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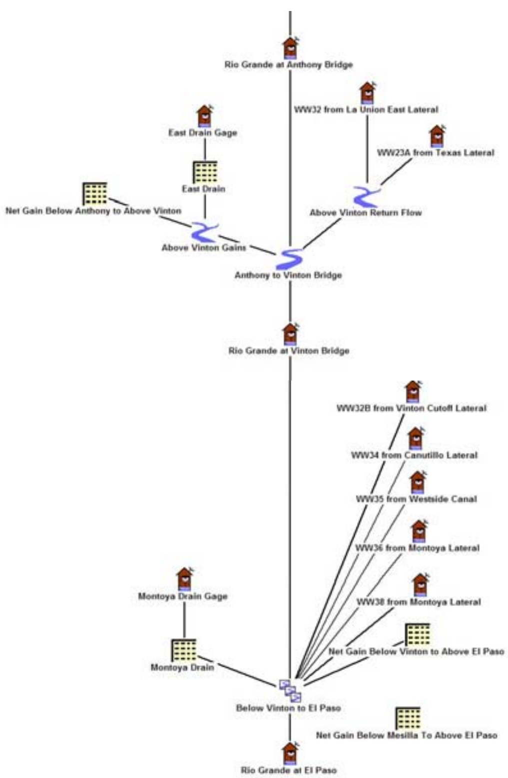

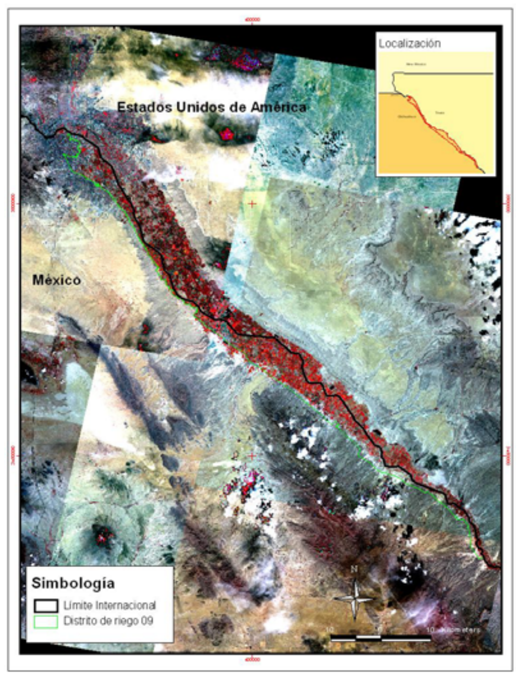

THE DEVELOPMENT OF A COORDINATED DATABASE FOR WATER RESOURCES AND FLOW MODEL IN THE PASO DEL NORTE WATERSHED (Phase III)

Part I
Lower Rio Grande Flood Control Model [LRGFCM] RiverWare Model Development

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Disclaimer

Lower Rio Grande Flood Control Model [LRGFCM]
RiverWare Model Development

Phase III Final Project Report of Work Completed under the Cooperative Agreement between the U.S. Army Corps of Engineers and Texas AgriLife Research

(TAES/03-PL-02)
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Abstract

This report fulfills the deliverables required by the cooperative agreement between the U.S. Army Corps of Engineers and Texas AgriLife Research (TAES/03-PL-02: Modification No. 3) on behalf of the Paso del Norte Watershed Council. Tasks accomplished in this phase include (a) assess the data availability for expansion of the URGWOM model, identify data gaps, generate data needed from historic data using empirical methods, compile and verify the water quality data for reaches between the Elephant Butte Reservoir, New Mexico and Fort Quitman, Texas; (b) develop the RiverWare^{TM} physical model for the Rio Grande flow for the selected reaches between Elephant Butte Reservoir and El Paso, beginning with a conceptual model for interaction of surface water and groundwater in the Rincon and Mesilla valleys, and within the limits of available data; (c) implement data transfer interface between the coordinated database and hydrologic models.

This Project was conducted by researchers at Texas A&M University (TAMU) and New Mexico State University (NMSU) under the direction of Zhuping Sheng of TAMU and J. Phillip King of New Mexico State University. It was developed to enhance the coordinated database, which was originally developed by the Paso del Norte Watershed Council with support of El Paso Water Utilities to fulfill needs for better management of regional water resources and to expand the Upper Rio Grande Water Operations Model (URGWOM) to cover the river reaches between Elephant Butte Dam, New Mexico, and Fort Quitman, Texas. In Phases I and II of this Project (TAES/03-PL-02), hydrological data needed for flow model development were compiled and data gaps were identified and conceptual model development. The objectives of this phase were to develop a physical model of the Rio Grande flow between Elephant Butte Dam and American Dam by using data collected in the first development phase of the PdNWC/Corps Coordinated Water Resources Database and to enhance the data portal capabilities of the PdNWC Coordinated Database Project.

This report is Part I of a three part completion report for Phase III and describes the development of RiverWare model of Rio Grande flows and a coordinated database for water related resources in the Rio Grande watershed. The RiverWare physical model for Rio Grande flows included selected reaches between Elephant Butte Reservoir and El Paso using historical data from 1985 to 1999. A conceptual model for interaction of surface and groundwater was developed using an ARIMA time-series *transfer function* analysis. ARIMA *transfer functions* are used as a means to estimate the interactions of surface and groundwater. Forecasting drain flows from diversion flows is demonstrated as a statistically valid method, and provides results highly correlated with the historic values.

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Lower Rio Grande Flood Control Model [LRGFCM] RiverWare Model Development

Introduction

This report is to cover the ***Development of RiverWare Model of the Rio Grande Flow***. Specifically, this report addresses the following subtasks:

- Assess the data availability for expansion of the URGWOM model, identify data gaps, estimate data needed from historic data using empirical methods, and recommend additional data collection for both surface water and groundwater.

- Develop the RiverWare physical model for the Rio Grande flow for the selected reaches between Elephant Butte Reservoir and El Paso, beginning with a conceptual model for interaction of surface and groundwater in the Rincon and Mesilla valleys, and within the limits of available data. Linking input data from and output data to the coordinated database by using the Data Management Interface of RiverWare.

Objectives

The main objective of this report is to describe the physical RiverWare model of the Lower Rio Grande pursuant to the subtask item requirements listed above. Besides developing the physical RiverWare model, the following objectives were also accomplished:

- A table was produced showing the data availability since 1975 for each of the locations specified in the schematics created for the reaches between the Rincon, Leasburg, and Mesilla diversion dams. This table shows where and for what time periods there are gaps in the data.

- Data were estimated as needed to fill in the data gaps, creating a complete set of historic data for the years 1985 to 1999 for the sites used by the model.

- A conceptual model for interaction of surface and groundwater was developed using an ARIMA time-series *transfer function* analysis of the relationship between diversion from the Mesilla Dam and flow in the Del Rio, La Mesa, East, and Montoya Drains.

- The RiverWare physical model was constructed based on the reach schematics, available data and the ARIMA time-series *transfer function* relationships. This model simulates the Lower Rio Grande flow between Caballo Dam and the Rio Grande at El Paso gage for monthly observed data from 1985 through 1999 and it was in preparation for a flood control model.

- Data Management Interface control files were created to input all the necessary data to the model, and output the results from the model.

Reach Schematics

The reach schematics used to develop the physical model were created based primarily on the physiography of the study area and on the locations of the major diversion dams. This conceptual development of the reaches is intended to resemble the actual geometry of the system and also to fit the available data.

The Rio Grande from Caballo Reservoir, New Mexico, to El Paso, Texas, flows across the Rincon Valley Basin and the Mesilla Bolson as shown in FIGURE 1. At the southern end of each basin, the Rio Grande crosses a structurally high bedrock constriction. Selden Canyon between Rincon and Leasburg, and the El Paso Narrows at El Paso represent these high bedrock zones that delineate the southern end of each basin. These constrictions create separate groundwater systems that are linked by the common river (King and Maitland, 2003).

The upper portion of the Rio Grande Project from the River below Caballo Dam to the River at El Paso was divided into three reaches, which are delineated by the major diversion dams in this length of the Rio Grande and by the physiography of the area. The three reaches are:

- The Rincon Reach,
- The Leasburg Reach, and
- The Mesilla Reach.

These reaches are described in the following sections.

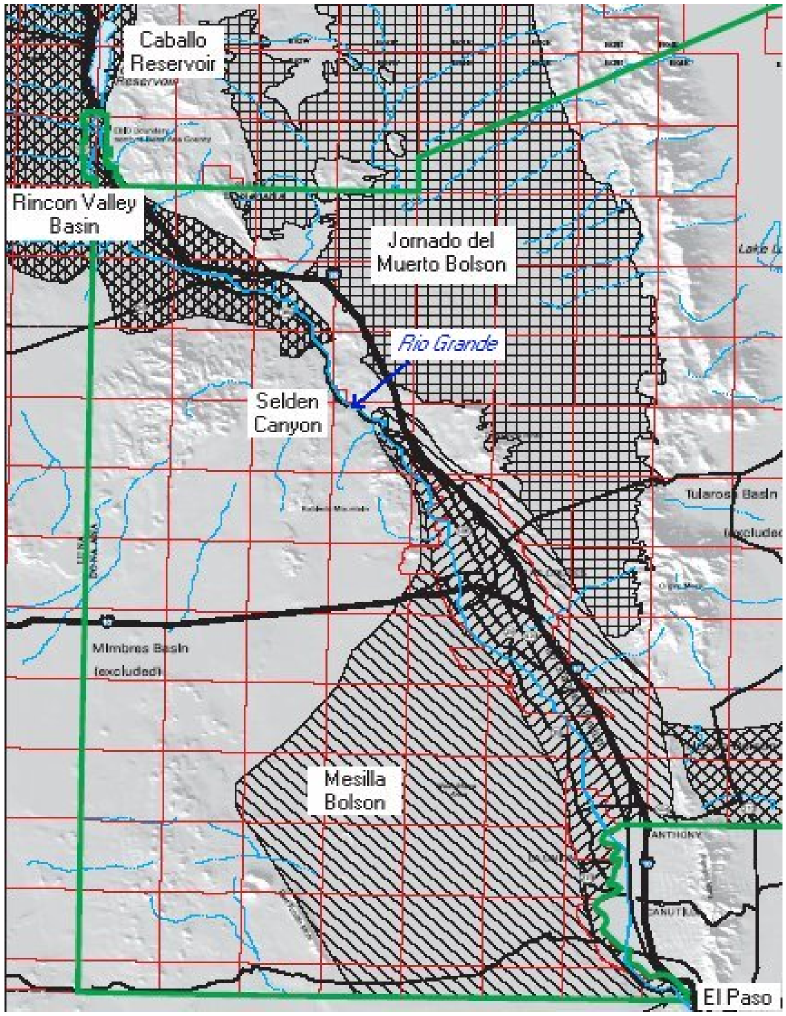

FIGURE 1. Physiography of the Rio Grande between Caballo and El Paso (Terracon et al., 2004)

Rincon Reach

The Rincon Reach of the model was created to simulate the Rio Grande from below Caballo Dam to above Leasburg Diversion Dam (simplified as Above Leasburg). The Percha Diversion Dam is located approximately one mile south of Caballo Dam and is the initial diversion point of the system. At this location, water is diverted for irrigation into the Arrey Canal and into the Percha Lateral. The Arrey Canal carries the majority of the water diverted at this dam, and distributes the irrigation water throughout the entire Rincon Valley. The Percha Lateral diverts a small amount of water to irrigate farms in the vicinity of the diversion dam only. The net gains are estimated by the model for the reach from Below Caballo to Above Haynor and the reach from Below Hayner and Above Leasburg (see more detail in later sections). The schematic for this reach is shown in FIGURE 2. All of the return flows to the river in this reach are from the water diverted to the Arrey Canal.

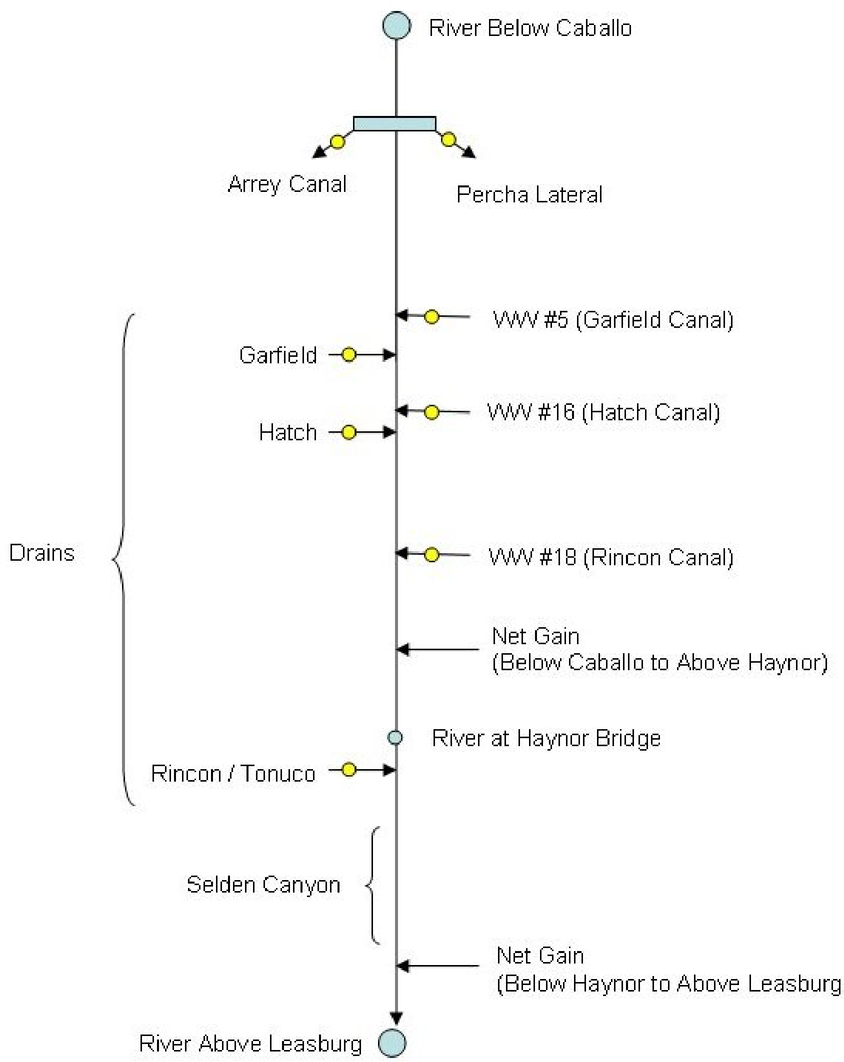

FIGURE 2. Schematic of the Rincon Reach
Blue circles are the gauged river stations and yellow circles are the gauged diversions and return flows.

Leasburg Reach

The Leasburg Reach of the model was created to simulate the Rio Grande between the Leasburg Diversion Dam and the Mesilla Diversion Dam. At the Leasburg Diversion Dam, water is diverted for irrigation into the Leasburg Canal. The schematic for this reach is shown in FIGURE 3.

