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Modeling the Forgotten River Segment of the Rio Grande/Bravo Basin

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Modeling the Forgotten River Segment of the Rio Grande/Bravo Basin

by

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The segment of the Rio Grande/Bravo that extends from El Paso to Presidio along the Texas-Mexico border is often referred to as the Forgotten River. This segment has been named the Forgotten River because there is little population in the region, little scientific information about the area and often there is little to no flow in the river. However, this region is an important transboundary resource for Mexico and the United States. To aid decision makers in flow restoration projects, a simulation model for the region was created in HEC-ResSim using hydrologic information about the region which was collected and stored in an Arc Hydro geodatabase. A set of tools were developed to transfer time series data quickly and efficiently from the Arc Hydro geodatabase to the simulation model. The HEC-ResSim model proved to be a good first approximation model for propagating streamflow hydrographs downstream with a set of diversions and returns; however the daily time step was not large enough to effectively handle the monthly time step of the input data. In addition to the simulation model, a hydrologic analysis was completed for the Forgotten River reach. The hydrologic analysis indicated that the streamflow characteristics have changed from the period of 1925-1945 compared to 1984-2004. The Forgotten River reach appears to have fewer and smaller magnitude floods and is flowing at lower levels recently than it was in the earlier period. The cause of these changes is unknown and further research is recommended.

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List of Abbreviations

CRWR – Center for Research in Water Resources

CILA – Comisión Nacional de Límites y Aguas

CNA – Comisión Nacional de Agua

DLL – Dynamic Linked Library

GIS – Geographic Information Systems

HEC – Hydrologic Engineering Center

HEC-DSS – Hydrologic Engineering Center Data Storage System

IBWC – International Boundary & Water Commission

IHA – Indicator of Hydrologic Alteration

RJBCO- R.J. Brandes Company

TCEQ – Texas Commission on Environmental Quality

TWDB – Texas Water Development Board

USACE – U.S. Army Corp of Engineers

WAM – Water Availability Modeling

WWF – World Wildlife Fund

WRAP – Water Rights Analysis Package

1 Introduction

1.1 Background

The Rio Grande or Rio Bravo as it is known in Mexico, arises in the San Juan Mountains of Colorado and travels over 3,000 km to the Gulf of Mexico passing through three United States’ states and four Mexican states and drains an area of about 868,900 km^2. The Rio Grande/Bravo forms 1,200 km of the international border that falls between Mexico and Texas (Figure 1-1). The basin supports a population of over 10 million inhabitants. Rapid growth and industrialization along the U.S.-Mexican border has placed additional strain on the system and the population along the border is projected to double by the year 2030 (Natural Heritage Institute, 2001). This research will focus specifically on a section of the Rio Grande/Bravo basin called the Forgotten River that encompasses part of the river along the Texas-Mexico border.

The Texas Commission on Environmental Quality and the U.S Army Corp of Engineers are preparing a preliminary feasibility study for flow enhancement and habitat restoration along the Forgotten River section (USACE, 2005). A component of this study is the evaluation and characterization of existing hydrologic data for the Forgotten River reach. The project proposal emphasized that the flows through the Forgotten River are considered extremely important to local agricultural interests and downstream protected areas. Downstream of the Forgotten River are Big Bend Ranch State Park, Big Bend National Park and the Wild and Scenic stretch of the Rio Grande/Bravo which extend 169 miles beginning at the western edge of Big Bend National Park (National Park Service, 2005).

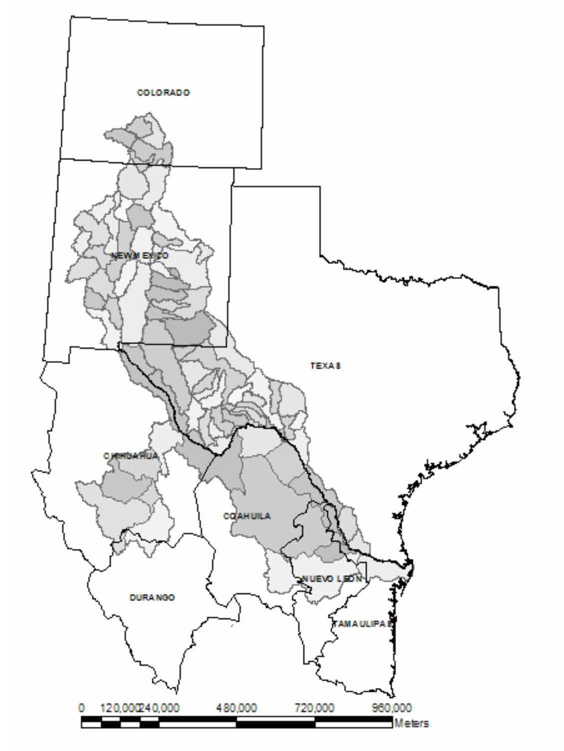


Figure 1-1 Rio Grande/Bravo Basin (CRWR, 2004)

While this project meets the goals of the Forgotten River feasibility study, the tools developed and utilized in this research can find applicability in the rest of the Rio Grande/Bravo basin. As the stresses on this binational basin increase, the development of tools to manage this basin becomes increasingly important. Water resources management, especially in the Rio Grande/Bravo basin, is a complex and varied topic that requires consideration of a broad range of social, economic and environmental interests. Many governmental and non-governmental organizations are concerned with the sustainable management of this particular area. Two of these projects are the Sustainable Agricultural Water Conservation in the Rio Grande Basin project and the Physical Assessment Project.

The Sustainable Agricultural Water Conservation in the Rio Grande Basin project headed by researchers at Sul Ross State University aims to develop an integrated and comprehensive method to achieve water sustainability in the Rio Grande basin. This approach will consider modeling the basin's surface water and groundwater resources, the issues associated with water demand, water quality and human health issues, agricultural water use practices and characterize the basin's biology and related habitats This project will also use an Arc Hydro geodatabase to contain all spatial and temporal information related to the basin (Urbanczyk et al., 2004).

The Physical Assessment Project is developing a basin-wide hydrologic planning model to be used as a tool for assessing opportunities for improved water management in the Rio Grande basin. The modeling objective is stated as follows:

> *To evaluate the physical viability of scenarios for management options in the basin (taking into consideration the physical hydrology). Physical viability includes both hydrologic feasibility and potential to provide mutual net benefits to water user communities throughout the basin. Feasibility will be evaluated at both the planning level (month time steps) and operational level (daily time steps), depending on the scenario* (CRWR, 2005).

As the world's water resources become increasingly stressed, effective tools for management become increasingly important. One tool often used in water resources management is decision support systems (DSS). McKinney and Watkins (1995) define a DSS as "an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems." The Arc Hydro Geographic Information Systems (GIS) data model (Maidment, 2002) is becoming a standard tool for organizing and managing water resources data according to the "basin" principle. These GIS geodatabases provide spatial and temporal data in a format that can support integrated watershed planning with a decision support system.

Many water resource DSS exist, however very few of them have an effective interface with GIS. As geodatabases increase in size, the ability to easily transfer information between DSS and the geodatabases becomes more important. For example, the geodatabase for the Rio Grande basin encompasses over 20,000 monitoring points in three U.S. states and five Mexican states (Patino, 2005).

Developing an interface between water resources management DSS and GIS geodatabases will allow decision makers to utilize information stored in existing large scale geodatabases. GIS geodatabases contain temporal data that is spatially related. This time series data corresponds to monitoring points. Considering again the Rio Grande geodatabase, if each of the over 20,000 monitoring points had corresponding time series, and each time series record had over 50 years of daily historical data, there could potentially be over 365 million records. Selecting an appropriate subset of these data and transferring them to a model would be time consuming. The ability to automatically transfer time series would enable larger amounts of historical data to be used more efficiently in management models. Additionally, this time series transfer ability would allow models to be updated easily as new time series information becomes available.

1.2 Objective

The objectives of this research are two-fold:

1. Develop a first approximation model of the Forgotten River that can be used to determine effects on streamflow from restoration work along the river. This model will use water resources data stored in an Arc Hydro geodatabase.
2. Evaluate streamflow in the Forgotten River to determine if significant alteration has occurred over time, as well as, recommend restoration hydrographs.

1.3 Overview of Thesis

This thesis is divided into five chapters. The first chapter provides some general background information and the objectives for this research. A description of the physical setting of the Forgotten River reach and environmental issues associated with the reach are included in Chapter 2. Also included in Chapter 2 are a discussion of water resources data available along the Forgotten River and a description of the tools utilized to meet the objectives of this research, including HEC-ResSim, Arc Hydro and Environmental Flow Assessment Methodologies. Chapter 3 describes the methodologies used to transfer time series data to the simulation model, the data used and creation of an Arc Hydro geodatabase, the hydrologic analyses performed and finally the simulation model used. Chapter 4 presents results and analysis of the methodologies described in Chapter 3. Finally, conclusions drawn from this research and recommendations for further research are presented in Chapter 5.

2 Background

The focus of Chapter 2 is to provide a description of the research location and a general overview of the tools that were utilized in this research. The overview of the Forgotten River includes a physical description of the location and ecosystem issues within that region. The tools include the modeling system used in this project, the Arc Hydro data model concept, and the concept of environmental flow assessment and methodologies.

2.1 The Forgotten River

The Forgotten River is the name that has been given to a reach of the Rio Grande/Bravo along the United States – Mexico border that is remote, sparsely populated and for which little scientific information is known, compared to the rest of the Rio Grande/Bravo. Often there is little to no water flowing in this particular reach of the river. Some publications refer to the Forgotten River as the section from El Paso/ Ciudad Juarez to just above the confluence with the Rio Conchos (Landis, 2001) while others consider the Forgotten River to be the section from Fort Quitman to Presidio/Ojinaga (Brock et al., 2001). This project considers the 340 km section that extends from Fort Quitman/Colonia Luis Leon to just above the confluence with the Rio Conchos at Presidio/Ojinaga (Figure 2-1). This reach of the Rio Grande/Bravo will be referred to as the Forgotten River throughout this document.

The Forgotten River lies within the Chihuahuan Desert with small valleys and canyons comprising its topography. Ephemeral streams in the Forgotten River provide little inflow into the Rio Grande/Bravo. The first perennial tributary along the Rio Grande/Bravo is the Rio Conchos at the bottom of the Forgotten River at Presidio/Ojinaga (Stotz, 2000: Brock, et al., 2001). The ephemeral streams can provide “flash floods” which are flows of high peaks and short duration caused by runoff from thunderstorms.

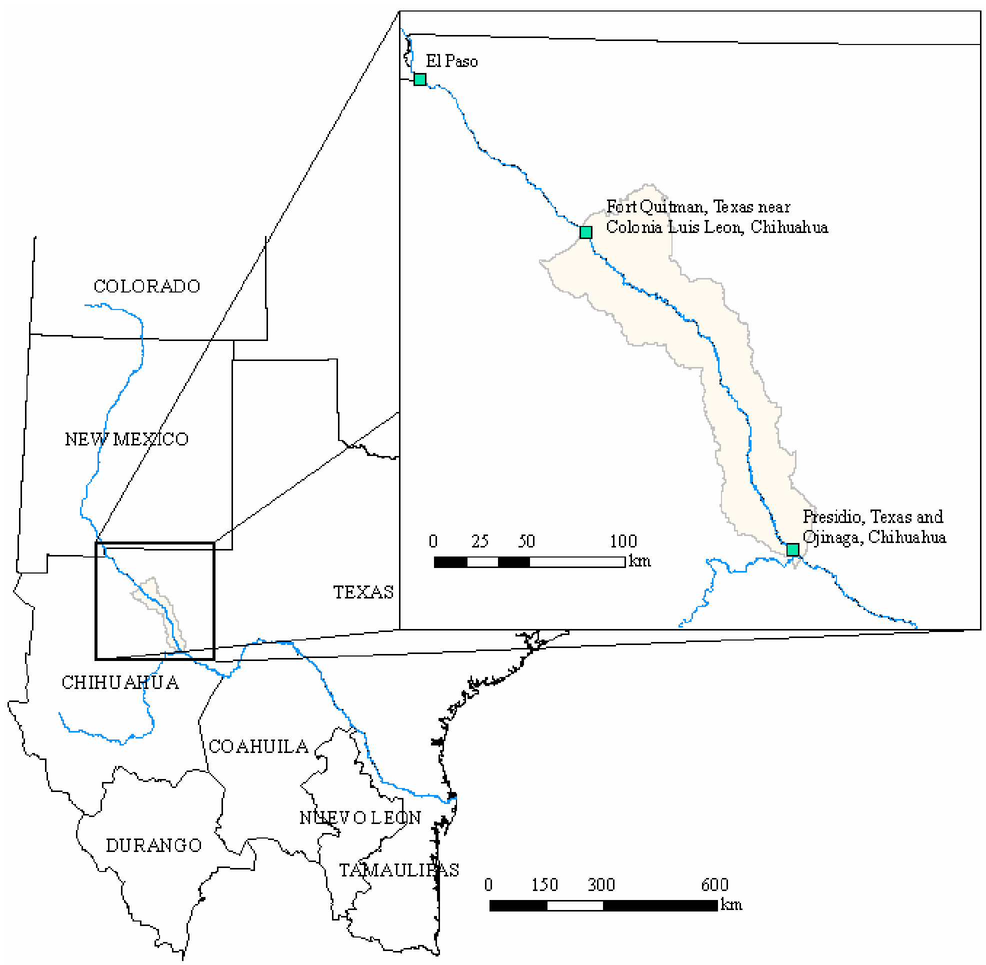


Figure 2-1 Location map for the Forgotten River watershed shown as the shaded region between Fort Quitman, Texas / Colonia Luis Leon, Chihuahua and Presidio, Texas / Ojinaga, Chihuahua

2.1.1 Salt Cedar and Its Effects on the Ecosystem

Tamarisk (*Tamarix* spp.), or salt cedar as it is commonly known, is a plant native to Eurasia which was introduced into the United States in the mid-1800s as an ornamental plant that was also commonly used for erosion control, wind breaks and bank stabalization. Salt cedar is now considered to be an invasive species which has taken over riparian habitats and out-competed native plants in many areas of the arid western United States and northern Mexico (Shafroth et al., 2005).

The Forgotten River section has been greatly impacted by the introduction of salt cedar. Salt cedar was first introduced into the Rio Grande watershed 1926 when the Middle Rio Grande Conservancy District began planting it along the river's tributary, the Rio Puerco, for erosion control (Everitt, 1998). Salt cedar was later observed in the Presidio Valley near Candelaria in 1935 (IBWC 1978). By 1967 aerial photographs showed that most farmland in the Presidio Valley had been abandoned and overgrown by salt cedar (Everitt, 1980). Figure 2-2 is an aerial photograph depicting a section of the Rio Grande/Bravo which has been overgrown by salt cedar.

Figure 2-2 Rio Grande/Bravo channel overgrown with salt cedar
(Michael Collier, USGS 1993)

Salt cedar is a highly drought and salinity resistant plant allowing it to thrive in the arid environments found along the Rio Grande/Bravo. Salt cedar has many characteristics which allow it to out survive the native riparian vegetation such as willows and cottonwood trees. Salt cedar is a facultative phreatophyte, meaning that it can survive in unsaturated soils and does not need to be in contact with the water table to survive. Native willow and cottonwood are obligate phreatophytes which mean that they can only lose contact with the water table for short period of time and still survive. Salt cedar is also fire resistant allowing it to survive while native cottonwood and willows are killed. Salt cedar has the ability to remove salt from saline groundwater or surface water by uptake through its roots and then it excretes the salt through glands on its leaves. The salt then falls to the ground surface and accumulates creating alkialine soil conditions that kill less salt tolerant native plant species (DeLoach et al., 2000).

The construction of large dams in the Rio Grande basin has changed the streamflows from conditions which favor native plant species to conditions that promote the growth and spread of salt cedar. Cottonwoods produce seeds that establish themselves on riverbanks following the recession of annual spring floods. However, dams have controlled these natural spring floods caused by snowmelt or heavy rainstorms and shifted the flow pattern to low flood cycles that extend into the summer or fall. By the time these low floods recede the cottonwood has stopped producing seeds. Salt cedar can produce seeds throughout the summer and fall so when these controlled floods recede the salt cedar has a chance to establish itself (Everitt, 1980).

Besides out competing natural plant species, salt cedar has other environmental concerns. One major concern, especially in the Forgotten River, is the large consumption of surface and groundwater. Salt cedar consumes large quantities of water through evapotranspiration. Early estimates of evapotranspiration ranged from about 9700-17000 m^3/year per ha (3.2 - 5.7 acre-ft/year per acre) (DeLoach et al., 2000). Recently, evapotranspiration from salt cedar has been studied extensively along the Rio Grande/Bravo in New Mexico using Eddy Covariance methodologies. Estimates of evapotranspiration from salt cedar in these studies range from 1 to 10 mm/day (0.04 –

0.40 in/day) per tree (Shafroth et al, 2005; Cleverly et al., 2002; Dahm et al., 2002). If a stand of salt cedar is large enough, the evapotranspiration from the salt cedar can lower water tables and reduce streamflow.

2.1.2 Streamflow Constraints

The Forgotten River reach has a limited amount of streamflow entering at Fort Quitman/Colonia Luis Leon. This section is tightly controlled by the 1944 Treaty between the U.S. and Mexico. The 1944 Treaty delivers 740 Mm^3 (60,000 acre-ft) of Rio Grande/Bravo water annually to Mexico through the Acequia Madre canal just below El Paso (IBWC, 1944). In addition to the 1944 Treaty with Mexico, the amount of water available above Fort Quitman is controlled by the Rio Grande Compact, which is an inter-state agreement between Colorado, New Mexico and Texas. Signed by Congress in 1938, this compact determines the amount of water that must be delivered to each state from the Rio Grande/Bravo.

2.1.3 Forgotten River Hydrologic Assessments

Numerous studies have been completed evaluating the flow changes along the Rio Grande/Bravo as the result of the construction of Elephant Butte reservoir in New Mexico in 1915. When Elephant Butte began filling, it changed the character of the hydrologic regime in the downstream channel. Prior to Elephant Butte, late spring/early summer floods from snow melt were observed, however, after the construction of Elephant Butte these floods, typically seen in the spring, shifted to the summer and their magnitudes were decreased. This effect was caused by releasing water for the irrigation season and in a more controlled manner (Landis, 2001; Stotz, 2001). The irrigation season now typically begins in April and lasts until October (Landis, 2001)

Landis (2001) estimated that the average annual amount of water reaching Presidio had been reduced by 77% by the construction of Elephant Butte reservoir. Fullerton and Batts (2003) note that the streamflow has been greatly reduced by the construction of Elephant Butte reservoir, but most of this reduction happens before Fort

Quitman/Colonia Luis Leon. The author's observed that there is streamflow reduction through the Forgotten River reach, but not as significantly as upstream from El Paso to Fort Quitman/Colonia Luis Leon.

2.2 Forgotten River Data Sources

Data for the Forgotten River segment is very limited. This section outlines the two sources of data and data types utilized in this research.

2.2.1 The Rio Grande/Bravo Geodatabase

Previously, an Arc Hydro geodatabase was created for the entire Rio Grande/Bravo basin. This geodatabase was developed at the Center for Research in Water Resources at the University of Texas at Austin in cooperation with the National Water Commission of Mexico (Patino, 2005). The Rio Grande/Bravo binational geodatabase contains both spatial and temporal information about the entire basin collected from both U.S. and Mexican agencies. These data include gaging stations and associated time series data, water rights locations, climatic stations, diversions and returns for irrigation districts and municipalities as well as information about reservoirs and groundwater.

2.2.2 Water Availability Model

The Texas Commission on Environmental Quality (TCEQ) Water Availability Model (WAM) is a computer-based simulation predicting the amount of water that would be in a river or stream under a specified set of conditions. WAM utilizes the software package Water Rights Analysis Package (WRAP) developed at Texas A&M University (Wurbs, 2003) and it is used to determine whether water would be available for a newly requested water right or amendment. If water is available for the new or amended water right, these models estimate how often the applicant could count on water under various conditions. The WAM for the Rio Grande/Bravo basin was the final model prepared, out of 23 for Texas river basins. The Rio Grande WAM encompasses the Rio Grande/Bravo from El Paso to the Gulf of Mexico including the Pecos River and the Rio Conchos from Mexico (TCEQ, 2005).

The WAM model for the Rio Grande/Bravo was prepared by the R.J. Brandes Company (RJBCO). The model was created for the period of 1940 – 2000 and simulates on a monthly time step. The model contains information related to water consumption along the Rio Grande/Bravo from both the United States and Mexico necessary to estimate streamflow. These data include, but are not limited to, naturalized streamflow, water rights, spring flows, return flows, channel loss factors and reservoir storage. For the Forgotten River reach naturalized streamflows and water rights only for the United States were available. Naturalized flows from Mexico were not available along this reach because there are no major tributaries from Mexico contributing flow to the Forgotten River. The following sections describe the process used in the creation of the naturalized flows and a detailed description of Texas water rights along the Rio Grande/Bravo. Mexican water rights are not discussed in this section because none were identified along the Forgotten River reach. The following sections do not include consideration of the WAM data for either the Pecos River or Rio Conchos.

2.2.2.1 Naturalized Flows

Naturalized streamflows are flows that represent the "natural" flows in a river basin without anthropogenic effects. Naturalized streamflows are calculated from historical gaged streamflow with all historical upstream losses, such as irrigation diversions, added into the streamflow and all historical upstream additions, such as irrigation return flows, subtracted from the historical streamflow. The WAM model utilizes naturalized streamflow in its simulations for water availability for water rights. Naturalized streamflows were developed for the Rio Grande/Bravo from El Paso to the Gulf of Mexico and along the major tributaries of the Pecos River and the Rio Conchos.

The naturalized streamflows for the Rio Grande/Bravo were developed using the following equation (RJBCO, 2004):

Naturalized Streamflow	=	Historical Gaged Streamflow
	+	Historical Upstream Diversions
	–	Historical Upstream Return Flows
	+	Historical Changes in Upstream Reservoir Storage
	+	Historical Upstream Reservoir Evaporation Loss
	-	Historical Upstream Miscellaneous Adjustments (e.g. spring flows)

When available, historical data were collected from both Texas and Mexico for the creation of naturalized streamflows. The historical diversions identified include diversions from municipal, industrial, and irrigation sources. The historical return flows include returns from irrigation, industrial wastewater and municipal wastewater sources.

The miscellaneous adjustment shown in the above naturalized streamflow equation refers to streamflow additions such as spring flow and streamflow abstractions including channel losses which incorporate evaporation, and evapotranspiration. Channel losses were determined by RJBCO (2004) based on the analysis of previous studies of the geology and hydrogeology for the Rio Grande/Bravo.

Where previous studies on channel losses were not available an analysis of the historical gaged streamflows was completed taking into account the evaporative streamflow losses and plant uptake (evapotranspiration) streamflow losses. The analysis of the gaged streamflow was completed by subtracting the upstream gaged streamflow values from the downstream gaged streamflow values. This analysis was completed with streamflows that occurred during the non-irrigation season (October to March). This time period was selected because it minimized diversions and return flow related to irrigation, minimized evapotranspiration and also minimized evaporation. During the non-irrigation seasons, the temperatures are lower leading to less evaporation and evapotranspiration than at other times of the year with higher temperatures. With these three factors at a minimum, the loss calculated between gages could be assumed to more closely reflect the channel losses due to seepage.

The total streamflow losses were adjusted to include evaporation and evapotranspiration. Evaporation rates in Texas were derived from the Texas Water Development Board (TWDB) one-degree quadrangle maps. The TWDB developed these one-degree quadrangle maps from all data available for precipitation and evaporation from the National Weather Service and the TWDB. The precipitation data was used to adjust reservoir storage while the evaporation rates were used to both adjust historical reservoir storage and develop naturalized flows by estimating the evaporation from the free surface of the river.

Evapotranspiration rates were calculated from estimates of salt cedar coverage and an annual consumption rate of 1.5 m^3/m^2 (5.0 acre-ft/acre). This consumption rate was applied to either known acreage of salt cedar or an estimated acreage based on an assumed width of salt cedar growth along a specific reach.

2.2.2.2 Texas Water Rights

The Texas surface water rights along the Rio Grande/Bravo are permitted through the TCEQ and are governed by an adjudication of the prior appropriation law. Unlike riparian water rights which are related to land ownership, prior appropriation water rights are governed by compliance with statutory requirements (Kaiser, 1986). Elements of the Texas prior appropriation law include: 1) the definition of "beneficial use", 2) the possibility of cancellation for non-use, 3) "no injury" for the transfer of water rights, and, 4) municipal diversions take precedence over all other uses in periods of water shortage (Brock et al. 2001). The possibility of cancellation for non-use rarely occurs but is possible if a water right is not used for 10 consecutive years or more. The 'no injury" for transfer of water rights principal protects downstream water rights by not allowing a transfer which might increase consumption (i.e. decrease return flows) therefore decreasing availability to downstream water right holders. The priorities of water rights are assigned based on the "first in time, first in right" principal meaning that older water rights are honored first before newer water rights. This means that in times of drought, newer water rights may not be satisfied.

The RJBCO organized the Rio Grande water rights from the data in the TCEQ water rights database (WRDETAIL). RJBCO updated the TCEQ data from hard copies of water permits and certificates of adjudication. Appendix A of the final report for the Water Availability modeling for the Rio Grande Basin as prepared for the TCEQ contains all of the water right information. Some of the information contained in this table includes water right number, water right type, the county the right is held in, the river owner, the diversion amount, the owner name, priority date and location of the water right.

Water rights are assigned with an annual use amount, however; the WAM model uses a monthly time step for simulation. A set of monthly use factors were developed for the water rights based on their use type to distribute the annual amount to each month. The factors were developed from historical information obtained from the TCEQ and the IBWC. These factors were developed for Texas and Mexico for municipal, industrial, irrigation and other uses such as instream flow requirements or recreation. These factors are also dependent on the diversion location in the basin. For example, irrigation diversions near El Paso have a different set of diversion factors than an irrigation diversion below the confluence of the Rio Conchos.

2.3 Environmental Flow Assessment Methodologies

Historically, managing a river for ecosystem protection was limited to water quality standards and minimum flow requirements. The minimum flow requirements were defined as the minimum flows for sensitive species to survive. Recently perspectives on ecosystem management have shifted towards managing rivers with a more natural flow regime. Researchers have recognized the importance of flow variability to the health of an ecosystem and methodologies have been developed to attempt to capture this flow variability as a range of flows which account for seasonable variability, magnitude, timing, frequency and the rate at which these flows change (Poff et al., 1997, Postel and Richter, 2003 and Richter et al., 1997).

Environmental Flow methodologies can be divided into four categories including hydrologic, hydraulic rating, habitat simulation and holistic flow methodologies. Each category increases in the amount of data required as input. Hydrologic methodologies, such as the Tenant Method or Indicators of Hydrologic Alteration, are considered the most simple because these methodologies usually use historical hydrologic data to make flow recommendations. Hydraulic models use river channel geometry to correlate flow with available habitat. Habitat models, such as IFIM or PHABSIM, model habitat changes with changing flows using multiple measured cross sections with identified habitat preferences for specific target species. Finally, holistic flow methodology such as the Building Block Methodology, set ecosystem flow requirements and use multi-disciplinary experts to evaluate flow alterations (Tharme, 2000).

Due to lack of data in the Forgotten River reach, a hydrologic methodology was utilized to create flow recommendations. The Indicators of Hydrologic Alteration (IHA) software package was developed at The Nature Conservancy based on the IHA methodology developed by Brian Richter. The IHA method statistically characterizes hydrologic variation based on 33 biologically significant hydrologic parameters. The IHA uses daily historical streamflow as input (Richter et al., 1996).

Table 2-1 Summary of the 33 hydrologic parameters used in Indicators of Hydrologic Alterations software (Richter et al., 1996)

IHA Statistics Group	***Hydrologic Parameters***
Group 1: Magnitude of monthly water conditions	• Mean value for each calendar month
Group 2: Magnitude and duration of annual extreme water conditions	• Annual 1-day minima • Annual minima, 3-day means • Annual minima, 7-day means • Annual minima, 30-day means • Annual minima, 90-day means • Annual 1-day maxima • Annual maxima, 3-day means • Annual maxima, 7-day means • Annual maxima, 30-day means • Annual maxima, 90-day means • Number of zero-flow days
Group 3: Timing of annual extreme water conditions	• Julian date of each annual 1-day maximum • Julian date of each annual 1-day minimum
Group 4: Frequency and duration of high and low pulses	• Number of low pulses within each year • Mean duration of low pulses within each year • Number of high pulses within each year • Mean duration of high pulses within each year
Group 5: Rate and frequency of water condition changes	• Means of all positive differences between consecutive daily values • Means of all positive differences between consecutive daily values • Number of hydrological reversals

2.4 HEC-ResSim

HEC-ResSim was developed by the U.S. Army Corp of Engineers (USACE) as the successor to HEC-5 (USACE, 2003). This program simulates reservoir operations including all characteristics of a reservoir and channel routing downstream. The model also allows users to define alternatives and run simulations simultaneously to compare results. HEC-ResSim has a graphical user interface (GUI) and utilizes the USACE Data Storage System (HEC-DSS) for storage and retrieval of input and output time-series data. HEC-DSS was designed as a database system which efficiently stores and retrieves data such as time series data, curve data, and spatially-oriented gridded data (USACE, 1995).

In HEC-ResSim users develop a representation of the physical system with network elements which include reservoirs, routing reaches, diversions, and junctions. Watersheds consist of streams, projects (i.e. reservoirs, levees), gage locations, impact areas, time-series locations and hydrologic and hydraulic data for that specific area. HEC-ResSim allows users to import ArcGIS Shapefiles as background layers upon which schematic elements representing watershed, reservoir networks and simulation data can be placed visually in a geo-referenced context that interacts with associated data. Example inputs for HEC-ResSim include streamflow, municipal/industrial withdrawals and returns, reservoir operations and power generation. To assist in analyzing simulation results, HEC-ResSim includes plots, summary reports, and HEC-DSSVue. HEC-ResSim does not deal with water quality, environmental in-stream flows, recreation, etc. HEC-ResSim allows time series to be input with a time step varying from 5 minutes to one month (USACE, 2003).

Limited hydrologic data is available for the Forgotten River reach. This limited data made it impractical to use a hydrologic rainfall-runoff model such as HEC-RAS for analysis of this reach. However, HEC-ResSim's flood routing capabilities provided the functionality necessary to propagate streamflow hydrographs downstream from a recommended upstream hydrograph with defined diversions and return flows. HEC-ResSim also allows for definition of channel losses through seepage or channel gains by defining negative seepage. The hydrograph propagation from HEC-ResSim can be used evaluate the effects of river restoration on streamflow.

2.5 Arc Hydro Data Model

Arc Hydro is a data model and a set of tools developed to manage spatial and temporal data related to water resources in the ArcGIS environment (Maidment, 2002). The Arc Hydro data model organizes data into classes to represent a physical basin (Figure 2-3). Spatial attributes of a basin, such as watersheds, streams or stream gages are stored in feature class tables. Similarly, non-spatial attributes of a basin, such as time series data, are stored within object classes. Relationship classes are used to represent the hydrologic interaction among these spatial and non-spatial attributes of a basin. For example, a relationship class relates an outlet to its watershed, or a stream gage to its location on a stream network, or even a time series of streamflow data to its stream gage.

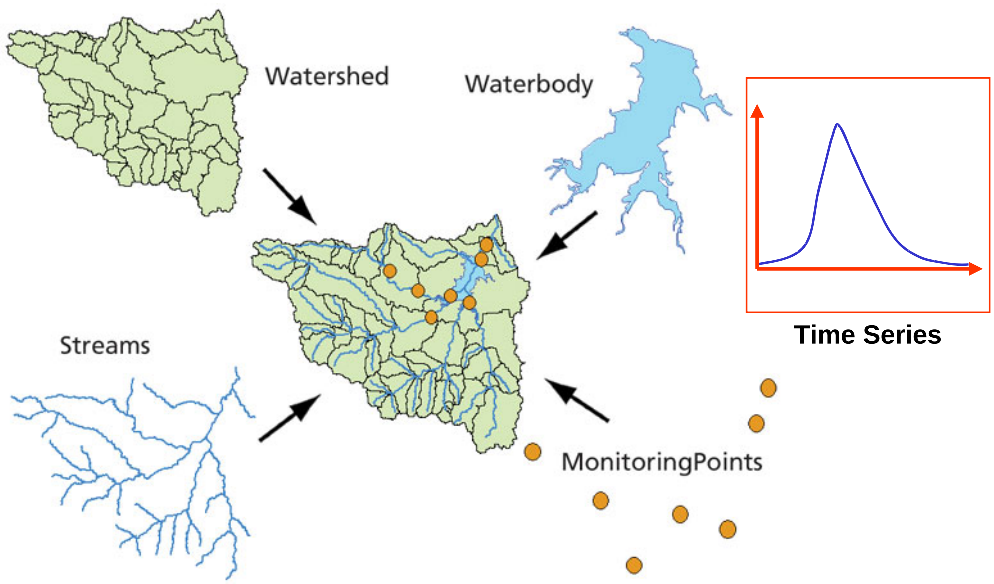


Figure 2-3 Arc Hydro data model framework with time series (Maidment 2002)

The Arc Hydro data model provides a framework for storing geospatial and temporal hydrologic data that are necessary for water resources modeling. The Arc

Hydro framework is flexible and extensible and allows for the customization of the framework to fit the needs of a specific model. The Arc Hydro toolset performs function that support hydrologic models such as delineating drainage areas and streams, calculating parameters such as length, area and slopes or establishing the connectivity between hydrologic features of the physical system. The connectivity between the hydrologic features in the landscape further supports water resources modeling by establishing the flow of water between features in a model (Whiteaker, 2004). Water resource system modeling is accomplished by exchanging data between Arc Hydro and an independent model through the use of a dynamic linked library (.dll), which is a library of executable functions that can be utilized by other programs (Maidment, 2002).

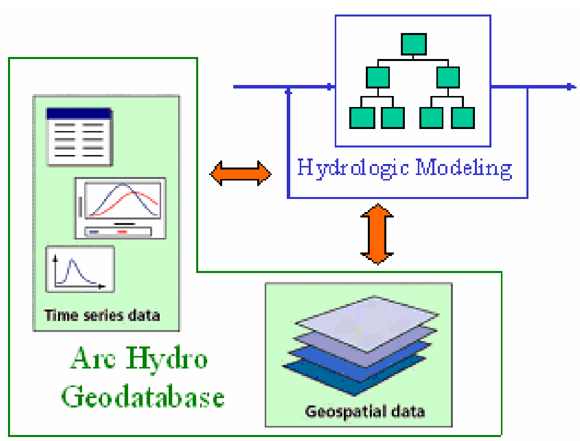


Figure 2-4 Interfaces for hydrologic modeling (Maidment, 2002)

3 Methodology

This chapter presents the methodology used for the three main tasks of this research including, the methodology used to develop the tools to transfer time series data from the Arc Hydro geodatabase to the HEC-ResSim model data collection and creation of an Arc Hydro geodatabase, and finally, the hydrologic analysis.

3.1 HEC-DSS Transfer Tools

3.1.1 DSS Hydro Tools

A tool for transferring time series data from an Arc Hydro geodatabase into a HEC-DSS file and back to a geodatabase was developed at CRWR for use with USACE HEC Models (Robayo, 2005). The tool was comprised of two Visual Basic executable programs that utilize an object library and an object class within the geodatabase structure. These tools allow for a DSS file to be created from an existing time series and/or allow for the creation of a time series in the geodatabase from an existing DSS file. This tool was used as the basis for the creation of the DSS Hydro Tools.

The DSS Hydro Tools are a set of public domain utilities developed in Visual Basic which operates in the ArcGIS ArcMap environment (Patino, 2005). The DSS Hydro Tools are contained on a toolbar which is comprised of four commands to transfer time series information between an Arc Hydro geodatabase and a HEC-DSS file (Figure 3-1). As with the previous version of the tools, the Arc Hydro Tools utilize an object library and an object class within the geodatabase structure. The object class within the geodatabase (DSSTSType) contains all relevant DSS records and descriptors to automatically transfer the time series.

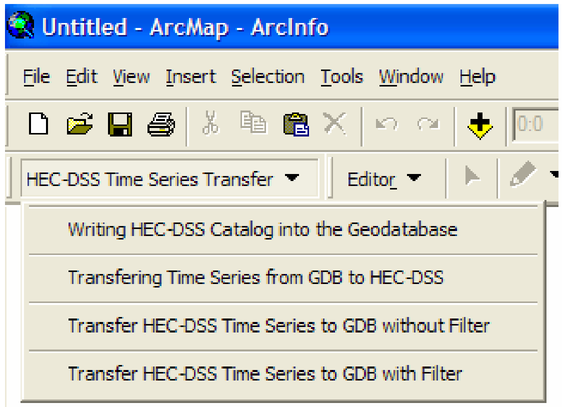


Figure 3-1 DSS Hydro Toolbar

A key step in transforming a time series from an Arc Hydro geodatabase into the DSS format is the creation of the HEC-DSS catalog (DSSTSType) inside the geodatabase. The DSSTSType is the object class table within the geodatabase that contains the information related to the DSS data and its pathname. The DSS pathname consists of six parts in the following format:

/A/B/C/D/E/F/

where

- **A -** group name for the data such as a watershed name, study name or any identifier which allows the records to be recognized as belonging to a group.
- **B -** location identifier for the data. The location identifier may be a site name or organization ID such as a USGS gage ID.
- **C -** the parameter of the data such as flow, precipitation, storage or evaporation. The DSS tools allow only the following seven parameters for Part **C**: flow, precipitation, storage, evaporation, volume, in flow and out flow. These parameters must be represented in the following format:
- **D -** the start date of the time series,
- **E -** the time interval for regular data or the block length for irregular-interval data.

- **F -** an optional descriptor that can be used for additional information about the data.

