GIS FOR WATER RESOURCES TERM PROJECT

WATER SCARCITY IN THE RIO GRANDE

Final Report

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To: Prof. David Maidment
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Acknowledgements:

This final report goes to everyone that has contributed actively or indirectly for its fruition. I have been fortunate to learn from our Veteran Professors Dr. Maidment and Dr. Tarboton the occult skills of information system applications, with a long history on their sleeves of mastery and dedication to improve practice in the field, attending the lectures was like diving into an inexhaustible well of knowledge.

I am also grateful for having shared the audience with the rest of the class, some have passionately offered their help and support, and it was needless to say a very rewarding learning experience.

"It was difficult and dangerous work, but of vital importance, and DesBarres's chart was one of the first to show longitudes (a word that Colin taught me to pronounce – naval fashion – with a soft 'g') based on the Greenwich meridian"

Sextant – David Barrie

I. INTRODUCTION:

One of the visible manifestations of this century's tortuous climate patterns is the heavy cycles of intermittent drought and rain across the globe. Natural resources are becoming luxurious commodities and signs of water recession are ever more apparent in developing and developed nations alike. The solution lies in our adaptive capacities as inhabitants of a world whose resources were never evenly distributed, we battle in values and judge who gets what share following systems of exploitation that we agree upon with all our differences. Judith Layzer describes categories of values as two competing hemispheres: environmentalists and cornucopians [1], each mutually exclusive of the other. Where administrations and politics are involved the zero sum game is almost always at somebody else's expense.

The Paso Del Norte (PDN) area has always been a point of contention in the US-Mexican transboundary water relations, a common trend observed in all international rivers is the upstream riparian's dilemma: Halting development in order to ensure the downstream riparian's rightful water supply. Treaties and understandings were ratified between different beneficiaries, notably the US-Mexico treaty of 1944 and the interstate Rio Grande compact of 1938, roughly 30 years after the river was defined as a subject of National reclamation and the Rio Grande was commissioned to the International Boundary and Water Commission (IBWC), or in Spanish: Comision Internacional de Limites Y Aguas (CILA).

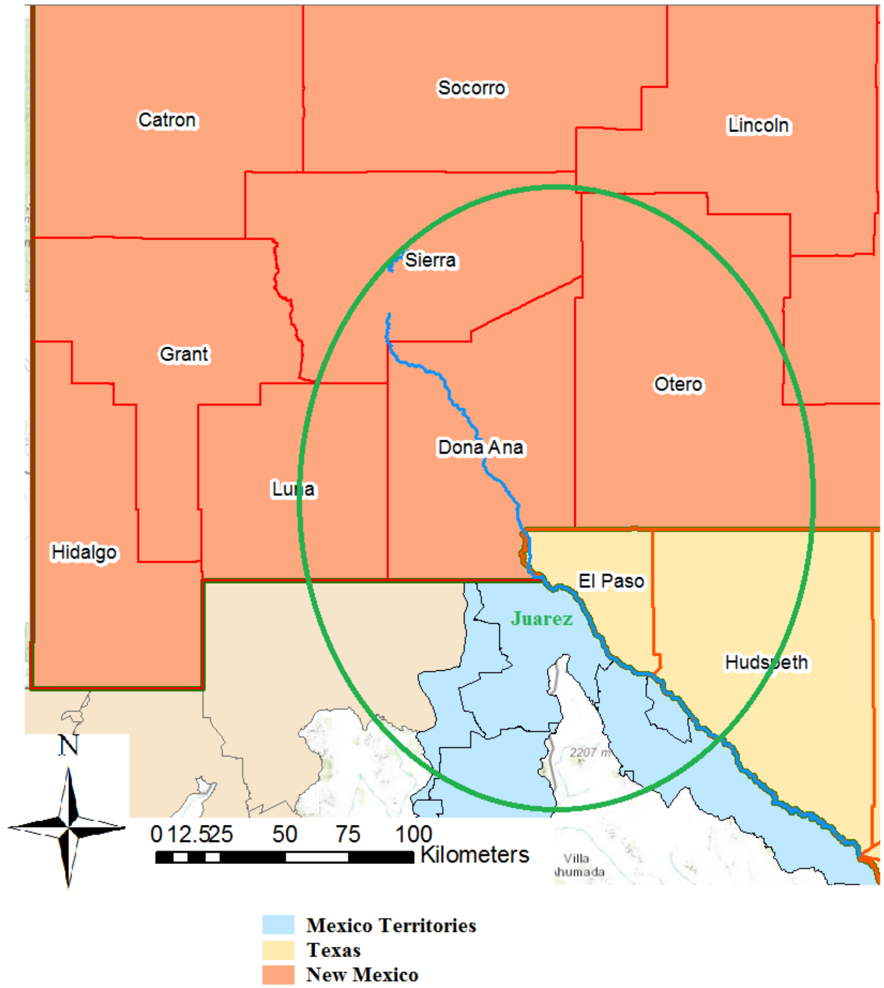
In the early days of what J.A Allan labels the "hydraulic mission"[2], a series of dams and diversions were constructed along the trail of the Rio Grande to utilize the surface flows. Among these the tandem reservoir system "Elephant Butte and Caballo" will serve as a subject for this study, located at the most downstream end before water travels from one State to another.

Scarcity itself is not easy to measure, and there are countless ways to make decisions about it. While in some fortunate areas policy makers can choose to be lenient and exploit a reservoir up to its recreational uses, some cannot allow it elsewhere. The dispute between Texas and New Mexico/Colorado pivots on the basis of equitable water sharing among the compact States which is hindered by how each decides to interpret "equity". This study will seek to present supporting evidence of a declining supply and an increasing demand along the tripartite interface of Paso Del Norte.

[1] Layzer, Judith, *The Environmental Case - Translating Values Into Policy*.
[2] Allan, "Water in the Environment/Socio-Economic Development Discourse: Sustainability, Changing Management Paradigms and Policy Responses in a Global System."

II. ADMINISTRATIVE FRAMEWORK

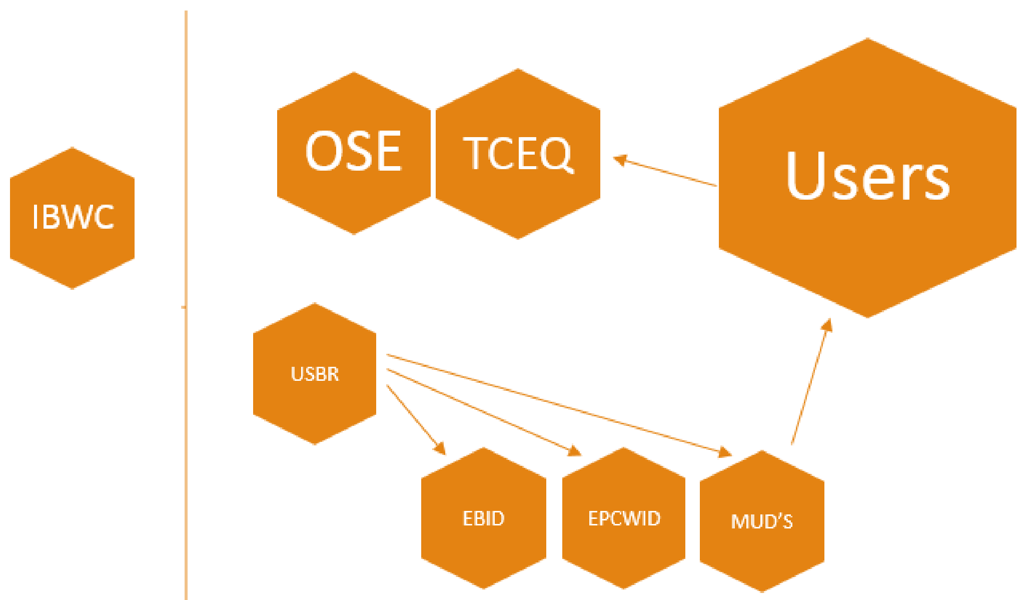
Area of Interest (Paso Del Norte)



The Paso del Norte constitutes a transitional zone for managerial jurisdiction, although still located within the common IBWC control areas the needs of people and businesses are administered by local groups, irrigation district organizations and municipal utilities (MUD's), working in conjunction with the US Bureau of Reclamation operating the reservoir upstream.

Overarching sectors include Agriculture, from production of Alfalfa to corn to cotton and almonds along the river reaches, and as Texas Water Plan suggests "agribusiness, manufacturing, tourism, wholesale and retail trade, government, and military. About 97 percent of the people in this planning area reside in El Paso County"[3]. Farmers are subordinates to two irrigation districts: Elephant Butte irrigation district (EBID) in South-East of Dona ana and the El Paso Water Improvement District (EPCWID) in El Paso and Ciudad Juarez while domestic water users purchase the services from the MUD's.

While these "servicers" also work on water development to enhance channel deliveries the population has to get approvals from the Office of the State Engineer (OSE) in NM and the Texas Commission on Environmental Quality (TCEQ) to receive water rightfully purchased. Irrigation districts rely heavily on surface water flows from the river to suffice their farmers, who also have the option of resorting to groundwater if granted the permission. The sources vary for all and they are dictated by availability and approval from superintendent stakeholders.

