Sources of Salinity to the Rio Grande

Fred M. Phillips, James Hogan, Heather Lacey, Elizabeth Bastien, & Suzanne Mills

New Mexico Tech & SAHRA

Coauthors

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

James

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Suzanne

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Heather and Liz

Center for Sustainability of semi-Arid Hydrology and Riparian Areas
(SAHRA)

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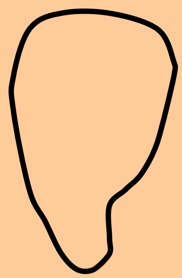
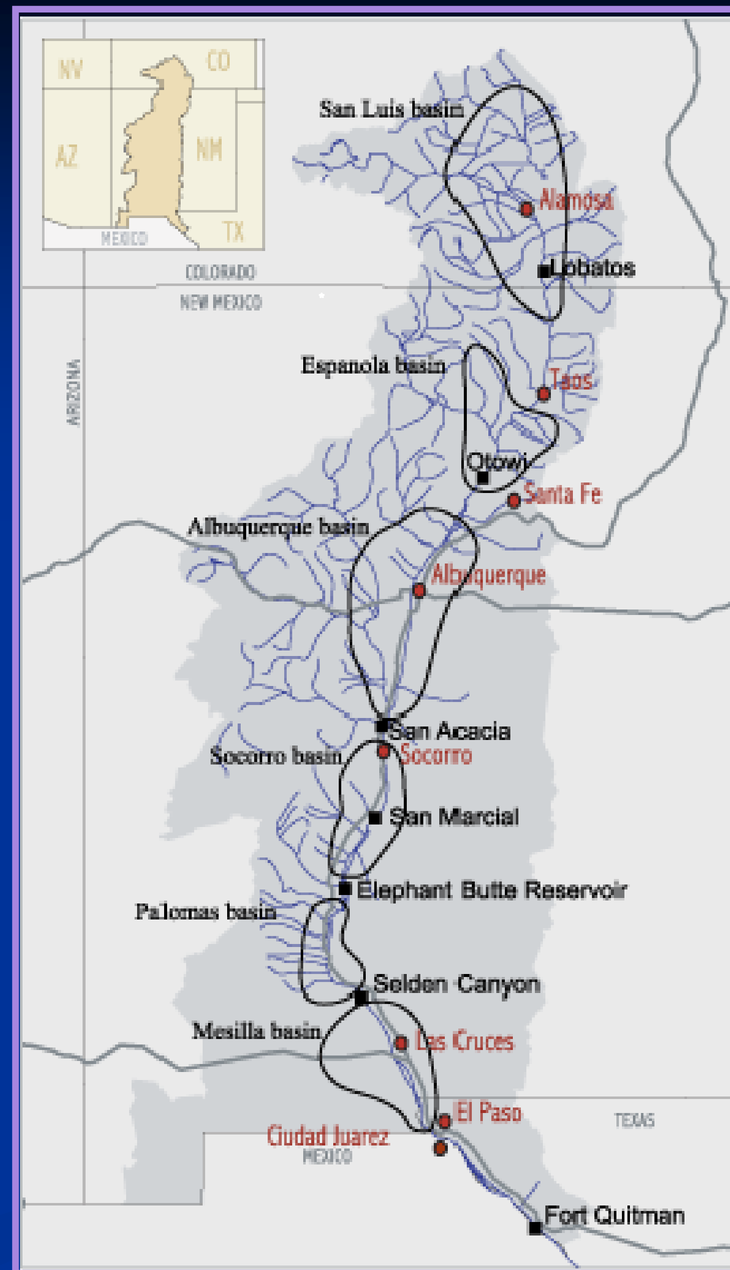
Rio Grande basin


