RGDSS Memorandum

To: Mr. Mike Sullivan P.E. SEO
Mr. Andy Moore, P.E. CWCB
From: HRS Water Consultants, Inc. Eric J. Harmon, P.E.
Subject: RGDSS: 2009 Hydrogeologic Evaluation of Del Norte – Sevenmile Plaza Area
Date: July 17, 2012

Introduction

As part of our RGDSS peer review consultation for the State, in 2009 HRS investigated the hydrogeology of the Del Norte – Sevenmile Plaza area. This memorandum documents the 2009 investigation. This particular study area is generally defined by Del Norte on the NW (upstream) end, about two miles SE of the village of Sevenmile Plaza on the SE (downstream) end, and extends approximately one mile SW and two to three miles NE of the Rio Grande floodplain (see location map in the attached Appendix).

The hydrogeologic evaluation was done in two overlapping stages. HRS initially was asked by the Peer Review Team (PRT) to review the hydrogeology in the Sevenmile Plaza area only. During the progress of that work in 2009, HRS was asked to extend the investigation upstream as far as Del Norte. HRS combined the two stages of work into a single investigation, resulting in the evaluation presented in this document. Several other projects and RGDSS tasks took precedence, and this document on the 2009 hydrogeologic evaluation was finalized in 2012. The work documented herein was done by Barbara A. Ford, P.E. (formerly of HRS) and Eric J. Harmon, P.E. of HRS.

Statement of the Problem

Comparison of water level data with RGDSS model calibration results for the study area shows differences between the two that the computer modelers and PRT had not anticipated. Also, discussions with members of the PRT indicated further unanticipated differences between observed data and model results. These include:

- The general reach of the Rio Grande between Del Norte and Sevenmile Plaza shows little if any gain or loss within the bounds of uncertainty of the available data.
- Aquifer water levels in and near the Rio Grande floodplain in the study area indicate the possible presence of a perched water table, and possible discontinuity between the water levels in the river and the underlying aquifer in some areas.
- The hydrologic and geomorphic evidence observed to date does not adequately explain the presence and longevity, at least during historic times, of two distinct Rio Grande channels (North and South Channels), nor does the available evidence explain the elevation differences that persist in this area between the North Channel and the South Channel of the Rio Grande in this reach.
- Mapping of water level elevations reported in wells in the study area shows inconsistencies between water levels, even between wells relatively close together and apparently in the same approximate depth horizon, such that high local ground water gradients are observed at some locations.

From these observed or suspected differences, it is apparent that the current relatively simple conceptual hydrologic model of this local area is not adequate to explain the observed data. Currently, the conceptual hydrogeologic and hydrologic model of the study area is much the same as the conceptual model in the reach of the Rio Grande further downstream between Monte Vista and Alamosa, as represented in the RGDSS model. To summarize, the key points of the current conceptual model of the study area are:

- Continuous hydrologic connection between the active river channels of the Rio Grande and the underlying aquifer layers, such that changes in the ground water gradient in this local area should be reflected by changes in river gain / loss (corrected for surface inflows and outflows), and vice versa.
- A relatively consistent and continuous "layer-cake" geologic framework with strata dipping generally 3 to 5 degrees to the NE, from the SW edge of the study area downward into the Closed Basin area to the northeast.

- A continuous water table gradient reflecting ground water moving from the recharge areas (valley edge and upper Rio Grande fan area, including deep percolation from the Rio Grande and area canals) into the unconfined and confined aquifer layers.

The objective of this investigation is to review and analyze the available hydrogeologic data of the study area in order to improve the current conceptual hydrologic model of this area and thereby arrive at recommendations for improved RGDSS model representation.

Method of Investigation

This investigation included two separate field reconnaissance trips to the study area during the spring and summer, 2009, to observe and gain an understanding of the local geologic and hydrologic features. Also, HRS discussed the geology and hydrology of this study area with members of the RGDSS Peer Review Team (PRT) to review concepts and current model results. The work included collection and review of all available well records in the area, development of several hydrogeologic cross sections, and interpretation of the cross sections and water levels. The following segments of this memorandum focus primarily on the development and interpretation of the cross sections.

