RGDSS Memorandum
RGDSS Phase 6—Response Functions Development
FINAL

To: File
From: Modeling and Decision Support Systems Team
Colorado Division of Water Resources
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1. Introduction

A Response Function is a simplified representation of the cause and effect relationship between groundwater withdrawal and net depletions to one or more surface streams within Water Division No. 3. The Response Functions described in this memorandum are based on results from the Rio Grande Decision Support System (RGDSS) Groundwater Model (Model). Impulse Runs are conducted with the Model to generate data for the development of Response Functions. The output files are provided in a file folder called Response Function Tables (RFs.zip (WITH) and RFp.zip (without)) and contain the Model output files needed for the Response Function development process.

In 2012 the RGDSS Model version 6P35 (version 6P35) was utilized to develop updated Subdistrict No. 1 Response Functions. This effort was documented in the attached memoranda entitled "Development of Revised Response Functions to Estimate Stream Depletions from Groundwater Pumping in *Subdistrict No.1* Using the Phase 6 RGDSS Groundwater Model (version 6P35)" and "Expert Opinions– Concerning the Office of the State Engineer's Approval of the 2012 Annual Replacement Plan for Special Improvement District No. 1 of the Rio Grande Water Conservation District" (Slattery, 2012).

This memorandum describes the development of the Response Functions in 2015 utilizing the RGDSS Model version 6P98 (version 6P98). The Response Functions were developed for all Response Areas. This memo discusses the Response Functions methods, groupings, calibration and application approaches. The objective of this report is to:

- *Document the development of Response Functions to calculate the net stream depletions to streams caused by Net Groundwater Consumptive Use in Water Division No. 3 based on Model version 6P98*

For version 6P98, Response Functions were generated individually for stream reaches using a Calibration Workbook. Twenty-seven individual Response Functions were generated using 27 separate Calibration Workbooks. Calibration Workbook information was collected from all the selected streams in a Response Area into a Response Area Application Workbook where total impacts are tracked for the entire Response Area. Seven Application Workbooks were created, one for each Response Area.

The following sections of this memorandum are:

- Definition of Terms
- Initial (Phase 5) Response Function
- Calibration Workbook (Response Function) Process
- Application Workbook Process
- Response Functions Results Summary
- References
- Appendices

2. Definitions of Terms

Definitions of some of the terms used in the processes of Response Functions development are described below.

- **Annual Replacement Plan (ARP)** refers to a compilation of data, calculation of Stream Depletions, and projected operations to replace or remedy injurious stream depletions that a Subdistrict with an approved Subdistrict Groundwater Management Plan must submit to the State and Division Engineer by April 15th of each year, containing the information required by Rule 11 (Rule 4.1[1]).
- **Credits or Surface Water Returns** refers to Municipal and Industrial (M&I) effluent which is discharged directly to a stream. Where appropriate, such direct effluent returns are offset against gross M&I pumping to determine net consumption for those uses in the Response Function spreadsheet.
- **Impact Run** refers to the difference between the first Model run in historical hydrologic conditions and the second model run with the appropriate pumping turned off for each particular Response Area. The difference between these two runs determines the stream depletions that are caused by pumping in the Response Area (Exhibit 95: Schreüder, 2009).
- **Impulse Run** refers to the Model run data used to generate impulse curves to create Response Functions. The impulse curves are derived from the difference between two model runs: the first run uses historical hydrologic conditions in the first year followed by 19 years of average hydrologic conditions whereas the second run uses no Net Groundwater Consumptive Use in the first year followed by 19 years of average hydrologic conditions. The 1990 through 1998 period is used for the average monthly hydrologic conditions (Calibration Package, CDWR, Sept 23, 2015).
- **Net Groundwater Consumptive Use (NetGWCU)** is the groundwater consumed by the operations of one or more Wells, and represents the difference between groundwater withdrawals less any return flow to the hydrogeologic system within Water Division No. 3 (Rule 4.16).
- **Response Functions** are a simplified representation of the cause and effect relationship between groundwater withdrawal and net depletions to one or more surface streams within Water Division No. 3. The Response Functions used are derived from the Model and used to quantify the amount, timing, and location of Net Stream Depletions caused by groundwater withdrawals within a Response Area (Rule 4.21).
- **Response Area** refers to a specific geographic area and vertical interval within the Model Domain where Response Functions are used (Rule 4.20). Response Areas defined in Phase 6 are: 1) Response Area No. 1, 2) Rio Grande Alluvium, 3) Conejos, 4) Alamosa/La Jara, 5) San Luis, 6) Saguache and 7) Trinchera.
- **RGDSS** refers to the Rio Grande Decision Support System (RGDSS), including the RGDSS Groundwater Model, developed by the Colorado Water Conservation Board and the Colorado Division of Water Resources (Rule 4.22)
- **RGDSS Groundwater Model (Model)** means the finite difference model (commonly known as "MODFLOW"), developed by the U.S. Geological Survey to simulate, among other things, the flow of groundwater, its pre- and post-processors, and its associated modular computer programs, as adapted and applied by the Office of the State Engineer to simulate Unconfined Aquifers and the Confined Aquifer System. The Model means the model as it currently exists and as it may be revised under Rule 24 (Rule 4.23).
- **RGDSS Model Domain** refers to the physical area within Water Division No. 3 where the Model makes flow computations (Rule 4.24).
- **Stream Depletions** refers to net depletions to streams caused by the withdrawal of tributary groundwater in Water Division No. 3 (Rule 4.26).

[1] Rules Governing The Withdrawal Of Groundwater In Water Division No. 3 (The Rio Grande Basin) And Establishing Criteria For The Beginning And End Of The Irrigation Season In Water Division No. 3 For All Irrigation Water Rights.

- **Stream Reach** refers to a segment or stream within a stream system.

3. Initial (Phase 5) Response Functions

Response Functions were originally developed under RGDSS Groundwater Model Phase 5 (version 5P12) encompassing the Subdistrict No. 1 area. The Response Functions developed in that phase were reviewed and approved by the Water Court for Water Division No. 3 in the litigation concerning Subdistrict No. 1's Plan of Water Management in 2007CW52/2010SA224. Those Response functions relied on a Model study period of 1970-2005 and were based on NetGWCU. (See 2007CW52 Exhibit 95 (Schreüder, 2009) and Exhibit 99 (Slattery, 2009)).

4. Calibration Workbook (Response Function) Process

Using Model version 6P98 Impulse Runs, Response Functions were developed for seven Response Areas. Given the number of Response Functions to be developed it was determined that a consistent process for development was needed. The modeling team developed a Calibration Workbook that could be used for developing each Response Function. Outputs from the Groundwater Model were reviewed under the criteria set out in Rule 7.2 to determine which streams/reaches required development of a Response Function. Response Functions were generated individually for each appropriate stream reach within a Response Area using the Calibration Workbook. **Version 1.1 of the Calibration Workbooks** for all reaches can be found on the DWR website at the following address:

(http://water.state.co.us/SurfaceWater/RulemakingAndAdvising/SLVAC/Pages/SLVResponseFunctions.aspx).

The general approach for generating Response Functions involved six major steps:

1. Transfer Streamflows Data from HydroBase to the Calibration Workbook
2. Transfer Calibrated Data from the Model to the Calibration Workbook
3. Determine Stream Reaches/System to Generate Response Functions
4. Define Response Function Groupings
5. Define Response Function Methods
6. Perform Calibration or Create Response Functions

4.1 Transfer Streamflows Data from HydroBase to the Calibration Workbook

Streamflow data for the Index Gages from 1970 to 2010 were required in the calibration and were imported before the calibration process was started. The streamflows data (1970-2010) are pulled from HydroBase using TSTool command file ("Streamflows.commands.TSTool") that outputs the file "Streamflows.dv" which was then linked to the "Streamflow Data" worksheet in a Calibration Workbook. The Index Gages used in the calibrations are Rio Grande at Del Norte Stream Gage, Saguache Creek near Saguache, Alamosa Creek above Terrace Reservoir, La Jara Creek near Capulin, Conejos River near Mogote, San Antonio River at Ortiz, Los Pinos River near Ortiz, and Trinchera Creek above Turners Ranch. Three Index Gages were not collected by the script and were added manually to the Calibration Workbooks of Trinchera, San Luis (Crestone Creek), Saguache (San Luis Creek) Response Areas. The three Index Gages are Trinchera below Smith Reservoir, Ute Creek near Fort Garland, and Sangre De Cristo Creek near Fort Garland.

4.2 Transfer Calibrated Data from the Model to the Calibration Workbook

For each Response Area, the impact run output data, generated from RGDSS Groundwater Model version 6P98, was uploaded to the Calibration Workbook. For Response Areas where reaches have Credits, two sets of data were provided. One set was without Credits and one was "WITH Credits". The data includes: Annual Stream Depletions (with/without Credits), Order of Stream Depletions, Monthly Stream Depletions (with/without Credits), and Stream Reach Data (with/without Credits). The data were imported from an "html" document of groundwater model output data using the Data/Connection Menu from the workbook and following the appropriate link to the selected Response Area data. Descriptions of the process used to import the groundwater model output data for each category are provided below and can also be found in each Calibration Workbook.

4.2.1 Annual Stream Depletions

The annual stream depletions data derived from the Model are in an "html" document with a file format named "budget[a-h].htm". The imported annual stream depletions identified as "WITH Credits" and "Without" Credits are used to separate the M&I surface return flows from the stream depletions data. Each set of data (WITH and Without) for a Response Area has "budget" files containing a letter (a-h) at the end as shown below where:

- ✓ "budgeta" – Response Area No.1 (RANo.1)
- ✓ "budgetb" – Rio Grande Alluvium (RGA)
- ✓ "budgetc" – Conejos
- ✓ "budgetd" – Alamosa- La Jara
- ✓ "budgete" – San Luis Creek
- ✓ "budgetf" – Saguache Creek
- ✓ "budgeth" – Trinchera

For each Response Area the annual stream depletions data for 1970-2010, without and WITH Credits were imported into the Workbook spreadsheets titled "Annual Stream Depletions" (Without) and "Annual Stream Depletions WITH", respectively. Where the stream reach does not contain M&I surface water return flows, the annual stream depletion without Credits were imported to both "Annual Stream Depletions" and "Annual Stream Depletions WITH" worksheets and the difference was confirmed to be zero in the "Monthly Stream Depletions DIFF" worksheet.