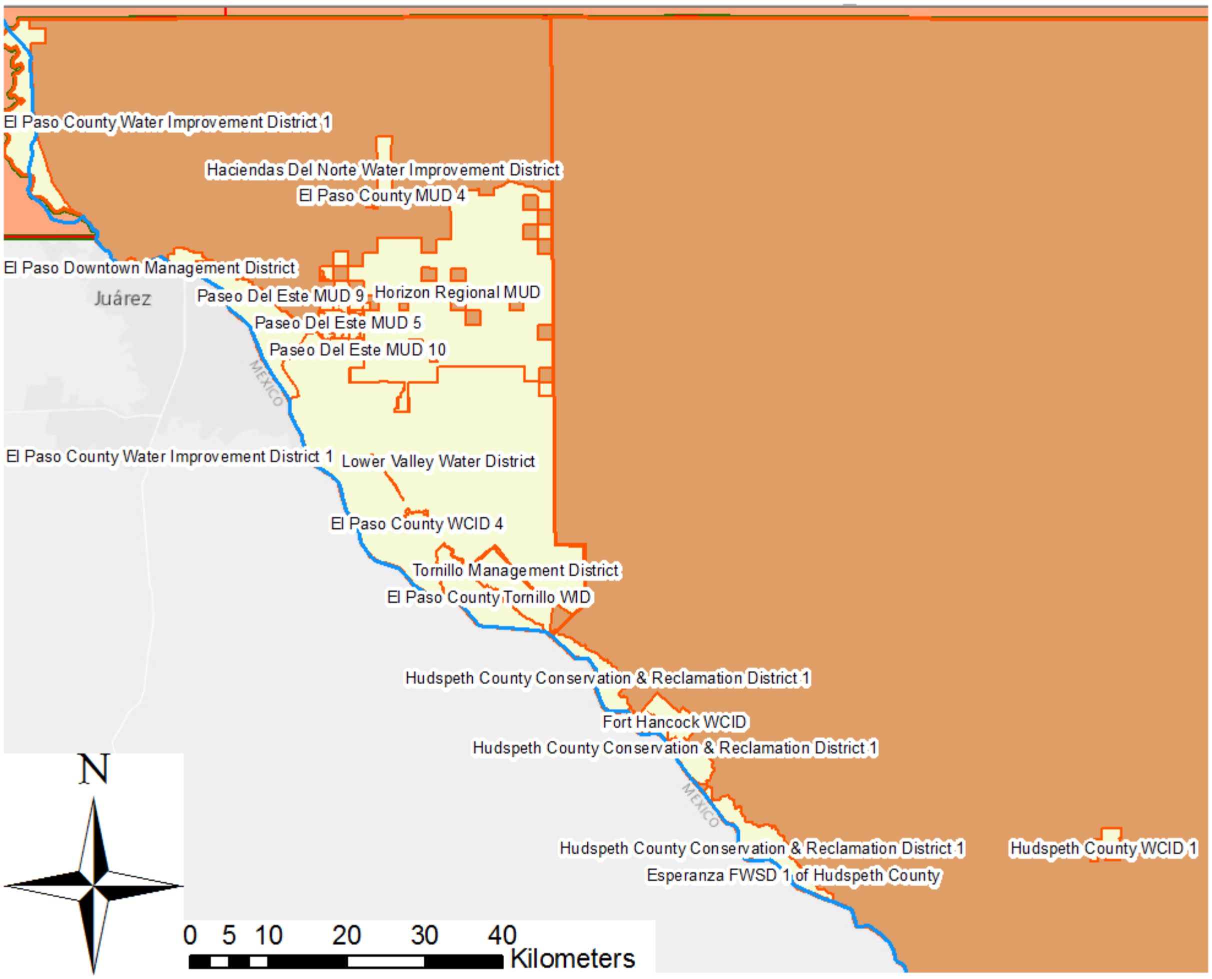


The study won't go as far as evaluating the effectiveness of this managerial structure in establishing a "broader economic equilibrium"[4], however it is important to notice that this socio-economic region could benefit from more cohesive and integrated approaches to resolve emerging issues of water scarcity. The compact agreement of 1938 provides a safe ideal and refuge for cooperation on shared resources encouraging basin level management but unfortunately we live in an era where no water crisis should go to waste. The drought of early 2011 exacerbated the

[3] "Water For Texas 2012 State Water Plan."
[4] Stefano Pozzoli et al., "Performance and Governance Models of Companies in the Integrated Water System."

relations between Texas and New Mexico precluding further chances for consolidated efforts in the face of growing populations and an inestimable water availability.

El Paso and Hudspeth Counties Water Administrators

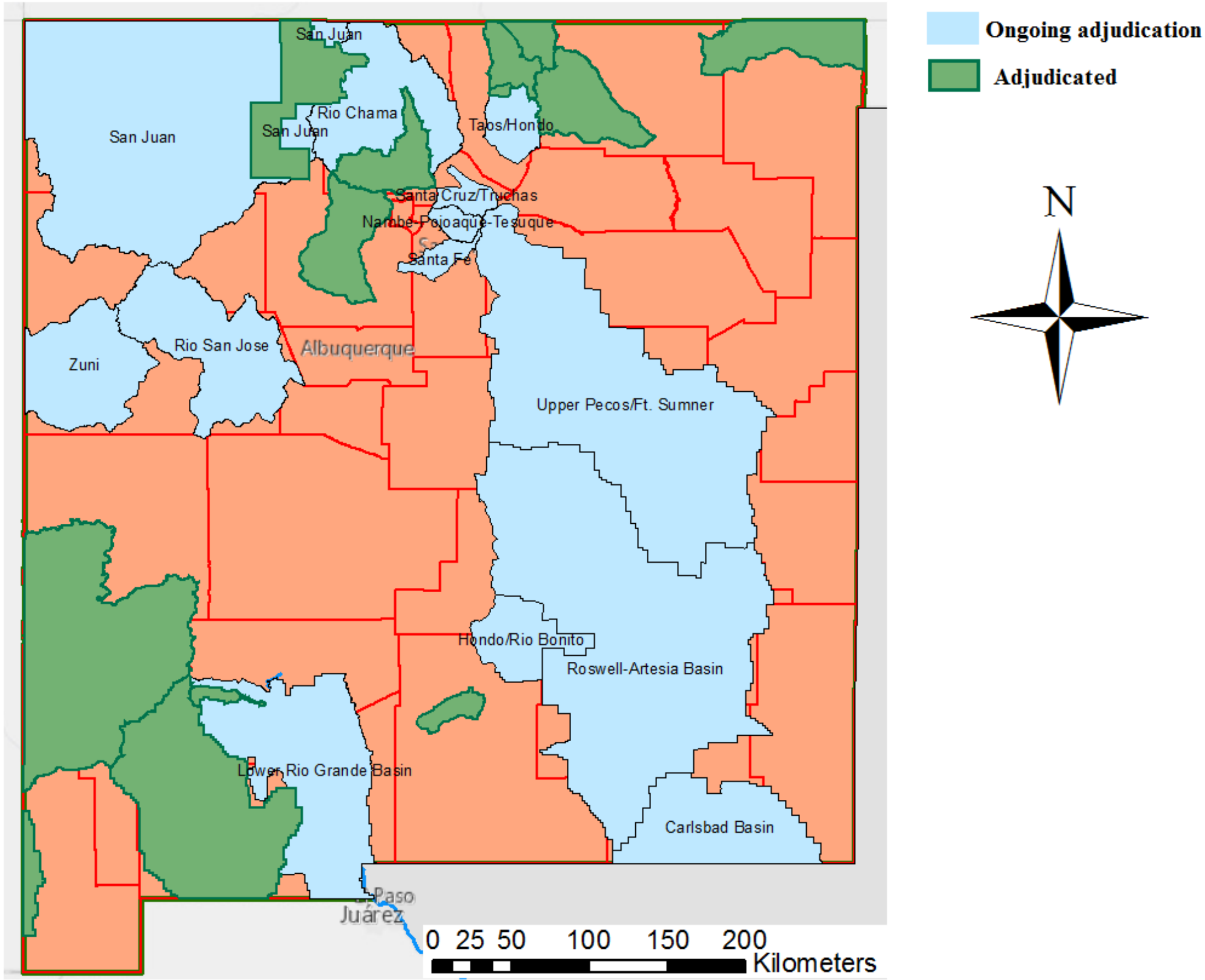


Upstream of El Paso, EBID manages water distribution to all users before the river enters Fort Quitman, a map of total irrigated acreage will be provided later.

Below on the other hand is a map of the NM water adjudications by the Office of the State Engineer. These adjudications "determine who owns what water rights and in what amount"[5]. And we can notice that only a small portion of the land was adjudicated, the Lower Rio Grande still isn't. We can deduce NM's inferior legal power in claiming the water downstream of Elephant Butte and Caballo.

[5] "New Mexico Office of the State Engineer / Interstate Stream Commission."

Office of the State Engineer NM Adjudicated areas



III. <u>WATER AVAILABILITY AND POPULATION PROJECTIONS:</u>

El Paso Municipal Utilities customers of the EPCWID and own about 70000 AF of water per year they use to service the population from the Rio Grande Project, acquired from the water right holders or other land acquisitions in the RGP areas. In regards to the pricing of water, the minimum charge is for a monthly allowance of 400 cubic feet per household with additional franchise and metering charges.

Currently as listed on the El Paso Water Utilities website, the total population demand is approximately around 118000 AF / year. And the per capita required amounts were reduced within the span of 20 years starting 1990 from 225 gal/pers/day to 130 gal/pers/day through different pricing measures and conservancy incentives. Some even argue that El Paso is so efficient that it could serve as a sustainability model.

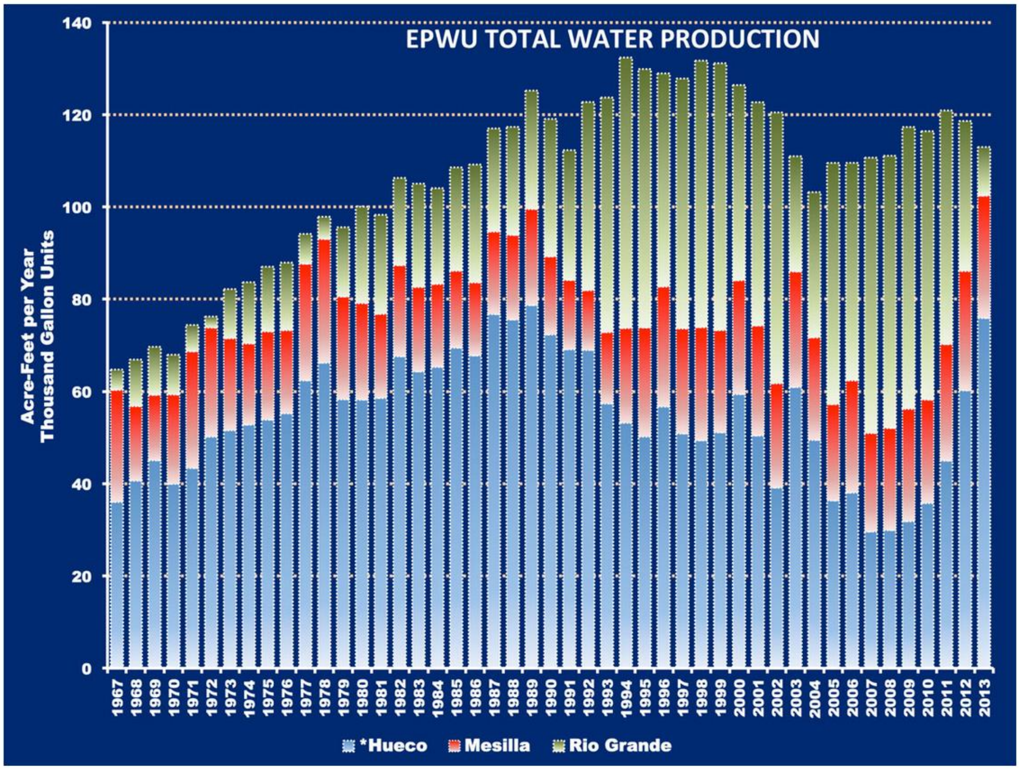


Figure 1: El Paso Water Utility Annual Production suggests a reasonably high dependence on Groundwater (http://www.epwu.org/water/water_resources.html)

A zone projected to account for a 74% increase in its population by 2060, El Paso along with Hudspeth, Jeff Davis and Presidio counties are part of Water region E that is the Far West. The following charts are obtained from the State Water Plan of 2012. Showing current and projected water uses. Texas Water Development Board is planning for an increase in volumes for region E by an amount of **130526 AF/ Year**.