= sedimentary basin

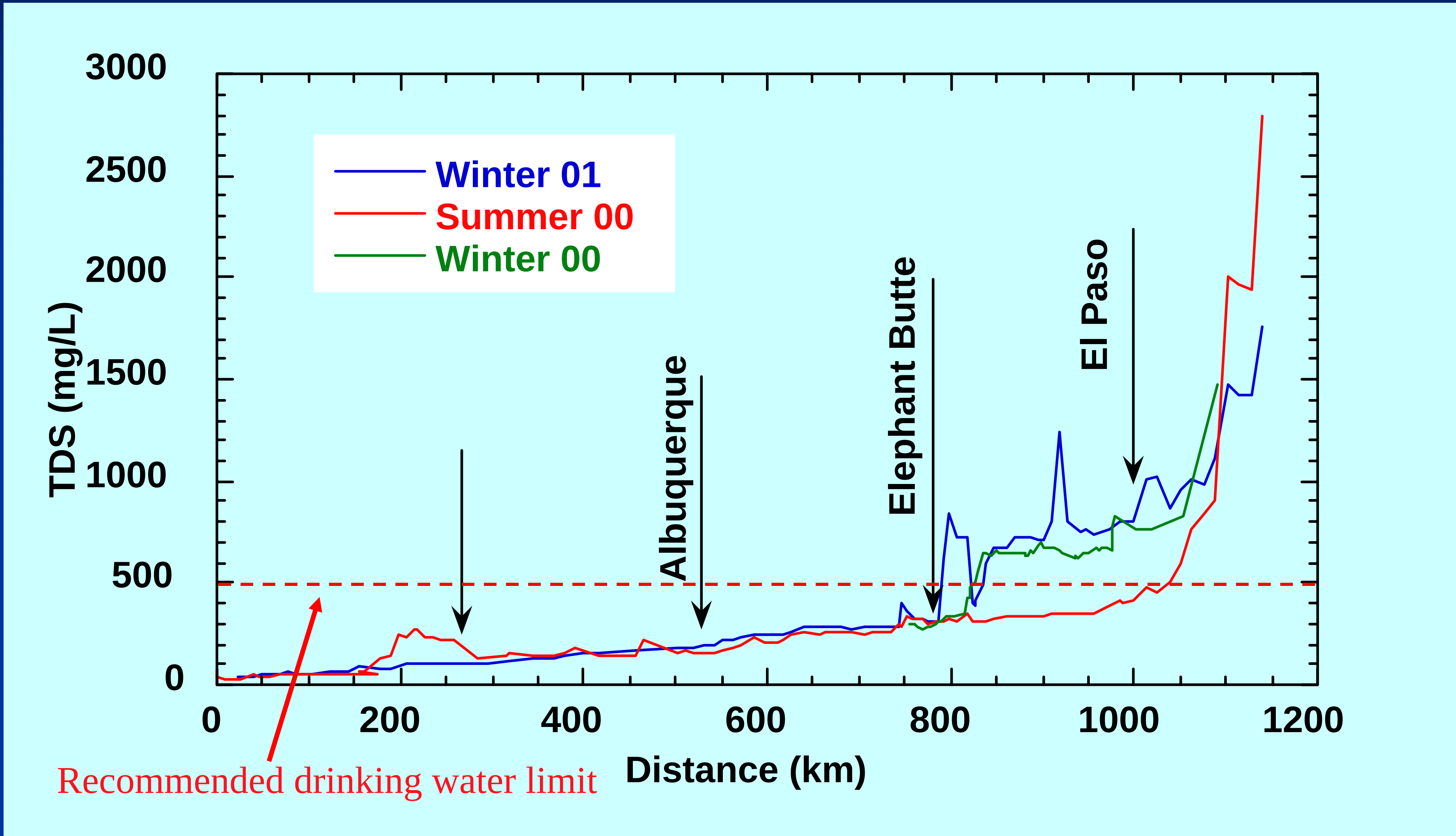
- Basin Area - 32,210 mi^2
- Precipitation - 6 to >50 in.
- Population - 1,072,000 (1990)
- Irrigation - 914,000 acres



Facts about Rio Grande

- Current mean annual discharge at Otawi Bridge (northern New Mexico) is 49 $m^3 s^{-1}$
- Natural discharge (without ag diversions) at this point would have been ~70 $m^3 s^{-1}$
- TDS at headwaters is ~40 mg L^{-1}
- TDS at El Paso averages ~750 mg L^{-1}
- TDS at Fort Quitman is >2,000