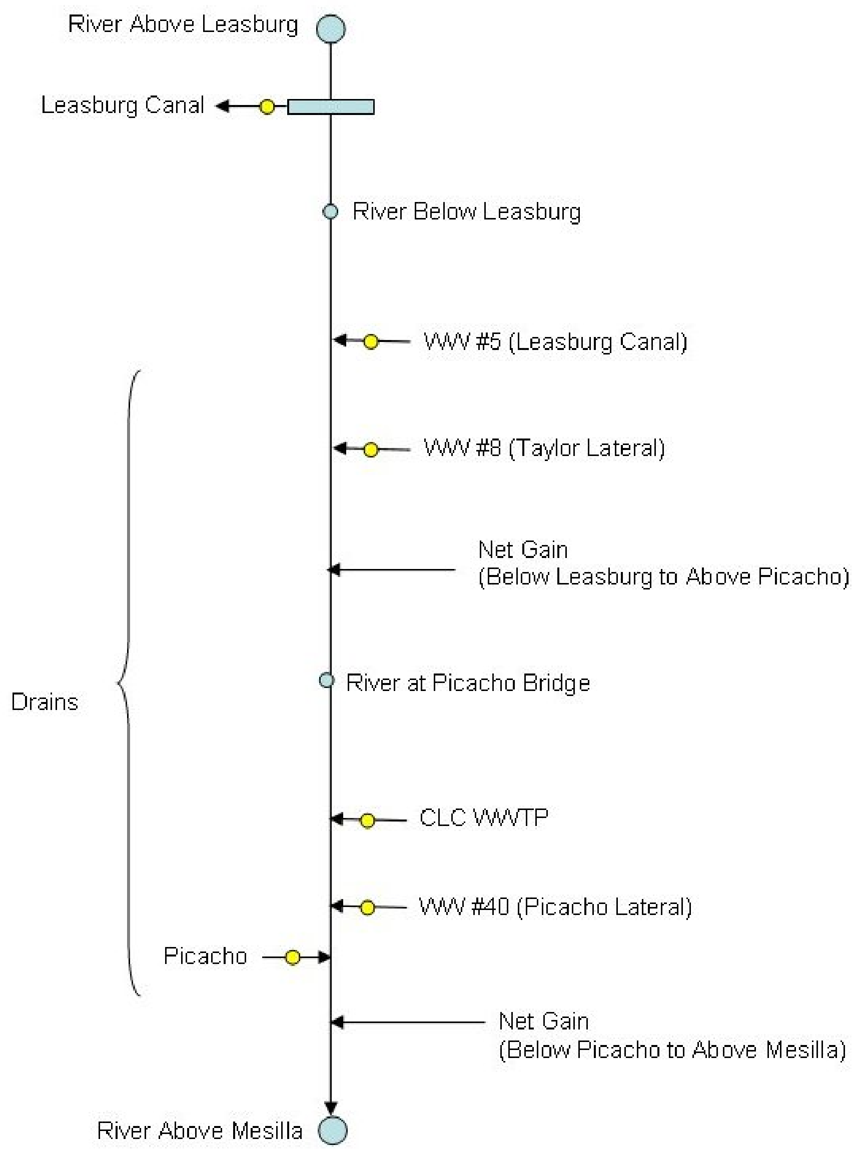

FIGURE 3. Schematic of the Leasburg Reach
Blue circles are the gauged river stations and yellow circles are the gauged diversions and return flows.

Mesilla Reach

The Mesilla Reach of the model was created to simulate the Rio Grande between the Mesilla Diversion Dam and the Rio Grande at El Paso gage. At the Mesilla Diversion Dam, water is diverted for irrigation into the Westside Canal, the Eastside Canal and the Del Rio Lateral. There are return flows to the river in this reach from the Westside and Eastside Canal diversions. The schematic for this reach is shown in FIGURE 4.

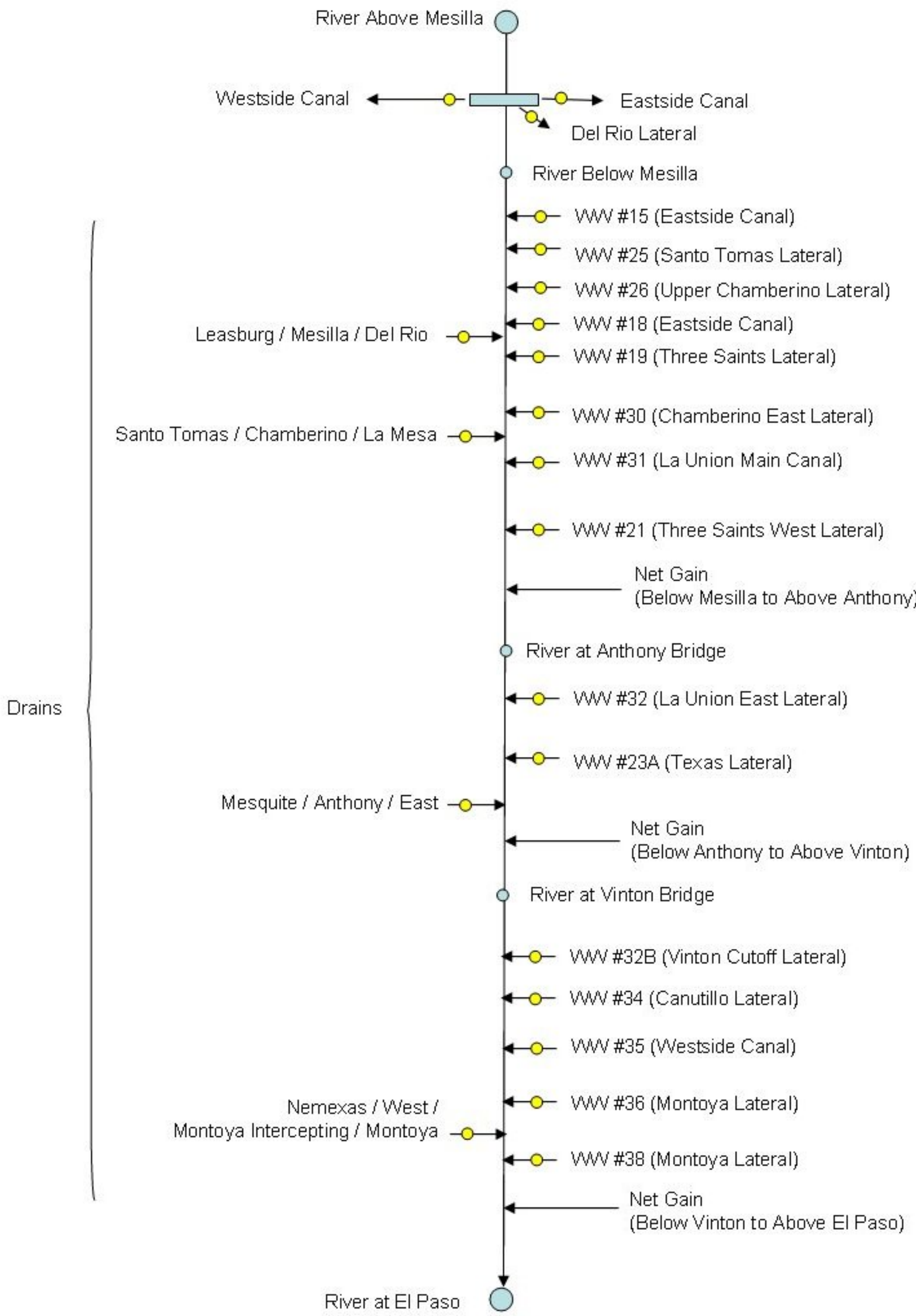

FIGURE 4. Schematic of the Mesilla Reach
Blue circles are the gauged river stations and yellow circles are the gauged diversions and return flows.

Relevant Hydrological Data

A summary of the data available since 1975 is shown in TABLE 1. This table spans sites along the Rio Grande from Below Caballo Dam to the Rio Grande at El Paso. Also indicated in the table is whether the data are daily data, monthly data, if no data are available, and if the station was discontinued. The largest gap in the data is for all of the Elephant Butte Irrigation District (EBID) stations for the year 2000. There should be records for this year, however to date, the authors have been unable to acquire them from EBID.

TABLE 1. Available Data since 1975 (Brown et al., 2004)

Site	***Available Data Since 1975*** [1]
Rio Grande Below Caballo Dam	1975-5/2005 (d)
Arrey Canal (Percha Div. Dam)	1975-1999 (d), 2000 (n), 2001-2004 (d)
Percha Lateral (Percha Div. Dam)	1979-1999 (d), 2000 (n), 2001-2004 (d)
WasteWay#5 (WW #5) (Garfield Canal)	1979-1984 (d), 1985-1986 (n), 1987 (d), 1988-1992 (n) 1993-1999 (d), 2000 (n), 2001-5/2005 (d)
Garfield Drain	1975-1981 (m), 1982-1999 (d), 2000 (n), 2001-2004 (d)
WW #16 (Hatch Canal)	1979-1999 (d), 2000 (n), 2001-5/2005 (d)
Hatch Drain	1975-1981 (m), 1982-1999 (d), 2000 (n), 2001-2004 (d)
WW #18 (Rincon Canal)	1979-1999 (d), 2000 (n), 2001-2004 (d)
Rio Grande at Hayner Bridge	2001-5/2005 (d)
Rincon/Tonuco Drain	1975-1981 (m), 1982-1999 (d), 2000 (n), 2001-2004 (d)
Rio Grande Above Leasburg Dam	1975-1983 (d)
Leasburg Canal (at Heading)	1975-1995 (d), 1996 (n), 1997-1999 (d), 2000 (n) 2001-6/2003 (d)
Rio Grande Below Leasburg Dam	1975-1999 (d), 2000 (n), 2001-5/2005 (d)
WW #5 (Leasburg Canal)	1979-1999 (d), 2000 (n), 2001-6/2003 (d)
WW #8 (Taylor Lateral)	1979-1999 (d), 2000 (n), 2001-5/2005 (d)
Rio Grande at Picacho Bridge	1991-1999 (d), 2000 (n), 2001-5/2005 (d)
City of Las Cruces WWTP	5/1976-2/1996 (d)
WW #40 (Picacho Lateral)	1991-1999 (d)
Picacho Drain	1975-1983 (m), 1984-1990 (n), 1991-1999 (d) 2000 (n), 2001-6/2003 (d)
Rio Grande Above Mesilla Dam	(n)
Westside Canal (Mesilla Div. Dam)	1975-1983 (d), 1984 (n), 1985-1999 (d), 2000 (n) 2001-6/2003 (d)
Eastside Canal (Mesilla Div. Dam)	1975-1999 (d), 2000 (n), 2001-6/2003 (d)
Del Rio Lateral (Mesilla Div. Dam)	1975-1992 (d), 1993 (n), 1994-1999 (d), 2000 (n) 2001-6/2003 (d)
Rio Grande Below Mesilla Dam	1985-1999 (d), 2000 (n), 2001-5/2005 (d)
WW #15 (Eastside Canal)	1985-1999 (d), 2000 (n), 2001-6/2003 (d)
Santo Tomas River Drain	1985-1990 (d)

[1] d - daily data, m - monthly data, n – no data

Site	***Available Data Since 1975*** [1]
WW #25 (Santo Tomas Lateral)	1985-1999 (d), 2000 (n), 2001 (d)
WW #26 (Upper Chamberino Lateral)	1979-1999 (d), 2000-5/2001(n), 6/2001-5/2005 (d)
WW #18 (Eastside Canal)	1985-1999 (d), 2000 (n), 2001-5/2005 (d)
Leasburg / Mesilla / Del Rio Drain	1975-1980 (m), 1981-1999 (d), 2000 (n), 2001-5/2005 (d)
WW #19 (Three Saints Lateral)	1982-1999 (d), 2000 (n), 2001-6/2003 (d)
WW #30 (Chamberino East Lateral)	1985-1999 (d), 2000 (n), 2001-5/2005 (d)
Santo Tomas/Chamberino/La Mesa Drain	1975-1980 (m), 1981-1999 (d), 2000 (n), 2001-5/2005 (d)
WW #31 (La Union Main Canal)	1981-1999 (d), 2000 (n), 2001-6/2003 (d)
WW #21 (Three Saints West Lateral)	1985-1991 (d), 1992-1996 (n), 1997-6/2003 (d)
Rio Grande at Anthony Bridge	1986-1989 (d), 1990-2000 (n), 2001-5/2005 (d)
WW #32 (La Union East Lateral)	1979-1992 (d), 1993-1996 (n), 1997-1999 (d), 2000 (n) 2001-6/2003 (d)
WW #23A (Texas Lateral)	1985-1992 (d), 1993-1996 (n), 1997-1999 (d), 2000 (n) 2001-6/2003 (d)
Mesquite/Anthony/East Drain	1975-1980 (m), 1981-1992 (d), 1993 (n), 1994-5/2005 (d)
Rio Grande at Vinton Bridge	1985-1992 (d)
WW #32B (Vinton Cutoff Lateral)	1985-1992 (d), 1993-1996 (n), 1997-2002 (d)
WW #34 (Canutillo Lateral)	1983 (d), 1984 (n), 1985-1992 (d), 1993-1996 (n) 1997-2002 (d)
WW #35 (Westside Canal)	1980-1992 (d), 1993-1996 (n), 1997-2002 (d)
WW #36 (Montoya Lateral)	1985-1992 (d), 1993-1996 (n), 1997-2002 (d)
Nemexas / West /Montoya Intercept./ Montoya Drain	1975-1980(m), 1981-1995 (d), 1996 (n), 1997-2002 (d)
WW #38 (Montoya Lateral)	1985-1992 (d), 1993-1996 (n), 1997-2002 (d)
Rio Grande at El Paso	1975-3/2003 (d)

Estimated Data

In order to develop the physical RiverWare model, it was necessary to have a complete historical data set. In considering the available data for all three reaches, it was apparent that the most data were available for the years 1985 through 1999. Therefore, monthly data were compiled for these years for the sites indicated in the reach schematics. Most of the gaps in the data were due to some missing or unspecified (usually labeled as "–") daily data for the non-irrigation months. So in general, linear interpolation was used to fill in missing daily data, and unspecified daily data for the non-irrigation months were set to zero. Then monthly values were generated from the daily data. Some stations had multiple years of data missing, and data for these years was estimated based on average monthly values of the historic data scaled by the percent of the annual data for each missing year for flows Below Caballo Dam relative to the average annual flow Below Caballo Dam.

Conceptual Model for Interaction of Surface and Groundwater

Physical models are useful for modeling the physical processes of a system, however, these models typically over-simplify some of the relationships between the diversions and return flows of the system. They do not adequately simulate the physical processes involved because they are not accounting for all of the processes involved. If a statistical method can account for current and past values in predicting a future value when modeling a physical system, it will provide a representation of the physical processes while maintaining statistical cohesion.

The statistical method chosen for modeling the relationships between the diversions and drain return flows along the Rio Grande Project is the **A**uto **R**egressive **I**ntegrated **M**oving-**A**verage (ARIMA) model. This type of model analyzes and forecasts equally spaced univariate time-series data. The predictions made by this model are from a linear combination of a variable's own past values, past errors (or residuals) and current and past values of other time-series. When an ARIMA model includes other time-series as input variables, the model is sometimes referred to as an ARIMA *transfer function model*. In a *transfer function model*, instead of assuming the residuals are independent, the residuals can be represented by an autoregressive-moving average (ARMA) model (SAS, 2000).

For a conceptual model of the interactions of surface and groundwater along the Lower Rio Grande, the main variables of interest are: diversion, conveyance infiltration, deep percolation from irrigation, groundwater withdrawal, and precipitation, which control the return flow component of the river water budget. The variable with the largest effect on the interactions is diversion, so this is the time-series variable used for the input series in a *transfer function model* that predicts drain flows and reach net gains. Even though groundwater withdrawals can be significant, groundwater pumping is strongly correlated to diversions because groundwater pumping supplements the surface diversion, so using the diversion data will also indirectly account for the effects of groundwater pumping on return flow. It should be noted that the significant effects of groundwater pumping on the surface water delivered in the Rio Grande during an irrigation season must be accounted for either implicitly or explicitly.

