APPENDIX M
WATER QUALITY TECHNICAL REPORT

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Appendix M Addendum:

Water Quality Technical Report

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This addendum to Appendix M includes the revised regression analyses performed by the USGS member of the Water Quality Technical Team. While there is some repetition of narrative to provide context, tables that are skipped in the numbering system are the same as those already included in Chapter 4 of Appendix M and are not repeated here. New graphs displaying updated model output are shown at the end of this section.

4.0 Development of Upper Rio Grande Basin surface water quality models

4.1 Introduction

In river systems, including the Rio Grande, the boundary conditions that govern water quality include both environmental and anthropogenic factors. For example, environmental factors such as climate, air quality, geology, and biology can affect the water quality in a river system. Anthropogenic factors such as point source and non-point source inputs of pollution also influence the water quality of a system. To explain the observed variation, numerical models can be used to simulate natural conditions and to predict how water quality variables in a given system will respond to changes in boundary conditions.

Spatial variability of water quality is an important consideration for numeric models. Throughout a given river system, a change in location may result in a change in boundary conditions. For example, location within a river system can determine the amount of water entering the stream channel. The amount of water entering a stream from direct runoff in response to a precipitation event or by ground water inflow, determines the water budget of the system, and in turn affects the quality of surface water. Differences in physical basin characteristics such as the angle of the channel slope or the thickness or composition of surrounding bedrock or surficial deposits can cause a change in erosion-sediment yield. As a result, different locations within the Project Area can have environmental characteristics that may affect surface water quality differently from one location to the next.

Dam releases and water storage can influence water quality in a system, regardless of whether climate, air quality, geology, and biology are held constant. Dams within the Project Area, which are used to control the release and storage of surface water within the system, add to the inherent stream discharge variability. The annual average of mean daily discharge at locations throughout the project area illustrates the spatial variability of stream discharge. At a given stream gage, mean annual stream flow can vary from year to year, which could affect water quality variables. Short-term and seasonal variations of water quality resulting from changes in boundary conditions also affect water quality.

To estimate the response of selected water quality variables to spatial and temporal changes in environmental conditions, numeric, models were developed at locations distributed throughout the project area (Map M-1). To develop these models, historic data from 1975 to 2001 were loaded to a project database from federal and state water quality and climate data sources. Data in the project database provided an efficient and accessible method for storing, filtering, and analyzing water quality data.

4.2 Water Quality Database Development

Historical surface water quality and stream discharge data were collected from stream gages within the project area, including tributary streams. Data were obtained from the U.S. Geological

Survey (USGS), State of New Mexico, U.S. Environmental Protection Agency (EPA), and U.S. International Boundary Water Commission (IBWC). Climate data including daily air temperature and precipitation records were obtained from National Oceanographic and Atmospheric Administration (NOAA) sources. Data were obtained for the main stem channel and tributary streams from the headwaters of the Rio Grande in south-central Colorado to Fort Quitman, Texas. Time-series data was variable for each study location, and ranged from January 1, 1975 to September 30, 2001. The database contains information for more than 1,500 water quality collection locations in the project area. Over 38,000 records of water quality data are stored in the database for over 80 physical and chemical water quality variables. In addition, 797,756 mean daily stream discharge data were loaded for selected gages throughout the project area.

4.2.1 Database Tables

Data loaded from federal and state systems were stored in tables containing individual records for each sampling date within the 1975 to 2001 time series. To ensure that data were organized appropriately, the database was designed to store data in tables that are normalized at a reasonable level. For this project, we use the term "normalize" to refer to the elimination of redundant or repetitive data. In addition, the term applies to the organization of related data stored in separate tables that can be tied together with other data sets by a logical matching field or characteristic. For example, water quality and stream discharge data are stored in separate tables. Each dataset is, in turn, related by the date and location where the measurements were collected. By relating each table to one another by date and location, the database is able to organize data in separate tables, while enabling information from these tables to be compared with one another.

4.2.2 Database Queries

The second stage of development was to create a series of queries, or requests for the database to gather and display information from a defined set of data. Queries of all data were selected by the user to be sorted and filtered. In addition, queries can combine information from one or more separate tables. For example, to examine the relationship between stream discharge and water temperature or any other combination of variables, a query could be designed to gather the necessary information from the two individual tables that store water quality data and stream discharge data separately.

4.3 Considerations for Model Input Parameters

Air temperature data were used as an input parameter for the models used to estimate each alternative's effects on surface water quality. Data were obtained from stations that are part of the National Oceanic and Atmospheric Administration (NOAA) and National Weather Service (NWS) Co-operative Observer's Program (Co-op). Given the spatial distribution of the Co-op stations throughout the project area, not all locations are close to USGS stream gages selected for model development. As a result, data were applied from a neighboring Co-op station for stream gages that did not share a location with a Co-op station (**Table M-4.1**).

Table M-4.1. Historical NOAA climatic data

USGS Station ID	USGS Station Name	NOAA Co-op ID	NOAA Co-op Gage Name	Begin	End
8251500	RIO GRANDE NEAR LOBATOS, CO	055322-5	Manassa	1975	2003
8276500	RIO GRANDE BLW TAOS JUNCTION BRIDGE NR TAOS, NM	055322-5	Manassa	1975	2003
8286500	RIO CHAMA ABOVE ABIQUIU RE, NM	290041-2	Abiquiu Dam	1975	2003
8287000	RIO CHAMA BL ABIQUIU DAM, NM	290041-2	Abiquiu Dam	1975	2003
8290000	RIO CHAMA NEAR CHAMITA, NM	290041-2	Abiquiu Dam	1975	2003
8313000	RIO GRANDE AT OTOWI BRIDGE, NM	290041-2	Abiquiu Dam	1975	2003
8319000	RIO GRANDE AT SAN FELIPE, NM	290234-5	Albuquerque Intl. Airport	1975	2003
8329000	JEMEZ RIVER BELOW JEMEZ CANYON DAM, NM	290234-5	Albuquerque Intl. Airport	1975	2003
8330000	RIO GRANDE AT ALBUQUERQUE, NM	290234-5	Albuquerque Intl. Airport	1975	2003
8332010	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	298387-5	Socorro	1975	2003
8354800	CONVEYANCE CHANNEL AT SAN ACACIA, NM	298387-5	Socorro	1975	2003
8354900	FLOODWAY AT SAN ACACIA, NM	298387-5	Socorro	1975	2003
8358300	RIO GRANDE CONVEYANCE CHANNEL AT SAN MARCIAL, NM	291138-5	Bosque Del Apache	1975	2003
8358400	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	291138-5	Bosque Del Apache	1975	2003
8361000	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	292848-5	Elephant Butte Dam	1975	2003
8363500	RIO GRANDE AT LEASBURG DAM, NM	412797-5	El Paso Intl. Airport	1975	2003
8364000	RIO GRANDE AT EL PASO, TX	412797-5	El Paso Intl. Airport	1975	2003
8370500	RIO GRANDE AT FORT QUITMAN, TX	413266-5	Fort Hancock	1989	2003

4.4 Methodology

The Water Quality Team utilized linear regression models developed for selected water quality variables at locations evenly distributed throughout the Project Area to analyze potential impacts to water quality from different water management scenarios. Regression is a statistical estimation theory used to estimate the value of a variable "*Y*" for a corresponding input of "*X*". This approach uses a numerical equation to represent the statistical relationship between the input variables and the estimated result. Given the need to estimate the outcome of a particular set of conditions, regression is commonly used by federal agencies to simulate surface water quality for planning and management purposes.

Water quality, climate, and discharge data were queried from tables to create a refined dataset for model development. Given data availability (see Section 3.1.1), only a select number of gages were used to develop surface water quality models (**Table M-4.3).** Stream gages selected for model development are distributed throughout the project area to ensure that each stream reach would be represented during the modeling process.

Table M-4.3. Stream Gages Selected for Surface Water Quality Model Development

(Gages are Listed According to Stream Section, Stream Name, and Corresponding USGS Stream Gage Number.)

Section	Station Name	Gage No.
Chama	RIO CHAMA NEAR CHAMITA, NM	8290000
Chama	RIO GRANDE AT OTOWI BRIDGE, NM	8313000
Central	RIO GRANDE AT ALBUQUERQUE, NM	8330000
Central	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	8332010
San Acacia	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	8354900
San Acacia	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	8358400
Southern	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	8361000

4.4.1 Assumptions

The following assumptions form the framework used for developing surface water quality models described in this document:

- Mean daily stream discharge, as reported by the U.S. Geological Survey, was used to develop the historical relationship between water quality variables and discharge.
- All boundary conditions except for stream discharge and air temperature were assumed constant for model development. This assumption can both overestimate and underestimate a given water quality variable because the mean daily discharge could be above or below the instantaneous conditions during which the water quality variable was sampled.
- Output data from URGWOM were used as input data for stream discharge for estimating potential effects on water quality for the 40-year sequence.
- Input data for air temperature were assigned using the historical time-series reconstruction developed for URGWOM (SSP&A 2002).

4.4.2 Regression Model Development

General linear models (GLM) were used to build linear equations to describe the effects of alternatives on surface water quality. For each linear model, correlation for a given dependent variable (e.g. water temperature) and several independent variables (e.g. discharge, air temperature, reservoir storage) was measured. The significance of regression models variables were assessed by only including variables than had p-values at a level of alpha < 0.05.

Output for each model included a numerical equation, corresponding adjusted R-square statistic, a standard error statistic S, and a P-value statistic for each model variable. For each regression a saved dataset for model residuals, plus all the variables in a data file for each GLM were stored. Based on these results, individual model equations were compiled into a database table according to stream gage and water quality constituent. **Table M-4.4** displays the numerical equations (models) developed for the alternatives analysis.