Development of Hydrogeologic Cross Sections

Ten cross sections were constructed to develop an improved understanding of the hydrogeology of the study area. As discussed above, our primary interest in locating the cross sections was to develop an improved understanding of unexplained features in the local hydrogeology, including observations of ground water gradient differences upstream and downstream of Sevenmile Plaza, and also an apparent perched river condition between Del Norte and Sevenmile Plaza where the Rio Grande flows in two distinct branches, called the North Channel and the South Channel.

Both of the initial study areas: the Sevenmile Plaza area, and the Sevenmile Plaza to Del Norte Area, have been investigated using drillers logs and water levels available from the Colorado

DWR State Engineer's Office well permit database. The two requested study stages now are combined into a single study area. The SEO well data for the study area were supplemented with geologists' logs and water levels provided by Davis Engineering. Lithologic logs were provided to by Davis Engineering for the Brownell recharge site at which several monitoring wells were installed in Section 1, T40N, R9E, NMPM. The logs of these monitoring wells were used to extend the coverage of cross-section H-H''.

Initial Investigation of Sevenmile Plaza Area

Development and interpretation of the first three cross sections A-A', B-B' and C-C', all in close proximity to the Rio Grande in the river reach just below Sevenmile Plaza, indicated a possible shallow water table associated with the river and a deeper, more regional water level, the two being separated in most of this locality by some tens of feet. (Note that A-A' later was made part of the "river channel" cross sections - see the attached Appendix for a map of the cross-section locations.) Cross sections A-A', B-B', and C-C' also are in the Appendix.

A layer generally described in driller's logs as a brown clay appeared to have some persistence across this area, and was mapped based on the available driller's logs. This clay unit appears to be closely associated with the water table. The preliminary conclusion or hypothesis from our first stage of work in this study area was that a shallow water table may be a consequence of a clay layer of relatively low permeability that caused perching of a near-surface water table associated with the Rio Grande.

General mapping of the geologic formations and structure just south of the Sevenmile Plaza area was published in 1976 by Peter Lipman (USGS Map I-952). Lipman mapped faults that extended to the southern edge of this study area, but was limited to just the area south and west of the Rio Grande floodplain where the crystalline rock layers composed of volcanic lava flows and ignimbrites (ash-flow tuffs) are exposed at the ground surface. Lipman's mapping did not extend to subsurface mapping of the structure, as he did not include well data in his analysis and mapping.

Because our three initial cross sections were limited to the vicinity of the Rio Grande in the Sevenmile Plaza region, the identification of bedrock was confined to the southwestern area where the volcanic rocks are mapped within shallow depths of ground surface. As a second part of the initial interpretation effort, HRS extended the B-B' and C-C' cross sections further to the northeast. The sections were constructed to trend from southwest to northeast because initial review of the data indicated that the ground water flow direction generally was orthogonal to the cross sections; that is; generally subparallel to the Rio Grande in the area southeast of Sevenmile Plaza. Hence the B-B' section generally is located along the 7690 ft ground water elevation contour and the C-C' section generally is oriented along the 7680 ft ground water elevation contour.

In extending these cross sections to the northeast, several observations were made. The first occurrences of blue clay are noted in many of the driller's logs in this extended area. The blue clay is probably indicative of the southwestern extent of the clay units that generally define the bottom of the unconfined aquifer in the Closed Basin. Identification of the blue clay allowed us to interpret the extent and depth of the younger alluvial deposits associated with the Rio Grande. Due to the relatively limited areal coverage of the first three cross sections, and only after later data review in the extended study area between Sevenmile Plaza and Del Norte, did a distinctive faulting pattern, best described as subparallel normal faulting trending to the northeast, become apparent. The subsurface faults, as we have now mapped them, trend largely subparallel to the equipotential lines of the regional water table. Because the extended study area upriver to Del Norte provides more opportunity to see this regional geologic pattern, the discussion will now focus on the extended study area, and the observations then will be extrapolated back to the more localized area below Sevenmile Plaza.