Transfer function models for the relationships between diversions as the input series and drain-flow and river gain in the Rincon Reach and Mesilla Reach as the response series were derived. Monthly historic data from 1979 through 1999 were used for this analysis. No transfer function model was developed for the Leasburg Reach due to lack of data. One of the requirements for this type of analysis is that the variance values remain constant. If the variance is not constant, a natural log transform may be introduced to stabilize the variance. The data can also be shifted if there are zeroes in the data so that valid log values can be taken. Neither the log transform nor the shift of the data affects the correlation of the data, which is the main property used in the time-series analysis. Therefore, the flow data for some drains was assessed and then log transformed prior to performing the model estimation and forecasts by using the following equation:

$$Z = LN(Y + C) \tag{4-1}$$

where

Y = *drain flow (AF);*

Z = *natural log of (drain flow + C);*
C = *a constant added to the data series before taking the natural log.*

To retransform the forecast values for *Z* back to flow data *Y*, the following equation was used:

$$Y = \exp\left(Z + \frac{se^2}{2}\right) - C \qquad (4\text{-}2)$$

where

se = *the standard error of the forecast Z.*

The reason for this equation not being the exact inverse of a LN equation is that the equation gives a forecast for the median of the series, but underpredicts the mean of the original series when the forecast value is simply exponentiated to retransform the data back (Bradu and Mundlak, 1970). To predict the expected value of the series, the standard error of the forecast also needs to be taken into account (SAS, 2000).

For a *transfer function* model to be considered adequate, the coefficient of determination, R^2, of the historic values vs. the forecast values should be close to 1; and the residuals from the model should be independent and have the attributes of a "white noise process," that is,

1. Have mean = 0,
2. Have a constant variance about the mean, with most points within ± 2 standard errors (se), and
3. Have no observable pattern or trend in the data.

Note that in the forecast equations developed in the following sections, values for the forecast Z and for residuals in the observed months 1 through 24 cannot always be calculated. It is therefore assumed that these values are equal to 0 for these months. This will introduce a bias into the forecasts for the early months after month 24, so it is recommended to have at least several years of observed data before using the *transfer function* equations to forecast data.

This document assumes the reader has some familiarity with *transfer function* methods, and therefore will not provide detailed explanations for the results presented herein. For complete descriptions of *transfer function* and results, see Box and Jenkins (1976) and SAS (2000). The *SAS System for Windows, V9.1,* a statistical software package was used to develop the transfer function equations and estimate the model parameters.

Rincon Reach Transfer Functions

For the Rincon Reach transfer functions, the diversion to Arrey Canal at Percha Diversion Dam was used as the input series, and the response series for Garfield Drain, Hatch Drain, Rincon Drain and the Net Gain between Caballo Dam and Leasburg Dam were forecast. Monthly data from 1979 through 1999 were used for these analyses, with the drain return flow data being log transformed prior to the analysis. The actual Net Gain values were calculated as:

Net Gain = Rio Grande Above Leasburg – Rio Grande Below Caballo + Arrey Canal + Percha Lateral – Garfield Drain – Hatch Drain – Rincon Drain – WW#5 (Garfield Canal) – WW#16 (Hatch Canal) – WW#18 (Rincon Canal) (4-3)

A summary of the estimation results calculated by the SAS software for the sites in the Rincon Reach are shown in TABLE 2.

TABLE 2. SAS Estimation Results for the Rincon Reach

Parameter	*LN Garfield Drain*	*LN Hatch Drain*	*LN Rincon Drain*	*Caballo to Leasburg Gain*
θ_1 Estimate	0.72055	0.79007	0.62584	0.62557
φ_1 Estimate	0.54189	0.63503	0.66352	0.49761
φ_2 Estimate	0.22134	0.23539	NA	NA
ω_o Estimate	0.00005324	0.00004721	0.00002912	-0.31687
θ_1 Lag	12	12	12	12
φ_1 Lag	1	1	1	1
φ_2 Lag	11	10	NA	NA
ω_o Lag	0	0	0	0
Std Error Estimate	0.500462	0.317019	0.263484	3634.194
C	10	10	10	NA
Input Series	Arrey Canal	Arrey Canal	Arrey Canal	Arrey Canal

The *transfer function* models and resulting forecast equations for the Rincon reach are shown in TABLE 3.

TABLE 3. Transfer Function Models and Forecast Equations for the Rincon Reach

Response Series	*Transfer Function Model*	*Transfer Function Forecast Equation*
Garfield Drain	$(1-B^{12})Z_t = \omega_o(1-B^{12})X_t + \frac{(1-\theta_1 B^{12})}{(1-\phi_1 B)(1-\phi_2 B^{11})}a_t$	$\hat{Z}_n = Z_{n-12} + \phi_1(Z_{n-1} - Z_{n-13}) - \phi_1\phi_2(Z_{n-12} - Z_{n-24}) + \phi_2(Z_{n-11} - Z_{n-23}) + \omega_o[X_n - X_{n-12} - \phi_1(X_{n-1} - X_{n-13}) + \phi_1\phi_2(X_{n-12} - X_{n-24}) - \phi_2(X_{n-11} - X_{n-23})] - \theta_1(Z_{n-12} - \hat{Z}_{n-12})$
Hatch Drain	$(1-B^{12})Z_t = \omega_o(1-B^{12})X_t + \frac{(1-\theta_1 B^{12})}{(1-\phi_1 B)(1-\phi_2 B^{10})}a_t$	$\hat{Z}_n = Z_{n-12} + \phi_1(Z_{n-1} - Z_{n-13}) - \phi_1\phi_2(Z_{n-11} - Z_{n-23}) + \phi_2(Z_{n-10} - Z_{n-22}) + \omega_o[X_n - X_{n-12} - \phi_1(X_{n-1} - X_{n-13}) + \phi_1\phi_2(X_{n-11} - X_{n-23}) - \phi_2(X_{n-10} - X_{n-22})] - \theta_1(Z_{n-12} - \hat{Z}_{n-12})$

Response Series	*Transfer Function Model*	*Transfer Function Forecast Equation*
Rincon Drain	$\left(1-B^{12}\right)Z_t=\omega_o\left(1-B^{12}\right)X_t+\dfrac{\left(1-\theta_1 B^{12}\right)}{\left(1-\phi_1 B\right)}a_t$	$\hat{Z}_n=Z_{n-12}+\phi_1\left(Z_{n-1}-Z_{n-13}\right)+\omega_o\left[X_n-X_{n-12}-\phi_1(X_{n-1}-X_{n-13})\right]-\theta_1\left(Z_{n-12}-\hat{Z}_{n-12}\right)$
Caballo to Leasburg Net Gain	$\left(1-B^{12}\right)Y_t=\omega_o\left(1-B^{12}\right)X_t+\dfrac{\left(1-\theta_1 B^{12}\right)}{\left(1-\phi_1 B\right)}a_t$	$\hat{Y}_n=Y_{n-12}+\phi_1\left(Y_{n-1}-Y_{n-13}\right)+\omega_o\left[X_n-X_{n-12}-\phi_1\left(X_{n-1}-X_{n-13}\right)\right]-\theta_1\left(Y_{n-12}-\hat{Y}_{n-12}\right)$

where the model parameters are defined as:

a_t = *residuals at time period t, where*
$a_t = Z_t$ *(actual) -* Z_t *(forecast), or*
$a_t = Y_t$ *(actual) -* Y_t *(forecast)*

t = *time period;*
B = *back-shift operator, used to take differences over time of a value; For example:*

$$\left(1-B^{12}\right)Z_t=Z_t-Z_{t-12}$$

$$\left(1-\theta_1 B^{12}\right)a_t=a_t-\theta_1 a_{t-12}$$

C = *arbitrary constant to shift the data if any zeros are present;*
X_t = *diversion to Arrey Canal at time period t (AF);*
Y_t = *net gain at time period t;*
Z_t = *LN (response series flow + C) at time period t;*
θ_1 = *moving-average parameter for the residuals ARMA model;*
φ_1, φ_2 = *autoregressive parameters for the residuals ARMA model;*
ω_o = *regression coefficient for Arrey Canal.*

and where the forecast equation parameters are defined as:

i = *number of months of lag;*
n = *index of month;*
X_{n-i} = *Arrey Canal (AF) at month n-i;*
$\hat{Y}_n$ = *net gain for next month (AF);*
$\hat{Z}_n$ = *forecast for LN (response series flow + C) for next month (AF);*
Z_{n-i} = *LN (response series flow + C) at month n-i.*

Rincon Reach Results

The response series historic data were plotted along with the results of the SAS forecasts, giving the graph for Garfield Drain in FIGURE 5, the graph for Hatch Drain in FIGURE 6, the graph for Rincon Drain in FIGURE 7, and the graph for the Net Gain between Caballo and Leasburg in FIGURE 8. These graphs show that the one-step ahead forecasts for the drains track well with the historic data. The net gain forecast doesn't follow the historic data as closely as the drain forecasts because the diversion from the river does not take into account many of the groundwater and surface-water interaction processes. This limitation could influence results of the model simulation. Additional assessment on the impacts of such limitation is recommended.

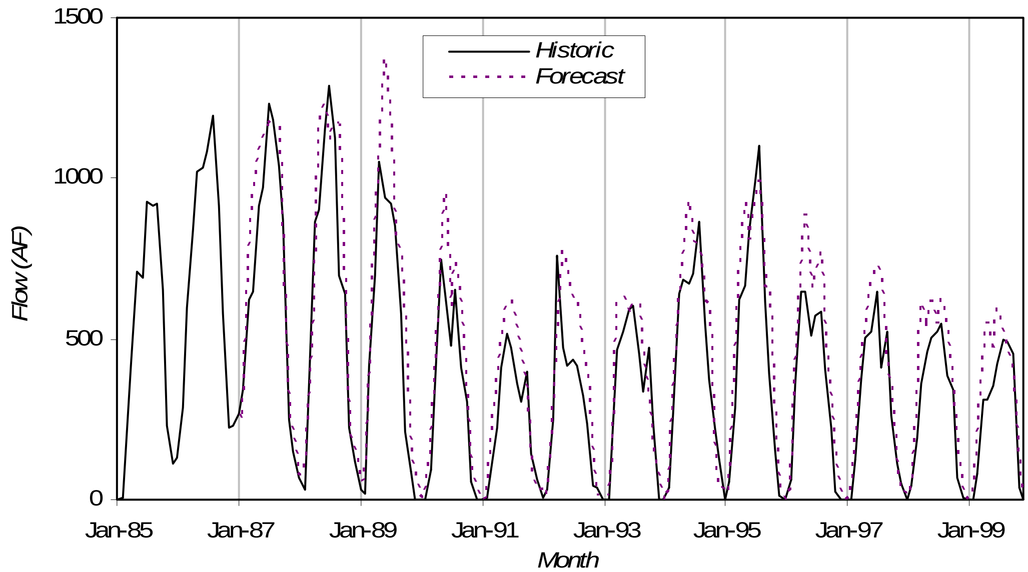

FIGURE 5. Transfer Function Forecast for Garfield Drain

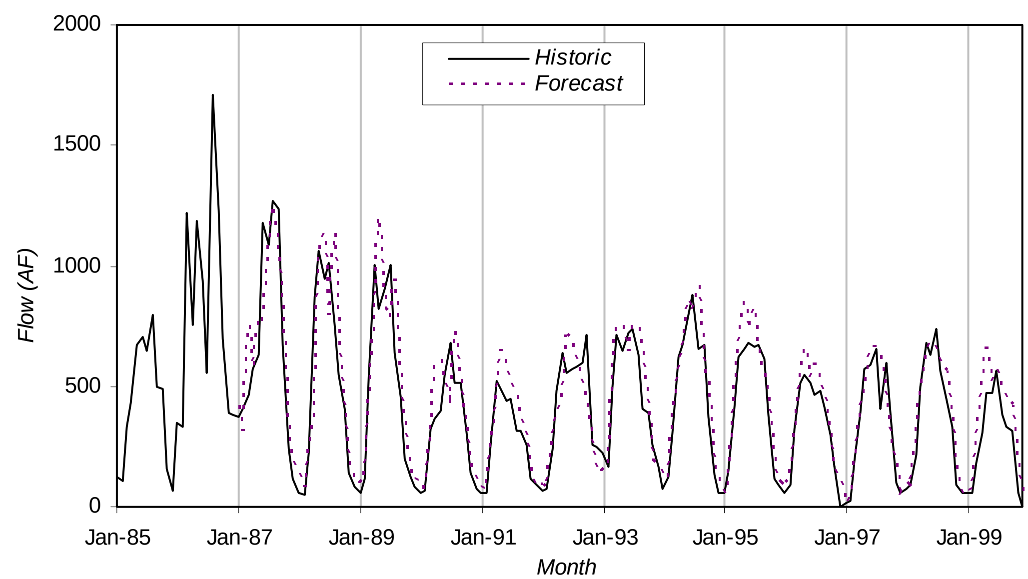

FIGURE 6. Transfer Function Forecast for Hatch Drain

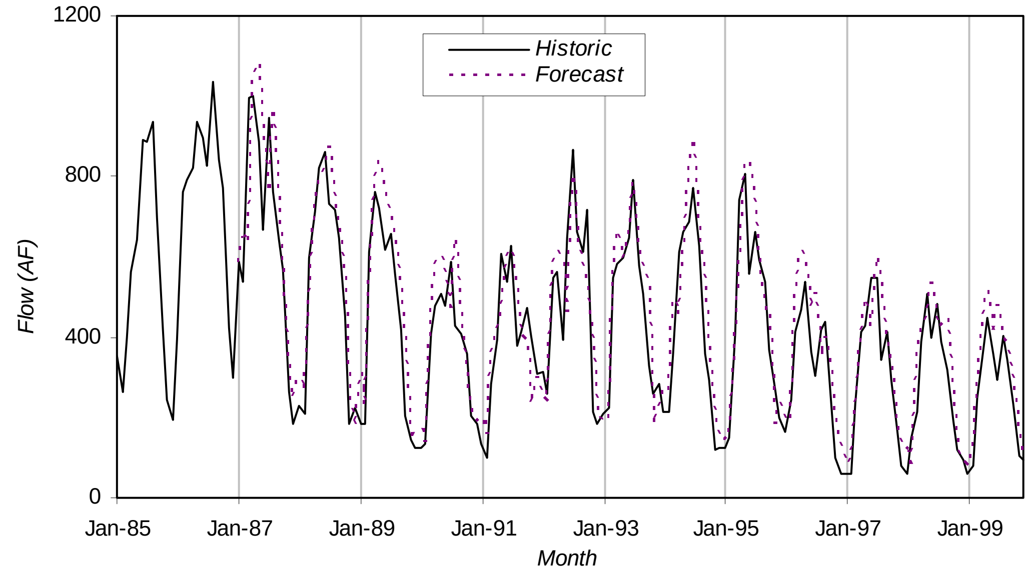

FIGURE 7. Transfer Function Forecast for Rincon Drain

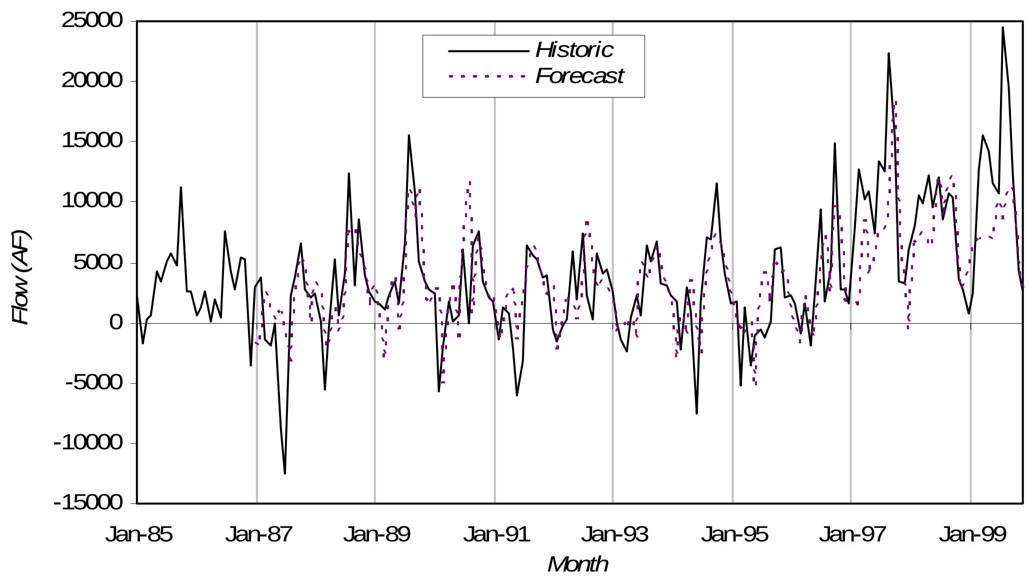

FIGURE 8. Transfer Function Forecast for Caballo to Leasburg Net Gain

Correlations of the forecast data vs. the historic data were done to check the model fit. In these correlations, a good fit of the model to the data is indicated when the R^2 value approaches one and the coefficient of the trend line with a zero offset approaches one. The correlation plots for Garfield Drain and Hatch Drain are shown in FIGURE 9, and for Rincon Drain and the net gain between Caballo and Leasburg in FIGURE 10.

