Executive Summary

Lower Rio Grande Basin Study

Under the Authority of the SECURE Water Act (Public Law 111-11)
Great Plains Region, Oklahoma-Texas Area Office

U.S.Department of the Interior
Bureau of Reclamation
Denver, Colorado

Rio Grande Regional Water Authority

December 2013

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Executive Summary

Lower Rio Grande Basin Study

Under the Authority of the SECURE Water Act (Public Law 111-11)
Great Plains Region, Oklahoma-Texas Area Office

U.S.Department of the Interior
Bureau of Reclamation
Denver, Colorado

Rio Grande Regional Water Authority

December 2013

Acronyms

2010 Region M Plan	*Rio Grande Regional Water Plan*, dated October 1, 2010
ac-ft/yr	acre-feet per year
Basin Study	Lower Rio Grande Basin Study
BGD	brackish groundwater desalination
DMI	domestic-municipal-industrial
GHG	greenhouse gas
GNEB	Good Neighbor Environmental Board
IBWC	International Boundary and Water Commission
Interior	U.S. Department of the Interior
M&I	municipal and industrial
MGD	million gallons per day
mg/L	milligrams per liter
P&Gs	*Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies*
P.L.	Public Law
Reclamation	Bureau of Reclamation
RGRWA	Rio Grande Regional Water Authority
RO	reverse osmosis
SB1	Senate Bill 1
SRWA	Southmost Regional Water Authority
State Water Plan 2012	Statewide plan entitled *Water for Texas – 2012*
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
Treaty	*Treaty of 1944 Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande*
TWDB	Texas Water Development Board
USGS	U.S. Geological Survey
VIC	Variable Infiltration Capacity Hydrology Model
WAM	Water Availability Model
WaterSMART	Sustain and Manage America's Resources for Tomorrow
WMS	water management strategy

Symbols

%	percent
§	section

Table of Contents

Tables

Figures

EXECUTIVE SUMMARY

The focus area for this Lower Rio Grande Basin Study (Basin Study) is comprised of the Lower Rio Grande River Basin, which extends from Fort Quitman, Texas, along the U.S./Mexico border, to the Gulf of Mexico (figure 1). The study was conducted in partnership with the Rio Grande Regional Water Authority (RGRWA) with its 53 member entities, which shares an approximate boundary with the Region M Water Planning Group, also denoted on figure 1. The study area also is comprised of Amistad and Falcon Reservoirs, which are operated as a system by the International Boundary and Water Commission (IBWC) for flood control and water supply purposes.

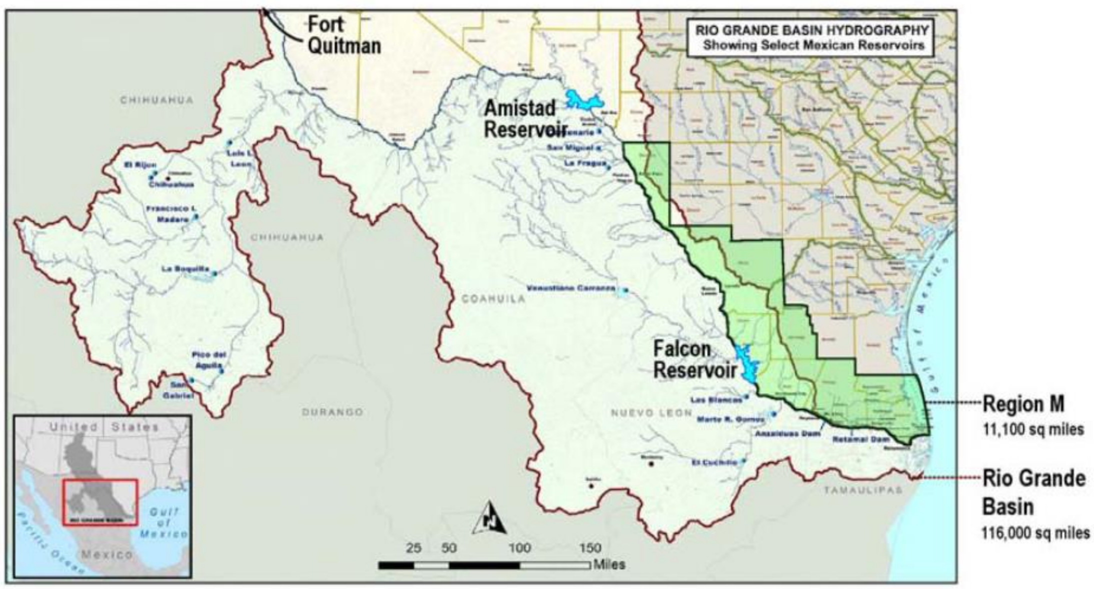

Figure 1: Lower Rio Grande Basin, Texas.

The Lower Rio Grande River Basin lies within the much larger Rio Grande Basin, which extends from southern Colorado and through New Mexico and Texas. Between El Paso, Texas, and the Gulf of Mexico, the Rio Grande forms the International Boundary between the United States and Mexico, a straight-line distance of 700 miles and a river mile distance of nearly 1,250 miles. Once the river reaches Fort Quitman, Texas, just downstream from El Paso, diversions have significantly depleted riverflows. Also, from Fort Quitman to the Gulf of Mexico, the basin's topography shifts dramatically as it becomes fed by watersheds emanating from Mexico rather than the United States.

In Mexico, the Rio Conchos, Rio Salado, and Rio San Juan are the largest tributaries of the Lower Rio Grande Basin. The Rio Conchos drains over 26,000 square miles and flows into the Rio Grande near the town of Presidio, Texas, about 350 river miles upstream of Amistad Reservoir. The Rio Salado has a drainage area of about 23,000 square miles and discharges directly into Falcon Reservoir on the Rio Grande. Falcon Reservoir is located between the cities of Laredo, Texas, and Rio Grande City, Texas, about 275 river miles upstream of the Gulf of Mexico. The Rio San Juan has a drainage area of approximately 13,000 square miles and enters the Rio Grande about 36 river miles below Falcon Dam near Rio Grande City, Texas. The Amistad-Falcon Reservoir System is designated as a special water resource by the Texas Water Development Board (TWDB).[1]

The Texas portion contributing to the Lower Rio Grande Basin encompasses approximately 54,000 square miles, 8,100 square miles of which are “closed” sub-basins that do not contribute flows to the Lower Rio Grande Basin. The Pecos and Devils Rivers are the principal tributaries of the Lower Rio Grande Basin. Both rivers flow into Amistad Reservoir, located upstream of the city of Del Rio, Texas, about 600 river miles from the mouth of the Rio Grande.

The majority of surface water within the Lower Rio Grande Basin study area is comprised of flows within the Rio Grande River. Nearly all of the dependable surface water supply that is available to the Lower Rio Grande Basin is from yields of Amistad and Falcon International Reservoirs. These reservoirs provide controlled storage for over 8.0 million acre-feet of water owned by the United States and Mexico, of which 2.25 million acre-feet are allocated for flood control purposes and 6.05 million acre-feet are reserved for water supply.

Under the authority of the SECURE Water Act (Public Law [P.L.] 111-11), the U.S. Department of the Interior (Interior) established the WaterSMART (Sustain and Manage America’s Resources for Tomorrow) Program in February 2010 to facilitate the work of Interior’s bureaus in pursuing a sustainable water supply for the Nation. This Basin Study was selected for fiscal year 2011 funding in July 2011. The Bureau of Reclamation (Reclamation) and the RGRWA, with its 53 member entities, collaborated with the IBWC and Texas water and environmental agencies to conduct this Basin Study. Although the Basin Study area considered hydrologic inputs for the entire Lower Rio Grande Basin, an eight-county region under the jurisdiction of the RGRWA (roughly similar to Texas water planning Region M) was selected as the area of focus for evaluating supply imbalances and system reliability and for formulating water management strategies (WMSs) that consider risks associated with climate variability and change. The overall Basin Study was conducted at a cost of $412,798 (52 percent [%] RGWRA; 48% Federal cost share) and was completed within 24 months.

[1] 31 TAC 357.5(g).

I. Public Involvement

Public involvement was actively sought and achieved throughout the study primarily through study partner and stakeholder representation at bimonthly public meetings of the RGRWA Board of Directors. The RGRWA board consists of 18 members representing irrigation districts, the public, municipalities, water supply corporations, and counties. Meeting agendas always included a presentation on Basin Study progress, and consensus was obtained following discussion and a formal vote on major study actions, including acceptance of the climate change-affected future conditions projections, formulation of the planning objective, evaluation of alternatives, and recommended alternative analysis. Stakeholders were specifically reminded by Reclamation at meetings that they are expected to represent all of their relevant member interests. Communications were also held on a case-by-case basis as needed to solicit input, expertise, and data. In addition, meetings of the RGRWA board also included representatives from the following:

- Texas Water Development Board
- Region M Planning Group
- Texas Commission on Environmental Quality, Office of Rio Grande Watermaster
- Texas Parks and Wildlife Department
- International Boundary Water Commission
- U.S. Department of Agriculture Cooperative Extension Service
- U.S. Geological Survey (USGS)

RGRWA's consulting team, which performed technical analyses for the study, regularly attended the biweekly Region M Planning Group public meetings to stay abreast of water planning issues in the study area. Some member companies of the Basin Study consulting team were also subcontractors to the team contracted by the Region M Planning Group to perform the required 5-year update of the Region M Plan, which facilitated communication and coordination with this Basin Study. For example, proposed criteria emerging from this Basin Study for the location of the preferred alternative brackish groundwater desalination (BGD) plants were circulated in a Region M Plan survey on water supply strategies.

Also, Reclamation was invited to speak and conducted presentations on the study at two different meetings that involved both governmental and public attendees, which included:

- U.S. Army Corps of Engineers Conference on the Lower Rio Grande, October 2011

- IBWC Citizens' Forum, October 2012

Public involvement was also achieved through the Internet, where a link on the RGRWA Web site was maintained to provide up-to-date information on this Basin Study.[2] The following was provided on the Web link:

- Summary and background information
- A link to the original proposal for funding
- A link to the final Plan of Study
- Updates/news releases on completed milestones
- Points of contact

II. Basin Study Findings

The Basin Study Program focuses on improving water conservation and sustainability and helping water resource managers make sound decisions about water use. It identifies strategies to ensure that this and future generations will have sufficient supplies of clean water for drinking, economic activities, recreation, and ecosystem health. The program also identifies adaptive measures to address climate change and its impact on future water demands. Basin studies include four required elements:

1. Projections of water supply and demand within the basin, including an assessment of risks to the water supply relating to climate change as defined in section 9503(b)(2) of the SECURE Water Act.

   The study finds that climate change is likely to result in increased temperatures, decreased precipitation, and increased evapotranspiration in the study area. As a result, in addition to the 592,084 acre-feet per year (ac-ft/yr) of supply shortfall (demand minus supply) predicted by the existing regional planning process by 2060, it is projected that an additional 86,438 ac-ft/yr will be needed due to climate change.

[2] http://www.rgrwa.org/projects/lower-rio-grande-basin-study/

2. Analysis of how existing water and power infrastructure and operations will perform in the face of changing water realities, such as population increases and climate change, as well as other impacts identified within section 9503(b)(3) of the SECURE Water Act as appropriate.

   The supply imbalances exacerbated by climate change will greatly reduce the reliability of deliveries to all users who are dependent on deliveries of Rio Grande water via irrigation systems. For example, only about 40% average volume reliability of interruptible irrigation and mining water rights would be achieved in the middle range of our future condition scenarios.

3. Development of appropriate adaptation and mitigation strategies to meet future water demands.

   The study developed a planning objective that would reduce dependency on the Rio Grande in the part of the study area most susceptible to water supply imbalances and would meet the additional shortfall projected. This planning objective was to alleviate projected water supply imbalances in the study area by developing one or more alternatives in Cameron, Willacy, and Hidalgo Counties that will (1) provide a minimum of 86,438 acre-feet of water year round by 2060; (2) protect existing water rights; (3) be compatible with regulations, policies, and environmental law; and (4) be implementable within the reasonable control of study sponsors.

4. A tradeoff analysis of the strategies identified and findings and recommendations as appropriate. This includes an analysis of all proposed alternatives in terms of their relative cost, environmental impact, risk (probability of not accomplishing the desired/expected outcome), stakeholder response, or other attributes common to the alternatives.

   The study examined the existing WMSs proposed by the regional planning process against the planning objective and selected four for further study (seawater desalination, brackish groundwater desalination, reuse, and fresh groundwater development) while emphasizing the continuing need for conservation and the need for a portfolio approach to include all approved elements of the regional planning process. The four strategies were examined further, and BGD was recommended as being most suitable for preliminary engineering and affordability analysis. This strategy was further developed to recommend three generalized locations for future desalination plants, which were then analyzed using the TWDB’s Unified Costing Model, and an affordability analysis was conducted.