Extension of the Investigation to the Del Norte – Sevenmile Plaza Area

The surface geomorphology of the area between Del Norte and Sevenmile Plaza is distinguished primarily by the following characteristics:

- A well-defined floodplain of the Rio Grande, containing two subparallel channels of the Rio Grande (locally termed the North Channel and the South Channel, a convention which we adopt here). With the exception of several meander cutoffs observed by comparing old maps and photos with recent aerial coverage, the locations of the present channels in this reach have changed remarkably little in historic times, as compared to several documented channel avulsions (shifts to a new location on the floodplain) in the Monte Vista – Alamosa reach of the river.[1]
- Southwest of the Rio Grande floodplain, generally coincident with the area southwest of U.S. Hwy 160, is an area of generally Northeast-dipping lava flows and ignimbrites that have been mapped with several Northwest-trending normal faults that have vertical offsets ranging from a few tens of feet up to 100 feet.[2]
- Northeast of the Rio Grande floodplain, the apex area of the Rio Grande alluvial fan consists of coarse alluvial soils with abundant coarse gravel and cobbles. This area, when viewed from aerial photographs, shows east- and northeast-trending relict braided stream channels. The surface sediments are interpreted to be of latest Pleistocene age, as the ancestral Rio Grande flowed northeast from Del Norte rather than southeast as we see today.[3]

Analysis of Rio Grande base flow by Jim Slattery, P.E., as part of the RGDSS peer review investigations, indicated a relatively small net gain-loss for this reach of the Rio Grande.[4] The

1 Jones, L.S., Haper, J.T., 1998, Channel Avulsions and Related Processes, and large-scale sedimentation patterns since 1875, Rio Grande, San Luis Valley, Colorado. In Geological Society of America Bulletin, April 19989, pp. 411-421.
2 Lipman, P.W., 1976, Geologic Map of the Del Norte Area, Eastern San Juan Mountains, Colorado. USGS Miscellaneous Investigations Series Map no. I-952.
3 Madole, R.F., et al, On the Origin and Age of the Great Sand Dunes, Colorado. In Geomorphology, 2007.10.06, p.109.
4 From discussions with Mr. Slattery during RGDSS peer review team meetings.

hydrogeology researched through development and interpretation of cross sections in this area, combined with the cross sections downstream of Sevenmile Plaza, tend to support the conclusion of relatively small gain-loss, in the sense that the Rio Grande appears to be perched and is locally isolated from the regional water table, which itself may, at least in part, be controlled by faulted structures in this area. The next section of our report discusses these interpretations.

Structural Interpretation of the Hydrogeologic Cross sections

The first cross-section constructed D-D' (see Appendix) subparallel to B-B' and upstream of Sevenmile Plaza, did not at first appear to be very informative, primarily because information about the bedrock was sparse in this area once the cross section was extended past the volcanic terrace at the section's southwest terminus. Even the previously discussed clay layer, which we treated as a geologic marker bed in the cross sections near Sevenmile Plaza, is noted infrequently in the driller's logs in this cross-section.

Cross-section E-E' located farther upstream and subparallel to D-D', was constructed specifically to be located upstream of the confluence of the North and the South channels of the Rio Grande. The driller's logs along this cross-section provided useful information, showing a distinctly erratic water level trend, and useful information on the bedrock. Cross-section F-F', constructed upstream of E-E' also was informative in regard to a developing concept of erratic and spatially-varying bedrock depths and ground water levels in the subsurface. This cross-section also pointed to an evident change in the regional water table gradient. This is also evident on a regional potentiometric surface map for the unconfined aquifer, dated 2007, provided to HRS by Davis Engineering. The E-E' and F-F' sections appeared to be oriented at an oblique angle to the ground water gradient. Consequently, cross-section H-H' was constructed approximately North-South, which is approximately orthogonal to the apparent ground water gradient. Except for the extension of the gradient to the Davis Engineering monitoring wells at the recharge test site a few miles to the north-northeast, this cross-section orientation appeared to be approximately coincident with equipotential lines. The portion of the study area generally defined by cross sections H-H' to D-D', where the gradient assumes a more southeasterly direction, includes a steepening ground water gradient which is nearly double that observed upstream of cross-section D-D’, in the area where the gradient is more generally directed from west to east. From comparison of these cross sections, it appears the rapid spatial variations in water levels and gradients may depend on three controlling factors:

- Complex geologic structure beneath the Rio Grande floodplain.
- Presence of a shallow perched water table generally coincident with the Rio Grande surface channels.
- The presence of a regional water table that is erratic at a small scale, but which, at a larger scale, generally coincides with regional gradients of the surrounding areas of the Closed Basin.