The original ArcHydro Time Series framework was modified to automatically create the DSSTSType object class table within the Arc Hydro structure when the Arc Hydro schema is applied to a geodatabase. In addition to creating the DSSTSType object class, a relationship class is created between the DSSTSType object class and the existing Arc Hydro time series object class. Appendix A outlines the necessary fields which are used as descriptors to create HEC-DSS files.

The DSSTSType table is automatically populated using the "Writing DSS Catalog into the Geodatabase" option on the DSS Hydro Toolbar (Figure 3-1). The DSSTSType is populated based on the temporal information contained in the existing TimeSeries object class in the Arc Hydro geodatabase utilizing the relationship class that was established by the tools. From the TimeSeries object class, the tools determine the FeatureID (B Part), data type (C Part), date range (D Part), the data interval (ie days or months) (E Part). The F Part is an optional descriptor which is used to describe whether the data is observed historical data or calculated data.

After the creation of the DSSTSType, the time series can be transferred from the geodatabase to the HEC-DSS format using the "Transferring Time Series from GDB to HEC-DSS" option on the toolbar. This transfer creates the HEC-DSS files that are used for simulation with HEC-ResSim. Upon completion of the simulation, tools are available to transfer the simulated time series back into the time series table in the geodatabase. The ability to transfer simulated time series data back into a geodatabase can be useful for decision making. The geodatabase adds a geospatial element to the time series data. A description of the DSS Hydro Toolbar, including the tools not described here, can be found in Appendix A.

3.1.2 Arc Hydro Time Series to HEC-DSS Conversion

When time series data are converted into HEC-DSS format it is important that the time series be continuous, without gaps in dates. The methodology which converts the data into HEC-DSS format assumes that the data are continuous and finds the first date of the period of record and assigns the rest of the dates instead of reading them. For example, consider the following series with a beginning date of 10/1/1920 on the left in Figure 3-2a. Note that there is a gap in the data in the original time series data with data missing between 10/4/1920 and 11/1/1924. The conversion methodology finds the start date of 10/1/1920 and then assigns the dates sequentially resulting in the table on the right in Figure 3-2a. The data which were originally related to the date 11/1/1924 are now related to 10/5/1920. These are two very different time series. To maintain the integrity of the original time series, the data must be checked for continuity. Each time series, for each gage must be checked and any gaps in dates must be filled in and a value of -901 assigned to the flow record indicating that the data do not exist. For example, the table on the left in Figure 3-2b shows the original time series with a data gap between 10/4/1920 and 11/1/1924. The table on the right in Figure 3-2b shows how the missing dates are filled in and a corresponding time series value of -901 is assigned.

Time Series Date	Time Series Value
10/1/1920	10
10/2/1920	12
10/3/1920	10
10/4/1920	11
11/1/1924	30
11/2/1924	31
11/3/1924	35

DSS Date	DSS Value
10/1/1920	10
10/2/1920	12
10/3/1920	10
10/4/1920	11
10/5/1920	30
10/6/1920	31
10/7/1920	35

(a)

Time Series Date	Time Series Value
10/1/1920	10
10/2/1920	12
10/3/1920	10
10/4/1920	11
11/1/1924	30
11/2/1924	31
11/3/1924	35

Time Series Date	Time Series Value
10/1/1920	10
10/2/1920	12
10/3/1920	10
10/4/1920	11
10/5/1920	-901
10/6/1950	-901
10/7/1950	-901

(b)

Figure 3-2 (a) Incorrect Geodatabase Time Series to HEC-DSS Conversion
(b) Correction to Geodatabase Time Series for HEC-DSS Conversion

3.2 Forgotten River Arc Hydro Geodatabase

Data for this project were collected from multiple agencies and converted into equivalent units appropriate for use with the HEC-ResSim model. The data was stored in an Arc Hydro geodatabase which related the data spatially and temporally. This section outlines the data available for the Forgotten River and how the data was stored in the newly created Forgotten River geodatabase.

3.2.1 Rio Grande/Bravo Geodatabase

The Rio Grande/Bravo geodatabase provided the delineated watersheds, the delineated stream network including flow direction, and the spatial and temporal data related to the stream gages in the Forgotten River. The Rio Grande/Bravo geodatabase also provided the geospatial location of the Texas Commission on Environmental Quality (TCEQ) Control Points that are described further in Section 3.2.2.1.

The geospatial location and temporal information of stream flow gages along the Forgotten River was extracted from the Rio Grande/Bravo geodatabase. Daily streamflow time series values related to these stream gages were obtained from the Rio Grande/Bravo geodatabase. The daily streamflow records for the Rio Grande/Bravo were originally obtained from the International Border and Water Commission (IBWC) website. The IBWC maintains three gages in the Forgotten River section. These gages are located at Fort Quitman/ Colonia Luis Leon (gage 08-3705.00, 130 km (80 mi) below El Paso), Candelaria/ San Antonio del Bravo (gage 08-3712.00, 190 km (120 mi) below Fort Quitman/Colonia Luis Leon), and Presidio/ Ojinaga (gage 08-3715, 150 km (93 mi) below Candelaria/San Antonio del Bravo) (Figure 3-3). The gage at Fort Quitman/Colonia Luis Leon began operation in 1924 while the gage at Candelaria/San Antonio del Bravo began operation in 1976 and the Presidio/Ojinaga gage began operation in 1900.

The daily streamflow time series records were converted into monthly values and stored in the Forgotten River geodatabase along with the original daily streamflow values. The Arc Hydro data model allows multiple time series types to be related to a single point through the use of the TSType variable in the time series table. For example, a TSType of 1 is daily streamflow while a TSType of 2 is monthly average streamflow.

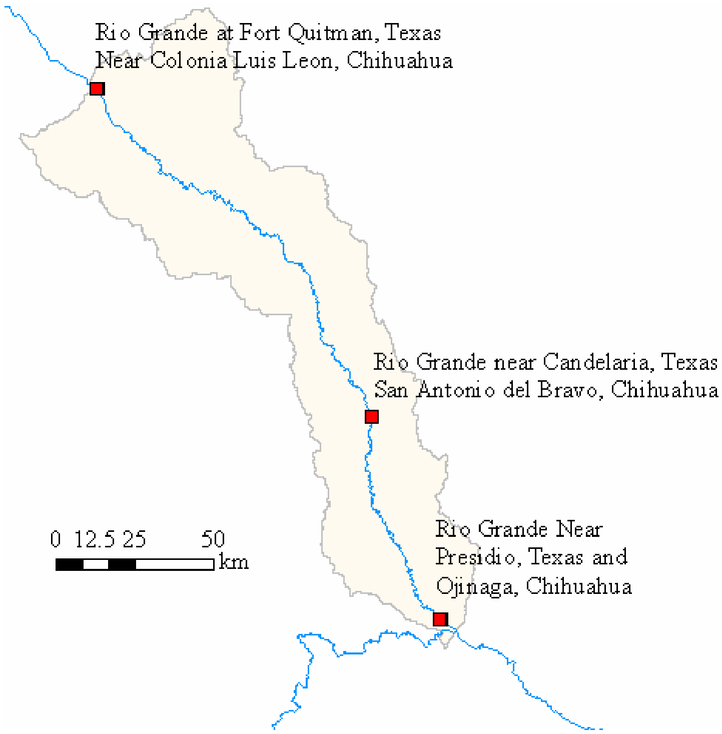


Figure 3-3 Location of IBWC Stream Gages along the Forgotten River (IBWC, 2004)

3.2.2 TCEQ WAM Data

Data was extracted from the TCEQ WAM model related to the Forgotten River reach of the Rio Grande/Bravo. Historical data related to municipal and industrial diversions along the main stem of the Rio Grande/Bravo were obtained from the IBWC, which maintains diversion records for water accounting. Because the Forgotten River is sparsely populated, diversion and return flows related to industrial and municipal uses do not occur in Mexico or Texas along this reach. Historical irrigation diversions for Mexico along this reach were not available and it is unlikely that they exist. This section also does not have significant reservoir storage or springflow discharge. The only historical diversions in this section were related to the irrigation water right diversions. The return flows for this section were limited to historical irrigation return flows. The following sections describe the naturalized streamflows and water right diversions along the Forgotten River.

3.2.2.1 Naturalized streamflows

The naturalized streamflows were calculated at Control Points identified by the TCEQ. Control Points are the points along the river, such as at stream gages or diversion points, where calculations occur in the WAM model. The Rio Grande/Bravo geodatabase contained the geospatial location of TCEQ's Control Points along the Rio Grande/Bravo and in the major tributaries of the Pecos River and the Rio Conchos. Along the Forgotten River, only two Control Points were identified as having associated naturalized streamflow data. These two points are at Ft. Quitman/Colonia Luis Leon and at Presidio/Ojinaga (Figure 3-4).

In the Rio Grande/Bravo geodatabase, these TCEQ Control Points were contained in the Monitoring Point feature class. The attributes of the Control Point contain the field HydroCode which enabled the correlation between the Control Points in the geodatabase and the Control Points in the WAM model. In the Arc Hydro geodatabase, the HydroCode is the original identifier assigned to an object by its originating agency.

Based on the correlation of the HydroCode, the Control Points with naturalized flows were identified. The time series for the naturalized flows were then assigned a FeatureID equal to the HydroID of their corresponding Control Point in the geodatabase to establish the relationship between the two (Figure 3-5). The TSType table was modified to contain a TSType of 17 corresponding to Naturalized Flows (Figure 3-6).

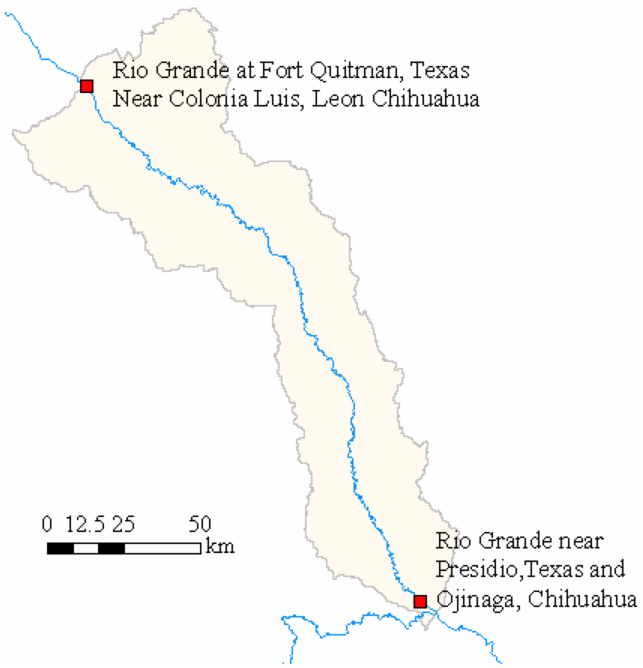


Figure 3-4 Location of the control points with associated naturalized flows along the Forgotten River

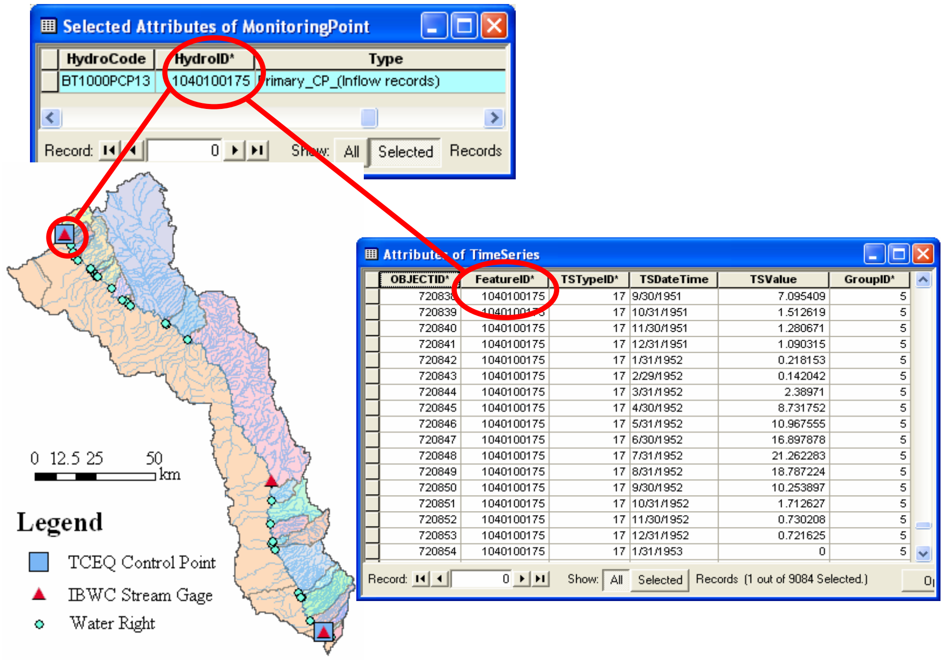


Figure 3-5 Arc Hydro relationship establishes a connection between a Control Point in the Monitoring Point feature class and the time series object class

Attributes of TSType

OBJECTID*	TSTypeID*	Variable	Units
1	1	Daily Streamflow	cms
2	2	Monthly Streamflow	cms
3	3	Real Time Streamflow	cms
4	4	Stage	m
5	5	Daily Runoff Volume	Million of m3
6	6	Monthly Runoff Volume	Million of m3
7	7	Daily Precipitation	mm
8	8	Monthly Precipitation	mm
9	9	Evaporation	mm
10	10	Storage	Million of m3
11	11	Volume-Demand	Million of m3
12	12	Volume-IN	Million of m3
13	13	Volume-OUT	Million of m3
14	14	Daily Storage	Million of m3
15	15	Inflow	cms
16	16	Outflow	cms
17	17	NaturalizedFlows	Million of m3

Record: 1 Show: All Selected Records (0 out of 17 Selected.) Options

Figure 3-6 Attributes of the modified TSType object class

3.2.2.2 Texas Water Rights

The locations of the water rights were obtained from the RJBCO Final WAM Report (2004). In the Forgotten River section, 30 active water rights were identified (Figure 3-7). Within the Arc Hydro geodatabase, a new feature class was created named WAMWaterRights to contain information related to these 30 water rights. The new WAMWaterRights feature class contained original information related to the water rights as obtained from the RJBCO Final WAM Report. The attributes of the new feature class contained information that was relevant to modeling or identification of these water rights. Additional information was available in the RJBCO water rights table but was not included for this project and can be found in Appendix B. The attributes of the WAMWaterRights feature class are shown in Figure 3-8 and are described as follows:

WAM_ID	the TCEQ Control Point ID used in the WAM model
AMNT_ACFT	the total allowable annual diversion amount in acre-ft
AMNT_M3	the total allowable annual diversion in m^3
USE	the identified use of the diverted water (i.e. municipal, irrigation, industrial, environmental, etc.)
CRWR_ID	the TCEQ HydroCode for the water right as identified by CRWR
OWNER	the name of the water right owner
WAM_LAT	latitude of the water right as provided in the RJBCO report
WAM_LONG	longitude of the water right as provided in the RJBCO report
JAN	the annual diversion amount (m^3) multiplied by the January distribution factor
FEB	the annual diversion amount (m^3) multiplied by the February distribution factor
MAR (etc)	the annual diversion amount (m^3) multiplied by the March distribution factor (continues through December)

The distributed water rights are contained in the attributes of the feature class for January through December.

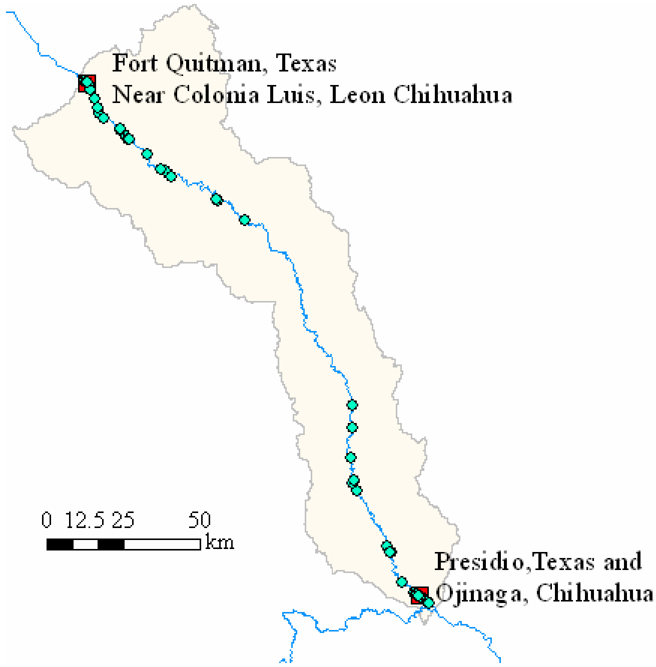
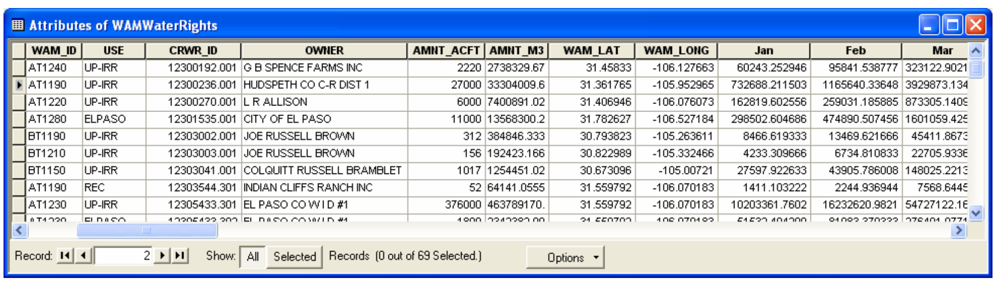


Figure 3-7 Location of the 30 water rights along the Forgotten River



Attributes of WAMWaterRights

WAM_ID	USE	CRWR_ID	OWNER	AMNT_ACFT	AMNT_M3	WAM_LAT	WAM_LONG	Jan	Feb	Mar
AT1240	UP-IRR	12300192.001	G B SPENCE FARMS INC	2220	2738329.67	31.45833	-106.127663	60243.252946	95841.538777	323122.9021
AT1190	UP-IRR	12300236.001	HUDSPETH CO C-R DIST 1	27000	33304009.6	31.361765	-105.952965	732688.211503	1165640.33648	3929873.134
AT1220	UP-IRR	12300270.001	L R ALLISON	6000	7400891.02	31.406946	-106.076073	162819.602556	259031.185885	873305.1409
AT1280	ELPASO	12301535.001	CITY OF EL PASO	11000	13568300.2	31.782627	-106.527184	298502.604686	474890.507456	1601059.425
BT1190	UP-IRR	12303002.001	JOE RUSSELL BROWN	312	384846.333	30.793823	-105.263611	8466.619333	13469.621666	45411.8673
BT1210	UP-IRR	12303003.001	JOE RUSSELL BROWN	156	192423.166	30.822989	-105.332466	4233.309666	6734.810833	22705.9336
BT1150	UP-IRR	12303041.001	COLQUITT RUSSELL BRAMBLET	1017	1254451.02	30.673096	-105.00721	27597.922633	43905.786008	148025.2213
AT1190	REC	12303544.301	INDIAN CLIFFS RANCH INC	52	64141.0555	31.559792	-106.070183	1411.103222	2244.936944	7568.6445
AT1230	UP-IRR	12305433.301	EL PASO CO W I D #1	376000	463789170.	31.559792	-106.070183	10203361.7602	16232620.9821	54727122.16

Record: 2 Show: All Selected Records (0 out of 69 Selected.) Options

Figure 3-8 WAMWaterRights feature class attributes

3.3 Forgotten River Arc Hydro Geodatabase

The data described in the previous sections were imported into a new geodatabase, named the Forgotten River Arc Hydro Geodatabase. The Arc Hydro schema was applied to establish the connectivity of the system. Figure 3-9 is a representation of the final system used for modeling. The Arc Hydro schema was altered as described in Section 3.1 to contain the object class table DSSTSType and the DSSTSType relationship class that established the relationship between the DSSTSType catalog and the time series table. These alterations enabled the use of the HEC-DSS tools. Figure 3-10 outlines the content of the new geodatabase.

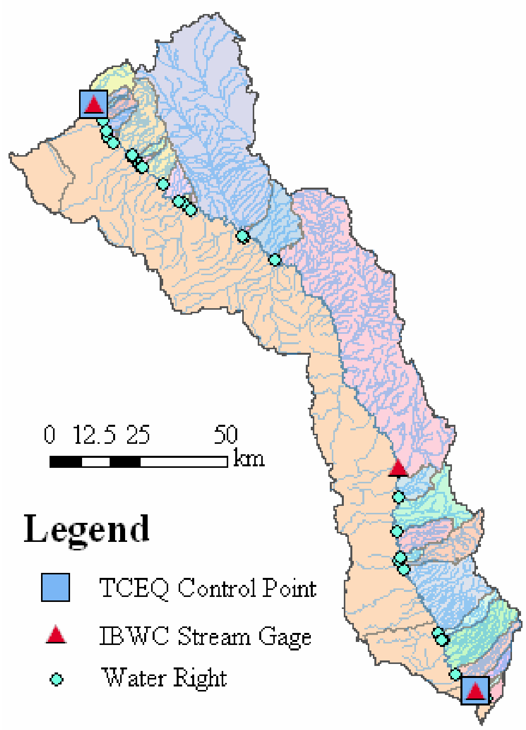


Figure 3-9 Map of the final Forgotten River Arc Hydro geodatabase

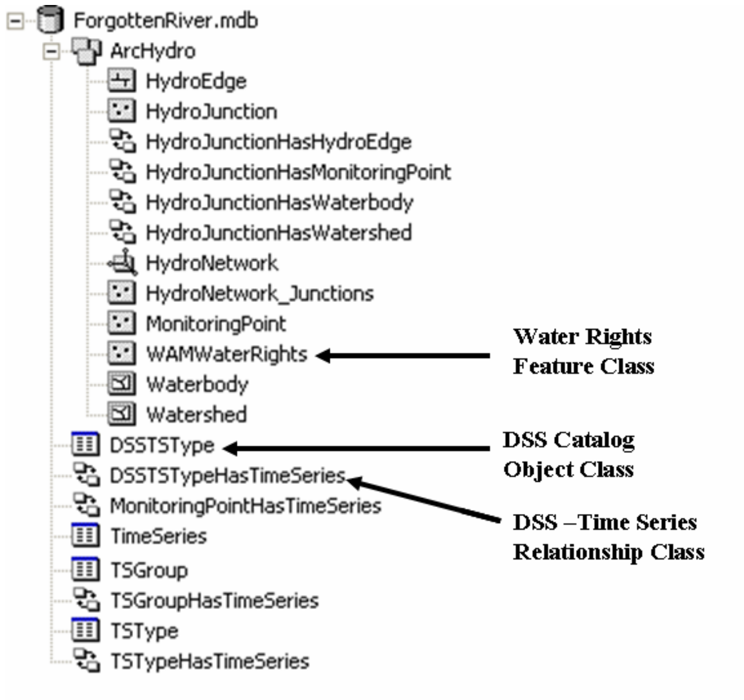


Figure 3-10 Contents of the final Forgotten River Arc Hydro geodatabase

3.4 Hydrologic Analysis

A hydrologic analysis was performed to characterize changes in the flow regimes along the Forgotten River. Two periods were chosen for the analysis to represent an earlier historical period and a more recent period. The early period was selected to represent a period with less salt cedar influence and less degradation along the channel, however selection of this early period was limited since the Fort Quitman/Colonia Luis Leon gage did not begin operation until 1923 and the Presidio/Ojinaga gage is missing data for the overlapping period of 1923-1925. Based on these characteristics the early period was selected as 1925-1945. This time period was also selected to represent a period of higher available streamflow by excluding the drought of record which occurred during the period of 1950 – 1957 (Vottler, 2005). 1984-2004 was selected as the recent time period to represent the most current 20 years of available data. This period represents the current conditions along the Forgotten River, including the recent drought decade. Currently the channel along the Forgotten River has a dense growth of salt cedar.

The following sections outline the hydrologic analyses performed. The first analysis was to determine if the Forgotten River reach is gaining or losing water for the two periods described above. The next analysis used the IHA software package to develop descriptive statistics of the hydrologic differences along the reach. The last section describes the development of streamflow hydrograph recommendations for the Forgotten River.

3.4.1 Loss/Gain Analysis

The Forgotten River was analyzed to determine whether certain sections of the segment can be defined as gaining or losing reaches. For the purposes of this analysis, a gaining reach is defined as a positive value when the flows from an upstream gage are subtracted from a downstream gage, meaning that water is entering into the reach between the two gages. Conversely, a losing reach is defined as a negative value when the flows from an upstream gage are subtracted from a downstream gage indicating that water is being lost between the two gages.

$$Q_{downstream} - Q_{upstream} > 0, \text{Gaining Reach}$$

$$Q_{downstream} - Q_{upstream} < 0, \text{Losing Reach}$$

Where:

$Q_{downstream}$ = the measured streamflow at the bottom of the reach

$Q_{upstream}$ = the measured streamflow at the top of the reach

3.4.2 Indicators of Hydrologic Alterations

The Indicators of Hydrologic Alterations (IHA) software was used to perform the hydrologic assessment. Average monthly flows were determined for each gage during the two periods of analysis. These average monthly flows demonstrate how the monthly flow trends have changed between the two periods. For example, this analysis shows how the average streamflow seen in every January in the each year of early period compare to the average streamflow seen in every January in each year in the later period (The Nature Conservancy, 2005).

Base flows (or low flows) were determined for all locations for both periods. The IHA calculates the base flow by dividing the 7-day minimum flow by the mean flow for the year. This flow describes the dominate flow in most rivers after rainfall events and after their associated surface runoff has subsided. The base flow is often the flow sustained by groundwater.

The IHA Environmental Flow Component (EFC) analysis was used to compute statistics for extreme low flows, low flows, high flow pulses, small floods and large floods. The default parameters for this analysis were used and are defined as follows:

- A high flow pulse begins when the flow increases by more than 25% per day or exceeds 75% of all flows for the period. A high flow pulse ends when the flow decreases by less than 10% per day or is less than 50% percent of all flows.
- A small flood is a high flow pulse with a recurrence time of at least 2 years
- A large flood is a high flow pulse with a recurrence time of at least 10 years.
- An extreme low flow is a flow in the lowest 10% of all low flows in the period.

The EFC analysis was computed for both the 1925-1945 and 1984-2004 periods.

Characteristics of the low flows and high pulses were determined for the two period analysis, including the date of the maximum and minimum flows, the number of high pulses and low pulses in each year and the duration of the high and low pulses for each year. These statistics were determined for both periods to determine how the flows have changed between the two periods.

Changes in extreme streamflow conditions (i.e. maximums and minimums) are determined in IHA for multi-day mean. The maximum and minimums for 1-day, 3-day, 7-day, 30-day, and 90-day averages were calculated for each gage. The 1-day minimum/maximum represents the single minimum/maximum observed in a year. The

3-day is the minimum/maximum values observed in a year for 3-day averages or the minimum/maximum for 122 3-day periods. The 7-day averages over weeks, 30-day over months and the 90-day over seasons.

The IHA software provides a table name the "IHA Scorecard" which contains the means for all of the parameters calculated within the IHA for the two period analyses. The table also contains a deviation factor that is defined as the magnitude of change in the mean values from the first period to the second period. This value is also expressed as percent change. These statistics are used to characterize the magnitude of change in the hydrology along the Forgotten River.

Recommended hydrographs were determined from the IHA percentile statistics. Percentiles were calculated to determine the 10%, 25%, 50% (median), 75% and 90% flows. The 10% flow represents the streamflow at which 10% of all observed streamflows in the analysis period are less than that value. The 25% represent the streamflows at which 25% of all observed streamflows are less than that value and so on. The 10% flows represent the extreme low flows, the 25% represent the low flows, the 50% the median flows, the 75% represent the high flows and the 90% represent the extreme high flows.

Daily hydrographs were constructed to represent what flow variation might look like at the recommended levels. These hydrographs are intended only to show the streamflow variation and are not a numerical recommendation for daily flow. These daily hydrographs were developed by choosing historical months which had means that closely matched the recommended flow levels determined by the percentile analysis. For example, if the 50% flow recommended a monthly average flow of 5.4 m^3/s for January then the historical monthly January averages were evaluated for a match. When one was found, that year's daily flows for January were used in the construction of the daily flow hydrograph. A daily hydrograph might have January flows from 1930 and February flows from 1942 and so on. Since this methodology is not an exact determination of a daily flow hydrograph, it is emphasized that these are only representation of what flow variation might look like at the recommended flow levels. This process was repeated for the 25% and 75% flows.

3.5 HEC-ResSim Model

The HEC-ResSim model was set up with data on a monthly time step. The naturalized streamflow data and water rights data were available in the WAM model for a monthly time step. The daily average streamflow data were converted to average monthly values for consistency.

The HEC-ResSim model used the naturalized streamflow at Fort Quitman/Colonia Luis Leon as the model input. The 30 water rights along the reach were modeled as diversions with monthly varying diversion rates (in m^3/s). The monthly average streamflow for the two gages, Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga, were entered as observed historical values for model calibration.

Losses from evaporation, evapotranspiration and seepage are not directly included in HEC-ResSim model. Additions from runoff, irrigation return flows or incremental inflows associated with streams or arroyos are also not included in the model. These losses and additions to the system are inherently included in the naturalized flows as described previously in Section 3.2.2.1. To represent all the unaccounted additions and losses between the two gages in the model, a single point for all additions was represented by a tributary (system inflow) while the losses were represented by a single diversion (system outflow). Next, a time series was calculated by subtracting the naturalized flow of the upstream gage (Ft. Quitman / Colonia Luis Leon) from the naturalized flow at the downstream gage (Presidio/Ojinaga) and splitting the new calculated time series into two new time series to represent losses and gains between the gages. Figure 3-11 demonstrates subtracting the upstream gage values from the downstream gage values to obtain the new calculated difference time series. Note that the negative time series values are shaded in the figure. The calculated difference time series was then split into two new time series as shown in Figure 3-12. All of the positive values were put into the incremental inflow time series, with zeros replacing all of the negative values and all of the negative values were put into the incremental outflow time series with zeros replacing all of the positive values.

Downstream Gage		Upstream Gage		Difference	
Time Series Date	**Time Series Value**	**Time Series Date**	**Time Series Value**	**Time Series Date**	**Time Series Value**
1/31/1987	78.2	1/31/1987	54.2	1/31/1987	23.9
2/28/1987	62.2	2/28/1987	52.2	2/28/1987	10.0
3/31/1987	47.5	3/31/1987	51.6	3/31/1987	-4.2
4/30/1987	47.5	4/30/1987	59.4	4/30/1987	-11.9
5/31/1987	62.6	5/31/1987	58.0	5/31/1987	4.5
6/30/1987	77.4	6/30/1987	47.3	6/30/1987	30.2
7/31/1987	57.7	7/31/1987	59.0	7/31/1987	-1.4
8/31/1987	33.9	8/31/1987	29.6	8/31/1987	4.3
9/30/1987	28.1	9/30/1987	23.9	9/30/1987	4.2
10/31/1987	19.6	10/31/1987	19.0	10/31/1987	0.6
11/30/1987	11.0	11/30/1987	11.2	11/30/1987	-0.2
12/31/1987	9.7	12/31/1987	9.9	12/31/1987	-0.2

Figure 3-11 Time series values for the upstream gage are subtracted from time series at the downstream gage to create the difference time series.

Difference	
Time Series Date	**Time Series Value**
1/31/1987	23.9
2/28/1987	10.0
3/31/1987	-4.2
4/30/1987	-11.9
5/31/1987	4.5
6/30/1987	30.2
7/31/1987	-1.4
8/31/1987	4.3
9/30/1987	4.2
10/31/1987	0.6
11/30/1987	-0.2
12/31/1987	-0.2

Positive Values

Incremental Inflow	
Time Series Date	**Time Series Value**
1/31/1987	23.9
2/28/1987	10.0
3/31/1987	0.0
4/30/1987	0.0
5/31/1987	4.5
6/30/1987	30.2
7/31/1987	0.0
8/31/1987	4.3
9/30/1987	4.2
10/31/1987	0.6
11/30/1987	0.0
12/31/1987	0.0

Negative Values

Incremental Outflow	
Time Series Date	**Time Series Value**
1/31/1987	0.0
2/28/1987	0.0
3/31/1987	4.2
4/30/1987	11.9
5/31/1987	0.0
6/30/1987	0.0
7/31/1987	1.4
8/31/1987	0.0
9/30/1987	0.0
10/31/1987	0.0
11/30/1987	0.2
12/31/1987	0.2

Figure 3-12 The difference time series is split into two new time series, one for the positive values and one for the negative values, to represent incremental inflow (positive) and incremental outflow (negative).

Model calibration was completed by running the simulation for the entire period of 1941-2000 and comparing the results of the simulation against observed streamflow values. The year 1940 was specified as the “look back” period for the model. The look back period is specified as a period that the model uses to start up the system so that the simulation does not begin at zero. HEC-ResSim allows users to plot observed historical streamflow against simulated streamflow values.

After calibration the recommended streamflow hydrographs from the hydrologic analysis were used as input into the model. The Forgotten River HEC-ResSim model uses naturalized streamflows as system input so a factor was created to turn the recommended streamflow hydrograph into a naturalized flow. Figure 3-13 shows the difference between the historical streamflow and the calculated naturalized flows. An assumption was made that the upstream adjustments for Fort Quitman/Colonia Luis Leon would be similar to those made since 1984. Taking this assumption into account, the annual naturalized streamflow were divided by the historical streamflows (Table 3-1). These values were then averaged over the 16 most recent years to develop a naturalized flow factor. This factor was then applied to recommended hydrographs to develop a rough estimate of naturalized flows for the recommended streamflows.

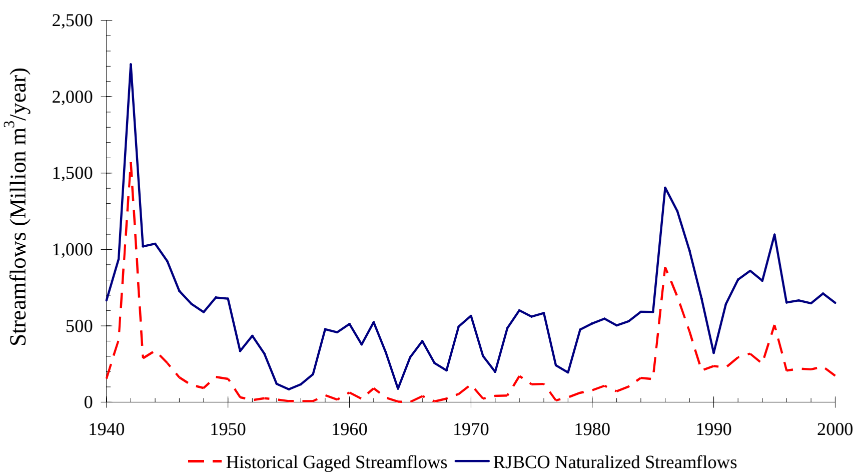


Figure 3-13 Comparison of WAM naturalized flows with gages streamflows at the Fort Quitman/Colonia Luis Leon gage (adapted from RJBCO, 2004)

Table 3-1 Naturalized flow factors for Fort Quitman/Colonia Luis Leon

Year	Historical Gaged Streamflow (acre-ft/year)	Naturalized Streamflow (acre-ft/year)	Naturalized Streamflow / Historical Gaged Streamflow
1984	128,604	480,200	4
1985	123,128	479,268	4
1986	716,920	1,138,470	2
1987	557,959	1,013,196	2
1988	374,017	804,462	2
1989	167,777	551,526	3
1990	191,517	261,613	1
1991	184,268	520,924	3
1992	238,241	650,280	3
1993	257,131	697,530	3
1994	205,003	644,864	3
1995	409,614	889,526	2
1996	167,600	528,810	3
1997	177,426	540,750	3
1998	174,463	524,932	3
1999	189,036	577,272	3
2000	139,529	527,783	4

Simulation was performed for a period that represents the most current conditions along the Forgotten River. The losses and gains for the most recent 16 years were averaged. These average monthly values were used as the time series for the gains and losses in the HEC-ResSim model. The recommended hydrograph and the gain and loss time series were duplicated for two years. The first set of data was used for the "look back" start up period for the model. This was done with the assumption that the conditions in the previous year were similar to the conditions in the modeling year. To test the sensitivity of the model to the loss and gain time series assumptions, the 50% hydrograph was simulated with varying levels of loss and gain.

4 Results and Discussion

The objective of this section is to present the results of the hydrologic analysis and of the HEC-ResSim modeling. The hydrologic analysis contains results from flow analysis and period analysis to characterize changes over time in the streamflow. The HEC-ResSim modeling includes a comparison of simulated streamflow to historical streamflow, simulated results from streamflow recommendations and a simple sensitivity analysis.

4.1 Hydrologic Analysis

4.1.1 Stream Gages

The average monthly streamflow for all three stream gages in the Forgotten River were plotted for the period of 1923-2004. Appendix C contains the daily hydrographs for the three gages for the period 1923 – 2004. Figures 4-1, 4-2, 4-3 show the hydrologic trends along the Forgotten River. Note that the Candelaria/San Antonio del Bravo gage did not begin recording data until 1976. The Fort Quitman/Colonia Luis Leon gage (Figure 4-2) and the Presidio/Ojinaga gage (Figure 4-4) show the flood that occurred in the spring of 1942 which caused Caballo Reservoir located upstream in New Mexico to reach its highest storage ever recorded (USBR, 2005). The period from 1950 to 1980 shows reduced flows at both the Fort Quitman/Colonia Luis Leon gage and Presidio/Ojinaga gage. During this period, there were multiple droughts in the region, including the drought of record in Texas which lasted from 1950 to 1957 (Vottler, 2005). Beginning in the 1980's the flows begin to increase to magnitudes similar to the flow prior to 1950. In 1987, high flows occurred once again and is represented as a peak at all three gages (Figures 4-1 to 4-3). These flows caused Elephant Butte reservoir to spill and the Riverside Diversion Dam located upstream near El Paso, Texas to fail (Allen, 2003).