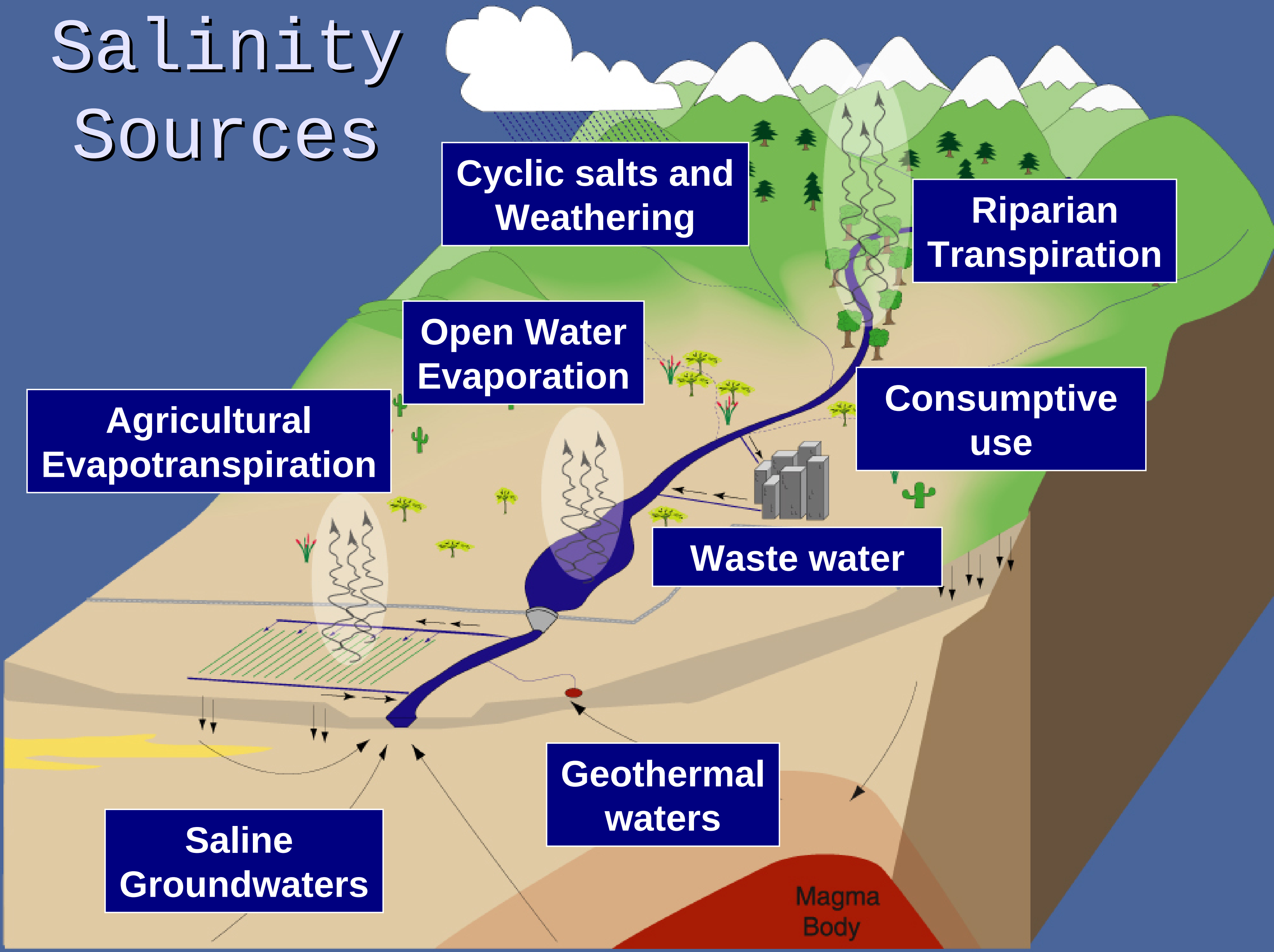
TDS of the Rio Grande



Questions we will try to answer

- Where is the salt coming from?
- What is the salt budget of the river?
- What are the controls on salt and water dynamics in the river system?
- How is the river responding to prolonged drought?

Salinity Sources



Where is the salt coming from?

- There are no known evaporite deposits under the Rio Grande rift
- There are a few moderately saline hot springs, but salt output is small
- River water is consumed by three major irrigation districts along the course of

What have previous investigators said?

Hypothesis 1: Effects of evapotranspiration

J.B. Lippincott (1939): "The increase in salinity of the waters of the Rio Grande [is] due to their use and re-use [for irrigation] in its long drainage basin..."

