APPENDIX C
RED RIVER WATERSHED FLOW MODEL

Flow Modeling Methodology

The mass loading during a specified time interval (e.g., day) of any constituent is related to flow through the following equation:

Equation B1. Mass Load (mass units) = Q x C

Where Q = Discharge (volumetric units) and C = Concentration (mass per unit volume). Therefore, the discharge for each designated segment (natural or artificial) must be estimated in order to determine the TMDL.

Background

The following describes the approach applied to estimate ungaged inflows to the Red River between the USGS gage station/SWQB established flow measurement site below the Zwergle dam site near Red River, New Mexico, and the confluence of the Red River with the Rio Grande. Estimation of ungauged inflows is one of the most difficult, and common, tasks in hydrology. All approaches take into account contributing area. Some approaches add other variables such as precipitation, elevation of the gage site, and/or land use patterns. Many approaches use the "transfer" method whereby information from similar gauged sites is "transferred" to the site of interest. In sparsely gauged areas, this transfer can be problematic, as the gauged sites may be dissimilar in area, elevation, or land use and the information may not be reliably transferred.

Furthermore, groundwater flow in the watershed is controlled by fractures and faults, preferred channels within debris flow material, and differences in hydraulic conductivity between bedrock, mine waste rock piles (near Molycorp), and valley fill/alluvium. Hydrogeologic units include a Pre-Cambrian aquitard, volcanic and sedimentary rock aquifers, and valley fill alluvial or debris flow aquifers. Groundwater gradients are toward the Red River, except for the cone of depression created by mine dewatering. Fan delta deposits at the mouths of tributary canyons are the principal hydraulic connection between the river and upgradient sources.

The Red River watershed is sparsely gauged. Some information has been collected from contributing streams and from points of seepage. This information, although not definitive, does allow a "reality" check on estimated values.

Methods

The Red River flow model stations were positioned below major tributaries, NPDES outfalls, and known acidic seepage locations. All stations lie between the former Zwergle gage station, which is located just above the town of Red River, and the mouth on the Rio Grande. The flow stations also coincide with SWQB and biological stations when present. Automated measurement tools within ArcView were used to determine sub-basin areas for significant tributaries to the Red River and the watershed areas above each of the flow stations.
Model development involved matching, as closely as possible, measured streamflows at the current and former gage stations. Streamflow records for these stations were downloaded from

the National Water Information System web site (USGS, 2001). Data from the last 50 years at the Questa gage station was used to estimate the missing flows for the same time period at the remaining gage stations. This was accomplished for the three months of interest by developing a relationship between the data collected at the Questa station with each of the remaining stations. The result was a target average daily streamflow value for May, August, and October (Table B1) that the flow model attempted to match at each of the USGS stations on the Red River.

Table B1. Target Streamflows for USGS Gage Locations

Location	**Flow Model Station**	**Target Streamflow (cfs)**		
		May	August	October
Near Red River Gage	N/A	35.0	16.0	7.15
Zwergle Gage	1	49.6	20.6	11.0
Questa Gage	14	118	38.8	22.0
Fish Hatchery Gage	17	164	64.7	48.8
Mouth Gage	18	169	79.8	60.7

The average daily streamflows at the remaining model stations were simulated based on the area-weighted gains between the Zwergle and Questa gage stations, and between the Questa and fish hatchery gage stations. These gains were apportioned among the tributaries and groundwater seepage areas as described below.

Area-Weighting Approach

The approach used in the Red River TMDL study relies on measured river flows and various point measurements of tributary and seepage flows to estimate the ungaged flows. The approach will be described using the river reach between the gage sites at Questa (Red River near Questa, NM) and Zwergle. The contributing area to the river flow at Zwergle is 25.7 square miles. At Questa, the area is 113 square miles. Therefore, the intervening contributing area is 87.3 square miles, 44.5 square miles of which is assigned to tributaries and the remaining 42.8 square miles is assigned to non-tributaries, or seeps in this usage. The river distance between the Zwergle and Questa is 14 miles allowing direct (not time-lagged) comparisons between the average daily flows at the two sites. The gains or losses in the average daily flows can be calculated as:

Equation B2. $dQ = Q_Q - Q_Z$

Where dQ is the difference in the average daily flow (for a specific measurement day such as May 5, 1970, for example) between Questa and Zwergle, Q_Q is the average daily flow at Questa and Q_Z is the average daily flow at Zwergle for the same day. The value of dQ can be either positive (gains) or negative (losses). The period of overlapping measurements for the two sites or stations is from May 1, 1963 through December 31, 1973, or 3,898 days. The gain or loss on a daily basis is calculated as:

Equation B3. $q = dQ/dA$

Where q is the contributing flow in cfs per square mile and dA is the change in area between the stations. Rearranging and expanding equation (B3) yields:

$$\textit{Equation B4.} \quad dQ = q_t A_t + q_s A_s$$

Where q_t and A_t are the contributing flow and area from the designated tributaries and q_s and A_s are the same measures for the non-tributaries, or seeps. The total change of area is:

$$\textit{Equation B5.} \quad dA = A_t + A_s$$

Equation (B4) can be modified to:

$$\textit{Equation B6.} \quad dQ = q_s (K A_t + A_s)$$

Where $K = q_t / q_s$. The problem is to assign values to q_t, q_s, and/or K. These values are dynamic, i.e. they change with time, and vary from source to source. However, without detailed and prolonged measurements, only general values can be used.