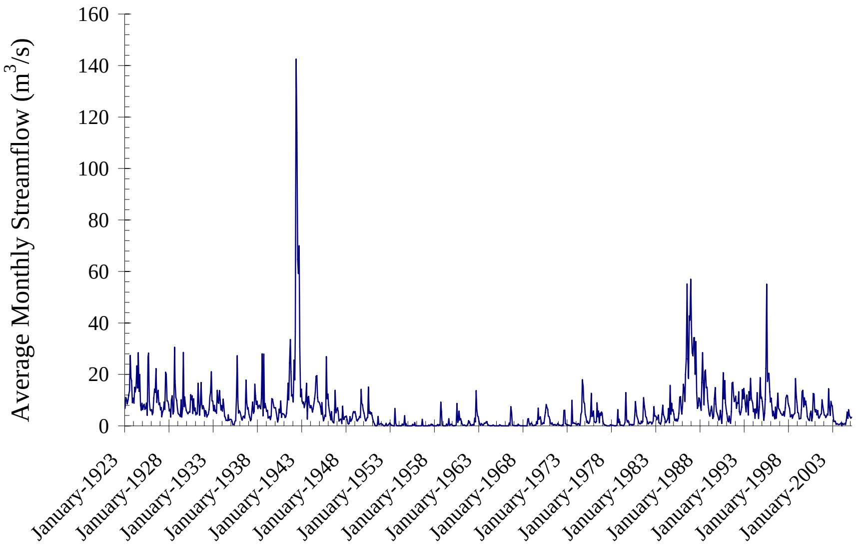


Figure 4-1 Average monthly streamflow at Fort Quitman/Colonia Luis Leon calculated from average daily streamflow (IBWC, 2004)

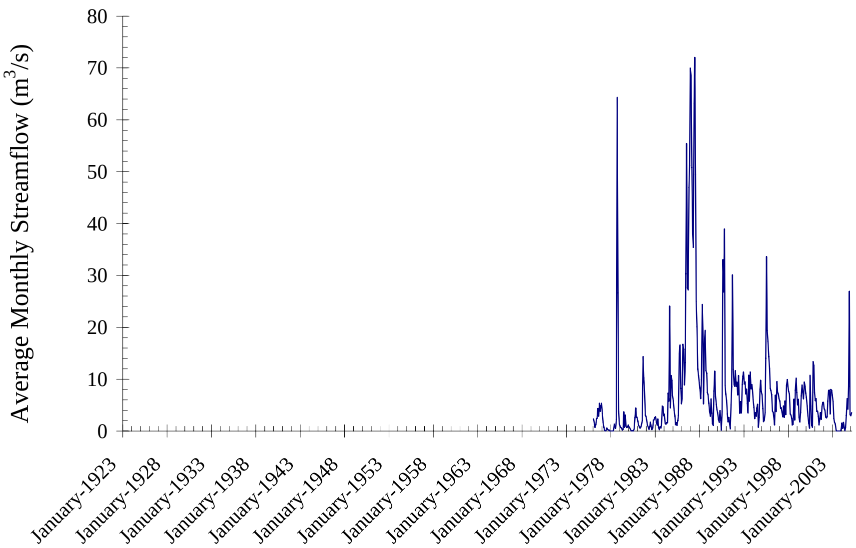


Figure 4-2 Average monthly streamflow at Candelaria / Colonia Luis Leon calculated from average daily streamflow (IBWC, 2004)

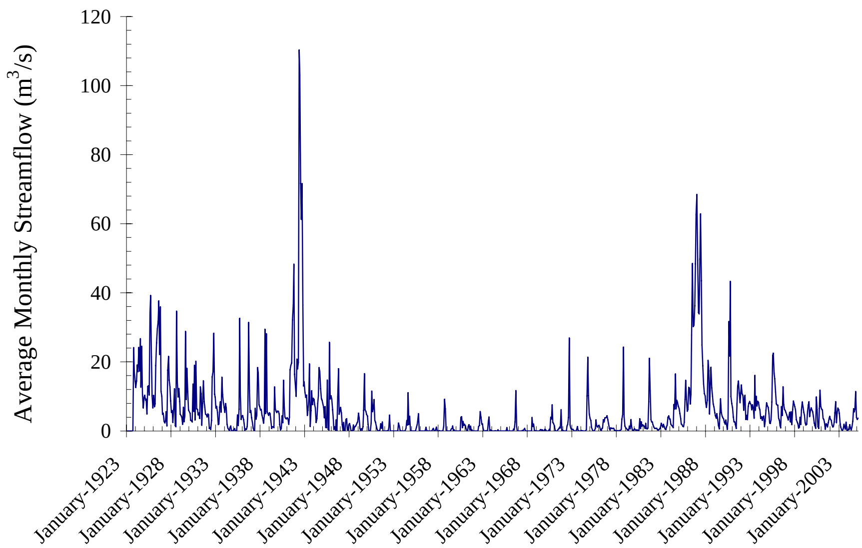


Figure 4-3 Average monthly streamflow at Presidio/Ojinaga calculated from average daily streamflow (IBWC, 2004)

The data from the Candelaria/San Antonio del Bravo gage were not used in the hydrologic analysis outlined in this research. The data were not utilized because they appear to be inconsistent with the upstream and downstream gages at Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga, respectively. Figure 4-4 contains the daily hydrographs for all three of the Forgotten River gages for the year 1995. Closer inspection of the peak flow period around July shows that the hydrograph for the Candelaria/San Antonio del Bravo gage is linear while the hydrographs for the upstream and downstream gages have variation over time (Figure 4-5). This linear trend in the Candelaria/San Antonio del Bravo gage may indicate that data were not recorded correctly by the gage. This linear trend was also observed during other time periods for this gage.

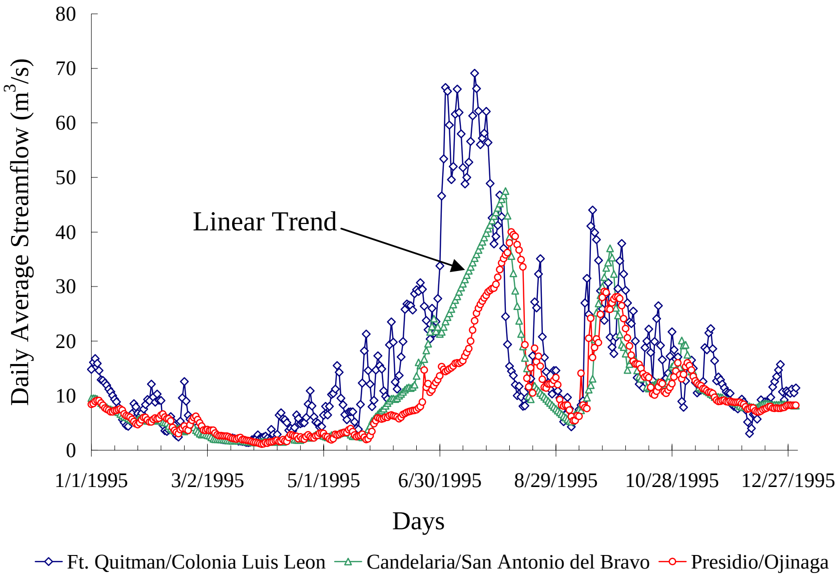


Figure 4-4 Hydrographs of daily flow for the three gages on the Forgotten River for the year 1995

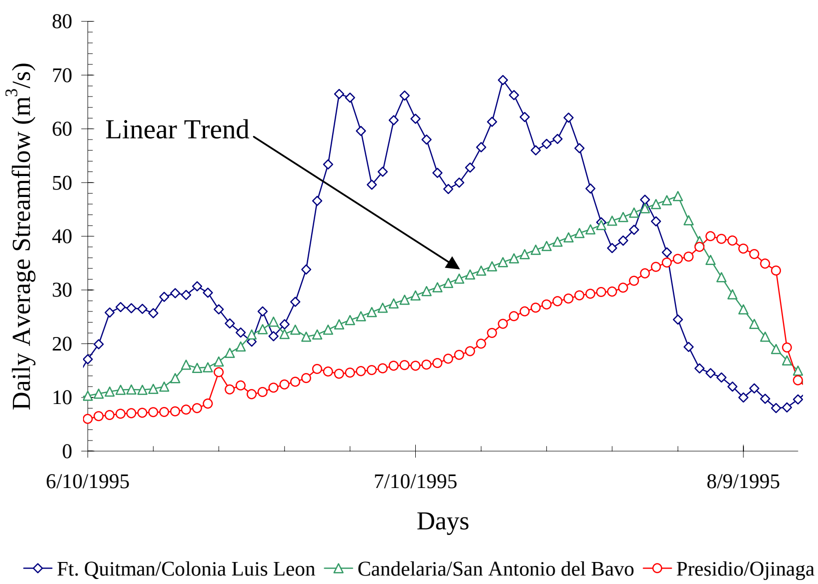


Figure 4-5 Hydrographs of daily flow for the three gages on the Forgotten River for the year 1995

Another inconsistency observed at the Candelaria/San Antonio del Bravo gage was extremely large peaks that were not observed upstream and did not translate downstream. A flash flood caused by a thunderstorm could produce a large peak at one gage that may not be seen at an upstream gage especially since the distance between the two gages is significant. However, if a large peak was created by a thunderstorm it would translate downstream and be recorded by a downstream gage. Figure 4-6 shows a significant peak over 500 m^3/s at the Candelaria/San Antonio del Bravo gage, but the resulting downstream peak at Presidio/Ojinaga is about 100 m^3/s. That is a streamflow loss of over 400 m^3/s between the two gages. This inconsistency might also indicate a misreading by the gage or improperly recorded data.

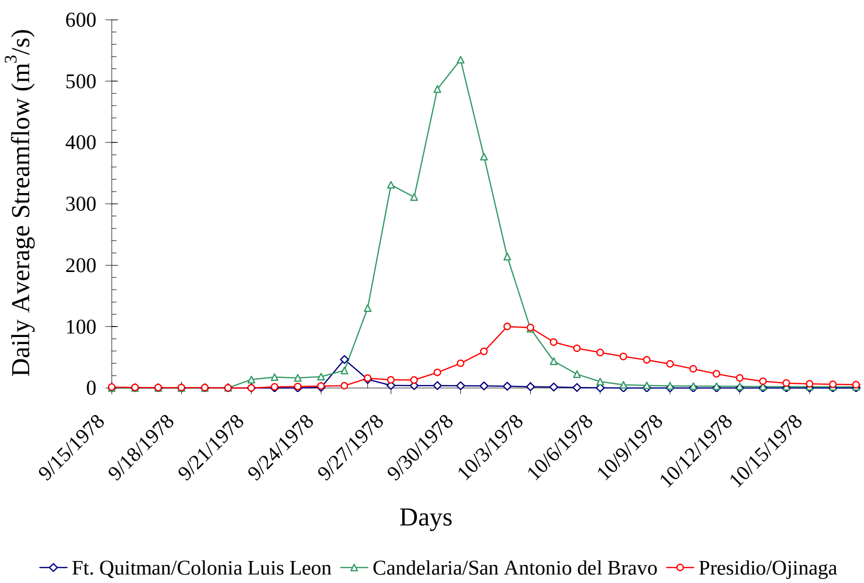


Figure 4-6 Example of inconsistent streamflows for the Candelaria/San Antonio del Bravo gage

4.1.2 Two Period Analysis

The first analysis completed was the characterization of gaining and losing using average daily streamflow. Figure 4-7 shows that the Forgotten River reach between the Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga gages alternates between gaining and losing. The large losses around May 1942 correspond to the 1942 flood and could represent a misread by one or both of the gages. Table 4.1 compares the percentage of time that the reach is gaining and losing between the two time periods. In the early period (1925-1945) the reach is losing 59% of the time and gaining 41% of the time. The later period (1984-2004) shows that the reach is now losing at 64% of the time and gaining only 36% of the time. This increase in loss could be attributed to more unaccounted for diversions along the reach or the increase in salt cedar with an associated increase in evapotranspiration rates.

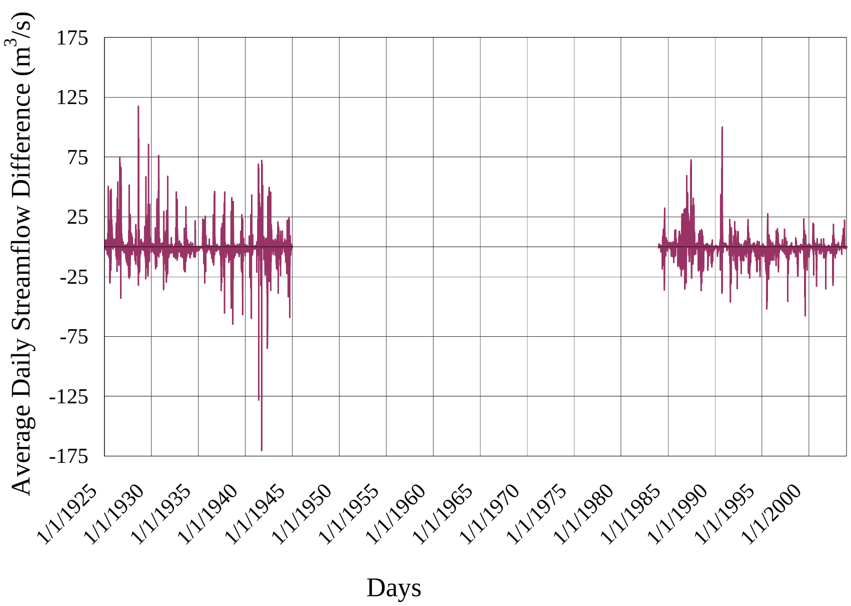


Figure 4-7 Gain/Loss analysis along the Forgotten River for the two periods of 1925-1945 and 1984-2004

Table 4-1 Percentage of time of gain and loss along the Forgotten River for the two periods of 1925-1945 and 1984-2004

Period	Percentage Gaining (%)	Percentage Losing (%)
1925-1945	41	58
1984-2004	36	64

To show this gain/loss on an average monthly basis, the average monthly flows for the two periods were calculated for both gages. The values for both gages are compared for the early period (1925-1945) shown in Figure 4-8. The months of February through June show little difference with Fort Quitman/Colonia Luis Leon showing slightly greater values for most of this period. This shows that the losses occurred through this part of the year. August through October show greater values for the Presidio/Ojinaga gages indicating that the river is gaining in these months.

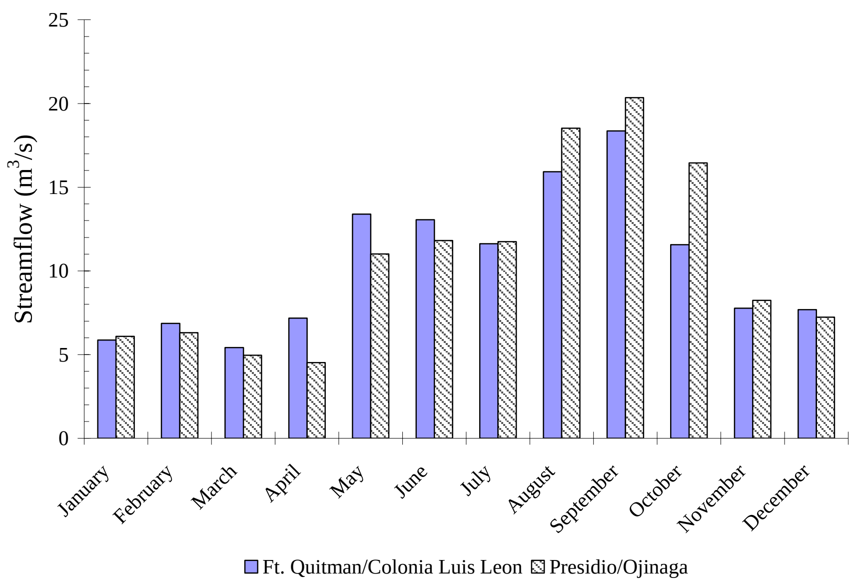


Figure 4-8 Comparison of the average monthly streamflows at the Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga gages for the period of 1925-1945

The later period (1984-2004) shows that the streamflow magnitudes have decreased in the irrigation months compared to the earlier period. Figure 4-9 is a comparison of the streamflows at Fort Quitman/Colonia Luis Leon gage to the streamflows at the Presidio/Ojinaga gage. There is little variation between the two gages indicating that there is little gain or loss in streamflow through the Forgotten River reach. The largest losses in this period occurred in July and October.

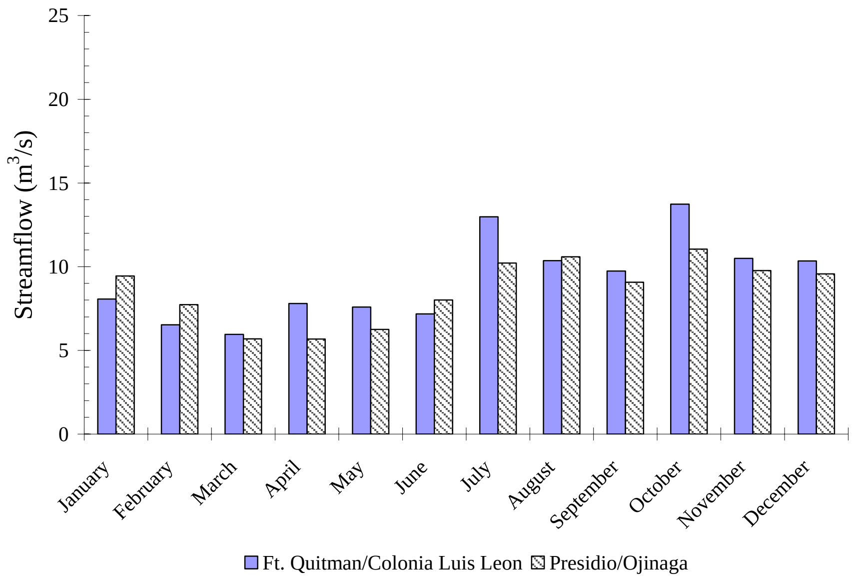


Figure 4-9 Comparison of the average monthly streamflows at the Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga gages for the period of 1984-2004

4.1.3 Fort Quitman/Colonia Luis Leon Gage

A two period analysis with the IHA software was completed for the Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga gages to characterize streamflow changes from the period 1925-1945 to the period 1984-2004 (Figure 4-10). The percent change shown in this analysis was calculated within the IHA software as the Deviation Factor. The Deviation Factor is the percentage of change of the mean values from the first period to the second period. Additional statistics calculated by the IHA software are included in Appendix D for the Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga gages.

The Fort Quitman/Colonia Luis Leon gage, at the top of the Forgotten Reach, has had decreases and increases in streamflow from the earlier period to the more recent period. There is no clear trend in the increases and decreases at this gage. The average monthly streamflows for May, June, and August have decreased by an IHA deviation factor of 43% to 46% decrease. September has the largest decrease at a 47% decrease. In comparison, the non-irrigation months of November through January have experienced a slight streamflow increase of 34% to 37%. Streamflow in February through April show little change with February decreasing slightly by 4% and March and April increasing by about 9%. The average July streamflow has seen little change with a slight increase of 11% change. The early period shows a clear increase in streamflow with the irrigation season starting in May and lasting through October. The more recent period has a peak which has shifted to July through October and has a decreased magnitude.

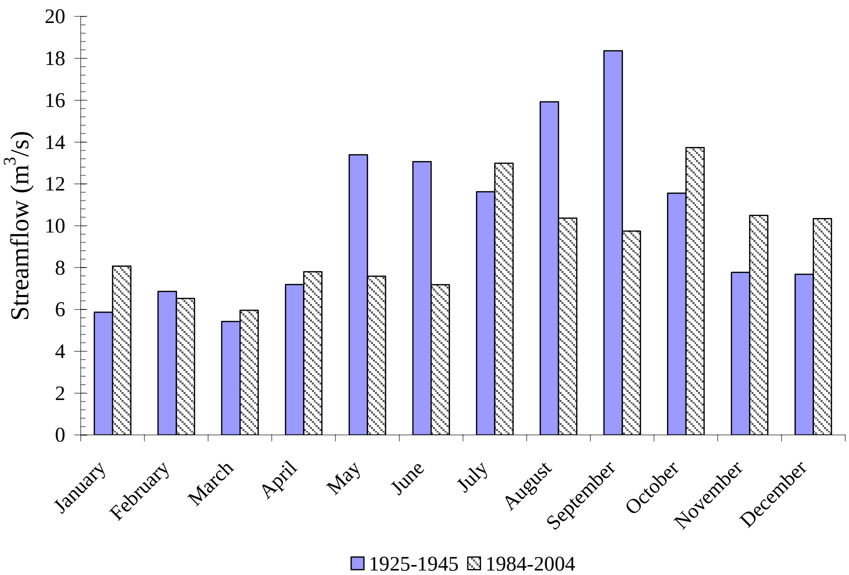


Figure 4-10 Two period comparison of the average monthly streamflows for the Fort Quitman/Colonia Luis Leon gage.

The IHA software was used to determine the magnitude, frequency and timing of extreme high flows and extreme low flows at the Fort Quitman/Colonia Luis Leon gage. Appendix C contains the plots generated by the IHA for these analyses. The changes in magnitude, timing and frequency of the extreme events with corresponding Deviation Factor percentages are as follows:

- The average number of zero flow days increased by an average of 0.5 days;
- Baseflow increased slightly from an average of 0.16 m^3/s to 0.20 m^3/s or 20%;
- A slight change (6%) in the average timing of the minimum flow which occurs in mid – June;
- A slight change decrease of 2% the number of low pulse events;
- The duration of low pulse events increased by an average of 6 days or 59%;
- A slight 1% change in the timing of the maximum flow which occurs in mid-August;
- A slight 1% change in the number of high pulse events; and
- The duration of the high pulse events decreased by an average of 1 day which corresponds to a 25% change.

The maximums and minimums of the streamflow were calculated on for multi-day means. These multi-day means represent average on different time scales. The 1-day minimum/maximum represents the single minimum/maximum observed in a year. The 3-day is the minimum/maximum values observed in a year for 3-day averages or the minimum/maximum for 122 3-day periods. The 7-day averages over weeks, 30-day over months and the 90-day over seasons. These averages can be found on the IHA scorecard in Appendix D. At the Fort Quitman/Colonia Luis Leon gage the minimum values decreased slightly for all multi-day means except the 1-day minimum which increased by 0.5%. The largest decrease was 7% for the 30-mean. In contrast, a large decrease was observed for all maximums for all multi-day means. The largest decrease was 30% for the 1-day maximum and 28% for both the 3-day and 7-day maximums. These results show that the observed minimum streamflows have not changed significantly while the maximums have experienced a significant decrease as the magnitude of floods entering the Forgotten River reach have decreased.

4.1.4 Presidio/Ojinaga Gage

A two period analysis was performed for the Presidio/Ojinaga gage in the same manner as with the Fort Quitman/Colonia Luis Leon gage (Figure 4-11). Average monthly streamflow for the Presidio/Ojinaga gage has decreased in the irrigation months May through October with decreases of over 32% occurring. The largest decrease in streamflow happened in September with a 55% decrease. The smallest decrease of 13% occurred in July. The average monthly streamflow for the months of November through April has increased with the largest increase of 55% in January. The smallest increase in this time period occurred in March at 14%. As with the Fort Quitman/Colonia Luis Leon gage, the early period showed a clear peak in streamflow corresponding to the irrigation season. The more recent period has a peak that starts in June and lasts through July and has a reduced magnitude compared to the earlier period.

The changes in magnitude, timing and frequency of the extreme events with corresponding Deviation Factor percentages for the Presidio/Ojinaga gage are as follows:

- The average number of zero flow days decreased by an average of 20 days or 100% decrease;
- Baseflow increased from an average of 0.05 m^3/s to 0.13 m^3/ s corresponding to a 166% change;
- A slight 5% change in the average timing of the minimum flow which occurs in late June;
- The number of low pulse events increased slightly from an average of 5.6 to 7.2 corresponding to a 28% increase;
- The duration of low pulse events decreased by an average of 6 days or 36% decrease;

- The timing of the maximum flow shifted by an average of 22 days which is only a 12% change;
- The number of high pulse events decreased from an average of 5.7 to 1.6 or a 73% decrease; and
- The duration of the high pulse events increased by an average of 3 day which corresponds to a 51% increase.

The maximums and minimums of the streamflow were calculated on for multi-day means for the Presidio/Ojinaga gage. Unlike the Fort Quitman/Colonia Luis Leon gage, the minimum flows at the Presidio/Ojinaga gage have increased for most of the multi-day means. The largest increases of 70% and 63% correspond to the 1- and 3-day minimums, respectively. Only the 90-day minimum showed a slight decrease of 1%. These results indicate that there is more water in the channel during low flows in the more recent period. Similar to the Fort Quitman/Colonia Luis Leon gage, the maximum flows at the Presidio/Ojinaga gage have also decreased for each multi-day means. However, unlike the Fort Quitman/Colonia Luis Leon gage, the decreases are larger. The largest decrease of 51% occurred with the 1-day maximum and the smallest of 30 % occurred with the 90-day maximum. The decrease in maximums shows that the floods are decreasing in magnitude along the Forgotten River reach.

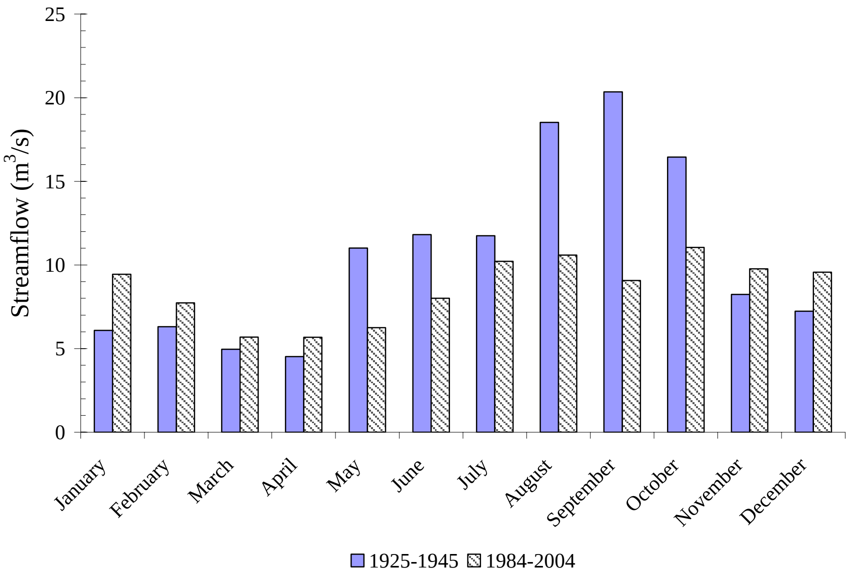


Figure 4-11 Two period comparison of the average monthly streamflows for the Presidio/Ojinaga gage

4.1.5 Recommended Hydrographs

The recommended hydrographs were calculated only for the Fort Quitman/Colonia Luis Leon gage to determine input streamflow for the Forgotten River reach. The recommended hydrographs are calculated by percentile statistics in the IHA software. The software calculates 10%, 25%, 50%, 75% and 90% streamflows. The 10% and 90% streamflow hydrographs represent the extreme low flows and high flows, respectively. These were not used in this analysis which is focused on the typical streamflow range of 25% to 75%.

The 25% hydrograph is a low flow situation with a maximum flow around 6 m^3/s (Figure 4-12). The hydrograph shows a peak towards September which lasts through February. This hydrograph could be considered as a minimum set of flows for restoration along the Forgotten River. The 50% hydrograph represents typical flows which are observed at the Fort Quitman/Colonia Luis Leon gage (Figure 4-13). This hydrograph shows a larger peak starting in the late summer months and reaching its peak in September. Finally, the 75% hydrograph represents a higher flow situation along the Forgotten River. These flows peak in August with a magnitude of 20 m^3/s. These flows would represent the periodic high flow conditions that should be seen along the Forgotten River.

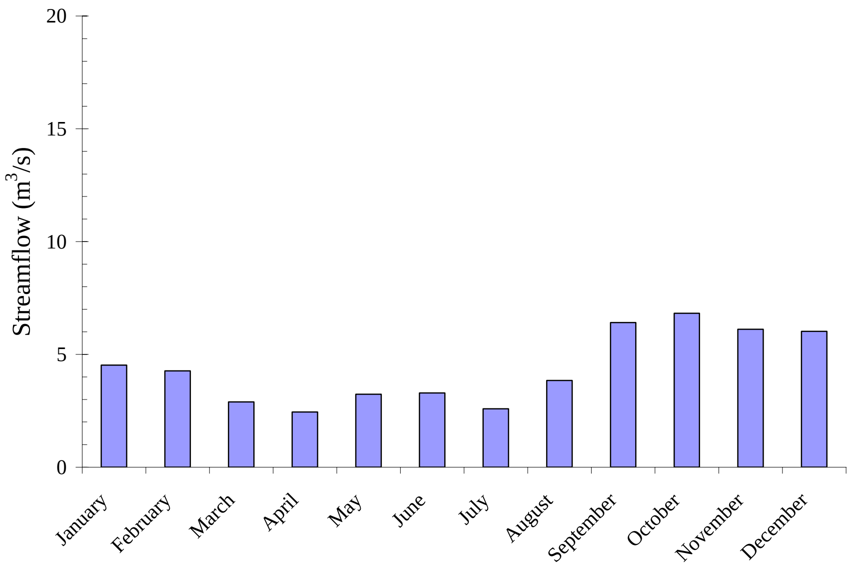


Figure 4-12 25% recommended monthly streamflow hydrograph

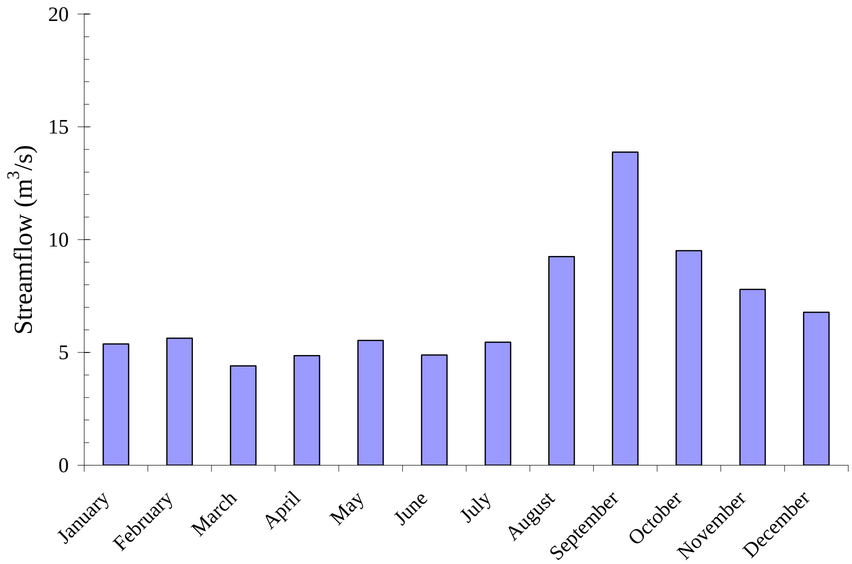


Figure 4-13 50% (median) recommended monthly streamflow hydrograph

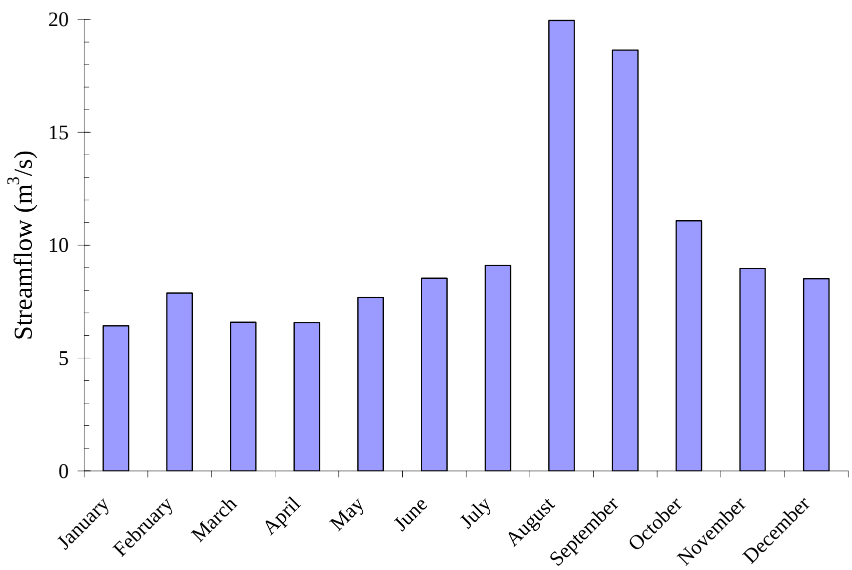


Figure 4-14 75% recommended monthly streamflow hydrograph

4.1.6 Daily Streamflow Hydrograph Representation

Daily streamflow hydrograph representations were developed to demonstrate what the flow variation might look like through the year with the recommended monthly hydrographs. The daily streamflow hydrographs were created for the 25%, 50% and 75% streamflows shown in the previous section. It is again emphasized that these hydrographs are representations of what the streamflow variation might look like over the year rather than actual numerical values.

The 25% hydrograph, considered to be the low flow case, is a series of low and extreme low flows, until the summer months when high flow pulses occur (Figure 4-15). These high flow pulses represent flash floods that typically occur along the Forgotten River in the summer months. This hydrograph shows that there are periods of extreme low flows that would occur along the Forgotten River under these conditions.

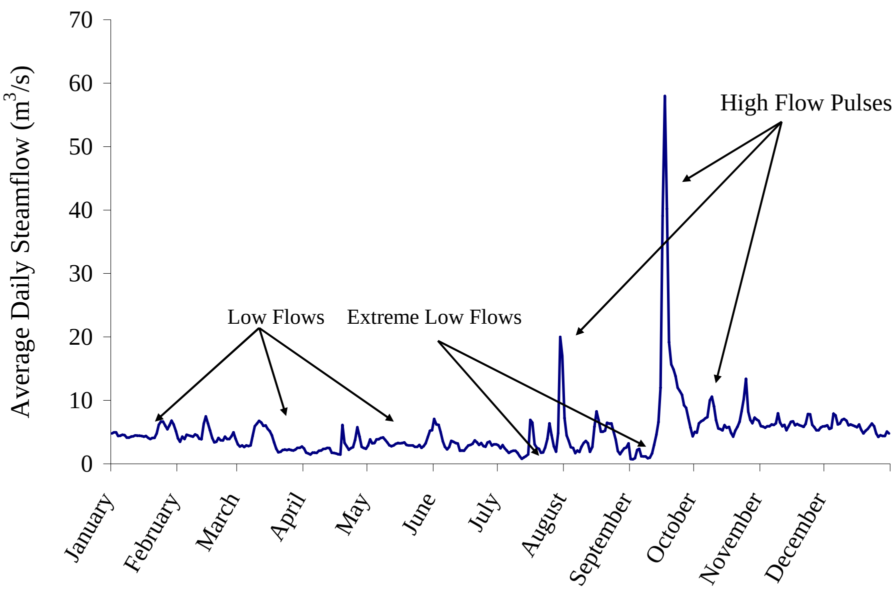


Figure 4-15 25% Daily streamflow hydrograph representation

The 50% daily hydrograph, which represents the median flow values and is considered a typical hydrograph is a combination of low flows and high flow pulses. The extreme low flows observed in the 25% hydrograph representation, do not occur in the 50% hydrograph representation. The largest of the high flow pulses occur in the summer months and are likely a product of flash floods caused by thunderstorms.

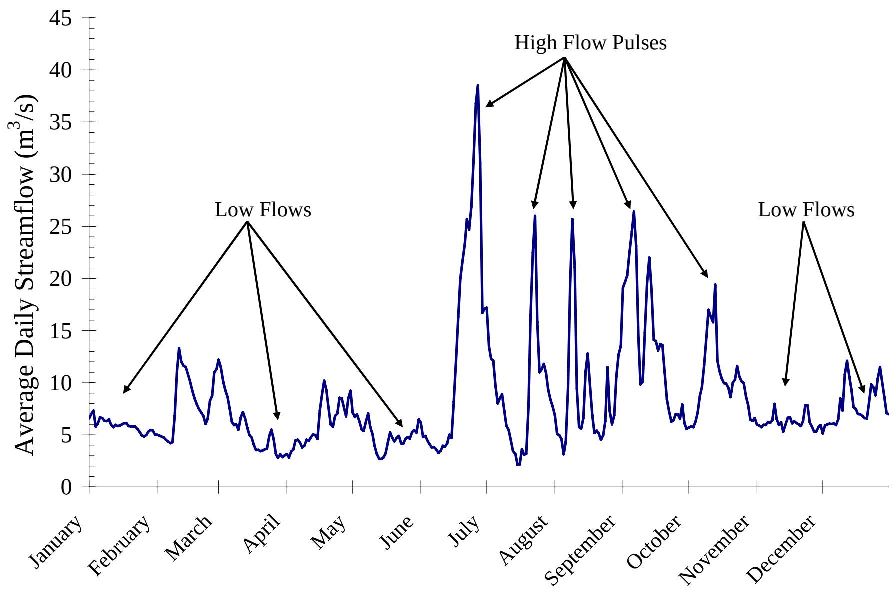


Figure 4-16 50% Daily streamflow hydrograph representation

Finally, the 75% daily hydrograph represents a higher flow condition along the Forgotten River (Figure 4-17). This hydrograph shows the increase in streamflow during the irrigation season from May through October. This case has a series of a large flood and small floods later in the summer and early fall. This hydrograph demonstrates that the system tends to be flashy and has more floods rather than high flow pulses. This means that the flows from a flood event subside quickly and rise quickly giving it the hydrograph characteristics of flooding.