Numerical models developed by the Water Quality Team are listed according to each stream gage and water quality constituent where:

- Mean air temperature = air temperature (°C)
- Corrected air temperature = air temperature (°C) from corrected gage
- Galisteo Dam Gage = mean daily stream discharge (cfs) at Galisteo Creek
- Embudo Gage = mean daily stream discharge (cfs) at Embudo
- Alameda Gage = mean daily stream discharge at (cfs) North Floodway
- Rio Puerco Gage = mean daily stream discharge at (cfs) Rio Puerco
- Rio Chama Inflow = Abiquiu to Chamita Inflow (cfs) (Ojo Caliente Gage)
- Rio Chama at Chamita Gage = mean daily stream discharge at (cfs) Chamita
- Bernardo Gage = mean daily stream discharge at (cfs) Bernardo Floodway
- San Acacia Conveyance Gage = mean daily discharge at (cfs) San Acacia Conveyance
- Abiquiu Reservoir Outflow = mean daily discharge at (cfs) Abiquiu Dam
- Cochiti Reservoir Outflow = mean daily discharge at (cfs) Cochiti Dam
- Gallisteo Reservoir Outflow = mean daily discharge at (cfs) Galisteo Creek below Galisteo Reservoir
- Jemez Reservoir Outflow = mean daily discharge at (cfs) Jemez River below Jemez Canyon Dam
- Precipitation = mean daily precipitation (cm)
- Heron Storage = storage (acre feet) in Heron Reservoir
- El Vado Storage = storage (acre feet) in El Vado Reservoir
- Abiquiu Storage = storage (acre feet) in El Vado Reservoir
- Jemez Storage = storage (acre feet) in Jemez Reservoir
- Elephant Butte Storage = storage (acre feet) in Elephant Butte Reservoir

4.5 Model Performance

Of the eighteen (18) gages selected for predictive water quality model development, only seven (7) gages for selected water quality constituents were included in the alternatives analysis process (**Table M-4.5**). Selected gages used to evaluate alternatives based on data availability (Section #.3.1.1). The Northern Section was not selected, as conditions would not be affected by each of the seven alternatives. The water quality constituents dissolved oxygen (DO), water temperature, and total dissolved solids (TDS) are marked for each gage where the individual constituent was used as part of the Alternatives evaluation. Blank boxes indicate that a given water quality was not used to evaluate Alternatives for a given gage.

Table M-4.5. Gages selected to evaluate alternatives

Section	Station Name	Station Name	Gage No.	DO	Water Temperature	TDS
Chama	Rio Chama near Chamita, NM	Chamita	8290000		x	x
Chama	Rio Grande At Otowi Bridge, NM	Otowi	8313000		x	x
Central	Rio Grande At Albuquerque, NM	Albuquerque	8330000		x	x
Central	Rio Grande Floodway Near Bernardo, NM	Bernardo	8332010		x	x
San Acacia	Rio Grande Floodway At San Acacia, NM	San Acacia	8354900		x	x
San Acacia	Rio Grande Floodway At San Marcial, NM	San Marcial	8358400	x	x	x
Elephant Butte-Caballo	Rio Grande Below Elephant Butte Dam, NM	Elephant Butte Dam	8361000	x	x	

Based on data availability and r-square values (Ramsey and Schafer 1997) for each model (**Tables M-4.6a – M-4.6c**), these seven locations exhibit the highest correlation between the dependent and independent variables used to develop the models. P-values (Ramsey and Schafer 1997) for each model input parameter were used to quantify the significance of individual model input parameters. All independent variables used for alternatives analysis are significant at alpha<0.05.

Model predicted output was compared to historical data and a 1:1 line to give a visual feeling for the model fit and the additional variability that would partially be explained by the daily varaition in dissolved oxygen and water temperature. As a preliminary evaluation of model performance, this comparison illustrated whether or not the regression models for the individual stations were over- or under-estimating (**Figures M-4.1 – 4.21**). These graphs provide a comparison of the historical data were compared with modeled data to evaluate the predictive capabilities of the 21 regression models. Relationship between historic water quality constituents and model predicted output for all seven USGS streamflow gages on the Rio Grande and Rio Chama are illustrated in the following series of figures.

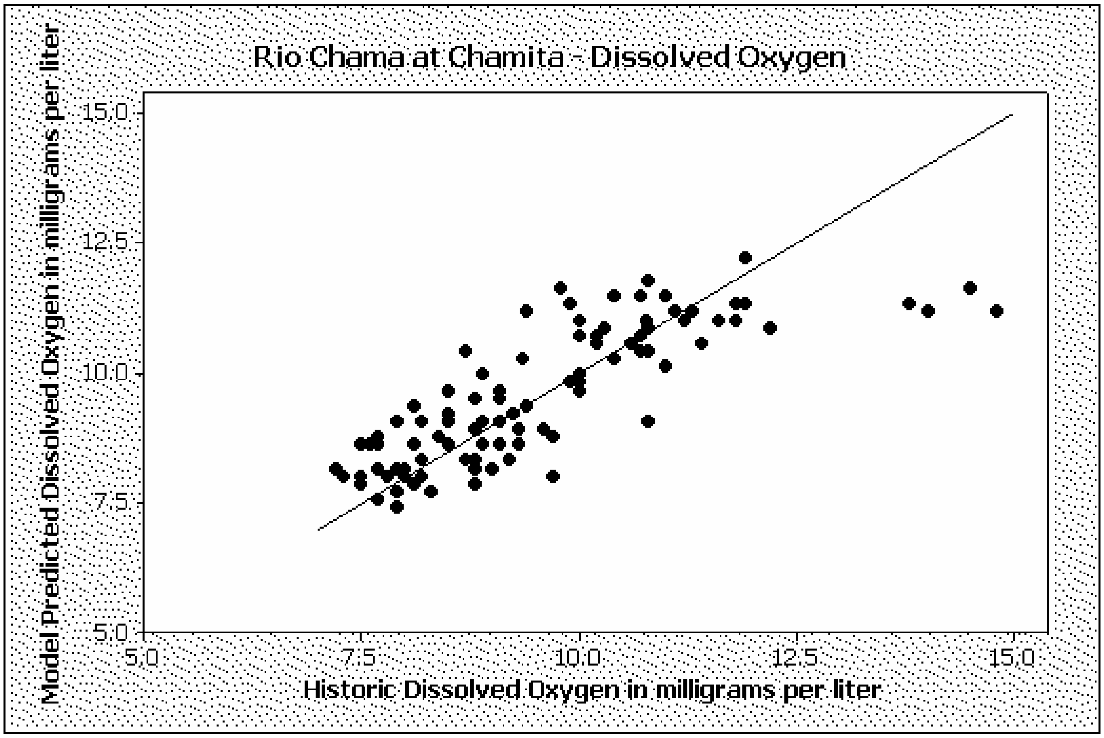
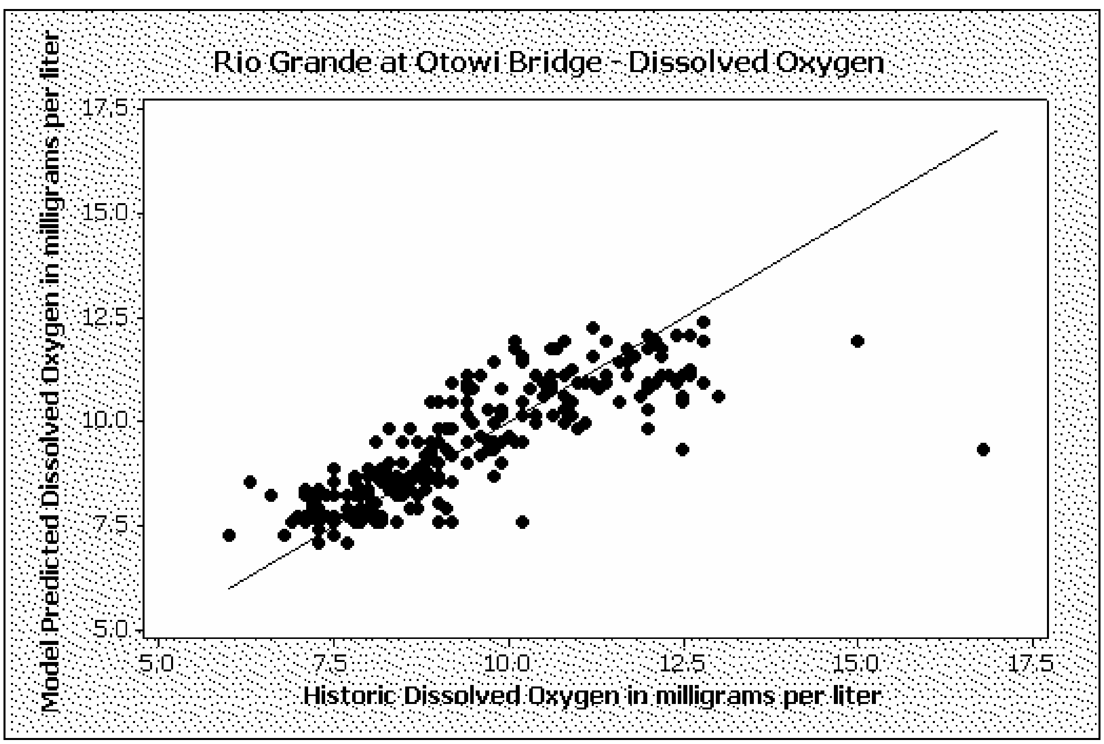