4.2.2 Order of Stream Depletions

Model data for each Response Area, organized by stream reach according to the magnitude of stream depletions, are in an "html" document with a file format named as "order[a-h].htm". This file was imported into each Calibration Workbook to the spreadsheet titled "Order of Stream Depletions." Each Response Area has 'order" files containing a letter (a-h) as shown below where:

- ✓ "ordera" – Response Area No.1 (RANo.1)
- ✓ "orderb" – Rio Grande Alluvium (RGA)
- ✓ "orderc" – Conejos
- ✓ "orderd" – Alamosa- La Jara
- ✓ "ordere" – San Luis Creek
- ✓ "orderf" – Saguache Creek
- ✓ "orderh" – Trinchera

The order of stream depletions data shows the latest 10 years (2001-2010) average stream depletions from all reported stream reaches. Based on this data for a Response Area, stream reaches/systems are identified for which Response Functions are generated. Once in the spreadsheet the Order of Stream Depletions tab lists the affected reaches in descending order according to the magnitude of stream depletions.

4.2.3 Monthly Stream Depletions

The monthly stream depletions data from the Model outputs are in "txt" file format in the form of "20150513[a-h]-imp.txt" for the stream Response Area that do not contain M&I surface water return flows or "20150513[a-h]-ims.txt" those Response Area that contain M&I surface water return flows. The monthly stream depletions data must be imported two times, first "Without Credits" and then "With Credits" to separate the M&I surface water return flows if they exist. If the stream reach does not contain M&I surface water return flows, then the monthly stream depletion without surface water return flows should be imported to both "Monthly Stream Depletions" and "Monthly Stream Depletions WITH" worksheets and the difference should be zero in the ""Monthly Stream Depletions DIFF" worksheet.

4.2.4 Stream Reach Data

The RGDSS GW Model output reports for streams and reaches for all runs (**Table 1**). The "Reach Data" are the monthly stream depletions time series for the annual Response Function Model runs that were imported to the Calibration Workbook. The Calibration Workbook is arranged to accommodate data for up to six reaches in the same stream system. The individual reach data (Reach 1 Data to Reach 6 Data) is summed up in a "Combined Reach Data" worksheet which is used in the calibration process. The Reach 1 Data is imported two times, first "Without Credits" and then "With Credits", to separate the M&I surface water return flows. If the stream depletions are estimated from a single stream reach, then the "Reach 1 Data" and "Reach 1 Data WITH" worksheets were used and the remaining reach sheets were zeroed out by importing "RFxNONEx.txt". If multiple stream reaches exist in the system that should be combined, the data must be imported to "Reach 2 Data". The same process is used for additional reaches. To update the appropriate tables and indicate the correct stream reach, the "Index Gage" value for the stream reach was entered in the yellow cells of the "Admin Reach Calib Data" worksheet. Stream reaches with the largest stream depletions were entered first in the case where reaches were combined. Additional descriptions are provided in the "ReadMe" worksheets in the Calibration Workbook.

Table 1: RGDSS Groundwater Model Reported Streams and Reaches

No.	Streams	*No.*	Stream Reaches
1	**Rio Grande**	*1*	Rio Grande Del Norte-Excelsior
		2	Rio Grande Excelsior-Chicago
		3	Rio Grande Chicago-State Line
2	**Conejos**	*4*	Conejos above Seledonia/Garcia
		5	Conejos below Seledonia/Garcia
		6	San Antonio River
3	**Alamosa**	*7*	Alamosa River
4	**La Jara**	*8*	La Jara Creek
5	**Saguache**	*9*	***Saguache Creek***[2]
		10	Saguache Creek Malone to Hearn
		11	Saguache Creek Braun Bros to Oklahoma
		12	Saguache Creek above Malone
		13	Saguache Creek Hearn to Braun Bros
		14	Werner Arroyo below Mountfield
		15	Werner Arroyo above Mountfield
		16	***Werner Arroyo***
6	**La Garita**	*17*	La Garita Creek
7	**Carnero**	*18*	Carnero Creek
8	**San Luis**	*19*	San Luis Creek above Artur Young
		20	San Luis Creek below Arthur Young and Kerber Creek
9	**Rito Alto**	*21*	Rito Alto
10	**San Isabel**	*22*	San Isabel Creek
11	**Crestone**	*23*	Crestone Creek
12	**Spanish**	*24*	Spanish Creek
13	**Deadman**	*25*	Deadman Creek
14	**Willow**	*26*	Willow Creek
15	**Cottonwood**	*27*	Cottonwood Creek
16	**Cotton**	*28*	Cotton Creek
17	**Wild Cherry**	*29*	Wild Cherry Creek
18	**Sand**	*30*	Sand Creek
19	**Medano**	*31*	Medano Creek
20	**Big Spring**	*32*	Big Spring Creek
21	**Little Spring**	*33*	Little Spring Creek
22	**Zapata**	*34*	Zapata Creek
23	**Trinchera**	*35*	Trinchera Creek System above Smith Reservoir
		36	Trinchera Creek below Smith Reservoir
24	**Costilla**	*37*	Costilla Creek

[2] The Bolded Saguache Creek and Werner Arroyo reaches were reported from 6P98 as both reaches and as a summary. For the calibration the summary values were used for these streams.

4.3 Determining When to Generate a Response Function

The decision as to when a Response Function is generated was based on the lower limit of reliability of the Model as described in the Rules (7.2: 7.2.1 -7.2.6). For RGDSS Groundwater Model 6P98, an absolute value (absolute value means the value of depletions or accretions) of 50 acre-feet was used as the lower limit of reliability of the Model (2007CW52). Based on this lower limit of the reliability, the following criteria were applied to identify where it was appropriate to develop Response Functions.

i. If the average net stream depletions for the last 10 years (2001-2010) in the Model for all stream reaches in the stream system totals greater than an absolute value of 50 acre-feet, then a Response Function will be generated for all depletions in that stream system. If the minimum average net stream depletions for the last 10 years in the Model for all stream reaches in the system sum to less than the absolute value of 50 acre-feet, then a Response Function will not be generated

ii. For those stream systems where Response Functions are to be generated, if the average depletions for any stream reach for the latest 10 years (2001-2010) in the Model are greater than the absolute value of 50 acre-feet, then a separate Response Function will be generated for that reach.

iii. For those stream systems where Response Functions are to be generated, if the average depletions for a stream reach for the latest 10 years in the groundwater model are less than the absolute value of 50 acre-feet, then the depletions will be moved to the nearest stream reach in that stream system and a combined Response Function will be generated.

An example of this decision process is provided in **Table 2,** which shows the thirty-seven streams or reaches where data were reported for Response Area No.1. All reported stream reaches were assessed based on the criteria stated above to determine which reaches exceeded the lower limit of reliability making it appropriate to generate Response Functions. Based on the criteria, Response Functions in Response Area No. 1 were generated for:

- Rio Grande(Del Norte – Excelsior Ditch): Depletions of 2963 acre-feet
- Rio Grande (Excelsior Ditch – Chicago Ditch): Depletions of 1495 acre-feet
- Rio Grande (Chicago Ditch – Stateline): Depletions of -181 acre-feet

Table 2: Reported Stream Reaches and Order of Stream Depletions for Response Area No. 1

No	Response Area No. 1 Reported Stream reaches	Average Depletions 2001-2010	No	Response Area No. 1 Reported Stream reaches	Average Depletions 2001-2010
1	Rio Grande Del Norte-Excelsior	2963	20	Trinchera Creek below Smith Res.	0
2	Rio Grande Excelsior-Chicago	1495	21	Saguache Creek Braun Bros to Oklahoma	0
3	San Luis Creek below Arthur Young and Kerber Creek	35	22	Spanish Creek	0
4	Saguache Creek Malone to Hearn	33	23	San Luis Creek above Arthur Young	0
5	**Saguache Creek**[3]	30	24	Costilla Creek	0
6	Deadman Creek	23	25	San Antonio River	0
7	Conejos below Seledonia/Garcia	16	26	**Werner Arroyo**	0
8	Big Spring Creek	12	27	La Garita Creek	0
9	Crestone Creek	7	28	Carnero Creek	0
10	La Jara Creek	6	29	Cottonwood Creek	0
11	Rito Alto	6	30	Cotton Creek	0
12	Saguache Creek above Malone	5	31	Wild Cherry Creek	0
13	Alamosa River	3	32	Medano Creek	0
14	Sand Creek	1	33	Zapata Creek	0
15	Little Spring Creek	1	34	Trinchera Creek System above Smith Reservoir	0
16	San Isabel Creek	1	35	Werner Arroyo below Mountfield	0
17	Werner Arroyo above Mountfield	0	36	Saguache Creek Hearn to Braun Bros	-9
18	Willow Creek	0	37	Rio Grande Chicago-State Line	-181
19	Conejos above Seledonia/Garcia	0			

[3] Saguache Creek and Werner Arroyo were reported from 6P98 as both reaches and as a summary. For the calibration the summary values were used for these streams.

Table 3 shows the stream reaches/systems in the respective Response Areas where the stream depletions exceeded the lower limit of reliability of the Model so that Response Functions were developed.