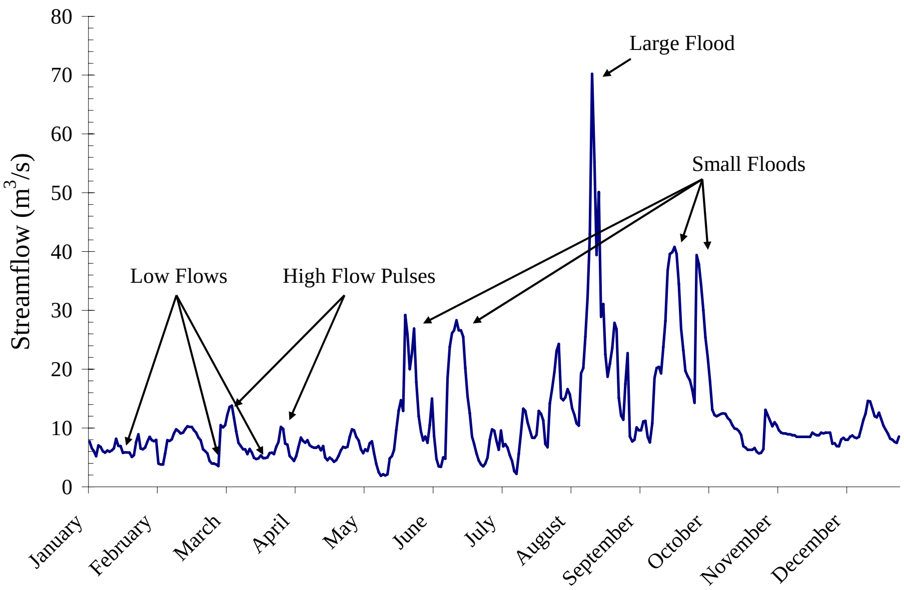


Figure 4-17 75% Daily streamflow hydrograph representation

4.2 HEC-ResSim Results

4.2.1 Model Validation

The HEC-ResSim model was run for the period 1941-2000 using 1940 as the "look back" period. Figure 4-18 is the simulated streamflow plotted with the historical observed streamflows at the Presidio/Ojinaga for the most recent 16 years (1984-2000). The simulated streamflow follows the trends seen in the historical data but tends to overestimate the historical streamflow in the low flow periods and underestimates in periods of high flow. These results indicate that further evaluation of incremental losses and gains are required to calibrate the streamflow in the model. Adjustment of incremental losses and gains to more closely reflect the natural conditions might reduce some of the over- and underestimation seen in the model.

The simulated streamflow values from the HEC-ResSim model reasonably match the historical streamflow values for the Forgotten River reach showing that the model results do provide a reasonable estimate of streamflow. The simulated values do not closely match the historical daily values shown in Figure 4-18 because the HEC-ResSim model has monthly data as input and simulates on a daily time step. While HEC-ResSim allows for an input of a month time step, a daily time step is the largest time step available in HEC-ResSim for simulation. To simulate on a daily time step with monthly data, HEC-ResSim interpolates between monthly values. This interpolation causes the over and under estimation seen in Figure 4-18. These results show that input data on a daily time step are required; however, this model can be viewed as an appropriate first approximation model for the Forgotten River.

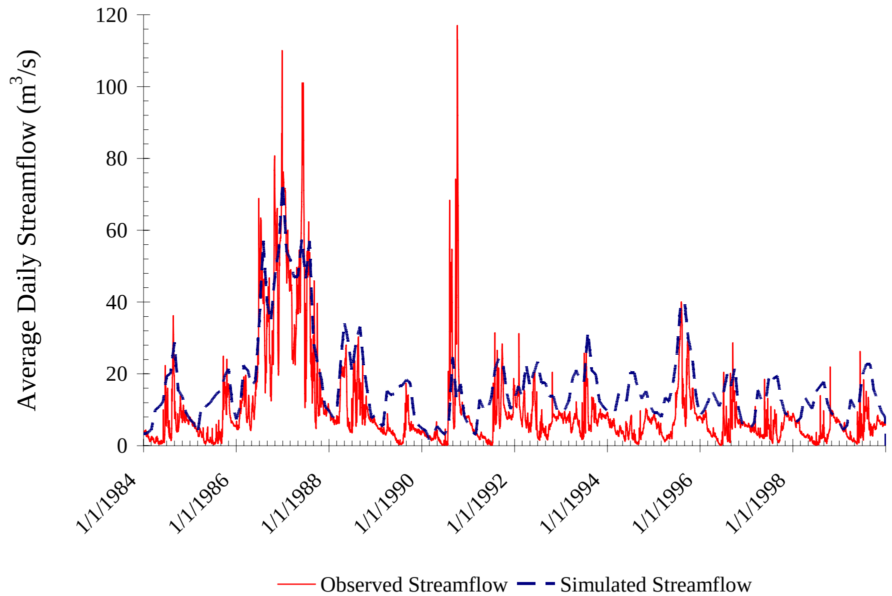


Figure 4-18 HEC-ResSim simulated daily streamflows vs. observed daily historical streamflow values at the Presidio/Ojinaga gage

4.2.2 Recommended Hydrograph Results

The assumed loss and gains for the simulation period were calculated from the average values of the losses and gains for the period of 1984-2000 (Figure 4-21). The average losses peak in the summer and decrease in the winter following the trend of increased evaporation and evapotranspiration in the summer months and increased irrigation. The average gains do not show a clear trend (Figure 4-22).

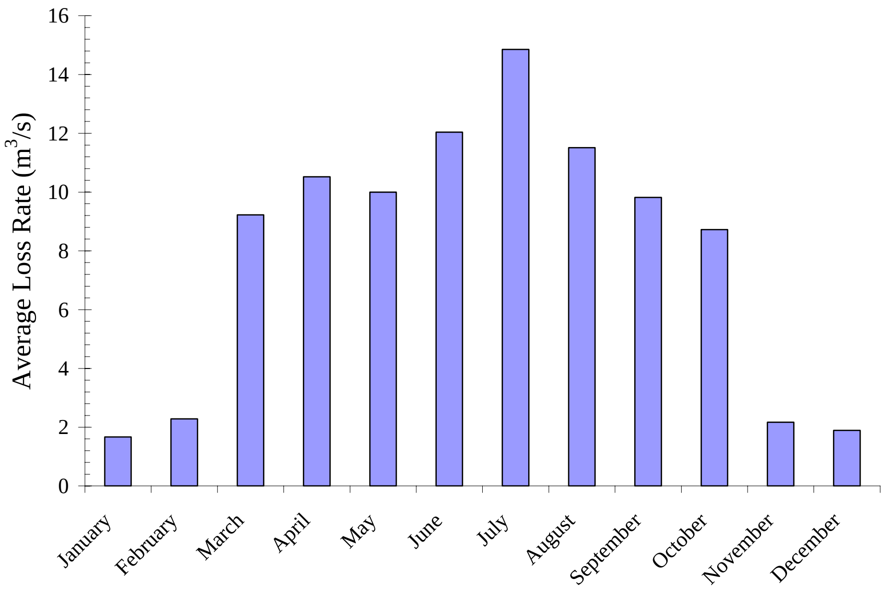


Figure 4-19 Calculated average losses time series for the period 1984-2000

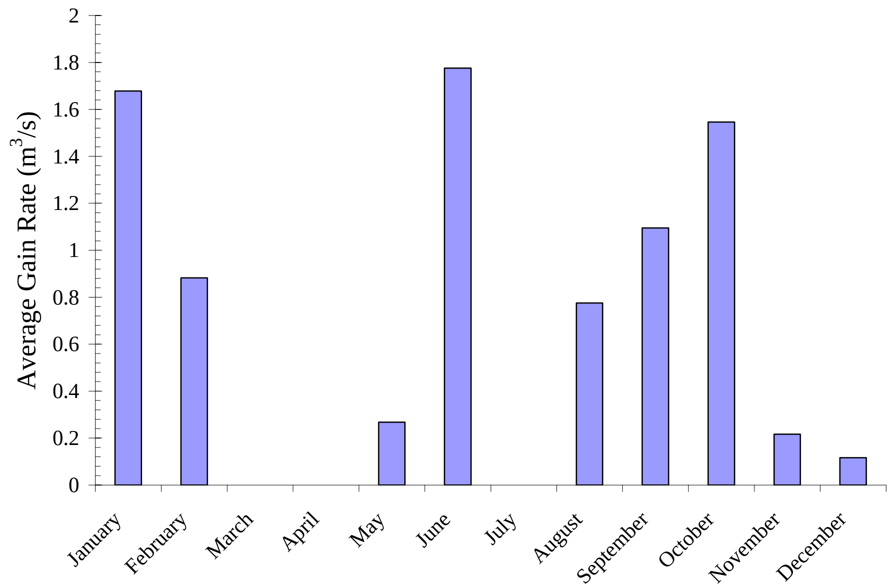


Figure 4-20 Calculated average gains time series for the period 1984-2000

The recommended hydrographs were used as system input at Fort Quitman/Colonia Luis Leon. The HEC-ResSim simulation was performed for one year with the losses and gains shown in Figures 4-19 and 4-20. The 25% hydrograph produced a hydrograph at Presidio/Ojinaga that had zero flow values for the period of April through September (Figure 4-21). This result may be due to the assumed loss and gain factors. These factors may be too large to represent the gain and loss conditions that would occur during a flow of this magnitude.

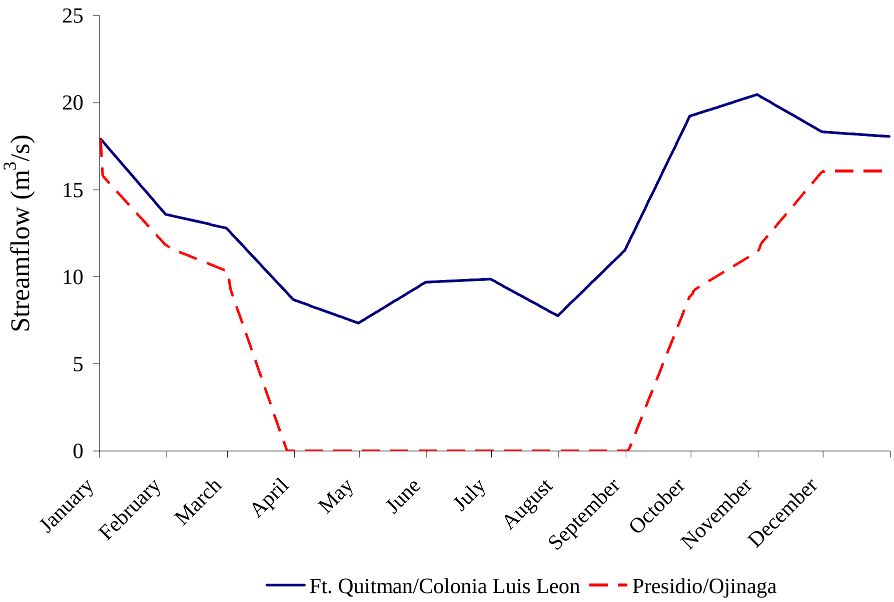


Figure 4-21 HEC-ResSim results for the 25% recommended hydrograph

The 50% recommended flow hydrograph produced a hydrograph at Presidio/Ojinaga with a near zero flow during the month of July (Figure 4-22). A large difference in the streamflow at Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga occurs in the period of April through August. Comparing this result to the historical streamflow differences shown previously in Figures 4-8 and 4-9, the simulated difference in flow is too large. These results indicate once again that the loss factors may be too large or the gain factors too small for flows of this magnitude.

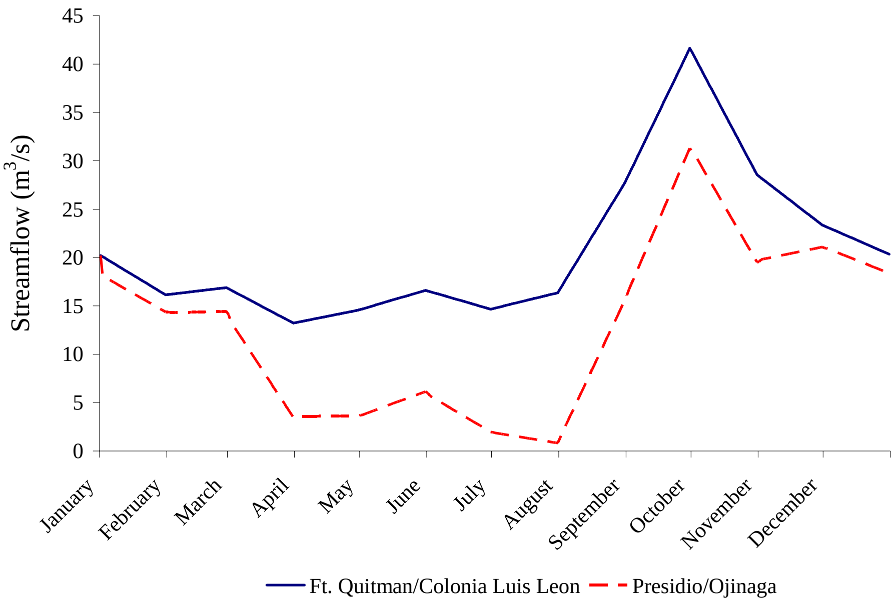


Figure 4-22 HEC-ResSim results for the 50% recommended hydrograph

Finally, the 75% hydrograph produces resulting hydrograph with a smaller difference between the Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga gages in the period of April through August than seen with the 25% and 50% hydrographs. These results indicate that the loss and gain factors may be appropriate for flows of this magnitude; however, further calibration of the HEC-ResSim model is necessary before drawing significant conclusions.

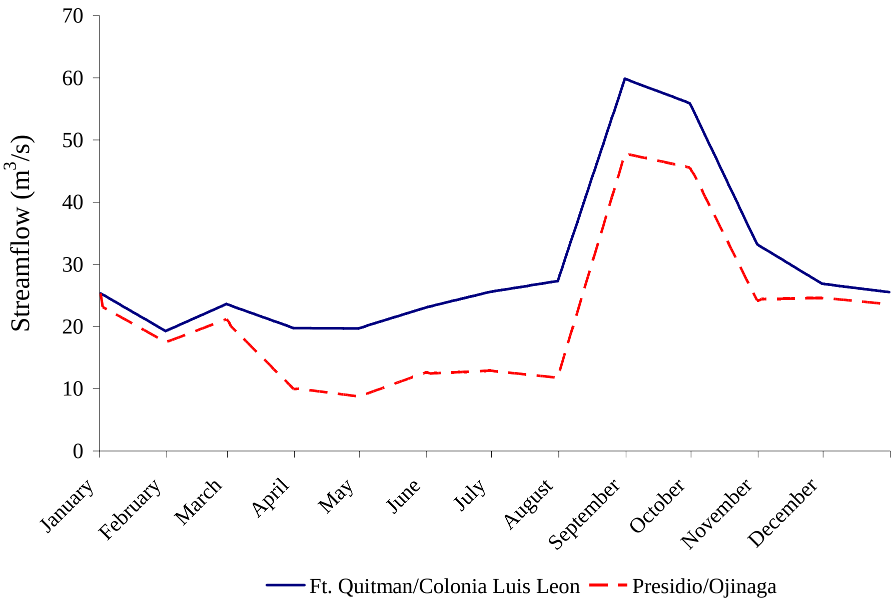


Figure 4-23 HEC-ResSim results for the 75% recommended hydrograph

4.2.3 Sensitivity Analysis

To test the sensitivity of the HEC-ResSim model to the assumed incremental losses and gains a simple sensitivity analysis was performed. This sensitivity analysis was performed by varying the incremental losses and gains and comparing the results to the modeled 50% recommended hydrograph presented in Figure 4-22. To test the incremental gains, the incremental losses were held constant while the gains were varied. In this simple analysis, the assumed incremental gains were set to zero, set to double the assumed value and 10 times the assumed value. The results did not change with this variation indicating that the assumed incremental gains are too small compared to the streamflow to affect the overall outcome of the hydrograph.

The incremental losses were tested with the same method as the incremental gains. The incremental gains were held constant while the losses were halved and doubled and compared to the modeled 50% recommended hydrograph. These results, presented in Figure 4-24 indicate that the incremental loss factor had a large effect on the resulting hydrograph at Presidio/Ojinaga. The smaller incremental losses increased the magnitude of the hydrograph while the larger incremental losses decreased the hydrograph from the simulated 50% hydrograph. These results indicate that further calibration of the model is needed through better definition of the loss factors. Rather than assume the loss factors by the difference in gage flows the losses could be calculated directly from historical channel seepage, evaporation and evapotranspiration.

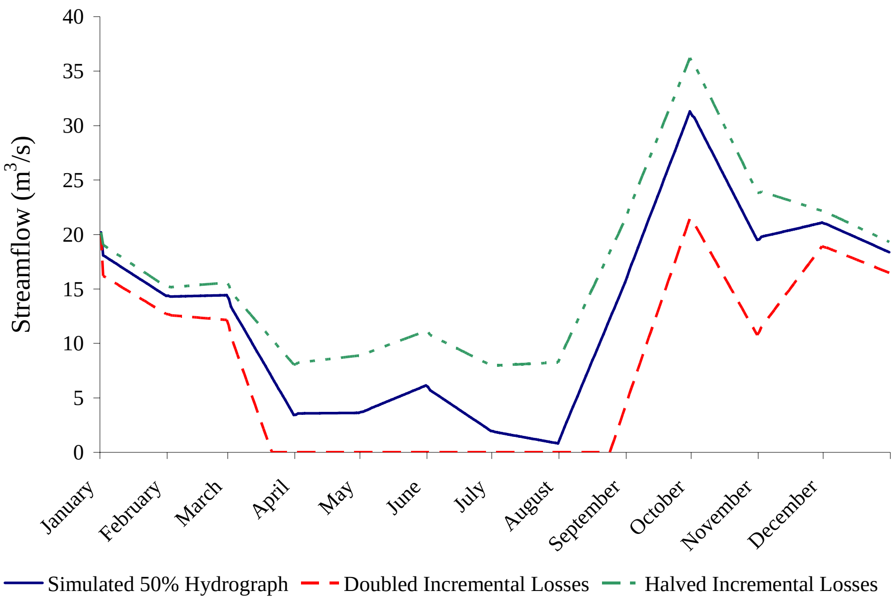


Figure 4-24 Resulting hydrographs at Presidio/Ojinaga from changing the incremental losses

5 Conclusions and Recommendations

The Forgotten River segment of the Rio Grande/Bravo basin is highly impaired. To support restoration along this segment a hydrologic analysis was completed to characterize streamflow alterations over time and create recommendations for restoration hydrographs. A first approximation model was developed in HEC-ResSim for the Forgotten River reach to simulate the results of the restoration hydrographs. This model used water resources data stored in an Arc Hydro geodatabase and utilized tools which were developed to easily and quickly transfer the Arc Hydro time series data to the model.

5.1 Conclusions

The hydrologic analysis indicates that changes have occurred in the hydrology of the Forgotten River from the period of 1925-1945 compared to the period of 1984-2004. The following conclusions can be drawn from the hydrologic analysis:

1. The peak flows in April through September observed in the period 1925-1945 have decreased in magnitude for the period 1984-2004 at both Fort Quitman/Colonia Luis Leon and Presidio/Ojinaga gages.
2. The frequency and magnitude of extreme events have not changed significantly at the Fort Quitman/Colonia Luis Leon gage. However, the duration of the extreme events have changed so that the river is in low flow for a longer period than it was in the early period and the high flows do not last as long as in the early period.
3. The Presidio/Ojinaga gage has experienced little change in the timing of extreme events. However, the river enters low flow periods more frequently than the early period but the river these low flow periods do not last as long as they did in the earlier period. Additionally, the number of high flow periods has

decreased and the duration of these high flow pulses has decreased compared to the earlier period indicating that the river has fewer floods.

4. The multi-day mean minimums at the Fort Quitman/Colonia Luis Leon gage have decreased slightly (less than 7%) indicating that there is slightly more water in the river during low flow periods than in the early period. By contrast, the multi-day mean minimums at the Presidio/Ojinaga gage have increased significantly indicating that there is more water in the river during low flow periods at the Presidio/Ojinaga gage than in the early period.
5. The multi-day maximums for both the Fort Quitman/Colonia Luis Leon gage and the Presidio/Ojinaga gage have decreased significantly indicating that the magnitude of floods in the reach have decreased in the recent period.
6. Clear conclusions about specific changes in the hydrology cannot be drawn from this analysis because the gages are too far apart to clearly capture changes and pinpoint where the changes might be occurring.

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The HEC-ResSim model was shown to be a good first approximation for simulation of streamflow along the Forgotten River. The following conclusions are drawn from the modeling and calibration:

1. The DSS Hydro Tools are an easy methodology for transferring time series data between and Arc Hydro geodatabase and HEC-ResSim.
2. The HEC-ResSim model over- and underestimates historical streamflow because the input data has a monthly time step but the model simulates on a daily time step. The daily time step requires the model to interpolate between average monthly values and causes the model to miss high and low variation that occurs during the month.
3. The model is sensitive to the incremental loss assumption. This assumption needs further refinement to calibrate the model to natural conditions.

5.2 Recommendations for Further Research

Further hydrologic analysis should be completed to characterize the causes of hydrologic changes along the Forgotten River. The data from the Candelaria gage requires further validation before it should be used in modeling. Data from this gage would add valuable information to characterizing the flows along the Forgotten River reach, however until validation is completed this data should be used with caution.

The HEC-ResSim model is a good first approximation for modeling the Forgotten River segment; however, due to the sensitivity of the incremental loss assumption, further calibration is necessary. The assumptions made for incremental losses and gains in the model are an over simplification. Ideally, to capture the behavior of the incremental gains and losses the following factors must be determined:

- evapotranspiration related to salt cedar
- free surface evaporation
- channel seepage
- channel gains from groundwater contributions
- historical water right diversion amounts
- historical return flow amounts
- historical data for diversions and return flows for Mexico

The HEC-ResSim model provided a good first approximation for hydrologic analysis along the Forgotten River, however, the discrepancy in the time step of the input data and model simulation must be addressed. The time step of the data and the simulation model need to correspond. Since the data available along the Forgotten River was limited to a monthly time step, a different model which can simulate on a monthly time step, such as WEAP, should be considered for application along this reach.

Appendix A

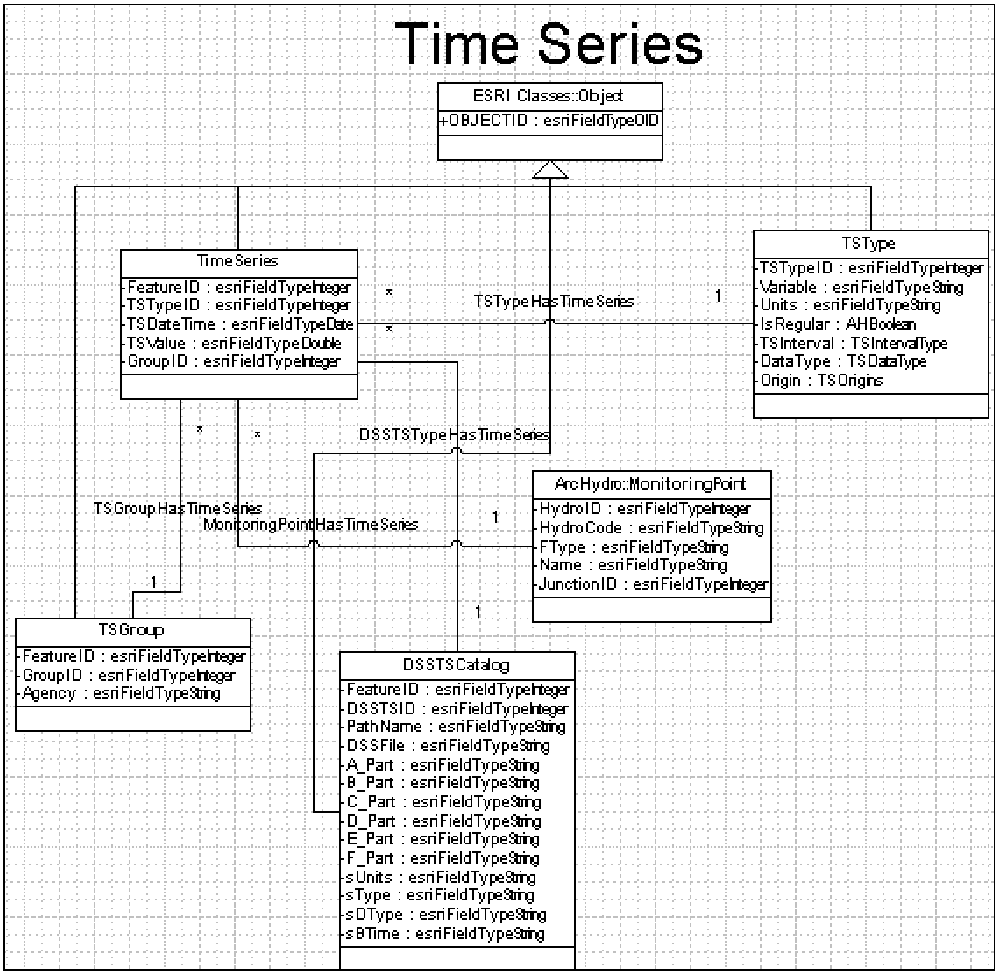
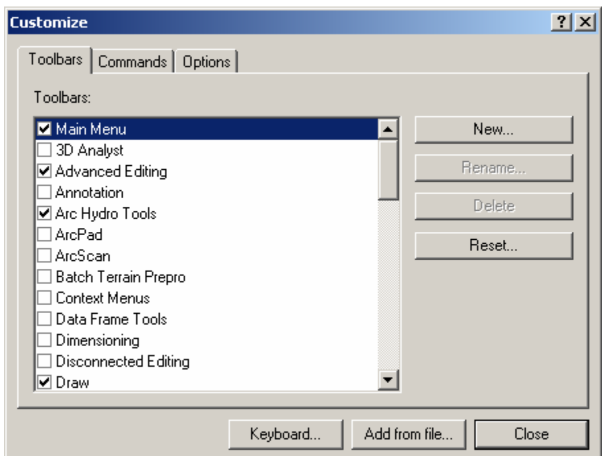


Figure A - 1 Modified Arc Hydro with Time Series framework

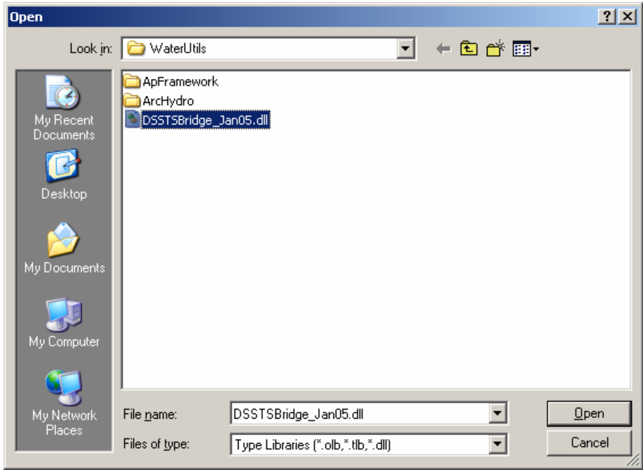
By Carlos Patino
CRWR – UT at Austin
March 2005

INSTALLING THE DSS HYDRO TOOLBAR DLL

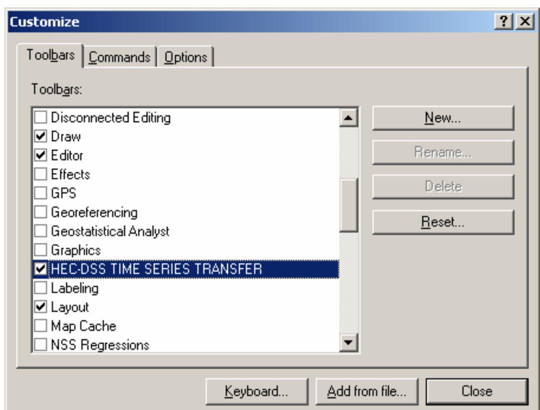
- Open ArcMap
- Go to the Customize option in the Toolbars option.



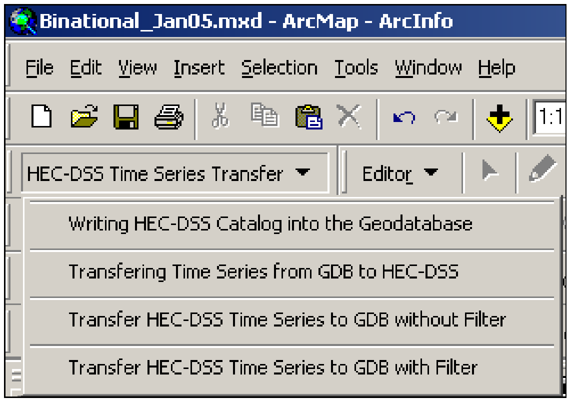
Click the “Add from file” button and select the “DSSTSBridge_Jan05.DLL” from your folder where you have the dll



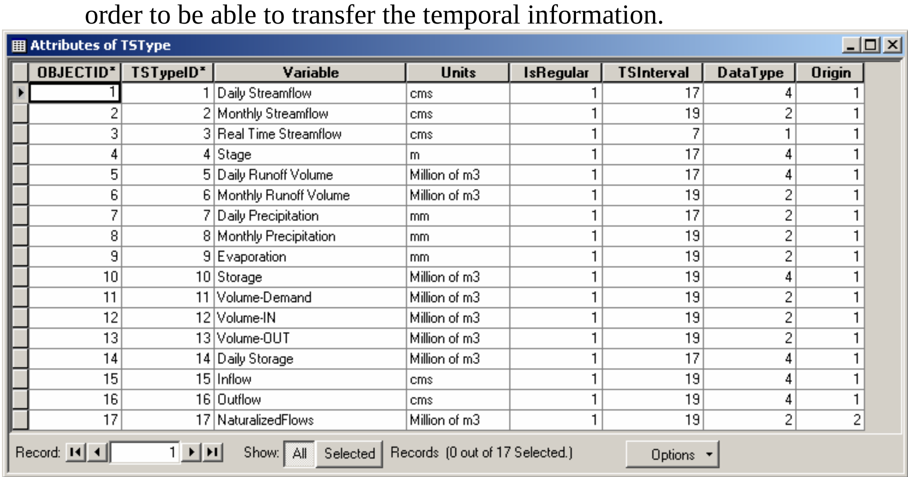
Activate the "HEC-DSS TIME SERIES TOOLBAR" option…..and now you should have the DSS Toolbar in your ArcMap document



DSS Hydro Toolbar Description (After you have installed the DLL in ArcMap)



1. Writing HEC-DSS Catalog into the geodatabase: This option allows populating automatically the DSSTSType table, which was created previously by the ArcHydro schema. This function takes the temporal information from the Time Series and the TSType tables included in the ArcHydro geodatabase. The TSType table must have the next structure in order to be able to transfer the temporal information.



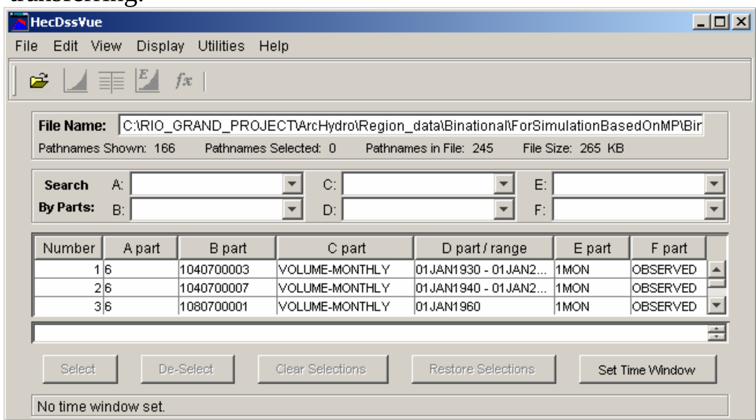
Attributes of TSType

OBJECTID*	TSTypeID*	Variable	Units	IsRegular	TSInterval	DataType	Origin
1	1	Daily Streamflow	cms	1	17	4	1
2	2	Monthly Streamflow	cms	1	19	2	1
3	3	Real Time Streamflow	cms	1	7	1	1
4	4	Stage	m	1	17	4	1
5	5	Daily Runoff Volume	Million of m3	1	17	4	1
6	6	Monthly Runoff Volume	Million of m3	1	19	2	1
7	7	Daily Precipitation	mm	1	17	2	1
8	8	Monthly Precipitation	mm	1	19	2	1
9	9	Evaporation	mm	1	19	2	1
10	10	Storage	Million of m3	1	19	4	1
11	11	Volume-Demand	Million of m3	1	19	2	1
12	12	Volume-IN	Million of m3	1	19	2	1
13	13	Volume-OUT	Million of m3	1	19	2	1
14	14	Daily Storage	Million of m3	1	17	4	1
15	15	Inflow	cms	1	19	4	1
16	16	Outflow	cms	1	19	4	1
17	17	NaturalizedFlows	Million of m3	1	19	2	2

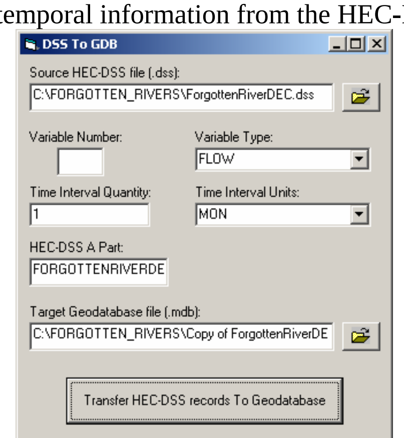
Record: 1 Show: All Selected Records (0 out of 17 Selected.) Options

2. Transferring Time Series from GDB to HEC-DSS: This function transfers all temporal information contained in the ArcHydro Time Series table into

a HEC-DSS file. The DSSTSType is the key table to make this transferring.



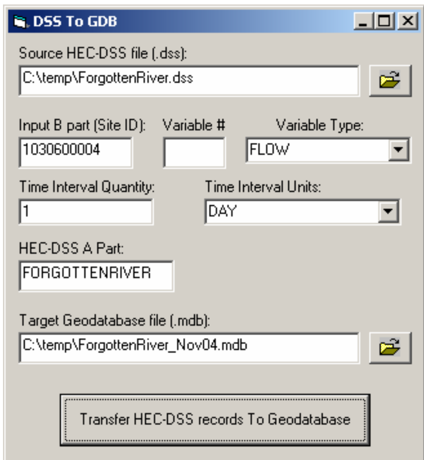
3. Transfer HEC-DSS Time Series to the GDB without Filter. This option transfers ALL temporal information from the HEC-DSS files to the GDB.



Choose the HEC-DSS file from where you want to transfer the information. Select the number variable appearing in the A Part of the HEC-DSS file (Number 6 in this example). Select the Variable Type that should be the same appearing in the C Part of the HEC-DSS file (VOLUME-MONTHLY). Select the time interval units, and type the HEC-DSS A Part (6 for this example, and it must be the same value as appears in the

A Part of the HEC-DSS table). Finally select the target geodatabase where you want to store this temporal information.

4. Transfer HEC-DSS Time Series to the GDB WITH filter. This option transfers JUST THE INFO RELATED TO ONE SPECIFIC POINT from the HEC-DSS files to the GDB.



Choose the HEC-DSS file from where you want to transfer the information. Select the HydroID of the Monitoring Point in the “Input B Part (Site ID)” box. This ID must be the same as appears in the B Part of the HEC-DSS table. Select the number variable appearing in the A Part of the HEC-DSS file (Number 6 in this example). Select the Variable Type that should be the same appearing in the C Part of the HEC-DSS file (VOLUME-MONTHLY). Select the time interval units, and type the HEC-DSS A Part (6 for this example, and it must be the same value as appears in the A Part of the HEC-DSS table). Finally select the target geodatabase where you want to store this temporal information.