Figure M-4.1



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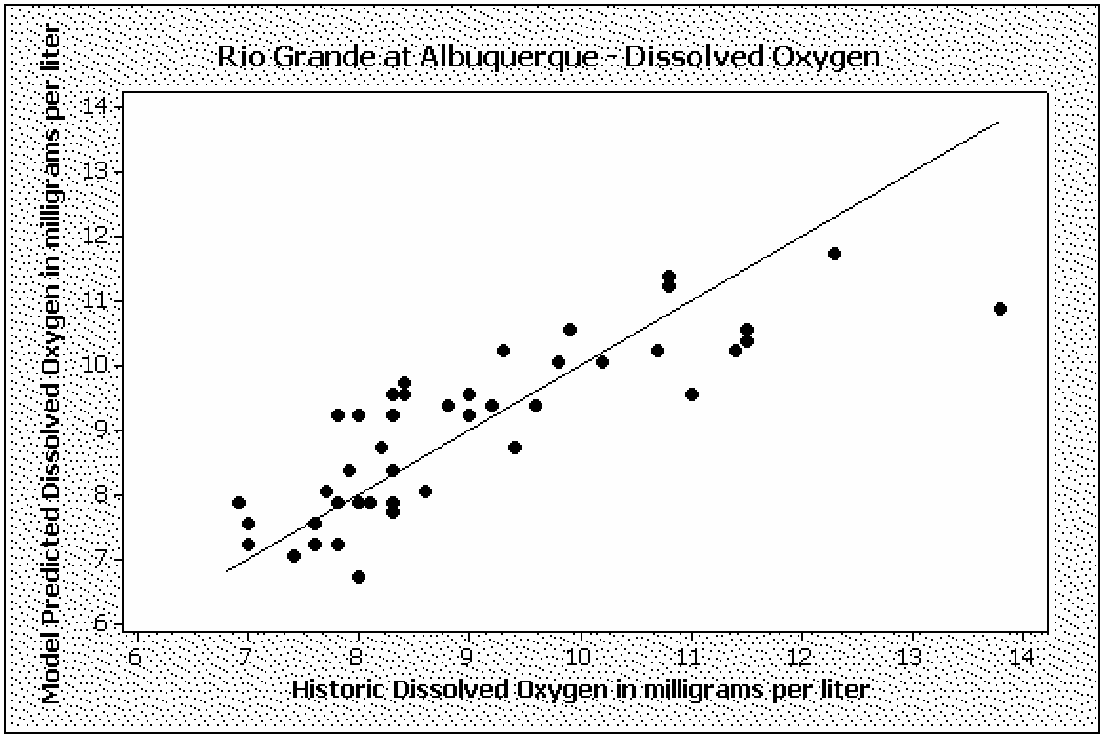

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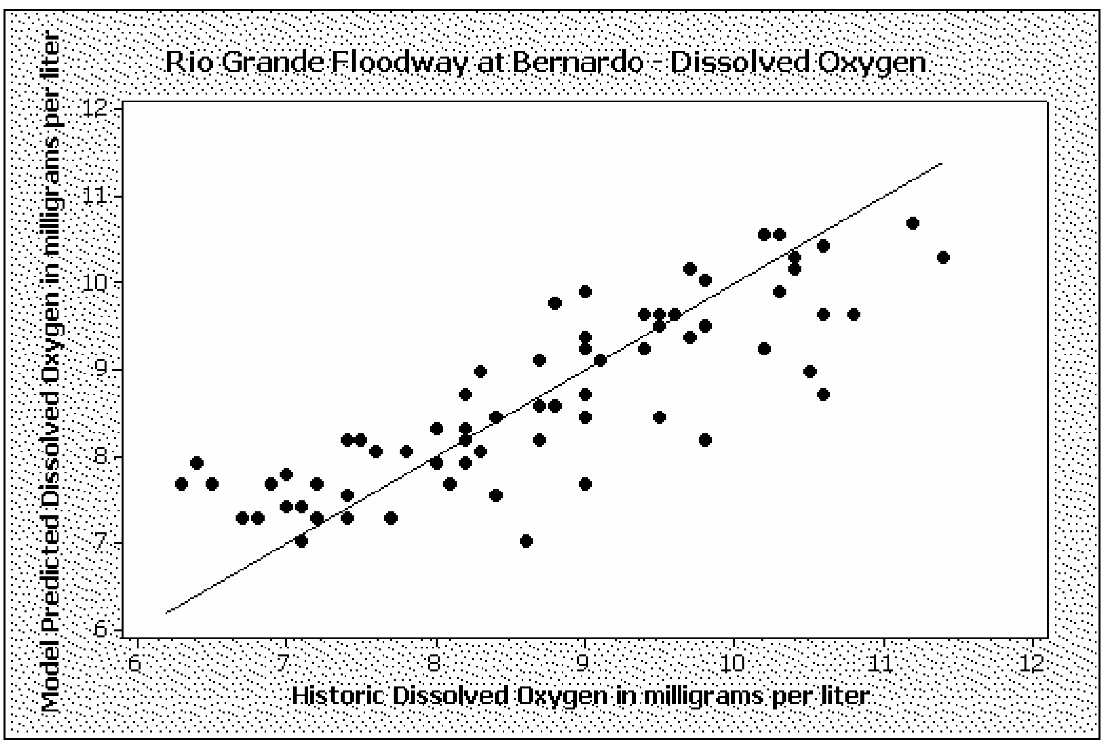

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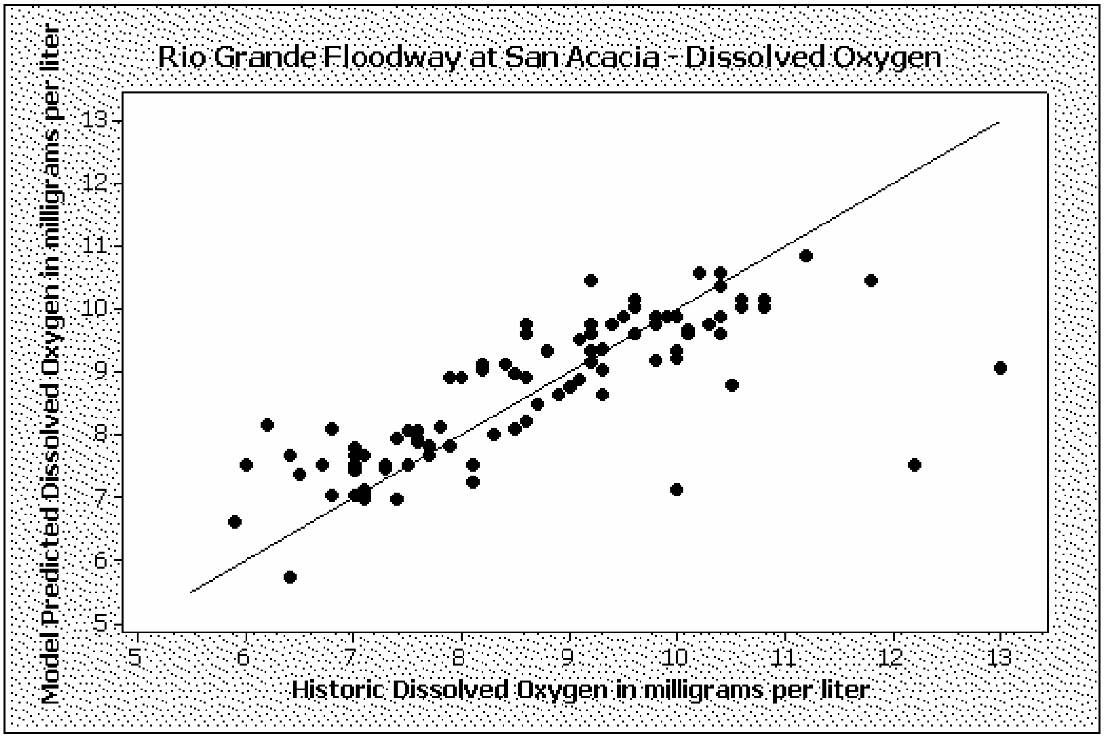