Table 3: Stream Reaches/Systems for which Response Functions were Generated

		Response Area						
		Response Area No. 1	**Rio Grande Alluvium**	**Conejos**	**Alamosa La Jara**	**San Luis**	**Saguache**	**Trinchera**
Stream Reaches	1	Rio Grande: Del Norte to Excelsior	Rio Grande: Del Norte to Excelsior	Alamosa River	Alamosa River	Crestone Creek	Rio Grande (RG123)*	Conejos River (CON21)*
	2	Rio Grande: Excelsior to Chicago	Rio Grande: Excelsior to Chicago	Conejos above Seledonia/ Garcia	Conejos above Seledonia/ Garcia	San Luis Creek	Saguache Creek	Rio Grande (RG21)*
	3	Rio Grande: Excelsior to State Line	Rio Grande: Excelsior to State Line	Conejos below Seledonia/ Garcia	Conejos below Seledonia/ Garcia		San Luis Creek	Rio Grande Excelsior to State Line
	4			Rio Grande: Del Norte to Excelsior	Rio Grande: Del Norte to Excelsior			Trinchera Creek (TRIN21)*
	5			Rio Grande: Excelsior to Chicago	Rio Grande: Excelsior to Chicago			
	6			Rio Grande: Excelsior to State Line	Rio Grande: Excelsior to State Line			

Note: * Indicates stream reaches where the net stream depletions are combined to the nearest stream reach

** Response Function for La Jara Creek in the Alamosa/La Jara Response Area was not generated and is pending additional hydrogeologic review.

4.4 Define Response Function Groupings

The Response Functions for individual reaches were developed for dry, average, and wet conditions based on either NetGWCU or streamflows for the Response Area. The Impulse Runs data for those reaches were aggregated in to wet, dry, and average years based on the NetGWCU and streamflows conditions in the Response Area. In Model versions 5P12, 6P35, and 6P98 NetGWCU groupings were applied in Response Area No. 1. In Response Area No. 1 NetGWCU groupings provided a better calibration by incorporating the extensive surface water recharge operations that occur in that area. For the remaining Response Areas stream drying occurs. Streamflow groupings were used for the remaining Response Areas to better reflect the stream drying.

4.5 Define Response Function Methods

Two methods were used to generate Response Functions:

1. 2009 Method – This is a method originally developed for RGDSS Groundwater Model Phase 5. Enhancements were made in Phase 6P35 to improve calibration.
2. Ratio Method – This is a method developed to better calibrate Response Function where intermittent stream flow significantly influences stream depletions.

4.5.1 2009 Method

The 2009 Response Function Method (2009 Method) was used in 2009 and 2012 for Response Area No. 1 (Subdistrict No. 1) stream depletion calculations. The 2009 Method was also used to develop the Response Functions for Response Area No. 1 in September, 2015 based on RGDSS Groundwater Model 6P98 output. The method uses the 23 impulse curves generated by the Model that were used to create the Response Functions. Each impulse result was derived from the difference between two model runs.

1. The first run uses historical hydrologic conditions in the first year followed by 19 years of "average hydrologic conditions[4]".
2. The second run uses no NetGWCU in the first year followed by 19 years of average hydrologic conditions.

The hydrologic conditions are the dry, average, and wet years classified based on the amount of NetGWCU and streamflow in each year in the Response Area. The impulse runs from the Model were used to calibrate dry, average and wet Response Functions. One impulse run was created for each year from 1988-2010 where the model was run with that year's pumping followed by 20 years of no pumping under average hydrologic conditions. Then, the scaled Response Functions were multiplied by NetGWCU to determine the Response Functions depletion for individual years. The 2009 Method uses the stream depletions estimated from the Model for the years 1988 to 2010 to generate the Response Functions in dry, average and wet year conditions.

4.5.2 Ratio Method

The Ratio Method maintains the concepts and criteria from the 2009 Method approach, but addresses non-linear behavior where intermittent streamflow significantly influences depletions. The Ratio Method was developed for stream reaches that do not calibrate well using the 2009 Method due to zero or low streamflows that create a disconnection between the aquifer and the stream for periods of time. Under these conditions the Ratio Method calibrates better than the 2009 Method.

The Ratio Method uses the stream depletions estimated from the Model for the years 2001 to 2010 to generate the Response Functions in dry, average and wet years. The steps employed to generate the dry year Response Function are given below as an example:

1. Using the dry years determined in 4.4 calculate the average stream depletions that occur in January.
2. Average the annual NetGWCU for the last 10 years for each dry year in the analysis.
3. Divide the value in the first step by the value in the second step. This process is repeated for all 12 months to generate a dry response curve.

[4] The 1990 through 1998 period monthly data is used for the "average hydrologic conditions

4. The same procedure is used to generate the Response Function for average and wet years.
5. Finally all the Response Functions are scaled by a scaling factor so that the volumes from the Response Functions match the volumes from the Model using a slope equal to one.

The Ratio Method was used to develop Response Functions in the following stream reaches

- Saguache and San Luis Creek in Saguache Response Area
- Trinchera Creek in Trinchera Response Area
- Crestone Creek and San Luis Creek in San Luis Response Area,
- Conejos River above Seledonia/Garcia and the Alamosa River in the Conejos and the Alamosa-La Jara Response Areas

4.6 Perform Calibration

Calibration processes were carried out in the Calibration Workbook after importing both the necessary data from the Groundwater Model and the "Index Gage" streamflow data from HydroBase. Excel "Solver" was the tool used in this calibration process.

The goal was to have one continuous curve for a Response Function which incorporates dry, average, and wet years. Dry, average, and wet year groupings didn't always match seamlessly on the same line. Therefore a scaling factor for each grouping was used to bring the dry, average and wet year plots into alignment for calculation of response function. Initially a scaling factor between 0.8 – 1.21 were assigned to the dry, average, and wet year groupings. For most Response Functions scaling factors between these initial limits provided optimum initial results. For 5 Response Functions more aggressive scaling was used to achieve optimum initial results.

The calibrations were carried out by keeping the offset value zero and adjusting the groupings (dry, average, and wet years) and the scaling factors to obtain a slope of one and the highest value possible (1.0) for the coefficient of determination (r^2) between the model and Response Functions data. Optimum calibration results were achieved by changing the variables (groupings and scaling factors) and using "Solver" installed in Excel until the lowest possible Sum of Square Error (SSE) was reached.

The Calibration Workbook graphs both the Model output and the Response Function output. The final step was to review the graphed results including the graphs of the Monthly, Annual, and Cumulative Net Stream Depletions. When the results reached the extent where further calibration could not change the outcome, the results were transferred to the Application Workbook for the next process.

5. Application Workbook Process

An Application Workbook summarizes the net stream depletions at the Response Area level as generated by the Calibration Workbooks. The Application Workbook is to be utilized by groundwater users to determine the impacts of their groundwater use. The Application Workbook is a Response Area level product and includes all of the stream reaches in the Response Area where Response Functions were generated and where net stream depletions were estimated.

After entering the necessary data, discussed below, from the Calibration Workbook to the Application Workbook, calculations occur automatically using functions stored in an included VBA module using data stored in pairs of reference data sheets for each stream reach's Response Functions. However, these reference sheets are not for editing and are not formatted for user interaction. They were left in the general form of the sheets in the workbooks that process the Model results to make it easier to copy updated data into them when necessary in the future.

5.1 Data Transfer to the Application Workbook

The application process to calculate net stream depletions on a monthly and annual basis were carried out in the Application Workbook. The process required the latest calibrated data from the Calibration Workbook and data from the recent years (2011-2015) NetGWCU and Returns to Streams spreadsheet before calculating the net stream depletions for historical, current, and post plan years for each stream reach. **Table 4** shows the data that should be transferred from completed Calibration Workbook to Application Workbook.

5.1.1 Calibrated Data

The calibrated data from the Calibration Workbook was transferred to the Application Workbook to calculate the net stream depletions. The data from all calibrated stream reaches were transferred to the corresponding stream reaches appropriate worksheets and cells. The stream reaches data in a Response Area was copied from individual Calibration Workbook and transferred to a single Application Workbook that contained the appropriate worksheets for all calibrated stream reaches for the Response Area. To maintain consistency in data transfer, given the large number of transfers required, a script was developed for this process. **Table 4** shows the calibrated data that was copied from the Calibration Workbook and pasted as a value to the Application Workbook.

Table 4: Data to Transfer from Calibration Workbook to Application Workbook

	FROM CALIBRATION WORKBOOK		TO APPLICATION WORKBOOK		Remark
	WORKSHEET	**CELLS**	**WORKSHEET**	**CELLS**	
1	Reach Calibrated RF	B2:D5	Reach “X” Calibrated RF	B2:D5	
2		B10:D249		B10:D249	
3	Reach Calibration or Reach Calibration Ratio	G162:G653	Reach “X” Calculations or Reach “X” Calculations Ratio	G162:G653	
4		I83:I123		I83:I123	
5		V3:V7		V3:V7	
6		A3:B9		A3:B9	
7		M161:M165		M161:M165	
8		AI81		AI81	
9		A4:A9	Reach “X” Calibrated RF	B8:G8	*Note: A4 to B8, A5 to C8, etc.*
10	Monthly Stream Depletions DIFF	‘XX’8:’XX’499	Reach “X” Calculations/Ratio	H162:H653	*If Surface Water Returns exist in the Response Area*

5.1.2 2011-2015 NetGWCU

The Model (6P98) utilized the historical NetGWCU and returns to streams data from 1970 to 2010. For recent years (2011-2015) a spreadsheet was developed named “NetGWCU and Returns to Streams Estimates2.xlsx”. The recent years (2011-2015) estimated NetGWCU data must be included in the estimation of net stream depletions and must be imported to the Application Workbook. The NetGWCU for 2011 to 2015 were determined from metered groundwater pumping values and measured stream diversions. The resulting NetGWCU and recharge values were used in the output worksheets of Projected Depletions

Monthly, Projected Depletions Annual and “ARP Tables” worksheets. For the details of each worksheet and data transfers, refer to the “ReadMe” worksheets in the Application Workbooks.

5.2 Response Area Summary Output Tables

After the calibrated data and the NetGWCU data were imported to the Application Workbook, the surface water depletions and the annual replacement obligations are automatically calculated. The summarized results can be found in the output tables of the Application Workbook and discussed below.

5.2.1 Surface Water Impact Summary Tables

The projected surface water depletions for a Response Area for which Response Functions were generated were summarized on a monthly and annual basis. The projected annual depletions and the projected monthly depletions were both numerically and graphically provided for historical, current year and future years depletions for individual reaches and for the Response Area as a whole.