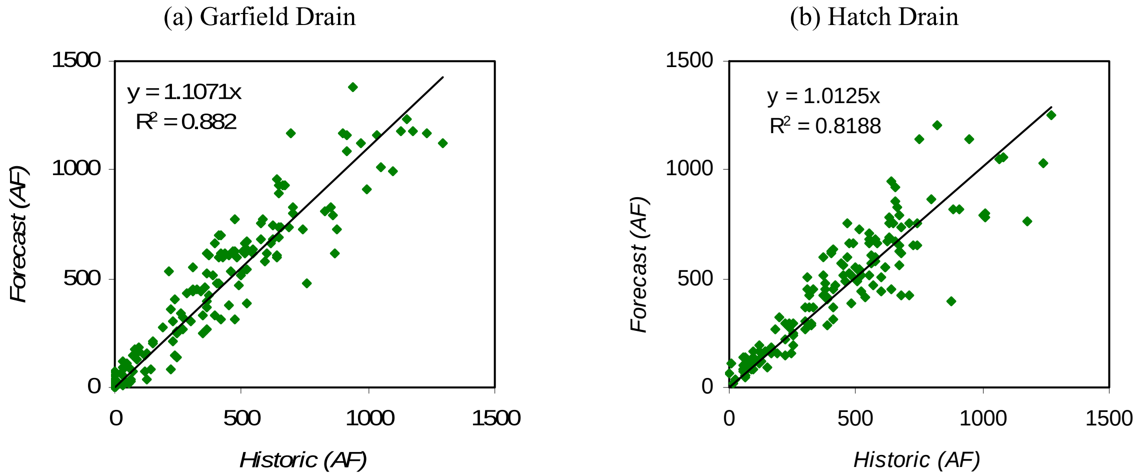

FIGURE 9. Correlations for Garfield and Hatch Drains

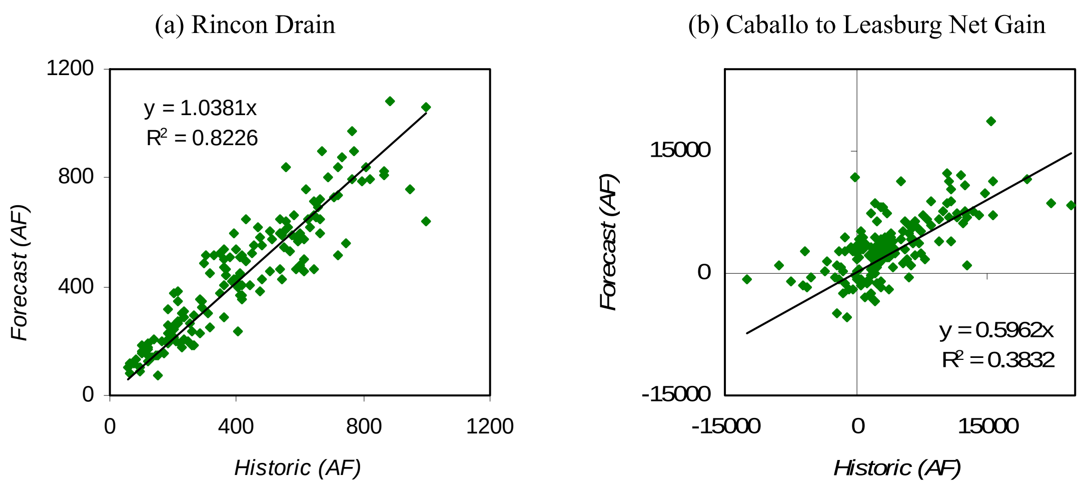

FIGURE 10. Correlations for Rincon Drain and Caballo to Leasburg Net Gain

These plots show that for the drains, the correlation trend coefficient is very close to one and the R^2 values are also quite high, indicating a good fit of these models to the data. Again the net gain correlation is not as good as for the drains, but this was expected due to other factors that influence the hydrologic process of the reach between the Caballo to Leasburg.

Finally the residuals of the observed/historic and forecast data were plotted to verify they meet the criteria for a “white noise process,” which is required for this statistical method to be appropriate. To be considered a white noise process, the residuals must have a mean close to zero with no obvious trend, must be mostly within 2 standard errors of the mean, and have no discernable pattern. Plots of the residuals for Garfield and Hatch Drains are shown in FIGURE 11, and for Rincon Drain and the Caballo to Leasburg Net Gain are shown in FIGURE 12. From these plots, it is evident that the residuals for the drains and for the net gain do meet the criteria for a white noise process, thereby further confirming the adequacy of the *transfer function* method for estimating these return flows from the diversion at Arrey Canal.

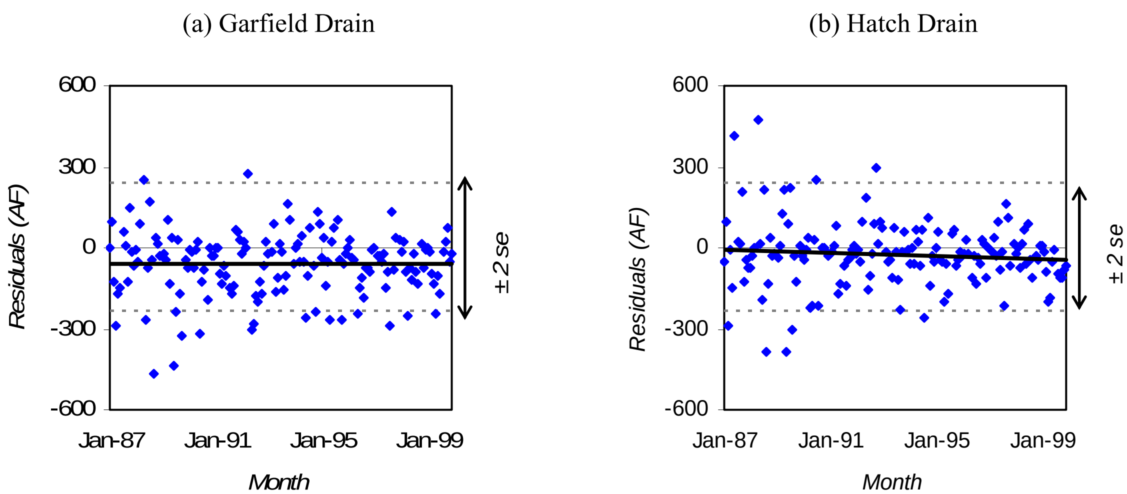

FIGURE 11. Residuals for Garfield and Hatch Drains

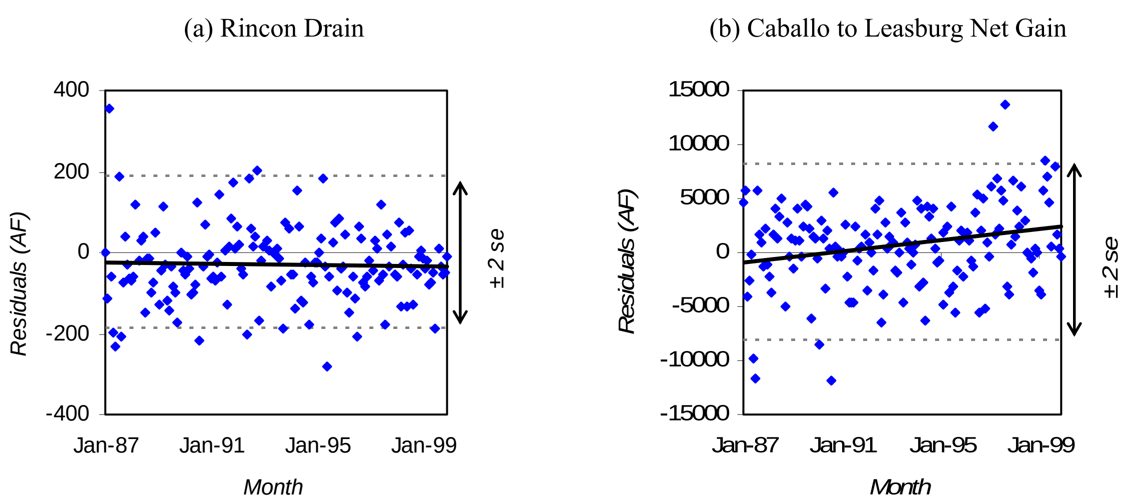

FIGURE 12. Residuals for Rincon Drain and the Caballo to Leasburg Net Gain

Mesilla Reach Transfer Functions

For the Mesilla Reach *transfer functions*, the diversion to the Eastside Canal at Mesilla Diversion Dam was used as the input series when Del Rio Drain or East Drain was the response series; and the diversion to the Westside Canal at Mesilla Diversion Dam was used as the input series when La Mesa Drain or Montoya Drain was the response series. Monthly data from 1979 through 1999 were used for these analyses, with the Del Rio Drain return flow data being log transformed prior to the analysis.

A summary of the estimation results calculated by the SAS software for the sites in the Mesilla Reach is shown in TABLE 4.

TABLE 4. SAS Estimation Results for the Mesilla Reach

Parameter	*LN Del Rio Drain*	*La Mesa Drain*	*East Drain*	*Montoya Drain*
θ_1 *Estimate*	0.21247	0.52316	0.75546	0.71856
φ_1 *Estimate*	0.65917	0.50600	0.62424	0.74617
φ_2 *Estimate*	0.12837	NA	0.22091	0.16715
ω_o *Estimate*	0.00002532	0.02566	0.07353	0.02853
θ_1 *Lag*	12	12	12	12
φ_1 *Lag*	1	1	1	1
φ_2 *Lag*	8	NA	11	12
ω_o *Lag*	0	0	0	0
Std Error Estimate	0.145104	266.1974	315.1792	410.6995
C	0	NA	NA	NA
Input Series	Eastside Canal	Westside Canal	Eastside Canal	Westside Canal

The *transfer function* models and resulting forecast equations for the Mesilla Reach are shown in TABLE 5.

TABLE 5. Transfer Function Models and Forecast Equations for the Mesilla Reach

Response Series	*Transfer Function Model*	*Transfer Function Forecast Equation*
Del Rio Drain	$(1-B^{12})Z_t = \omega_o(1-B^{12})X_t + \frac{(1-\theta_1 B^{12})}{(1-\phi_1 B)(1-\phi_2 B^8)}a_t$	$\hat{Z}_n = Z_{n-12} + \phi_1(Z_{n-1} - Z_{n-13}) + \phi_2(Z_{n-8} - Z_{n-20}) + \omega_o[X_n - X_{n-12} - \phi_1(X_{n-1} - X_{n-13}) - \phi_2(X_{n-8} - X_{n-20})] - \theta_1(Z_{n-12} - \hat{Z}_{n-12})$
La Mesa Drain	$(1-B^{12})Y_t = \omega_o(1-B^{12})X_t + \frac{(1-\theta_1 B^{12})}{(1-\phi_1 B)}a_t$	$\hat{Y}_n = Y_{n-12} + \phi_1(Y_{n-1} - Y_{n-13}) + \omega_o[X_n - X_{n-12} - \phi_1(X_{n-1} - X_{n-13})] - \theta_1(Y_{n-12} - \hat{Y}_{n-12})$
East Drain	$(1-B^{12})Y_t = \omega_o(1-B^{12})X_t + \frac{(1-\theta_1 B^{12})}{(1-\phi_1 B)(1-\phi_2 B^{11})}a_t$	$\hat{Y}_n = Y_{n-12} + \phi_1(Y_{n-1} - Y_{n-13}) + \phi_2(Y_{n-11} - Y_{n-23}) + \omega_o[X_n - X_{n-12} - \phi_1(X_{n-1} - X_{n-13}) - \phi_2(X_{n-11} - X_{n-23})] - \theta_1(Y_{n-12} - \hat{Y}_{n-12})$

Response Series	*Transfer Function Model*	*Transfer Function Forecast Equation*
Montoya Drain	$(1-B^{12})Y_t = \omega_o(1-B^{12})X_t + \frac{(1-\theta_1 B^{12})}{(1-\phi_1 B)(1-\phi_2 B^{12})} a_t$	$\hat{Y}_n = Y_{n-12} + \phi_1(Y_{n-1} - Y_{n-13}) + \phi_2(Y_{n-12} - Y_{n-24}) + \omega_o[X_n - X_{n-12} - \phi_1(X_{n-1} - X_{n-13}) - \phi_2(X_{n-12} - X_{n-24})] - \theta_1(Y_{n-12} - \hat{Y}_{n-12})$

where the model parameters are defined as:

X_t = *diversion to Eastside or Westside Canal at time period t (AF);*
Y_t = *response series return flow at time period t;*
ω_o = *regression coefficient for Eastside or Westside Canal.*

and where the forecast equation parameters are defined as:

X_{n-i} = *Eastside or Westside Canal (AF) at month n-i;*
$\hat{Y}_n$ = *Response series return flow for next month (AF);*
$\hat{Z}_n$ = *forecast for LN (response series flow + C) for next month (AF);*
Z_{n-i} = *LN (response series flow + C) at month n-i.*

Mesilla Reach Results

The response series historic data were plotted along with the results of the SAS forecasts, giving the graph for Del Rio Drain in FIGURE 13, La Mesa Drain in FIGURE 14, East Drain in FIGURE 15, and Montoya Drain in FIGURE 16. These graphs show that the one-step ahead forecasts for the drains track well with the historic data.