Estimating Values

Because there are more unknowns than equations, the K factor was introduced to relate q_t and q_s. The range in K, based on the small number of point samples, is between 1 and 3, with 1 appropriate for the low flow months of August and October and 3 appropriate for the high flow month of May (the three months chosen for detailed analyses). Once a value of K was selected, then an optimum value of q_s could be calculated that yielded a minimum least squared errors summation or:

$$\textit{Equation B7.} \quad Min \sum (dQ\ measured - dQ\ estimated)^2$$

Where dQ measured is from equation (B2) and dQ estimated is from equation (B6). It should be obvious that the best estimate is the one that will yield a dQ equal to the average of the dQ values found from equation (B2). This optimal value is static over the time period from which it is derived, such as the May flows. Because q_s is a really a dynamic value, a refinement was developed. A linear regression model was developed for q_s as:

$$\textit{Equation B8.} \quad q_s = a + b\, Q_Z$$

Where a and b are regression parameters. The value of q_s was related to the flow at Zwergle because that flow was the known upstream boundary condition. The individual values of q_s were back calculated by rearranging equation (B6) with an assumed K value and the difference in daily flows found from equation (B2). The relationships for the Zwergle to Questa reach for the months of May, August, and October were reasonable and were incorporated into the flow estimation model. The final form of the estimation equation for the Zwergle to Questa reach is:

$$\textit{Equation B9.} \quad Q_Q = Q_Z + (a + b\, Q_Z) \times (K A_t + A_s)$$

Equation (B9) was used to estimate the daily flows at Questa based on the flow at Zwergle and the estimated inflows. The results were reasonable. This comparison was made for all three detailed months and for the entire period of overlapping record.
Similarly, the reach between Questa and the Red River below Fish Hatchery near Questa, NM, site was also analyzed. It this reach, the K value was set to 0.0 (no tributary inflows, i.e. A_t was 0.0 as well) and only q_s was considered. The linear relationships, in the form of equation (B8), were poor, so only the optimum value of q_s was employed in the flow estimation procedure.

Flow Model Results

The gains were estimated for each reach as described above and were then summed to the Zwergle station target flow value to calculate a flow at each of the downstream model locations. Flow model results for May are shown in Table B2. The model sites corresponding to the Questa, Fish Hatchery, and Red River at Mouth gage stations have estimated average daily streamflows that are within 10 percent of the target flow values shown in Table B1.

Table B2. Flow Model Results for May

Model Station	Location	Area (m^2)	Q/A cfs per m^2	Flow cfs
1	Zwergle Gage	25.7		49.6
	Goose Creek	5.5	1.039	5.7
	Placer Creek	2.4	1.039	2.5
	Bobcat Creek	5.8	1.039	6.0
	seepage	5	0.346	1.8
2	Above town of Red River	44.6		65.6
	Bitter Creek	10	1.039	10.4
	seepage	1.9	0.346	0.7
3	Below Bitter Creek	56.5		76.7
	Pioneer Creek	5.3	1.039	5.5
	seepage	8.9	0.346	3.1
4	Below town of Red River	70.7		85.3
	Haut n Taut Creek			0.0
	seepage	1.6	0.346	0.6
5	Junebug Campground	72.3		85.8
	Straight Creek			0.0
	Red River WWTP outfall			0.98
	seepage	1.9	0.346	0.7
6	Elephant Rock Camp	74.2		87.5
	Hansen Creek			0.0
	seepage	2.3	0.346	0.8
7	Below Hansen Creek	76.5		88.3
	seep#1	2.1	0.346	0.7
8	At Mine Boundary	78.6		89.0
	seepage	7.5	0.346	2.6

Table B2. Flow Model Results for May

Model Station	Location	Area (m^2)	Q/A cfs per m^2	Flow cfs
9	Above Portal	86.1		91.6
	seep#2	0.6	0.346	0.2
10	Above Columbine Creek	86.7		91.8
	Columbine Creek	15.5	1.039	16.1
	seep#3	1.5	0.346	0.5
11	Below Columbine Creek	103.7		108.4
	seep#4	3	0.346	1.0
12	Above Goathill Gulch	106.7		109.5
	seep#5	5.9	0.346	2.0
13	Eagle Rock Campground	112.6		111.5
	seep#6	0.4	0.346	0.1
14	Questa Gage	113		111.7
	Cabresto Creek	36.7		33.8
	seepage	6	0.395	2.4
15	Below Cabresto Creek	155.7		147.8
	Mine outfall			0.54
	seepage	19.6	0.395	7.7
16	Below Mine Outfall	175.3		156.1
	Fish Hatchery outfall			14.5
	seepage	9.7	0.395	3.8
17	Fish Hatchery Gage	185		174.4
	seepage	5	0.395	2.0
18	Mouth Gage	190		176.4

The estimated average daily streamflows for May (high flow) were used to calculate the TMDL for the Red River. Streamflow samples taken during the spring runnoff period of 1999 showed the highest aluminum and sediment loadings. Therefore, an implicit MOS, with respect to average conditions, is provided in the loading allowances.

References

U.S. Geological Survey. 2001. Surface-Water Data for USA. <http://water.usgs.gov/nwis/sw>