Hypothesis 1: Effects of evapotranspiration

Trock et al. (1978) “The deterioration in the water quality of the Rio Grande ... is due principally to the concentrating effect of irrigation.”

Hypothesis 2: Groundwater displacement

Wilcox (1957): “There is a relatively large increase in the tonnage of both sodium and chloride from the upper to the lower stations... [that can be] attributed to the displacement of salty groundwater in the course of irrigation and drainage operations.”

Hypothesis 3: “Continental solute erosion”

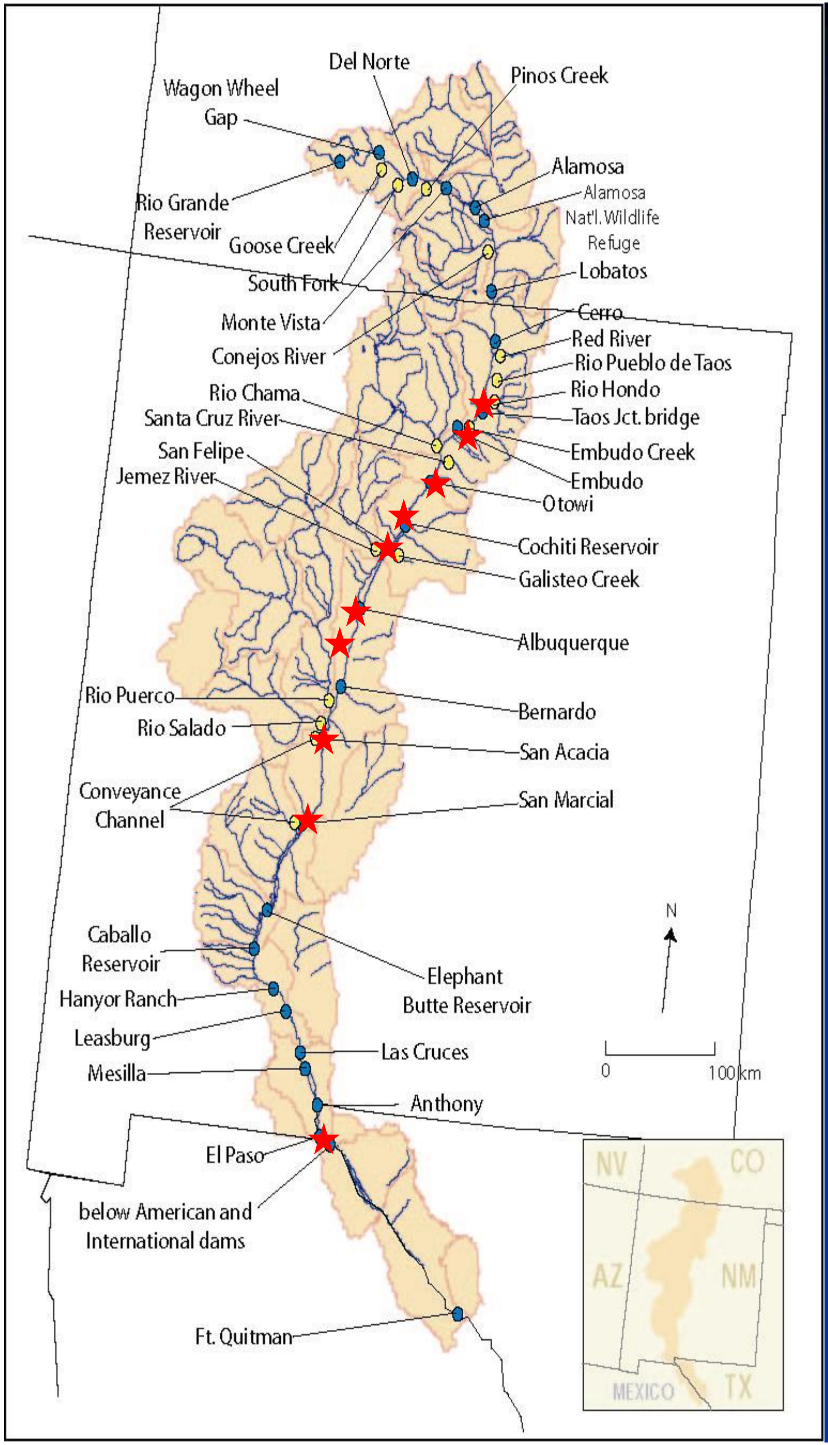
van Denburgh and Feth (1965): Noted that only 4.2% of the chloride burden of the Rio Grande originated from atmospheric deposition over the catchment and attributed the remainder to“continental solute erosion”.