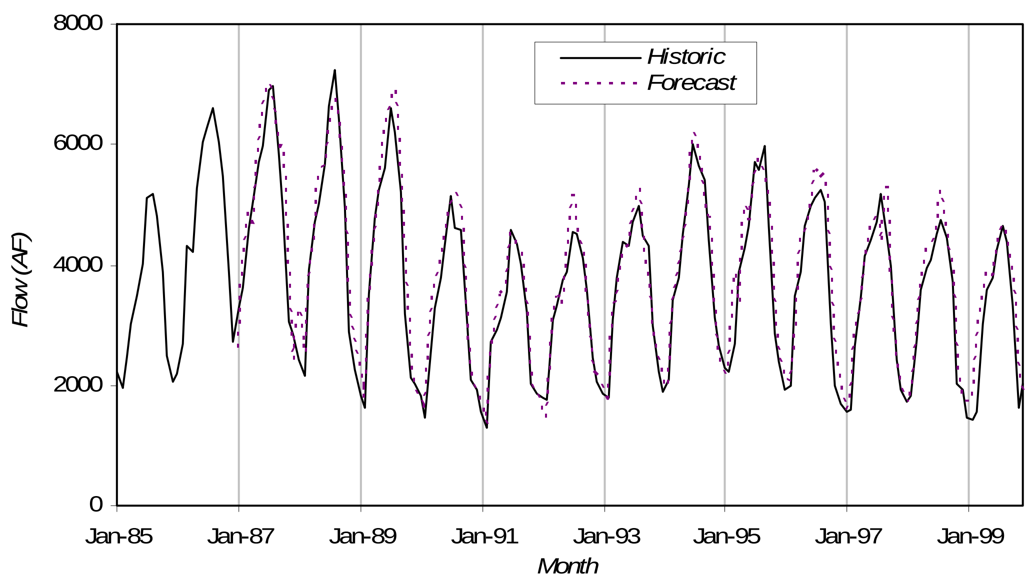

FIGURE 13. Transfer Function Forecast for Del Rio Drain

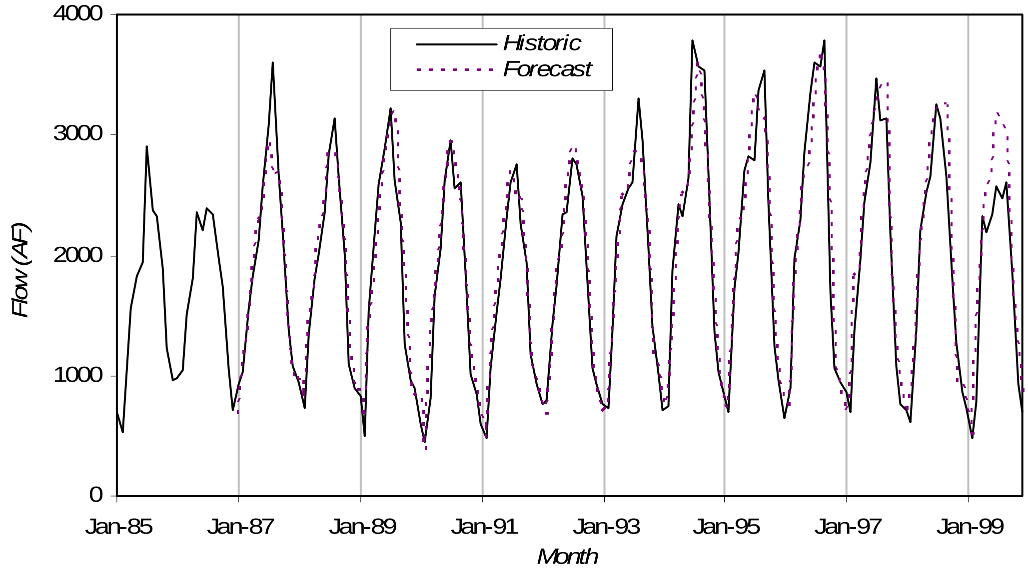

FIGURE 14. Transfer Function Forecast for La Mesa Drain

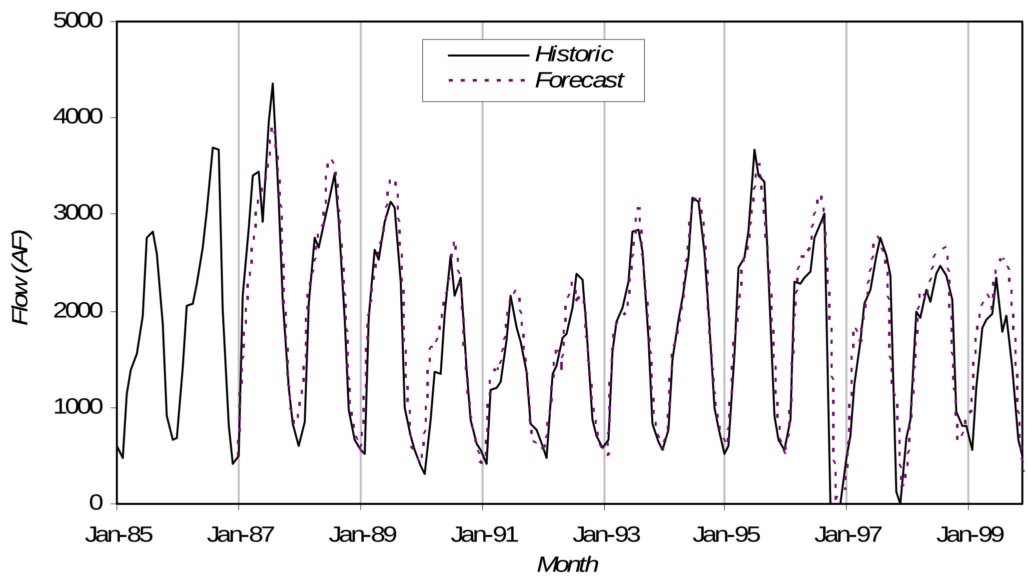

FIGURE 15. Transfer Function Forecast for East Drain

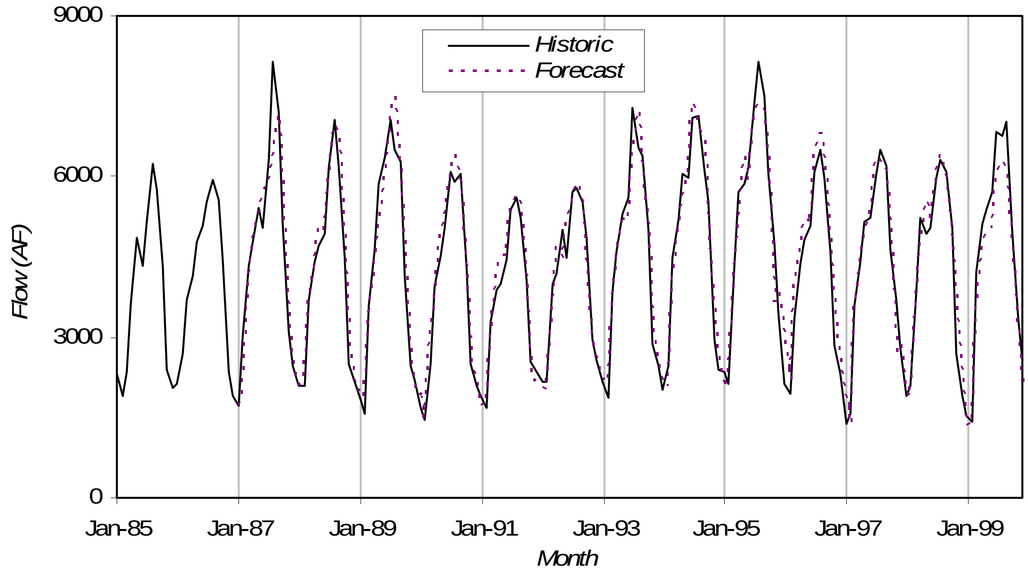

FIGURE 16. Transfer Function Forecast for Montoya Drain

Correlations of the forecast data vs. the historic data were done to check the model fit. The correlation plots for Del Rio Drain and La Mesa Drain are shown in FIGURE 17, and for East Drain and Montoya Drain in FIGURE 18. These plots show that the correlation trend coefficients are very close to one and the R^2 values are also quite high, indicating a good fit of these models to the data.

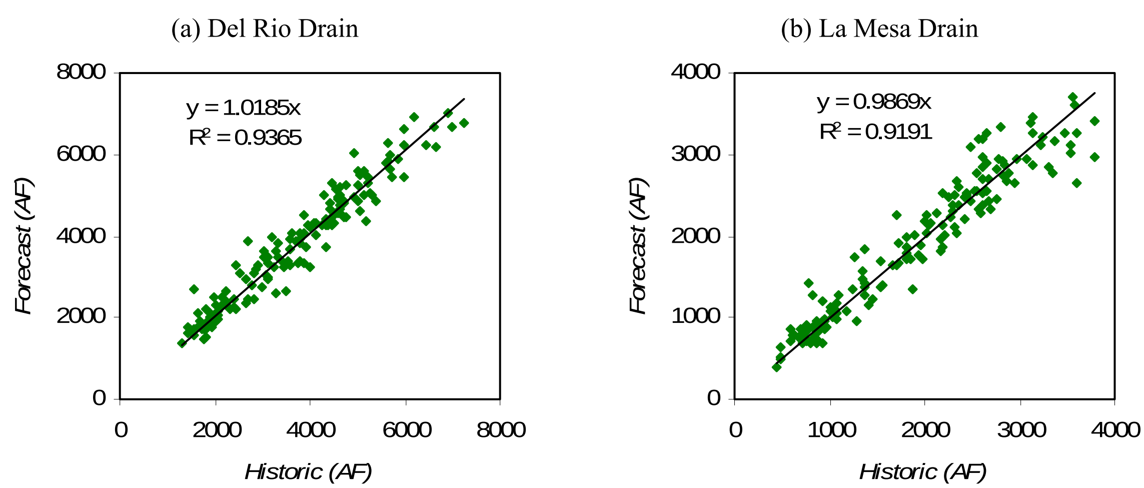

FIGURE 17. Correlations for Del Rio and La Mesa Drains

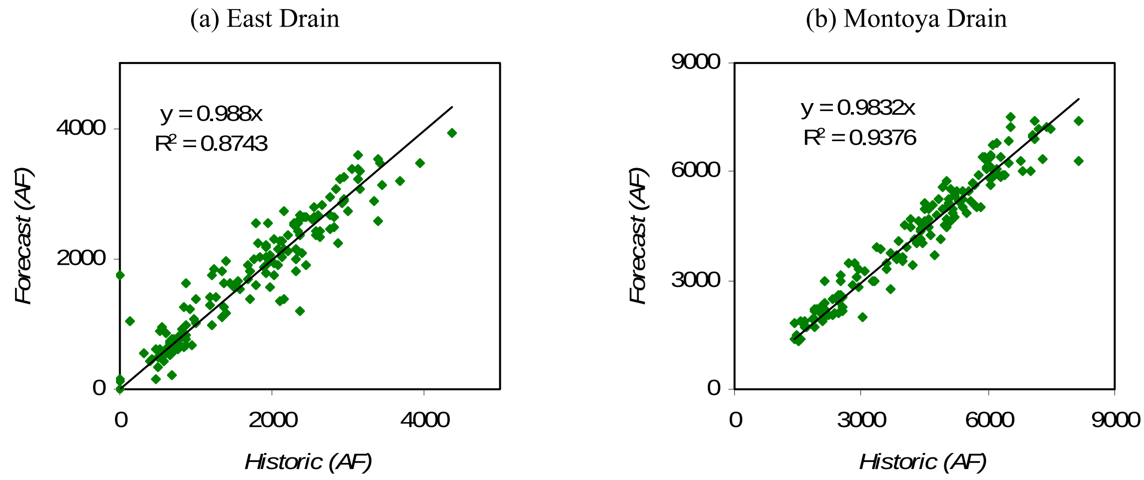

FIGURE 18. Correlations for East and Montoya Drains

Finally the residuals of the historic and forecast data were plotted to verify they meet the criteria for a white noise process. Plots of the residuals for Del Rio and La Mesa Drains are shown in FIGURE 19, and for East and Montoya Drains are shown in FIGURE 20. From these plots, it is evident that the residuals meet the criteria for a white noise process, thereby further confirming the adequacy of the *transfer function* method for estimating these return flows from the diversions at the Eastside and Westside Canals.

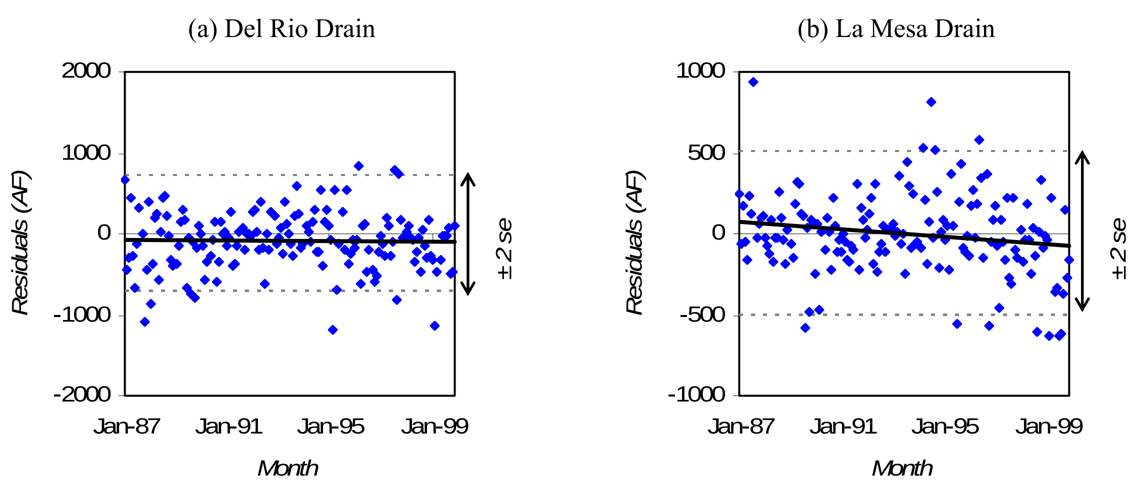

FIGURE 19. Residuals for Del Rio and La Mesa Drains

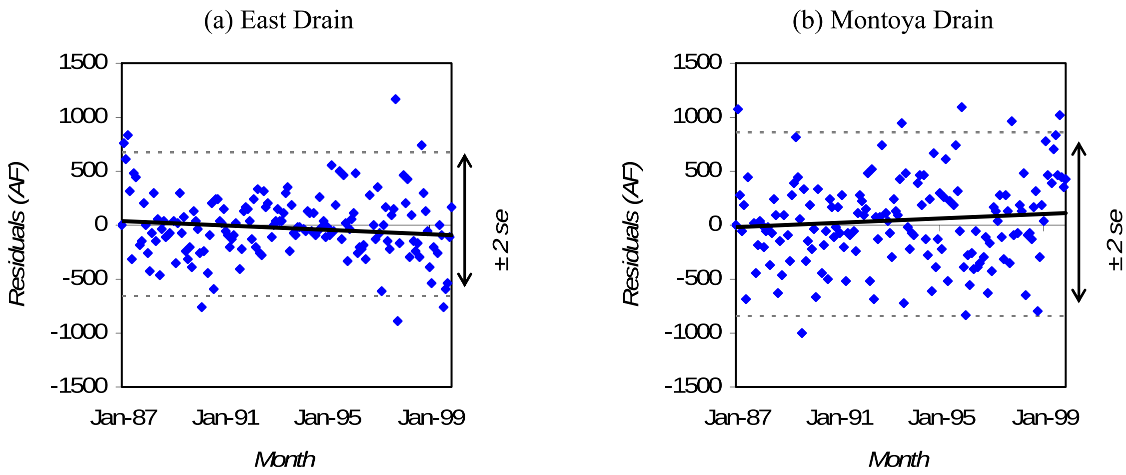

FIGURE 20. Residuals for East and Montoya Drains

RiverWare Physical Model Development

For the development of the RiverWare physical model of the Lower Rio Grande, the time period used was January 1985 through December 1999, verified with the observed data for 1985 through 1998.

All input and output data are monthly in units of acre-feet/month. The input data are transformed to a dimensionless form for processing in the *transfer function* equations. The results from these equations are then transformed back to units of acre-feet/month for the links to the inflow and outflow nodes on the RiverWare objects. This is necessary for two reasons: 1) to circumvent RiverWare's automatic conversions on monthly data based on the number of days in the month, and 2) the exponential function does not work with units of acre-feet/month on the value to be exponentiated.

Forecasts are made for the drains and net gain in the Rincon reach using the Arrey Canal flow as the input series. Forecasts are made for the drains in the Mesilla Reach using the Eastside or Westside Canal flow as the input series.