TABLE E.1. POPULATION, WATER SUPPLY, DEMAND, AND NEEDS 2010–2060

	2010	2020	2030	2040	2050	2060
Projected Population	863,190	1,032,970	1,175,743	1,298,436	1,420,877	1,542,824
Existing Supplies (acre-feet per year)						
Surface water	85,912	85,912	85,912	85,912	85,912	85,912
Groundwater	384,650	384,650	384,650	384,650	384,650	384,650
Reuse	44,031	44,031	44,031	44,031	44,031	44,031
Total Water Supplies	**514,593**	**514,593**	**514,593**	**514,593**	**514,593**	**514,593**
Demands (acre-feet per year)						
Municipal	122,105	140,829	156,086	168,970	181,995	194,972
County-other	7,371	10,479	12,968	14,894	16,877	19,167
Manufacturing	9,187	10,000	10,698	11,373	11,947	12,861
Mining	2,397	2,417	2,424	2,432	2,439	2,451
Irrigation	499,092	489,579	482,538	469,084	460,402	451,882
Steam-electric	3,131	6,937	8,111	9,541	11,284	13,410
Livestock	4,843	4,843	4,843	4,843	4,843	4,843
Total Water Demands	**648,126**	**665,084**	**677,668**	**681,137**	**689,787**	**699,586**
Needs (acre-feet per year)						
Municipal	0	3,867	7,675	10,875	19,239	31,584
County-other	0	3,114	5,625	7,589	9,584	11,876
Manufacturing	0	813	1,511	2,186	2,760	3,674
Irrigation	209,591	201,491	195,833	183,734	176,377	169,156
Steam-electric	0	3,806	4,980	6,410	8,153	10,279
Total Water Needs	**209,591**	**213,091**	**215,624**	**210,794**	**216,113**	**226,569**

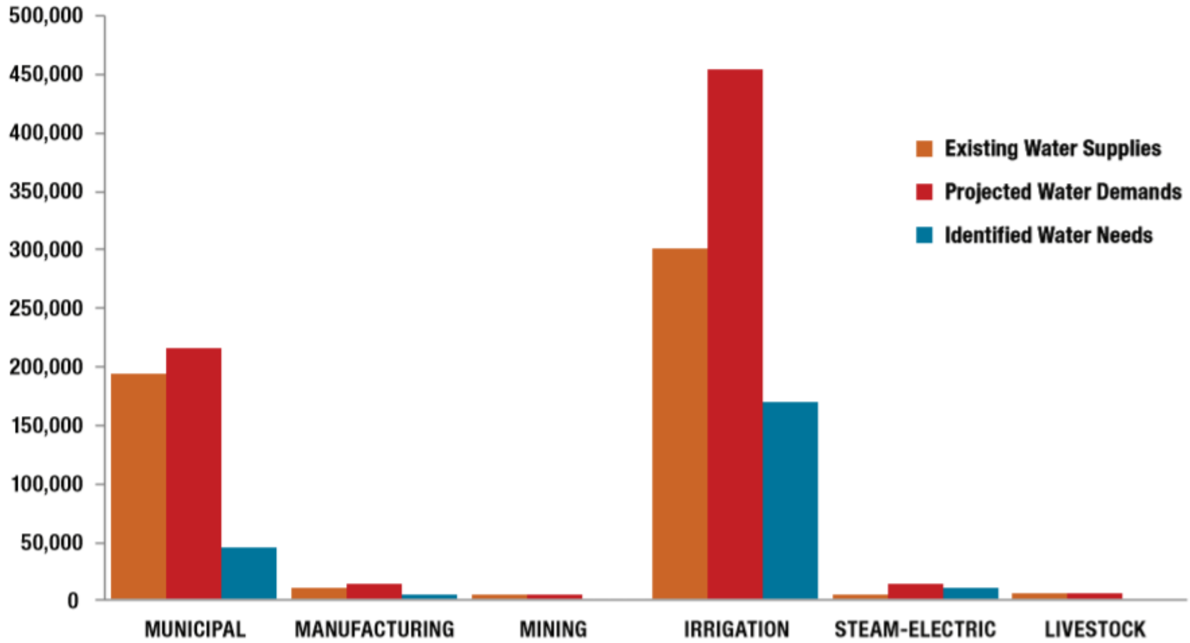
In that sense we can interpolate the current demand for water used in all sectors to be around **656605 AF/ Y**, of which Irrigation is currently in a **211341 AF** deficit. This and the observed increase in needs in other sectors will make the current supply relying on the sources listed above deficient in the next 40 years.

TWDB suggests a series of improvements for a total development budget of 842.1 Million Dollars to address the deficit: *"municipal conservation, direct reuse of reclaimed water, increases from the Rio Grande managed conjunctively with local groundwater, and imports of additional desalinated groundwater from more remote parts of the planning area. In all, the strategies would provide 130,526 acre-feet of additional water supply by the year 2060"*[6]

Which is an impressive amount that exceeds the current demand for domestic use but still not enough to resolve scarcity.

[6] "Water For Texas 2012 State Water Plan."

FIGURE E.2. 2060 FAR WEST TEXAS EXISTING SUPPLIES, PROJECTED DEMANDS, AND IDENTIFIED WATER NEEDS BY WATER USE CATEGORY (ACRE-FEET PER YEAR).



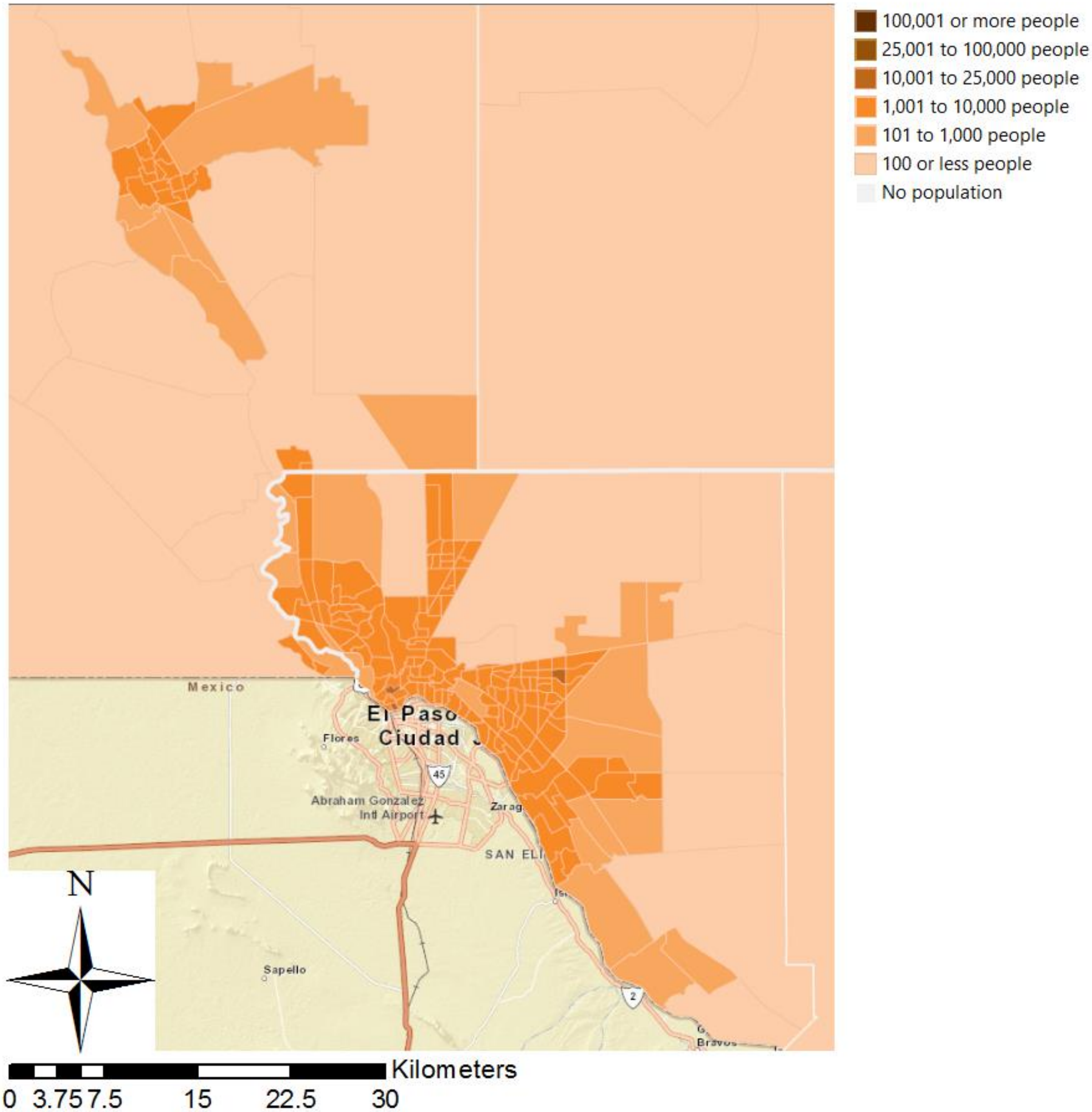
Although the difference between demands and needs in the table above is not very clear, the separation does suggest that the increasing demand will be met since it is not included in the need calculations.

If the demands and needs are combined region E will require:
699586 + 226569 – 514593 = **381562 AF / year** by the year 2060.

Refocusing the attention on Paso del Norte, EPWU advanced plans to countenance the projected deficit by conjunctive reliance on Ground/Surface water, however the solution foreseen in the State Water Plan will be municipal conservation and Groundwater Desalination. There must be enough testimony that most gains will be obtained from these measures.

Among the limitations faced by water condition improvements are the agreed upon reclamation amounts which leave no room for extra sharing bargains on river flows to account for the surface supply increases. However, the emergency measures in times of severe drought enable slight changes in the protocols that could top off the water accounts and balance the scale of credits and debits.
We will be exploring tangible quantitative regulations while accounting for the additional beneficiaries of the surface water upstream of El Paso.

El Paso & Las Cruces Population Density

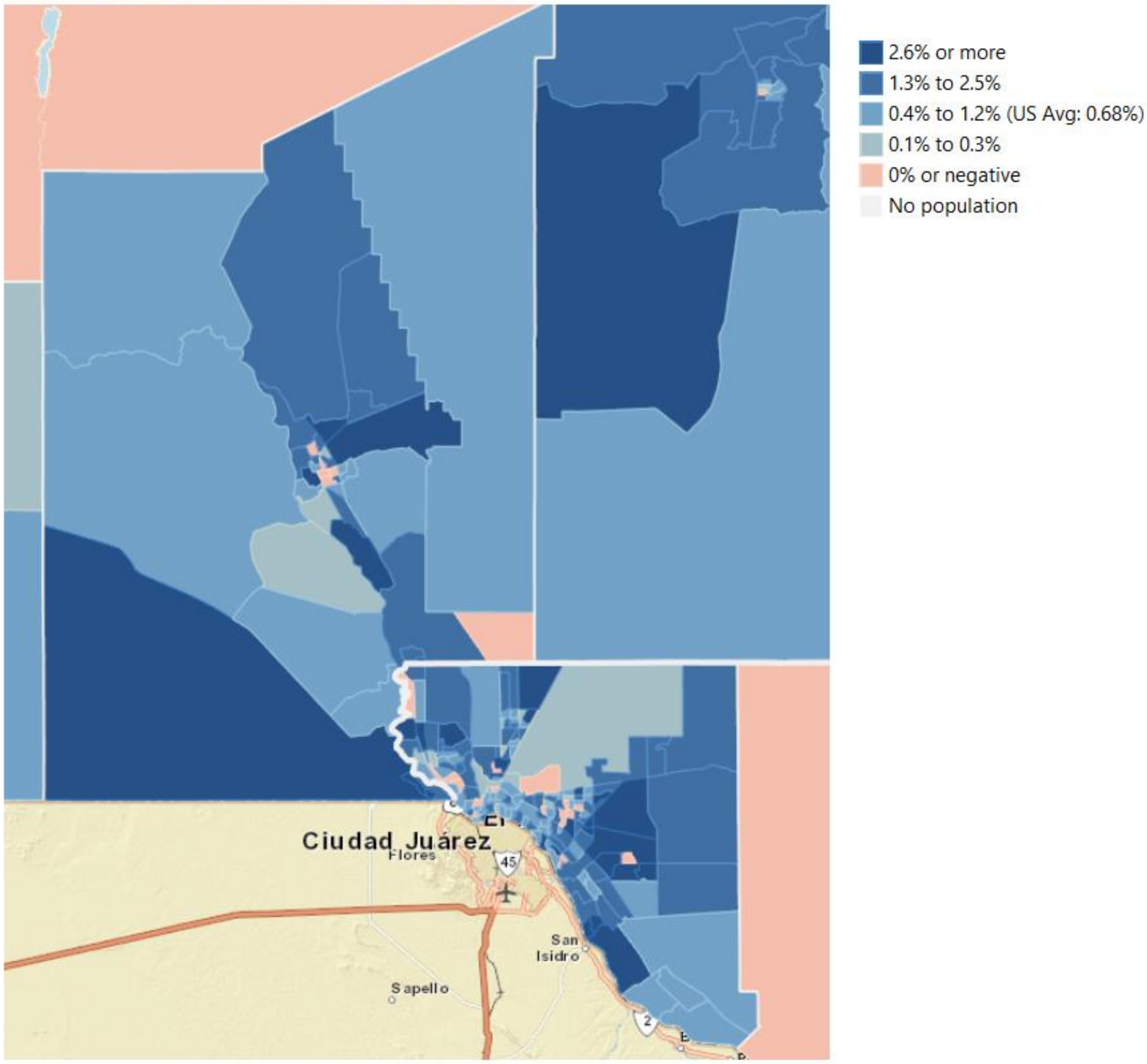


In comparison to the rest of the border territories these are the most densely populated. (Obtained from esri's last updated demographics services).