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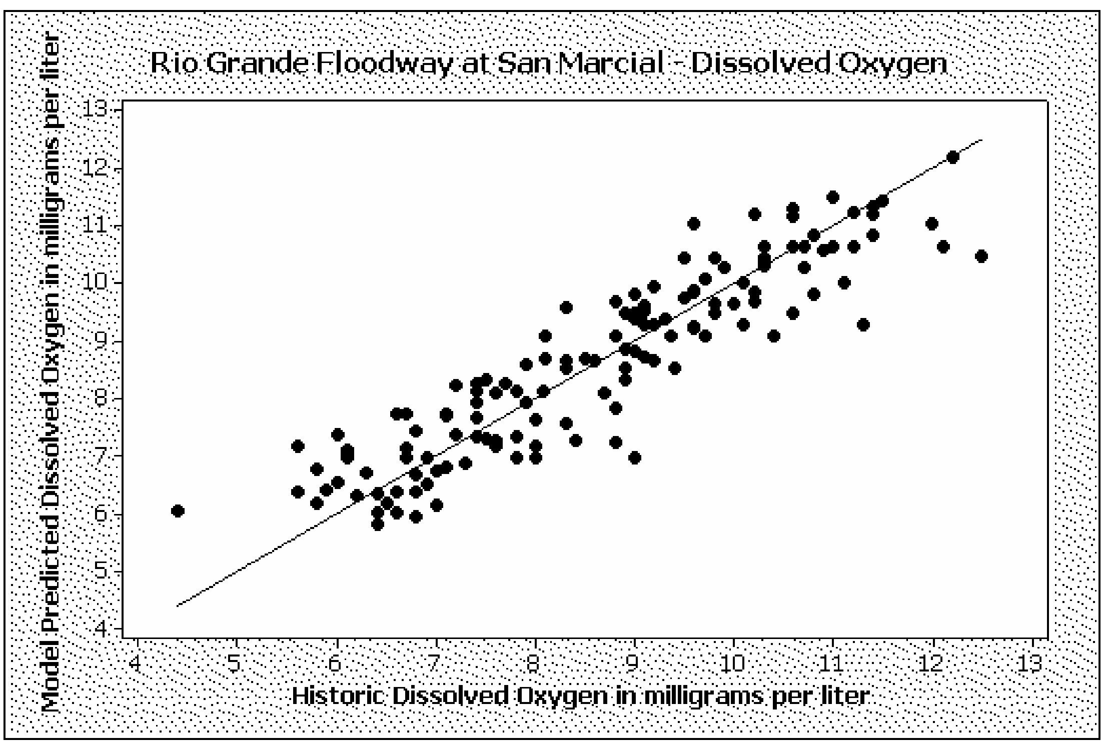

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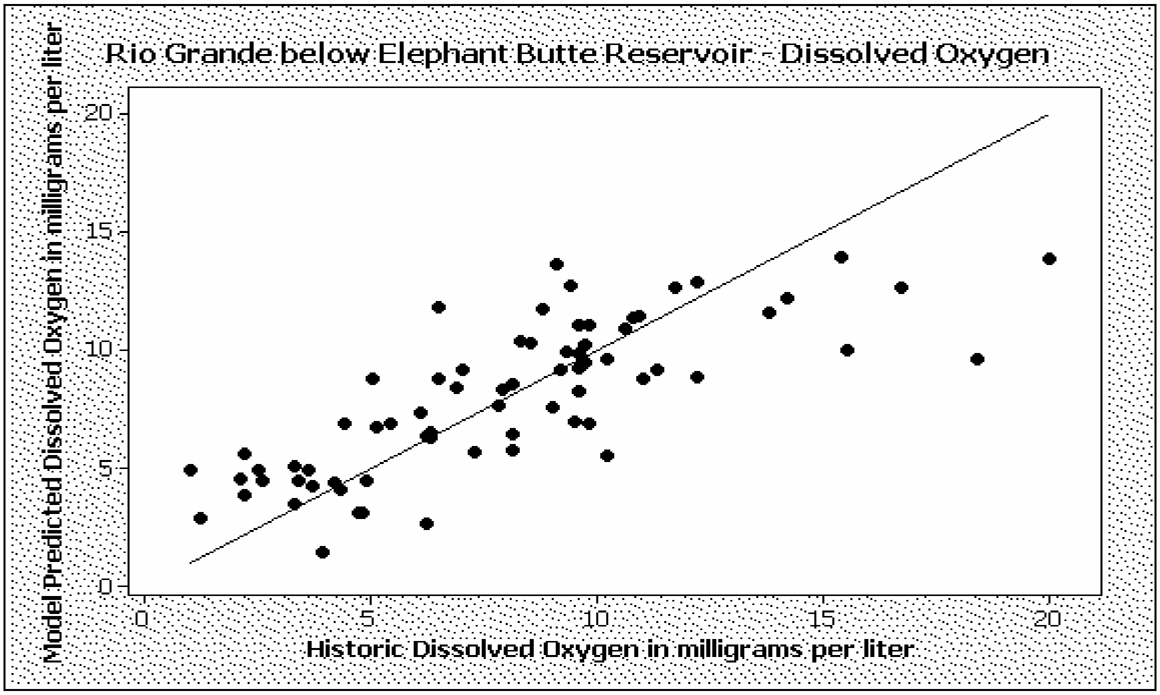

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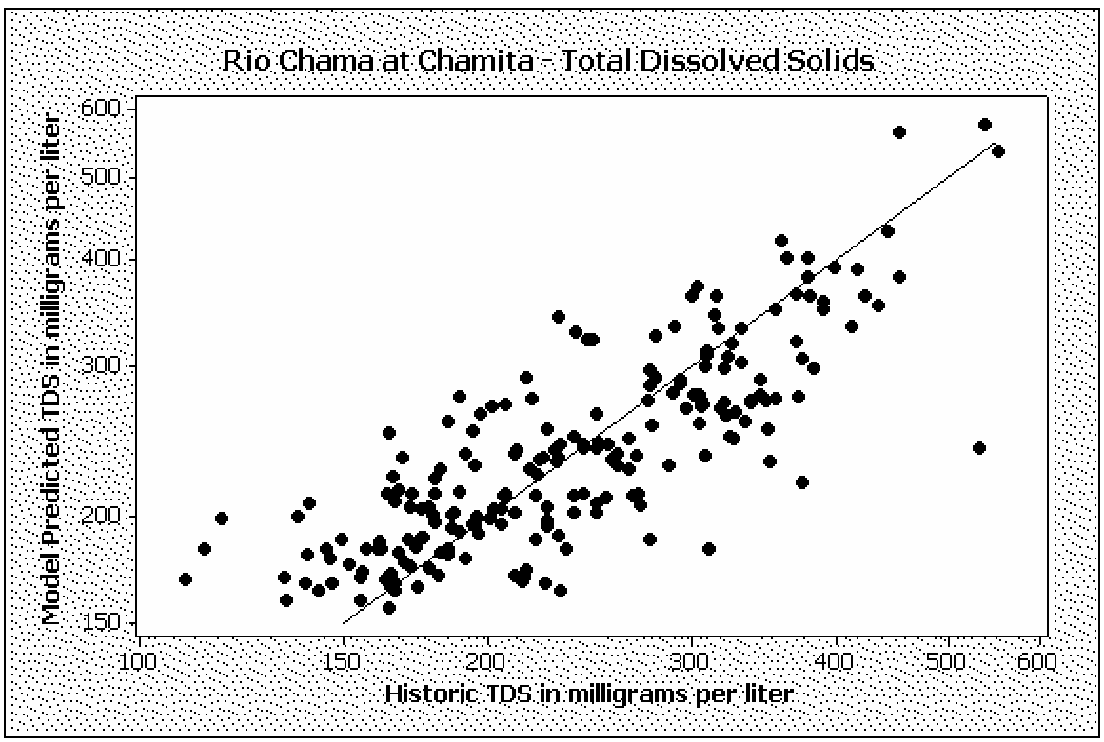

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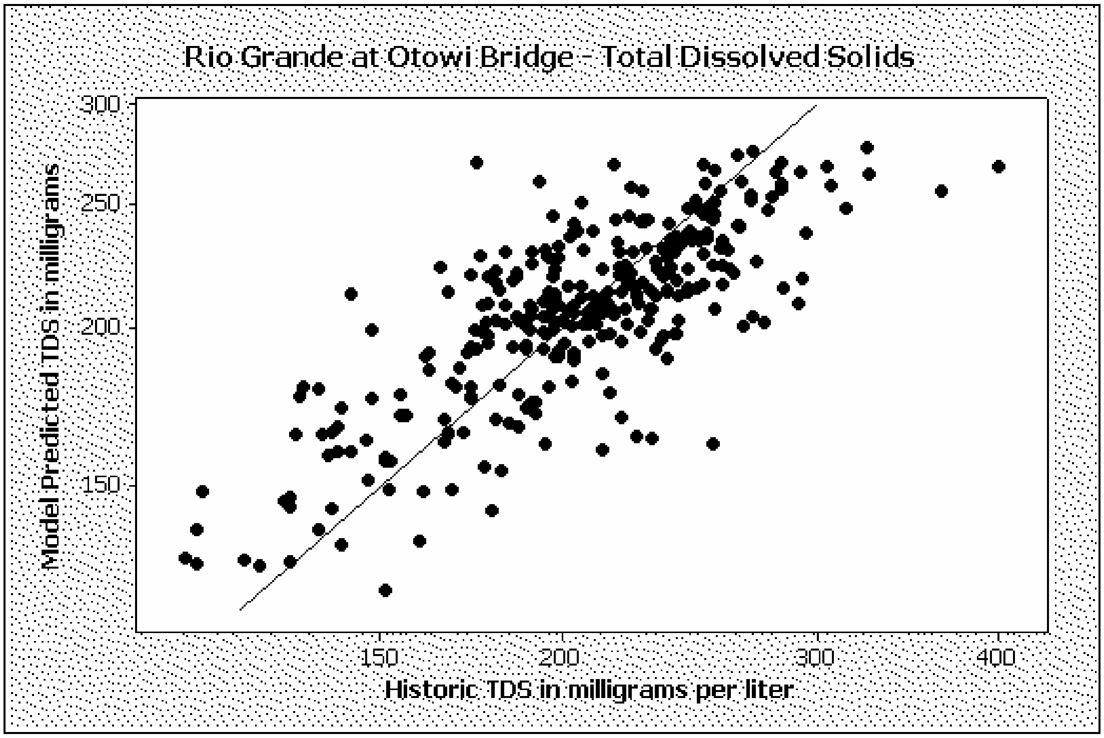