Besides the change in the regional gradient, erratic water level elevations again are evident on cross-section H-H', just as they were on E-E’ and F-F’. Even in close proximity to the Rio Grande stream channels, and notwithstanding the erratic nature of the water level data, the water levels from local well data are consistently deeper than the Rio Grande surface elevation. This supports an interpretation of a perched river condition and a deeper water table for the extended study area, consistent with the original interpretation from cross sections A-A', B-B' and C-C', which were based on fewer data points for the smaller Sevenmile Plaza local study area.

An alternative interpretation, or at least a potential complicating factor, which becomes more evident through construction of additional cross sections, is that the water table in some areas appears, at some locations, to mimic the subsurface structural offsets associated with a series of horst and graben structures (i.e. upthrown and downthrown blocks, respectively) due to normal faulting apparently trending NW-SE, subparallel to the Rio Grande, and generally coincident with Lipman's (1976) surface fault mapping where bedrock units are exposed at the surface along U.S. Hwy 160 and to the southwest in the San Juan foothills. Cross-section I - I’, constructed subparallel to H-H', and cross-section G-G’, generally subparallel to F-F’, help show the analogous features. There is an apparent correlation between shallower bedrock and shallower water level (and also a shallower clay horizon) versus deeper bedrock and deeper water level (and deeper clay also, where the driller’s log data are of sufficient quality and coverage to allow this interpretation). At some well locations where the bedrock was not identified, the driller's indications of clay were used to help identify this pattern.

In order to better discern the hydrogeology along the North Channel as compared to the South Channel of the Rio Grande, cross sections “North Channel” and “South Channel” (see Appendix) were constructed. The terminal points of both of these cross sections are coincident, tying into the furthest upstream point on original cross-section A-A’, located below where the Rio Grande North and South channels have joined back into one channel, and tying again at the upstream cross-section terminus at well 3147-F, located in Del Norte where the Rio Grande also flows in one channel upstream of its bifurcation.

The two “river” cross sections, once constructed, showed a previously undetected feature: a possible second fault, or fault zone, which apparently post-dates the regional NW-SE subparallel or *en echelon* normal faults, and possible horst/graben features, that parallel the Rio Grande. This potentially younger fault, or fault zone, may disrupt the aforementioned pattern of correlated higher water table and higher bedrock versus lower water level and lower bedrock. The clay layers also show a pattern of inconsistency with depth that could be fault related. Because the “river” cross sections, trending as they do approximately WNW – ESE are not within the plane of the younger interpreted fault (N-S to NNW - SSE), the structural offsets and disruption in the stratigraphic layering and the water levels, tentatively interpreted as a fault or fault zone, emerge more clearly. Likewise, until its presence was identified in these WNW-ESE cross sections, all of the other cross sections oriented generally N-S or NE-SW, were essentially coplanar to the younger structure, and did not help this discernment.

The North Channel and South Channel cross sections are at an oblique angle to the trend of the regional normal faulting or horst and graben structures, as is apparent in the other cross sections with the characteristic pattern of shallower water level and shallower clay versus the analogous deeper water levels and clay depths. However, between approximately five and seven miles downstream from well 3147-F (NW terminus of the “river” cross sections), there is an anomaly with a shallow bedrock level associated with a relatively deep water level. As an additional contra-indicator, the clay marker is difficult to identify through this interval in the available driller's logs, and appears to be largely absent through part of this locality. This interval lies just upstream of the confluence of the two channels near Sevenmile Plaza.