How to Quantify Sources and Causes of Salinization?

- Traditional approach: Measure discharge and salt concentrations at gaging stations and compute salt burden
- Alternative Approach: Measure environmental tracers at high spatial resolution and employ dynamic simulation to interpret results

Potential Tracers

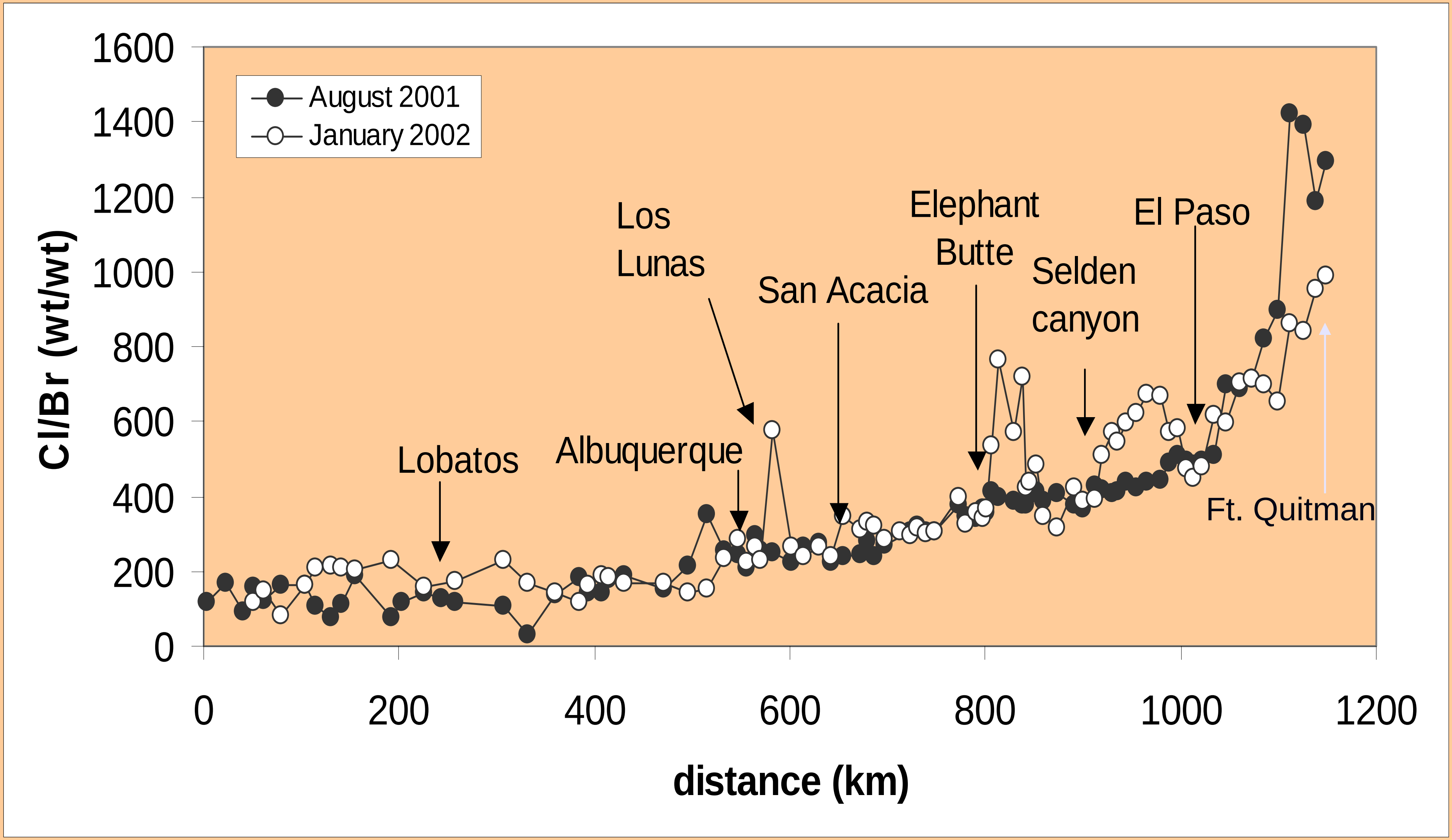
- Cl
- Cl/Br
- ^{36}Cl
- $\delta^{37}Cl$
- $\delta^{18}O$ and $\delta^{2}H$
- $^{87}Sr/^{86}Sr$
- $^{234}U/^{238}U$