III. Projected Future Water Supply and Demand

This section first examines existing projections of future water supplies and demands and then adjusts those projections based on climate change scenarios.

A. Pre-climate Change Supply and Demand Projections

Much of the pre-climate analysis in this Basin Study is based on the current plan adopted by Region M entitled *Rio Grande Regional Water Plan*, dated October 1, 2010 (2010 Region M Plan).[3] In 1997, the 75th Texas Legislature enacted Senate Bill 1 (SB 1), legislation that grew out of the drought of the early to mid-1990s and the increasing public awareness of rapidly growing water demands in the State. SB 1 radically altered the manner in which State Water Plans are prepared, establishing a “bottom up” approach based on Regional Water Plans that are prepared and adopted by appointed Regional Water Planning Groups representing 11 different stakeholder interests. The planning process is coordinated by the TWDB, which assembles the 16 Regional Water Plans into 1 comprehensive State Water Plan. Initially designated by TWDB as “Region M,” the Rio Grande Regional Water Planning Area (or the Rio Grande Region) consists of the eight counties adjacent to or in proximity to the Lower Rio Grande: Cameron, Hidalgo, Jim Hogg, Maverick, Starr, Webb, Willacy, and Zapata. The planning group is tasked with developing a 50-year water supply plan in response to a repeat of the record drought. In the hydrologic models used for availability, the record drought occurred in the mid-1950s.

The findings and information provided in the 2010 Region M Plan were then incorporated into the current Statewide Plan entitled *Water for Texas – 2012*[4] (State Water Plan 2012). There is an ongoing effort within Region M to produce a revised 2013 plan, but the data for that later plan have not yet been available for inclusion in this Basin Study. However, the development of this Basin Study has been presented at the Rio Grande Regional Planning Group meetings held every 2 months, and many of this study’s findings, particularly regarding climate-affected future outcomes and planning alternatives, will be incorporated into the 2013 Region M Plan.

The supply issues facing the Lower Rio Grande Basin in both the United States and Mexico are extremely complex, ranging from a multinational to local scale. Water supplies in the area are primarily from the Rio Grande, with much of the drainage located in Mexico and regulated by releases from the Falcon and

[3] http://www.twdb.state.tx.us/wrpi/rwp/3rdRound/2011_RWP/RegionM/
[4] http://www.twdb.state.tx.us/wrpi/swp/swp.asp

Amistad Reservoirs, which are managed by the IBWC, in compliance with the *Treaty of 1944 Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande* (Treaty) between the United States and Mexico.

Figure 2 shows the projected (pre-climate analysis) firm yield of the Amistad-Falcon Reservoirs and demand. These yield values represent the maximum amount of water that can be withdrawn from the reservoirs on a continual basis by the United States should conditions similar to the drought of record recur.

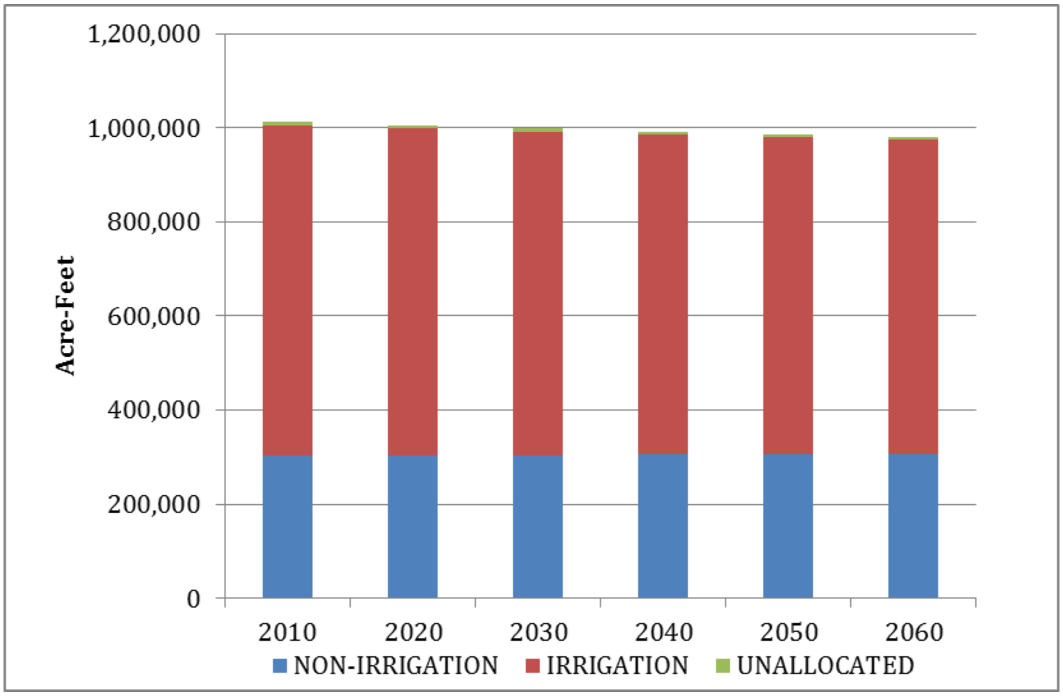

Figure 2: Projected (pre-climate analysis) firm yield of Amistad-Falcon Reservoirs and demand.
Source: 2010 Region M Regional Water Plan.

The major aquifers within the region include the Gulf Coast aquifer, which underlies the entire coastal region of Texas, and the Carrizo aquifer that exists in a broad band that sweeps across the State beginning at the Rio Grande north of Laredo and continuing northeast to Louisiana. In general, groundwater from the various aquifers in the region has total dissolved solids (TDS) concentrations exceeding 1,000 milligrams per liter (mg/L) (slightly saline) and often exceeds 3,000 mg/L (moderately saline). The salinity hazard for groundwater ranges from high to very high.

A pre-climate analysis of combined surface and groundwater supplies for Region M are shown in table 1.

Table 1: Projected 2010–2060 groundwater and surface water supplies

	Region M projected water supply (ac-ft/yr)					
	2010	**2020**	**2030**	**2040**	**2050**	**2060**
Groundwater	341,692	341,692	341,692	341,692	341,692	341,692
Surface water	1,015,958	1,008,958	1,002,458	995,958	989,458	989,458
Total	**1,357,650**	**1,350,650**	**1,344,150**	**1,337,650**	**1,331,150**	**1,331,150**

Source: TWDB State Water Plan 2012.

According to the Region M Plan, the study area faces a projected shortage of water that is going to grow by 60% over the next 50 years. The biggest changes are in the conversion of irrigation water to municipal use due to population growth and urbanization. There was a projected shortage of 156,257 acre-feet in 2010 and 410,936 acre-feet of need (shortage) in 2060. This is shown on figure 3.

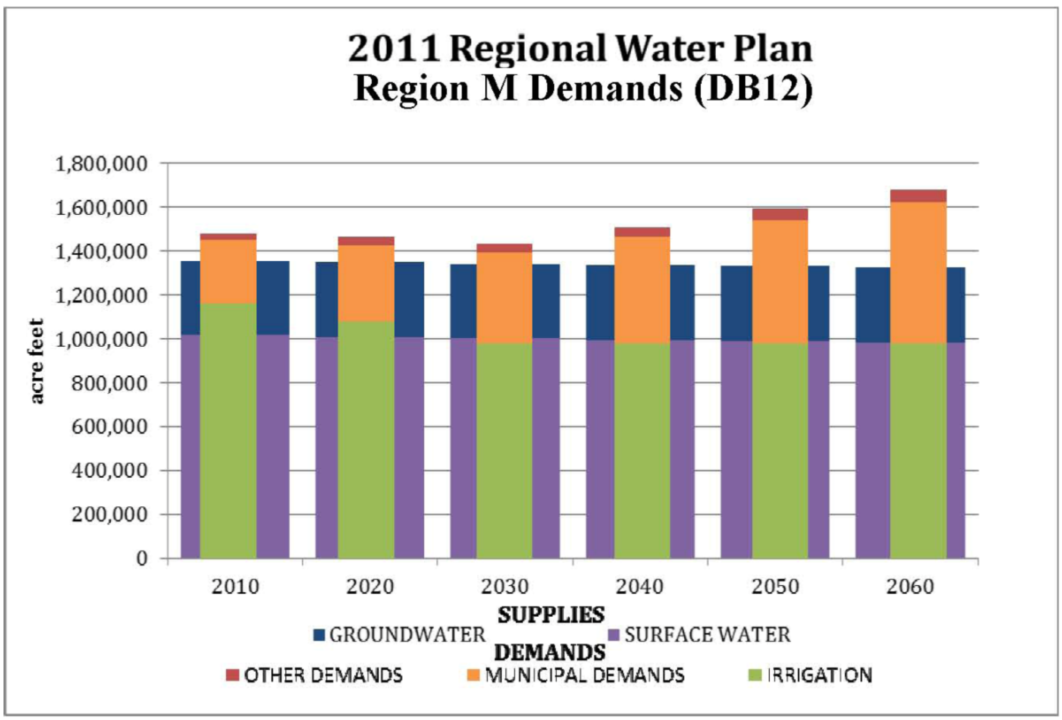

Figure 3: Projected supply imbalances without climate change factors.
Source: Texas State Water Plan 2012.

The State Plan does not account for any potential impacts in projections due to climate variability. The following discussion outlines the methodology for how changes in hydrology were simulated in evaluating climate impacts on State water availability models for Texas.

Much of the surface water deliveries in the study area for all user groups are made through a network of canals that are managed by 27 different irrigation districts. As a result of severe drought conditions since 2011, several irrigation districts in the region announced in spring 2013 that agricultural deliveries were being curtailed, which also subsequently affected municipal supplies that depend on agricultural conveyance systems for water deliveries.

B. Climate Change Scenarios Considered

The project team generated 112 climate change-affected outcomes based on three different future global emission scenarios:

- The A2 scenario is representative of high population growth, slow economic development, and slow technological change. It is characterized by a continuously increasing rate of greenhouse gas (GHG) emissions and features the highest annual emission rates of any scenario by the end of the 21st century.

- The A1B scenario features a global population that peaks mid-century and rapid introduction of new and more efficient technologies balanced across both fossil- and nonfossil-intensive energy sources. As a result, GHG emissions in the A1B scenario peak around mid-century.

- The B1 scenario describes a world with rapid changes in economic structures toward a service and information economy. GHG emission rates in this scenario peak prior to mid-century and are generally the lowest of the scenarios.

The climate scenario outcomes were then run through the Variable Infiltration Capacity Hydrology Model (VIC). The VIC includes the physical characteristics of each 12-kilometer cell within the study area to simulate runoff and other water/land/atmosphere interactions at each grid cell. The VIC uses the climate projections along with land cover, soils, and elevation information to simulate hydrologic interactions, resulting in a prediction of runoff used in this study.

The hydrologic interactions were then routed to each of the 43 natural flow locations within the study area using a routing network derived from the topography. These 43 locations are also matched to the Texas Water Availability Model (WAM) so existing water rights and allocations in practice could be calculated. The VIC control points are distributed in both Mexico and the United States, giving a model of climate-affected flows on all major tributaries as affected by water rights for the entire Basin Study area.

Figure 4 shows the projection for six hydroclimate indicators for the Rio Grande below Falcon Dam: (1) annual total precipitation (top left), (2) annual mean temperature (top right), (3) April 1 snow water equivalent (middle left), (4) annual runoff (middle right), (5) December – March runoff season (bottom left), and (6) April – July runoff season (bottom right). The heavy black line is the annual time-series of 50th percentile values (i.e., median). The shaded area is the annual time-series of 5th to 95th percentiles of the results when they are ordered from lowest to highest. This location was chosen because it is the most downstream point of the Rio Grande before withdrawals are made to meet the demands of the study area.