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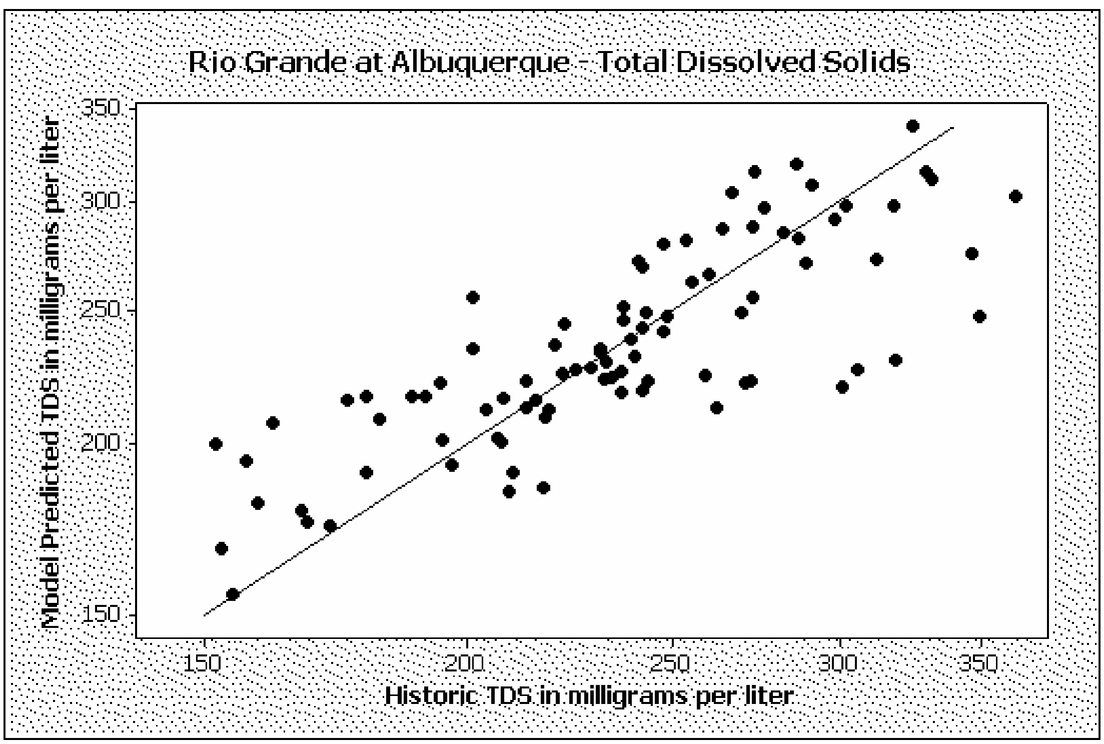

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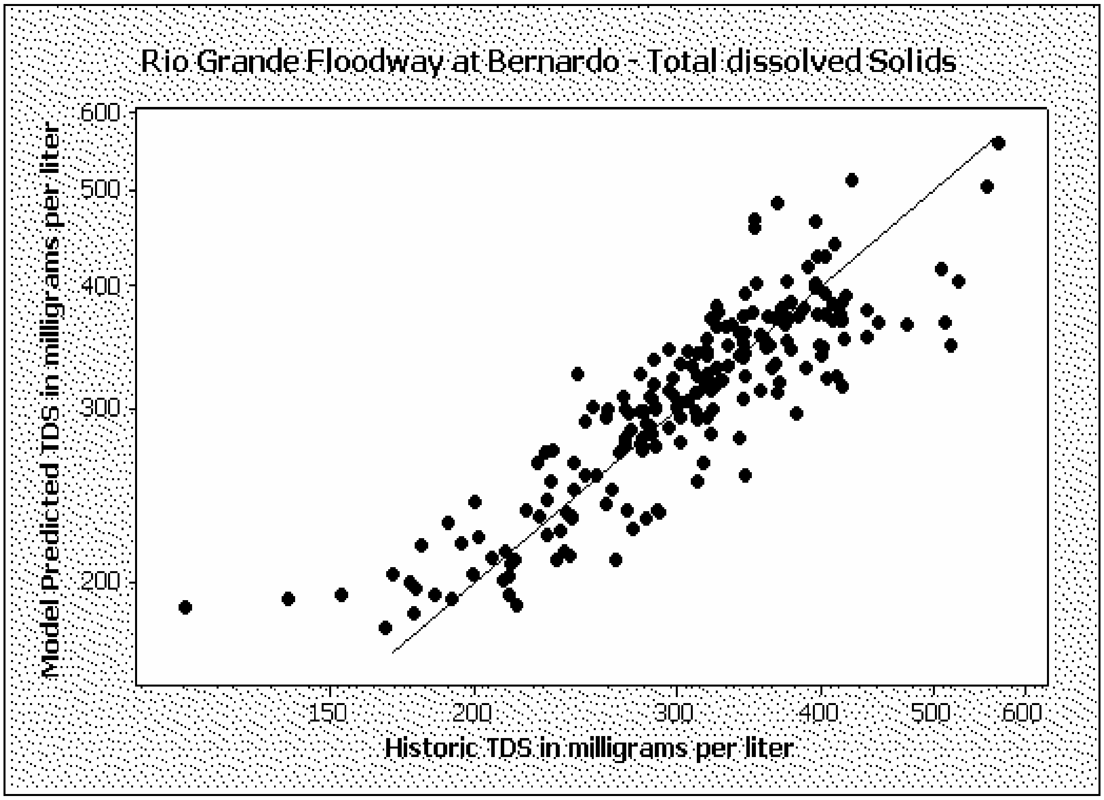

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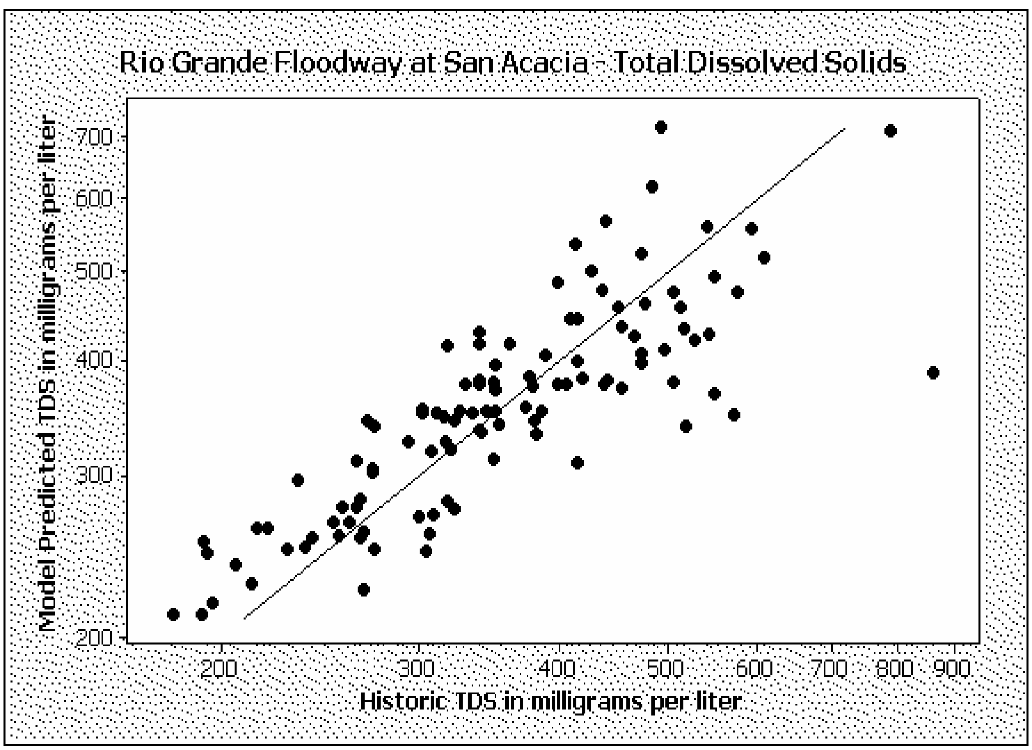

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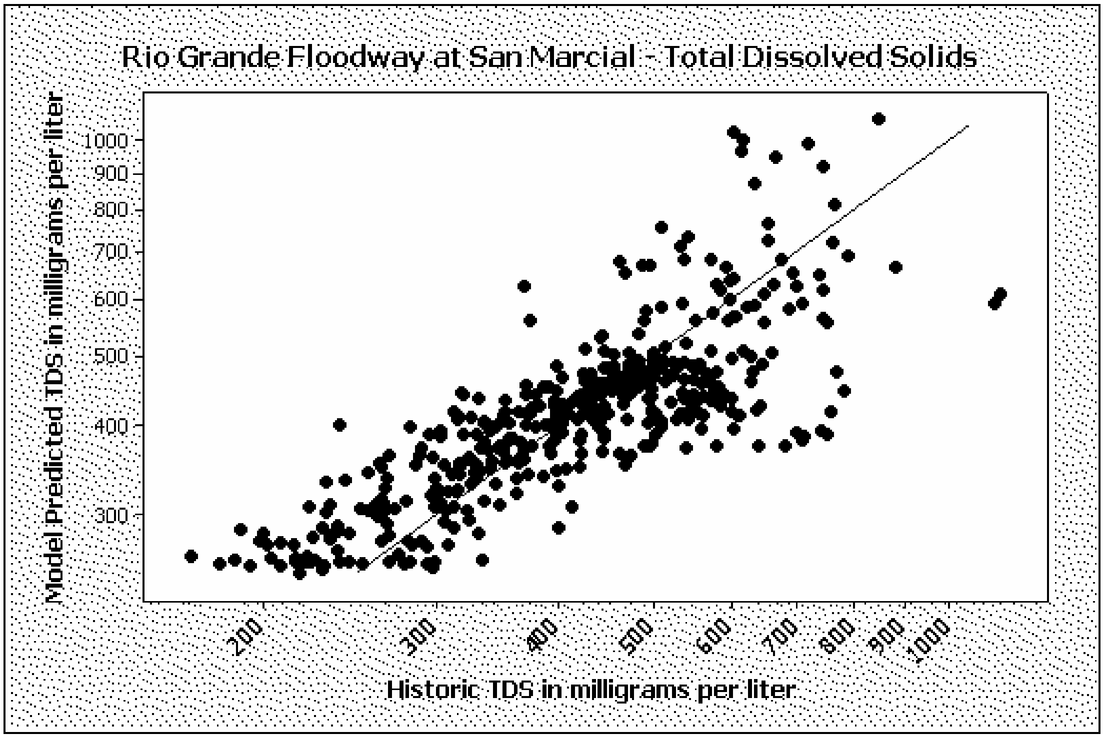

