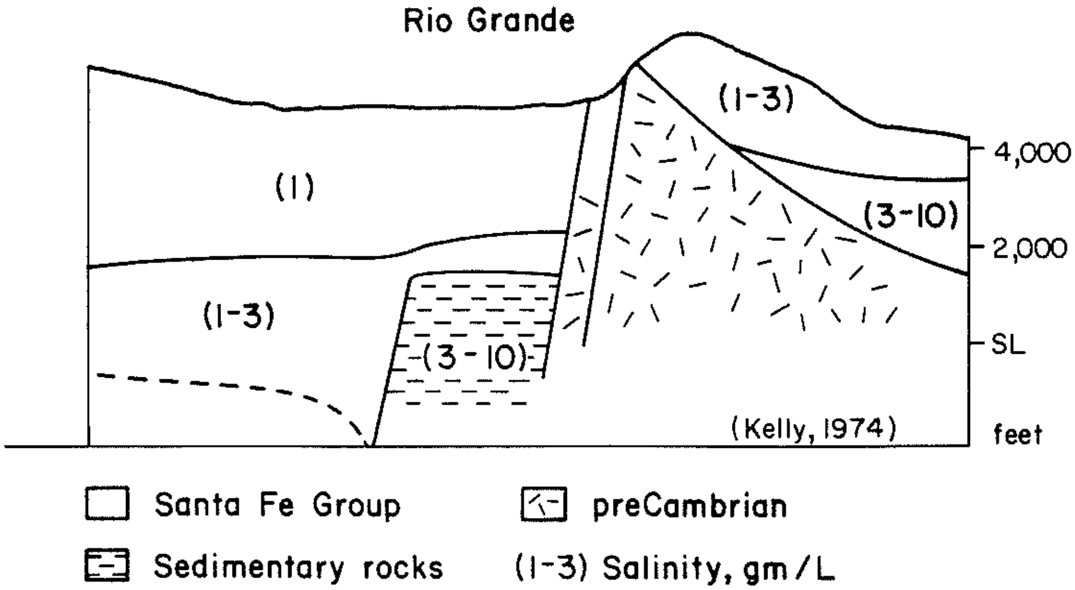


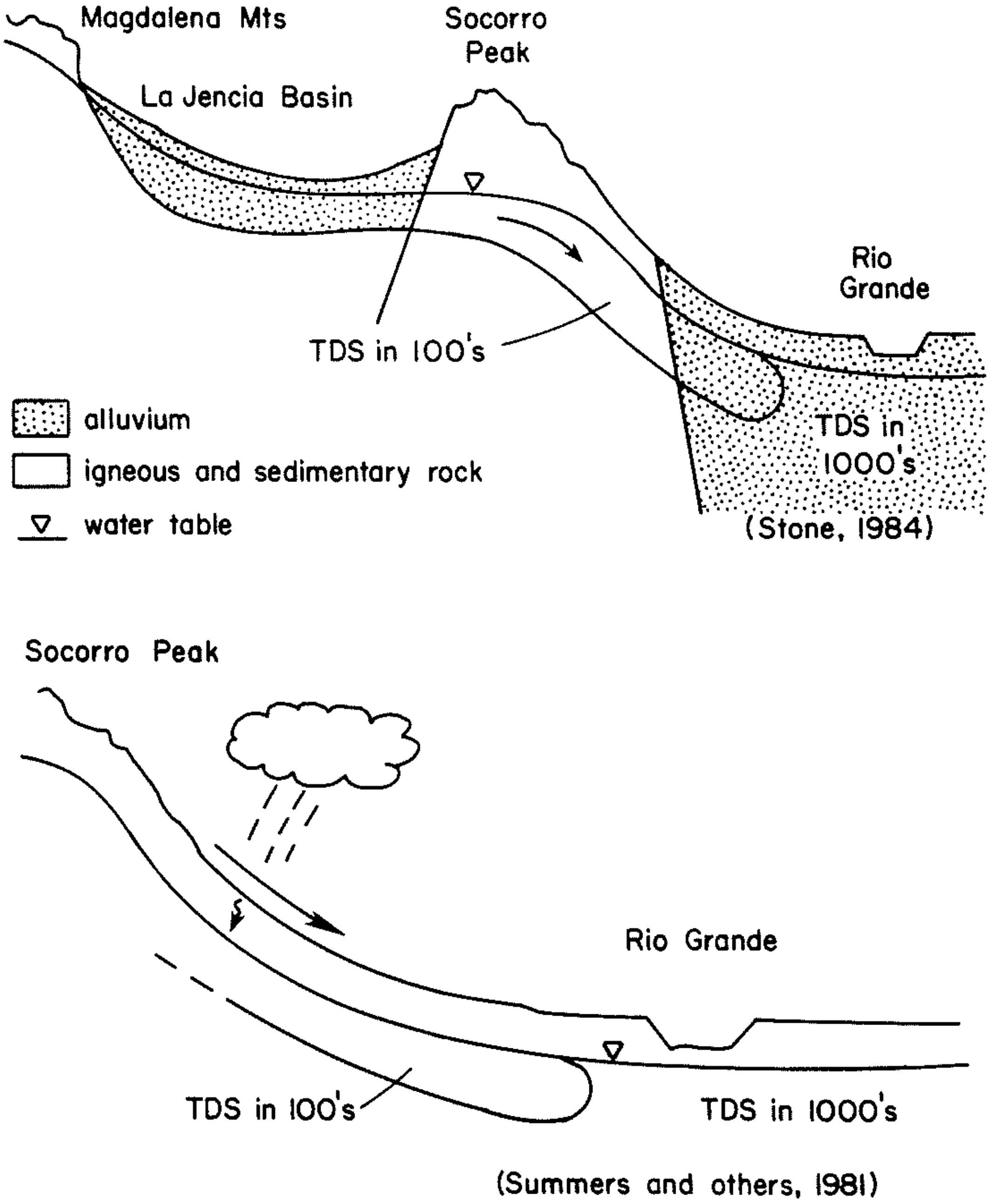
Figure 7. Cross section in northern Socorro County showing salinity layers in ground water.