5.2.2 Annual Replacement Plan (ARP) Tables

These subsets of tables in the Application Workbook provide the type of information generally needed in an ARP. The ARP tables are automatically updated when the current year changes in the future. The ARP output tables provide information to the following items:

- The recent year NetGWCU (2011-2015)
- Historical and future stream impacts by stream reach (1970-2035)
- Current year monthly stream impacts by stream reach (2015)
- Future years post plan impacts by stream reach (2016-2035)

The historical and current year depletions were estimated utilizing NetGWCU while the future years’ (post plan) depletions/accretions are estimated with no NetGWCU.

6. Response Functions Results Summary

The Response Functions for calibrated reaches and for Response Areas were summarized in the Calibration and Response Area summary packages, respectively. The calibration packages were prepared for twenty-seven reaches for which Response Functions were generated and stream depletions are calculated. Response Area summary packages were prepared for all seven Response Areas. A summary of the descriptions of the calibration and Response Areas summary packages were given below and the details provided in **Appendix A** (Calibration Package, CDWR, Sept 23, 2015) and **Appendix B** (Response Area Summary Package, CDWR, Sept 23, 2015).

6.1 Calibration Summary

The calibration packages contain a short summary of the calibration results including the name of stream reach, Response Functions method, and the groupings (NetGWCU or Streamflow) used in the calibration process. The results of the calibration processes provided in **Appendix B** are summarized as follows:

- Model Impulse Run Used to Generate Response Functions, One Curve per Year for 1988-2010
- Response Functions for Dry, Average, and Wet Years: **-** Net Stream Depletions as a Percent of Average Net Groundwater Consumptive Use

- Calibration Graphs
  - ✓ Monthly Net Stream Depletion Comparison: Model Versus Response Functions
  - ✓ Annual Net Stream Depletion Comparison: Model Versus Response Functions
  - ✓ Cumulative Net Stream Depletion Comparison: Model Versus Response Functions
  - ✓ Response Function Versus Model Annual Net Stream Depletions for 1988-2010

6.2 Response Area Summary

The Response Area Summary Packages are prepared for the seven Response Areas where Response Functions are developed. The packages contain the results including the name and location map of the Response Area and calibrated stream reaches. The results of the application process for each Response Area provided in **Appendix B** are summarized below

- Stream Reaches with Response Function in the Response Area
- Estimated Historical and Current Year Net Stream Depletions from Groundwater Withdrawals in the Response Area
- Estimated Post Plan Net Stream Depletions from Groundwater Withdrawals in Response Area
- 2001-2015 Estimated Net Stream Depletions and Post 2015 Projected Net Stream Depletions from Groundwater Withdrawals
- Monthly Net Stream Depletions for 2015 Plan Year in Response Area

7. Reference

CDWR, 2015, Rules Governing The Withdrawal of Groundwater in Water Division No. 3 (The Rio Grande Basin) and Establishing Criteria For The Beginning and End of The Irrigation Season in Water Division No. 3 For All Irrigation Water Rights,

Schreüder, W.A., 2009, 2007CW52 Exhibit 95: Using the RGDSS Groundwater Model to Compute Response Functions, Sept 22, 2009

Slattery, J.E., 2009, 2007CW52 Exhibit 99: Expert Disclosure of James Slattery

APPENDICES

{The files can be found at http://water.state.co.us/SurfaceWater/RulemakingAndAdvising/SLVAC/Pages/SLVResponseFunctions.aspx }

A. Calibration Packages For All Stream Reaches Where Response Function Were Generated (PDF)
B. Response Area Packages For All Response Areas (PDF)

ATTACHMENT 1

Development of Revised Response Functions to Estimate Stream Depletions from Groundwater Pumping in *Subdistrict No.1* Using the Phase 6 RGDSS Groundwater Model (version 6P35)

Slattery & Hendrix Engineering LLC
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To: William A. Paddock, Esq. – Carlson, Hammond & Paddock, LLC

From: James E. Slattery

Date: July 20, 2012

Subject: Development of Revised Response Functions to Estimate Stream Depletions from Groundwater Pumping in Subdistrict No. 1 Using the Phase 6 RGDSS Groundwater Model

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This memorandum describes the development of the response functions to estimate the stream depletions from groundwater pumping in Subdistrict No. 1 based on the phase 6 (6P35 version) of the RGDSS groundwater model[1]. In addition this memorandum describes the stream depletions from net groundwater consumptive use in Subdistrict No. 1 for the 2012 Annual Replacement Plan (May 1, 2012 to April 30, 2013). The response functions described in this memorandum were updated from the response functions described in my June 29, 2009 memorandum because of additional data collection and other improvements to the Rio Grande Decision Support System (RGDSS).

There were numerous improvements made to the RGDSS in the last three years based upon additional data collection and analysis described in the updated RGDSS documentation. In addition, a coding error was discovered in a post-processor used in the Phase 5 RGDSS groundwater model. That coding error resulted in overstating groundwater consumption and resulting stream depletions in wet years. The improvement that had the largest impact on the location of stream depletions from Subdistrict No. 1 net groundwater consumptive use was the refined geology in the southern portion of the San Luis Valley. As the result of these changes, the stream depletions from Subdistrict No. 1 net groundwater consumptive use are now limited to 3 reaches of the Rio Grande.

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[1] All references to the RGDSS ground water model in this memorandum are to the phase 6 model version 6P35, unless otherwise stated.

Attachment 1

In 2009 the Phase 5 RGDSS model predicted stream depletions that impacted the Rio Grande, Conejos River, San Antonio River, and La Jara Creek. The revised geology developed by Mr. Eric Harmon identified a previously unknown layer of relatively impermeable material separating the confined and unconfined aquifer in the area generally south of the Alamosa River and west of the Rio Grande as more completely described in Mr. Harmon's expert opinions and appendices. As a result, the impacts from the Subdistrict No. 1 net groundwater consumptive use were not as readily transmitted from the confined aquifer into the unconfined aquifer. In the Phase 5 model, there was a much higher degree of connection between the two aquifers in this southern area.

The following sections describe how the updated response functions were developed and the application of those response functions to estimate stream depletions from Subdistrict No. 1 well pumping.

1. Quantification of Net Groundwater Consumption

a. Estimate groundwater consumption as the Total Pumping minus the groundwater return flows associated with the pumping. These values were determined from the historical data input to the RGDSS groundwater model.

b. Determine imported water recharge that offsets groundwater consumption using diversion records and the procedures approved by the Court in the 2009 trial in Case No. 07CW52. ("Imported Water Offsets" from Recharge Decrees).

c. Estimate Net Groundwater Consumption as total groundwater consumption minus Imported Water Offsets. This was done for the period of 1970-2009. The study period ended in 2009 because the input to the groundwater model from the StateCU model was only available through 2009 at the time the response functions were developed.

2. Use RGDSS Groundwater Model to Estimate Stream Depletions

a. Run the RGDSS groundwater model with historical groundwater use and quantify stream/groundwater interaction by stream reach.

b. Run the RGDSS groundwater model simulating only the quantity of groundwater use (consumption) that is equal to the Imported Water Offset and determine stream/groundwater interaction by stream reach.

c. The difference between runs 1 and 2 is the amount of stream depletions estimated using the RGDSS groundwater model.

d. See Dr. Willem Schreuder's July 20, 2012 expert report for further details.

3. Use RGDSS Groundwater Model to Determine Response Functions

a. Repeat the process described in Step 2 above for each year for the 1988 to 2009 period to derive updated subdistrict-wide response functions by stream reach.

b. The updated response functions were calibrated against groundwater model output results for the 1988-2009 period. This is the time period established in paragraph 4.B.i. of the Annual Replacement Plan contained in Appendix 1 to the approved Plan of Water Management. It is also the time period that most nearly represents the typical distribution of groundwater pumping and recharge that is occurring in Subdistrict No. 1 under present conditions.

c. As provided in paragraph 4.B.ii of the Annual Replacement Plan, I examined the updated response functions to determine the variation in the updated response functions for different hydrologic conditions. Based upon that examination, there was a material difference in the updated response functions for three different hydrologic conditions: dry, average or wet years. A year was classified as being dry, average, or wet based on the amount of Net Groundwater Consumptive Use using the following criteria:

Year Type	Net Groundwater Consumptive Use (ac-ft/yr)
Wet	Less than 10,000
Average	Between 10,000 and 180,000
Dry	Greater than 180,000

These values were determined through the calibration process of the response functions.

d. An average, wet, and dry year response function was determined for the streams where the average historical annual stream depletions calculated by the RGDSS groundwater model exceeded 50 ac-ft/yr for the 2000 to 2009 period (last 10-years hydrologic data was available for the groundwater model). For small streams the stream depletions below the last diversion structure were not counted as injurious stream depletions.