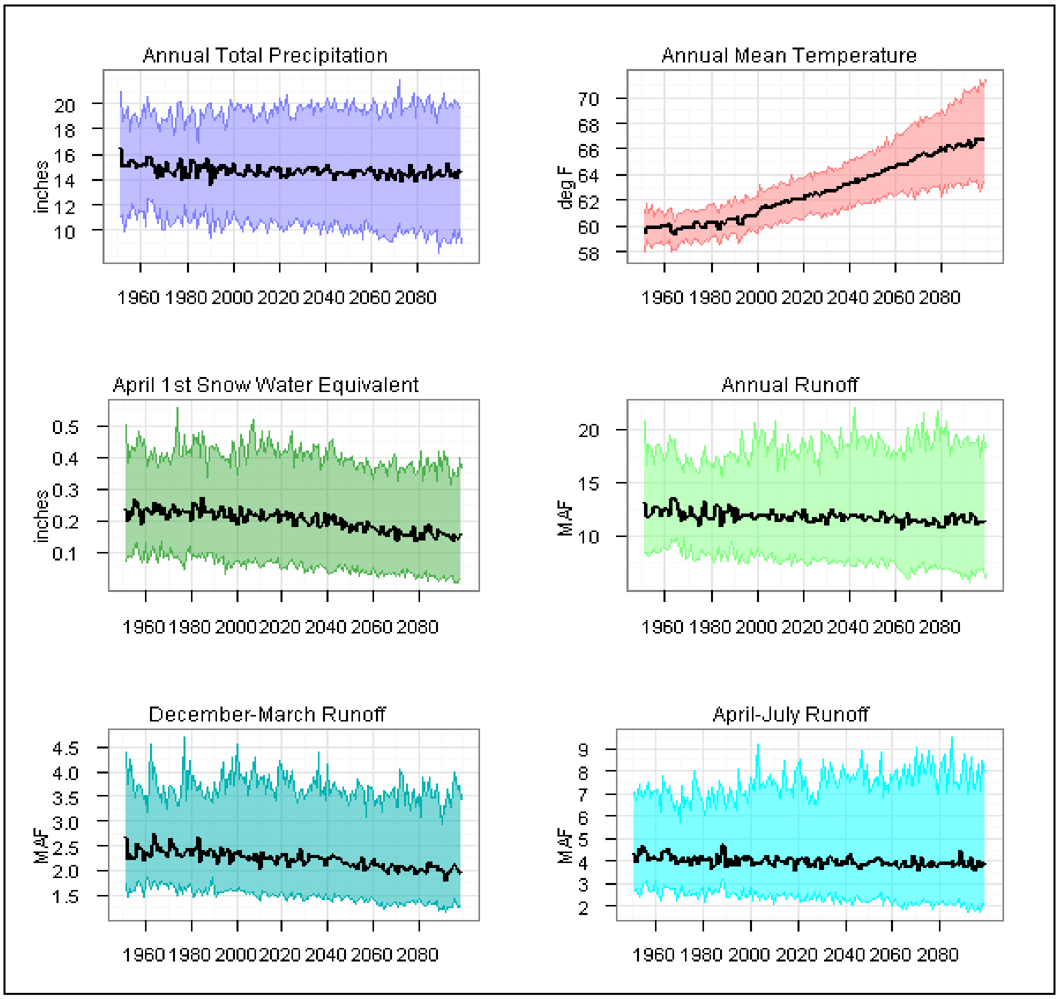

Figure 4: Projections for six hydroclimate indicators for the Rio Grande below Falcon Dam.

These data are summarized for selected future years on figure 5. Changes in mean runoff (annual or seasonal) are calculated for the three future decades—2020s, 2050s, and 2070s—from the reference 1990s decade. The results can be summarized as follows:

- Precipitation is expected to increase from the 1990s level during the 2020s and 2050s but decline nominally during the 2070s.
- Temperature shows a persistent increasing trend from the 1990s level.
- April 1 snowpack (Upper Rio Grande Basin) shows a persistent decreasing trend from the 1990s level.
- Annual runoff shows some increase from the 1990s level to the 2020s, but then declines to the 2050s and 2070s.

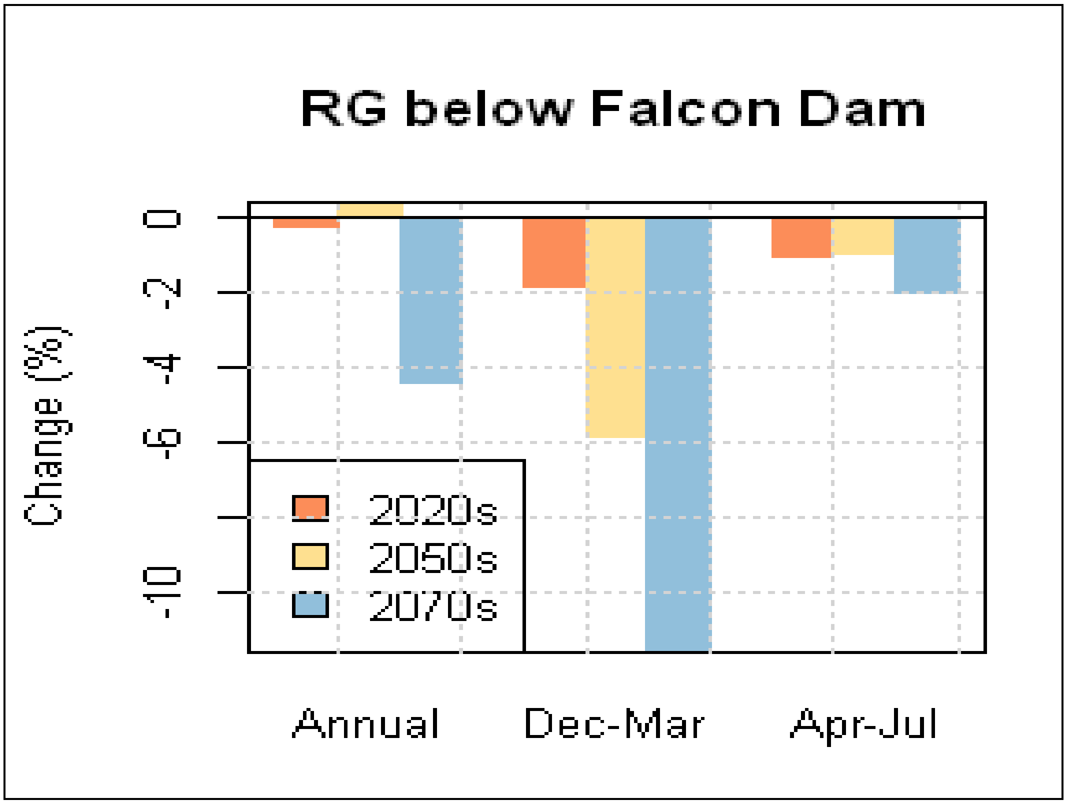

Figure 5: Simulated mean annual and mean seasonal runoff change.

Reservoir evaporation was estimated using the same approach to estimate changes in streamflow. Using the VIC open water evaporation output, change in monthly mean open water evaporation was estimated for each of the 112 climate projections and for each of the 25 reservoir sites used in the water allocation modeling effort. Next, median (50th percentile) and 95th percentile change for each month was calculated from the 112 change factors for each of the reservoir sites. The summer season (June – August) change for the median (50th percentile) from the 25 reservoir sites ranged from 0.85 to 3.72% with a median change of 2.58%. Similarly, the summer season change for the 95th percentile from the 25 reservoir sites ranged from 6.55 to 12.55% with a median of 9.61%. To simplify the system reliability analysis, three values considered representative of the above VIC output trends were selected for comparison purposes: (1) no change in reservoir evaporation, (2) a 4% change in reservoir evaporation, and (3) a 10% change in reservoir evaporation. These reliability comparisons are displayed in table 2.

C. Climate Change-affected Supply and Demand

The effect of potential climate change scenarios on the surface water supply imbalances from the Rio Grande was investigated using the Rio Grande WAM with modified naturalized flow inputs derived from the 112 climate change scenarios analyzed by Reclamation. The results of the analysis were then ordered from lowest to highest. Monthly median and 5th and 95th percentile flow factors from the 112 scenarios were used at all primary control points in the WAM to incorporate climate change effects into the monthly baseline naturalized flows for the 1940–2000 simulation period. For example, a value in the 5th percentile represents values of lower flow (exceeded by 95% of the other values resulting from the analysis), while a value in the 95th percentile represents values of higher flows (exceeded by only 5% of the others).

The evaporation rates for this period included in the WAM data input files were also increased by 4 and 10% to provide an indication of the potential effects of varying evaporation rates due to climate change. As with flow, evaporation rates for nine climate change scenarios and the baseline were evaluated for surface water availability effects.

Figure 6 compares firm yield from the Amistad-Falcon Reservoir System based on the WAM Run 3 baseline simulation with firm yield results for the three climate scenarios. These firm yields can be assumed to represent current (2010) conditions and do not represent future projections due to the lack of impact from sedimentation rates and changes in the distribution of water demands. Firm yield for baseline conditions is 1,032,123 acre-feet; climate change impacts would reduce this amount to 620,750 acre-feet under the 5th percentile simulation, a 40% reduction in firm yield volume for the study area.

Table 2: WAM baseline and climate simulation results

SUMMARY OF TEXAS WATER RIGHTS RELIABILITIES AND OTHER RESULTS FROM RIO GRANDE WAM SIMULATIONS CONSIDERING DIFFERENT CLIMATE CHANGE SCENARIOS

RUN ID	BASELINE	1	2	3	4	5	6	7	8	9
FLOW SCENARIO	WAM RUN3	MEDIAN FLOW FACTORS			5TH PERCENTILE FLOW FACTORS			95th PERCENTILE FLOW FACTORS		
EVAPORATION SCENARIO	WAM RUN3	LOW Same as Baseline	MEDIUM Baseline + 4%	HIGH Baseline + 10%	LOW Same as Baseline	MEDIUM Baseline + 4%	HIGH Baseline + 10%	LOW Same as Baseline	MEDIUM Baseline + 4%	HIGH Baseline + 10%
MIDDLE & LOWER RIO GRANDE										
AMISTAD-FALCON WATER RIGHTS										
TOTAL AUTHORIZED DIVERSIONS										
Domestic-Municipal-Industrial	301,920	301,920	301,920	301,920	301,920	301,920	301,920	301,920	301,920	301,920
Class A Irrigation & Mining	1,624,004	1,624,004	1,624,004	1,624,004	1,624,004	1,624,004	1,624,004	1,624,004	1,624,004	1,624,004
Class B Irrigation & Mining	187,078	187,078	187,078	187,078	187,078	187,078	187,078	187,078	187,078	187,078
Total (Ac-Ft/Year)	2,113,002	2,113,002	2,113,002	2,113,002	2,113,002	2,113,002	2,113,002	2,113,002	2,113,002	2,113,002
MONTHLY PERIOD RELIABILITY										
Domestic-Municipal-Industrial	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Class A Irrigation & Mining	55.1%	50.3%	50.1%	49.3%	18.2%	17.9%	17.6%	89.9%	89.6%	88.8%
Class B Irrigation & Mining	29.9%	28.1%	28.0%	27.6%	9.3%	9.3%	9.4%	75.8%	75.5%	75.1%
ANNUAL PERIOD RELIABILITY										
Domestic-Municipal-Industrial	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Class A Irrigation & Mining	27.9%	23.0%	23.0%	21.3%	1.6%	1.6%	1.6%	78.7%	75.4%	75.4%
Class B Irrigation & Mining	11.5%	8.2%	8.2%	8.2%	1.6%	1.6%	1.6%	54.1%	54.1%	52.5%
AVERAGE VOLUME RELIABILITY										
Domestic-Municipal-Industrial	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Class A Irrigation & Mining	66.7%	61.9%	61.7%	61.3%	31.3%	31.2%	31.0%	92.5%	92.3%	92.0%
Class B Irrigation & Mining	43.6%	40.9%	40.8%	40.5%	19.7%	19.7%	19.5%	80.2%	79.9%	79.5%
AVERAGE DELIVERY VOLUME										
Domestic-Municipal-Industrial	301,920	301,920	301,920	301,920	301,920	301,920	301,920	301,920	301,920	301,920
Class A Irrigation & Mining	1,083,211	1,005,258	1,002,011	995,514	508,313	506,689	503,441	1,502,204	1,498,956	1,494,084
Class B Irrigation & Mining	81,566	76,515	76,328	75,767	36,854	36,854	36,480	150,037	149,475	148,727
Total (Ac-Ft/Year)	1,466,697	1,383,693	1,380,259	1,373,201	847,087	845,463	841,841	1,954,161	1,950,351	1,944,731
RESERVOIRS U.S. FIRM ANNUAL YIELD										
All DMI, Irrigation & Mining Water Rights	1,032,123	983,781	977,131	968,039	628,155	620,750	610,179	1,509,056	1,501,655	1,491,107
AMISTAD-FALCON AVERAGE ANNUAL U.S. EVAPORATION LOSSES (Ac-Ft)	107,694	98,812	101,468	106,243	60,794	61,872	66,578	257,591	265,860	277,910
PRIOR APPROPRIATION RIGHTS										
IN TEXAS RIO GRANDE BASIN										
Total Authorized Diversions	1,062,655	1,062,655	1,062,655	1,062,655	1,062,655	1,062,655	1,062,655	1,062,655	1,062,655	1,062,655
AVERAGE VOLUME RELIABILITY	47.3%	42.1%	42.1%	42.0%	33.8%	33.8%	33.7%	50.6%	50.6%	50.6%