Expressions in data objects, a container for user-defined data to be imported to or exported from RiverWare were initially used to do the calculations for the transfer functions. This resulted in some problems related to what order the expressions were evaluated in. Also, the resulting slots would be designated as output-type slots, which when linked to the diversion object didn't produce results for the last time step of the model run. To make sure the equations were executed in the proper order and that valid values were produced for all time steps, rules, the specifications of prioritized "if-then" operating policy statement to drive the simulation, were added to the model as a means of performing these calculations.

RiverWare Model Layout

The layout for the RiverWare model includes objects for the gage stations, diversions, drain and wasteway return flows, flow at the river stations and data objects for the calculated values. The net gain is calculated by the model to account for the gain or losses within the reach. The layout for the Rincon Reach is shown in FIGURE 21.

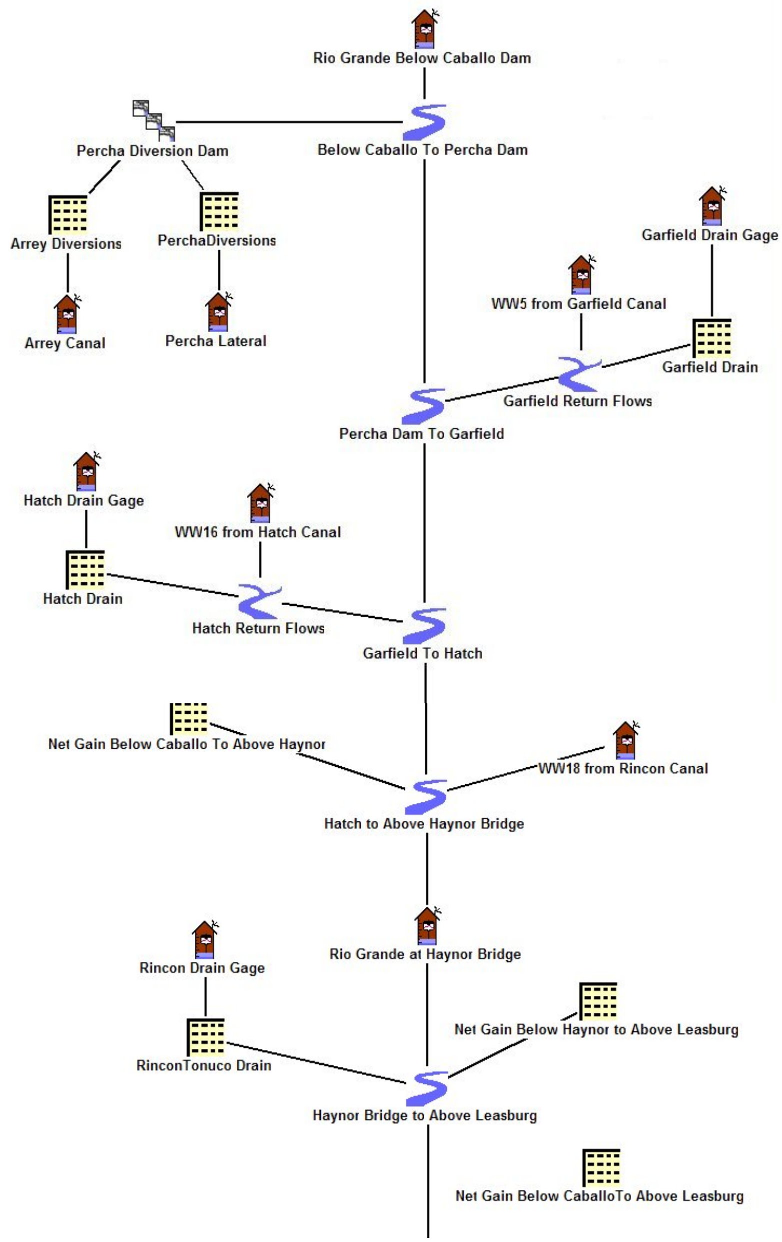

FIGURE 21. RiverWare Layout for Rincon Reach

The layout for the Leasburg Reach is shown in FIGURE 22.

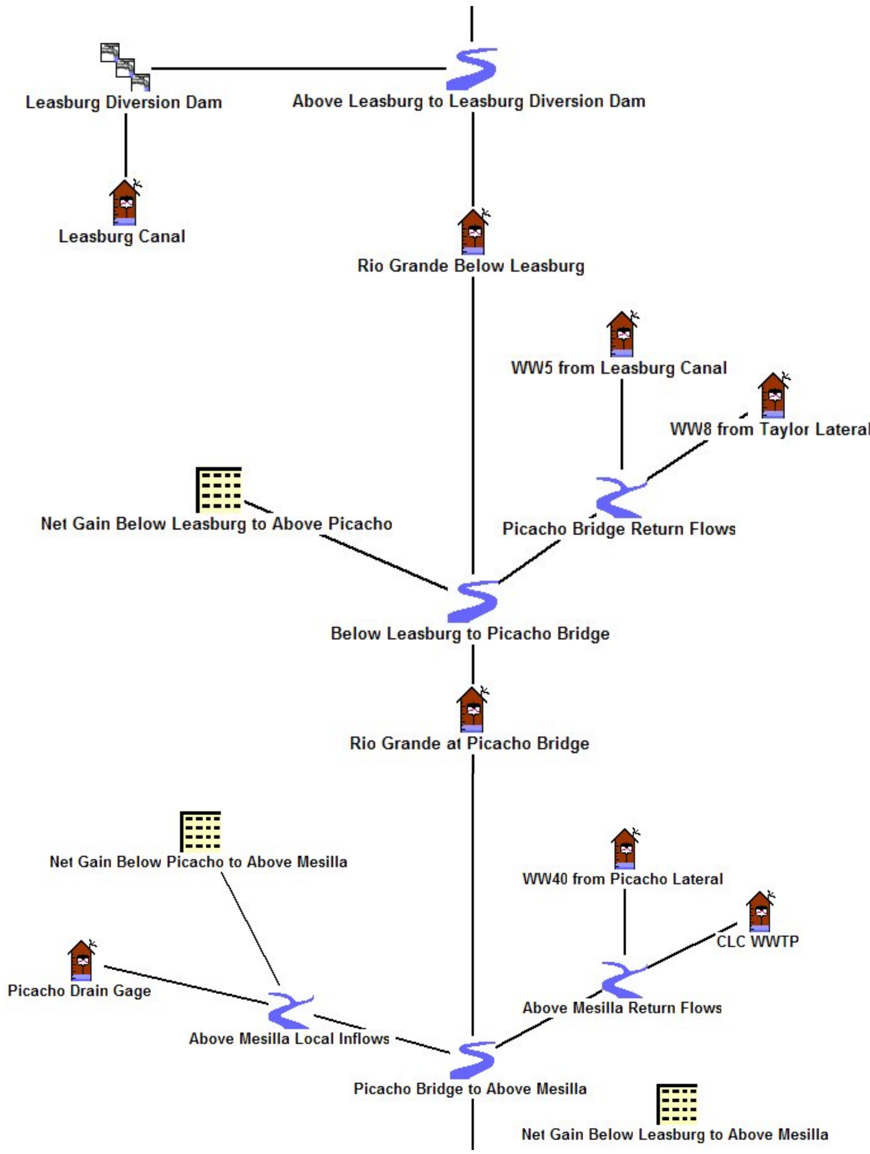

FIGURE 22. RiverWare Layout for Leasburg Reach

The layout for the Mesilla Reach to above the Anthony Bridge gage is shown in FIGURE 23 and for the Mesilla Reach from Anthony Bridge to El Paso is shown in FIGURE 24.

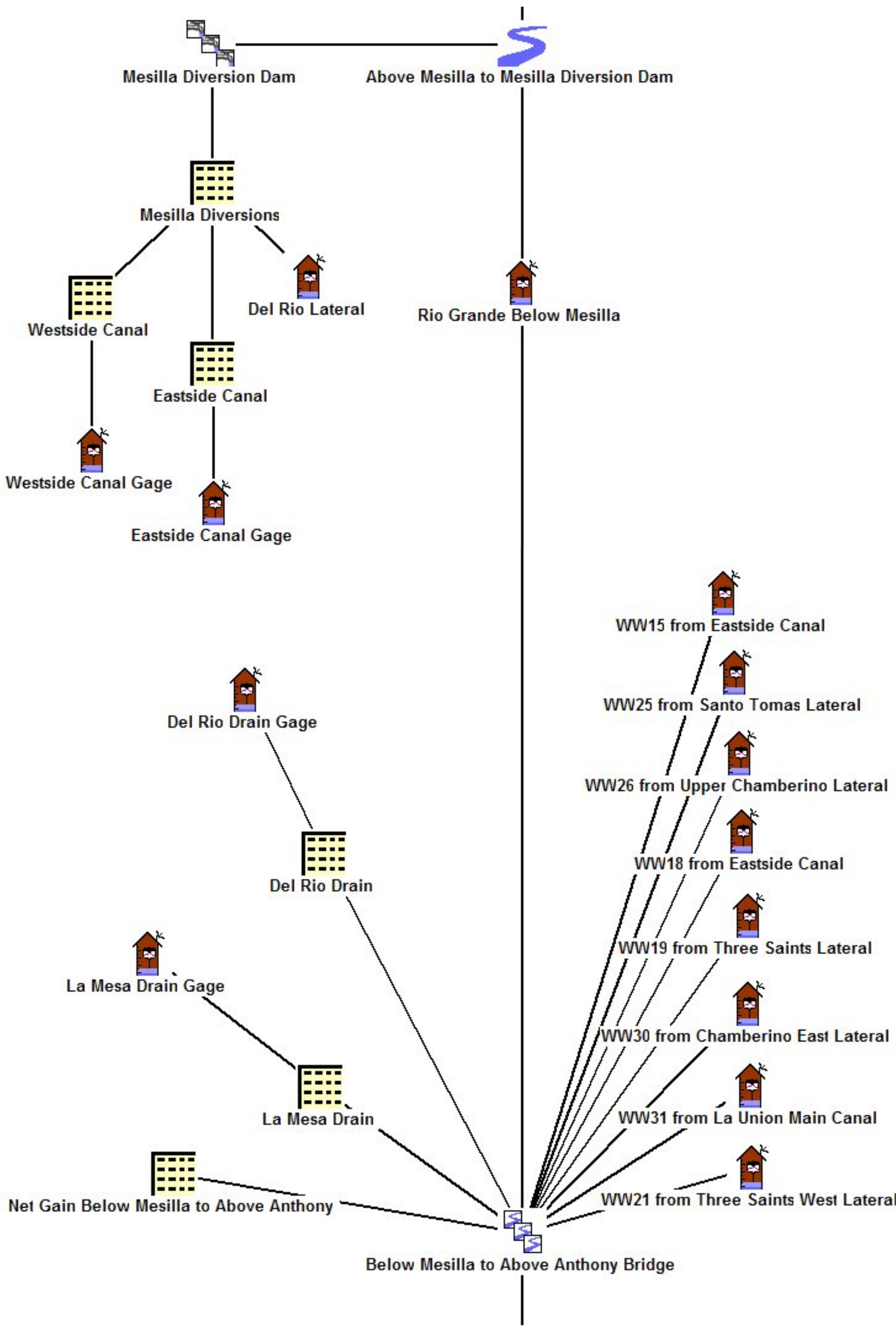

FIGURE 23. RiverWare Layout for Mesilla Reach to Above Anthony Bridge

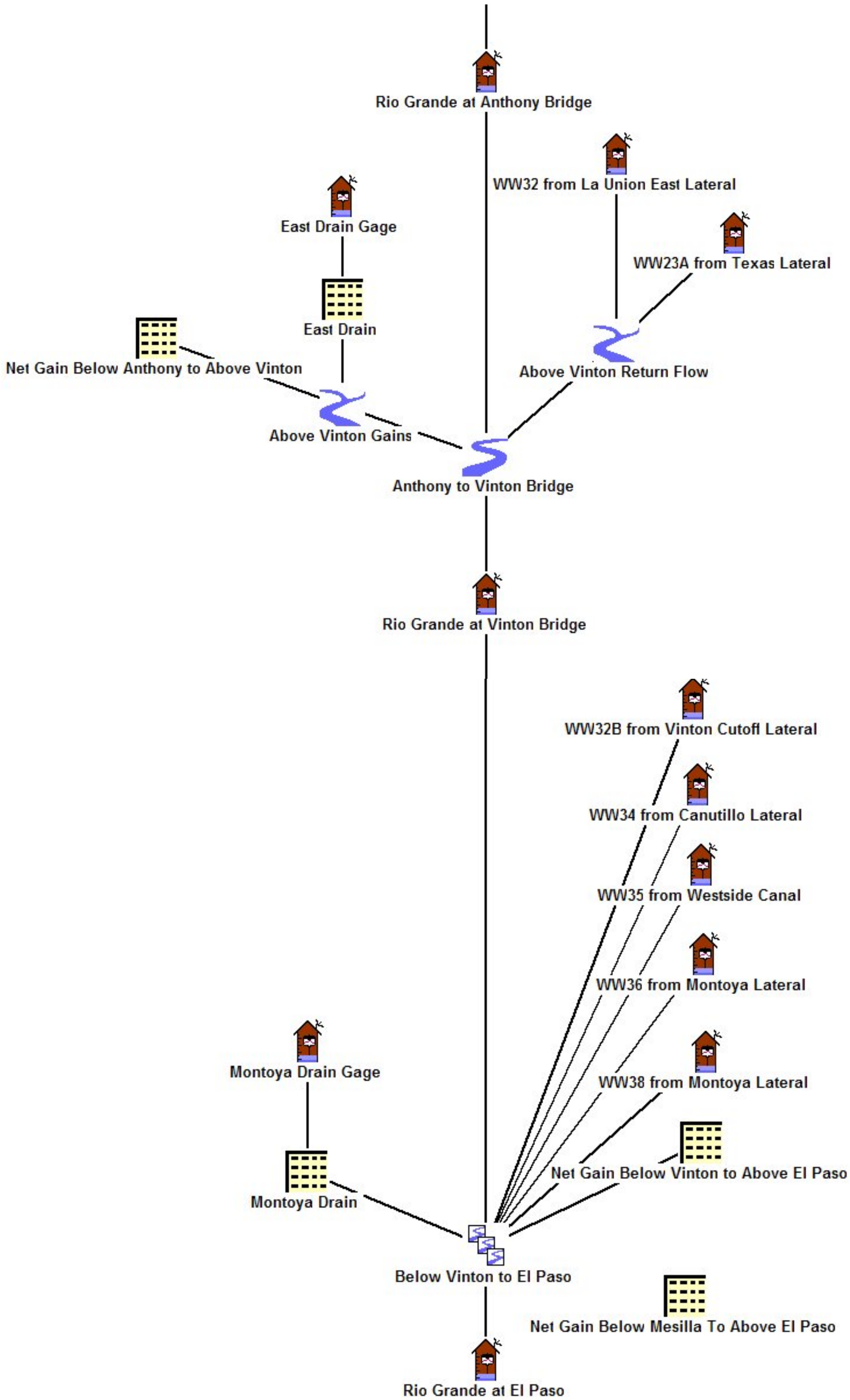

FIGURE 24. RiverWare Layout for Mesilla Reach from Anthony Bridge to El Paso

Input Data

The following locations in the model are specified as input data and require monthly historic data for the entire time span of the model, which currently is 1985 through 1999:

a. Rincon Reach
   - River Below Caballo Dam
   - Arrey Canal
   - Percha Lateral
   - WW #5 (Garfield Canal)
   - WW #16 (Hatch Canal)
   - WW #18 (Rincon Canal)

b. Leasburg Reach
   - Leasburg Canal
   - WW #5 (Leasburg Canal)
   - WW#8 (Taylor Lateral)
   - City of Las Cruces Wastewater Treatment Plant (CLC WWTP)
   - WW #40 (Picacho Lateral)
   - Picacho Drain
   - Net Gain Below Leasburg to Above Mesilla Diversion Dam

c. Mesilla Reach
   - Westside Canal
   - Eastside Canal
   - Del Rio Lateral
   - WW #15 (Eastside Canal)
   - WW #25 (Santo Tomas Lateral)
   - WW #26 (Upper Chamberino Lateral)
   - WW #18 (Eastside Canal)
   - WW #19 (Three Saints Lateral)
   - WW #30 (Chamberino East Lateral)
   - WW #31 (La Union Main Canal)
   - WW #21 (Three Saints West Lateral)
   - WW #32 (La Union East Lateral)
   - WW #23A (Texas Lateral)
   - WW #32B (Vinton Cutoff Lateral)
   - WW #34 (Canutillo Lateral)
   - WW #35 (Westside Canal)
   - WW #36 (Montoya Lateral)
   - WW #38 (Montoya Lateral)
   - Net Gain Below Mesilla Diversion Dam to El Paso