Within this part of the study area bedrock is detected at an approximate elevation of 7730 ft (approximately 7725 ft in the North Channel cross-section and 7740 ft in the South Channel cross-section). Each noted bedrock marker bed is associated with a respective downstream bedrock marker with an apparent upward displacement of about 50 feet. This causes the bedrock to occur at an elevation of 7780 ft approximately 1.5 miles downstream. This upward bedrock displacement is coincident with an apparent water level decline of nearly 200 ft in the South Channel cross section and nearly 100 ft in the North Channel cross section, based upon available data. This anomaly is clearly discernible on the Davis Engineering (2007) potentiometric contour map of the area. Downstream of this minimum reported water level elevation of about 7660 ft from driller’s logs, the water level apparently rises in an apparent stepwise manner, resuming the regional pattern of water level and bedrock level (or clay level as an indicator where bedrock is absent in the log). The presence of the localized anomalously deep water levels associated with shallow bedrock and faulting in the subsurface just downstream of Sevenmile Plaza may indicate that several perched water tables are present at different depths, only the deepest of which is discernible in the relatively coarse set of available water levels and driller’s logs. The general downward water table gradient indicates that this is probably a localized recharge area for the unconfined aquifer. We do not think it is appropriate to contour the shallow water table and the locally deep water level as a single mapped surface. The indication from the perched and deeper water tables is that water is moving downward, so that this is a local recharge area to the aquifers in the San Luis Valley.

In the map view of all of the cross sections, the normal faults, some of which appear to be horst - graben features, were identified and interpolated across the southwest to northeast cross sections. Similarly, the trend of the younger fault zone with an approximate N-S or NNW-SSE orientation, is apparent in water level offsets and lithology offsets on the South Channel, North Channel, E-E’ and F-F’ cross sections. The interpreted possible younger fault or fault zone in the North-South or NNW-SSE orientation is approximately coincident with an apparent change, in map view, in the orientation of both channels of the Rio Grande, and also appears to be related to the small erosional-remnant bluff (locally called Sevenmile Hill) just north of Sevenmile Plaza.

North of the North Channel of the Rio Grande

On cross sections H-H'' and I-I', which are oriented approximately transverse to the ground water flow direction, a well north of the North Channel exhibits a 25-foot lower water level than the nearest estimated North Channel river elevation. The apparent high water table gradient between the two wells coincident with the lithologic offsets suggests that the Rio Grande in this area is located on top of the hanging wall in the horst-graben normal fault structure interpreted from the cross sections. In section I-I', approximately one-half mile downstream from the point of bifurcation of the two channels near Del Norte, a similar condition exists with a 25-ft difference between the estimated North Channel river elevation and a well north of that location. Although the presence of structural offsets, probably buried normal faults, is fairly clear, it is not clear that the locations of the Rio Grande channels are related to, or controlled by, the structure to any degree.

Between the River Channels of the Rio Grande

Along section I-I', at a well located between the two channels, the water level is reported to be 10 ft lower than the estimated water level elevations at the nearest points in the river channels. This condition causes an apparent gradient towards that well of approximately 0.004 ft/ft. But at section H-H', located two miles downstream of I-I', the gradient from each channel elevation to the intervening well is approximately 0.006 ft/ft, or 50 percent higher than the comparable situation further upstream. Since wells have not been drilled directly into the channels, the presence or characteristics of any clay or clay-rich marker beds are not available to aid our evaluation of this area. Also, the driller's log information is not well defined in the uppermost few tens of feet, so the presence or absence of near surface clay-rich beds at about the level of the river channels is not defined. However, at H-H'', the clay interval mapped at the well north of the North Channel is the same thickness and lies at the same elevation as the clay mapped at the well between the channels, which is suggestive of control by the interpreted fault.

This interpretation suggests that in addition to possible subsurface structural control of the somewhat erratic aquifer water levels in the study area, we hypothesize that there may be a clay-rich layer or other low vertical conductance layer, probably quite shallow and of recent deposition (almost certainly post-faulting) that is either too thin or too shallow to be noted on driller's logs. Such a near-surface layer would have to be of sufficiently low vertical conductance that it locally creates a perching condition on which the two channels of the Rio Grande currently flow. Review of the soil types in the area of the Rio Grande floodplain between Del Norte and Sevenmile Plaza shows the following soil types to be predominant (see Table 1).