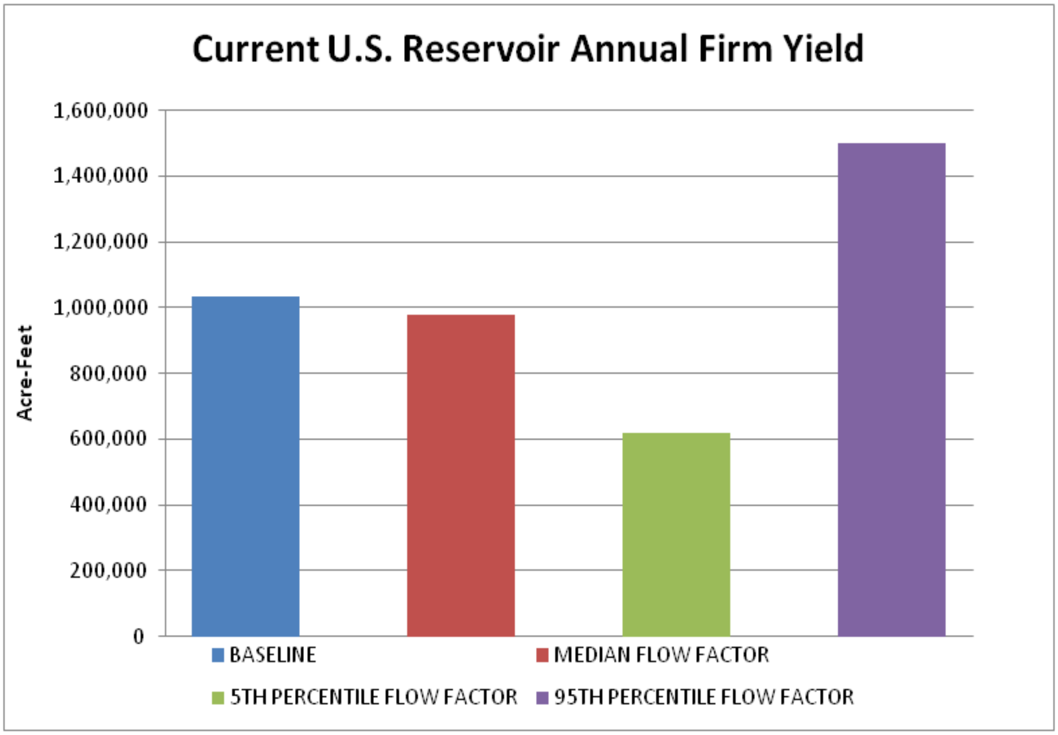

Figure 6: Amistad-Falcon Reservoirs U.S. firm annual yield comparison for baseline versus climate change impacts.

The effect of climate change on future evapotranspiration was also calculated and incorporated into seasonal agricultural demand figures to show quantified increases, further exacerbating the future supply/demand imbalance for the study area. Agricultural demands would be expected to increase by approximately 18% for the 95th percentile climate change scenario over baseline demands.

D. Effect on Future Water Supply Reliability

In total, 10 different sets of WAM input data were considered, 1 reflecting the historical baseline condition without climate change effects and 9 combinations of the 3 future flow conditions (median and 5th and 95th percentile flow factors) and 3 future evaporation conditions (baseline and 4 and 10% increases) with climate change effects. Table 2 describes the following scenarios in the columns from left to right:

- Baseline
- Scenario 1 – Median climate-affected flow factors with evaporation same as baseline

- Scenario 2 – Median climate-affected flow factors with + 4% evaporation
- Scenario 3 – Median climate-affected flow factors with + 10% evaporation
- Scenario 4 – 5th percentile climate-affected flow factors (low) with evaporation same as baseline
- Scenario 5 – 5th percentile climate-affected flow factors (low) with + 4% evaporation
- Scenario 6 – 5th percentile climate-affected flow factors (low) with + 10% evaporation
- Scenario 7 – 95th percentile climate-affected flow factors (high) with evaporation same as baseline
- Scenario 8 – 95th percentile climate-affected flow factors (high) with + 4% evaporation
- Scenario 9 – 95th percentile climate-affected flow factors (high) with + 10% evaporation

With these sets of modified input data, simulations of water availability throughout the Rio Grande Basin were made using the WAM, and the results are shown in table 2 in a few different terms. First, the total authorized diversion is the total volume of all water rights held for this section of the Rio Grande. Reliabilities are assigned to classes of water rights on the Lower Rio Grande as a way to deal with the volume of total authorized maximum diversions being larger than the firm yield of the reservoirs. Table 2 shows both period and volume reliabilities for all domestic-municipal-industrial (DMI) water rights and for all Class A[5] and Class B[6] irrigation and mining water rights that depend on Amistad and Falcon Reservoirs for their supply.

For the purpose of this study, the volume reliability percentage is defined as the average volume of water that a particular water right was able to divert during the 1940–2000 period, as simulated with the WAM, divided by the authorized maximum diversion amount for that water right. For example, in column 6 of table 2, for the 5th percentile flow factor (that point in the projected future flow

[5] Class A water right in the Rio Grande Basin for irrigation and mining use granted in the Adjudication in *State* v. *Hidalgo County Water Control & Improvement District No. 18.* If converted to a DMI water right, a Class A water right is converted to 50% of the existing water right.

[6] Class B water right in the Rio Grande Basin for irrigation and mining use granted in the Adjudication in *State* v. *Hidalgo County Water Control & Improvement District No. 18.* If converted to a DMI water right, a Class B water right is converted to 40% of the existing water right.

distribution curve of which 95% of the results were higher), under the high evaporation scenario, only 19.5% of the Class B irrigation and mining water rights would be met due to low surface water conditions.

Period reliability is the percentage of time for which a particular diversion is available in light of the historical observations. This applies to monthly and annual time steps. Monthly period reliability is the percentage of time for which all monthly authorized diversions are met. The annual period reliability is the percentage of time for which annual authorized diversions are met. The annual period reliability decreases dramatically over the monthly reliability due to the larger number of data points in the monthly historical record. For the purpose of the following discussion, the average volume reliability is used.

Firm yield is the maximum water volume a reservoir can provide each year under the drought of record conditions and is shown for each climate scenario.

For information purposes, the average annual evaporation losses from Amistad and Falcon Reservoirs and the minimum storage remaining in these reservoirs as simulated with the WAM for the 1940–2000 period are presented for the baseline case and for each of the nine climate change scenarios.

As shown in table 2, the water supply from Amistad and Falcon Reservoirs for the DMI water rights is 100% reliable because of the high priority assigned to these rights under the structure of the Texas Commission on Environmental Quality's (TCEQ) water rights administration rules for the Middle and Lower Rio Grande (the model predicts that adequate supply will exist under all climate scenarios to satisfy these rights). The Class A and Class B irrigation and mining rights have somewhat lower reliabilities because the available supplies of water for these rights from Amistad and Falcon Reservoirs are subject to allocation during periods of shortage, with the Class A rights allocated more water than the Class B rights. The reliabilities of the prior appropriation water rights, which are rights to Rio Grande water directly, not allocated from the reservoirs, generally fall in line with the Class A and Class B reservoir rights, except for the 95th percentile high-flow results (Scenarios 7, 8 and 9), where all of the Class A and Class B reliabilities are considerably higher.

From the average volume reliabilities, another metric can be generated: average volume diverted. Whereas firm yield was calculated as the largest volume that can be supplied with 100% reliability, average volume diverted is calculated by applying the average volume reliability to the total authorized diversions. This value represents the average volume that is likely to be diverted under each climate scenario.

The difference between the average volume diverted under the baseline condition and the median flow, 4% increased evaporation scenario (Scenario 2), is 86,438 acre-feet. This represents the difference between the Amistad-Falcon modeled availability that is currently used in the planning process and the availability that is predicted under the median climate-affected availability model. In other words, in addition to Region M's predicted supply imbalance of 592,084 ac-ft/yr, there will likely be another 86,438 ac-ft/yr also not available in 2060, further affecting delivery reliabilities of all users. Even though municipal and industrial (M&I) users have rights to 100% reliability in theory, extreme drought conditions in 2013 have shown that reductions in agricultural water deliveries can negatively affect the push water needed to supply M&I users. This important figure is used in this Basin Study as representative of the probable additional future supply imbalance that would result from climate change and, therefore, plays a major role in forming the planning objective.

IV. Options to Resolve Supply and Demand Imbalances

A. Development of the Planning Objective

The study's planning objective was developed to address the 86,438 ac-ft/yr shortfall in consideration of the following requirements and constraints:

1. Requirements

The study team's discussions as vetted through RGRWA public meetings have resulted in the following essential elements desired for any solution to future supply imbalances:

- **Reduce dependency on the Rio Grande:** The overappropriation of Rio Grande water rights, climate variability-affected Rio Grande supply projections, anticipated decreased firm yield of its reservoirs, projected worsening supply imbalance, and increasing competing demand from Mexico result in the need for supply alternatives that reduce dependency on the Rio Grande.

- **Preserve existing water rights:** The overappropriation of current supplies and the primacy of DMI rights over agricultural rights are exacerbated by the interdependent relationship of irrigation "push water" needed to enable delivery. Furthermore, recognition of valid uses that contributes to the health and economic vitality of the study area result in a guiding principle against adoption of an alternative that would benefit one user group to the detriment of another user group.

- **Preserve downstream flows for irrigation/push water/environmental reasons:** While not a regulatory requirement, the preservation of downstream flows for environmental and other users is a worthwhile constraint in itself and especially valuable in an area prone to drought and possible reduced flows from climate change.

- **Contain actions that are within the reasonable control of study sponsors:** The strategies selected by members of this Basin Study must involve relatively low risk in terms of being within the discretion of study partners to implement. For example, although a Treaty is in place, past performance and jurisdictional barriers indicate that there is high risk in involving alternatives that call for operational changes in Mexico.

2. Constraints

The following conditions exist that would affect all solutions to future supply imbalances:

- Competition with Supply and Demand in Mexico

  Seventy-eight percent of the watershed that feeds the Falcon and Amistad Reservoirs, which in turn supply the water for the study area, is in Mexico. Historically, Mexico has not always been able to meet its obligations under the governing Treaty due to drought and its own competing uses for tributary waters. Figure 7 shows the estimated volumes of water delivered to the United States from Mexico between 1988 and 2012 averaged over 5-year periods. The terms of the Treaty require a resetting of the 5-year monitoring period whenever the levels in the reservoirs reach conservation stage; therefore, not all of the lines represent 5-year periods. All lines that end below the diagonal red line represent 5-year periods in which Treaty obligations were not met. Some periods are less than 1 year, particularly following heavy rains.

  Conclusion: The reliability of the Rio Grande to meet future needs in the study area is severely compromised by the potential for diminishing supplies due to climate change and competing use from Mexico.

- Groundwater Supplies

  Fresh groundwater supplies are severely limited by the fact that approximately 80% of the wells in the study area yield only brackish supplies. Therefore, of the 176,355 ac-ft/yr of managed available groundwater (sustainable yield) designated by the study area’s Groundwater Management District, about 141,084 acre-feet are brackish.

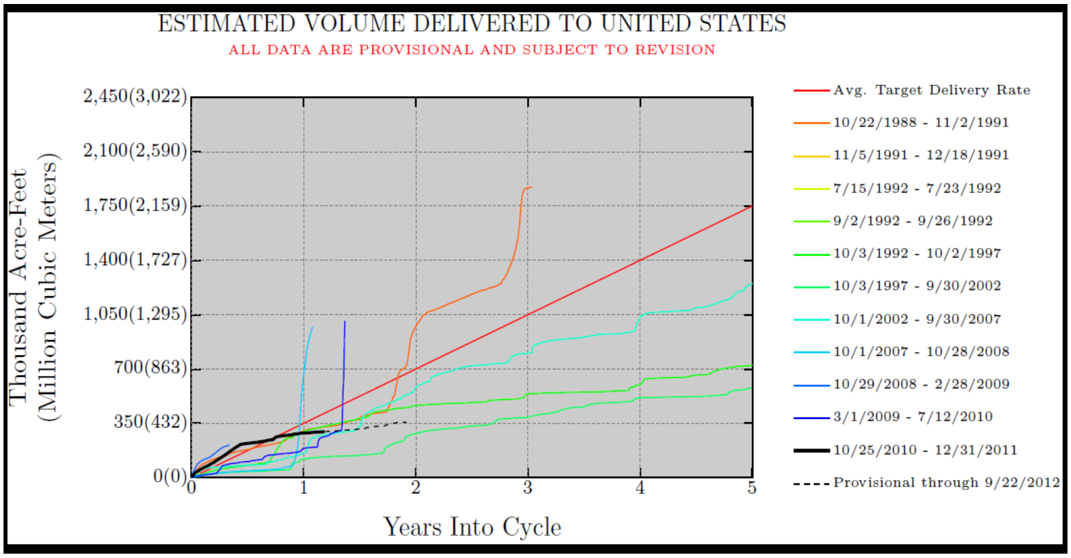

Figure 7: Volume of water delivered to the United States under the International Boundary Agreement.
Source: International Boundary and Water Commission.