Appendix B

TEXAS WATER RIGHTS IN THE RIO GRANDE BASIN

SORTED BY TCEQ WATER RIGHT NUMBER

WATER RIGHT NUMBER	WATER RIGHT TYPE	COUNTY	RIVER ORDER	OWNER	STREAM	ANNUAL DIVERSION AMOUNT acre-feet	TYPE OF USE	IRRIG. ACREAGE	CLASS	PRIORITY DATE	RESERVOIR NAME	RESERVOIR CAPACITY acre-feet	Latitude	Longitude
244	1	Hudspeth	9720000000	HUDSPETH CO C-R DIST 1	RIO GRANDE	27,000.0	3	9,000.0		9/11/1918			31.361765	-105.952965
244	1	Hudspeth	9720000000	HUDSPETH CO C-R DIST 1	RIO GRANDE		3			9/11/1918			31.361765	-105.952965
900	6	Hudspeth	9659700000	FORT QUITMAN LAND CO	RIO GRANDE	800.0	3	500.0		8/18/1977		395	31.124228	-105.667587
900	6	Hudspeth	9659700000	FORT QUITMAN LAND CO	RIO GRANDE	700.0	3			8/18/1977			31.124228	-105.667587
901	6	Hudspeth	9640000000	WILLIAM N ROTH ET AL	RIO GRANDE	507.0	3	169.0		8/18/1977			31.096102	-105.619896
902	6	Hudspeth	9639000000	SIDNEY W COWAN	RIO GRANDE	330.0	3	110.0		8/18/1977			31.091753	-105.615578
903	6	Hudspeth	9638250000	DOUGLAS A JOHNSTON	RIO GRANDE	63.0	3	21.0		8/18/1977			31.077007	-105.601074
904	6	Hudspeth	9638000000	J B BEAN	RIO GRANDE	831.0	3	277.0		8/18/1977			31.069632	-105.598221
905	6	Hudspeth	9637000000	RICHARD MARTINEZ, ET UX	RIO GRANDE	330.0	3	110.0		8/18/1977			31.048222	-105.584442
906	6	Hudspeth	9636000000	TOM H NEELY	RIO GRANDE	164.0	3	82.0		8/18/1977			30.999409	-105.562523
906	6	Hudspeth	9636000000	BETTY JO N WATERHOUSE ET AL	RIO GRANDE	82.0	3	82.0		8/18/1977			30.999409	-105.562523
907	6	Hudspeth	9635800000	LOUIS M FOIX SR	RIO GRANDE	150.0	3	50.0		8/18/1977			30.985186	-105.546509
908	6	Hudspeth	9635100000	LESTER RAY TALLEY JR ET AL	RIO GRANDE	138.0	3	46.0		8/18/1977			30.947828	-105.495346
909	6	Hudspeth	9635000000	LESTER RAY TALLEY JR ET AL	RIO GRANDE	144.0	3	48.0		8/18/1977			30.938053	-105.484802
910	6	Hudspeth	9634950000	MAX R HAMPTON	RIO GRANDE	126.0	3	42.0		8/18/1977			30.922899	-105.461075
911	6	Hudspeth	9634800000	LESTER RAY TALLEY	RIO GRANDE	216.0	3	72.0		8/18/1977			30.873602	-105.402954
912	6	Hudspeth	9634250000	MALCOLM MCGREGOR ET AL	RIO GRANDE	15.0	3			8/18/1977			30.823162	-105.332535
912	6	Hudspeth	9634250000	MALCOLM MCGREGOR ET AL	RIO GRANDE	162.0	3	59.0		8/18/1977			30.823162	-105.332535
913	6	Hudspeth	9632700000	GLORIA GUERRA ADDINGTON	RIO GRANDE	582.0	3	194.0		8/18/1977			30.756121	-105.160835
914	6	Hudspeth	9631500000	COLQUITT RUSSELL BRAMBLETT	RIO GRANDE	219.0	3	73.0		8/18/1977			30.684843	-105.065498
3215	2	Hudspeth	9670000000	HUDSPETH CO CONS & REC DIST 1	MACHO ARROY	200.0	3	600.0		2/17/1970		200	31.181089	-105.704193
3216	2	Hudspeth	9680000000	HUDSPETH CO CONS & REC DIST 1	MADDEN ARRO	200.0	3	600.0		2/17/1970		200	31.262712	-105.671867
3217	2	Hudspeth	9710000000	HUDSPETH CO CONS & REC DIST 1	ALAMO ARROY	200.0	3	1,800.0		2/17/1970		200	31.384245	-105.859848
3218	2	Hudspeth	9690000000	HUDSPETH CO CONS & REC DIST 1	DIABLO ARROY	1,032.0	3	1,432.0		2/17/1970		200	31.249968	-105.764931
3219	2	Hudspeth	9700000000	HUDSPETH CO CONS & REC DIST 1	CAMP RICE AR	200.0	3	600.0		2/17/1970		200	31.317986	-105.818741
3245	1	Hudspeth	9633900000	JOE RUSSELL BROWN	RIO GRANDE	312.0	3	104.0		1/7/1975			30.793823	-105.263611
3246	1	Hudspeth	9634260000	JOE RUSSELL BROWN	RIO GRANDE	156.0	3	52.0		1/7/1975			30.822989	-105.332466
3314	1	Hudspeth	9631010000	COLQUITT RUSSELL BRAMBLETT	RIO GRANDE	1,017.0	3	339.0		2/19/1975			30.673096	-105.00721
5406	1	Hudspeth	9999990300	HUDSPETH CO COMMISSIONERS CT	CORNUDAS DR	1,002.0	9			6/16/1992			31.985842	-105.277397
5467	6	Hudspeth	9999990219	C L RANCH PARTNERSHIP	CORNUDAS DR	2,200.0	3	1,600.0		3/28/1988		775	31.979326	-105.274223
5467	6	Hudspeth	9999990219	CONNECTICUT MUTUAL LIFE INS CO	CORNUDAS DRAW		3			3/28/1988			31.979326	-105.274223
5467	6	Hudspeth	9999990219	JAMES & MARY LYNCH JR	CORNUDAS DRAW		3			3/28/1988			31.979326	-105.274223
5468	6	Hudspeth	9999990069	C L MACHINERY CO ET AL	HITSON DRAW	2,400.0	3	1,800.0		3/28/1988		458	31.868	-105.263039
5468	6	Hudspeth	9999990069	CONNECTICUT MUTUAL LIFE INS CO	HITSON DRAW		3			3/28/1988			31.868	-105.263039
5469	6	Hudspeth	9999990019	C L RANCH A PARTNERSHIP	HITSON DRAW	2,100.0	3	898.0		3/28/1988		588	31.851086	-105.208977
121	1	Jeff Davis	6485000000	CLAYTON W WILLIAMS JR ET AL	MUSQUIZ CRK	124.0	11	0.0		12/30/1915		16	30.49041	-103.708466
375	3	Jeff Davis	7850000000	UNITED STATES DEPT OF INTERIOR	PHANTOM	900.0	3	300.0		6/29/1914			30.93169	-103.840378
1172	6	Jeff Davis	7117600000	DONALD D MCIVOR	LIMPIA CANYON	15.0	3	10.0		9/28/1978		20	30.608887	-104.003159
1173	6	Jeff Davis	7117010000	RUTH JOHNSON	LIMPIA CANYON	69.0	3	69.0		9/28/1978			30.603243	-103.899208
1174	6	Jeff Davis	7117000000	H E SPROUL	LIMPIA CANYON	224.0	3	112.0		9/28/1978		3	30.607067	-103.879662
1175	6	Jeff Davis	7116200000	ISABEL CECILIA THOMPSON	LIMPIA CANYON	5.0	3	20.0		9/28/1978			30.622225	-103.847023

1176	6	Jeff Davis	7116000000	JIMMY G & BESSIE J HIGGINS	LIMPIA CANYON	4.0	3	2.0	9/28/1978			30.626932	-103.840363
1177	6	Jeff Davis	7115800000	GEORGE A HOFFMAN MD ET AL	LIMPIA CANYON	50.0	3	25.0	9/28/1978			30.631907	-103.83477
1178	6	Jeff Davis	7115700000	ESTELLE LANGHAM SHARP	LIMPIA CANYON	15.0	3	14.0	9/28/1978			30.635284	-103.82946
1491	1	Jeff Davis	7855000000	U S BUREAU OF RECLAM	PHANTOM	18,000.0	3	0.0	10/2/1946			30.93169	-103.840546
5439	6	Jeff Davis	7845000000	CITY OF BALMORHEA	BIG AGUJA CAN	644.0	1		3/28/1988		109	30.788246	-103.841919
5440	6	Jeff Davis	7844000000	H C ESPY ESTATE	BOB MANNING	45.0	3	12.0	3/28/1988		2	30.798576	-103.880287
5452	6	Jeff Davis	6510000000	BARRY A BEAL	MUSQUIZ CRK	50.0	3	50.0	3/28/1988		2	30.530949	-103.793266
899	6	Presidio	9257400000	C & L COMPANY	RIO GRANDE	60.0	3	20.0	8/18/1977			29.545378	-104.363098
915	6	Presidio	9565000000	JOHN B MEADOWS TRUSTEE	RIO GRANDE	1,944.0	3	3,684.8	8/18/1977			30.107349	-104.691238
916	6	Presidio	9555000000	TEXAS PARKS & WILDLIFE DEPT	RIO GRANDE	714.0	3	476.0	8/18/1977			30.009521	-104.698517
917	6	Presidio	9540000000	BILL SHANNON	RIO GRANDE	405.0	3	135.0	8/18/1977			29.936419	-104.685463
918	6	Presidio	9528000000	BILLY O WALKER ET UX	RIO GRANDE	29.2	3	9.7	8/18/1977			29.883106	-104.650589
918	6	Presidio	9528000000	B J BISHOP	RIO GRANDE	18.8	3	6.3	8/18/1977			29.883106	-104.650589
919	6	Presidio	9480010000	JAVIER R MOLINA ET UX	RIO GRANDE	243.0	3	81.0	8/18/1977			29.743084	-104.568336
920	6	Presidio	9460000000	FERNWOOD ENTERPRISES	RIO GRANDE	495.0	3	165.0	8/18/1977			29.73353	-104.555099
920	6	Presidio	9460000000	FERNWOOD ENTERPRISES	RIO GRANDE		3	20.0	8/18/1977			29.6	-104.48
921	6	Presidio	9440000000	AC&L ARMENDARIZ PARTNERSHIP	RIO GRANDE	270.0	3	90.0	8/18/1977			29.648222	-104.517952
922	6	Presidio	9421500000	MERCED O GARCIA ET AL	RIO GRANDE	90.0	3	30.0	8/18/1977			29.626652	-104.50692
923	6	Presidio	9421000000	ROBERT L SOZA ET AL	RIO GRANDE	120.0	3	40.0	8/18/1977			29.619408	-104.50267
924	6	Presidio	9420950000	WILLIAM SOZA	RIO GRANDE	54.0	3	18.0	8/18/1977			29.624374	-104.491463
925	6	Presidio	9420850000	ERNESTINE CHAVEZ ET AL	RIO GRANDE	42.0	3	14.0	8/18/1977			29.616285	-104.484802
926	6	Presidio	9420800000	ROBERT L SOZA	RIO GRANDE	66.0	3	22.0	8/18/1977			29.616405	-104.484642
927	6	Presidio	9420750000	LAJITAS RESORT LTD	RIO GRANDE	72.0	3	24.0	8/18/1977			29.616224	-104.484932
928	6	Presidio	9420700000	LAJITAS RESORT LTD	RIO GRANDE	57.0	3	19.0	8/18/1977			29.616405	-104.484642
929	6	Presidio	9420650000	ALFREDO S BAEZA	RIO GRANDE	48.0	3	16.0	8/18/1977			29.616465	-104.484642
930	6	Presidio	9420600000	SOZA & COMPANY	RIO GRANDE	114.0	3	38.0	8/18/1977			29.616232	-104.484634
931	6	Presidio	9420550000	ASUNCION V SPENCER ESTATE	RIO GRANDE	111.0	3	37.0	8/18/1977			29.597404	-104.452957
932	6	Presidio	9420000000	FRANK ARMENDARIZ ET UX	RIO GRANDE	606.0	3	203.0	8/18/1977			29.593956	-104.446449
933	6	Presidio	9410000000	LUZ S ARMENDARIZ	RIO GRANDE	321.0	3	107.0	8/18/1977			29.589603	-104.442566
936	6	Presidio	9369000000	JOSE NATIVIDAD RODRIGUEZ	RIO GRANDE	23.6	3		8/18/1977			29.585087	-104.438347
936	6	Presidio	9369000000	LORENZO V RODRIGUEZ	RIO GRANDE	43.4	3		8/18/1977			29.585087	-104.438347
936	6	Presidio	9369000000	JOSE NATIVIDAD RODRIGUEZ	RIO GRANDE	79.3	3		8/18/1977			29.585087	-104.438347
936	6	Presidio	9369000000	LORENZO V RODRIGUEZ	RIO GRANDE	145.7	3	75.0	8/18/1977			29.585087	-104.438347
937	6	Presidio	9364900000	JOSE A RODRIGUEZ	RIO GRANDE	114.0	3	38.0	8/18/1977			29.586777	-104.420372
938	6	Presidio	9364850000	JOSE A RODRIGUEZ	RIO GRANDE	120.0	3	30.0	8/18/1977			29.586981	-104.420349
939	6	Presidio	9366000000	LORENZO HERNANDEZ	RIO GRANDE	45.0	3	15.0	8/18/1977			29.585825	-104.425217
940	6	Presidio	9340000000	LORENZO V RODRIGUEZ	RIO GRANDE	135.0	3	45.0	8/18/1977			29.585991	-104.415413
940	6	Presidio	9340000000	LORENZO V RODRIGUEZ	RIO GRANDE	45.0	3		8/18/1977			29.585991	-104.415413
941	6	Presidio	9332000000	RCS INC	RIO GRANDE	164.0	3	41.0	8/18/1977			29.583057	-104.412933
942	6	Presidio	9331500000	PAULINE JUAREZ CROSSON	RIO GRANDE	200.0	3	50.0	8/18/1977			29.577898	-104.408821
943	6	Presidio	9331000000	RCS INC	RIO GRANDE	420.0	3	105.0	8/18/1977			29.570807	-104.40538

944	6	Presidio	9330100000	SANTA CRUZ LAND & CATTLE INC	RIO GRANDE	743.0	3	231.4	8/18/1977			29.553022	-104.392159
946	6	Presidio	9270100000	RCS INC	RIO GRANDE	61.0	3	16.0	8/18/1977			29.547314	-104.375046
947	6	Presidio	9270000000	RCS INC	RIO GRANDE	800.0	3	202.0	8/18/1977			29.547077	-104.375237
948	6	Presidio	9257100000	C & L COMPANY	RIO GRANDE	880.0	3	220.0	8/18/1977			29.545374	-104.363258
949	6	Presidio	9257000000	C & L COMPANY	RIO GRANDE	267.0	3	89.0	8/18/1977			29.545496	-104.362999
950	6	Presidio	9253170000	OSCAR SPENCER	RIO GRANDE	39.0	3	13.0	8/18/1977			29.530699	-104.348427
952	6	Presidio	9253200000	PRESIDIO VALLEY FARMS INC	RIO GRANDE	8,059.0	3		8/18/1977			29.535997	-104.349091
953	6	Presidio	9253160000	CF&L ENTERPRISES	RIO GRANDE	407.0	3	136.0	8/18/1977			29.528542	-104.346268
954	6	Presidio	9253110000	CF&L ENTERPRISES	RIO GRANDE	684.0	3	171.0	8/18/1977			29.524588	-104.337402
955	6	Presidio	9253100000	CF&L ENTERPRISES	RIO GRANDE	172.0	3	43.0	8/18/1977			29.524439	-104.337631
956	6	Presidio	9253030000	MANUEL M RUBIO ET AL	RIO GRANDE	84.0	3	21.0	8/18/1977			29.523361	-104.329918
957	6	Presidio	9253000000	EVA MARIA NIETO ET AL	RIO GRANDE	536.0	3	134.0	8/18/1977			29.522211	-104.324219
958	6	Presidio	9252500000	MANUEL COVOS ET UX	RIO GRANDE	43.7	3	10.9	8/18/1977			29.522448	-104.320114
958	6	Presidio	9252500000	ESBEN CARRASCO	RIO GRANDE	48.3	3	12.1	8/18/1977			29.522448	-104.320114
960	6	Presidio	9251000000	LAURENCIO BRITO	RIO GRANDE	140.0	3	35.0	8/18/1977			29.524132	-104.310898
961	6	Presidio	9250980000	LAURENCIO BRITO	RIO GRANDE	72.0	3	18.0	8/18/1977			29.524351	-104.306267
962	6	Presidio	9250900000	REYNALDO HERNANDEZ	RIO GRANDE	96.0	3	24.0	8/18/1977			29.524351	-104.306267
963	6	Presidio	9250700000	RCS INC	RIO GRANDE	160.0	3	40.0	8/18/1977			29.521948	-104.303345
964	6	Presidio	9250680000	RCS INC	RIO GRANDE	376.0	3	94.0	8/18/1977			29.520145	-104.299545
965	6	Presidio	9250650000	GEORGE & CONSUELO HERNANDEZ	RIO GRANDE	60.0	3	15.0	8/18/1977			29.520147	-104.299446
966	6	Presidio	9250510000	HECTOR A HERNANDEZ	RIO GRANDE	80.0	3	20.0	8/18/1977			29.518185	-104.29631
967	6	Presidio	9250000000	ARTHUR T MCCALL	RIO GRANDE	260.0	3	65.0	8/18/1977			29.516514	-104.293045
969	6	Presidio	9251500000	JOHN T. MACGUIRE, ET UX	ALAMITO CRK	18,700.0	7		8/18/1977	SAN ESTEBAN	18,700	30.151278	-104.029251
970	6	Presidio	9251400000	HAYES MITCHELL JR	ALAMITO CRK	41.0	3	20.0	8/18/1977		35	30.053902	-103.994034
971	6	Presidio	9251300000	MINING HARD ROCK INC	ALAMITO CRK	35.0	3	50.0	8/18/1977			29.855007	-104.012253
972	6	Presidio	9251200000	LUCIA H RUSSELL ESTATE	ALAMITO CRK	80.0	3	40.0	8/18/1977			29.744505	-104.029266
973	6	Presidio	8990000000	JOSE A HERNANDEZ	RIO GRANDE	96.0	3	24.0	8/18/1977			29.512697	-104.277763
974	6	Presidio	8987200000	PRESIDIO CO WID 1	RIO GRANDE	2,780.0	3	700.0	8/18/1977			29.499342	-104.24855
975	6	Presidio	8987000000	LAJITAS RESORT LTD	RIO GRANDE	380.0	3	95.0	8/18/1977			29.476622	-104.223862
976	6	Presidio	8979780000	RUBEN H MADRID	RIO GRANDE	56.0	3	14.0	8/18/1977			29.43672	-104.200233
977	6	Presidio	8979750000	LYDIA MADRID	RIO GRANDE	40.0	3	10.0	8/18/1977			29.434349	-104.194305
978	6	Presidio	8979550000	E. H. MADRID	RIO GRANDE	32.0	3	8.0	8/18/1977			29.419275	-104.186516
978	6	Presidio	8979550000	E. H. MADRID	RIO GRANDE	304.0	3	76.0	8/18/1977			29.419275	-104.186516
979	6	Presidio	9420555000	JESUS ALONZO HERNANDEZ ET AL	RIO GRANDE	52.0	3	16.0	8/18/1977			29.61	-104.465
980	6	Presidio	8979400000	ALVARO PENA ET UX	RIO GRANDE	52.0	3	13.0	8/18/1977			29.419277	-104.186478
981	6	Presidio	8979200000	FAUSTINO PINEDA III	RIO GRANDE	168.0	3	42.0	8/18/1977			29.398556	-104.168335
982	6	Presidio	8979100000	JAIME REDE MADRID ET AL	RIO GRANDE	80.0	3	20.0	8/18/1977			29.398558	-104.168304
983	6	Presidio	8979000000	THOMAS A MALLAN	RIO GRANDE	84.0	3	21.0	8/18/1977			29.398848	-104.168312
985	6	Presidio	8978740000	A G RIMER ET UX	RIO GRANDE	20.0	3	12.0	8/18/1977			29.383291	-104.144638
3255	1	Presidio	8988010000	DANIEL T ESTRADA	RIO GRANDE	108.0	3	27.0	1/7/1975			29.505299	-104.264259
3256	1	Presidio	8987010000	LAJITAS RESORT LTD	RIO GRANDE	132.0	3	33.0	1/7/1975			29.476738	-104.223839
3392	1	Presidio	9251100000	LUCIA H RUSSELL ESTATE	VILLAGE CRK	100.0	3	100.0	4/9/1975			29.744566	-104.029106
3393	1	Presidio	8961000000	JEANNE NORSWORTHY	RIO GRANDE	156.0	3	39.0	5/13/1975			29.2735	-103.849007

Appendix C

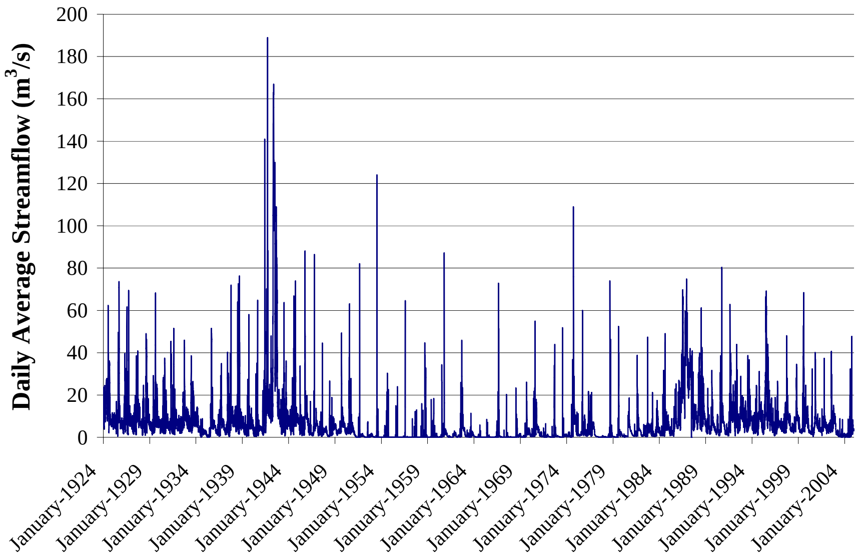


Figure C - 2 Average Daily Streamflow at the Fort Quitman/Colonia Luis Leon gage (IBWC, 2005).

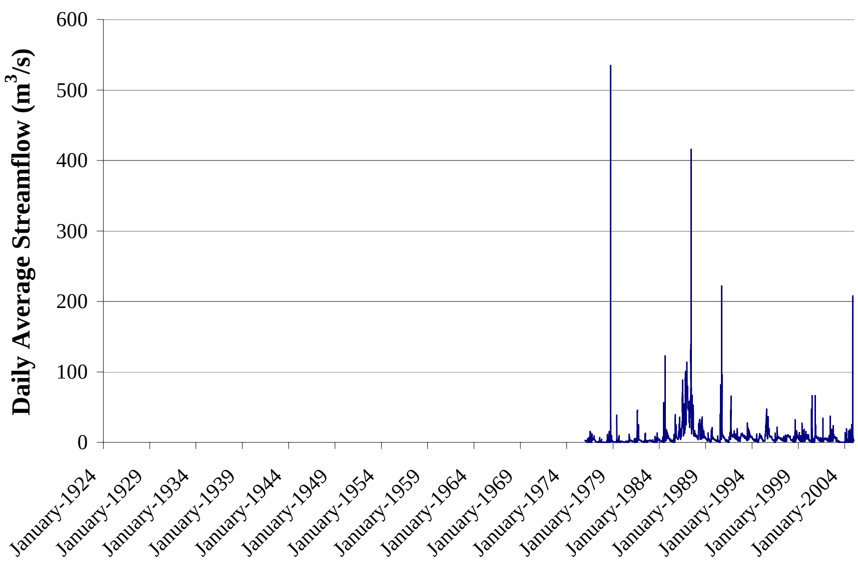


Figure C - 3 Average Daily Streamflow at the Candelaria/ San Antonio del Bravo gage (IBWC, 2005).

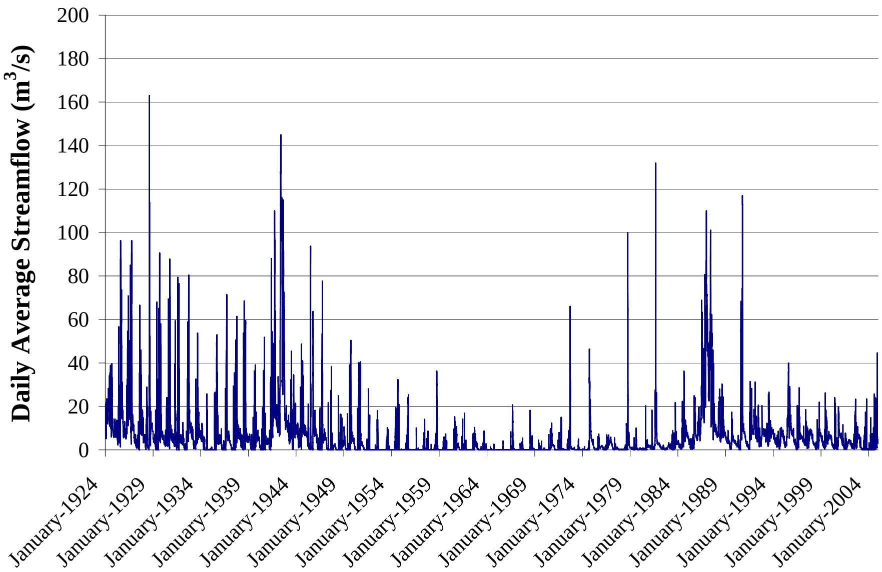


Figure C - 4 Average Daily Streamflow at the Presidio/Ojinaga gage (IBWC, 2005)

Fort Quitman/Colonia Luis Leon Gage Analysis

Figure C - 5 Average Monthly Flow for the Fort Quitman/Colonia Luis Leon gage

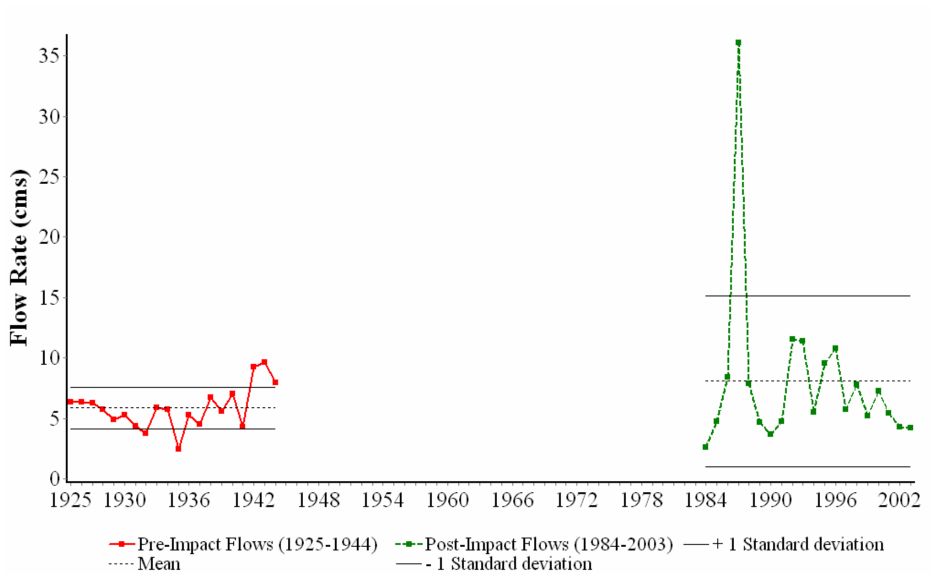


Figure C - 6 Monthly mean streamflows for January at the Fort Quitman/Colonia Luis Leon gage

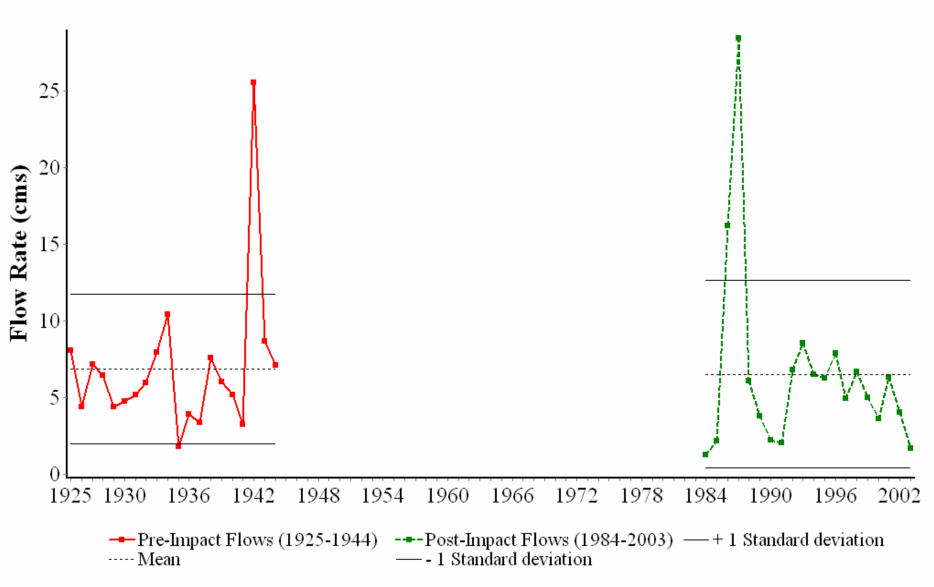


Figure C - 7 Monthly mean streamflows for February at the Fort Quitman/Colonia Luis Leon gage

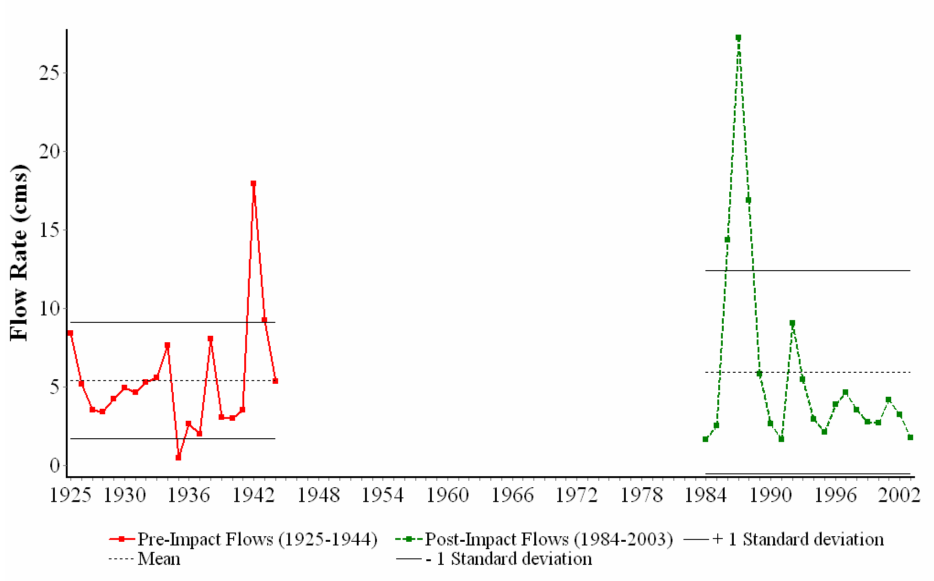


Figure C - 8 Monthly mean streamflows for March at the Fort Quitman/Colonia Luis Leon gage

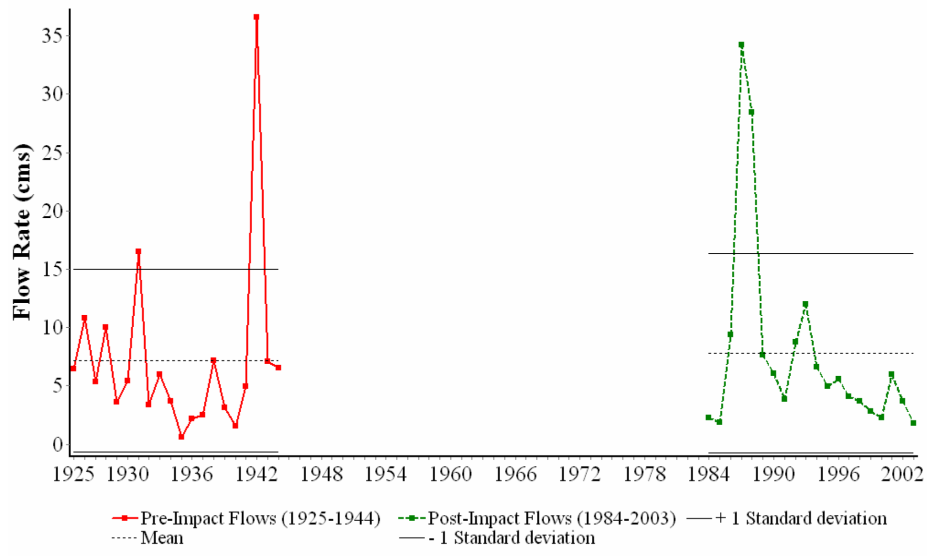


Figure C - 9 Monthly mean streamflows for April at the Fort Quitman/Colonia Luis Leon gage

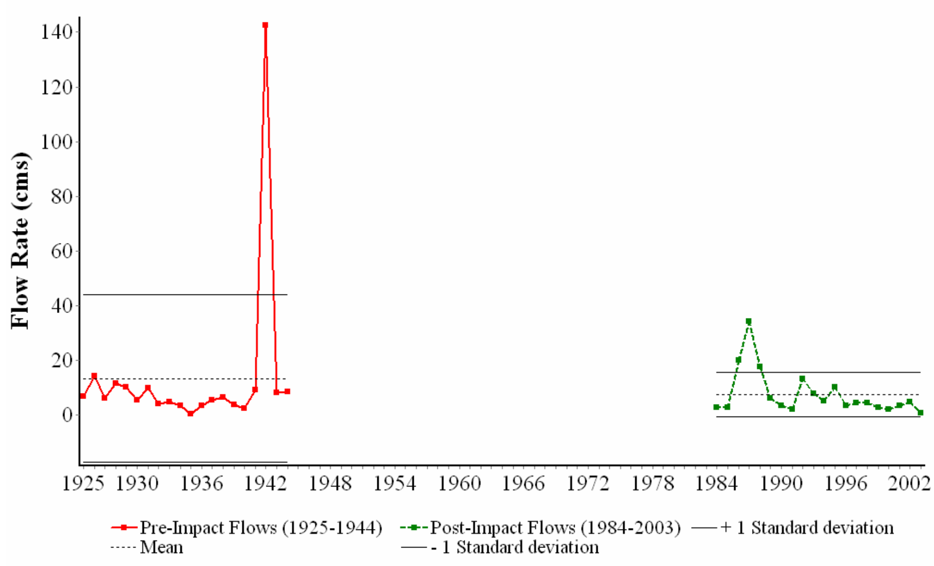


Figure C - 10 Monthly mean streamflows for May at the Fort Quitman/Colonia Luis Leon gage

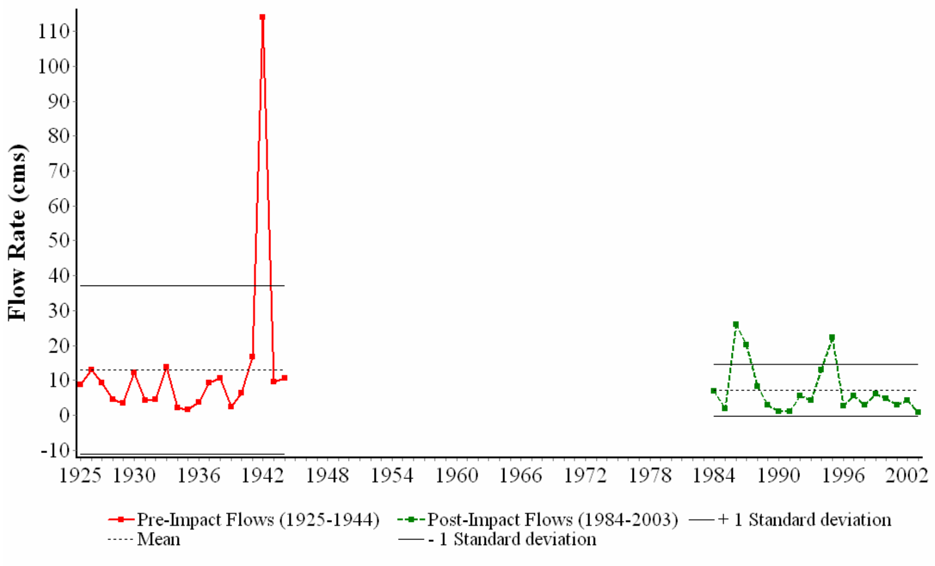


Figure C - 11 Monthly mean streamflows for June at the Fort Quitman/Colonia Luis Leon gage

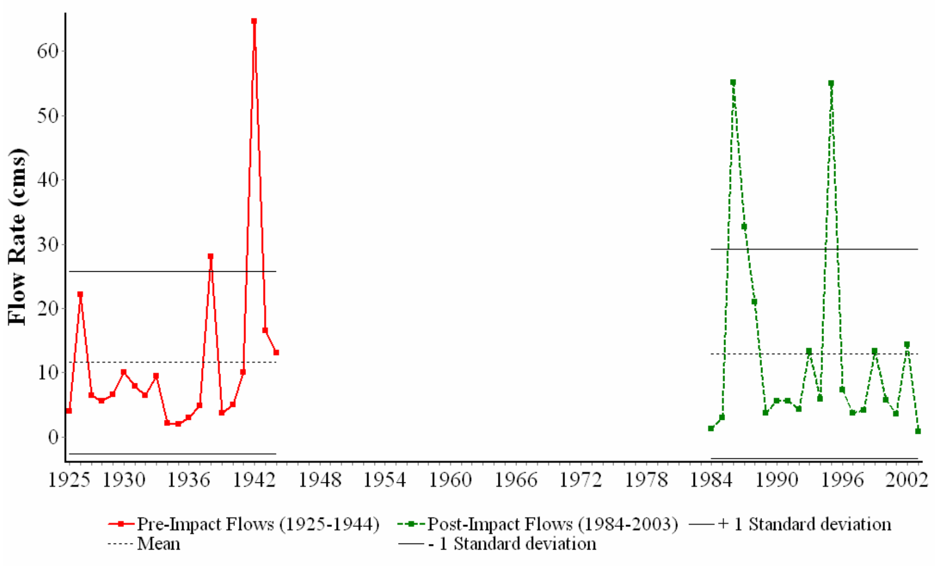


Figure C - 12 Monthly mean streamflows for July at the Fort Quitman/Colonia Luis Leon gage

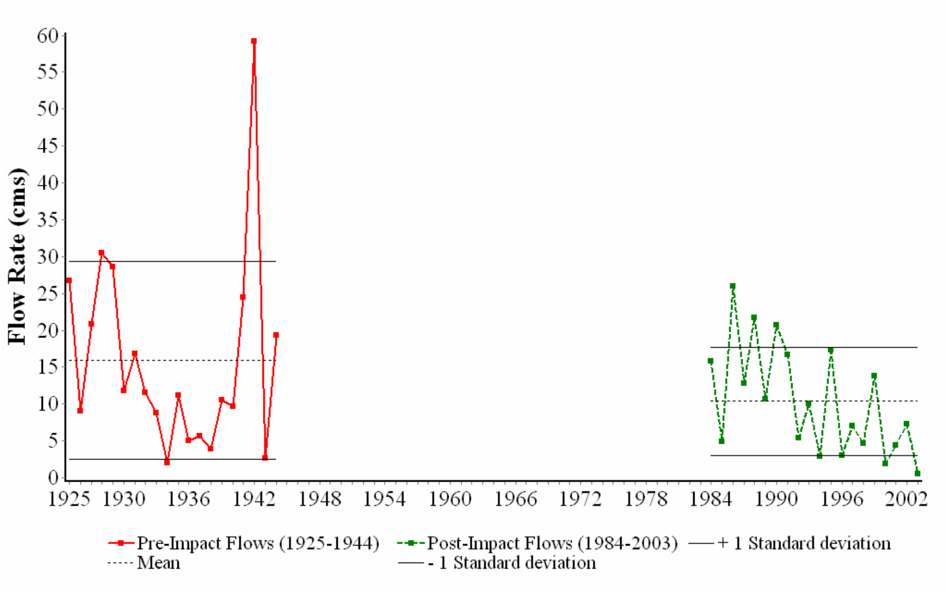


Figure C - 13 Monthly mean streamflows for August at the Fort Quitman/Colonia Luis Leon gage