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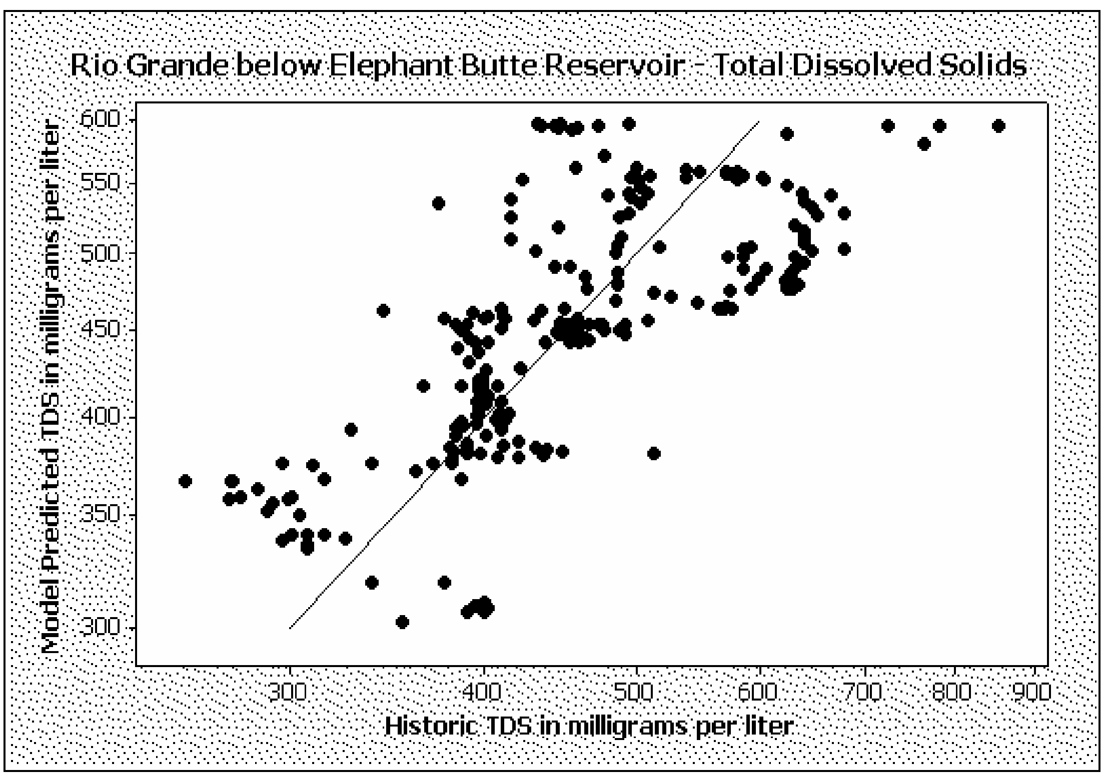

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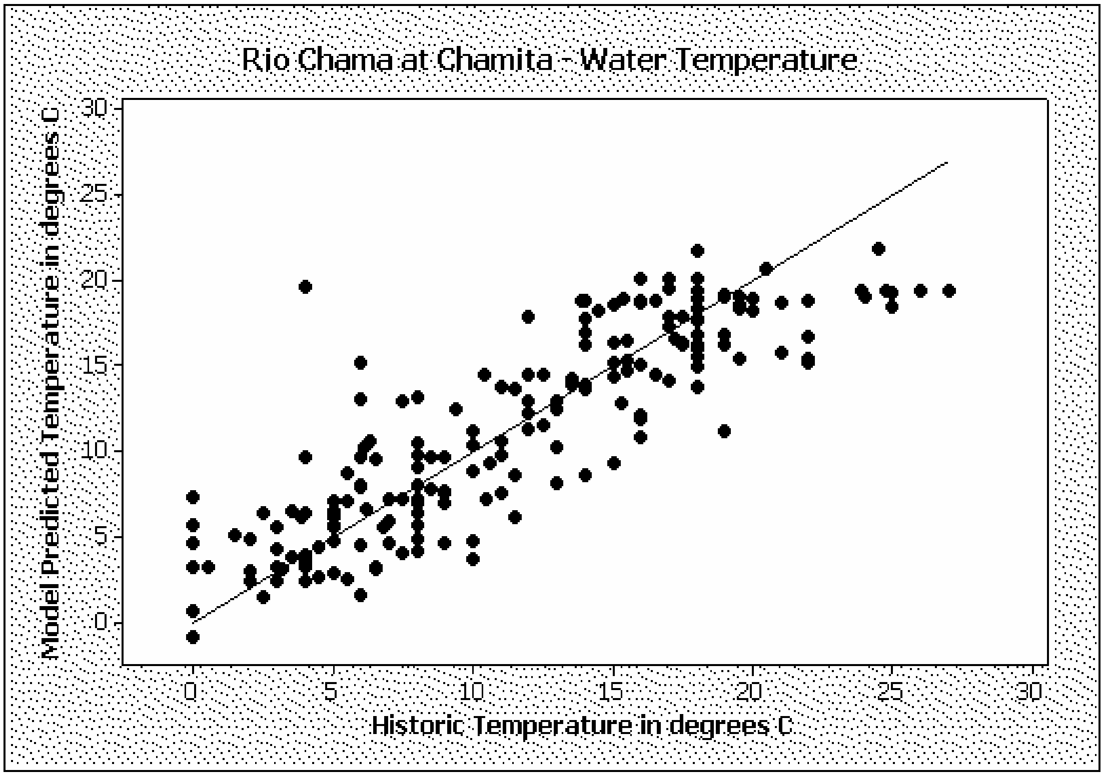

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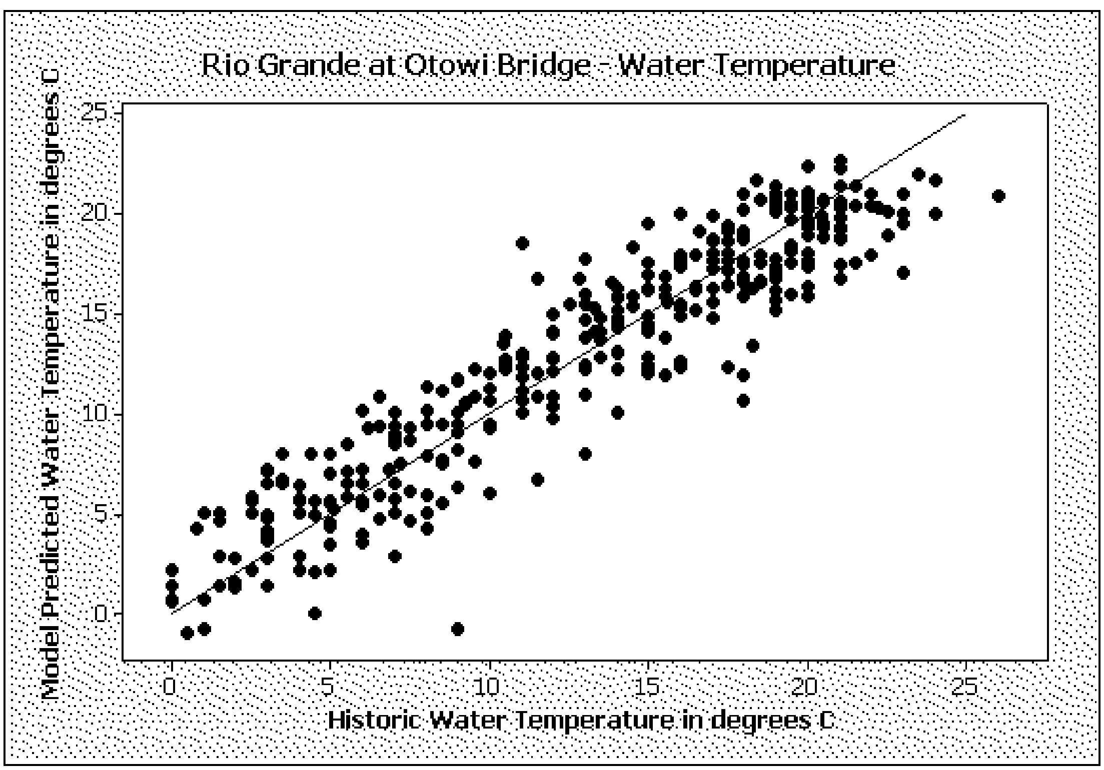