Sampling locations along the Rio Grande

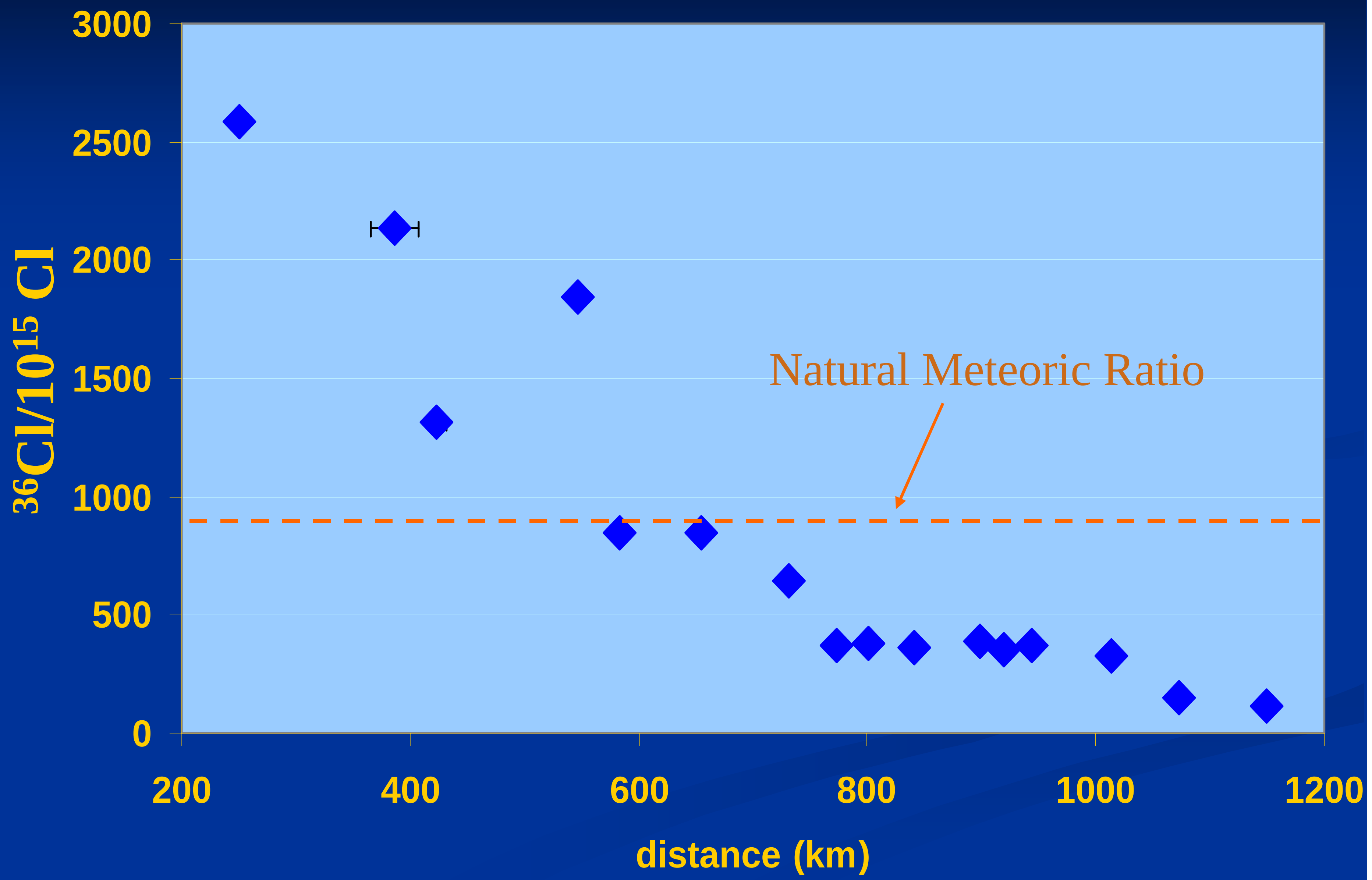
Chloride/Bromide Data

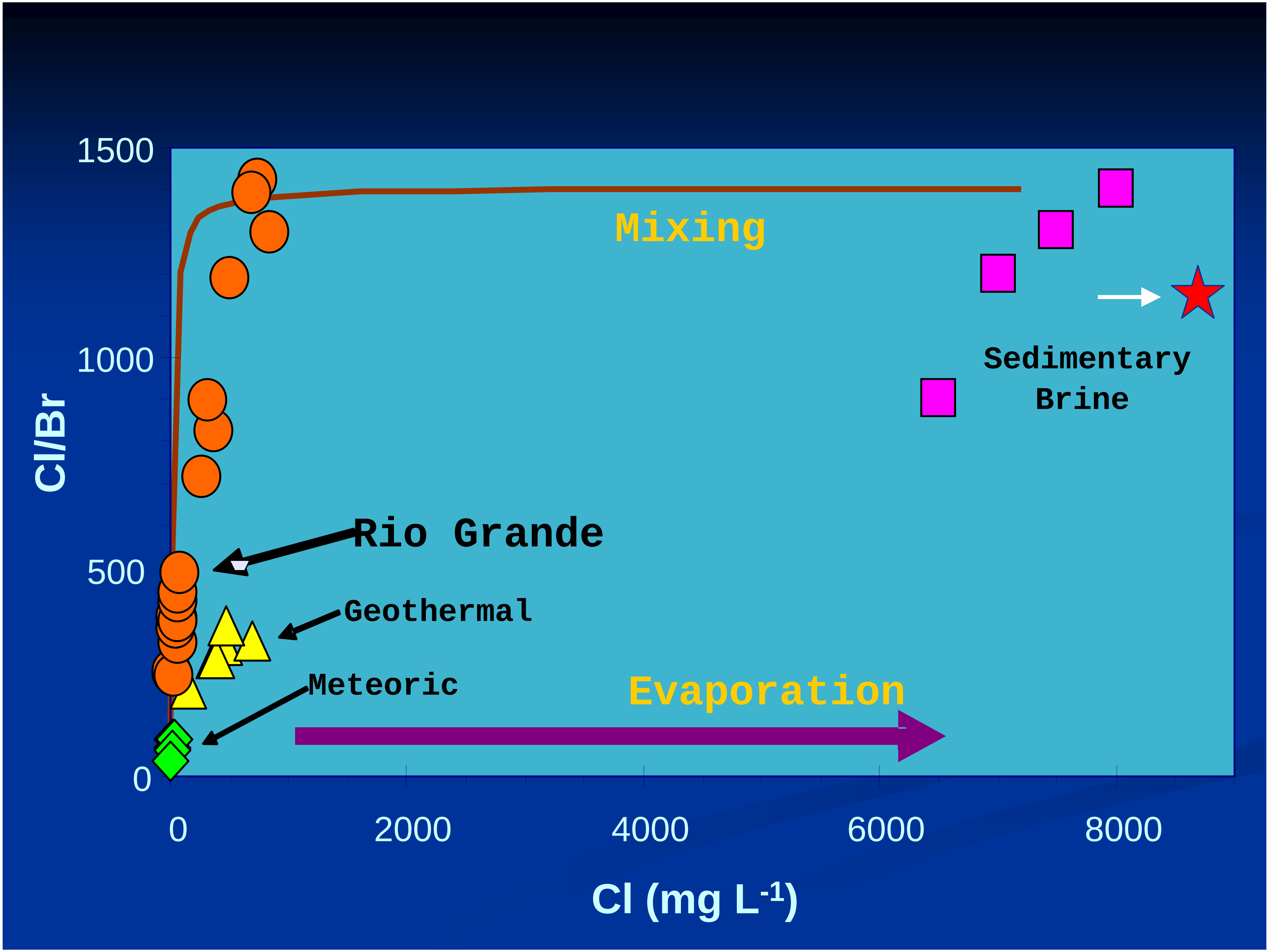
Patterns of Salt Addition cont'd: Cl/Br in the Rio Grande