The following locations in the model use the *transfer functions* to forecast data, and require monthly historic data for at least the first two years of the model time span, which is currently 1985 through 1987. The forecast equations also require previous forecast results for the prior year, so for the forecasts for 1987, previous forecast data for 1986 is required. These values are not calculated by this RiverWare model, so they are required input values taken from the results of the SAS estimation runs.

a. Rincon Reach
   - Garfield Drain
   - Hatch Drain
   - Rincon Drain
   - Net Gain Below Caballo Dam to Above Leasburg Diversion Dam

b. Leasburg Reach
   - None currently

c. Mesilla Reach
   - Del Rio Drain
   - La Mesa Drain
   - East Drain
   - Montoya Drain

The following locations in the model calculate intermediate net gain values for the reaches, and don't require any historic input data:

a. Rincon Reach
   - Net Gain Below Caballo Dam to Above Haynor
   - Net Gain Below Haynor to Above Leasburg Diversion Dam

b. Leasburg Reach
   - Net Gain Below Leasburg Diversion Dam to Above Picacho Bridge
   - Net Gain Below Picacho to Above Mesilla Diversion Dam

c. Mesilla Reach
   - Net Gain Below Mesilla Diversion Dam to Above Anthony
   - Net Gain Below Anthony to Above Vinton
   - Net Gain Below Vinton to Above El Paso

The following river stations are represented by the model and output is provided for these locations:

a. Rincon Reach
   - River at Haynor Bridge
   - River Above Leasburg Diversion Dam

b. Leasburg Reach

- River Below Leasburg Diversion Dam
- River at Picacho Bridge
- River Above Mesilla Diversion Dam

c. Mesilla Reach
- River Below Mesilla Diversion Dam
- River at Anthony Bridge
- River at Vinton Bridge
- River at El Paso

A Data Management Interface (DMI) control file has been created that will input all of the necessary input data to the model. The content of this control file is shown below:

```
Arrey Canal.Gage Inflow: file=~/ArreyCanal1985.Div
CLC WWTP.Gage Inflow: file=~/CLCWWTP1985.RetFlow
Del Rio Drain Gage.Gage Inflow: file=~/DelRioDrain1985.RetFlow
Del Rio Lateral.Gage Inflow: file=~/DelRioLateral1985.Div
East Drain Gage.Gage Inflow: file=~/EastDrain1985.RetFlow
Eastside Canal Gage.Gage Inflow: file=~/EastsideCanal1985.Div
Garfield Drain Gage.Gage Inflow: file=~/GarfieldDrain1985.RetFlow
Hatch Drain Gage.Gage Inflow: file=~/HatchDrain1985.RetFlow
La Mesa Drain Gage.Gage Inflow: file=~/LaMesaDrain1985.RetFlow
Leasburg Canal.Gage Inflow: file=~/LeasburgCanal1985.Div
Montoya Drain Gage.Gage Inflow: file=~/MontoyaDrain1985.RetFlow
Percha Lateral.Gage Inflow: file=~/PerchaLateral1985.Div
Picacho Drain Gage.Gage Inflow: file=~/PicachoDrain1985.RetFlow
Rincon Drain Gage.Gage Inflow: file=~/RinconDrain1985.RetFlow
Rio Grande Below Caballo Dam.Gage Inflow: file=~/RiverBelowCaballo1985.Outflow
Westside Canal Gage.Gage Inflow: file=~/WestsideCanal1985.Div
WW15 from Eastside Canal.Gage Inflow: file=~/WW15_Eastside1985.RetFlow
WW16 from Hatch Canal.Gage Inflow: file=~/WW16_Hatch1985.RetFlow
WW18 from Eastside Canal.Gage Inflow: file=~/WW18_Eastside1985.RetFlow
WW18 from Rincon Canal.Gage Inflow: file=~/WW18_Rincon1985.RetFlow
WW19 from Three Saints Lateral.Gage Inflow: file=~/WW19_ThreeSaints1985.RetFlow
WW21 from Three Saints West Lateral.Gage Inflow: file=~/WW21_ThreeSaintsWest1985.RetFlow
WW23A from Texas Lateral.Gage Inflow: file=~/WW23A_Texas1985.RetFlow
WW25 from Santo Tomas Lateral.Gage Inflow: file=~/WW25_SantoTomas1985.RetFlow
WW26 from Upper Chamberino Lateral.Gage Inflow: file=~/WW26_UpperChamberino1985.RetFlow
WW30 from Chamberino East Lateral.Gage Inflow: file=~/WW30_ChamberinoEast1985.RetFlow
WW31 from La Union Main Canal.Gage Inflow: file=~/WW31_LaUnion1985.RetFlow
WW32 from La Union East Lateral.Gage Inflow: file=~/WW32_LaUnionEast1985.RetFlow
WW32B from Vinton Cutoff Lateral.Gage Inflow: file=~/WW32B_VintonCutoff1985.RetFlow
WW34 from Canutillo Lateral.Gage Inflow: file=~/WW34_Canutillo1985.RetFlow
WW35 from Westside Canal.Gage Inflow: file=~/WW35_Westside1985.RetFlow
WW36 from Montoya Lateral.Gage Inflow: file=~/WW36_Montoya1985.RetFlow
WW38 from Montoya Lateral.Gage Inflow: file=~/WW38_Montoya1985.RetFlow
WW40 from Picacho Lateral.Gage Inflow: file=~/WW40_Picacho1985.RetFlow
WW5 from Garfield Canal.Gage Inflow: file=~/WW5_Garfield1985.RetFlow
WW5 from Leasburg Canal.Gage Inflow: file=~/WW5_Leasburg1985.RetFlow
WW8 from Taylor Lateral.Gage Inflow: file=~/WW8_Taylor1985.RetFlow
Arrey Diversions.PrevForecast: file=~/ArreyPrev1986.Div
Del Rio Drain.PrevForecast: file=~/DelRioDrainprev1986.RetFlow
```

East Drain.PrevForecast: file=~/EastDrainPrev1986.RetFlow
Garfield Drain.PrevForecast: file=~/GarfieldPrev1986.RetFlow
Hatch Drain.PrevForecast: file=~/HatchPrev1986.RetFlow
La Mesa Drain.PrevForecast: file=~/LaMesaDrainPrev1986.RetFlow
Montoya Drain.PrevForecast: file=~/MontoyaDrainPrev1986.RetFlow
RinconTonuco Drain.PrevForecast: file=~/RinconPrev1986.RetFlow
Net Gain Below CaballoTo Above Leasburg.Historic: file=~/CaballoToLeasburg1985.Gain
Net Gain Below CaballoTo Above Leasburg.PrevForecast: file=~/CabToLeasburgPrev1986.Gain
Net Gain Below Leasburg to Above Mesilla.Historic: file=~/LeasburgToMesilla1985.Gain
Net Gain Below Mesilla To Above El Paso.Historic: file=~/MesillaToElPaso1985.Gain

Output Data

Individual output files can be produced for the stations that have calculated values and for the river stations, as listed below:

a. Rincon Reach
   - Garfield Drain
   - Hatch Drain
   - Rincon Drain
   - Rio Grande at Haynor Bridge
   - Intermediate Net Gain Below Caballo Dam to Haynor Bridge
   - Intermediate Net Gain Below Haynor Bridge to Above Leasburg Diversion Dam
   - Total Net Gain Below Caballo Dam to Above Leasburg Diversion Dam

b. Leasburg Reach
   - Rio Grande at Picacho Bridge
   - Intermediate Net Gain Below Leasburg Diversion Dam to Above Picacho Bridge
   - Intermediate Net Gain Below Picacho Bridge to Above Mesilla Diversion Dam
   - Total Net Gain Below Leasburg Diversion Dam to Above Mesilla Diversion Dam

c. Mesilla Reach
   - Del Rio Drain
   - La Mesa Drain
   - East Drain
   - Montoya Drain
   - Rio Grande at Anthony Bridge
   - Rio Grande at Vinton Bridge
   - Rio Grande at El Paso
   - Net Gain Below Mesilla to Above Anthony Bridge
   - Net Gain Below Anthony Bridge to Above Vinton Bridge
   - Net Gain Below Vinton Bridge to Above El Paso

A DMI control file has been created to produce these output files. The content of this control file is shown below:

Del Rio Drain.Forecast: file=~/%o.%s
Garfield Drain.Forecast: file=~/%o.%s
Hatch Drain.Forecast: file=~/%o.%s
Net Gain Below Caballo To Above Haynor.Forecast: file=~/%o.%s
RinconTonuco Drain.Forecast: file=~/%o.%s
Net Gain Below Haynor to Above Leasburg.Forecast: file=~/%o.%s
Net Gain Below CaballoTo Above Leasburg.Forecast: file=~/%o.%s
Net Gain Below Leasburg to Above Picacho.Forecast: file=~/%o.%s
Net Gain Below Picacho to Above Mesilla.Forecast: file=~/%o.%s
Del Rio Drain.Forecast: file=~/%o.%s
La Mesa Drain.Forecast: file=~/%o.%s
Net Gain Below Mesilla to Above Anthony.Forecast: file=~/%o.%s
East Drain.Forecast: file=~/%o.%s
Net Gain Below Anthony to Above Vinton.Forecast: file=~/%o.%s
Montoya Drain.Forecast: file=~/%o.%s
Net Gain Below Vinton to Above El Paso.Forecast: file=~/%o.%s
Rio Grande at Haynor Bridge.Gage Outflow: file=~/%o.%s
Rio Grande Below Leasburg.Gage Outflow: file=~/%o.%s
Rio Grande at Picacho Bridge.Gage Outflow: file=~/%o.%s
Rio Grande Below Mesilla.Gage Outflow: file=~/%o.%s
Rio Grande at Anthony Bridge.Gage Outflow: file=~/%o.%s
Rio Grande at Vinton Bridge.Gage Outflow: file=~/%o.%s
Rio Grande at El Paso.Gage Outflow: file=~/%o.%s

RiverWare System Control Tables (SCTs) were also developed for each reach, and contain slots for all historic input data, all forecast data, and all river stations. The contents of the SCTs can be exported to Excel Spreadsheets that were developed to match the contents of the SCTs. A sample view for the Mesilla Reach SCT is shown in FIGURE 25, and the corresponding Excel Spreadsheet tab is shown in FIGURE 26.

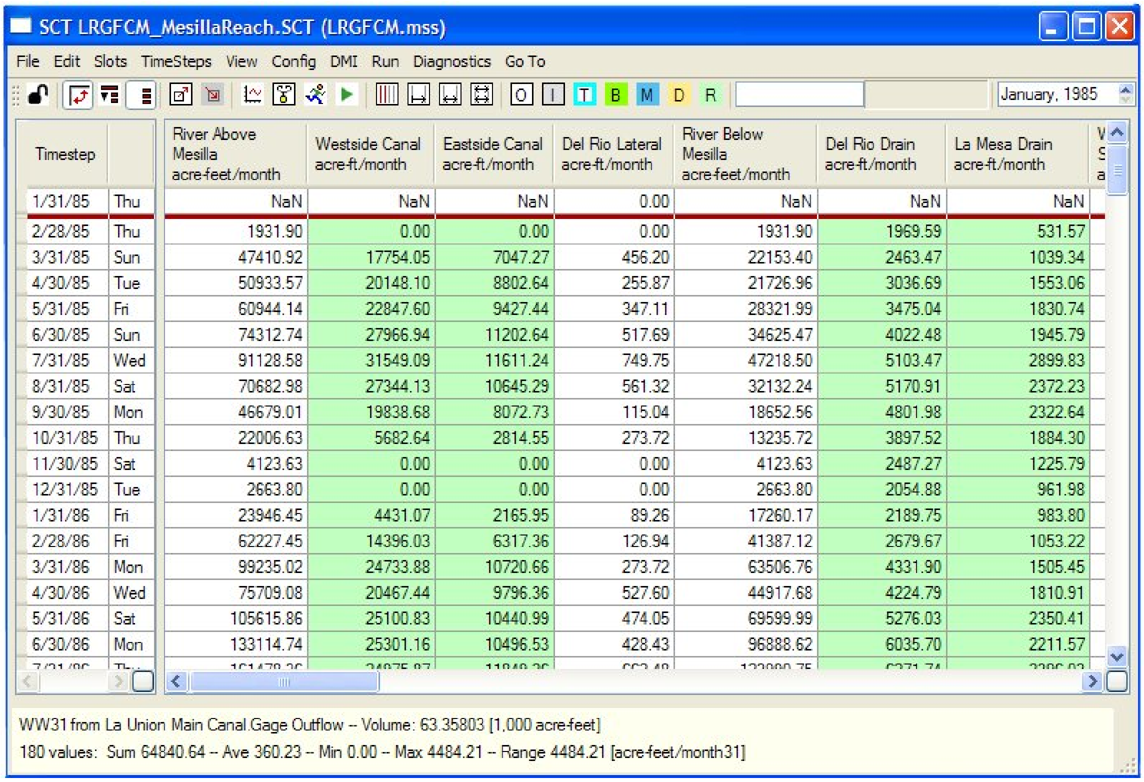

FIGURE 25. Sample of Mesilla Reach SCT

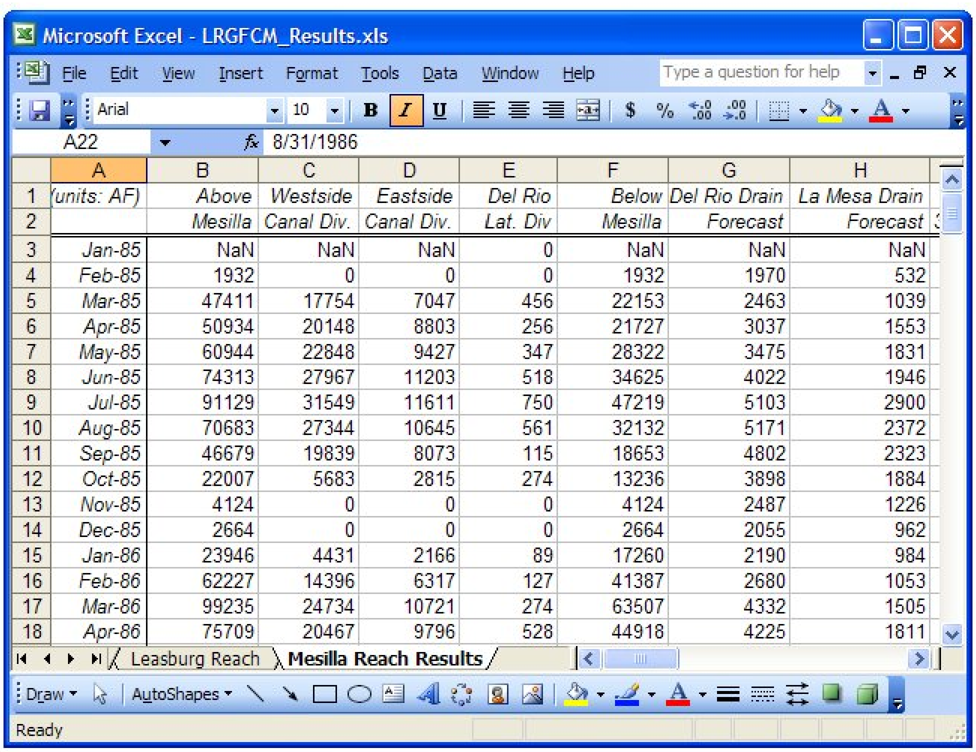

FIGURE 26. Sample of Mesilla Reach Excel Tab

Intermediate Net Gain Equations

The equations used to calculate the intermediate net gains at the river stations within reaches are described in this section. Generally, there is insufficient data for these intermediate net gains to perform a *transfer function* analysis for them. Instead, a simple proportion was applied to get the intermediate net gain values based on the net gain for the entire reach. An approximate percent of the physical extent of the intermediate reach was multiplied by the total net gain for the reach. For example, the distance between Caballo Dam and Haynor Bridge is approximately 75% of the distance between Caballo Dam and Leasburg Diversion Dam, so this percent was multiplied by the total net gain term to get the Net Gain Below Caballo Dam to Haynor Bridge.