Table 1

Soil Types Predominant in the Rio Grande Flood Plain
Del Norte - Sevenmile Plaza Reach

Soil Series	Map Symbol	Depth Range (inches)	USDA Texture	Unified Soil Classification	Percent passing no. 200 sieve (0.074 mm)
Typic Torrifluvents	Tu	0-15	gravelly sandy loam	SM	20-30
		15-60	gravel and sand	GP or SP	0-5
Dunul	Du	0-10	cobbly sandy loam	SC-SM or SM	15-30
	Du	10-60	very gravelly sand	GP or SP	0-5
Gerrard	Ge	0-14	loam	ML	50-75
	Ge	14-60	very gravelly clay loam	GM or SM	10-20
Alamosa	Am	0-9	loam	ML	60-75
	Am	9-48	clay loam, sandy clay loam	CL	70-80
	Am	48-60	sand and gravel	SM-SP	5-10
Shawa	Sma	0-60	loam	ML	60-75
Schrader	Sh	0-7	sandy loam	SM	30-40
	Sh	7-60	fine sandy loam, and loam	SM or ML	45-60

Source: USDA SCS, 1980, Soil Survey of Rio Grande County Area. Maps 3 and 4; and Table 6 pp. 56-63.

Although the soils in the area generally show a significant percentage of material that passes a 200-mesh sieve (i.e. silt and clay size material), and that clay loam to sandy clay loam is not uncommon in the area, the soil mapping is not sufficiently definitive, in our opinion, to establish the presence of a widespread, persistent clay layer beneath the present active river channels.

Testing of the shallow clay layer hypothesis would require a test drilling program across one or more transects of the flood plain, coupled with analysis of drive samples or core samples.

Overall, it should be noted that some of the water level differences from well to well noted on several of the cross sections were interpreted as fault offsets partly due to differences in lithology between wells, and partly due to the high ground water gradients that are indicated. Although faulting, as a general rule, should not be the first refuge of a hydrogeologist for explaining differences among driller's logs along cross sections, we believe the evidence justifies a fault-dominated interpretation of the erratic water levels observed in the Del Norte – Sevenmile Plaza area for several reasons:

- Previous geologic mapping has indicated the presence of NW-SE trending normal faulting in this study area (Lipman, 1976).
- HRS hydrogeologists are familiar with driller's logs and the variability in lithologic descriptions that we commonly associate with them. In this study area the lithologic variability along each cross section exceeded the normally expected variability in the driller's descriptions.
- Water levels from well to well suggest ground water gradients that were, in some instances, closely associated with lithologic differences from well to well.
- The suggested gradients in some places observed in this study area exceed the expected range of gradients that are likely under Darcian flow conditions for aquifer materials of the type suggested by the driller's logs and the specific capacity of wells in the study area. This suggests that some reason other than a high ground water gradient through a continuous porous medium must be hypothesized in order to explain the water level differences from well to well.

<u>Existence and Elevation of Two Rio Grande Channels</u>

As an ancillary question to the primary objectives of this investigation, HRS was asked to opine on whether the available geologic data from driller's logs suggests any reason for the existence of two subparallel channels in the Rio Grande in the Del Norte – Sevenmile Plaza reach, and whether there is any geological reason why the two river channels, when viewed in profile, appear to have different gradients and elevations for part of their courses, between the point of bifurcation near Del Norte and the point of confluence of the channels near Sevenmile Plaza.

Overall, the structural geologic picture is too complex, and well data collected to date is not sufficient, for us to be able to tie the presence or characteristics of the two river channels to geologic structures. The presence of the complex normal faulting parallel to the river channels clearly, as discussed above, in our opinion is a controlling factor in the regional aquifer water levels. From onsite observation and from observation of aerial photos and satellite imagery, with the exception of the exposed bedrock faulting along the southwestern side of the Rio Grande floodplain (roughly coincident with Highway 160), we do not find evidence of any fault movement so recent that it controls the present locations of the North Channel and the South Channel of the Rio Grande. Therefore, although it is possible that the WNW-ESE trending normal faulting has an influence on the presence of two distinct channels of the Rio Grande, the evidence to show a causative link is lacking.