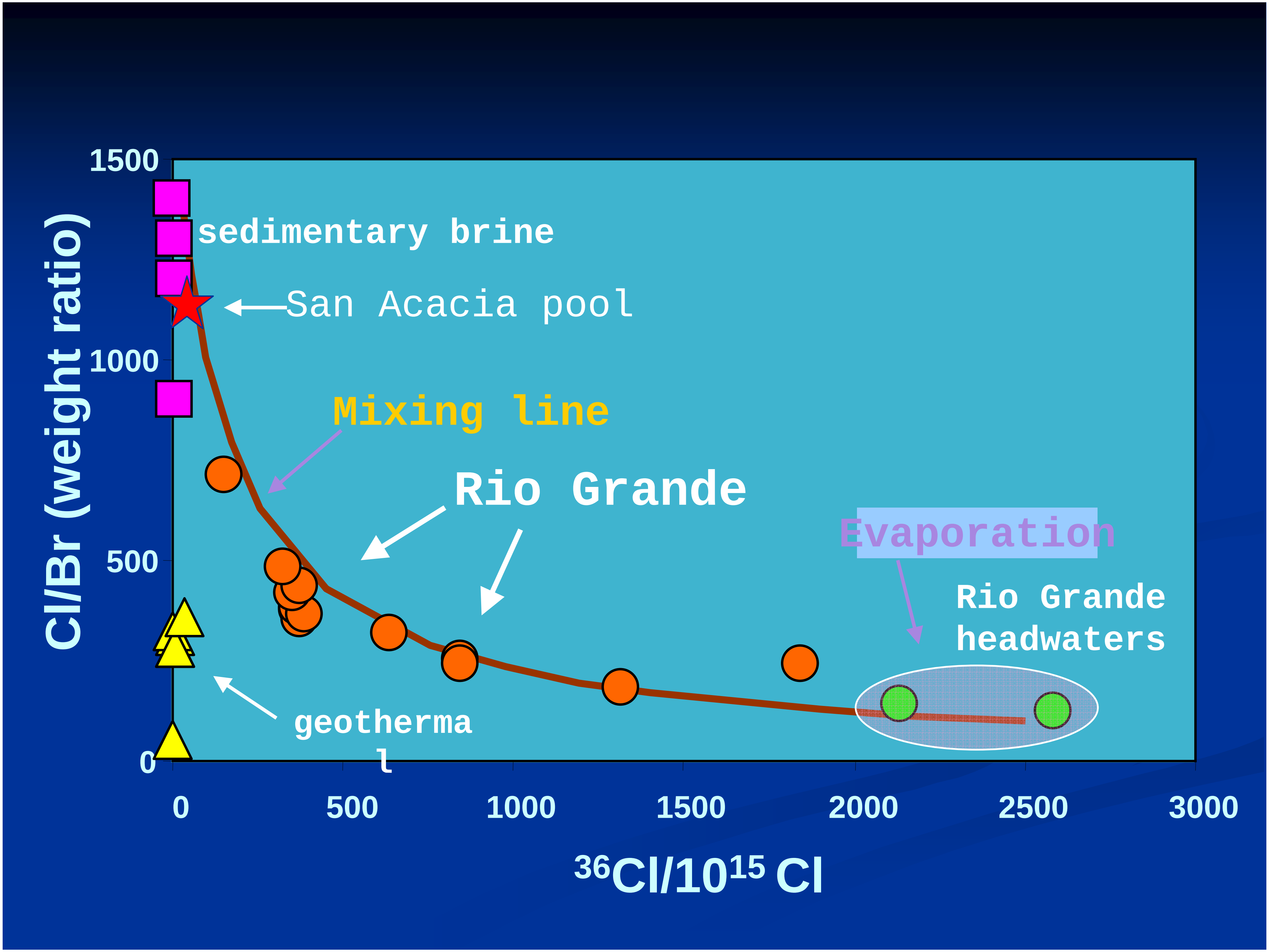
Chlorine-36 Data

^{36}Cl vs. flow distance





1500
1000
500
0
Cl/Br
Mixing
Sedimentary
Brine
Rio Grande
Geothermal
Meteoric
Evaporation
0
2000
4000
6000
8000
Cl (mg L-1)