The following stream reaches met the greater than 50 ac-ft/yr criteria: criteria:

1. Rio Grande – Del Norte stream gage to Excelsior Canal headgate
2. Rio Grande – Excelsior Canal Headgate to the Chicago Canal headgate
3. Rio Grande – Chicago Canal Headgate to the Lobatos stateline stream gage

e. A total of 9 updated response functions are used to estimate the monthly stream depletions. Three response functions, one each for the dry, average, and wet conditions, were developed for the three stream reaches.

f. Inspection and analysis of the RGDSS groundwater model results showed that the stream depletions were zero when the net groundwater consumptive use was approximately 60,000 ac-ft/yr. The 2009 version of the response curves were developed under the assumptions that stream depletions were zero when net consumptive use was zero. Upon closer inspection of the model results the peer review committee determined that the response functions should be adjusted for this change. The attached Figure 5 illustrates this concept. This type of mathematical adjustment to data is referred to as an axis shift. As a result the response functions were fit through a curve using an axis shift of 60,000 ac-ft/yr. The response function formula is then

Stream Depletion = Factor x (Net Groundwater Consumptive Use – 60,000)

The term “Factor” is a coefficient that is developed through the calibration process of the response functions. The axis shift concept was developed from analysis of groundwater model results and discussion among the peer review committee. It allows the updated response functions to more accurately simulate the stream depletions predicted by the RGDSS groundwater model.

g. The updated response functions were developed using a weighted average of the response functions generated for the 1988-2009 period. A weighted response function means that the response function in a year with greater stream depletions is given more weight than a year with less stream depletion. The concept of a weighted response function is a refinement that we have added since the 2009 version of the response functions. This refinement allowed a better calibration of the groundwater response functions and increased the accuracy and reliability of the response functions. In addition, the peer review committee felt that we had a greater level of confidence in the groundwater model when it was applied using larger differences in net groundwater consumptive use.

h. The predictive ability of the updated response functions was evaluated by comparing the annual stream depletions estimated using these response functions to the annual stream depletions estimated by the RGDSS groundwater model.

i. The updated response functions, like the original response functions, most accurately matched the RGDSS groundwater model runs with the use of a 20-year lagging of depletions, but with a scaling factor of 0.95 for the dry years, 0.91 for average years, and 1.21 for wet years. The scaling factor means that the values in the response curve generated by the RGDSS groundwater model is multiplied by the scaling factor to adjust the response curve values for use in estimating stream depletions for average, wet, and dry years.

j. Figure 1, Figure 2, and Figure 3 present the comparisons between the stream depletions estimated using the groundwater model and the stream depletions estimated using the response functions.

k. The analysis and calculations used to develop the response functions are contained within the file “Stream Impacts for Sub District 1 -2012 e.xls” *(available at http://www.prinmath.com/subdistrict1/2012).*

4. Use of the Updated Response Functions to Estimate Stream Depletions

a. The Net Groundwater Consumptive Use is the amount of groundwater consumptive use that exceeds the amount of consumptive use that is supplied by the Imported Water Offset. The amount of consumptive use allowed under Imported Water Offset is reduced by the amount of imported water diversions that are consumed by applying that water to surface water only lands.

b. As previously outlined the net groundwater consumptive use was estimated by the RGDSS models for the 1988-2009 period as part of the development of the updated response functions.

c. The Net Groundwater Consumptive Use for 2010 and 2011 was determined from metered groundwater pumping values and measured stream diversions. The 2012 pumping was estimated to be 15,000 ac-ft less than 2012 to account for the ongoing program to fallow irrigated lands and reduce groundwater pumping. The amount of recharge offset credit for 2012 was estimated by Mr. Allen Davey based upon forecasted runoff. Table 1 summarizes the 2010-2012 data and the resulting Net Groundwater Consumptive Use.

d. The projected future stream depletions that would result from groundwater pumping in Subdistrict No. 1 are shown in Table 2 and summarized in Figure 4. The stream depletions shown assume no groundwater pumping after the 2012 plan year.

e. The monthly stream depletions for the 2012 plan year based on the April 1st forecast of stream flows are shown in shown in Table 3.

f. The tables, figures, and supporting calculations to develop the response functions are contained in the EXCEL file “Stream Impacts for Sub District 1 - 2012 e.xls” *(see http://www.prinmath.com/subdistrict1/2012).*

g. In mid-June the NRCS forecasted runoff dropped below the April 1st forecasted runoff. Because the runoff was less than expected, the diversions into the 4 major canals that divert water from the Rio Grande into the closed basin were less than the value predicted in the April 1st forecasted runoff. Therefore, the measured diversions through the end of June were used in conjunction with the July-October forecasted diversions to make a mid-year adjustment to the estimated stream depletions for Subdistrict No. 1. See July 3, 2012 to Steve E. Vandiver from Dick Wolfe “Response to June 28, 2012 Letter Requesting to Increase Replacement Water”.

h. Table 3 presents a comparison between the April 1st and the revised stream depletions for Subdistrict No. 1. The revised stream depletions are referred to as the “July 1” version in Table 3.

Table 1 (April 15 version)
Estimated Net Groundwater Consumptive Use
(units of ac-ft)

	Subdistrict No. 1 Total			Recharge that Offsets Groundwater Consumptive Use					
Year	Irrigation Pumping to Center Pivots	Irrigation Pumping to Flood Irrigation	Groundwater Consumption	Rio Grande Canal	San Luis Valley Irrigation District	Prairie Ditch	San Luis Valley Canal	Total	Net Groundwater Consumptive Use
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2010	304,445	0	252,690	103,926	29,178	12,114	11,966	157,185	95,505
2011	323,761	0	268,722	79,887	9,645	7,592	8,301	105,425	163,297
2012	308,761	0	256,272	77,802	18,176	8,543	8,482	113,003	143,269
Avg	312,322	0	259,228	87,205	19,000	9,417	9,583	125,204	134,023

Explanation of Columns

(1) Calendar Year
(2) Determined from metered groundwater pumping
(3) Determined from metered groundwater pumping
(4) Calculated as 0.83xCol2 + 0.60xCol3
(0.83 and 0.60 are the consumptive use ratios of total pumping associated with sprinkler and flood irrigation practices, respectively)
(5) - (8) Determined by Allen Davey from analysis of historic diversions and recharge decrees
(W-3979, W-3980, 96CW0045, and 96CW0046)
(9) Calculated as Col5 + Col6 + Col7 + Col8
(10) Calculated as Col4 - Col9

Table 2 (April 15 version)
Estimated Historical and Projected Stream Depletions from Groundwater Pumping in Subdistrict No. 1
(units of ac-ft)

			Annual Stream Depletions (May-Apr) [a]			
Year	Rio Grande at Del Norte Stream Gage (Jan-Dec)	Net Groundwater Consumptive Use (Jan-Dec)	Rio Grande - Del Norte to Excelsior Ditch Headgate	Rio Grande - Excelsior Ditch Headgate to Chicago Ditch Headgate	Rio Grande - Chicago Ditch Headgate to Stateline	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1988	434,863	164,928	-446	271	319	144
1989	494,094	157,836	693	373	406	1,473
1990	525,955	79,388	565	324	346	1,235
1991	607,459	40,716	101	215	236	552
1992	487,150	60,384	191	183	198	572
1993	655,612	-25,314	-1,407	222	252	-932
1994	540,065	87,967	-1,554	206	253	-1,095
1995	831,422	-70,675	-3,660	265	329	-3,065
1996	397,712	184,625	-2,342	210	279	-1,852
1997	948,238	-7,006	-2,585	213	280	-2,092
1998	578,359	114,106	-1,979	237	305	-1,437
1999	918,902	-50,483	-3,733	282	354	-3,097
2000	391,249	210,234	-1,919	227	300	-1,392
2001	725,382	64,168	-592	202	243	-147
2002	154,156	318,998	3,336	270	249	3,855
2003	319,207	231,007	6,748	298	241	7,287
2004	527,758	124,917	7,565	368	301	8,234
2005	793,751	69,391	6,552	359	268	7,179
2006	570,183	117,920	6,424	377	315	7,116
2007	710,158	19,826	4,846	275	195	5,316
2008	710,146	47,930	3,995	189	135	4,320
2009	593,074	-2,896	2,222	216	178	2,617
2010	539,365	95,505	2,056	233	211	2,500
2011	502,700	163,297	3,323	364	344	4,030
2012	465,000	143,269	3,852	440	413	4,706
2013		0	3,288	359	327	3,974
2014		0	3,008	288	266	3,562
2015		0	2,927	255	222	3,404
2016		0	2,646	231	196	3,073
2017		0	2,594	208	170	2,972
2018		0	2,462	189	151	2,802
2019		0	2,405	169	129	2,703
2020		0	2,068	151	118	2,337
2021		0	1,795	129	100	2,024
2022		0	1,189	104	85	1,377
2023		0	825	84	72	980
2024		0	679	71	61	811
2025		0	599	59	51	709
2026		0	515	54	46	615
2027		0	599	57	47	702
2028		0	643	55	45	742
2029		0	668	47	36	752
2030		0	473	30	23	527

Table 2 (April 15 version)

Estimated Historical and Projected Stream Depletions from Groundwater Pumping in Subdistrict No. 1

(units of ac-ft)

			Annual Stream Depletions (May-Apr) [a]			
Year	Rio Grande at Del Norte Stream Gage (Jan-Dec)	Net Groundwater Consumptive Use (Jan-Dec)	Rio Grande - Del Norte to Excelsior Ditch Headgate	Rio Grande - Excelsior Ditch Headgate to Chicago Ditch Headgate	Rio Grande - Chicago Ditch Headgate to Stateline	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)
2031		0	171	9	7	187
2032		0	0	0	0	0
2033		0	0	0	0	0
2034		0	0	0	0	0
2035		0	0	0	0	0
2036		0	0	0	0	0
2037		0	0	0	0	0
2038		0	0	0	0	0
2039		0	0	0	0	0
2040		0	0	0	0	0
Avg	617,267	49,987	1,059	158	153	1,370
93-12 Avg	593,622	91,839	1,557	273	272	2,102

a) Estimated stream depletions shown in this table are greater than the stream depletions that potentially cause injury to surface water rights.