favorable settings along the valley, such as the Nutt-Hockett Basin, southwest of Hatch. Summers and others (1981) also recognized tongues of differing quality in the Socorro area. They attributed this to infiltration from mountain-front recharge (figure 8b). Depending on relative salinities, these tongues may freshen or degrade valley ground water.

Pollution

Based on the prevailing conceptual hydrogeologic model of the valley, pollutants from solitary sources, such as landfills, septic tanks, or gasoline storage tanks, ultimately wind up in the river through natural flow/discharge processes (figure 8). The river dilutes the contaminanted discharge and effectively eliminates the problem. But, if levels of pollutants are high, the river becomes a source of contamination.

Pumping water from wells reverses the process and high-salinity river water or contaminated river water moves into the ground water body and flows towards wells. Gallaher and others (1986) have identified pollutants in the Albuquerque south valley at depths of 220 ft that could only have come from the surface. Presumably pumping the city's wells has reversed hydraulic gradients and water now moves downward from the water table (and from the river). Pumping may also short circuit the natural flow of polluted water toward the



(Stone, 1984)

(Summers and others, 1981)

Figure 8. Schematic cross sections in Socorro area showing salinity tongues in ground water: a) due to elevated-side-basin discharge, b) due to mountain-front recharge.

river and divert it to wells. In Santa Fe County, Gallaher and McQuillan (1986) identified 17 locations at which one or more wells were polluted.

IMPLICATIONS FOR MANAGEMENT

Water Quantity

During periods of low flow, when reservoirs are low, surface runoff consists primarily of ground water discharge. If river flow remains low for an extended period, water levels in wells near the river may decline at abnormal rates and well yields may decline in response to reduced recharge from the river.

During periods of high flow, the ground water component of river flow is small. If river flow remains high over a long period, ground water levels may rise. This is not a problem except near dams and reservoirs where areas with a shallow water table may become water logged or actually flooded. This has become a problem around Cochiti Lake.

Presumably these areas could be protected by installing dikes to prevent direct flooding and high-capacity wells (discharging directly to the river) to prevent water-logging or indirect flooding. Protection of these areas demands long-term planning and installation of the dikes and wells during low reservoir periods.

Water Quality

A major problem that looms on the horizon is an increase in the total-dissolved-solids content of water pumped by wells. Seepage from the river may not be fast enough to sustain the chemical integrity of the ground water. In reaches where the river and ground-water reservoir receive a substantial volume of water with large dissolved solids concentrations from tributary systems, the location and pumping rates of wells will be especially critical.

Conflicts

We recognize two conflicts facing managers of river systems. One is water use. The other is the managers' objectives or responsibilities.

Changing water uses bring about changes in points of diversion from surface to ground water. As agricultural uses of water give way to municipal and industrial uses, wells divert an increasing volume of the total water used. In those areas where the water supply depends upon wells (as well as a surface-water diversion system), river management involves not only the controlling of the flow of water through the reservoir system to farmlands, but also the location of wells and the volume of water they pump.

Managers concerned with water quantity are not necessarily those responsible for water quality and vice versa. Although water may be allocated to a specific use without impairing the water supply, such use may ultimately impair water quality. More specifically, diversion of river water or pumping of ground water for an irrigation scheme may not significantly impact water levels in the area, but subsequent flushing of salts from the unsaturated zone beneath the irrigated lands (in response to enhanced recharge) may elevate salinity of ground water.

Feasibility studies of water diversions often focus solely on water quantity. For example, Hearne (1980) reported that 37.5 cfs could be pumped to irrigate new farmlands in the Pojoaque River Basin. Of this amount, 26 percent was expected to become return flow. Although Hearne carefully simulated the impact of development on quantitative aspects of the water resources, he did not address the impact on chemical aspects in his report. Investigators should devote as much effort to the chemical aspects of stressing hydrogeologic systems as they do the quantitative aspects.

In conclusion, managers of the Rio Grande must cope with concepts, strategies, and models advanced by a variety of specialists. The successful manager will discriminate among these. He will recognize their shortcomings and set into motion a data-collection program to reduce their data deficiencies. He will use their short-range predictions and compare these predictions with the eventualities. But most of all, he will be continually alert to our universal predicament: We live in a world of infinite variety, but must manage it with finite concepts and limited data.

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