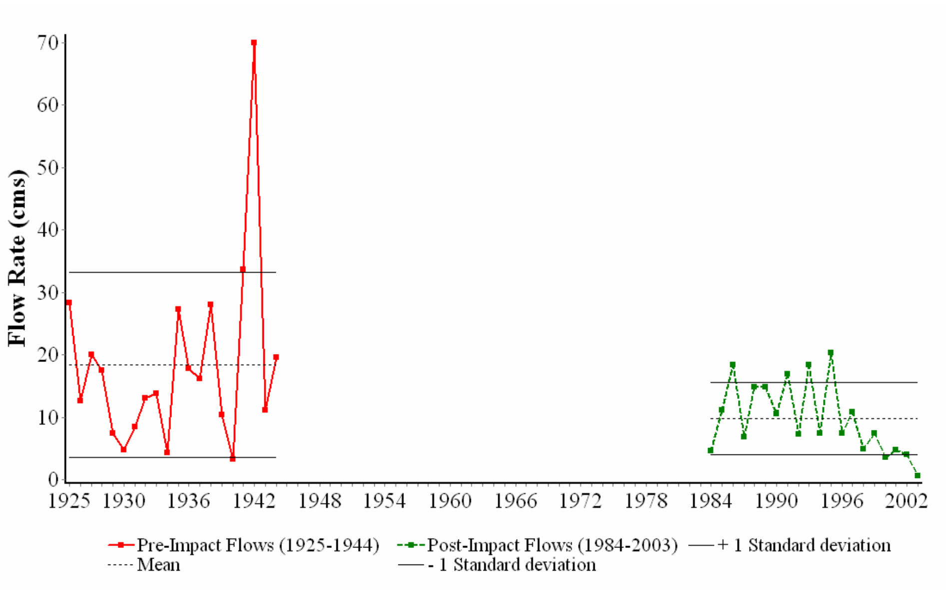


Figure C - 14 Monthly mean streamflows for September at the Fort Quitman/Colonia Luis Leon gage

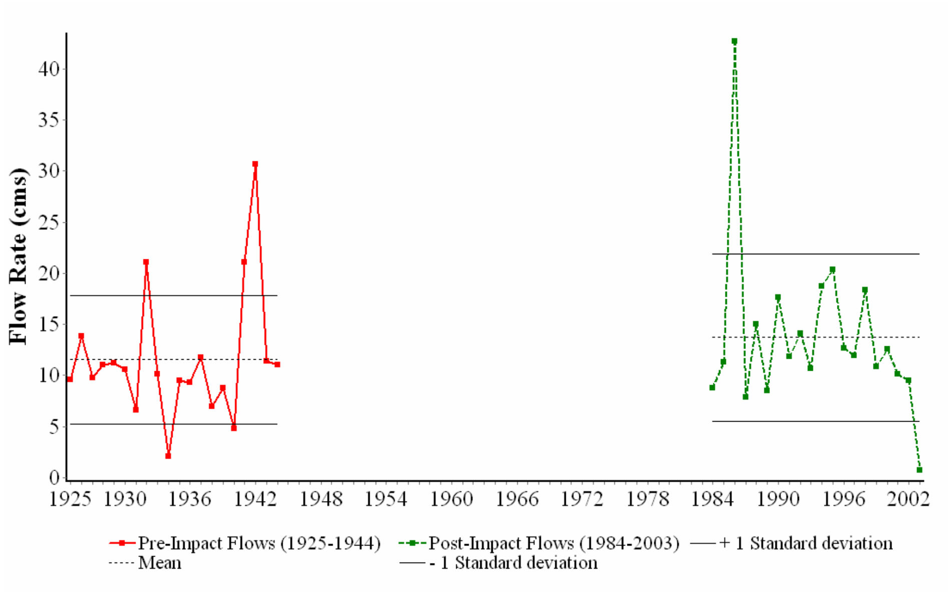


Figure C - 15 Monthly mean streamflows for October at the Fort Quitman/Colonia Luis Leon gage

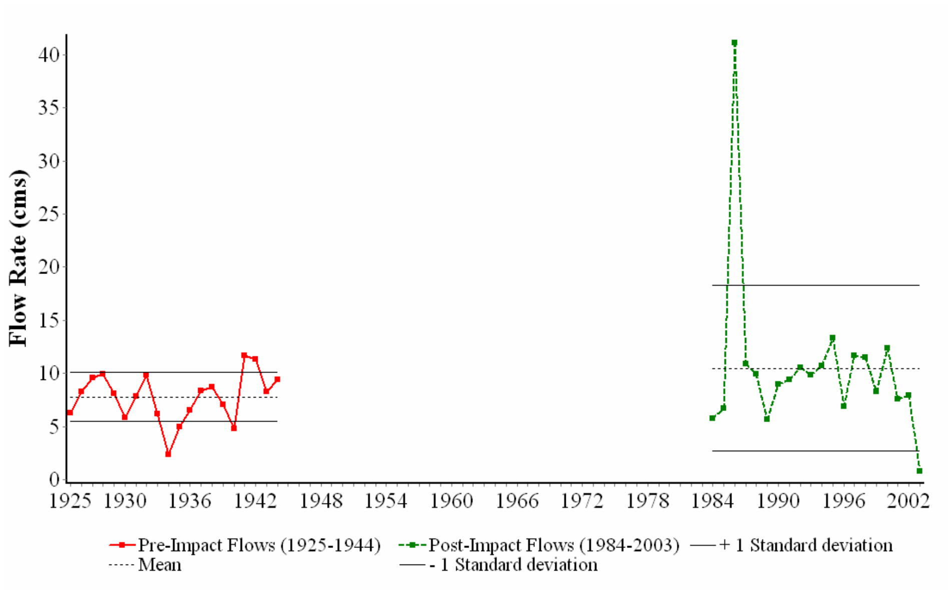


Figure C - 16 Monthly mean streamflows for November at the Fort Quitman/Colonia Luis Leon gage

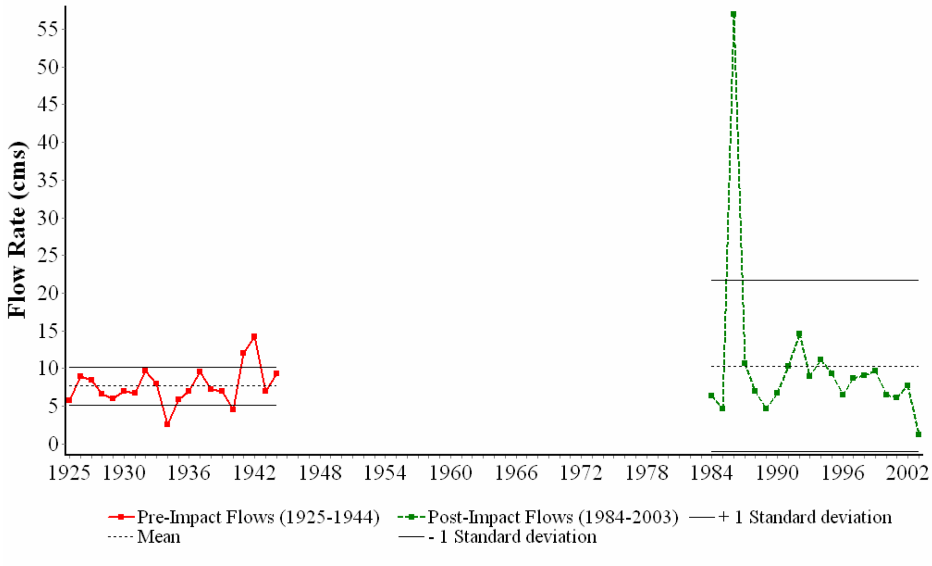


Figure C - 17 Monthly mean streamflows for December at the Fort Quitman/Colonia Luis Leon gage