Recent indicators show that water use for mining for hydraulic fracturing (fracking) related to oil and gas activities in the study area have increased tenfold over current Region M plan estimates (42,000 ac-ft/yr compared to 4,200 ac-ft/yr).[7] Supplies for fracking are based on some river diversions, but are more dependent on groundwater, primarily fresh groundwater. Although such usage may wane by 2030 when the current oil development boom in the northern portions of the study area may cease, groundwater recharge in the study area is insignificant, and the demand for fracking water is expected to affect fresh groundwater supplies throughout the planning horizon. An assessment of the usage and long-term effects of fracking demand is complicated by the fact that water use for oil and gas development is exempt from Texas groundwater regulation.

Conclusion: Brackish groundwater supplies are four times (80 versus 20%) more plentiful than fresh groundwater supplies and have much fewer competing demands.

- Temporal Aspects

The study area's warm climate provides for a year-round growing season. In addition, M&I demand (which includes landscape watering and residential/commercial uses) varies little year round. Because the demands are constant, irrigation districts that serve agricultural, municipal,

[7] This trend has been noted by the TCEQ Watermaster at Region M and RGRWA board meetings.

and industrial demand report difficulty diverting water flows in order to perform both maintenance and system improvements. Since demand for the Rio Grande waters exceeds supply year round, there is no season when the supply balance will not need amelioration.

The planning horizon for this Basin Study is through the year 2060. While assessments of supply imbalance are based on the planning horizon, imbalances already exist and are expected to worsen between now and 2060.

Conclusion: The planning objective should require a solution that provides a year-round source of water that provides for solution(s) as soon as they can be practically available, but with a goal of being operational and feasible throughout the planning horizon.

- Locational Aspects

  The Lower Rio Grande Valley Development Council states that solution(s) were sought that would provide from 25 to 40% of the projected supply imbalances of 2050 demand and are located within the three-county subarea of Cameron, Willacy, and Hidalgo.[8]

  The largest municipal, manufacturing, and mining users are further down river in Hidalgo and Cameron Counties and upriver in Webb County. The majority of the demand in Webb County was from the city of Laredo, which is not an RGRWA member, and they have opted out of this study. There are over 100 miles and two other counties between Webb County and the nearest of the three counties specified by the RGRWA. Demand from these users is expected to grow rapidly during the planning horizon, while demand from the agricultural group is expected to decline due to projected urbanization.

  Conclusion: The planning objective should require a solution that provides water supplies in one or more of the following counties: Cameron, Willacy, and Hidalgo.

3. Planning Objective

The planning objective presented by the study team and adopted by vote of the RGRWA at its public meeting on September 5, 2012, incorporates the above requirements and constraints:

[8] RGRWA's March 15, 2011, Letter of Intent.

Alleviate projected water supply imbalances in the study area by developing one or more alternatives in Cameron, Willacy, and Hidalgo Counties that will (1) provide a minimum of 86,438 acre-feet of water year round by 2060; (2) protect existing water rights; (3) be compatible with regulations, policies, and environmental law; and (4) be implementable within the reasonable control of study sponsors.

B. Identification of Water Management Strategies

1. Water Management Strategies from the Region M Plan

The relationship is strong between the Region M Plan and this Basin Study. The Regional Plan is the product of stakeholder vetted information compiled by subject matter experts. In addition, all chapters of this Basin Study were transmitted and reviewed as technical memoranda through the Region M Planning Team at their public meetings. The 2010 Region M Plan, as endorsed by the State of Texas and incorporated into the State Water Plan, recommends a portfolio of WMSs to ameliorate supply imbalances in the study area (figure 8). Because the WMSs were formulated to address the future supply imbalances that are incorporated into this Basin Study, and have been previously subjected to rigorous analysis based on local capabilities, they represent an excellent starting point for the development of appropriate adaptation and mitigation strategies to meet future water demands.

This Basin Study is limited by scope and budget to investigate those strategies that specifically address the planning objective. Using the planning objective, a selection of WMSs that meet those specific constraints have been investigated further in the study. Nevertheless, the most robust solution to the expected shortages in the study area will also include the continued development of the range of strategies recommended by Region M, many of which would increase the efficiency of the use of Rio Grande supplies. Together, the study may enable development of water sources independent of the Rio Grande, and the development of the other WMSs in the State Plan may provide more efficient use of Rio Grande supplies.

2. Water Management Strategies from the Region M Plan that Best Meet the Planning Objective

a. Evaluation Methodology

The WMSs that best meet the planning objective of the study are evaluated in the discussion below. Each major component of the planning objective has been matched to a major criterion of the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (P&Gs) (U.S. Water Resources Council, 1983), which govern the planning of all

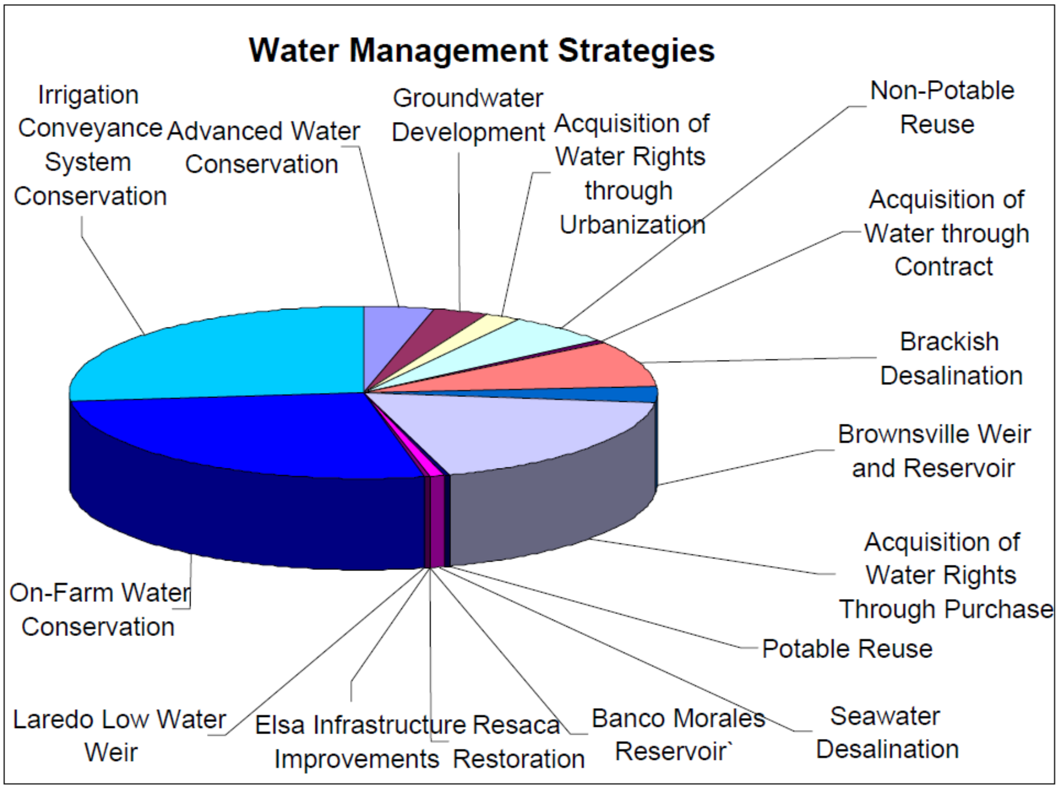

Figure 8: Region M Plan-recommended WMS potential supply contribution.

Federal water projects. Although the WMSs are not Federal projects, the policies established by these P&Gs are appropriate for use in this Basin Study. These criteria are:

(1) Effectiveness

Effectiveness measures the extent to which an alternative reliably meets the planning objective by alleviating a specified problem and achieving goals. Specifically, effectiveness was measured in terms of improving reliability by reducing dependency on the Rio Grande River. In addition, the temporal (year-round) and locational (Cameron, Willacy, and Hidalgo Counties) aspects described above were considered.

(2) Acceptability

Acceptability measures the workability and viability of an alternative with respect to how compatible it is with authorities, regulations, policies, and environmental law. Specifically, acceptability was measured in terms of protecting existing water rights and in meeting the planning objective to preserve downstream flow.

(3) Completeness

Completeness measures the extent to which an alternative accounts for all necessary investments or other actions to ensure realization of goals. Completeness was measured in terms of implementation potential within the reasonable control of study sponsors.

(4) Efficiency

Efficiency measures the extent to which an alternative is cost effective. Due to the time and study costs associated with development of design and cost estimates, the study team decided to apply the efficiency criterion only to the most viable WMS, which is based on the evaluation described below, and included siting and phasing components associated with BGD.

3. Strategies Receiving Further Evaluation

The following WMSs were formulated according to the planning objective as represented by three criteria: effectiveness, acceptability, completeness.

a. Reuse

EFFECTIVENESS	Reuse is an effective way to utilize existing reliable supply streams of water and alleviate the supply imbalance.
ACCEPTABILITY	Protects downstream flows and water rights. Effluent from existing water treatment plants is not returned to the Rio Grande.
COMPLETENESS	This WMS is within the reasonable control of the study partners via existing financial, managerial, and engineering mechanisms.

Non-potable direct reuse is defined as the application of wastewater effluent directly from the waste treatment plant to the point of use for non-potable purposes such as irrigation without co-mingling with State waters. This strategy requires a detailed assessment of the type and location of demands for non-potable water.[9] Users are categorized based on the level of treatment required for that application. This strategy is most likely to be successfully implemented by the end user, be it a municipality or industry, and is not the best aligned with the scope of the study.

[9] Type I and Type II reclaimed water categories are outlined in TCEQ §§210.33. Type I requires a higher standard of treatment; therefore, any Type I reclaimed water may also be utilized for any of the Type II uses. Specific quality standards for both reclaimed water categories are outlined in TCEQ §§210.33. The treatment required for each use is dependent on the initial effluent water quality, but typically primary effluent can only be used for Type II applications, and secondary effluent can only be used for both Type I and Type II applications. The cost of treatment is significantly higher for Type I water.

b. Brackish Groundwater Desalination

EFFECTIVENESS	Reduces dependency on the Rio Grande by developing a new water source that can be located throughout the desired areas.
ACCEPTABILITY	Protects downstream flows and water rights. Existing brackish desalination plants in Texas and in the study area have demonstrated that they can be built within regulations, policies, and environmental law.
COMPLETENESS	This WMS is within the reasonable control of the study partners via existing financial, managerial, and engineering mechanisms.

Desalination of brackish groundwater is most commonly accomplished through reverse osmosis (RO). A full-scale RO system to treat brackish groundwater would require pretreatment, which would include a cartridge filtration system to remove minimal suspended solids. Acid and a silica scale inhibitor would also be added to prevent scale formation. A full-scale system would be expected to have a membrane life of approximately 5 years. Chemical cleaning of the membrane would be required approximately one to four times per year.

Concentrate from the RO system must be disposed of in an environmentally acceptable manner. Most of the current or proposed systems utilize drainage canal discharge, which ultimately will discharge into the Laguna Madre or the Gulf of Mexico. Other options include disposal to a sewer system and deep well injection.

c. Seawater Desalination

EFFECTIVENESS	Reduces dependency on the Rio Grande by developing a new, reliable water source.
ACCEPTABILITY	Protects downstream flows and water rights. Existing seawater desalination plants in the United States, and a pilot project in Texas, have demonstrated that they can be built within regulations, policies, and environmental law.
COMPLETENESS	This WMS is within the reasonable control of the study partners via existing financial, managerial, and engineering mechanisms.