Currently Census Data estimates that population numbers are in the order of 833000 people in El Paso, and 100000 people in Las Cruces.

The projections that will be used are those provided by the TWDB forecasts mentioned earlier but it can be useful to note the rate of growth in that region of 1.3% to 2.6% and more.

Population Growth rate El Paso, Dona Ana



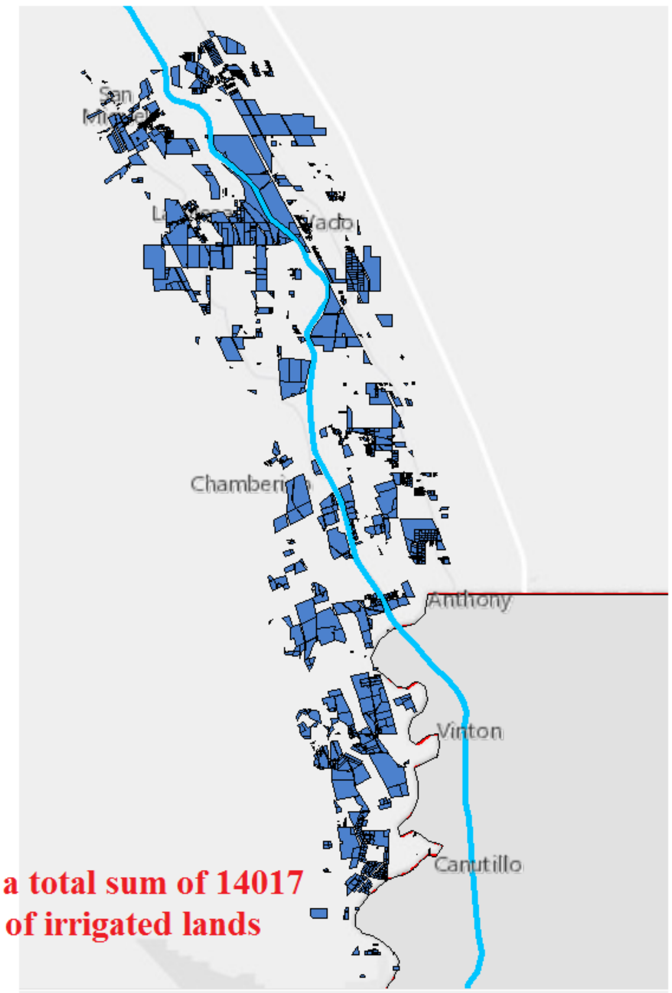
Without dismissing the consequential number of people already in Ciudad Juarez which is growing at almost the same rate, we will be content with demand assessments in US territories to evaluate the implications of scarcity from the perspective of State development plans.

IV. DEMAND AND SUPPLY CALCULATIONS:

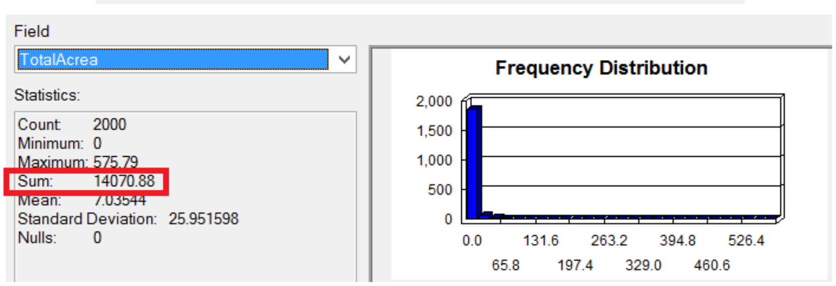
Calculations will be done using formulas from Ram Gupta's first chapter in Hydrology and Hydraulic Systems

1. Elephant Butte Irrigation District (Agricultural):

EBID irrigated areas from the EBID arcGIS server online



With a total sum of 14017 acres of irrigated lands



The sum obtained is in contradiction with that from a Water Task Force report on EBID agricultural data which asserts that there was as of 2001 a total of 90640 righted acres among which 75000 are irrigated (5 times as much as the specified number)[7]

In that report, Farm size distributions were provided with nature of plantations. Knowing each crop we can calculate the total plant evapo-transpirations, Pecan crops were replaced with Walnuts in the Analysis since Kc tables in the Manual didn't provide values for Pecans.

Farm size		Average	Alfalfa	Cotton	Walnuts	
2	5	4	290	40	164	
5	10	8	116	33	164	
10	20	15	73	37	4	
20	50	35	37	34	5	
50	100	75	8	20	3	
			4875	**3633**	**2264**	10772
	% of Total FARM		45	34	21	

These distributions will merely serve to apportion the EBID mapped lands above.

<u>Blaney – Criddle Method:</u>

U = $\sum Kt\ Kc\ tm\ \frac{p}{100}$
U: Consumptive use in/month
Kt: Climatic Coefficient related to mean monthly temperatures (Kt = 0.0173 tm – 0.314)
Kc: Growth stage coefficient
Tm: mean monthly temperature
P: Monthly percentage of annual daytime (Average of 8.33)

Calculation tables are provided below:

By optimizing different proportions of Land we can minimize the crop evapotranspirations. We can also test different scenarios and evaluate based on annual releases if the irrigated lands are deficient or not.

[7] Rhonda Skaggs and Zohrab Samani, "Irrigation Practices vs Farm Size: Data from the Elephant Butte Irrigation District."

Alfalfa						
Month	c	tm(F)	P	Kc	Kt	U
1	28	82	8.33	0.63	1.11	5
2	29	84	8.33	0.74	1.14	6
3	31	88	8.33	0.86	1.20	8
4	33	91	8.33	0.99	1.27	10
5	35	95	8.33	1.09	1.33	11
6	36	97	8.33	1.13	1.36	12
7	36	97	8.33	1.11	1.36	12
8	36	97	8.33	1.06	1.36	12
9	35	95	8.33	0.99	1.33	10
10	35	95	8.33	0.90	1.33	9
11	32	90	8.33	0.78	1.24	7
12	29	84	8.33	0.65	1.14	5
			Sum (Inches / year)			108

Cotton						
Month	c	tm(F)	P	Kc	Kt	U
1	28	82	8.33	0.20	1.11	2
2	29	84	8.33	0.25	1.14	2
3	31	88	8.33	0.33	1.20	3
4	33	91	8.33	0.50	1.27	5
5	35	95	8.33	0.79	1.33	8
6	36	97	8.33	0.97	1.36	11
7	36	97	8.33	0.97	1.36	11
8	36	97	8.33	1.12	1.36	12
9	35	95	8.33	1.06	1.33	11
10	35	95	8.33	0.94	1.33	10
11	32	90	8.33	0.81	1.24	7
12	29	84	8.33	0.67	1.14	5
				Sum (Inches / year)		87

Walnuts						
Month	c	tm(F)	P	Kc	Kt	U
1	28	82	8.33	0.10	1.11	1
2	29	84	8.33	0.14	1.14	1
3	31	88	8.33	0.23	1.20	2
4	33	91	8.33	0.43	1.27	4
5	35	95	8.33	0.68	1.33	7
6	36	97	8.33	0.92	1.36	10
7	36	97	8.33	0.98	1.36	11
8	36	97	8.33	0.88	1.36	10
9	35	95	8.33	0.69	1.33	7
10	35	95	8.33	0.49	1.33	5
11	32	90	8.33	0.31	1.24	3
12	29	84	8.33	0.15	1.14	1
			Sum (Inches / year)			62

Adding all consumptive uses and converting into acre.ft units for the given 14017 acres of irrigated land we obtain an agricultural demand of: **<u>106855 Acre-Feet / Year</u>.**

	Alfalfa	Cotton	Walnuts	
% of Total FARM	0.45	0.34	0.21	
Consumptive use (in/y)	108	87	62	
Consumptive use (ft/y)	9	7	5	
Irr. Land of each crop (acr)	6344	4766	2944	Total
Acre Ft / Y	**57095**	**34552**	**15208**	**106855**

Optimal crop redistribution:

If we sought to decrease this demand we would want to minimize our total consumption which will reflect on the final calculated demand.

That becomes a Non-Linear programming model, where we would seek to minimize an objective function with the following equation: 9 Xa + 7Xc + 5Xw. Using Lagrange calculations to optimize resources for a given set of constraints.

9, 7 and 5 represent the parameters in feet/year calculated for each crop type earlier, while Xa Xc and Xw would represent respectively the attributed farming acreage for Alfalfa Cotton and Walnuts.

The constraints should be carefully introduced:

- If these irrigated lands were to be always planted then we'd know their sum will be 14017 acres
- Since reductions and redistributions will be taking place, they should not be too cumbersome on farmers in EBID with an agribusiness structure according to current priorities. We observe that Alfalfa lands are larger than Cotton lands that are in turn larger than walnut lands: Xa >= Xc >= Xw.
- Non negativity constraints

Running Excel's solver yielded the following equi-distribution:

	Acres	Factors	Acre-ft	Portion
Xa	4672.33	9.00	42051.00	0.33
Xc	4672.33	7.25	33874.42	0.33
Xw	4672.33	5.17	24155.96	0.33
Sum of lands (Acr)	14017.00			
Demand (Acr.ft)	**100081.38**			

Demand was reduced by **6000 acre-ft** per year just by changing the agricultural apportioning of EBID. If we run the solver again with only the first constraint the minimum demand would be reached by shifting agricultural uses to full walnut plantations with a tremendous reduction of **34400 Acr-ft / year**.

	Acres	Factors	Acre-ft	Portion
Xa	0.00	9.00	0.00	0.00
Xc	0.00	7.25	0.00	0.00
Xw	14017.00	5.17	72467.89	1.00
Sum of lands (Acr)	14017.00			
Demand (Acr.ft)	**72467.89**			

2. El Paso demands:

Las Cruces relies almost entirely on Groundwater pumping, producing approximately 6.5 Billion gallons of fresh clean water or the equivalent of 20000 annual acre-ft, and therefore will not be accounted for in the calculations.