The intermediate net gain equation is therefore:

$$\hat{Y}_n = p\,\hat{X}_n \qquad (5\text{-}1)$$

where

p = *fraction representing the percent of the physical extent of the reach that is in the intermediate reach;*

$\hat{Y}_n$ = *estimate for intermediate net gain (AF);*

$\hat{X}_n$ = *total net gain for the reach, either forecast using a transfer function in the Rincon Reach, or the historic values for net gain in the Leasburg and Mesilla Reaches (AF).*

The intermediate reaches and their percents of the total reach are show in TABLE 6:

TABLE 6. Reach Percents for Intermediate Net Gains

Reach	*Intermediate Reach*	*Percent (%)*
Rincon	Below Caballo to Haynor Bridge	75
	Below Haynor Bridge to Above Leasburg	25
Leasburg	Below Leasburg to Picacho Bridge	70
	Below Picacho Bridge to Above Mesilla	30
Mesilla	Below Mesilla to Anthony Bridge	60
	Below Anthony Bridge to Vinton Bridge	5
	Below Vinton Bridge to El Paso	35

Physical Model Results

The RiverWare model described herein produces the results shown in the following sections for the river Above Leasburg, river Above Mesilla Diversion Dam, and river at El Paso.

River Station Flows

A comparison of the actual flows to the flows resulting from the RiverWare model is made to test the validity of this model. The graph for the river Above Leasburg is shown in FIGURE 27, for the river Above Mesilla is shown in FIGURE 28, and for the river at El Paso is shown in FIGURE 29. These graphs show that the one-step ahead forecasts for the river stations track well with the historic data.

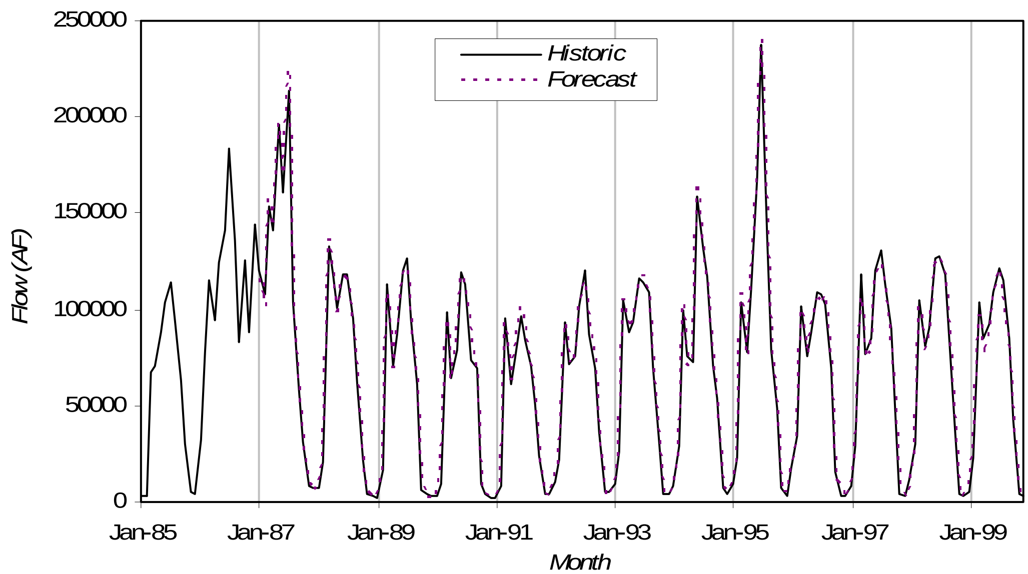

FIGURE 27. River Above Leasburg Results

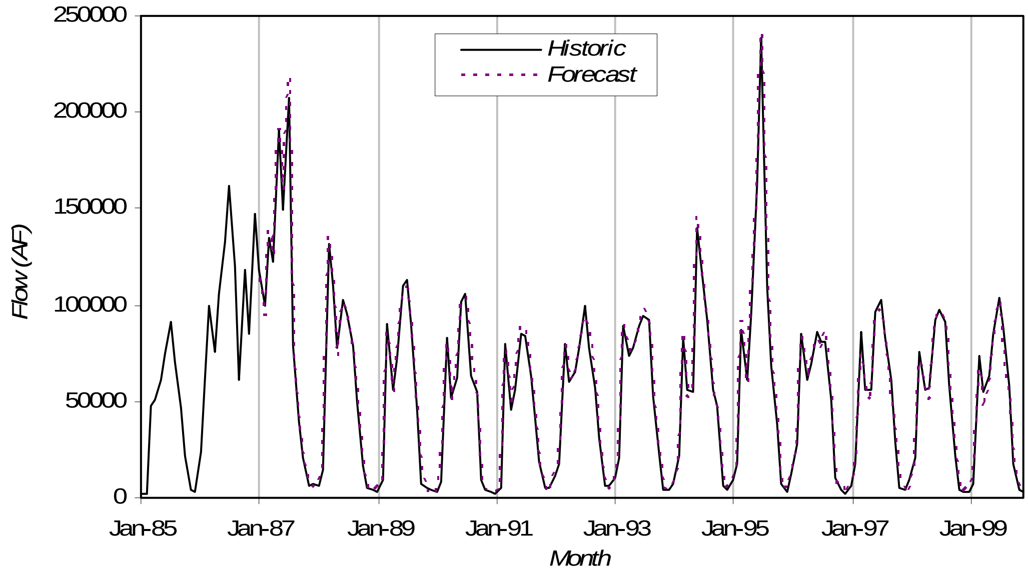

FIGURE 28. River Above Mesilla Results

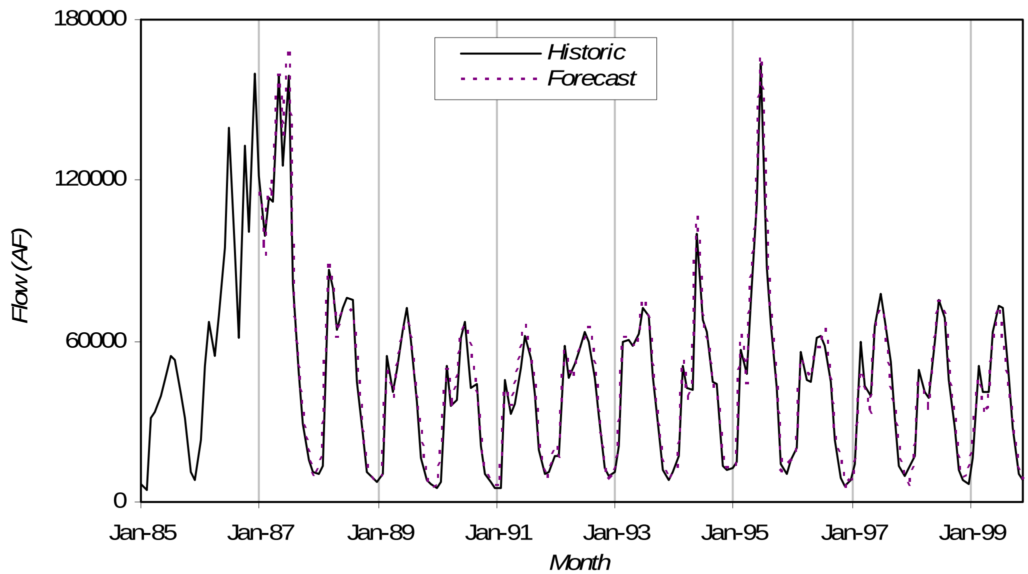

FIGURE 29. River at El Paso Results

River Station Correlations

A correlation check of the forecast data vs. the actual data for the river stations was done to evaluate the accuracy of the model results. Similar to the correlations for the SAS analysis, in these correlations R^2 values close to one, and coefficients of the linear equation close to one indicate very good fit of the data. The residuals resulting from the RiverWare model were also plotted to show they approximate white noise processes. The correlation (a) and residual (b) plots for the river Above Leasburg are shown in FIGURE 30, for the river Above Mesilla are shown in FIGURE 31, and for the river at El Paso are shown in FIGURE 32.

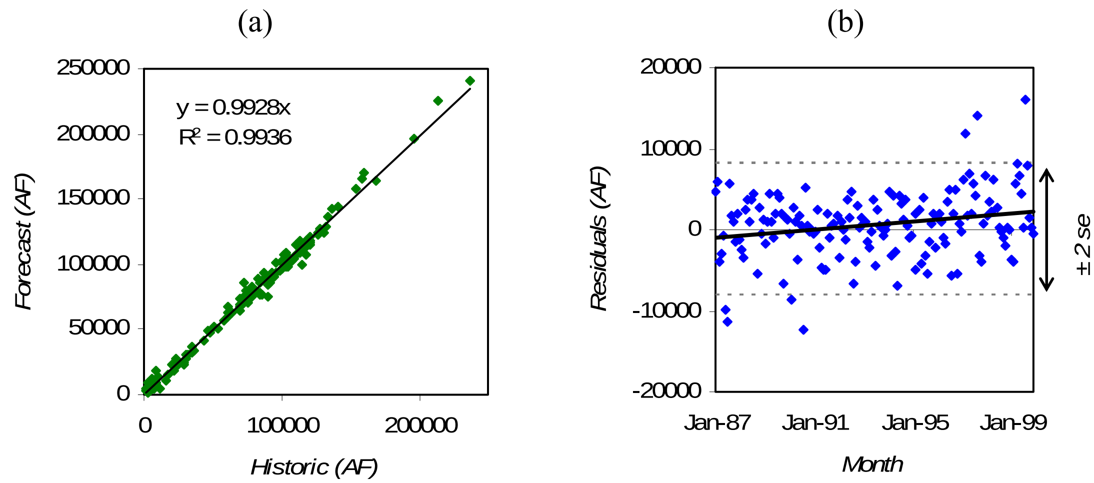

FIGURE 30. River Above Leasburg Correlation and Residuals Plots

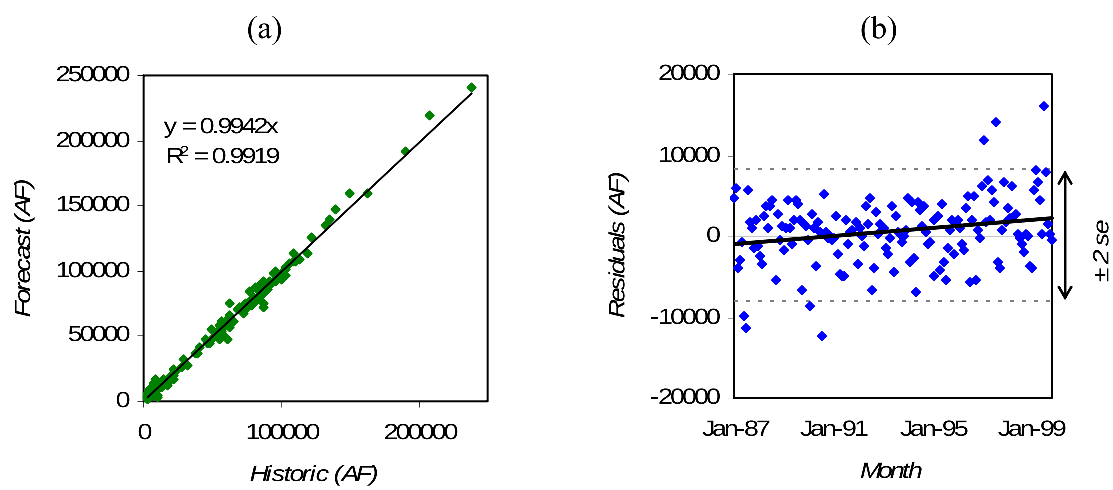

FIGURE 31. River Above Mesilla Correlation and Residuals Plots

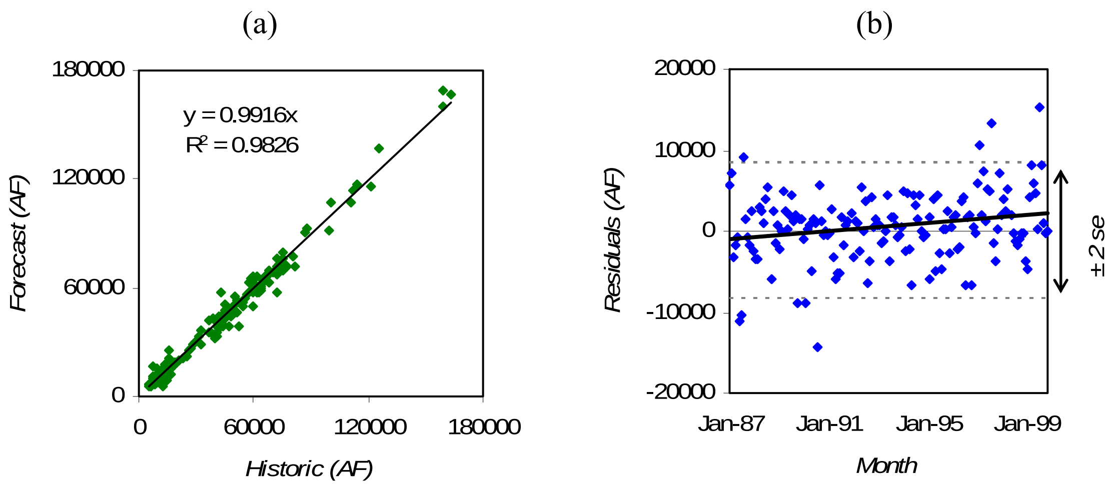

FIGURE 32. River at El Paso Correlation and Residuals Plots

Conclusions

The physical model was developed to simulate the Rio Grande flow for the selected reaches between Elephant Butte Reservoir and El Paso, designed for flood control planning. The current model uses a monthly time step, which needs to be modified to simulate daily flood event flow in the river.

One of the important components in the model configuration is interaction of surface and groundwater. This RiverWare model shows that using ARIMA *transfer functions* as a means of estimating the interactions of surface and groundwater by forecasting drain flows from diversion flows is a statistically adequate method, and provides results highly correlated with the historic values.

It is recommended that the physical model be enhanced by integrating interfaces or linkage for simulating surface and groundwater interaction. It is also recommended that the physical model be expanded to cover the reaches between El Paso and Fort Quitman for flood control planning.

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