There are several types of desalination methods to treat seawater. In addition to membrane technologies, methods include thermal processes such as multistage flash distillation, multiple-effect distillation, and vapor compression. These energy-intensive processes are more common in the Middle East where fuels are more abundant.

d. Fresh Groundwater Development

EFFECTIVENESS	Reduces dependency on the Rio Grande by developing a new water source that can be located throughout the desired areas.
ACCEPTABILITY	Protects downstream flows and water rights. Existing well technology is proven. Can be built within regulations, policies, and environmental law.
COMPLETENESS	This WMS is within the reasonable control of the study partners via existing financial, managerial, and engineering mechanisms.

The Gulf Coast aquifer contains fresh and brackish groundwater. The southern Gulf Coast Groundwater Availability Model indicates that groundwater is available from the aquifer in this area. Well production estimates range from 0.29 to 0.86 million gallons per day (MGD) (200 to 600 gallons per minute). The quality of the groundwater is expected to meet most standards for public water supplies and requires minimal treatment. If required, the groundwater may be mixed with treated surface water to improve water quality.

V. Evaluation of Options and Strategies to Resolve Supply and Demand Imbalances

As previously stated, study partners agreed that the scope and budget of this study would best be served by identifying **one** alternative strategy that best meets the planning objective and then developing preliminary engineering design and costs of that alternative to the extent needed to meet the planning objective. The following discussion summarizes the next phase of the evaluation.

A. Seawater Desalination

The Brownsville Public Utilities Board and Laguna Madre Water District have already confirmed the feasibility of seawater desalination along the Texas Gulf Coast through detailed investigations and pilot testing, and design and cost estimates of proposed facilities have already been produced. Other counties within the study area, including Hidalgo County, did not include seawater desalination as a WMS in the most recent 2010 Region M Water Plan, perhaps due to their relative farther distance from the Gulf Coast, and instead have proposed less costly options such as water reuse and BGD. Therefore, this alternative was eliminated from further consideration as part of this study.

B. Fresh Groundwater Development

Fresh groundwater is an important resource that should be considered in any water purveyor's portfolio of water supply options in the study area. As stated in the Task 4 Technical Memorandum, the 2010 Region M plan found that about 20% of the 822 groundwater wells in the study area yield fresh groundwater (<1,000 mg/L TDS). Therefore, of the 176,355 ac-ft/yr of managed available groundwater (sustainable yield) designated by the study area's Groundwater Management District, about 35,271 acre-feet are expected to be freshwater.[10] This amount is reduced to 12,094 ac-ft/yr when totaling the estimated fresh groundwater available in the three counties specified in the planning objective (Cameron, Hidalgo, and Willacy) as shown in table 3.

Table 3: Fresh groundwater yield by county

County	Cameron	Hidalgo	Jim Hogg	Maverick	Starr	Webb	Willacy	Zapata
Yield (ac-ft/yr)	2,947	9,147	65	0	4,188	7,918	0	0

Due to the limited number of production wells in the study area, the exact location of the 12,094 ac-ft/yr of fresh groundwater remains unknown. This amount is even less when fracking demand is accounted for and is insufficient to meet the planning objective. Efforts to quantify use for fracking are complicated by the fact that water use for oil and gas development is exempt from Texas groundwater regulation.[11] Therefore, this alternative was eliminated from further consideration as part of this study.

C. Comparison of Brackish Groundwater Desalination and Non-potable Reuse

Brackish groundwater desalination and non-potable reuse appear to be viable in terms of meeting the planning objective and, thus, were evaluated in more detail (the results are summarized in table 4). Given the multiple locations identified in the Region M Plan for both of these WMSs, and in order to maximize economies of scale, they are conceptualized as *regional* in nature. In the case of BGD, wells in different locations could feed into a large centralized

[10] 2011 Region M Plan, Chapter 4, Section 4.5.7.1 Strategy Description.
[11] Under Texas Water Code §36.117, production or injection wells drilled for oil and gas are exempted from regulation.

Table 4: Alternatives evaluation matrix

Evaluation Criteria		Alternative Concept			
Criterion	**Description**	**Regional Brackish Groundwater Desalination**	**Score (1 to 5)***	**Regional Water Reuse**	**Score (1 to 5)***
Effectiveness	**Extent to which an alternative reliably meets the planning objective**				
Water quantity	*Extent to which alternative can provide up to 86,000 acre-feet per year of water in Cameron, Willacy or Hidalgo Counties*	Dependent on availability in selected locations. Approximately 280,000 ac-ft of available brackish groundw ater in the Three-County area.	5	Assuming that 35% of the DMI usage is recoverable return flow , 75,700 AcFt could potentially be available for treatment and reuse in the 3-county target area. Treated w ater TDS may be too high for some uses.	3
Water reliability	*Extent to which quantity reduces dependency on the Rio Grande, is drought proof, secure for the planning horizon, and not subject to reduction/loss*	Independent of the Rio Grande River; considered a "new supply" that is drought proof and not subject to reduction/loss, assuming w ater rights are secured	5	Because most raw M&I w ater supply emanates from the Rio Grande River, w astew ater effluent also indirectly depends on the Rio Grande River, and is therefore subject to potential loss and lack of reliability.	3
Constructability	*Challenges associated with construction*	Locating ideal area for w ellfield, potential challenges in delivery/distribution from that location, disposal of concentrate, but it is a proven technology in use in the area.	4	Depends on the adaptability of existing w astew ater treatment plants, extent of treatment required, and identification of suitable users and the delivery to those users. High TDS levels in w astew ater effluent emanating from raw w ater w ithdraw n from the Rio Grande is expected to require advanced w ater treatment prior to reuse.	4
Servicability	*Challenges associated with operations and serviceability*	Issues associated w ith disposal of concentrate, RO maintenance, membrane fouling, etc, as w ell as energy requirements, may present operations and serviceability challenges	3	Operations and serviceability challenges limited to the extent of treatment and appurtenant infrastructure required.	4
			4.25		***3.5***
Acceptability	**The workability and viability of an alternative with respect to how compatible it is with authorities, regulations, policies, and environmental law**				
Protects existing water rights	*Extent to which satisfaction of existing water rights assigned to WUGs are not harmed.*	No impacts expected on existing surface w ater rights; little competition for brackish groundw ater.	5	Not aw are of surface w ater rights in the Arroyo Colorado w hich w ould be affected by reduced return flow s.	5
Impacts on instream flows	*Extent to which flows of the Rio Grande or Arroyo Colorado Rivers would impacted*	No impact expected on the Rio Grande; Impacts could be beneficial to the Arroyo Colorado depending on brine disposal methodology and saline requirements of the river	5	No impact expected on the Rio Grande; Reduction in instream flow s in the Arroyo Colorado expected due to reduced return flow s	4
Impacts on water quality	*Extent to which water quality of the Rio Grande or Arroyo Colorado Rivers, as well as bay/estuaries would be impacted*	Brine could be disposed of via the Arroyo Colorado, and impacts on the river remain unknow n, w ith potential to benefit the salinity of the costal estuaries.	4	Likely to benefit the Arroyo Colorado by decreasing nutrient loading, w hich has been identified as an issue in the river.	5
Impacts on fish & wildlife	*Extent of potential impacts on fish and wildlife habitat, sensitive areas, or T&E species*	Direct impacts include construction of facilities, w ellfields, and distribution pipelines. Operational impacts associated w ith brine disposal unknow n.	4	TDS accumulation in irrigated soils anticipated, w ith potential to affect ecology. Impacts of reduced instream flow s of the Arroyo Colorado due to reduced return flow s unknow n.	4
Stakeholder acceptance	*Extent to which study stakeholders view an alternative as favorable*	TBD	5	TBD	5
			4.6		***4.6***
Completeness	**Extent to which an alternative accounts for all necessary investments or other actions to be implemented**				
Control	*Extent to which implementation potential is within the reasonable control of study sponsors*	Expected to be w ithin the reasonable control of study sponsors.	4	Expected to be w ithin the reasonable control of study sponsors.	4
Coordination	*Extent to which multi-organizational coordination would be needed for construction and operation*	Coordination w ith TCEQ expected for pilot testing and brine disposal.	3	Coordination w ith TCEQ expected for application permits; coordination w ith end users expected in terms of identifying users and applications; coordination w ith irrigation districts if using canals for conveyance,	2
Risk	*The degree of engineering uncertainty and associated risk, as well as additional investigations that are needed to reduce risk*	Moderate degree of engineering uncertainty associated w ith source quantity and location, piloting, and brine disposal. Additional investigations required.	3	Moderate degree of engineering uncertainty associated w ith source quantity and location, as w ell as w ith conveyance. Additional investigations required.on advanced w ater treatment needs w here applicable. Some regulatory uncertainty remains in terms of emerging contaminants identified on EPA's CCL3 List	3
Permitting	*Extent to which facilities would require permits or clearances which entail risk that could affect the timely or successful completion of the project*	Timing of implementation through permitting associated w ith piloting, production w ells, and bring disposal.	3	Timing of implementation through permitting associated w ith use and application of reclaimed w ater.	4
			3.25		***3.25***
		TOTAL SCORE	***12.1***	TOTAL SCORE	***11.35***

* 1 = Least favorable, 3 = moderate, and 5 = most favorable.

plant, located as close as possible to the water recipients, with consideration for either pipeline or canal conveyance, or a combination of both. Co-location with, or modification of existing raw water treatment plants, should also be considered.

In the case of non-potable reuse, wastewater effluent in the study area emanates from M&I facilities that depend on flows from the Rio Grande River. This dependency may reduce the reliability of wastewater flows for reuse, especially during critical droughts when the river may be depleted. Furthermore, wastewater effluent is known to be high in salinity, so existing wastewater treatment plants may need to be upgraded to address high salinity levels, which would be costly. For these reasons, non-potable reuse was eliminated from further consideration in this Basin Study, and BGD was selected as the preferred strategy for which preliminary designs and costs would be developed.

D. Detailed Analysis of Brackish Groundwater Desalination Alternatives

Based on the ranking of criteria in table 4, BGD was determined to be the strategy best suited for a more detailed investigation in this study.

The next round of evaluation established criteria for evaluating one or more BGD facilities in the study area, including:

- Population served
- Short- and long-term needs/vulnerability to drought
- Potential for regionalization – existing infrastructure
- Productive aquifer accessible
- Opportunity for co-location with powerplant
- Legal and regulatory considerations, including brine disposal

Cost of service was also analyzed, which represents the overall efficiency criterion in the aforementioned P&Gs.

Three concepts for regional BGD were developed for this study with the goal of providing a portion of the region’s demands:

1. One 77-MGD facility serving a large portion of the three-county area
2. Expansion of existing BGD facilities
3. Regional BGD systems designed to meet a portion of the municipal demands of area cities by 2060

1. Single Regional BGD Facility

EFFECTIVENESS	Concerns of insufficient aquifer productivity to meet target production.
ACCEPTABILITY	Concerns of subsidence from geographically concentrated well fields.
COMPLETENESS	A single facility could be implemented by the study partners.
EFFICIENCY	Decreased efficiency due to conveyance costs.

It is considered unlikely that there is an area of the aquifer that would be sufficiently productive to supply a single regional BGD facility; therefore, a single regional BGD facility fails the effectiveness criteria. For this reason alone, this concept could be eliminated from further consideration. Currently, the largest groundwater desalination facility in the United States is the Kay Bailey Hutchison Desalination Plant in El Paso, Texas, which produces 27.5 million gallons of fresh water daily.

In terms of acceptability, the likelihood of ground subsidence would be much greater with BGD pumpage concentrated around one facility.[12] The cost (efficiency) would be increased at construction in order to build or expand trunk lines to and among all of the groups of municipalities, and the delivery costs associated with pumping would significantly increase energy use.

2. Expansion of Existing Groundwater Desalination Facilities

EFFECTIVENESS	Capacity of existing facilities may be too small to effectively expand to meet the target production volume.
ACCEPTABILITY	Distributed well fields and plants could meet acceptability objectives.
COMPLETENESS	The expansion necessary may not be feasibly implemented by the study partners.
EFFICIENCY	The degree of expansion could be more expensive than a similarly sized new facility.

[12] For information about subsidence, the USGS Web site provides an overview with specific references to Texas and south Texas (http://ga.water.usgs.gov/edu/earthgwlandsubside.html).

This alternative is rated low in all criteria except completeness. There are a number of wholesale water providers in the three-county region, four of which operate BGD plants (with current average production of 10.5 or less ac-ft/yr), to supply drinking water to municipalities and rural areas. Many of these facilities are not running at full capacity because Rio Grande water is sometimes available to users at a much lower cost than treated groundwater. In other cases, the limiting factor is the capacity of existing well fields.

While expansion of existing systems is not a viable approach to meeting the total planning objective, expansion of viable facilities should be pursued as a cost-effective first step toward providing reliable water to the region.