Required quantity P = (Pop. At the end of design period) * (per capita usage)

P = 833000 * 133 (Gal/day) = **140000 acre-ft per year**

According to water utilities in El Paso the current Municipal supply is of **131000 Acre-ft/year** comes from both surface and groundwater depending on the conditions of the season. Since surface water is only available throughout the irrigation season which lastly was from May to September 28 of this year (5 months), EPWU relies on conjunctive usage of available Ground and Surface water: withdrawing **66000 Acre-ft / year** under full surface allocation and **65000 Acre-ft** per year from the Hueco Bolson and Mesilla aquifers.

The municipal supply of 131000 acre-ft was estimated in 2013, the population had to be less by then. The extra 9000 Acre-ft per year would be compensated from groundwater withdrawals since there is a ceiling on reclaimed waters.

Similarly as was done in the previous section we will estimate the agricultural demand for El Paso:

There are 657 farms with a total area of 209393 acres, of which 25.4% (53186 acres) constitutes croplands with main productions of Pecan (Amount not provided) Cotton and forage crops[8].

	Pecans	Cotton	Hay	
% of Total FARM	45	42	14	
Consumptive use (in/y)	55.00	87.00	55.00	
Consumptive use (ft/y)	4.58	7.25	4.58	
Irr. Land of each crop	23715.00	22289.00	7200.00	Total
Acre Ft / Y	**108614.70**	**161594.60**	**32976.00**	**303185.30**

Current agricultural water demand for El Paso is **303185 acre-ft / year**.

The State Water Plan table estimates a result for all region E: 499092 acre-ft/year, we could later deduce demands for other counties in region E if we were confident in the result. Most farmers receive their water through ditches and diversions upon requests to the EPCWID.

[8] "2012 Census of Agriculture County Profile, El Paso County TX."

El Paso / Hydspeth Surface Water Rights table

OwnerName	OwnerTypeCode	DivAmtValue	UseCode	ResName	SiteName
UNITED STATES OF AMERICA	2	376000	1	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
UNITED STATES OF AMERICA	2		2	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
UNITED STATES OF AMERICA	2		3	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
UNITED STATES OF AMERICA	2		4	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
UNITED STATES OF AMERICA	2		7	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
EL PASO CO WID 1	2		1	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
EL PASO CO WID 1	2		2	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
EL PASO CO WID 1	2		3	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
EL PASO CO WID 1	2		4	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
EL PASO CO WID 1	2		7	ELEPHANT BUTTE RES & CABALLO RES	MESILLA, AMERICAN, RIVERSIDE DIV DAMS
CEMEX EL PASO INC	2	178	2	CEMENT LAKE	
CITY OF EL PASO	2	11000	1		
INDIAN CLIFFS RANCH INC	2		7		
UNITED STATES OF AMERICA	2	26600	3		
HUDSPETH COUNTY CRD 1	2		3		
HUDSPETH COUNTY CRD 1	2		2		
HUDSPETH COUNTY CRD 1	2		4	413778 acr.ft / yr	
HUDSPETH COUNTY CRD 1	2		7		

The United States of America is listed among the entitled right holders with a water share of 402600 acre-ft / year. These amounts should be guaranteed by the USBR because they are essential quantities to include in the IBWC international water sharing balance sheet.

As it is apparent in the list, there is no information on water rights for the irrigation districts. There still is a gap between legal ownership and amounts received, the rights are more or less a utile for remediation of deficiencies. EPWU is adopting a water rights leasing program, paying a lump sum fee to the right holder which lasts for 75 years, this processes redistributes ownership evenly again after increasing municipal supplies to utility subscribers[9].

3. Supply:

As we have demonstrated a portion of the Paso del Norte demand is met by Municipal Utility distributors and irrigation districts. But in order to evaluate total water availability, there needs to be a simplified model that can aggregate the variations into a pattern easy to analyze. The dimension in the context of annual flows can provide integrated accounts of volumetric quantities, however they are not very secure since drought seasons can be long and weather is unpredictable, what was once thought of as a conservancy level of reservoir operation during historical droughts of record is undermined by the uncertainty associated with assuming that this was the worst that could ever happen.

[9] "El Paso Water Utilities - Public Service Board | Water Rights."

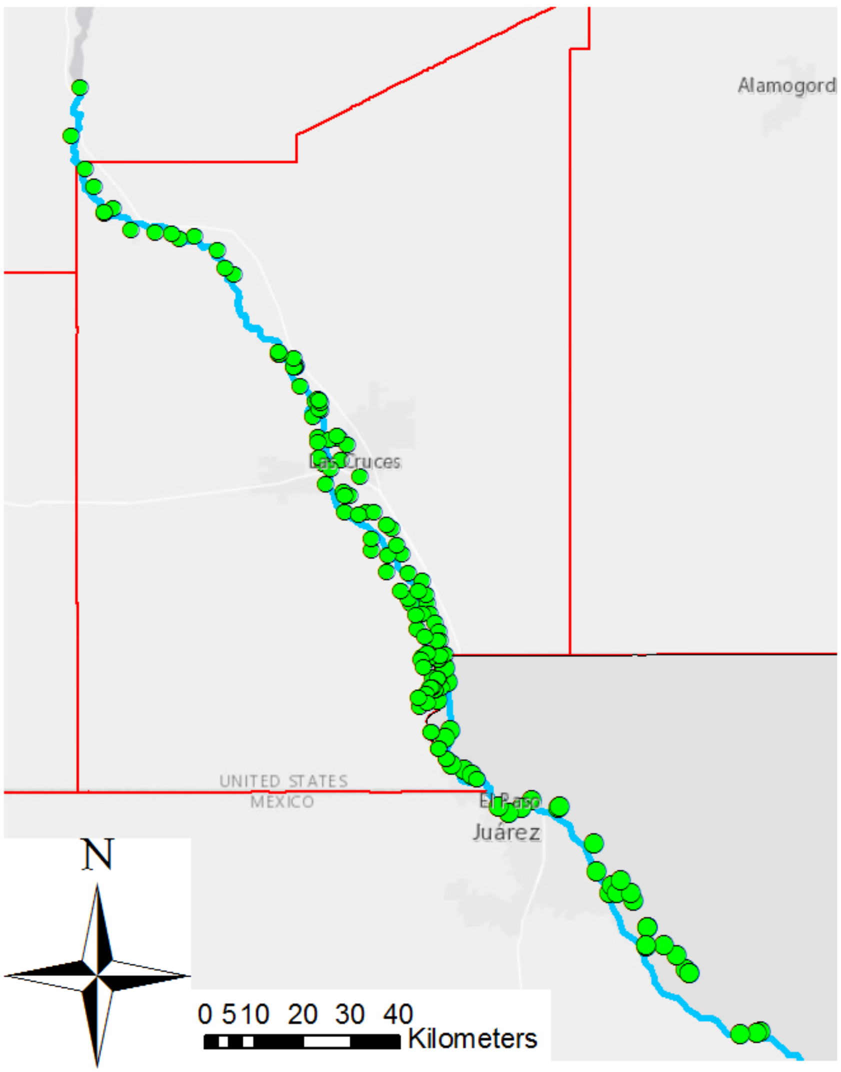
Reservoir operation should therefore adapt to the scenarios faced.

USBR currently operates Elephant Butte solely on the flood control basis, while guaranteeing flows from Caballo for irrigation purposes[10].

The five year reclamation plan also listed monitoring stations for the EB reservoir:

"Flow data and information from Elephant Butte Dam and Reservoir, Caballo Dam and Reservoir, gauging stations below Elephant Butte and Caballo dams, and river gauging stations on the Rio Grande from Caballo Dam to Fort Quitman, TX (Reclamation's Elephant Butte and El Paso field offices, USGS, IBWC, Mexico, EBID, and EP #1)."

EB/Caballo and El Paso Monitoring Stations

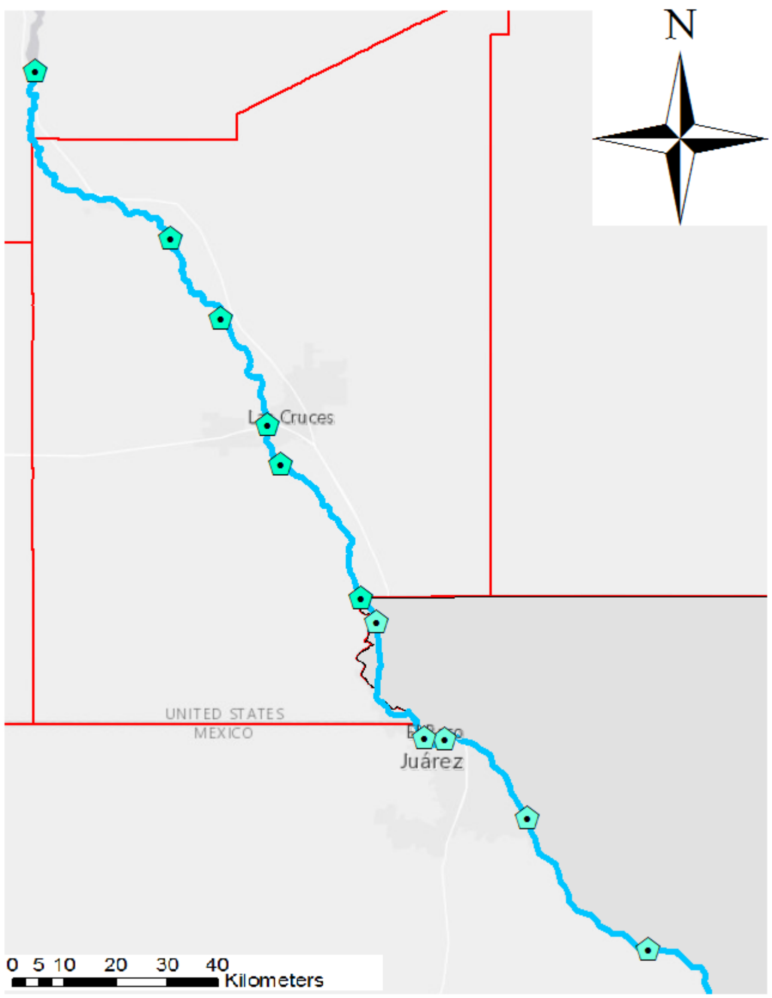


The stations shown on the left were combined from different sources (EBID, USGS, EPCWID), they comprise groundwater monitoring wells, stream gages and other wasteway gages. Not all are useful for the analysis. Only a selected few streamgages will serve the analysis.