Existence and Location of the "Ground Water Divide"

HRS also was asked, as an ancillary question related to this investigation, whether there is a geological control on the location and existence of the "ground water divide" that has been observed northeast of, and roughly parallel to, the North Channel. The presence of WNW-trending normal faulting in the area does suggest the possibility of geologic structure as a causative factor, but the data presently available are not sufficient, in our opinion, to reach a conclusion one way or the other with respect to the location of the "ground water divide". A test drilling program with careful sample collection would help to shed light on this question.

Summary of Conclusions

HRS has completed its investigation into the hydrogeology of the Del Norte – Sevenmile Plaza area of the San Luis Valley based on the available data. From the foregoing discussion, the following conclusions can be drawn:

1. The anomalous and complex water table gradients observed in the study area, in our opinion, almost certainly are, at least in part, a consequence of the complex normal faulting, including horst and graben structures, that underlie the study area. The presence of the localized anomalously deep water levels associated with shallow bedrock and faulting in the subsurface just downstream of Sevenmile Plaza may be due to several perched water tables at different depths, only the deepest of which is represented in the relatively coarse set of available water levels and driller's logs. The general downward water table gradient indicates that this is probably a localized recharge area for the unconfined aquifer.
2. The Rio Grande in the bifurcated-channels reach between Del Norte and Sevenmile Plaza is perched, and does not show a direct connection to the regional water table in this reach of the river. As a result of this study, our hypothesis is that this is due to the presence of a relatively thin and shallow low vertical conductance layer or layers, at depths approximately the same as the elevation of the riverbeds, but that are not reflected in the driller's logs of the area.
3. The regional water table gradient in the study area is disrupted, showing gradients across small horizontal distances that exceed what is reasonable under Darcian flow conditions. Correlated with this, in many places in the study area we find correlations between the water table changes and fault-controlled differences in bedrock and clay-layer depths across the area.

4. Overall, the current relatively simple conceptual model of the study area as reflected in the RGDSS is not sufficient to explain the complex geology and hydrogeology of the area.

Recommendations for the RGDSS

Based on the foregoing discussion, we have made the following recommendations for improvement of the RGDSS in the study area:

1. We recommend that the RGDSS should reflect the fact that the Rio Grande North and South Channels are perched above the regional water table in the Del Norte to Sevenmile Plaza reach, and should not attempt to reconcile the perched river elevations with the regional water table into a single layer, as the two are different and are not in direct hydrologic communication across the majority of the study area.
2. The available data suggest the presence of a low-conductance streambed. We recommend that it would be appropriate to revise the RGDSS model to reflect the lack of substantial gain or loss in this reach by representation of a low-conductance layer at the streambed in both the North Channel and the South Channel. Test drilling would be required to positively establish the presence of the hypothesized low-conductance layer.
3. The normal faults and horst/graben faults that appear to control the highly variable gradient in the regional water table in the study area need not be, and with the available data probably should not be, individually represented in the RGDSS model due to their complexity, and also due to the fact that the distance between faults commonly is less than the cell size in the model (1/2 mile). Acquisition of better data in the future may lead to a recommendation that a relatively simplified representation of the faulting is appropriate to be represented in the model.
4. If the State or others desire to further pursue the near-surface hydrogeologic differences that appear to control the perching of the Rio Grande in this study area; to further explore the hypothesized near-surface low-conductance layer or to identify the near-surface geology in the locality of the “ground water divide”, we recommend designing a test-

drilling project. Such a project ideally would consist of one or more transects, generally oriented SW-NE across the Rio Grande flood plain and to the Northeast, to describe and sample in detail the material types in the uppermost few tens of feet of the surface, particularly beneath the Rio Grande channels. Drilling in the channels at low stage may be feasible with appropriate equipment such as a drilling rig equipped with flotation tires. A test hole profile located in the vicinity of cross-section H-H', possibly tied into the monitoring well data at the Brownell recharge test site, would be a good location to consider for such a program. This program could require as many as 24 to 30 test holes, spaced at 4 to 6 per mile, each between 20 and 40 feet in depth, along with split-spoon or Shelby tube samples at selected intervals, and onsite observation by an experienced hydrogeologist, to provide the required high definition of the near-surface hydrogeology.