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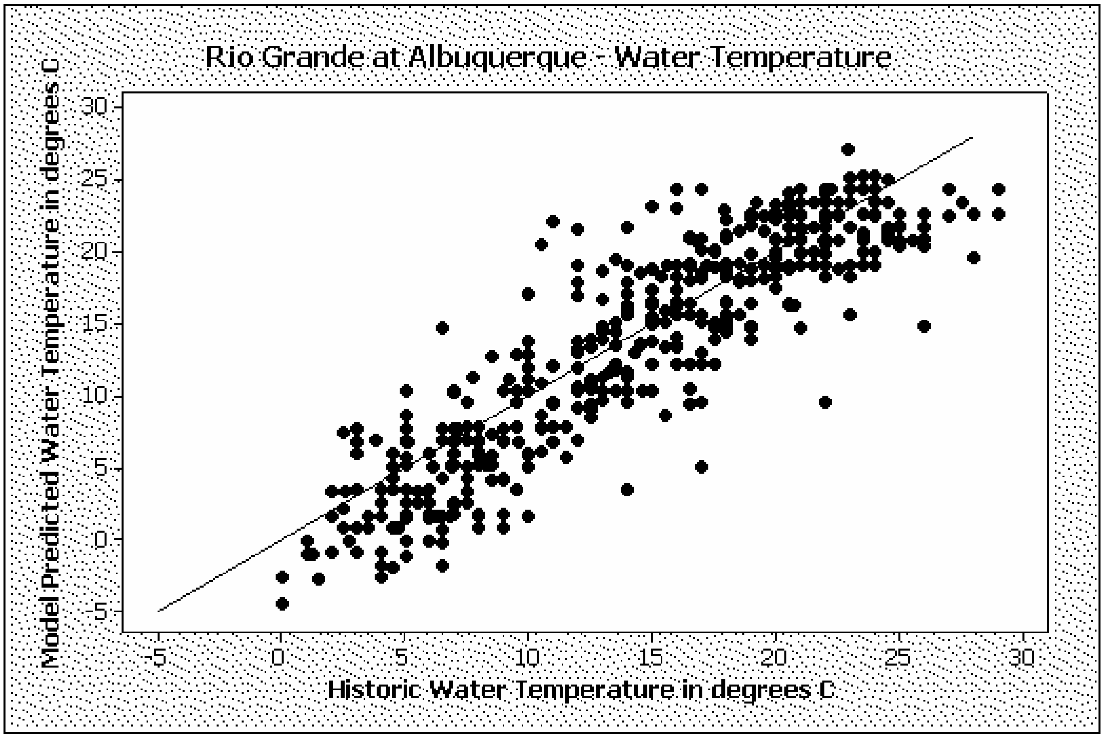

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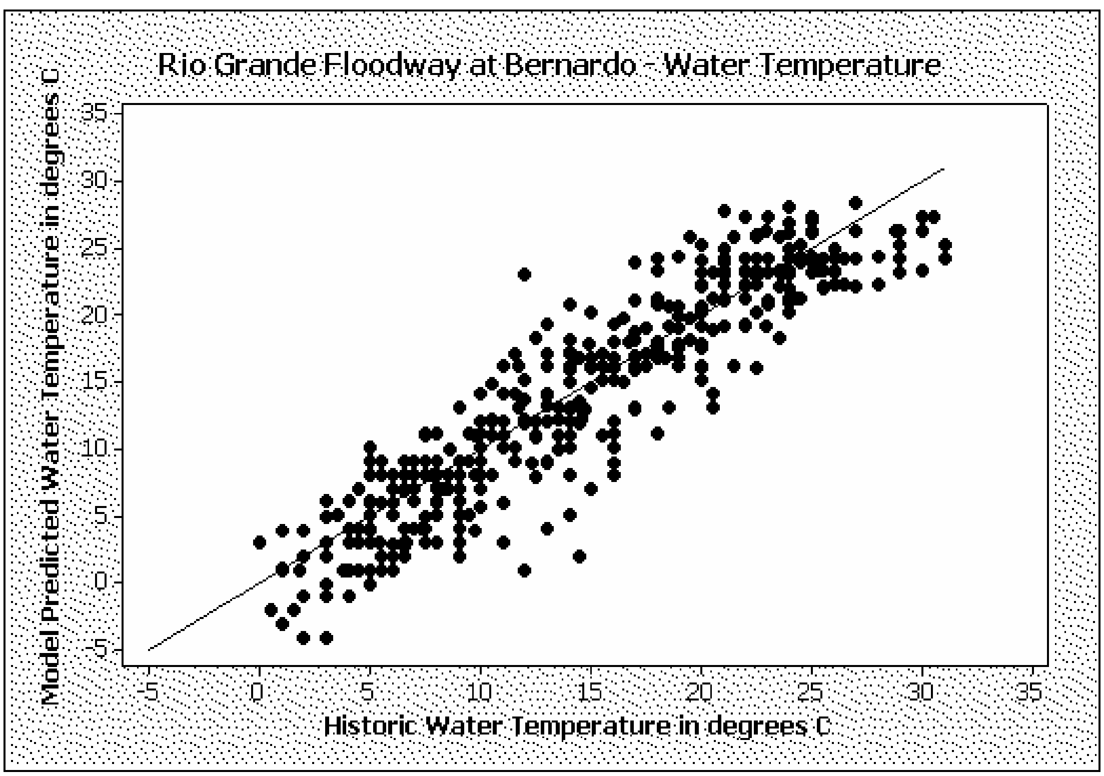

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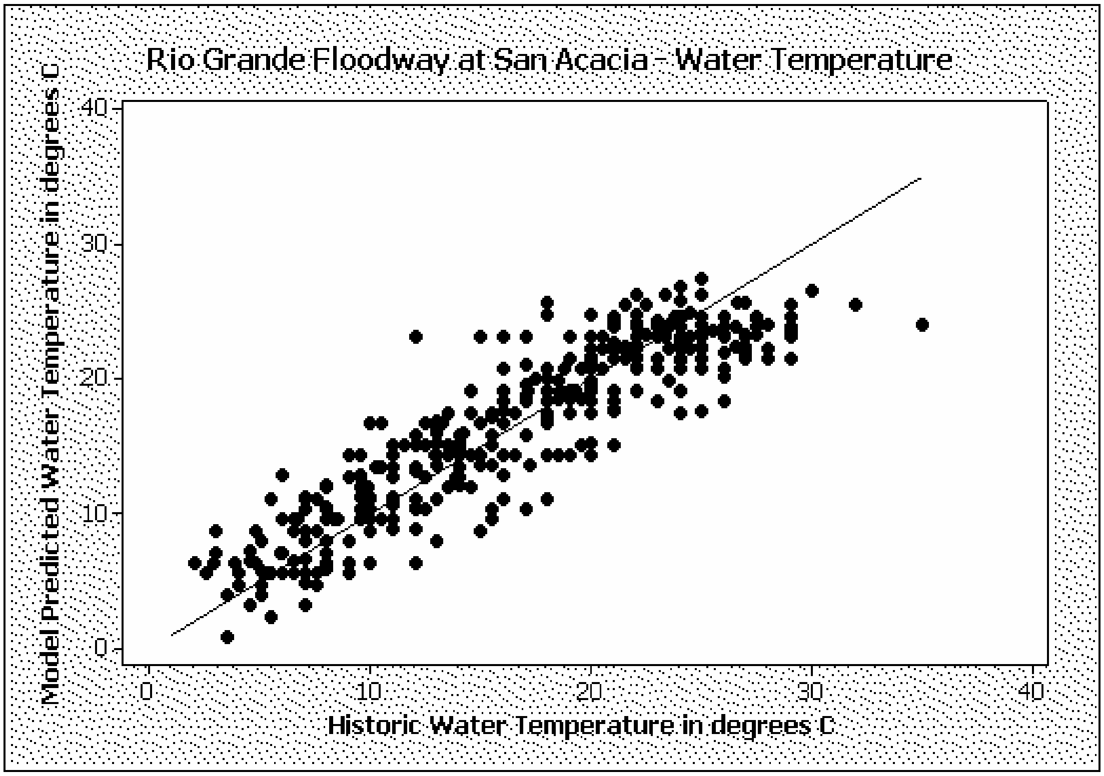

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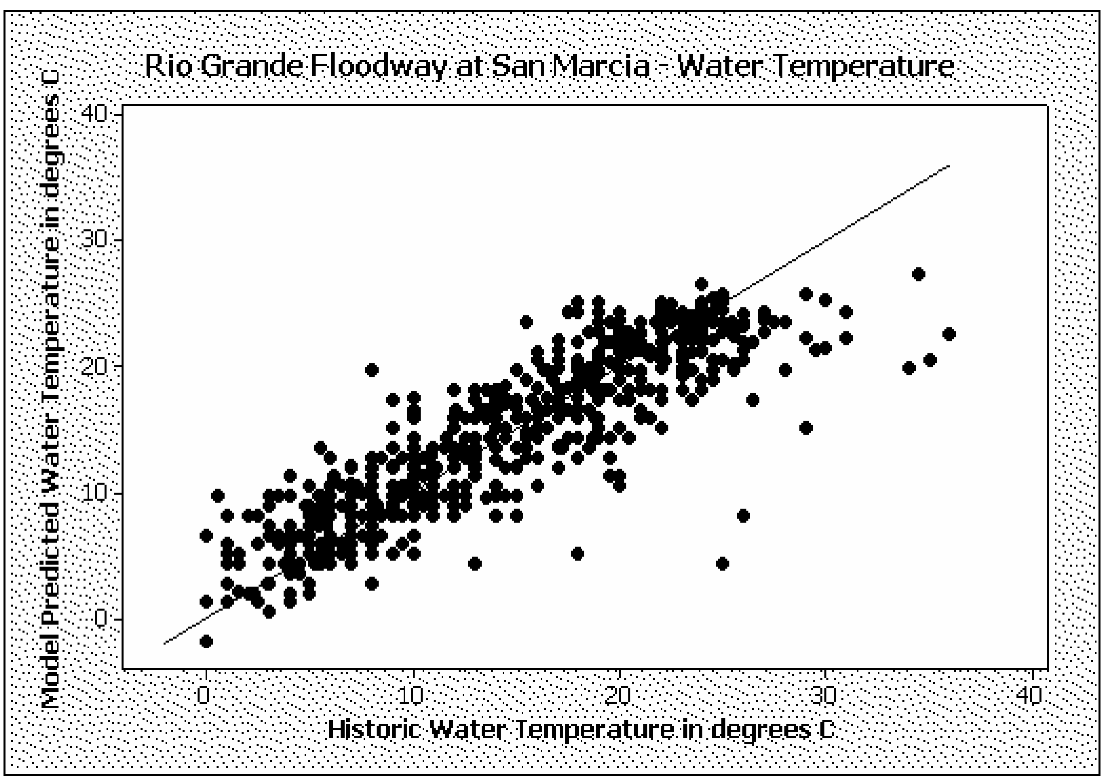