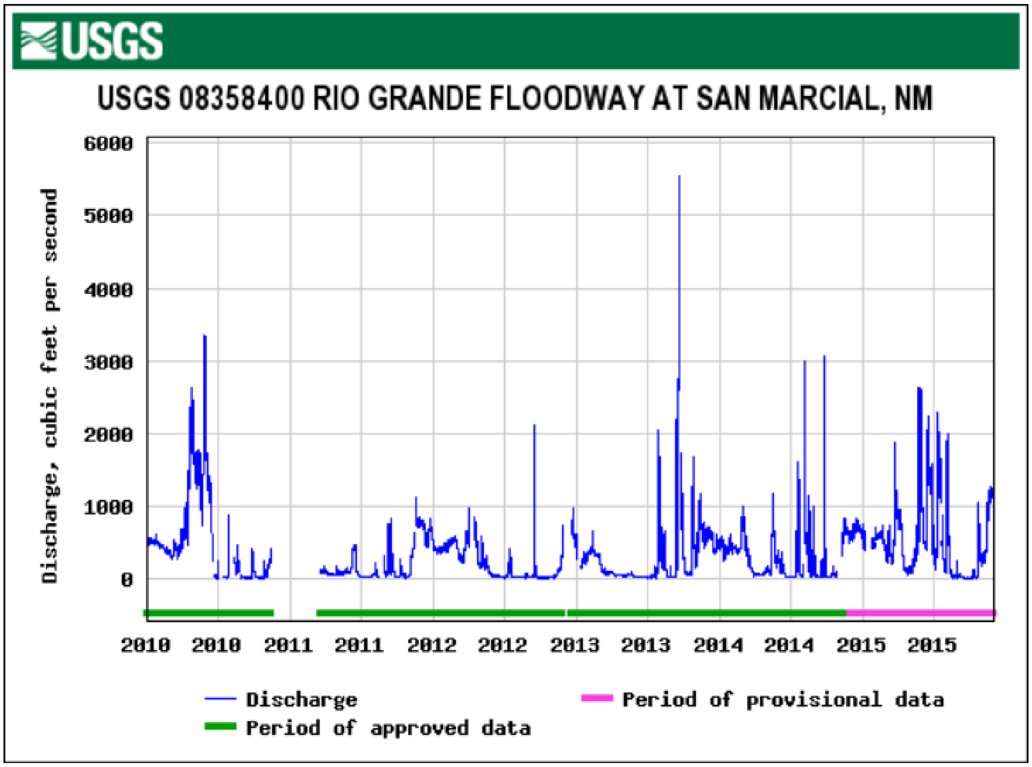
[10] "Elephant Butte Five Year Operational Plan, Biological Assessment."

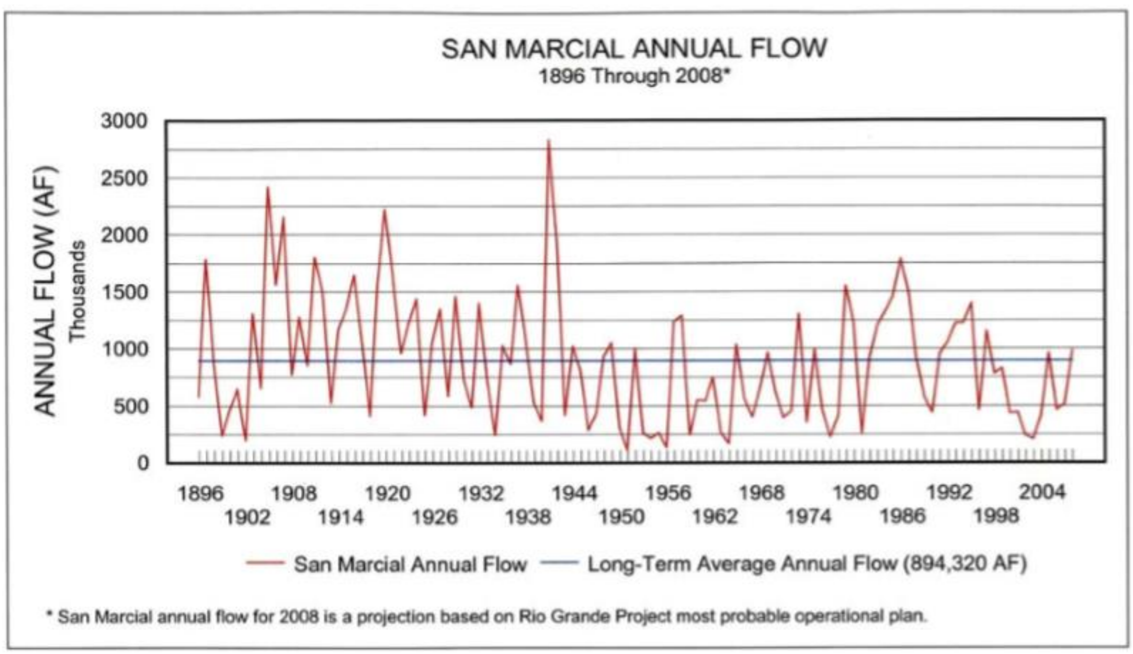
Gage #	Monitoring station	Reference
1	EB reservoir entry at San Marcial	http://waterdata.usgs.gov
2	Caballo	http://ebid.onerain.com/home.php
3	Haynor Bridge Station	http://ebid.onerain.com/home.php
4	Leasburg Dam	http://ebid.onerain.com/home.php
5	Picacho Station	http://ebid.onerain.com/home.php
6	Mesilla Dam	http://ebid.onerain.com/home.php
7	Anthony Station	http://ebid.onerain.com/home.php
8	Rio Grande at Canutillo	http://www.epcwid.org/telemetry/
9	American Canal Heading	http://www.epcwid.org/telemetry/
10	Americas Canal Ext Leon St	http://www.epcwid.org/telemetry/
11	Americas Ext at Border (2nd St)	http://www.epcwid.org/telemetry/
12	Riverside Canal Below RS WasteWay	http://www.epcwid.org/telemetry/
13	Hudspeth Feeder (Blr)	http://www.epcwid.org/telemetry/

River gage stations upon reservoir exit



With the first stream gage located at San Marcial, we can obtain from USGS data the inflow to the reservoir. If we observe the discharge sequence over 5 years we can discern the periods of time in which water accumulates, it is usually from June to December even though reclamation operations aren't tied to months of the year but to reservoir levels and conditions.

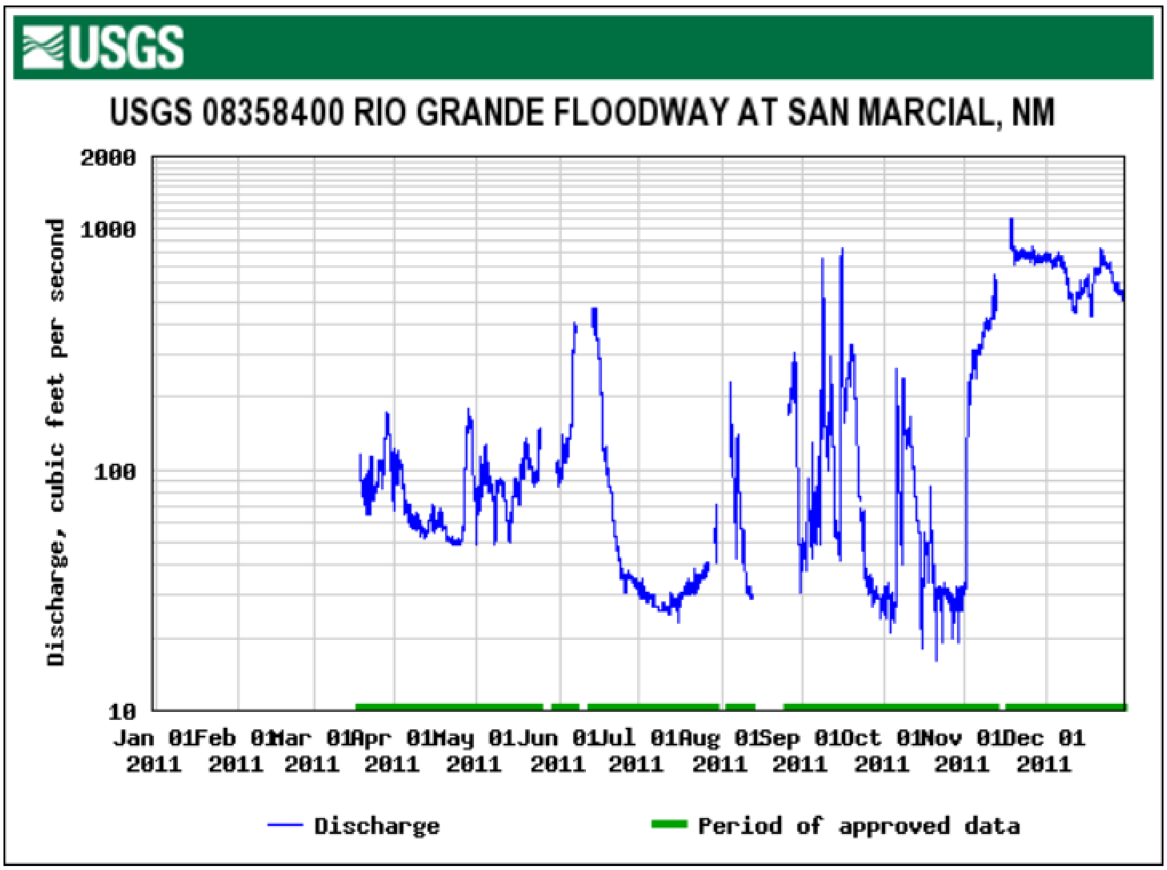




Historical data shown in the second graph displays the variability of water inflow through the monitoring station upstream of the reservoir. However these amounts are obviously receding when looking at the years between 2010-2011 and 2012-2013 we can sense the drought in the Far West.

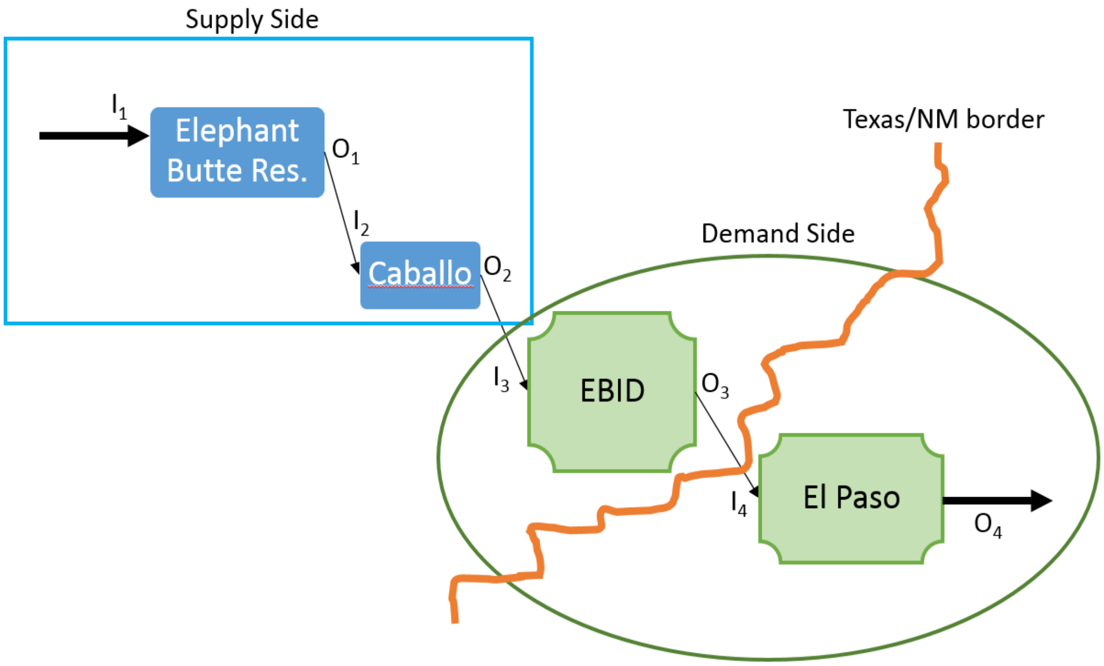
If we consider the mean annual discharge from San Marcial of approximately 900 cubic feet per second we can equate that amount to yearly volume of **<u>652464 acre-ft /year</u>** in regular times. In times of drought however that flow of 500 cubic ft/second becomes **<u>362479 acre-ft/year</u>**.