Explanation of Columns

- (1) Year (see column headers for Calendar (Jan-Dec) or Plan (May-Apr) year designations)
- (2) Measured total streamflow at the Gage for 1950-2011. 2012 value estimated.
- (3) Amount of Groundwater Consumption in Sub-District No. 1 that is greater than the amount of consumptive use that is offset by the recharge decrees as computed from input to the Groundwater Model for 1970-2009. 2010-2011 estimated from measured diversions and metered pumping records. 2012 estimated to be the same as 2011.
- (4) Stream depletion in the reach of the Rio Grande from the Del Norte gage to the Excelsior Ditch
- (5) Stream depletion in the reach of the Rio Grande from the Excelsior Ditch headgate to the Chica
- (6) Stream depletion in the reach of the Rio Grande from the Chicago Ditch headgate to the Statel
- (7) Calculated as Col4 + Col5 + Col6 + Col7

Table 3 (April 15 Version)

Subdistrict No. 1 Monthly Stream Replacement Obligation for 2012 Plan Year

(units of ac-ft)

	Sub-District No. 1 Total												
	2012								2013				
Reach of Rio Grande	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Rio Grande at Del Norte Gage to Excelsior Canal Headgate	275	305	349	376	353	345	302	323	328	286	316	295	3,852
Excelsior Headgate to Chicago Ditch Headgate	48	61	-5	-10	-1	29	61	57	49	42	63	46	440
Chicago Ditch Headgate to Stateline	29	2	2	4	17	49	57	68	59	47	47	32	413
Total	351	368	347	369	369	424	420	448	436	376	427	372	4,706

143,269 <--- Net Groundwater Consumptive Use in 2012 (ac-ft)
34,255 <--- Post Plan Stream Depletions 2013-2031 (ac-ft)

Table 3 (July 1 Version)

Subdistrict No. 1 Monthly Stream Replacement Obligation for 2012 Plan Year

(units of ac-ft)

	Sub-District No. 1 Total												
	2012								2013				
Reach of Rio Grande	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Rio Grande at Del Norte Gage to Excelsior Canal Headgate	278	317	371	409	386	375	325	347	350	304	334	311	4,107
Excelsior Headgate to Chicago Ditch Headgate	50	66	-8	-13	-2	30	68	62	52	45	70	50	470
Chicago Ditch Headgate to Stateline	28	0	2	1	18	57	63	74	65	52	51	35	446
Total	356	383	365	398	401	461	456	483	467	401	456	396	5,023

164,142 <--- Net Groundwater Consumptive Use in 2012 (ac-ft)
36,211 <--- Post Plan Stream Depletions 2013-2031 (ac-ft)

Table 3 Difference (July 1 version-April 15 version)

Subdistrict No. 1 Monthly Stream Replacement Obligation for 2012 Plan Year

(units of ac-ft)

	Sub-District No. 1 Total												
	2012								2013				
Reach of Rio Grande	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Rio Grande at Del Norte Gage to Excelsior Canal Headgate	3	13	22	34	32	30	23	24	22	18	18	16	254
Excelsior Headgate to Chicago Ditch Headgate	3	5	-3	-3	-1	1	7	4	3	3	7	4	29
Chicago Ditch Headgate to Stateline	0	-2	0	-3	1	7	6	6	6	5	4	3	33
Total	5	15	18	28	33	38	36	35	30	25	29	24	316

20,874 <--- Net Groundwater Consumptive Use in 2012 (ac-ft)
1,957 <--- Post Plan Stream Depletions 2013-2031 (ac-ft)

Figure 1

Response Function vs. Groundwater Model Estimated Stream Depletions

(starting with 1970 Net Groundwater Consumptive Use)

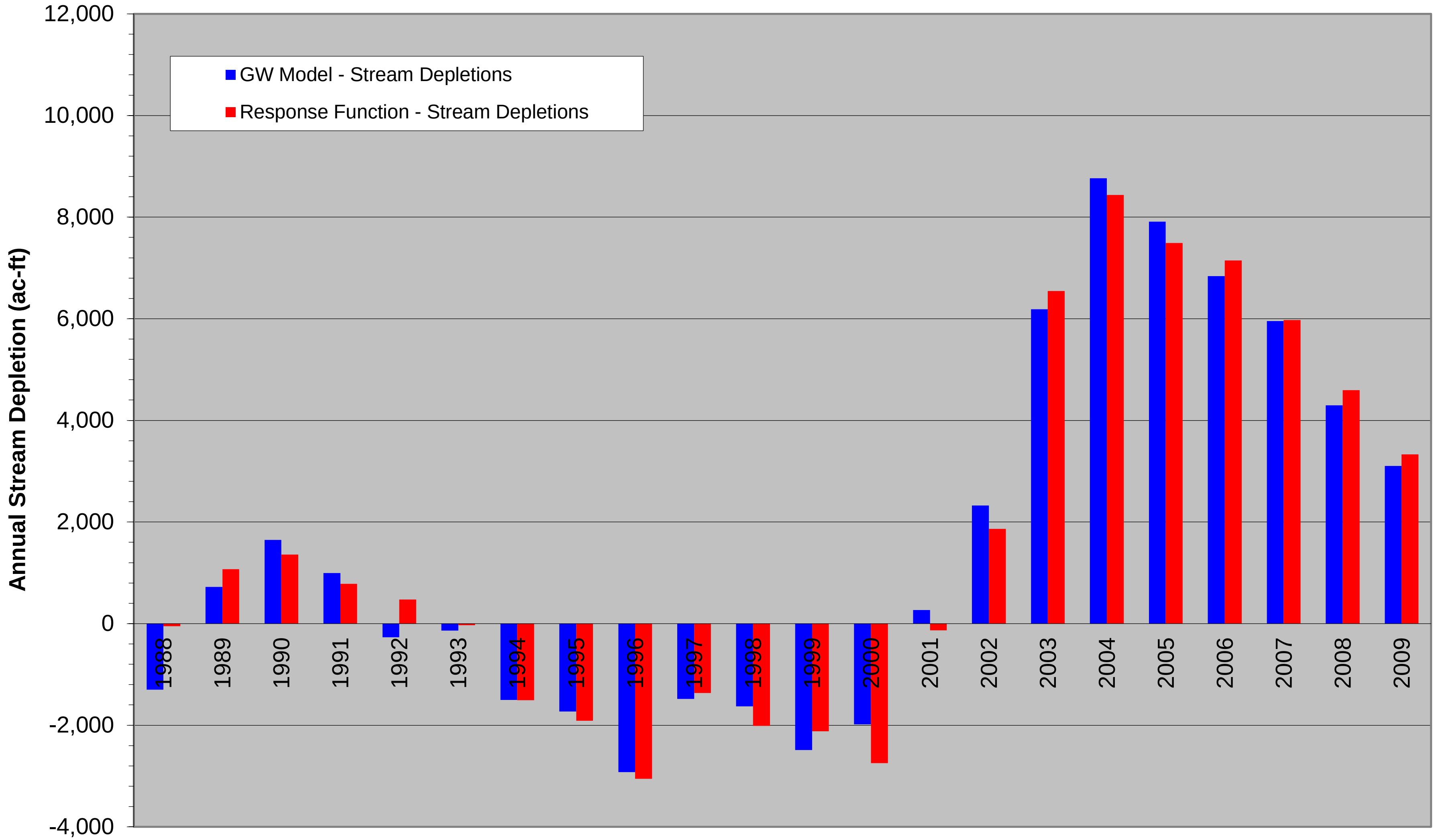


Figure 2

Response Function vs. Groundwater Model Estimated Cumulative Stream Depletions

(starting with 1988 Net Groundwater Consumptive Use)