3. Recommended Alternative: Three Regional BGD Systems

EFFECTIVENESS	Distributed systems could feasibly provide the target production volume to municipal groups.
ACCEPTABILITY	Brine disposal may be challenging depending on the particular location, but regional precedent is set for surface water discharge.
COMPLETENESS	Distributed facilities could be implemented by the study partners.
EFFICIENCY	Systems may be more cost effective for some municipal groups than others, but distributed facilities appear to be most efficient in operational costs.

The analyses show that the regional BGD systems alternative would best meet the planning objective. An appraisal-level plan formulation and evaluation process was conducted to determine potential locations of each regional BGD system within this alternative. The study area was divided into four major groups based on proximity and existing interconnecting pipelines and transfer agreements. Each group was evaluated based on vulnerability to drought (towns that have been in danger of losing access to water within 6 months according to the TCEQ's 180-day drought watch list[13]) and projected average annual shortages as shown in the 2012 State Water Plan. The distribution of demands among the groups was used to distribute proposed supplies.

The resulting estimated capacities and costs were determined:

[13] http://www.tceq.texas.gov/drinkingwater/trot/droughtw.html

- The Group 1 system is shown on figure 9 and would serve 10 communities by constructing two BGD facilities with a capacity of 31.4 MGD each and associated transmission pipelines and pumps. The 70,400 ac-ft/yr project is estimated to cost $308,046,000 (2012) (table 5).

  The costs presented in this section represent capital costs required to build and operate the proposed facilities in Phase 1 and Phase 2. Phase 1 is intended to begin construction in 2020, and the duration of construction is assumed to be 5 years. The Phase 1 well fields and plants are scaled to provide a portion of the demands for each group in 2040, but the Phase 1 transmission pipelines and pump stations for all groups are sized for the Phase 2 production, thus yielding significant cost savings when the plants are expanded. Phase 2 would include an expansion of the well fields and treatment facilities beginning in 2040 and increased delivery pumping but no additional transmission piping. Because the transmission pipeline and the right-of-way land acquisition will be completed in Phase 1, and because the Phase 2 expansions are smaller scale, the duration of construction for Phase 2 is predicted to be considerably shorter at 2 years.

  All financing for capital expenditures are assumed to have a 20-year term, so the costs for each phase are separate. A basic annuity payment is assumed on the capital cost.[14] Annual costs are shown with debt service and operation and maintenance.

- The Group 2 system is shown on figure 10 and would serve 10 communities. It would include one BGD facility with a capacity of 9.2 MGD and associated transmission pipelines and pumps. The cost is estimated at $86,477,000 (2012) and would provide 10,300 ac-ft/yr (table 6).

- The Group 3 system is shown on figure 11 and would serve eight communities. It would provide 12,300 ac-ft/yr and include an 11.8-MGD BGD facility and associated transmission pipelines and pumps. The cost is estimated at $99,551,000 (2012) (table 7).

[14] Annuity payment = (present value x interest rate per period)/(1-(1+rate per period)^(-number of periods)).

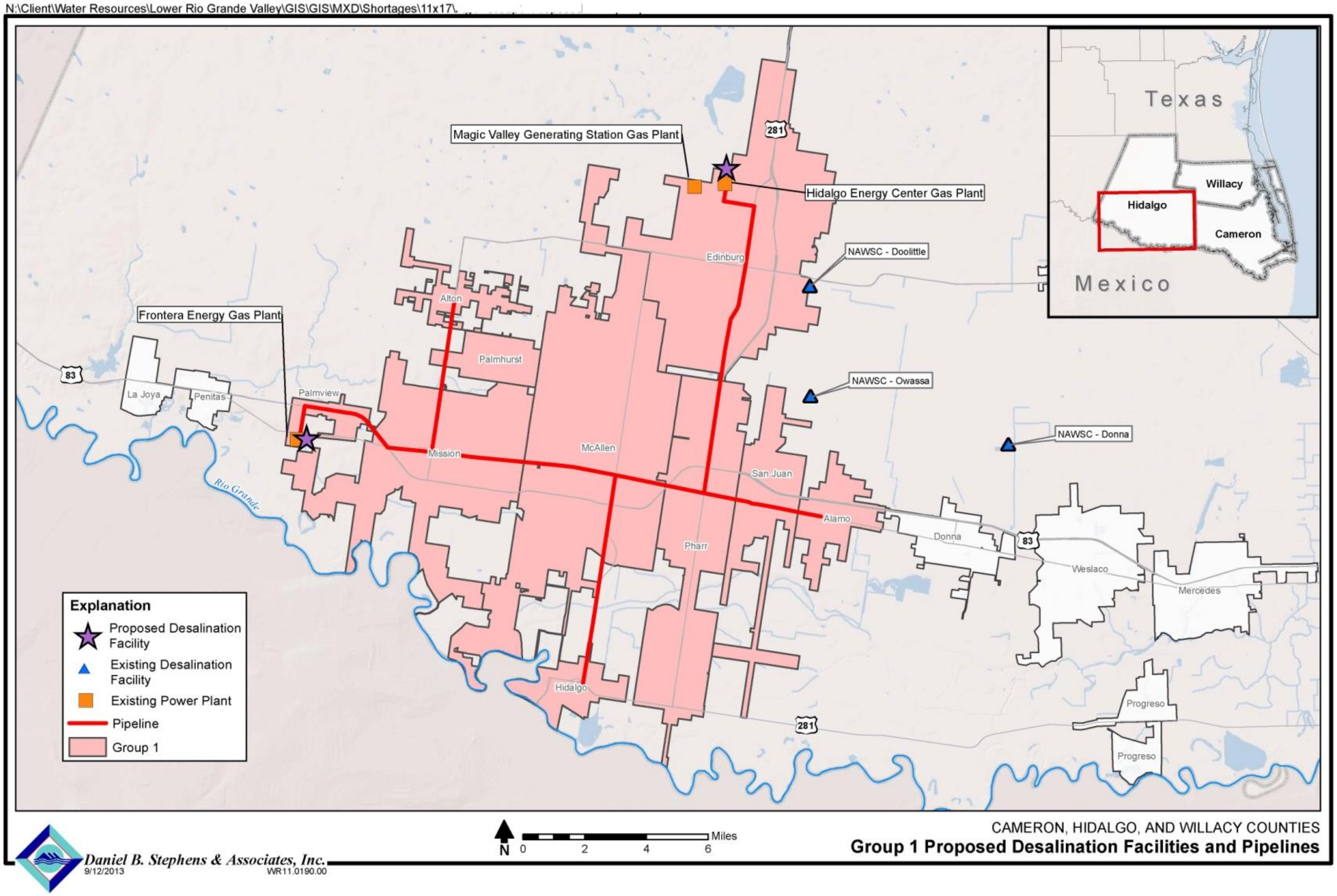

Figure 9: Group 1 facilities.

Table 5: Group 1 costs

Cost Estimate Summary: Group 1 Water Supply Project Option March 2012 Prices Bureau of Reclamation Lower Rio Grande Basin Study		
Cost based on ENR CCI 9268 for March 2012 and a PPI of 185.2 for March 2012		
Item	**Estimated costs for Phase 1**	**Estimated costs for Phase 2**
Transmission pump stations	$10,255,000	$3,262,000
Transmission pipeline (41.9 miles at buildout)	$45,919,000	$0
Well fields (wells, pumps, and piping)	$79,817,000	$22,170,000
Two water treatment plants (31.4 MGD and 31.4 MGD at buildout)	$101,589,000	$45,034,000
Total cost of facilities	**$237,580,000**	**$70,466,000**
Engineering and feasibility studies, legal assistance, financing, bond counsel, and contingencies (30% for pipes and 35% for all other facilities)	$80,857,000	$24,663,000
Environmental and archaeology studies and mitigation	$3,607,000	$910,000
Land acquisition and surveying	$2,126,000	$167,000
Interest during construction (4% for 5 years with a 3.75% return on investment	$34,444,000	$4,089,000
Total cost of project	**$358,614,000**	**$100,295,000**
Annual cost		
Debt service (5.5%, 20 years)	$30,009,000	$8,393,000
Operation and maintenance		
Wells, pipelines, pump stations	$1,514,000	$1,817,000
Water treatment plant	$19,786,000	$25,882,000
Transmission pumping energy costs ($0.0593/kilowatthour)	$4,094,000	$6,470,000
Purchase of water (ac-ft/yr at $/acre-foot)	$0	$0
Total annual cost	**$55,403,000**	**$42,562,000**
Available project yield (ac-ft/yr)	51,600	70,400
Annual cost of water ($ per acre-foot)	$1,074	$605
Annual cost of water ($ per 1,000 gallons)	$3.29	$1.86

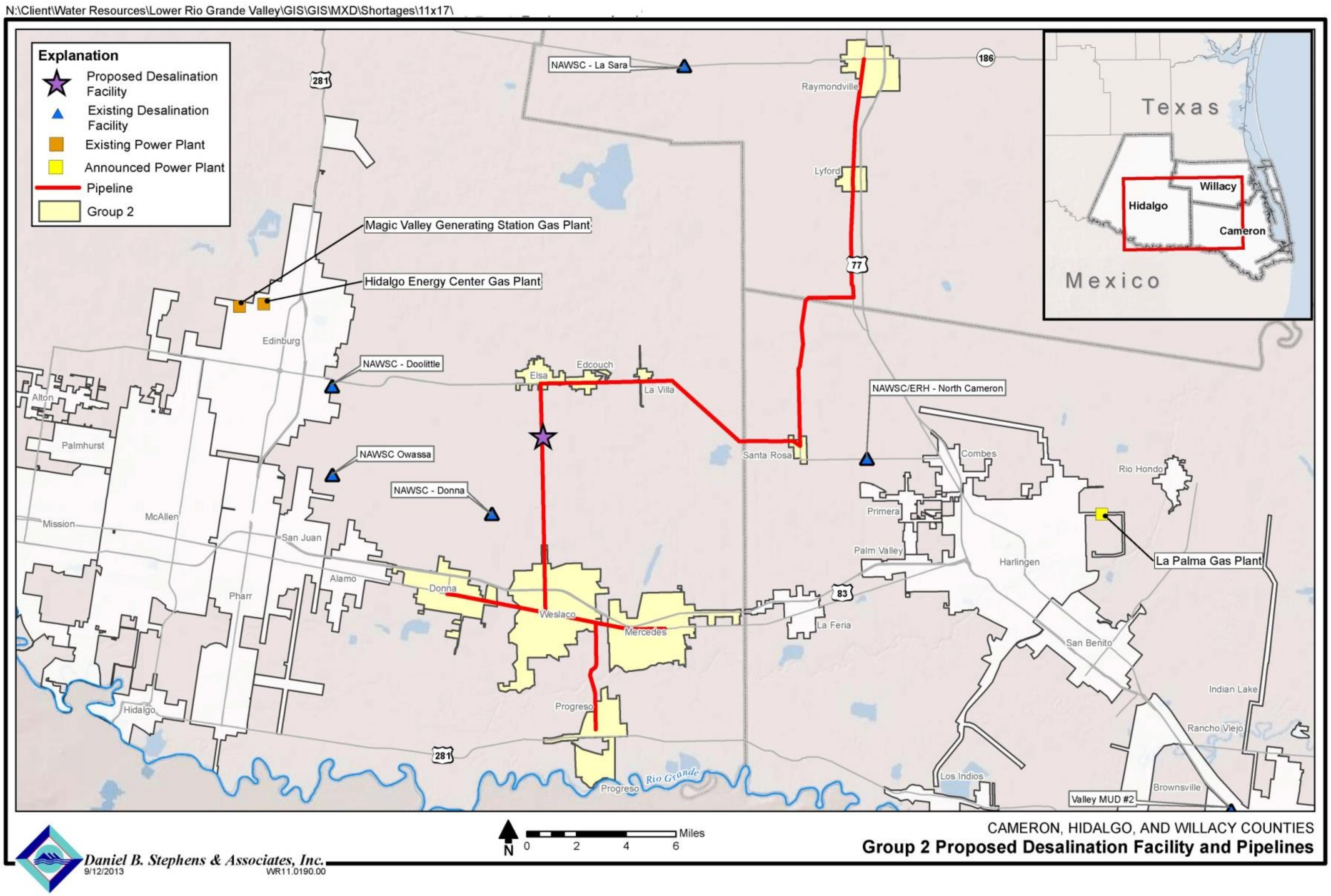

Figure 10: Group 2 facilities.