In 2010-2011 San Marcial station recorded the following flows:



Integrating that amount in results in a yearly volume of **<u>160661.4</u> Acre-ft**

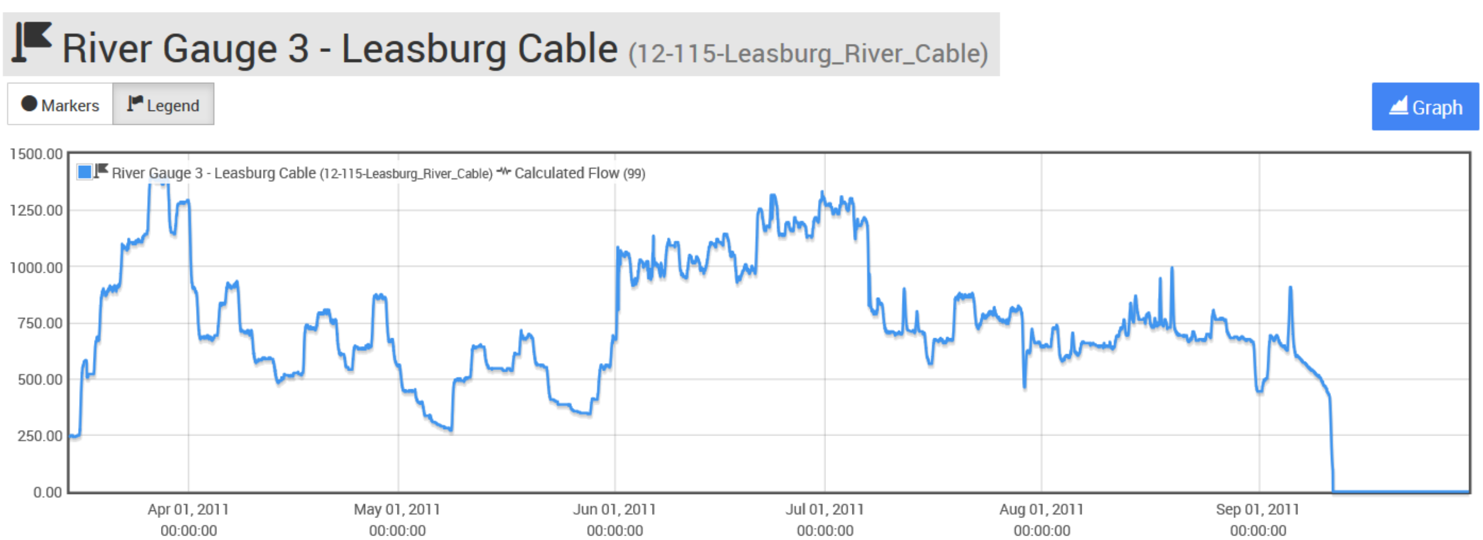
These will serve to represent the inputs of the abstracted water system for that year where supposedly a drought took place. (view model below).



Stream Gage Readings:

Thankfully we have a few river monitoring gages along the canal lines to calculate volumes delivered in that period (2010-2011). Some gages are out of function and so only a few were used to get readings

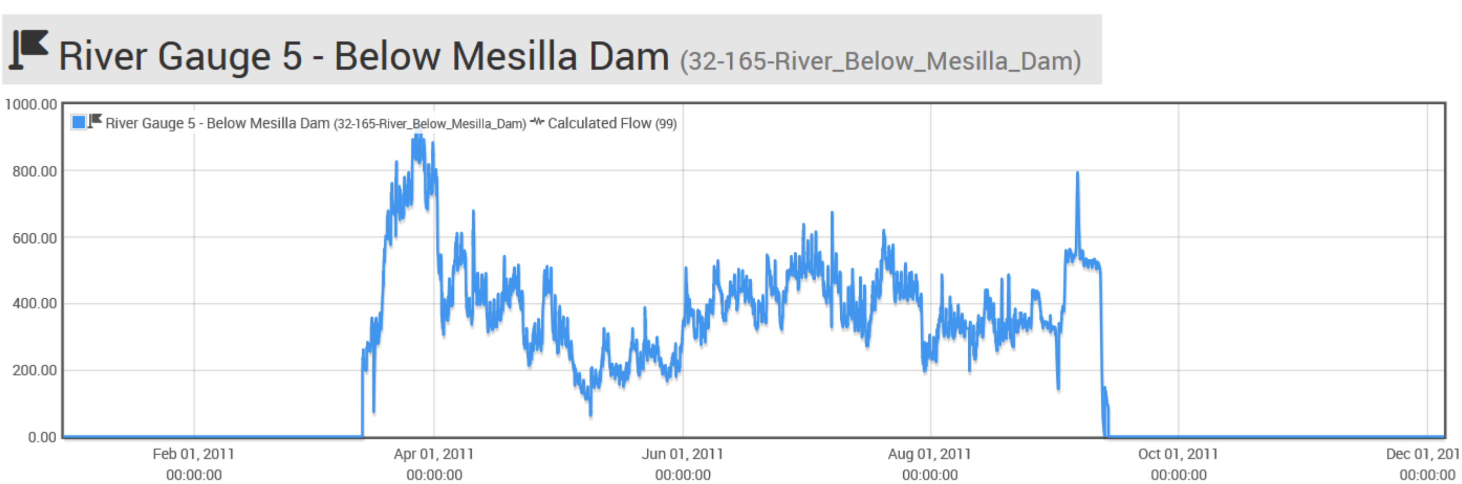
I. Gage #4 at Leasburg:



The total volume is obtained by integrating the flow over the whole year and converting to Acre-ft.

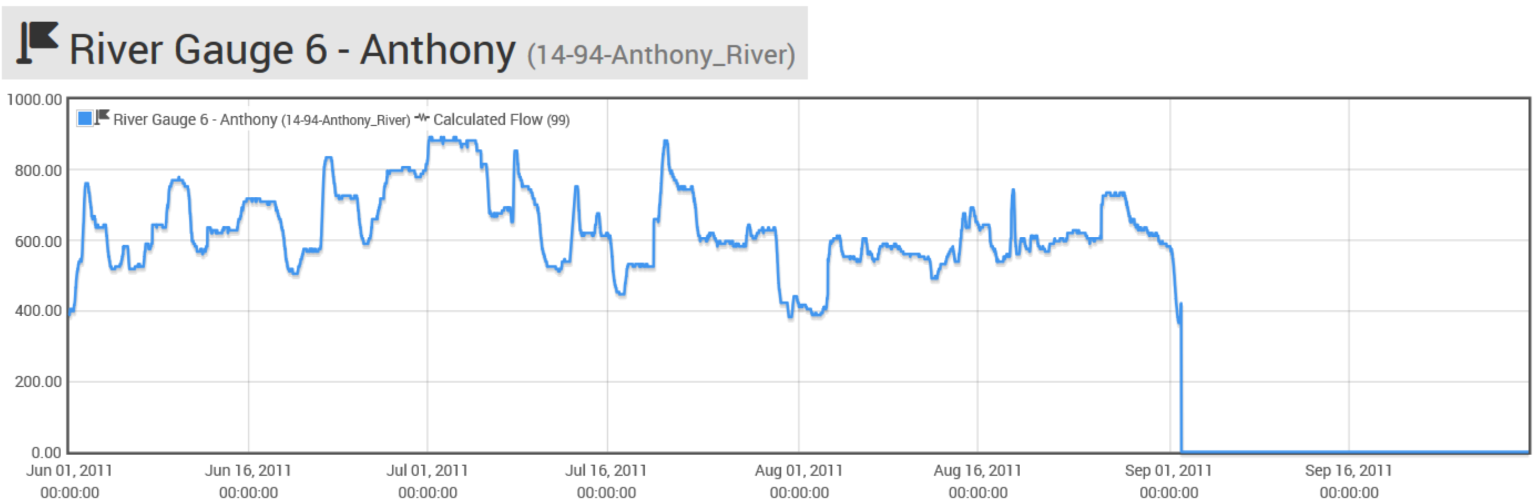
Month	CF/s	CF/d	D	CF
March				810000000
April	1200	103680000	22	2280960000
	700	60480000	4	241920000
	800	69120000	2	138240000
	900	77760000	2	155520000
	700	60480000	2	120960000
	600	51840000	6	311040000
	800	69120000	5	345600000
	620	53568000	6	321408000
	750	64800000	2	129600000
May	400	34560000	8	276480000
	600	51840000	8	414720000
	700	60480000	2	120960000
	550	47520000	2	95040000
	400	34560000	6	207360000
	500	43200000	4	172800000
June	1000	86400000	19	1641600000
	1200	103680000	11	1140480000
July	1300	112320000	7	786240000
	800	69120000	22	1520640000
Aug	700	60480000	30	1814400000
September	600	51840000	12	622080000
			Sum in Cubic Ft	13668048000
			Sum in Acre-Ft	**313776.0111**

II. Gage #6: Mesilla:



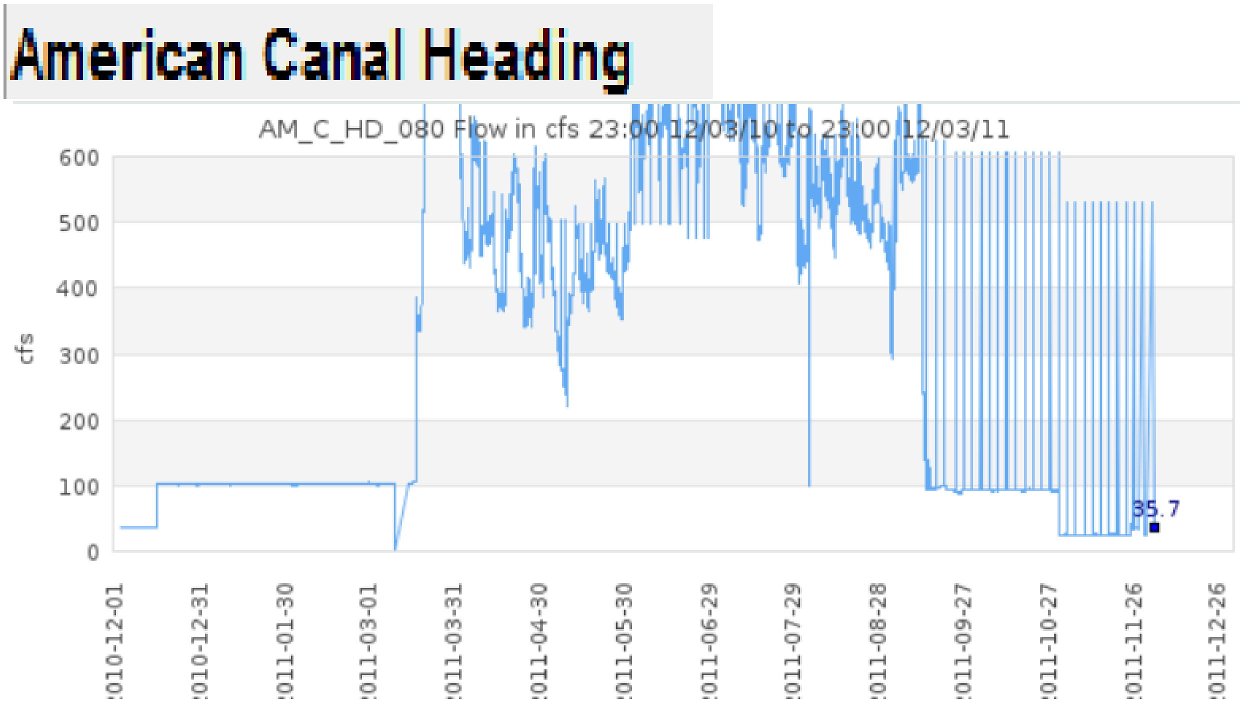
Month	CF/s	CF/d	D	CF
March	800	69120000	14	967680000
April September	150	12960000	400	5184000000
	500	43200000	13	561600000
			Sum in Cubic Ft	6713280000
			Sum in Acre-Ft	**154116.0976**