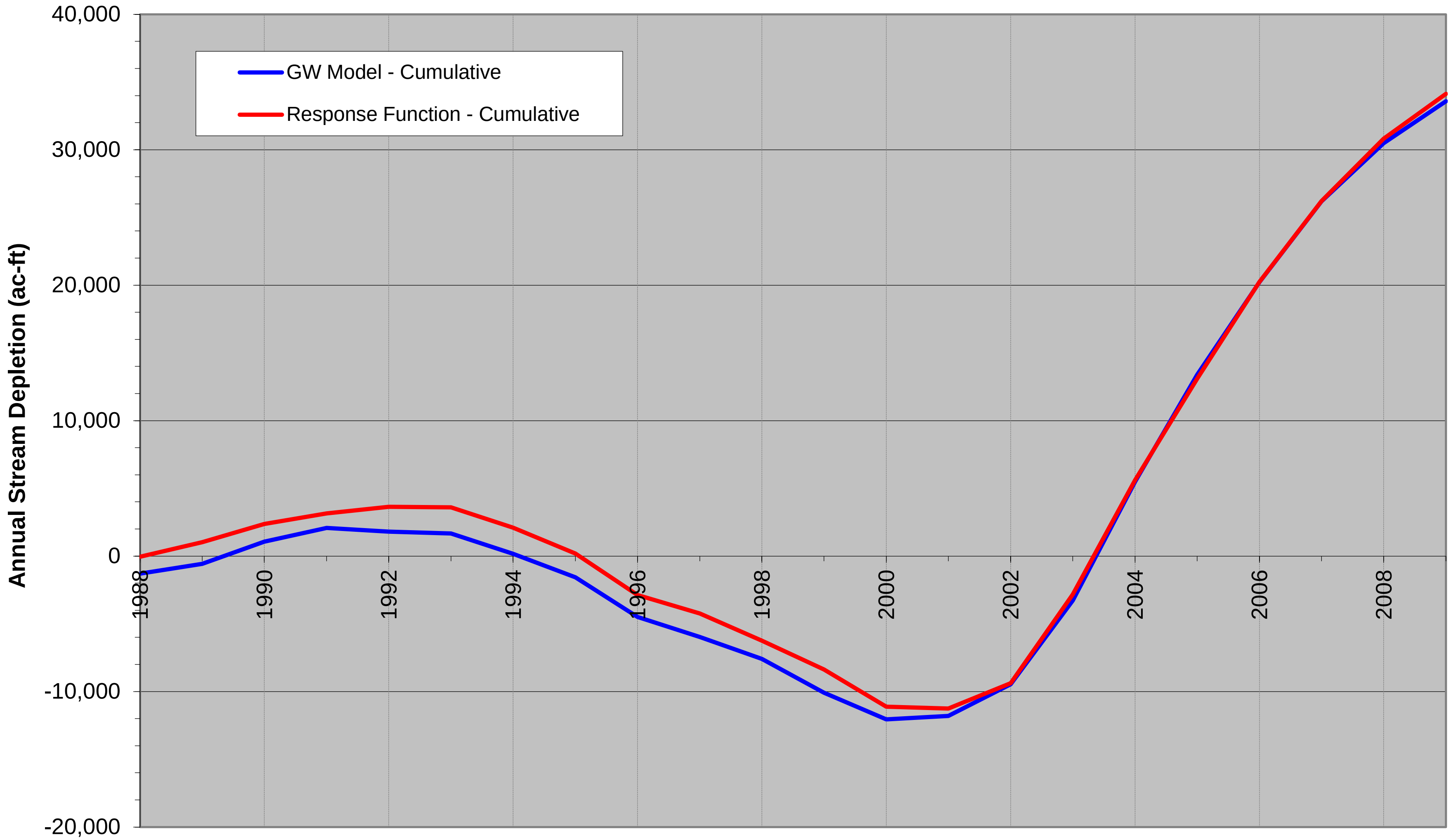


Figure 3
Response Function vs. Groundwater Model Estimated Stream Depletions

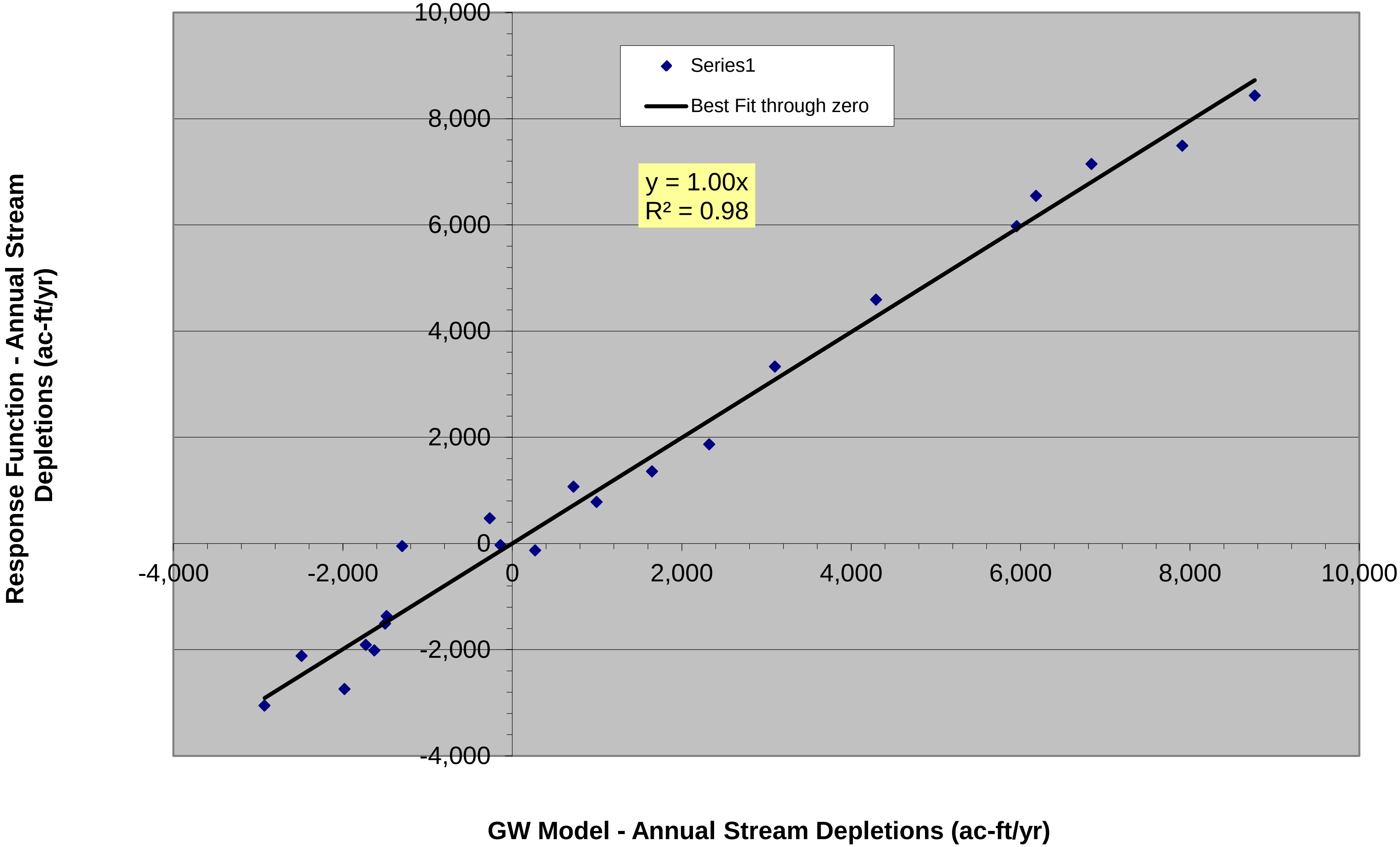
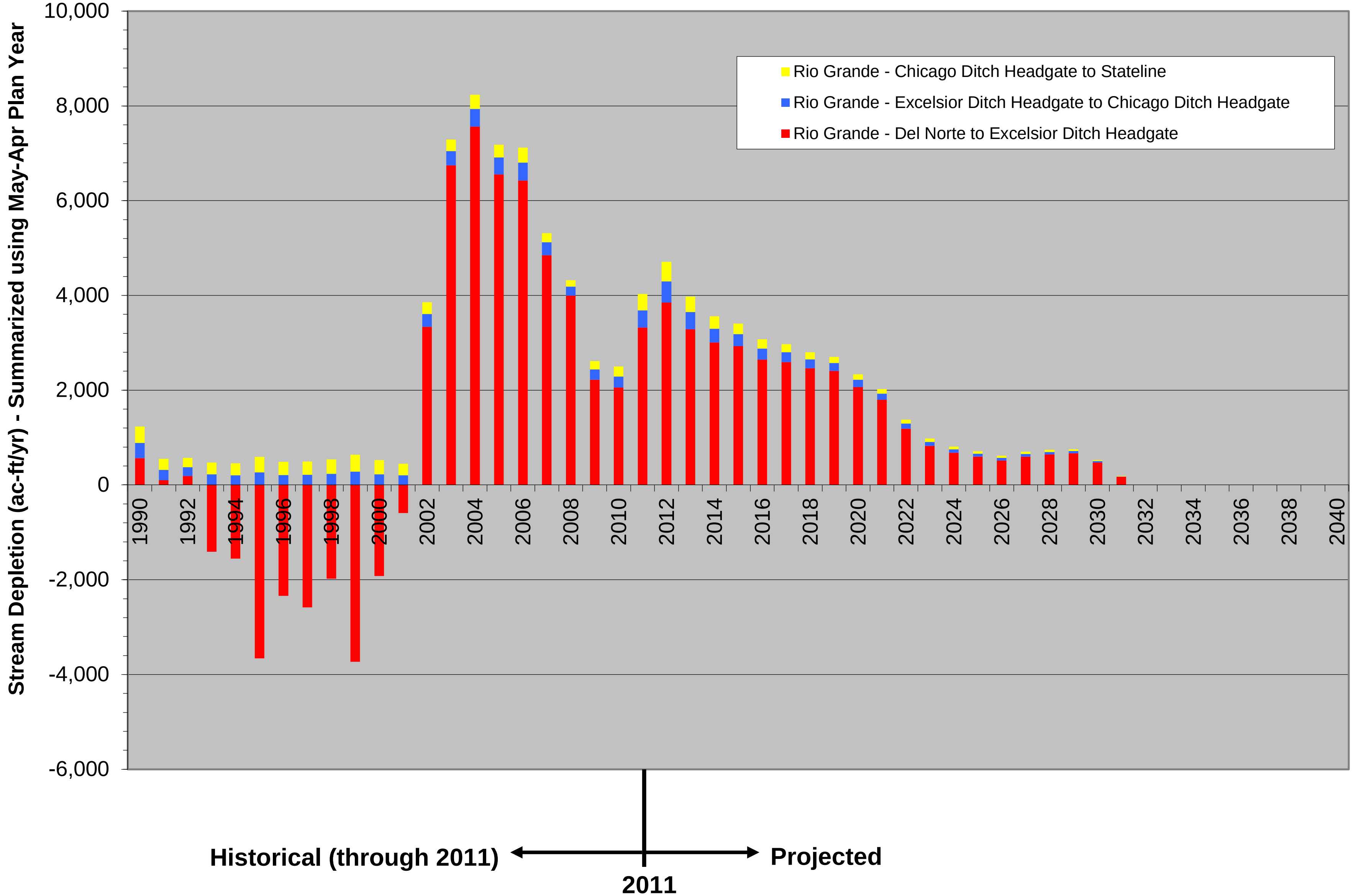


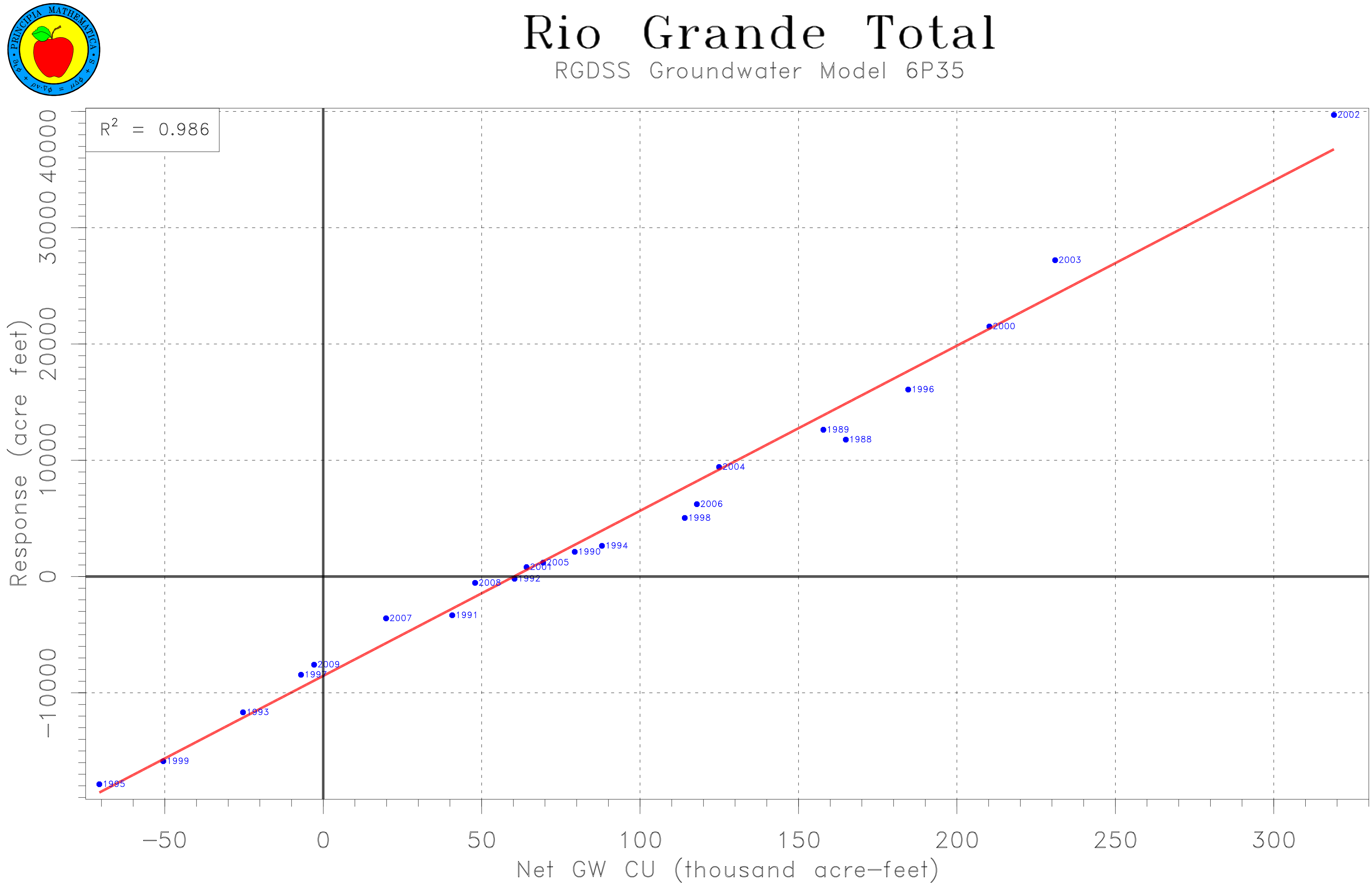
Figure 4 (April 15, 2012 version)