Table 6: Group 2 costs

Cost Estimate Summary: Group 2 Water Supply Project Option March 2012 Prices Bureau of Reclamation Lower Rio Grande Basin Study		
Cost based on ENR CCI 9268 for March 2012 and a PPI of 185.2 for March 2012		
Item	**Estimated costs for Phase 1**	**Estimated costs for Phase 2**
Transmission pump stations	$4,996,000	$1,190,000
Transmission pipeline (51.3 miles at buildout)	$11,716,000	$0
Well fields (wells, pumps, and piping)	$9,908,000	$2,175,000
Water treatment plant (9.2 MGD at buildout)	$20,272,000	$5,680,000
Total cost of facilities	**$46,892,000**	**$9,045,000**
Engineering and feasibility studies, legal assistance, financing, bond counsel, and contingencies (30% for pipes and 35% for all other facilities)	$15,826,000	$3,166,000
Environmental and archaeology studies and mitigation	$1,747,000	$115,000
Land acquisition and surveying	$2,073,000	$18,000
Interest during construction (4% for 5 years with a 3.75% return on investment	$7,070,000	$525,000
Total cost of project	**$73,608,000**	**$12,869,000**
Annual cost		
Debt service (5.5%, 20 years)	$6,159,000	$1,077,000
Operation and maintenance		
Wells, pipelines, pump stations	$341,000	$393,000
Water treatment plant	$3,948,000	$4,779,000
Transmission pumping energy costs ($0.0593/kilowatthour)	$790,000	$1,054,000
Purchase of water (ac-ft/yr at $/acre-foot)	$0	$0
Total annual cost	**$11,238,000**	**$7,303,000**
Available project yield (ac-ft/yr)	8,400	10,300
Annual cost of water ($ per acre-foot)	$1,338	$709
Annual cost of water ($ per 1,000 gallons)	$4.11	$2.18

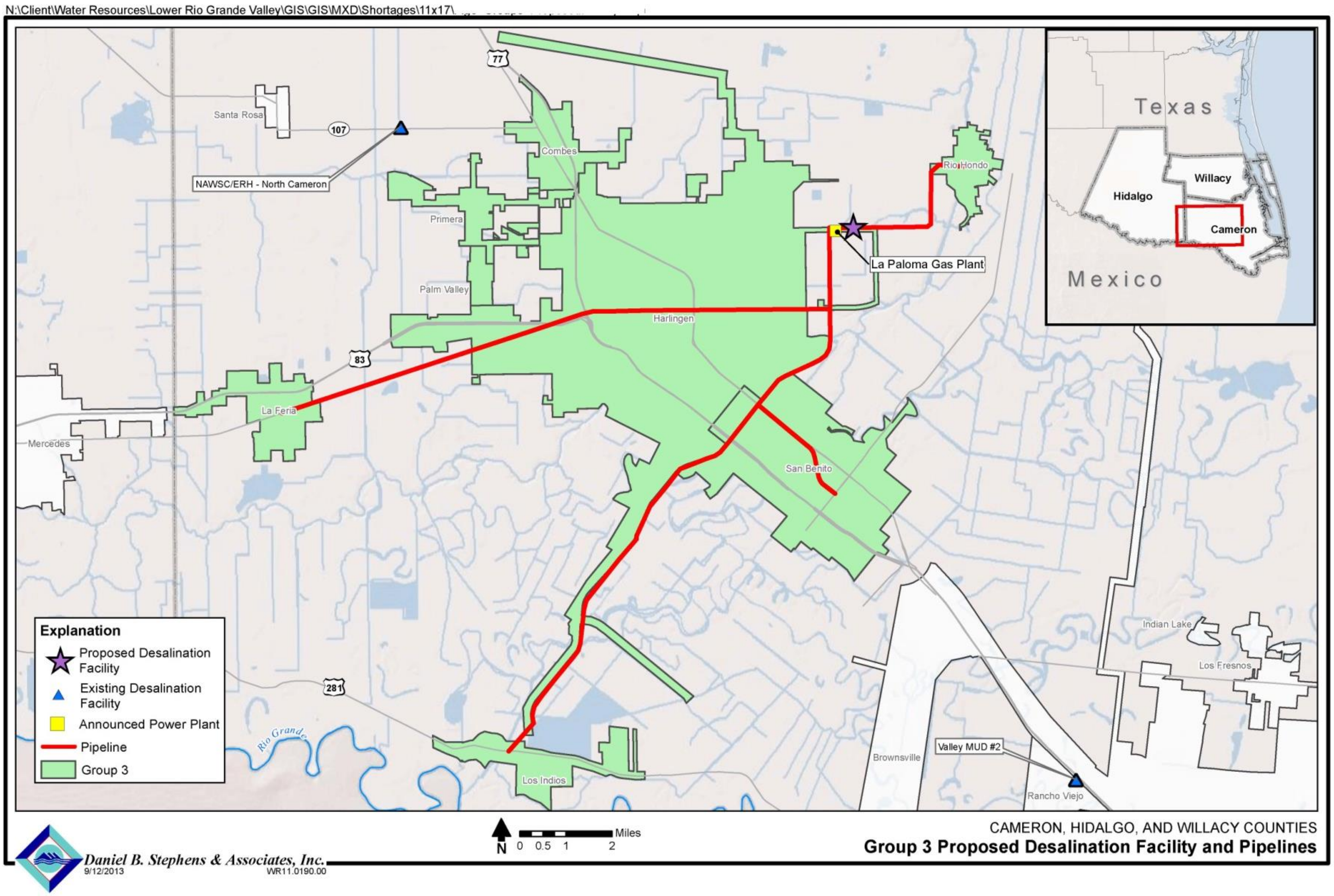

Figure 11: Group 3 facilities.

Table 7: Group 3 costs

Item	Estimated costs for Phase 1	Estimated costs for Phase 2
Cost Estimate Summary: Group 3 Water Supply Project Option March 2012 Prices Bureau of Reclamation Lower Rio Grande Basin Study		
Cost based on ENR CCI 9268 for March 2012 and a PPI of 185.2 for March 2012		
Transmission pump stations	$4,871,000	$2,319,000
Transmission pipeline (35.2 miles at buildout)	$9,538,000	$0
Well fields (wells, pumps, and piping)	$14,141,000	$2,175,000
Water treatment plant (11.8 MGD at buildout)	$26,333,000	$5,905,000
Total cost of facilities	**$54,883,000**	**$10,399,000**
Engineering and feasibility studies, legal assistance, financing, bond counsel, and contingencies (30% for pipes and 35% for all other facilities)	$18,732,000	$3,639,000
Environmental and archaeology studies and mitigation	$1,501,000	$116,000
Land acquisition and surveying	$1,516,000	$19,000
Interest during construction (4% for 5 years with a 3.75% return on investment	$8,143,000	$603,000
Total cost of project	**$84,775,000**	**$14,776,000**
Annual cost		
Debt service (5.5%, 20 years)	$7,094,000	$1,236,000
Operation and maintenance		
Well, pipeline, pump station	$359,000	$438,000
Water treatment plant	$5,129,000	$5,821,000
Transmission pumping energy costs ($0.0593/kilowatthour)	$741,000	$949,000
Purchase of water (ac-ft/yr at $/acre-foot)	$0	$0
Total annual cost	**$13,323,000**	**$8,444,000**
Available project yield (ac-ft/yr)	11,100	13,200
Annual cost of water ($ per acre-foot)	$1,200	$640
Annual cost of water ($ per 1,000 gallons)	$3.68	$1.96

- Group 4 includes Brownsville and shows the greatest projected shortage in 2060. However, since the Southmost Regional Water Authority (SRWA) Desalination Plant is operating at full capacity and is currently undergoing expansion, the communities that are served by this facility (and therefore the group) are not included in this BGD alternative. It is recommended that an expansion of the SRWA facilities be considered as a component in any regional water supply plan.

RGRWA is actively pursuing further development of this alternative through State funding mechanisms described in section VII of this Executive Summary.

VI. Study Limitations

The characterization of the WMSs was based on the information available in the Region M Plan. Because of the scope of the study, the characterization is limited and intended only as a starting point for the evaluation of the WMSs. The limitations of the characterization process are as follows:

- **WMSs evaluated:** The study is limited by scope and budget to investigate those strategies that specifically address potential water deficits related to climate change that have been identified by the study. One of the key constraints is that the selected WMS must reduce dependency on the Rio Grande. The growing need to develop alternative water sources within control of the study partners was expressed by the RGRWA and confirmed by the study analysis. Nevertheless, the most robust solution to the expected shortages in the study area will include the continued development of the portfolio of strategies recommended by Region M, many of which would increase the efficiency of the use of Rio Grande supplies.

- **Regional analysis:** Some of the strategies could be implemented in a wide range of locations, and the specifics of the location will affect everything from the scale of production to the permits required.

- **Potential for subjectivity:** The screening criteria used in the characterization process were relatively prescriptive; however, there was still some room for subjectivity when selecting the appropriate ratings for each evaluated option.

- **Uncertainty:** The characterization was performed based on limited and high-level analyses. Therefore, knowledge of items such as costs, permit requirements, and long-term feasibility are still highly uncertain.

VII. Future Considerations and Next Steps

A. Implications for International Cooperation

The Good Neighbor Environmental Board (GNEB) was created in 1992 by the Enterprise for the Americas Initiative Act, P.L. 102-532. The purpose of the board is to "advise the President and the Congress on the need for implementation of environmental and infrastructure projects (including projects that affect agriculture, rural development, and human nutrition) within the states of the United States contiguous to Mexico in order to improve the quality of life of persons residing on the United States side of the border." In its 8th report (2005), *Water Resources Management on the U.S.-Mexico Border*, the GNEB identified numerous challenges of working in international watersheds. As the 8th report noted, "Effective management of water resources is less than straightforward virtually everywhere, but in the U.S.-Mexico border region, it might be said that the task is particularly challenging. An arid climate, the presence of poverty, rapid population growth, aging infrastructure, an international border, and laws in both countries that were put into place in earlier times under different circumstances are just a few of the potential roadblocks."

Those challenges remained in 2012 when the 15th report recommended the U.S. Department of the Interior, the U.S. Department of Agriculture, the U.S. section of the IBWC, and the United States Environmental Protection Agency continue to take a cooperative binational approach to watershed level management. This specifically includes the IBWC continuing to lead discussions with Mexico on finding common areas for the sustainable management of shared water resources, including protection of the quality of life and the environment in both countries. The IBWC has been a regular attendee and participant at the Basin Study presentations at meetings of the RGRWA Board of Directors, which were held monthly during the first year of the study, and every other month since. In addition, the Basin Study manager presented the project findings on supply, demand, and predicted climate change for the study area at a meeting of the IBWC on October 10, 2012.

As stated in *Climate Vulnerability and Adaptive Strategies Along the Rio Grande/Rio Bravo Border of Mexico and the United States,*[15] and also as found by this Basin Study, decreasing runoff and streamflow in Mexico's arid north bordering the Rio Grande threaten not only Mexican irrigation and food production but also Treaty-obligated deliveries to the Rio Grande. We believe that the portfolio of solutions offered by this Basin Study are good examples of proactive climate change adaptation strategies that also meet the international cooperation goals established by the GNEB. Developing solutions that are not dependent on the Rio Grande as a water source not only make sense for the study

[15] Hurd, Brian. Universities Council on Water Resources, Journal of Contemporary Water Research & Education, Issue 149, December 2012.

area in meeting the planning objective, they also alleviate future competition for waters that are largely sourced from Mexico and are vulnerable in terms of both climate change and increased demand from both sides of the river.

B. Implementation of the Brackish Groundwater Desalination Alternative and Other Water Management Strategies

Brackish groundwater desalination facilities have been identified at an appraisal level of detail to meet the planning objective. There may be opportunities for Reclamation to assist the local entities in additional analyses through cost-shared WaterSMART Title XVI feasibility studies (P.L. 102-575) or SECURE feasibility studies (P.L. 111-11).

Non-Federal funding may be available through the following programs administered by the TWDB:

- Drinking Water State Revolving Fund
- Rural Water Assistance Fund
- State Participation Program
- Water Infrastructure Fund
- Economically Distressed Areas Program
- Regional Water Supply and Wastewater Facilities Planning Program

Future evaluation of the affordability of BGD should consider the debt obligations held by the member cities, the range of rates that are paid for potable water in the area, and opportunities to partner with existing operators and providers. The existing complex network of providers and rate structures could potentially be simplified and drinking water provided on a larger scale than has traditionally been done in the region. There is precedent in other parts of Texas for regionalization, and the associated benefits of shared expertise and efficiency of scale are realized in other systems.

Solutions to the expected shortages in the study area must also include the continued development of the range of strategies recommended by Region M and adapted by the State Water Plan, many of which would increase the efficiency of the use of Rio Grande supplies when implemented by the water user groups and government entities at all levels.