III. Gage #7 Anthony:



Month	CF/s	CF/d	D	CF
March	1500	129600000	15	1944000000
April September	600	51840000	60	3110400000
	600	51840000	120	6220800000
			Sum in Cubic Ft	11275200000
			Sum in Acre-Ft	**258843.6389**

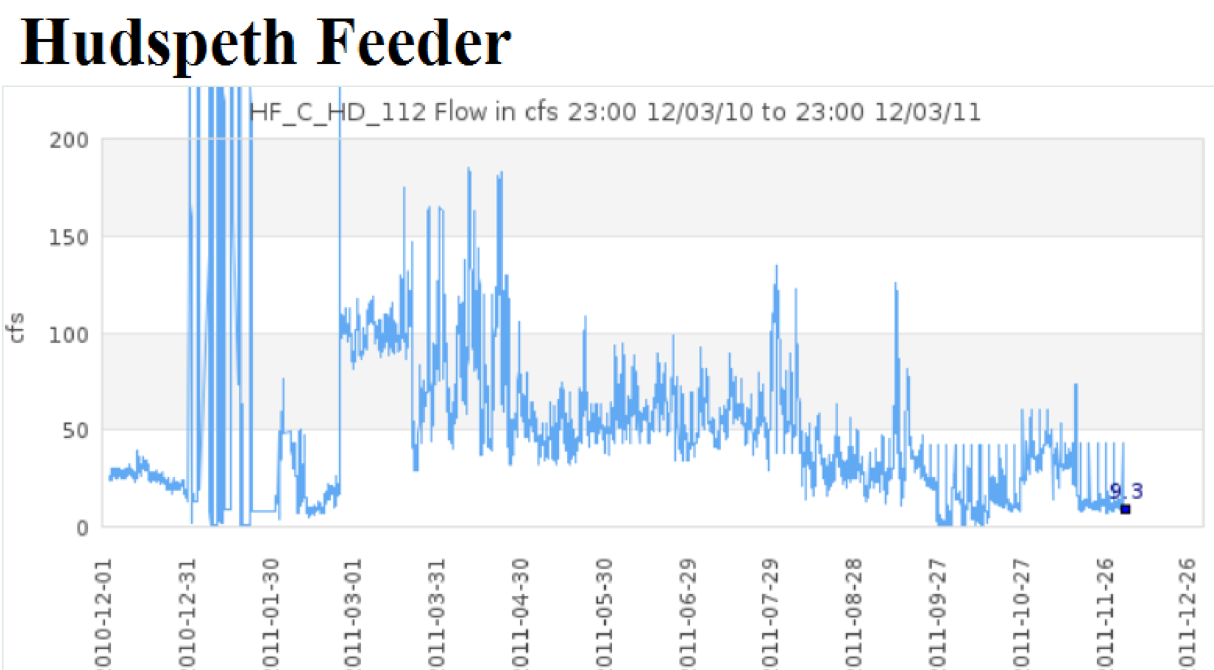
IV. Gage# 9 American Canal Heading:



Period	CF/s	CF/d	Days	CF
1	100	8640000	60	518400000
2 3	600	51840000	180	9331200000
	50	4320000	60	259200000
			Sum in Cubic Ft	10108800000
			Sum in Acre-Ft	**232066.7107**

As we move further downstream we realize that deliveries are receding, this is natural if one takes into consideration the losses along the river reach from evaporation and population uses.

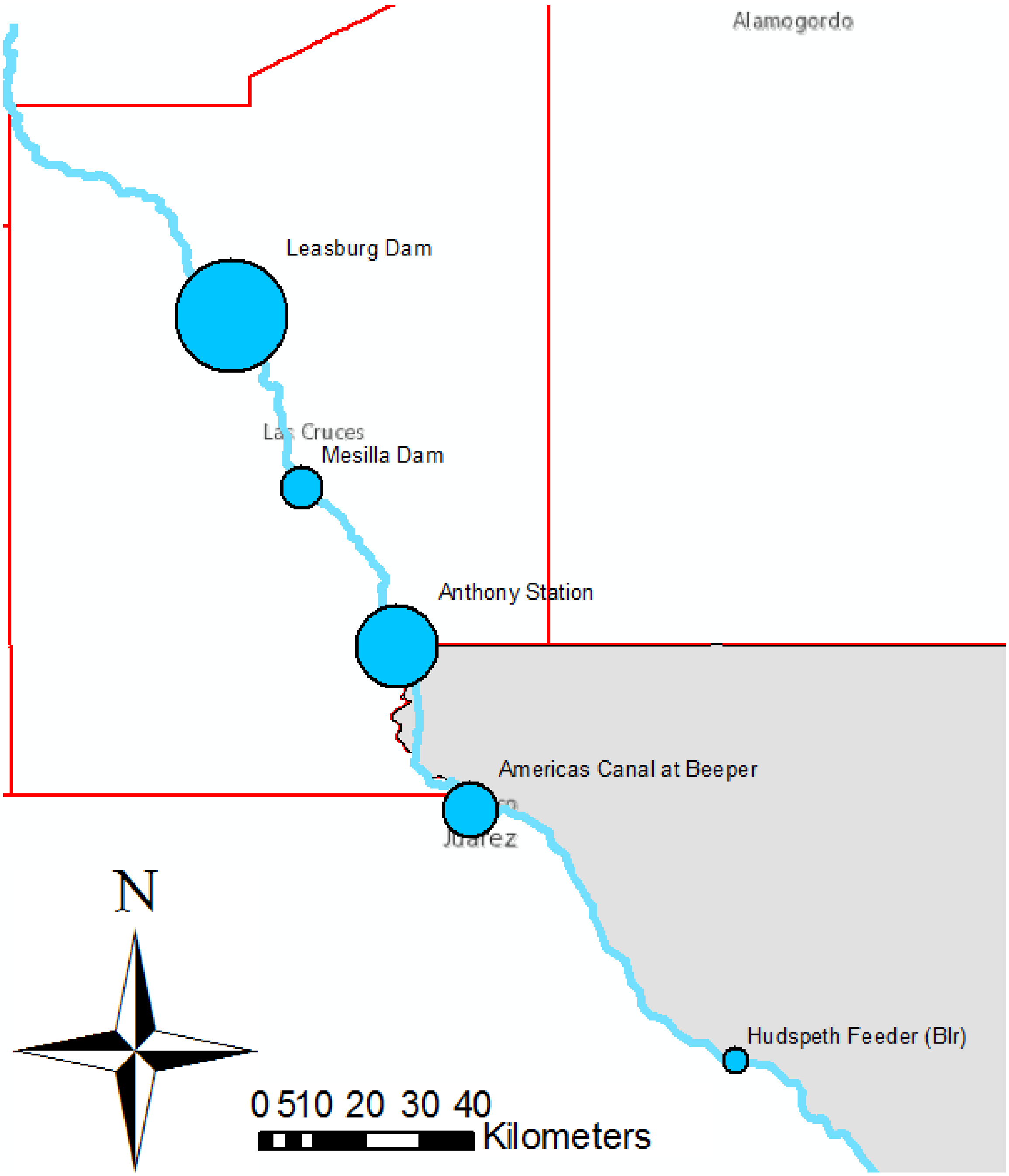
V. Gage#13 Hudspeth feeder:



Period	CF/s	CF/d	Days	CF
1	40	3456000	90	311040000
2	120	10368000	60	622080000
3	50	4320000	120	518400000
4	40	3456000	60	207360000
			Sum in Cubic Ft	1658880000
			Sum in Acre-Ft	**38082.74227**

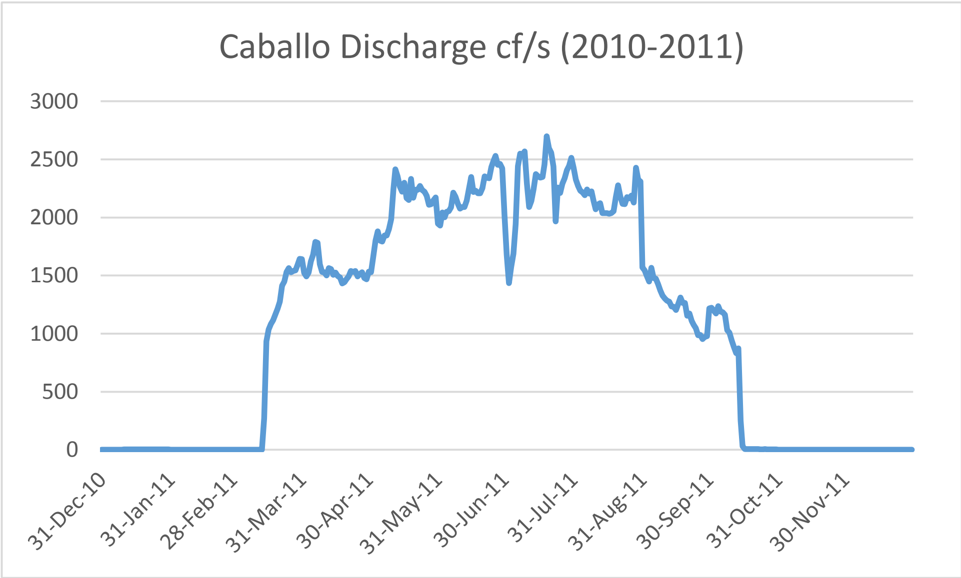
We will use these numbers to estimate the budgets of the year, the demand according to city will then be compared with deliveries.

Annual deliveries at stream gage locations (Weight attributed by Volume)



VI. Dam releases:

Releases for Caballo and Elephant Butte were acquired by chance for the year of 2010-2011 before the web services became inaccessible, it became impossible to monitor how the dams are operated over time to observe the supply.



With a total released amount of **772935 acre- ft** in that year.

Prof. Ward's report states that water budgeting *"deals with aggregated transports of water, that is, integrations (or averages) over large areas of space and long intervals of time"*[11]. That is exactly what will be done once the interval has been chosen.

The budget should include all inputs and outputs of the system, however with the available data we will only be concerned with stream flows in engineered canals, the variation of which along the timeline could be explained by rain inputs and evaporation outputs. Engineered canals are designed to handle a specific amount of water issued from all possible sources in a watershed.

The accounts were not completed but that is another task to focus on for future work.

[11] Ward, "Water Budgets."