Estimated Historical and Projected Stream Depletions from Groundwater Pumping in Sub-District No. 1 (Plan Year)



Stream Impacts for Sub District 1 - 2012e (April 15).xlsx, Fig 4, 7/20/2012

Figure 5



Rio Grande Total
RGDSS Groundwater Model 6P35
R2 = 0.986
Response (acre feet)
Net GW CU (thousand acre-feet)
2002
2003
2000
1996
1989
1988
2004
2006
1998
1994
1990
2005
2001
2008
1992
1991
2007
2009
1997
1993
1999
1995

ATTACHMENT 2

Expert Opinions– Concerning the Office of the State Engineer's Approval of the
2012 Annual Replacement Plan for Special Improvement District No. 1
of the Rio Grande Water Conservation District

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July 20, 2012

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Subject: Expert Opinions – Concerning the Office of the State Engineer's Approval of the 2012 Annual Replacement Plan for Special Improvement District No. 1 of the Rio Grande Water Conservation District

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This letter contains my engineering opinions on behalf of the Rio Grande Water Users Association ("RGWUA") in regards to the State Engineer's Approval of the 2012 Annual Replacement Plan for Special Improvement District No. 1 of the Rio Grande Water Conservation District. For this case, I was asked to estimate the stream depletions associated with the groundwater pumping in Subdistrict No. 1 and to address improvements to the Rio Grande Decision Support System (RGDSS) models that have been made since the fall of 2009.

Background

I began working for the RGWUA in 1995. The RGWUA is an organization of mutual ditch and reservoir companies, individual ditch associations, and the San Luis Valley Irrigation District, whose members own the majority of the pre-compact water rights that divert from the Rio Grande. The diversions from the Rio Grande by the RGWUA members water rights average approximately 500,000 ac-ft/yr for the irrigation of approximately 300,000 acres.

I have worked on behalf of the RGWUA in the development of the Rio Grande Decision Support System (RGDSS) since 1999 and became a member of the Technical Review Committee (a.k.a. Peer Review Team) when it was formed in 2003. The RGWUA continues to work with the State of Colorado and other water users to develop and improve this decision support system, which assists the RGWUA and other water users in developing sustainable water use practices. Sustainable water use practices are essential for the future of irrigated agriculture in the San Luis Valley. The RGDSS is applied in this case to estimate the stream

Attachment 2

depletions associated with groundwater pumping in Subdistrict No. 1 and contract wells covered by the Annual Replacement Plan.

In 2006 I testified as an expert witness in Case No. 2004CW24 "Concerning the Matter of the Rules Governing New Withdrawals of Ground Water in Water Division 3 Affecting the Rate or Direction of Movement of Water in the Confined Aquifer System". I also testified as an expert witness in Case No. 2007CW52 – Concerning the Office of the State Engineer's Approval of the Plan of Water Management for Special Improvement District No. 1 of the Rio Grande Water Conservation District" in 2009. I have been involved in approximately 20 other water right change application on behalf of the RGWUA.

Expert Opinions

The following are my expert opinions and the basis for those opinions:

Opinion 1: The RGDSS groundwater model version 6P35 is an improvement over the previous model version and has resulted in the model having an increased reliability and accuracy in estimating stream depletions associated with pumping from Subdistrict No. 1.

Basis for Opinions:

1. Information listed in Exhibit A.
2. The model calibration results demonstrate that the model more closely simulates the historical groundwater levels and the historical gains and losses in the streams.

Opinion 2: The RGDSS groundwater model version 6P35 is the appropriate tool to generate response functions to estimate the stream depletions in the Subdistrict No. 1 Plan of Water Management.

Basis for Opinions:

1. Information listed in Exhibit A.
2. The use of groundwater models to generate response functions is a reliable and scientifically accepted engineering methodology.
3. This methodology has been used in this case and elsewhere in Colorado. For example, in the Arkansas River Basin a groundwater model was utilized to generate response functions to estimate the impact on streamflows from groundwater pumping.
4. The RGDSS groundwater model incorporates the complex geohydrologic properties of the San Luis Valley and these properties are then incorporated into the response functions that are generated using the RGDSS model.

Opinion 3: **The application of response functions derived from the RGDSS groundwater model version 6P35 are a reliable method to estimate stream depletions for wells covered by the Subdistrict No. 1 Annual Replacement Plan.**

Basis for Opinions:

1. Information listed in Exhibit A.
2. The use of response functions is a reliable and scientifically accepted engineering methodology to estimate stream depletions. This methodology is commonly used by engineers to estimate stream depletions in water court cases and has been accepted by this Court in this case and other Water Courts throughout the State of Colorado.
3. The stream depletions from Net Groundwater Consumption in Subdistrict No. 1 determined from the response functions, match very closely to the stream depletions estimated using the RGDSS groundwater model version 6P35. The difference between the two estimates is within the range of uncertainty of the groundwater model.
4. The response functions were updated since the values presented at the October 2009 trial because of improved data and other efforts that resulted in improvements to the RGDSS groundwater model contained in version 6P35.

Opinion 4: **The use of a dry, average, and wet year response functions continue to reliably account for the variation in location, time, and amount of stream depletions under different hydrologic conditions.**

Basis for Opinions:

1. Information listed in Exhibit A.
2. The relative amount and distribution of groundwater recharge within Subdistrict No. 1 varies between dry, average, and wet years. For example, in a dry year ditches with more junior water rights will have relatively less diversions than ditches with senior water rights. This results in a change in the pattern of stream depletions. The use of three different response functions for dry, average, and wet years continues to properly account for this variability.
3. The ranges that define a dry, average, and wet year changed in version 6P35 as would be expected because of model refinements and enhancements.

Opinion 5: **Different response functions are still needed for the 3 key administrative reaches of the Rio Grande, in order to account for the differences in timing of stream depletions from Net Groundwater Consumption in Subdistrict No. 1.**

Basis for Opinions:

1. Information listed in Exhibit A.
2. The 3 key administrative reaches of the Rio Grande remain the same as those that were previously selected in 2009 after consultation with both the current and the previous two Division Engineers to identify locations where the Rio Grande is occasionally dried up by diversions:
    a. Rio Grande – Del Norte stream gage to Excelsior Canal headgate
    b. Rio Grande – Excelsior Canal Headgate to the Chicago Canal headgate
    c. Rio Grande – Chicago Canal Headgate to the Lobatos stateline stream gage
3. The distance from Subdistrict No. 1 to a stream and the location of the recharge is the primary factor in estimating the timing of stream depletions and therefore a different response function is used for each of the three stream reaches affected by pumping in Subdistrict No. 1.

Opinion 6: **The use of the revised response functions based on version 6P35 of RGDSS groundwater model to estimate stream depletions from Net Groundwater Consumptive Use provides reliable estimates of the time, place, and amount of depletions to the stream. These stream depletion estimates will enable the State Engineer to administer the Plan of Water Management for Subdistrict No. 1 to prevent injury to senior surface rights.**

Basis for Opinions:

1. Information listed in Exhibit A.
2. Opinions 1 through 5 above.
3. The RGDSS groundwater model will be utilized to periodically update the response functions as described in Subdistrict's No. 1 Plan of Water Management and this Court's decree.

Summary

The documents and information I considered are shown in Exhibit A.

Slattery & Hendrix Engineering LLC

James E. Slattery

James E. Slattery, P.E.

Exhibit A
Documents and Information Considered

1. Memorandum entitled “Development of Response Functions to Estimate Stream Depletions from Groundwater Pumping in Subdistrict No. 1”, prepared by James E. Slattery dated July 20, 2012, and the supporting engineering analysis conducted to prepare memorandum.
2. Expert Opinions prepared for these proceedings by Mr. Allen Davey, Dr. Willem Schreüder, Mr. Eric Harmon, Dr. Charles Brendecke, and Mr. James Heath.
3. Report entitled “Using the RGDSS Groundwater Model to Compute Response Functions”, prepared by Dr. Willem Schreüder dated June 26, 2009.
4. The RGDSS models, databases, documentation, task memoranda and model inputs and outputs. Also see Heath, J.R. RGDSS “Phase 6 Ground Water Model Enhancements”, May 1, 2012.
5. Documents and supporting information submitted by Subdistrict No. 1 for the 2012 Annual Replacement Plan.
6. My educational training and my 26 years of professional engineering experience, including the information gained during my 14 years of work in the San Luis Valley and my participation in the RGDSS Technical Review and Peer Review committees. Knowledge and experience of using RGDSS models and supporting documentation.