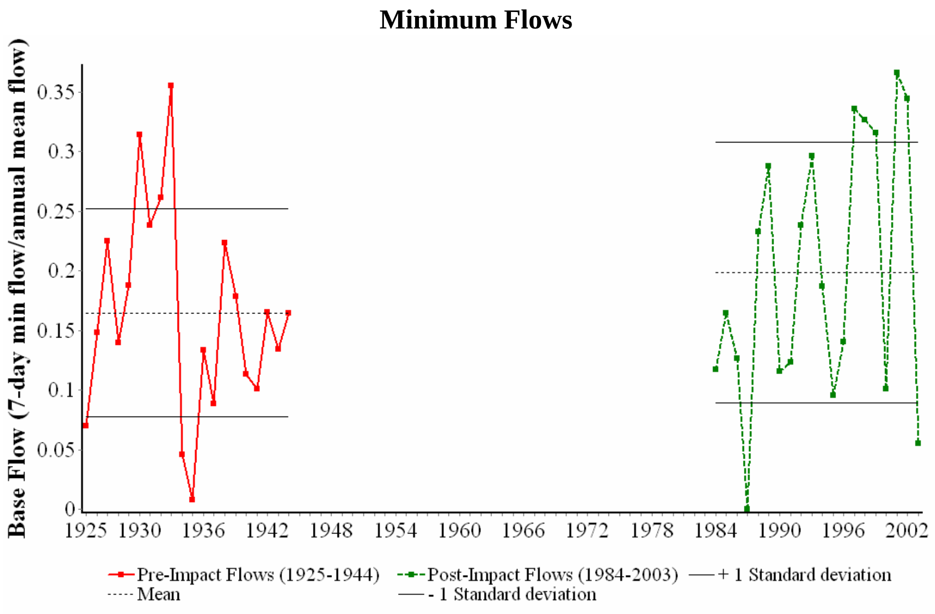


Figure C - 18 Base flow for the Fort Quitman/Colonia Luis Leon gage

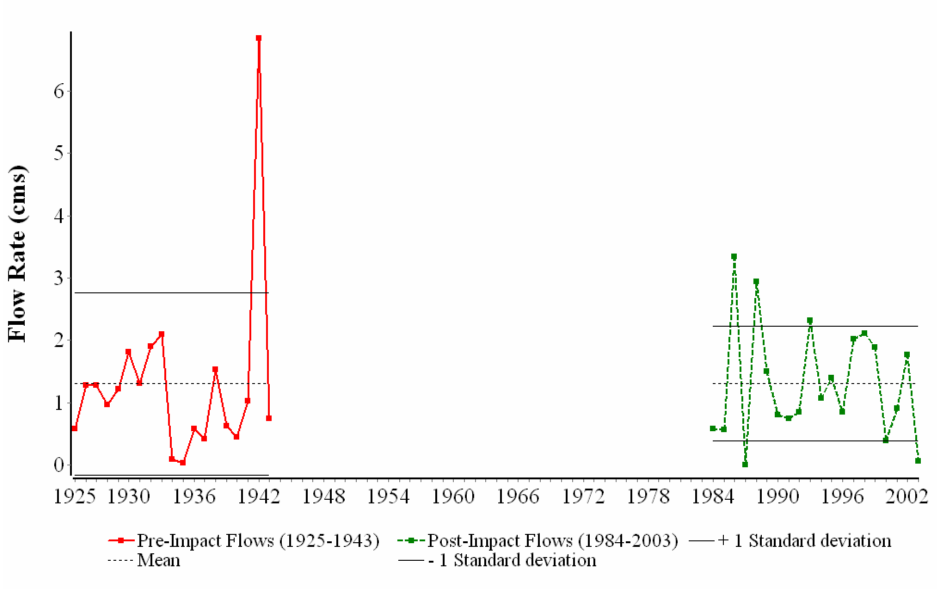


Figure C - 19 1-day minima for the Fort Quitman/Colonia Luis Leon gage

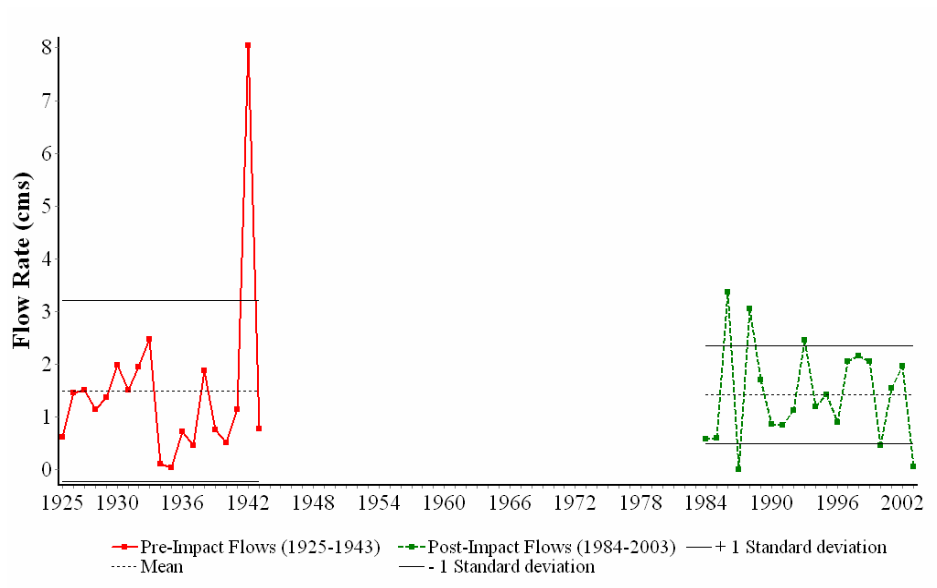


Figure C - 20 3-day minima for the Fort Quitman/Colonia Luis Leon gage

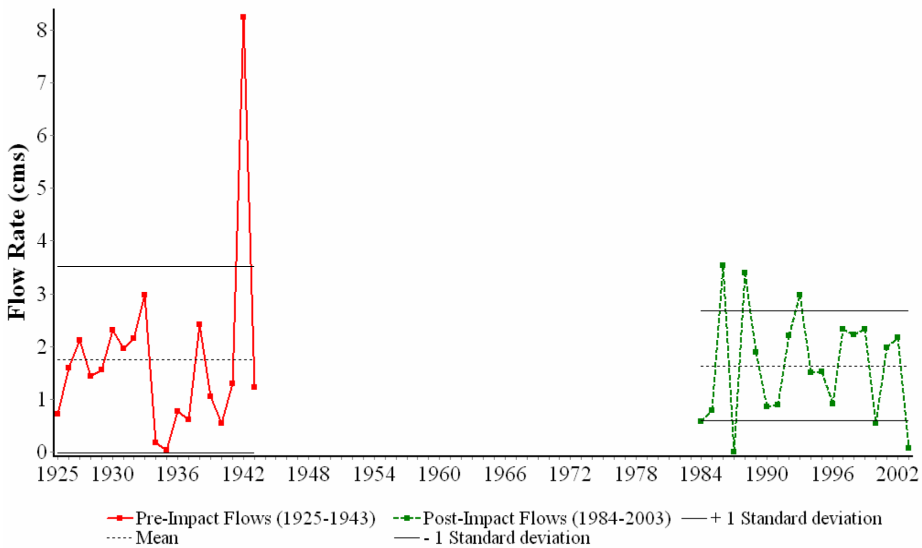


Figure C - 21 7-day minima for the Fort Quitman/Colonia Luis Leon gage

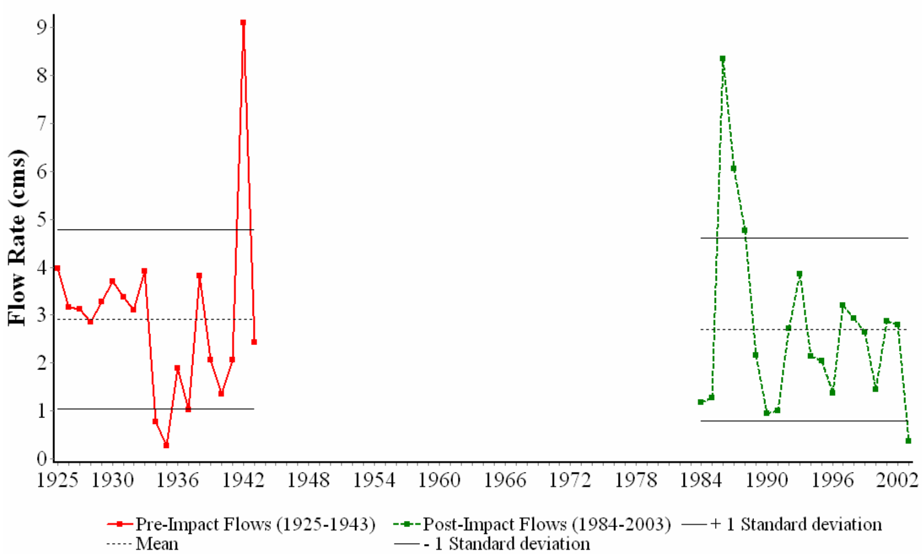


Figure C - 22 30-day minima for the Fort Quitman/Colonia Luis Leon gage

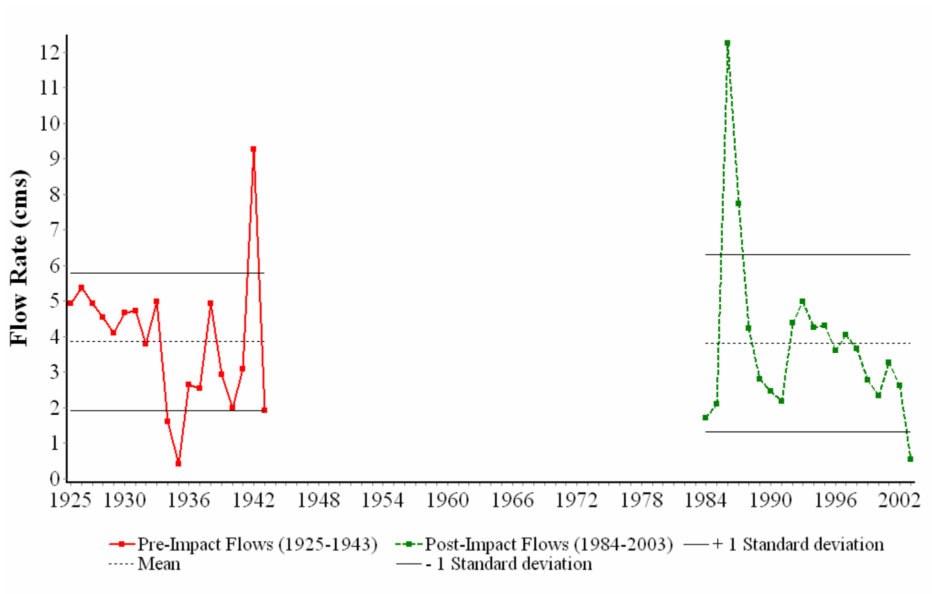


Figure C - 23 90-day minima for the Fort Quitman/Colonia Luis Leon gage

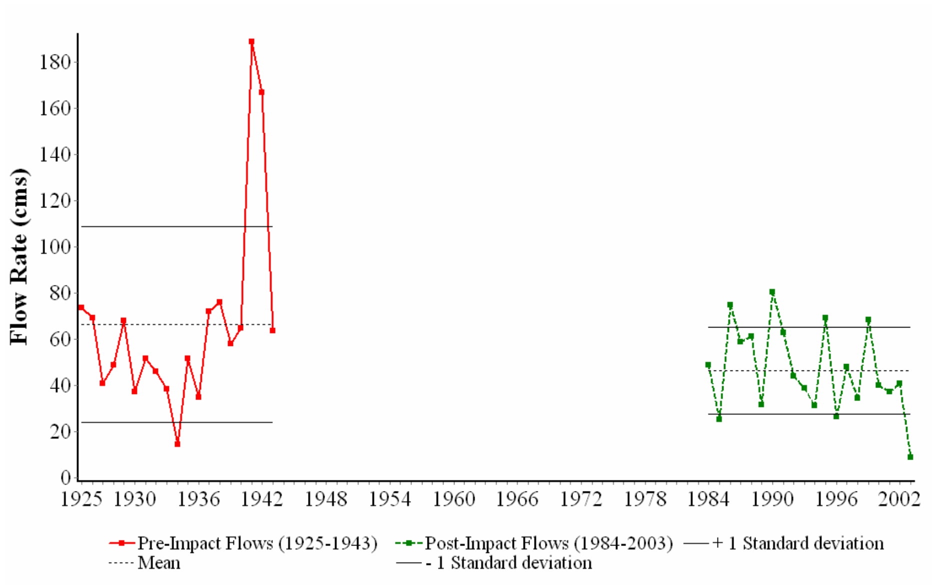


Figure C - 24 1-day maxima for the Fort Quitman/Colonia Luis Leon gage

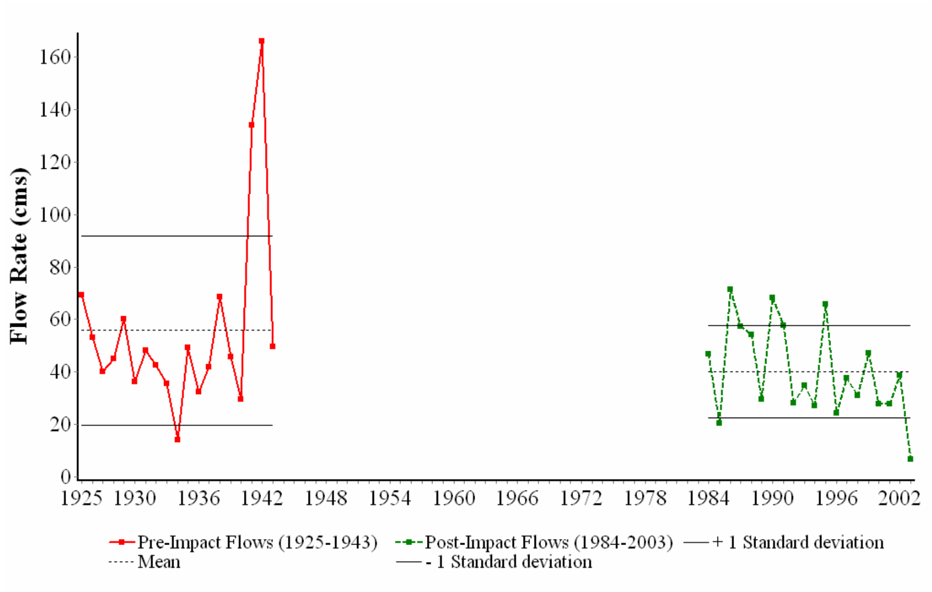


Figure C - 25 3-day maxima for the Fort Quitman/Colonia Luis Leon gage

Maximum Flows

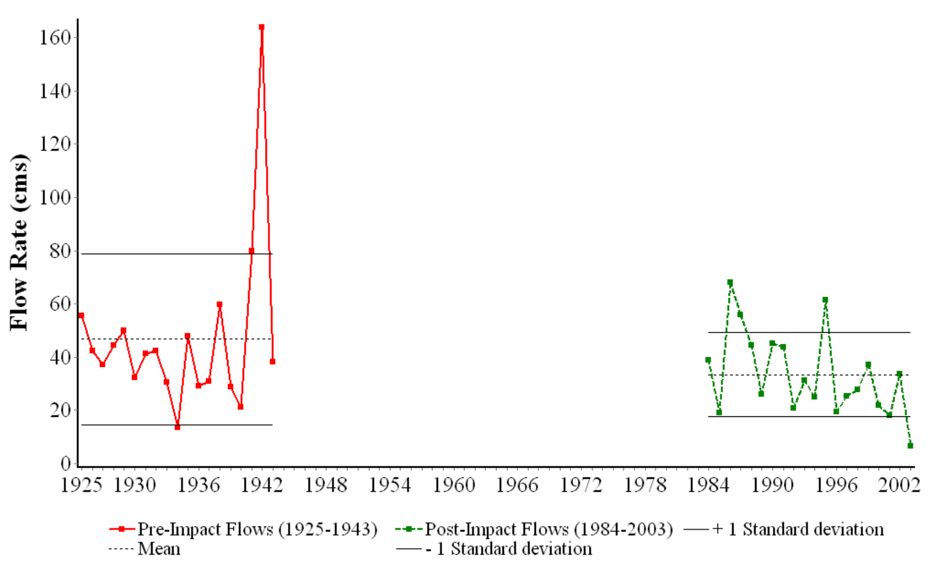


Figure C - 26 7-day maxima for the Fort Quitman/Colonia Luis Leon gage

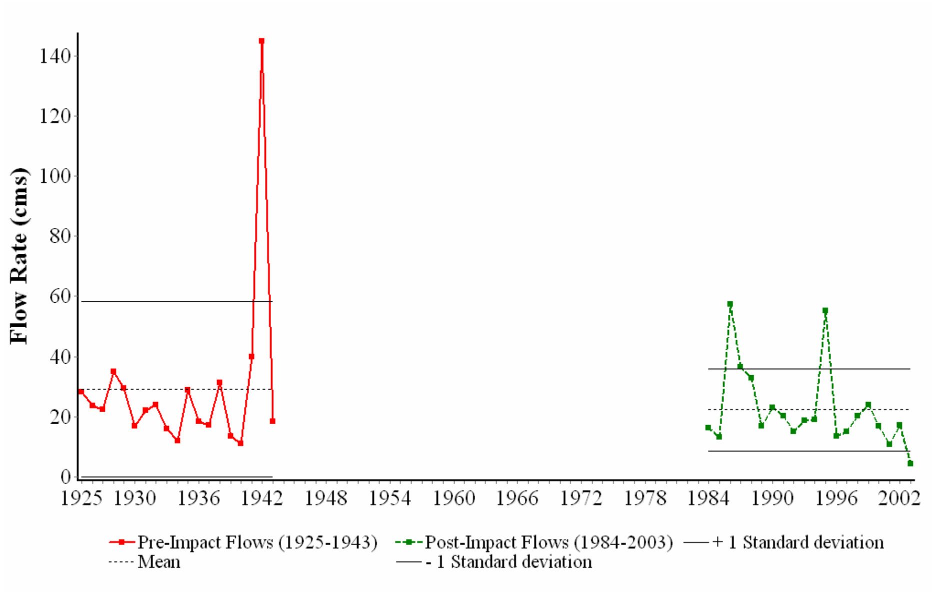


Figure C - 27 30-day maxima for the Fort Quitman/Colonia Luis Leon gage

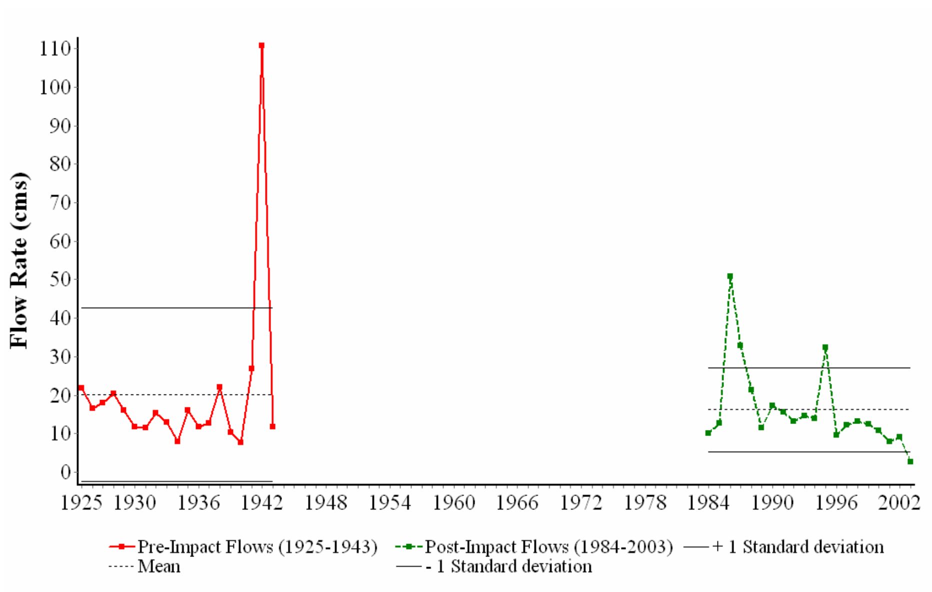


Figure C - 28 90-day maxima for the Fort Quitman/Colonia Luis Leon gage

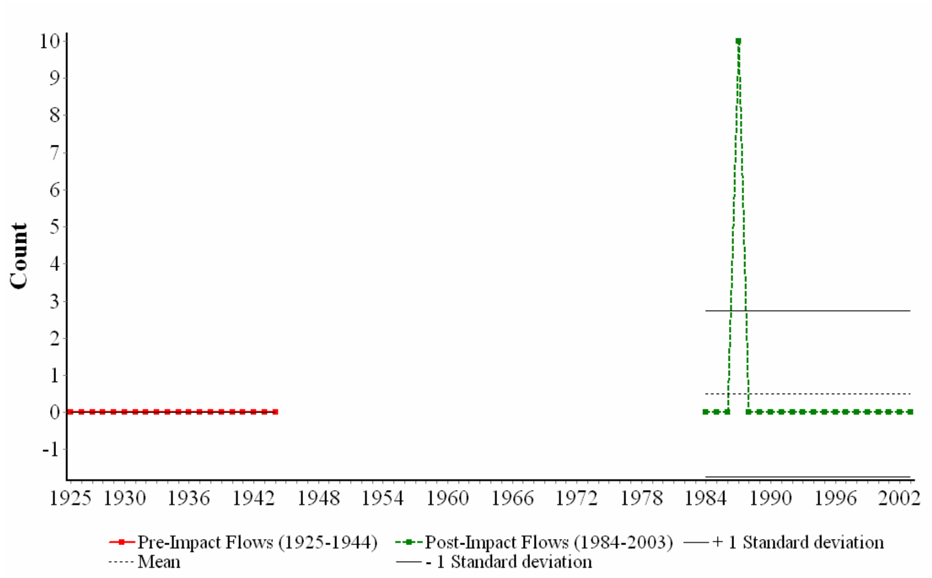


Figure C - 29 Zero flow days at Fort Quitman/Colonia Luis Leon

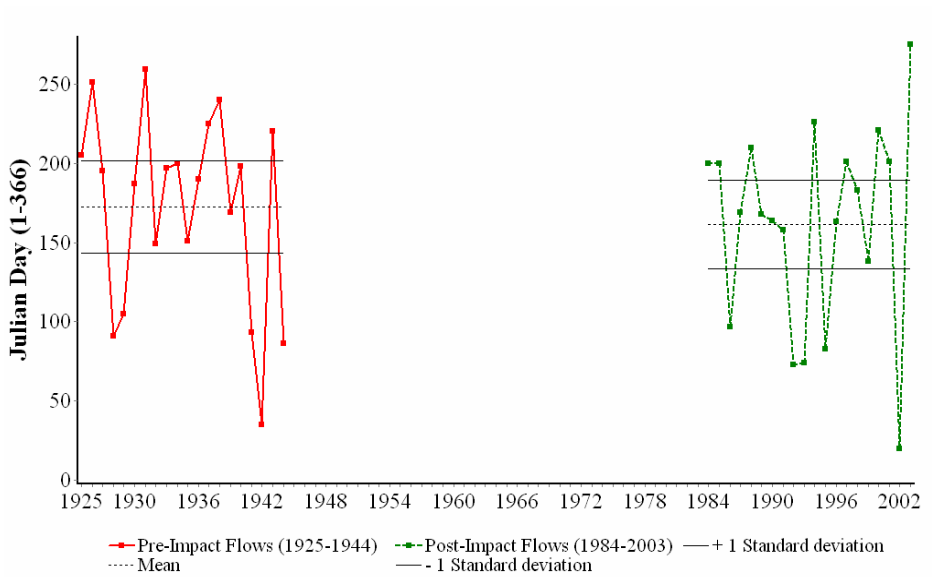


Figure C - 30 Date of minimum flows at Fort Quitman/Colonia Luis Leon

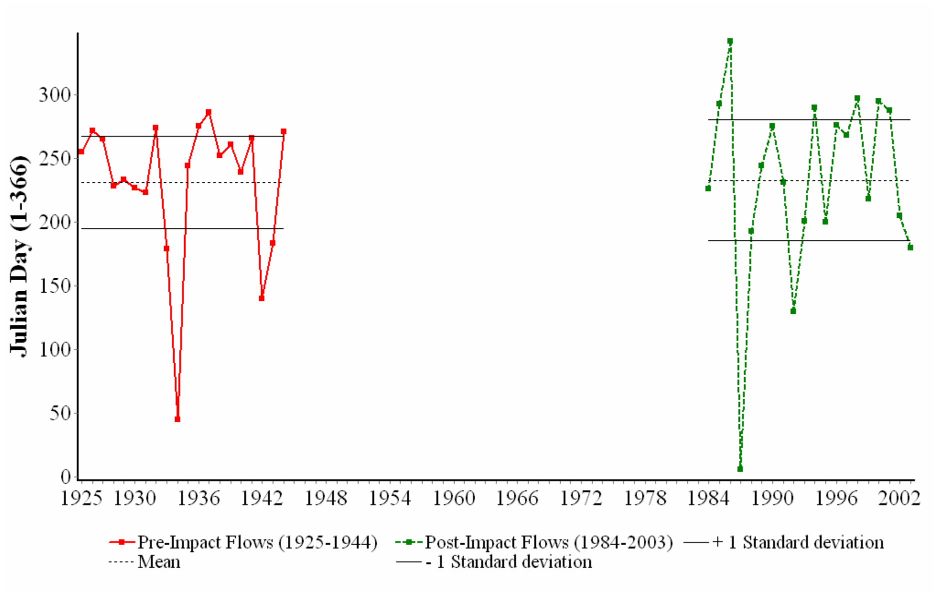


Figure C - 31 Date of maximum flows at Fort Quitman/Colonia Luis Leon

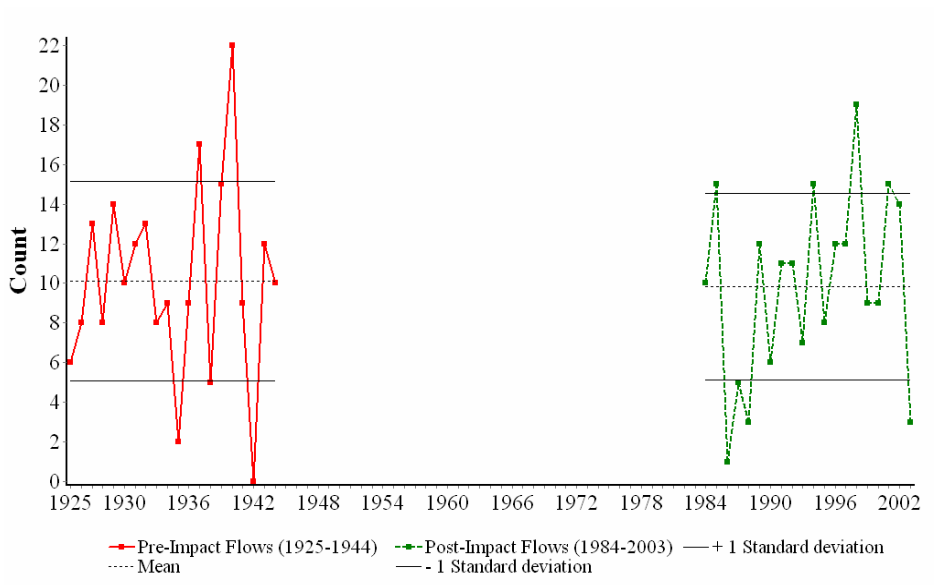


Figure C - 32 Low pulse count at Fort Quitman/Colonia Luis Leon

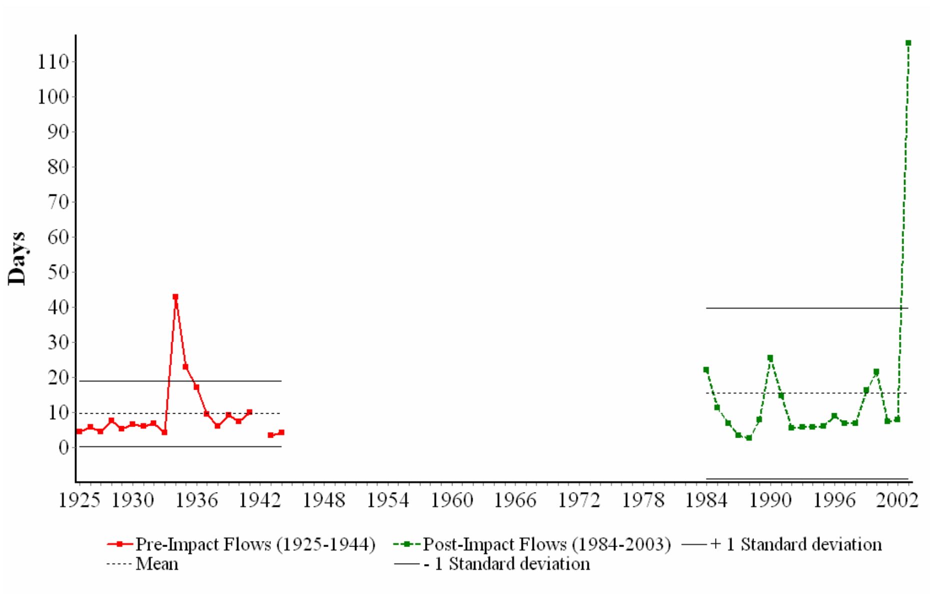


Figure C - 33 Low pulse duration at Fort Quitman/Colonia Luis Leon

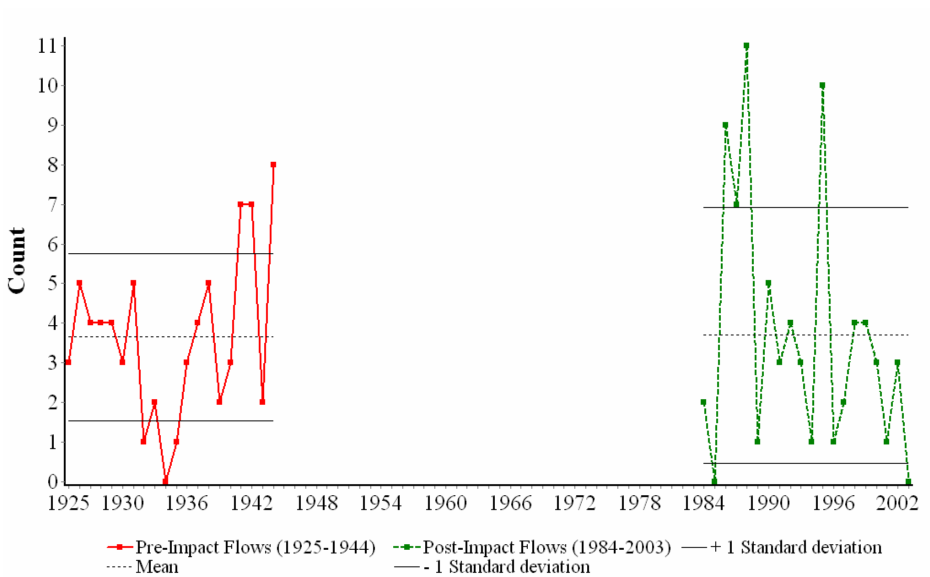


Figure C - 34 High pulse count at Fort Quitman/Colonia Luis Leon

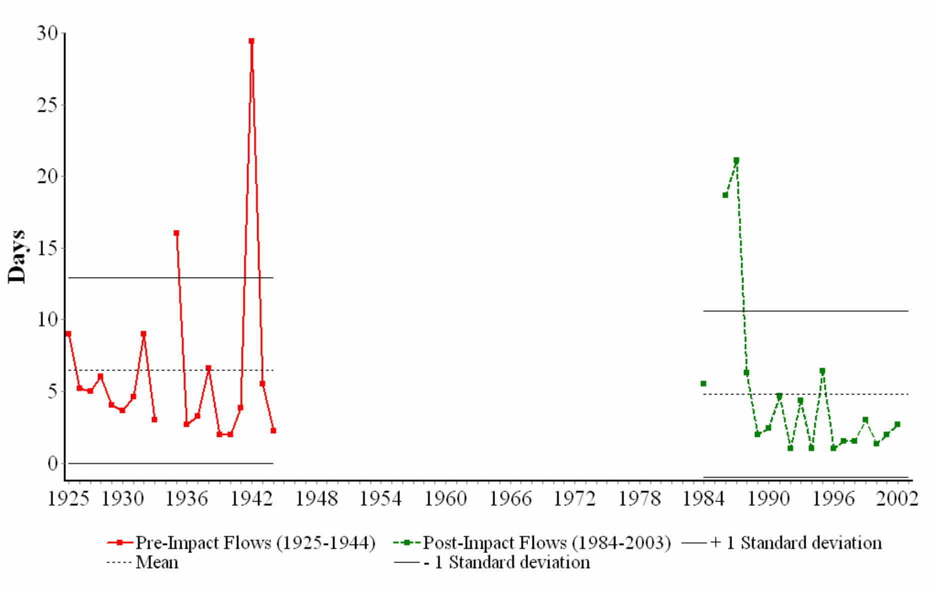


Figure C - 35 High pulse duration at Fort Quitman/Colonia Luis Leon

Presidio/Ojinaga Gage

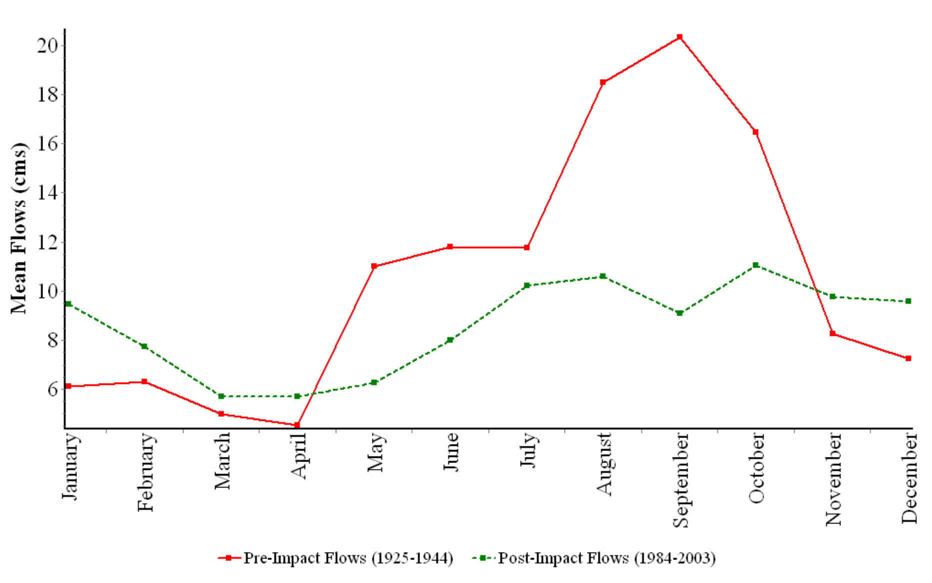


Figure C - 36 Average monthly streamflows at the Presidio/Ojinaga gage

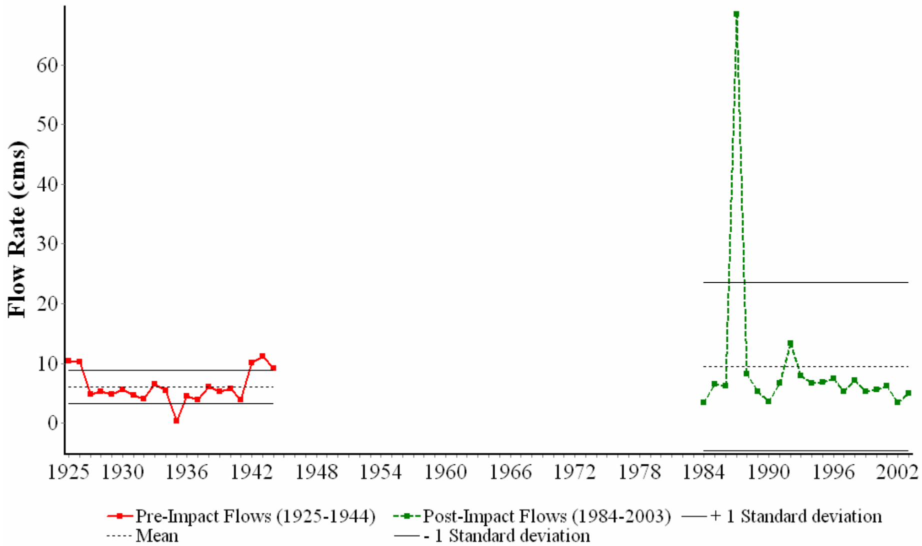


Figure C - 37 Monthly streamflows for January at the Presidio/Ojinaga gage

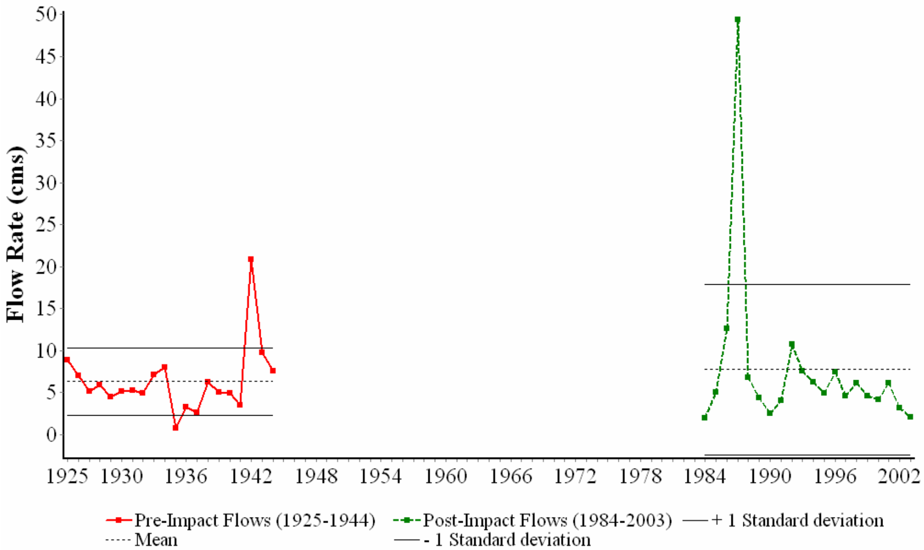


Figure C - 38 Monthly streamflows for February at the Presidio/Ojinaga gage

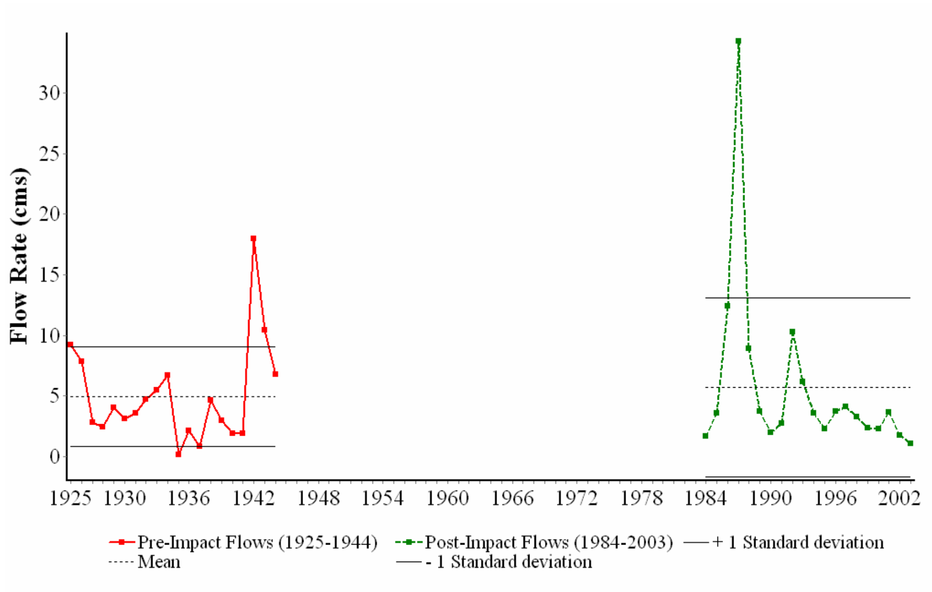


Figure C - 39 Monthly streamflows for March at the Presidio/Ojinaga gage

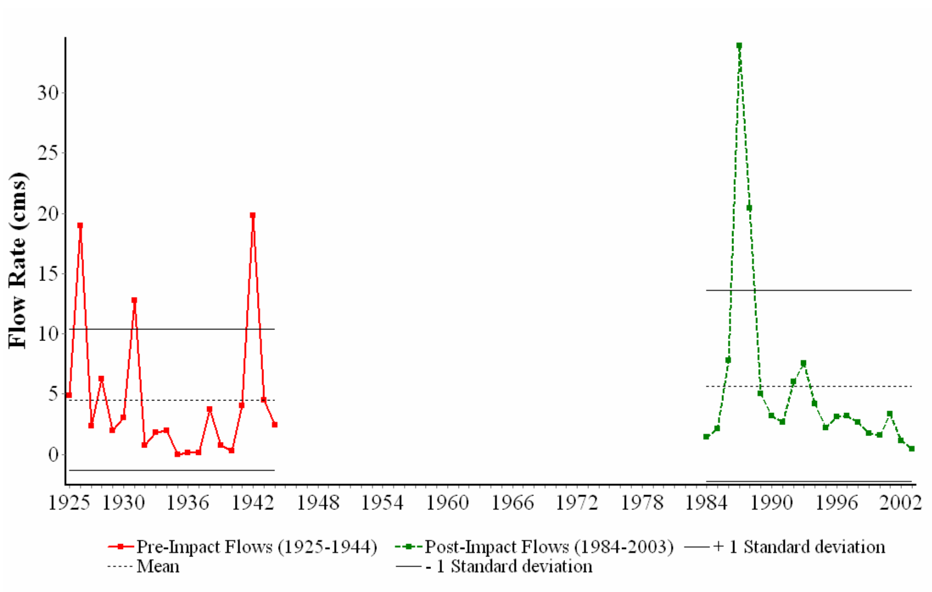


Figure C - 40 Monthly streamflows for April at the Presidio/Ojinaga gage

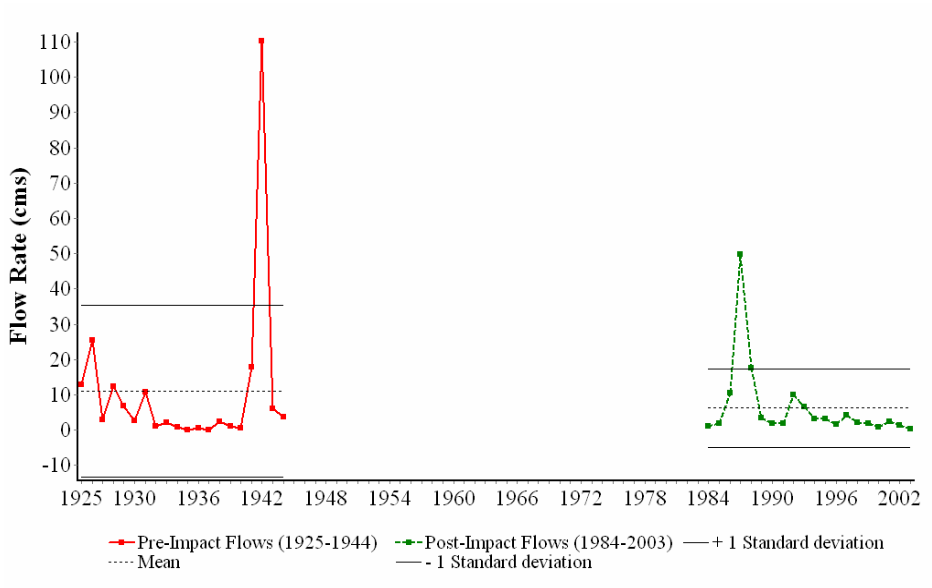


Figure C - 41 Monthly streamflows for May at the Presidio/Ojinaga gage

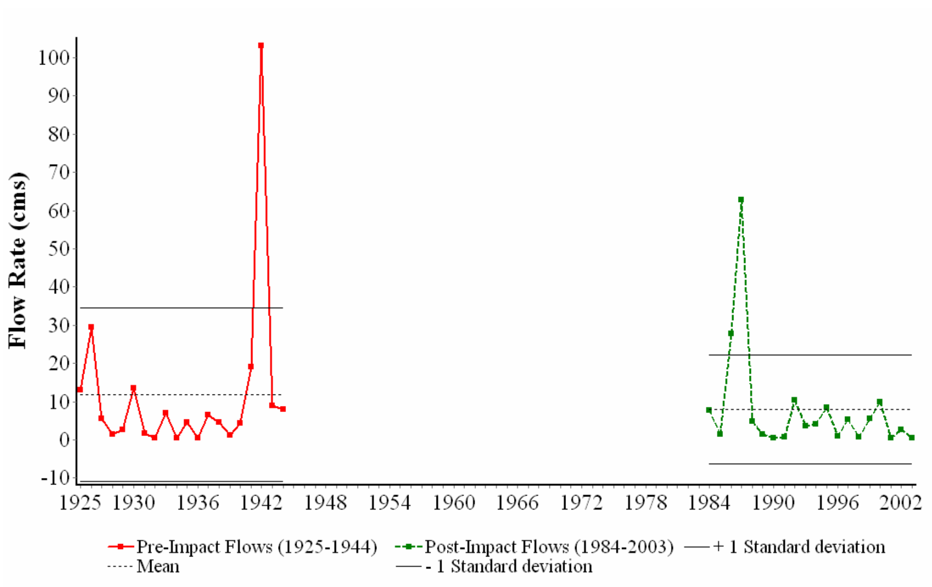


Figure C - 42 Monthly streamflows for June at the Presidio/Ojinaga gage

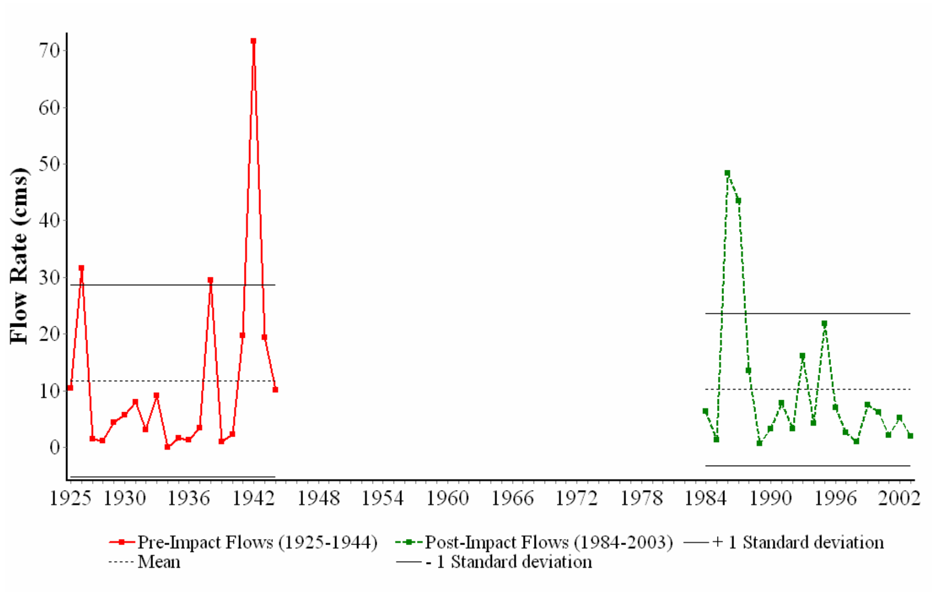


Figure C - 43 Monthly streamflows for July at the Presidio/Ojinaga gage

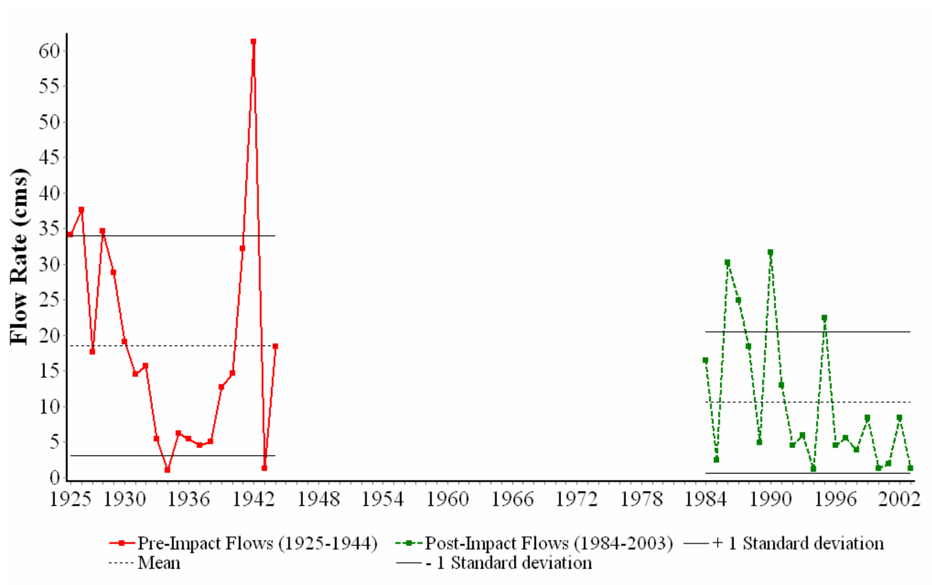


Figure C - 44 Monthly streamflows for August at the Presidio/Ojinaga gage

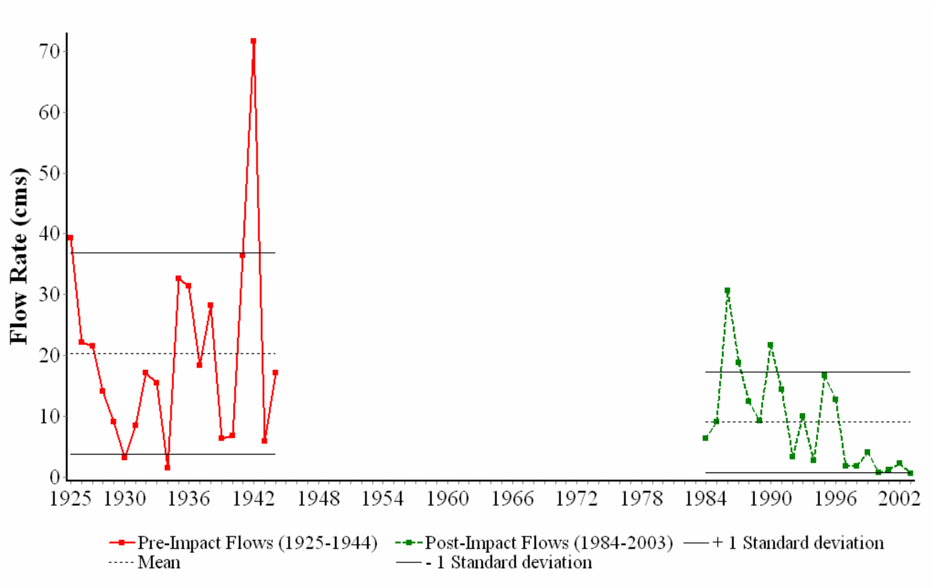


Figure C - 45 Monthly streamflows for September at the Presidio/Ojinaga gage

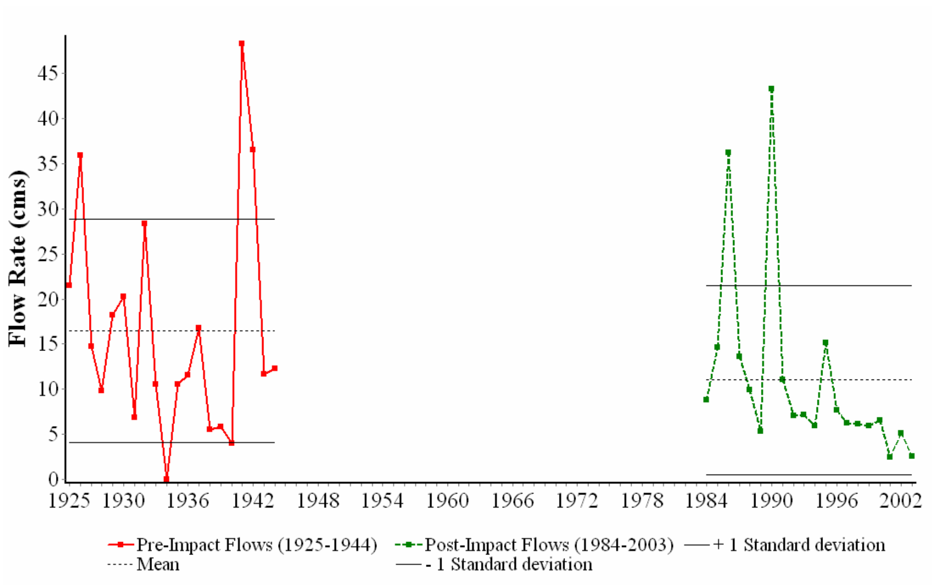


Figure C - 46 Monthly streamflows for October at the Presidio/Ojinaga gage

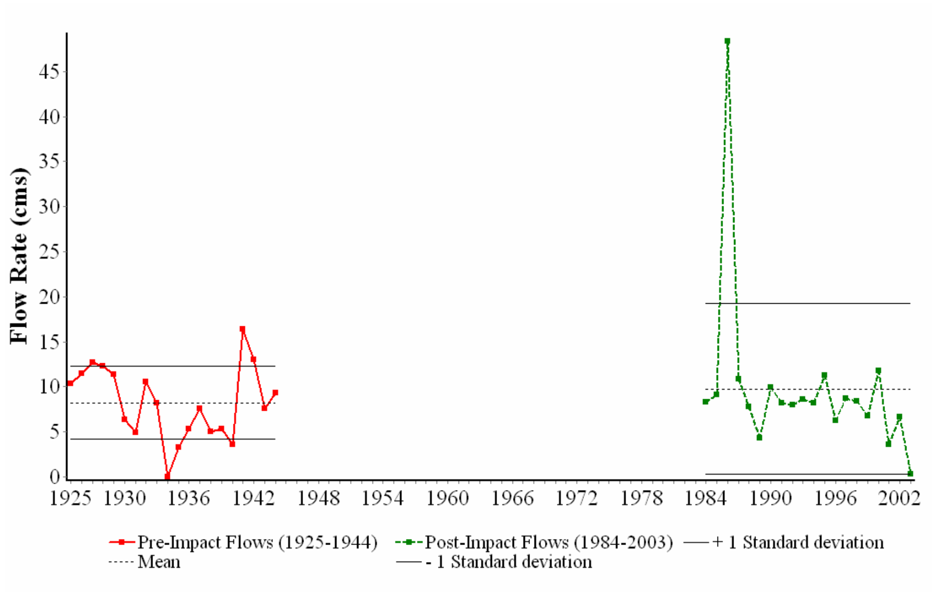


Figure C - 47 Monthly streamflows for November at the Presidio/Ojinaga gage

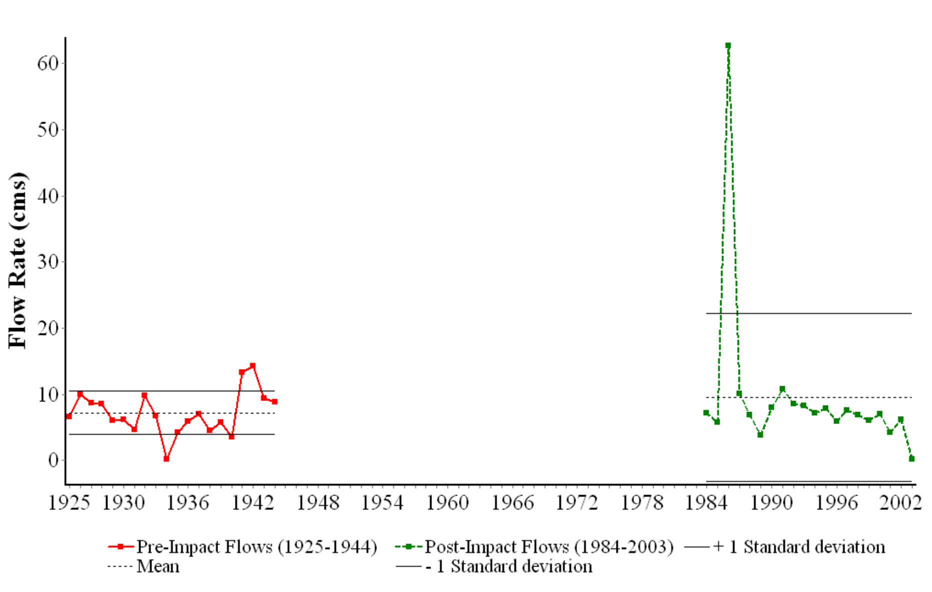


Figure C - 48 Monthly streamflows for December at the Presidio/Ojinaga gage

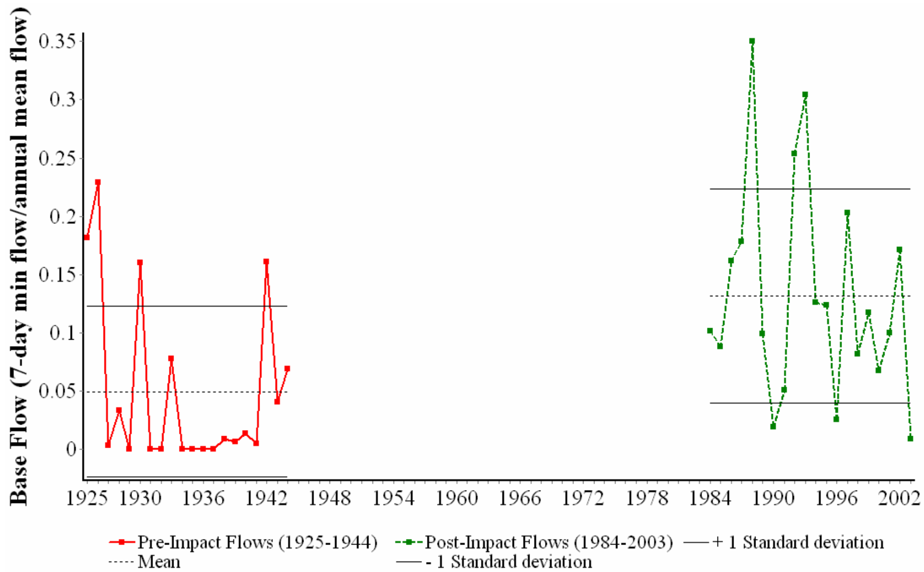


Figure C - 49 Base flow for the Presidio/Ojinaga gage

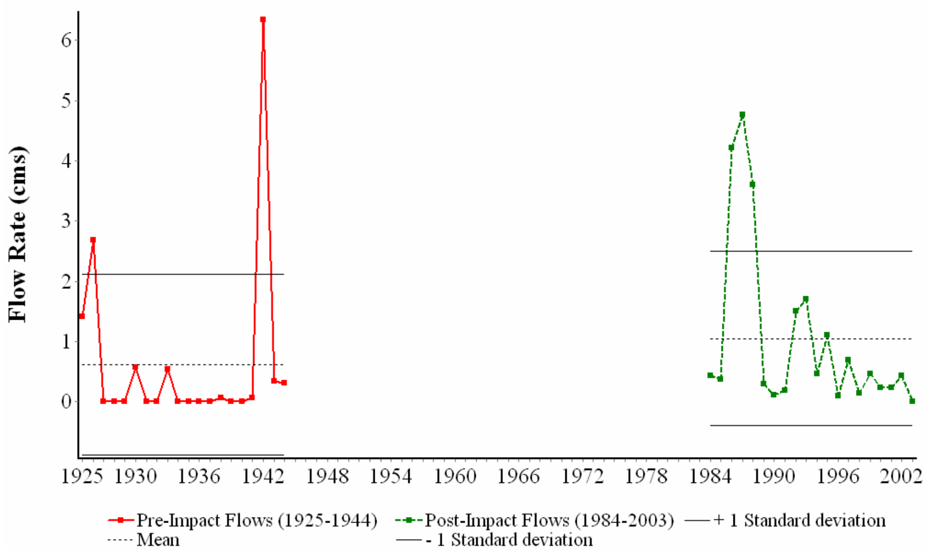


Figure C - 50 1-day minima for the Presidio/Ojinaga gage

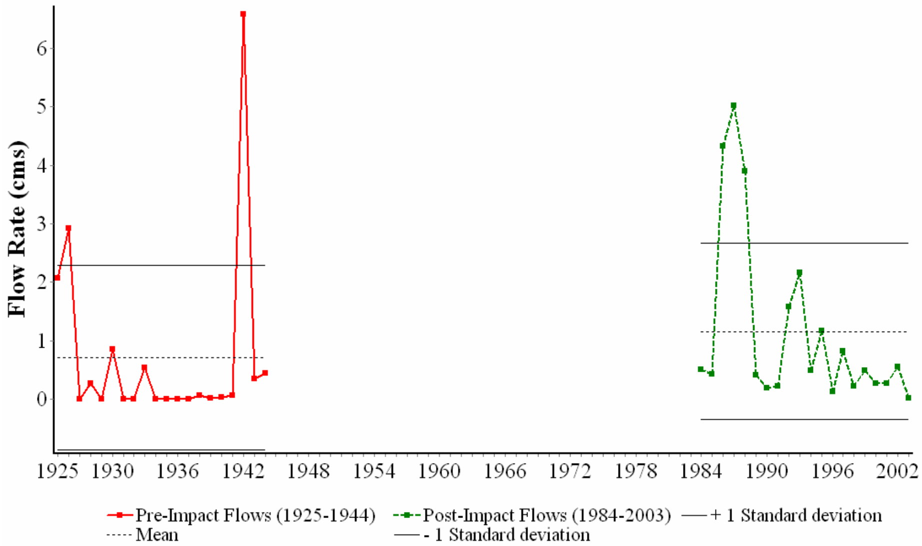


Figure C - 51 3-day minima for the Presidio/Ojinaga gage

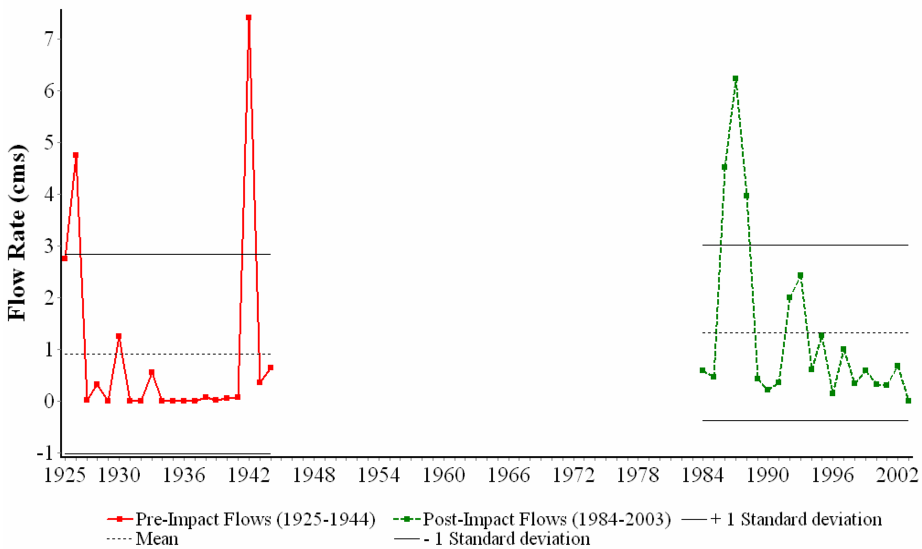


Figure C - 52 7-day minima for the Presidio/Ojinaga gage

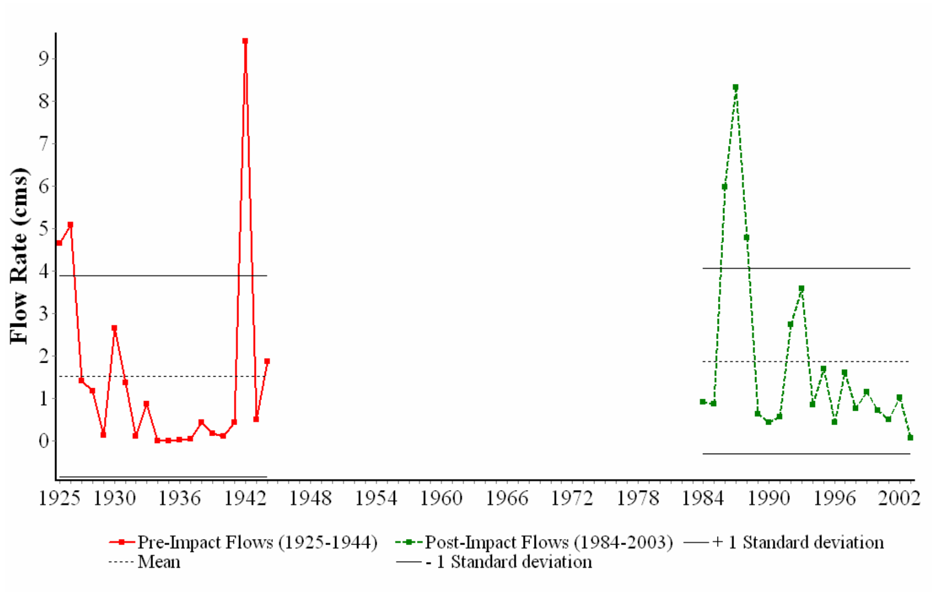


Figure C - 53 30-day minima for the Presidio/Ojinaga gage

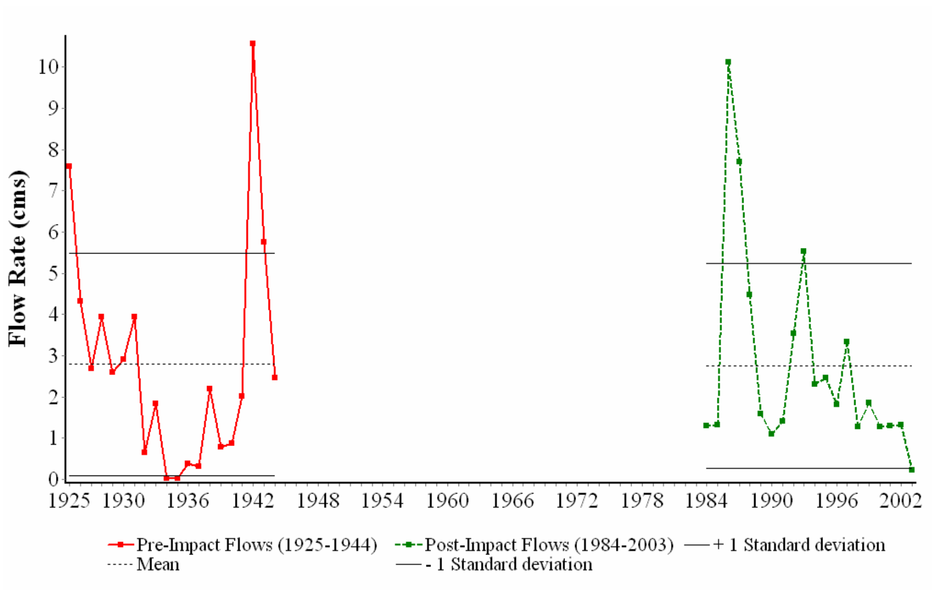


Figure C - 54 90-day minima for the Presidio/Ojinaga gage

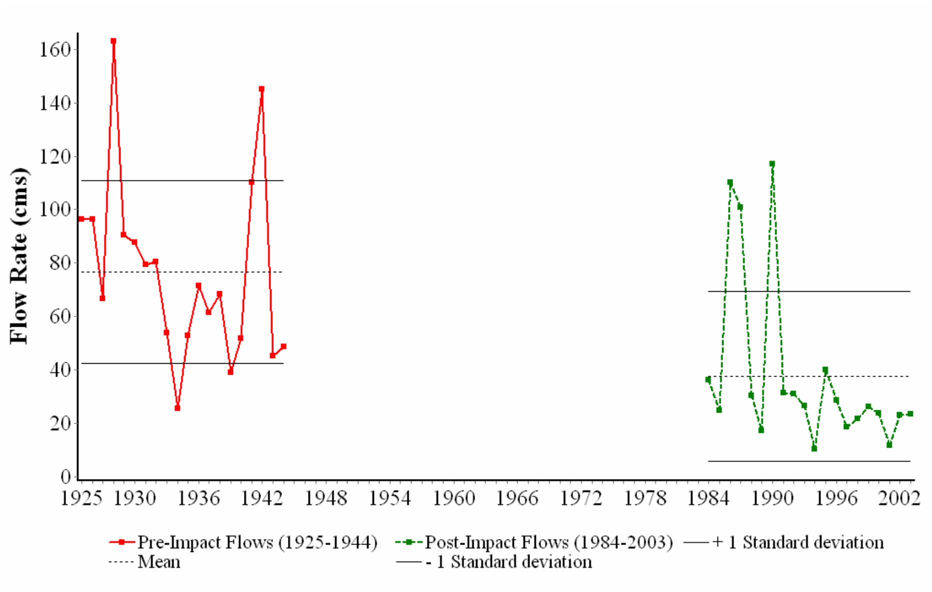


Figure C - 55 1-day maxima for the Presidio/Ojinaga gage

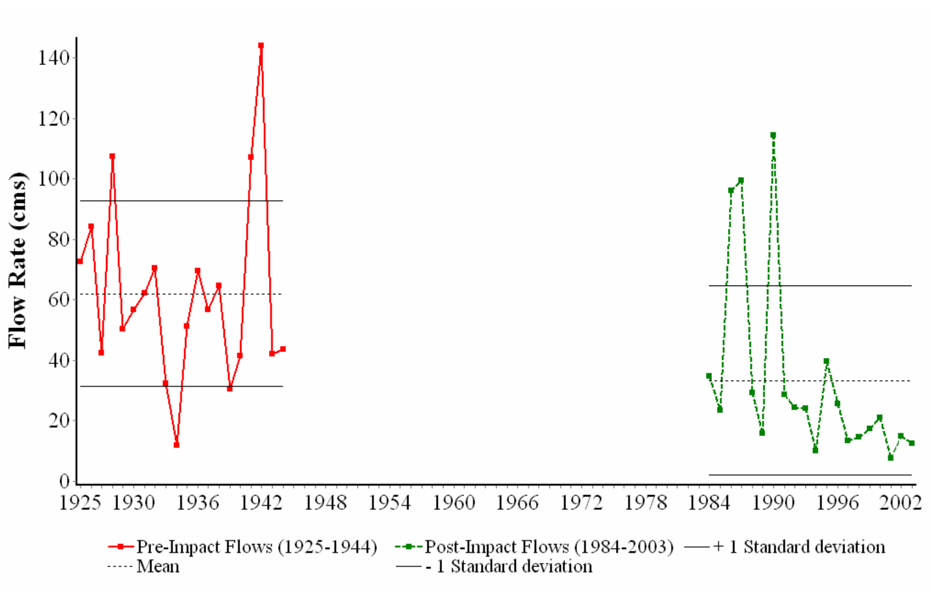


Figure C - 56 3-day maxima for the Presidio/Ojinaga gage

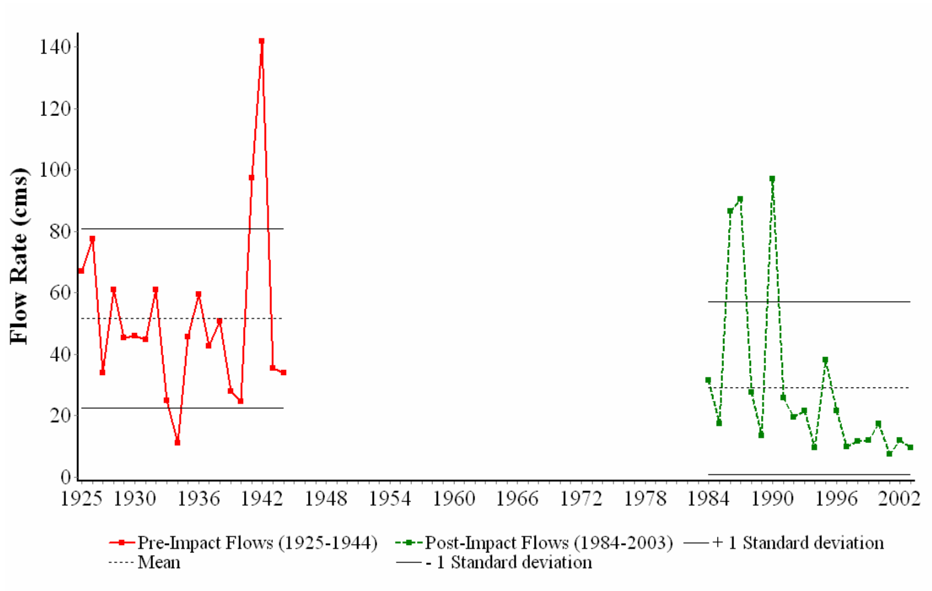


Figure C - 57 7-day maxima for the Presidio/Ojinaga gage

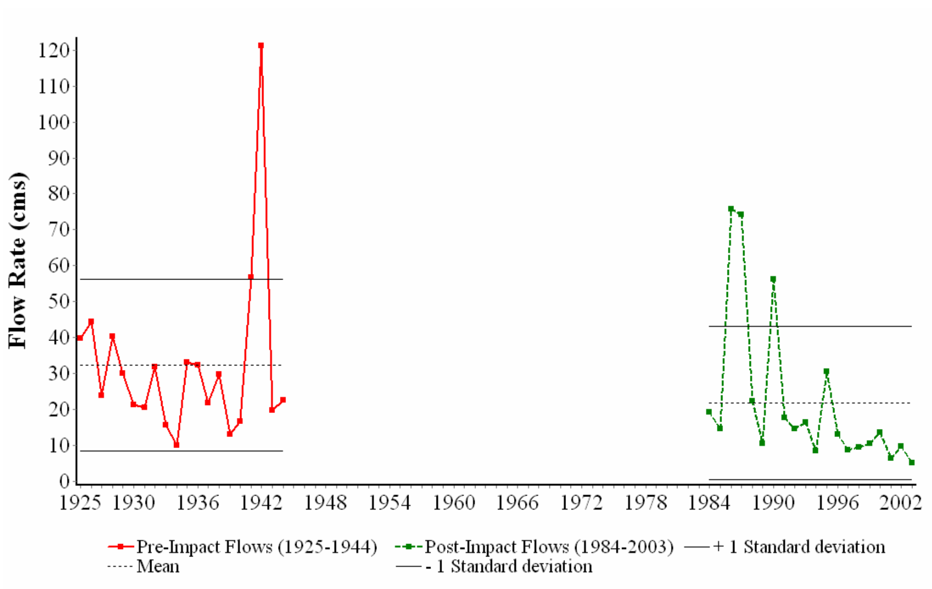


Figure C - 58 30-day maxima for the Presidio/Ojinaga gage

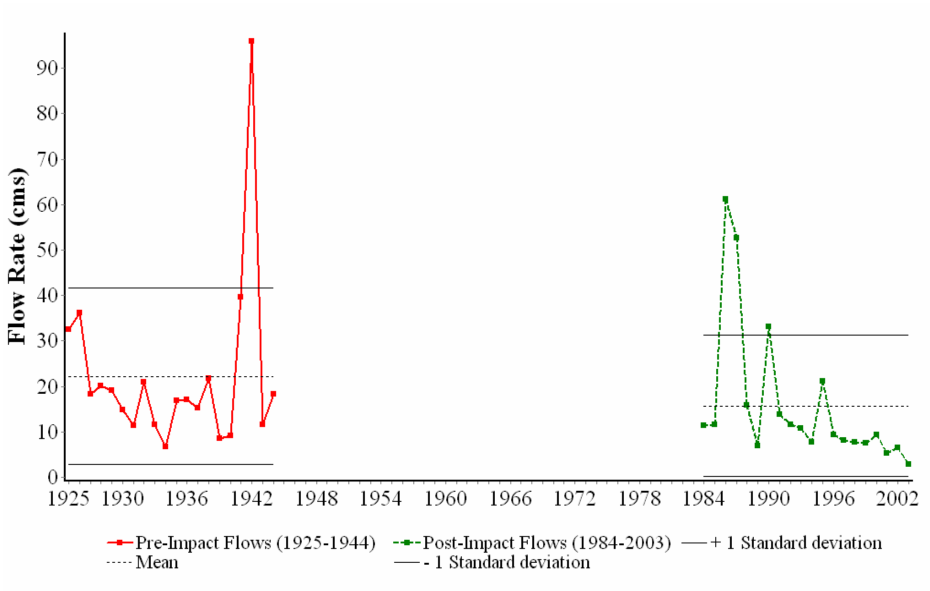


Figure C - 59 90-day maxima for the Presidio/Ojinaga gage

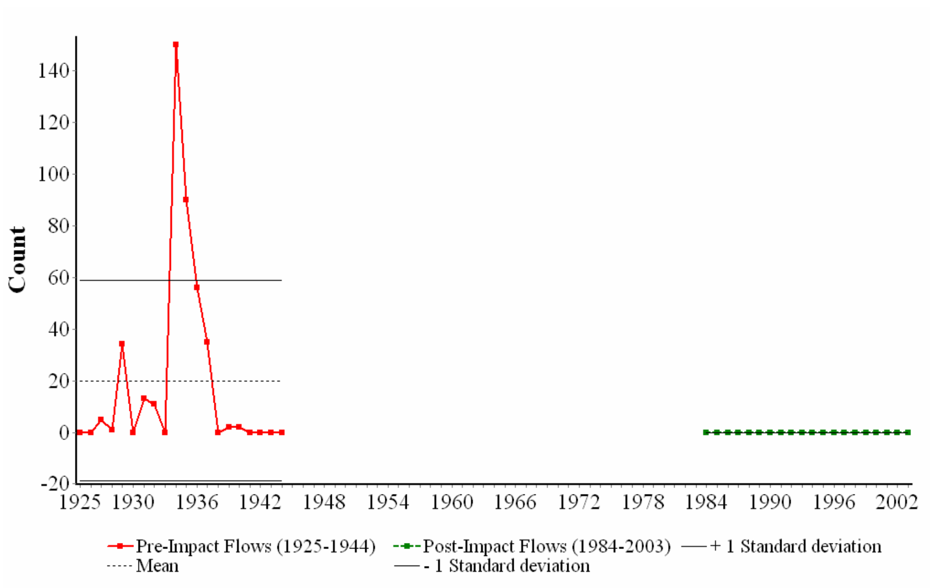


Figure C - 60 Zero flow days at Presidio/Ojinaga

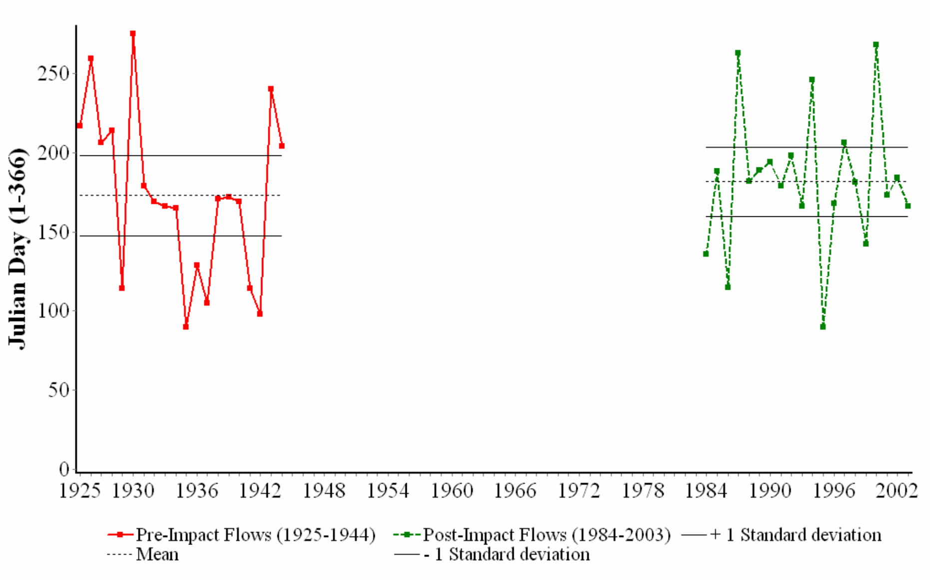


Figure C - 61 Date of minimum flows at Presidio/Ojinaga

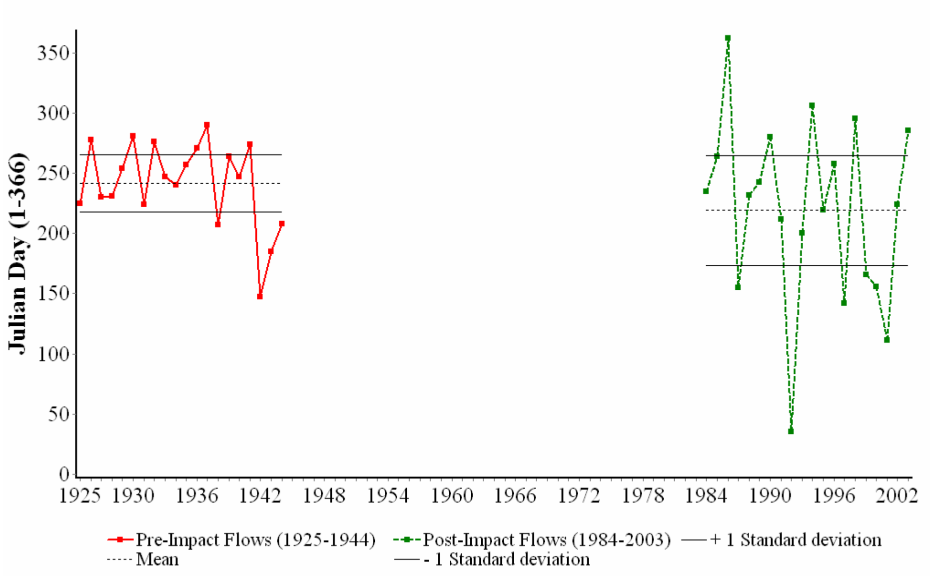


Figure C - 62 Date of Maximum flows at Presidio/Ojinaga

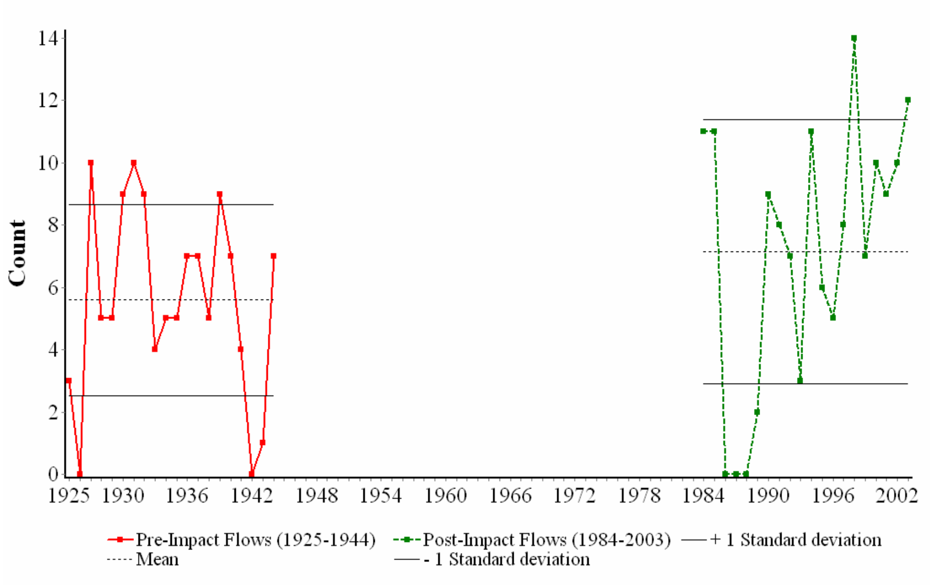


Figure C - 63 Low Pulse Count at Presidio/Ojinaga

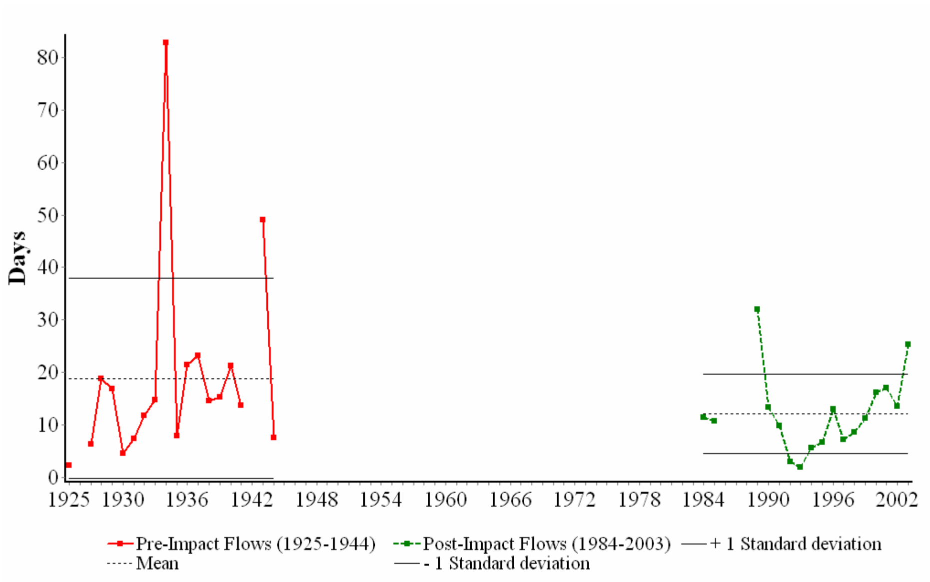


Figure C - 64 Low Pulse Duration at Presidio/Ojinaga

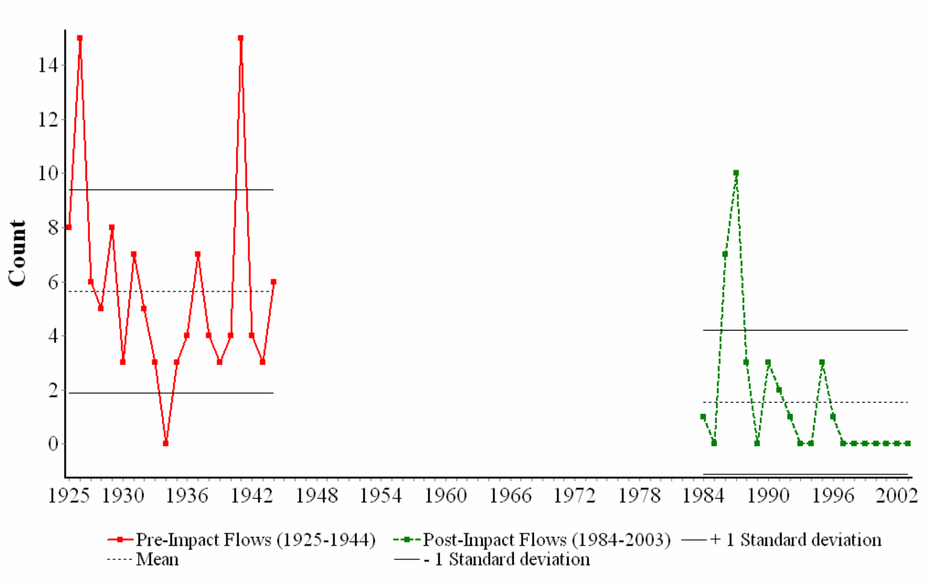


Figure C - 65 High Pulse Count at Presidio/Ojinaga

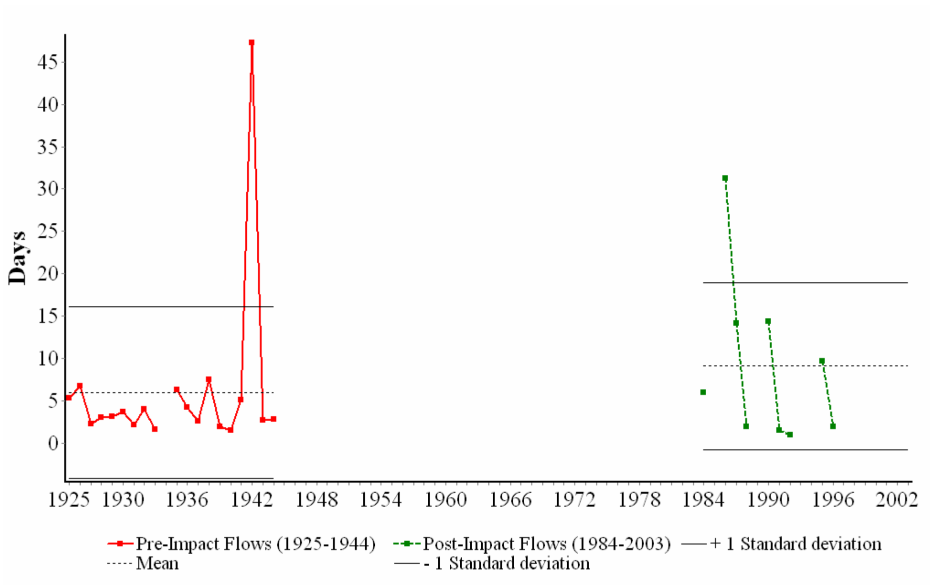


Figure C - 66 High Pulse Duration at Presidio/Ojinaga

Appendix D

Formatted: Left: 1.25", Right: 1.25", Top: 1.25", Bottom: 1.25", Width: 11", Height: 8.5"

Fort Quitman/Colonia Luis Leon IHA Scorecard

IHA Parametric Scorecard

Fort Quitman/Colonia Luis Leon

	Pre-impact period: 1925-1944 (20 years)	Post-impact period: 1984-2003 (20 years)
Watershed area	1	1
Mean annual flow	10.15	9.25
Mean flow/area	10.15	9.25
Annual C. V.	1.57	1.11
Flow predictability	0.45	0.43
Constancy/predictability	0.7	0.68
% of floods in 60d period	0.51	0.51
Flood-free season	110	11

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #1								
January	5.866	8.067	0.2948	0.8805	2.201	37.52	0.5856	198.6
February	6.861	6.521	0.7097	0.9396	-0.3404	-4.96	0.23	32.41
March	5.416	5.951	0.683	1.087	0.5354	9.886	0.4044	59.21
April	7.184	7.8	1.09	1.095	0.6165	8.581	0.004801	0.4404
May	13.39	7.585	2.283	1.079	-5.809	-43.37	-1.204	-52.75
June	13.06	7.179	1.85	1.029	-5.877	-45.01	-0.821	-44.38
July	11.62	12.98	1.221	1.257	1.361	11.72	0.0357	2.924
August	15.92	10.36	0.8445	0.7129	-5.56	-34.93	-0.1316	-15.59
September	18.36	9.741	0.8097	0.5917	-8.617	-46.94	-0.218	-26.92
October	11.56	13.73	0.5468	0.5948	2.169	18.77	0.048	8.779
November	7.772	10.49	0.2957	0.7392	2.719	34.98	0.4435	150
December	7.678	10.34	0.333	1.096	2.661	34.65	0.7635	229.3
Mean |%| change						27.6		68.4

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #2								
1-day minimum	1.295	1.301	1.103	0.7062	0.006	0.4633	-0.3968	-35.98
3-day minimum	1.481	1.417	1.131	0.6585	-0.06367	-4.299	-0.4729	-41.8
7-day minimum	1.75	1.638	0.9799	0.6334	-0.1124	-6.421	-0.3466	-35.37
30-day minimum	2.908	2.706	0.6253	0.7059	-0.2019	-6.943	0.08054	12.88
90-day minimum	4.014	3.815	0.4974	0.6517	-0.1992	-4.962	0.1543	31.01
1-day maximum	66.97	46.57	0.6186	0.4028	-20.41	-30.47	-0.2158	-34.89
3-day maximum	55.51	40.1	0.6325	0.4406	-15.4	-27.75	-0.1919	-30.34
7-day maximum	46.22	33.49	0.6756	0.4722	-12.73	-27.55	-0.2034	-30.11
30-day maximum	28.82	22.3	0.9843	0.6089	-6.521	-22.62	-0.3753	-38.13
90-day maximum	20.07	16.18	1.093	0.6743	-3.886	-19.37	-0.4184	-38.29
Number of zero days	0	0.5	0	4.472				
Base flow	0.1646	0.1984	0.5292	0.552	0.0338	20.53	0.02278	4.304
Mean |%| change						15.6		30.3

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #3								
Date of minimum	172.3	161.2	0.1685	0.1728	11.1	6.066	0.004321	2.565
Date of maximum	230.9	232.9	0.1568	0.2025	2	1.093	0.04568	29.13
Mean |%| change						3.6		15.8

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #4								
Low pulse count	10.1	9.85	0.4975	0.4776	-0.25	-2.475	-0.01991	-4.002
Low pulse duration	9.788	15.55	0.9555	1.567	5.763	58.89	0.6113	63.98
High pulse count	3.65	3.7	0.5779	0.8729	0.05	1.37	0.295	51.04
High pulse duration	6.475	4.799	1	1.208	-1.676	-25.88	0.2078	20.78
Low Pulse Threshold	3.88							
High Pulse Level	26.36							
Mean |%| change						22.2		34.9