Figure M-4.20

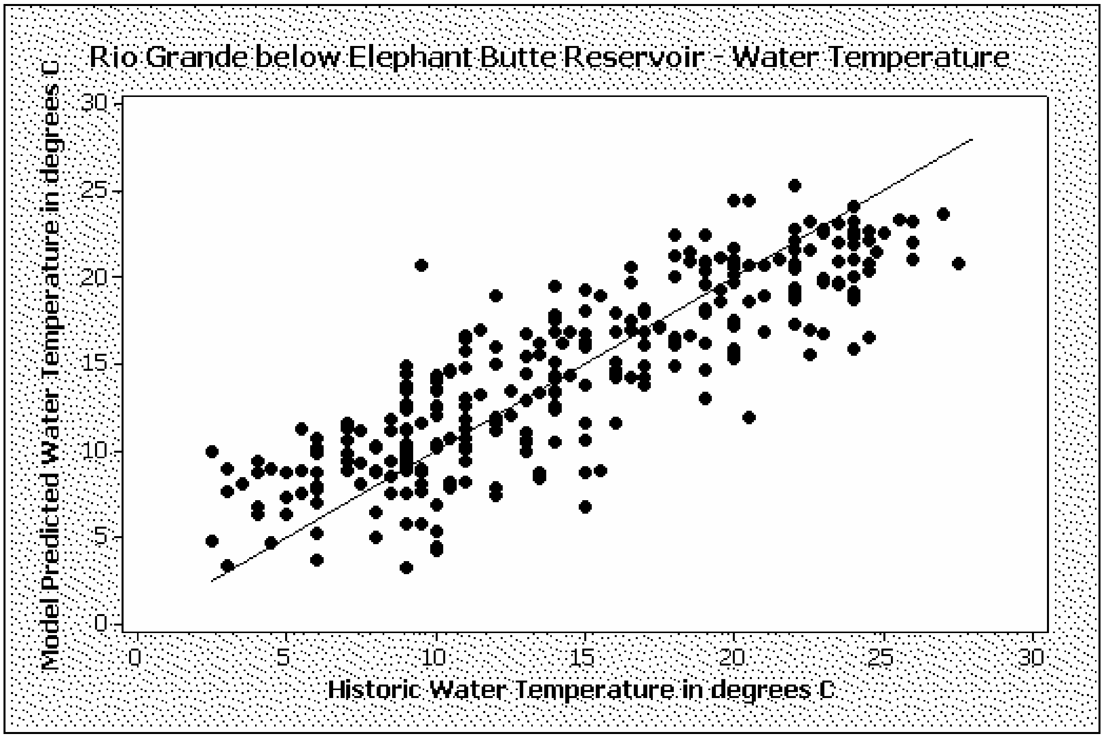
Rio Grande below Elephant Butte Reservoir - Water Temperature
Model Predicted Water Temperature in degrees C
0
5
10
15
20
25
30
Historic Water Temperature in degrees C

Figure M-4.21

Table 4.6a. Data Availability, Variables, R-Square Value, and N for Dissolved Oxygen By Gage

Dissolved Oxygen (mg/L)						
Section	**Station ID**	**Station Name**	**Variable**	**Variable Value (P-Value)**	**Adj R^2**	**n**
Chama	8290000	RIO CHAMA NEAR CHAMITA, NM	Constant	11.47 (0.000)	64.90	96
			Applied NOAA Temperature	-.150 (0.000)		
Chama	8313000	RIO GRANDE AT OTOWI BRIDGE, NM	Constant	11.27 (0.000)	66.40	236
			Applied NOAA Temperature	-.161 (0.000)		
Central	8330000	RIO GRANDE AT ALBUQUERQUE, NM	Constant	11.54 (0.000)	68.54	44
			NOAA Temperature	.167 (0.000)		
Central	8332010	RIO GRANDE FLOODWAY AT BERNARDO	Constant	10.69(0.000)	60.85	72
			NOAA Temperature	-.131(0.000)		
San Acacia	8354900	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	Constant	10.84 (0.000)	56.94	90
			Applied NOAA Temperature	-.138(0.000)		
			Rio Puerco Flow	-.0033(0.011)		
San Acacia	8358400	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	Constant	11.80 (0.000)	82.70	139
			NOAA Temperature	0.99 (0.000)		
			Rio Puerco Flow	0.98 (0.007)		
			San Acacia Conveyance	-.0038(0.004)		
Southern	8361000	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	Constant	15.36 (0.000)	60.90	71
			NOAA Temperature	-0.378 (0.000)		
			Elephant Butte Storage	-0.0000017((0.050)		

Table M-4.6b. Data Availability, Variables, R-Square Value, and N for TDS by Gage

Section	Station ID	Total Dissolved Solids Station Name	Variable	Exponent or Multiplier (P-Value)	Adj R^2	n
Chama	8290000	RIO CHAMA NEAR CHAMITA, NM	Multiplier	7400(.000)	64.50	208
			Ojo Caliente Flow	0.025(.041)		
			Chama Chamita Flow	-0.176(.000)		
			Abiquiu Storage	-0.0456(.000)		
			Heron Storage	-0.157(.001)		
Chama	8313000	RIO GRANDE AT OTOWI BRIDGE, NM	Multiplier	1820(.000)	60.05	314
			Lag1 Embudo Flow	-0.184(.001)		
			Lag1 Chama Chamita Flow	-0.124(.000)		
			Heron Storage	-0.069(.001)		
Central	8330000	RIO GRANDE AT ALBUQUERQUE, NM	Multiplier	2040(.000)	62.30	91
			Cochiti Reservoir Outflow	-0.193(.000)		
			Jemez Reservoir Outflow	0.046(.000)		
			Lag1 Galisteo Creek + .01	0.019(.000)		
			Abiquiu Storage	-0.076(.000)		
Central	8332010	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	Multiplier	2590(.000)	75.92	204
			Bernardo Floodway + .01	-0.052(.000)		
			Lag1 Cochiti Outflow	-0.186(.000)		
			Abiquiu Storage	-0.01(.022)		
			Cochiti Storage	-0.035(.007)		
San Acacia	8354900	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	Constant	2190(.000)	68.00	109
			Bernardo Floodway + .01	-0.038(.000)		
			Lag2 Cochiti Outflow	-0.025(.000)		
			Rio Puerco Flow + .01	-0.229(.000)		
San Acacia	8358400	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	Constant	1950(.000)	67.35	21
			Lag3 Cochiti Outflow	-0.199(.000)		
			Bernardo Floodway + .01	-0.033(.000)		
Elephant Butte	8361000	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	Constant	7310(.000)	54.88	10
			Elephant Butte Storage	-0.22(.000)		

Table M-4.6c. Data Availability, Variables, R-Square Value, and N for Water Temperature by Gage

Water Temperature (C)					
Section	**Station ID**	**Station Name**	**Variable**	**Variable Value (P-Value)**	**Adj R^2**
Chama	8290000	RIO CHAMANEAR CHAMITA, NM	Constant	04.69 (0.000)	74.60
			NOAA Temperature	0.652 (0.000)	
			Abiquiu Outflow	-0.0015 (0.000)	
Chama	8313000	RIO GRANDE AT OTOWI BRIDGE, NM	Constant	4.36 (0.000)	87.40
			NOAA Temperature	0.727 (0.000)	
			Abiquiu Outflow	0.0011 (0.000)	
Central	8330000	RIO GRANDE AT ALBUQUERQUE, NM	Constant	4.17 (0.000)	80.93
			NOAA Temperature	.703 (0.000)	
			Cochiti Outflow	- 0.000564 (0.000)	
Central	8332010	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	Constant	2.85 (.0000)	85.38
			NOAA Temperature	.885 (0.000)	
			Cochiti Outflow	- 0.000307 (0.001)	
San Acacia	8354900	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	Constant	3.95 (0.000)	80.70
			NOAA Temperature	.797 (0.000)	
			Rio Puerco Flow	0.0023 (0.015)	
San Acacia	8358400	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	Constant	3.57 (0.000)	77.90
			NOAA Temperature	.769 (0.000)	
			Rio Puerco Flow	0.0028 (0.009)	
Southern	8361000	RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	Constant	6.67 (0.000)	72.62
			NOAA Temperature	.612(0.000)	
			Elephant Butte Storage	-.0000049(0.000)	

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