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #5								
Rise rate	2.022	1.42	0.5504	0.434	-0.6026	-29.79	-0.1164	-21.15
Fall rate	-1.576	-1.204	-0.5448	-0.4155	0.3719	-23.6	0.1293	-23.74
Number of reversals	136.2	145.9	0.1264	0.1903	9.7	7.125	0.06384	50.5
Mean |%| change						20.2		31.8
EFC Low Flows								
January Low Flow	5.647	5.745	0.2708	0.3181	0.09827	1.74	0.04727	17.46
February Low Flow	4.926	4.562	0.2862	0.4007	-0.3636	-7.382	0.1146	40.03
March Low Flow	4.592	3.638	0.3954	0.4622	-0.9541	-20.78	0.06683	16.9
April Low Flow	4.508	4.355	0.3679	0.3856	-0.1525	-3.383	0.01776	4.827
May Low Flow	4.279	4.156	0.235	0.343	-0.1224	-2.86	0.108	45.95
June Low Flow	4.523	3.78	0.3351	0.4657	-0.7429	-16.42	0.1306	38.97
July Low Flow	4.179	3.936	0.2628	0.1986	-0.2436	-5.828	-0.0642	-24.43
August Low Flow	5.21	4.537	0.4113	0.347	-0.6731	-12.92	-0.06434	-15.64
September Low Flow	5.552	5.109	0.3541	0.3197	-0.4433	-7.984	-0.03444	-9.725
October Low Flow	6.955	7.676	0.2649	0.2044	0.7213	10.37	-0.06051	-22.84
November Low Flow	6.871	8.11	0.2533	0.164	1.239	18.03	-0.08937	-35.28
December Low Flow	6.592	6.913	0.2444	0.2808	0.3203	4.858	0.03636	14.87

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
EFC Parameters								
Extreme low peak	1.16	1.087	0.2322	0.3698	-0.07374	-6.354	0.1376	59.27
Extreme low duration	5.544	7.625	1.173	0.7837	2.081	37.52	-0.3894	-33.2
Extreme low timing	136.4	95.92	0.1101	0.05542	40.49	22.12	-0.05471	-49.68
Extreme low freq.	3.9	3.3	0.9109	1.408	-0.6	-15.38	0.4971	54.57
High flow peak	16.03	15.37	0.1977	0.2299	-0.6666	-4.157	0.03219	16.28
High flow duration	8.232	7.777	0.4796	0.4208	-0.4552	-5.53	-0.0588	-12.26
High flow timing	214.1	199	0.1783	0.1918	15.08	8.24	0.0135	7.572
High flow frequency	13.6	12.3	0.4634	0.4311	-1.3	-9.559	-0.03236	-6.981
High flow rise rate	3.748	3.602	0.4591	0.4144	-0.1459	-3.894	-0.04461	-9.718
High flow fall rate	-1.912	-2.341	-0.3276	-0.5794	-0.4293	22.46	-0.2518	76.86
Small Flood peak	77.04	69.04	0.3153	0.1001	-8.003	-10.39	-0.2152	-68.24
Small Flood duration	20.67	57.92	0.4939	1.344	37.25	180.2	0.8499	172.1
Small Flood timing	87	87	0	0	0	0		
Small Flood freq.	0.6	0.35	1.257	1.678	-0.25	-41.67	0.421	33.5
Small Flood riserate	19.29	7.665	0.9264	0.7701	-11.62	-60.26	-0.1563	-16.88
Small Flood fallrate	-7.427	-4.192	-0.7344	-0.584	3.235	-43.56	0.1504	-20.48
Large flood peak	178		0.0874					
Large flood duration	154.5		0.4256					
Large flood timing	87		0		-999500	-546200		
Large flood freq.	0.1	0	3.078	0	-0.1	-100	-3.078	-100
Large flood rise	3.699		0.2128					
Large flood fall	-2.232		-0.8116					

Flow level to begin a high flow event is 10.200
Flow level to end a high flow event is 6.310
Flow level to begin an extreme low flow is 1.640

Presidio/Ojinaga IHA Scorecard

IHA Parametric Scorecard

Presidio/Ojinaga

	Pre-impact period: 1925-1944 (20 years)	Post-impact period: 1984-2003 (20 years)
Watershed area	1	1
Mean annual flow	10.4	8.59
Mean flow/area	10.4	8.59
Annual C. V.	1.59	1.41
Flow predictability	0.36	0.39
Constancy/predictability	0.53	0.61
% of floods in 60d period	0.54	0.54
Flood-free season	103	12

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #1								
January	6.091	9.443	0.4527	1.488	3.353	55.05	1.036	228.8
February	6.307	7.725	0.6391	1.316	1.418	22.48	0.6769	105.9
March	4.964	5.68	0.8286	1.299	0.7161	14.43	0.4699	56.71
April	4.518	5.673	1.298	1.398	1.155	25.56	0.1	7.709
May	11.01	6.247	2.213	1.774	-4.758	-43.23	-0.4382	-19.8
June	11.81	8	1.919	1.792	-3.813	-32.28	-0.1276	-6.648
July	11.75	10.21	1.441	1.312	-1.543	-13.12	-0.1295	-8.984
August	18.52	10.59	0.8343	0.9406	-7.929	-42.82	0.1063	12.74
September	20.35	9.062	0.8111	0.9098	-11.29	-55.47	0.09875	12.18
October	16.45	11.04	0.7525	0.9505	-5.406	-32.87	0.198	26.31
November	8.235	9.765	0.4949	0.97	1.53	18.57	0.4751	96.01
December	7.24	9.569	0.4538	1.328	2.33	32.18	0.8745	192.7
Mean |%| change						32.3		64.5

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #2								
1-day minimum	0.6165	1.053	2.431	1.366	0.4365	70.8	-1.065	-43.8
3-day minimum	0.7097	1.158	2.23	1.305	0.4478	63.1	-0.9253	-41.5
7-day minimum	0.9172	1.326	2.107	1.284	0.4089	44.58	-0.8229	-39.06
30-day minimum	1.522	1.877	1.56	1.163	0.3548	23.32	-0.3979	-25.5
90-day minimum	2.793	2.763	0.9676	0.8994	-0.02995	-1.072	-0.06815	-7.043
1-day maximum	76.7	37.69	0.4462	0.8441	-39.01	-50.86	0.3979	89.18
3-day maximum	62.08	33.39	0.4925	0.9395	-28.69	-46.22	0.447	90.76
7-day maximum	51.65	29.04	0.5643	0.9681	-22.61	-43.77	0.4038	71.55
30-day maximum	32.26	21.88	0.7408	0.975	-10.38	-32.18	0.2342	31.61
90-day maximum	22.24	15.7	0.8744	0.9918	-6.542	-29.41	0.1174	13.43
Number of zero days	19.95	0	1.941	0	-19.95	-100	-1.941	-100
Base flow	0.04947	0.1315	1.479	0.6976	0.08202	165.8	-0.7819	-52.85
Mean |%| change						55.9		50.5

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #3								
Date of minimum	172.8	181.7	0.1459	0.1199	8.9	4.863	-0.02601	-17.83
Date of maximum	241.8	219	0.09828	0.2071	22.85	12.49	0.1088	110.7
Mean |%| change						8.7		64.3

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #4								
Low pulse count	5.6	7.15	0.5478	0.5939	1.55	27.68	0.04606	8.408
Low pulse duration	18.88	12.16	1.009	0.6229	-6.717	-35.58	-0.3863	-38.28
High pulse count	5.65	1.55	0.6654	1.719	-4.1	-72.57	1.054	158.4
High pulse duration	6.004	9.098	1.689	1.084	3.094	51.53	-0.6049	-35.81
Low Pulse Threshold	2.32							
High Pulse Level	27.15							
Mean |%| change						46.8		60.2

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
Parameter Group #5								
Rise rate	3.147	0.9962	0.3828	0.6122	-2.151	-68.35	0.2294	59.92
Fall rate	-1.684	-0.8733	-0.4448	-0.7548	0.8109	-48.15	-0.3101	69.71
Number of reversals	101	125.6	0.1555	0.1282	24.65	24.42	-0.02733	-17.58
Mean |%| change						47		49.1
EFC Low Flows								
January Low Flow	5.703	6.038	0.519	0.3036	0.3345	5.865	-0.2153	-41.5
February Low Flow	4.62	5.223	0.3279	0.4055	0.6028	13.05	0.07763	23.68
March Low Flow	4.022	3.673	0.6197	0.5492	-0.349	-8.676	-0.0705	-11.38
April Low Flow	2.504	3.14	0.9556	0.596	0.6356	25.38	-0.3595	-37.63
May Low Flow	3.07	3.181	0.8935	0.8464	0.1105	3.599	-0.04718	-5.28
June Low Flow	2.869	2.642	0.7813	0.7122	-0.2267	-7.902	-0.06909	-8.843
July Low Flow	3.47	2.749	0.8855	0.5413	-0.721	-20.78	-0.3441	-38.86
August Low Flow	3.968	3.536	0.5639	0.6097	-0.4319	-10.88	0.04583	8.127
September Low Flow	4.348	4.302	0.7402	0.5893	-0.04609	-1.06	-0.1509	-20.39
October Low Flow	6.684	6.812	0.3405	0.4299	0.1273	1.904	0.08938	26.25
November Low Flow	7.081	7.116	0.3461	0.339	0.03495	0.4936	-0.007144	-2.064
December Low Flow	6.401	6.339	0.3976	0.3218	-0.06236	-0.9742	-0.07581	-19.07

	MEANS		COEFF. of VAR.		DEVIATION FACTOR		DEV. of C.V.	
	Pre	Post	Pre	Post	Magnitude	%	Magnitude	%
EFC Parameters								
Extreme low peak	0.01864	0.04	1.22		0.02136	114.6		
Extreme low duration	10.63	4.313	1.137		-6.313	-59.42		
Extreme low timing	109.8		0.0805		-999500	-546200		
Extreme low freq.	2.15	0.8	1.256	4.472	-1.35	-62.79	3.216	256.1
High flow peak	20.06	15.81	0.2103	0.4362	-4.248	-21.18	0.2259	107.4
High flow duration	10.82	11.32	0.8277	1.393	0.5025	4.645	0.565	68.26
High flow timing	208.7	217.7	0.1723	0.1343	9.033	4.936	-0.038	-22.05
High flow frequency	9.55	6.95	0.3472	0.4633	-2.6	-27.23	0.116	33.41
High flow rise rate	5.92	4.597	0.499	0.3918	-1.323	-22.36	-0.1073	-21.5
High flow fall rate	-2.98	-3.071	-0.4773	-0.5124	-0.0914	3.067	-0.03512	7.359
Small Flood peak	86.76	113.5	0.1092	0.04361	26.74	30.82	-0.06555	-60.05
Small Flood duration	47.19	256	0.7797	1.193	208.8	442.5	0.4136	53.04
Small Flood timing	87	87	0	0	0	0		
Small Flood freq.	0.55	0.1	1.38	3.078	-0.45	-81.82	1.698	123
Small Flood riserate	19.66	2.89	0.7517	1.187	-16.77	-85.3	0.4348	57.85
Small Flood fallrate	-4.318	-2.843	-0.8065	-1.217	1.475	-34.16	-0.4106	50.91
Large flood peak	154		0.08265					
Large flood duration	130		0.9573					
Large flood timing	87		0		-999500	-546200		
Large flood freq.	0.1	0	3.078	0	-0.1	-100	-3.078	-100
Large flood rise	6.983		0.7189					
Large flood fall	-3.222		-1.086					

Flow level to begin a high flow event is 11.300
Flow level to end a high flow event is 5.610
Flow level to begin an extreme low flow is .060

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Vita

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