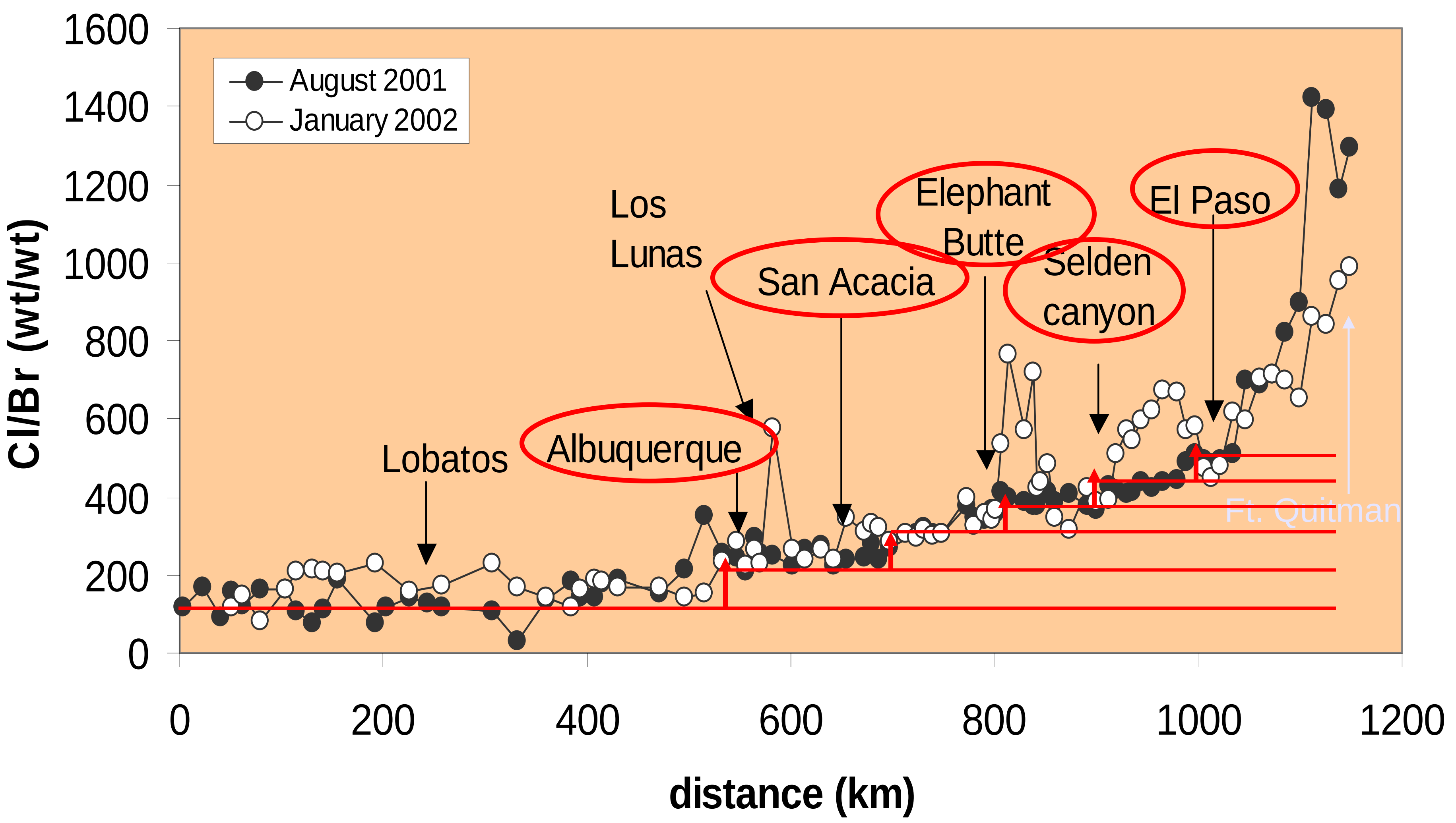
1500
1000
500
0
sedimentary brine
San Acacia pool
Mixing line
Rio Grande
Evaporation
Rio Grande
headwaters
geotherma
l
0
500
1000
1500
2000
2500
3000
Cl/Br (weight ratio)
$^{36}Cl/10^{15}$ Cl

Result from tracer work

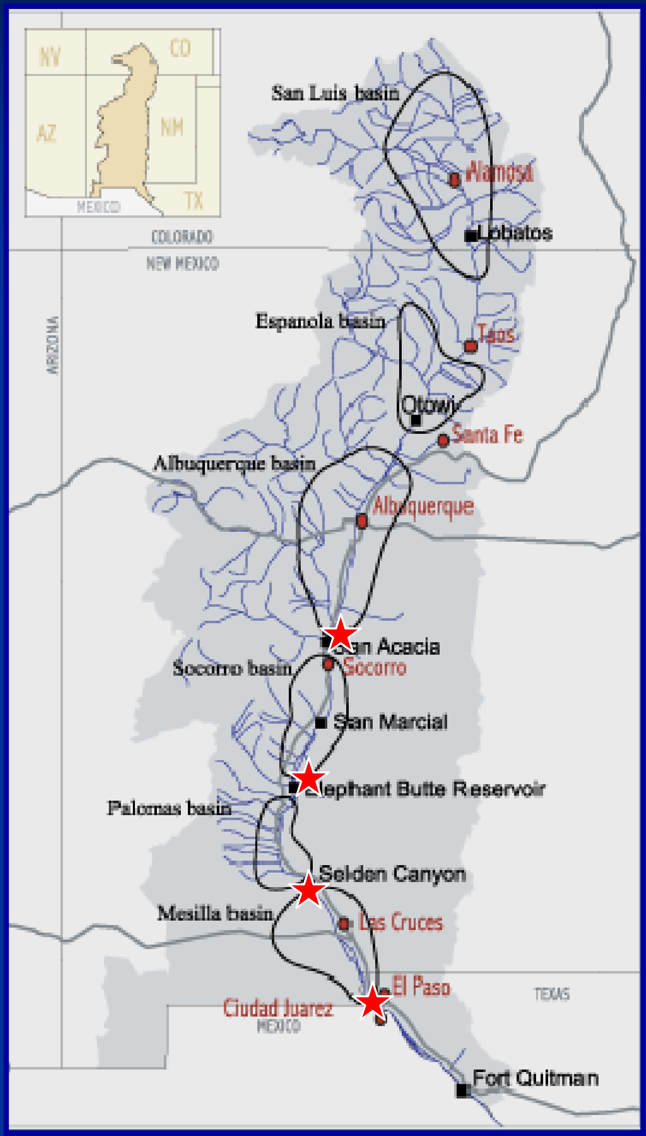
A large part of the salinization of the Rio Grande is due to seepage of deep, sedimentary-origin brines

Where are these brines entering the Rio Grande?

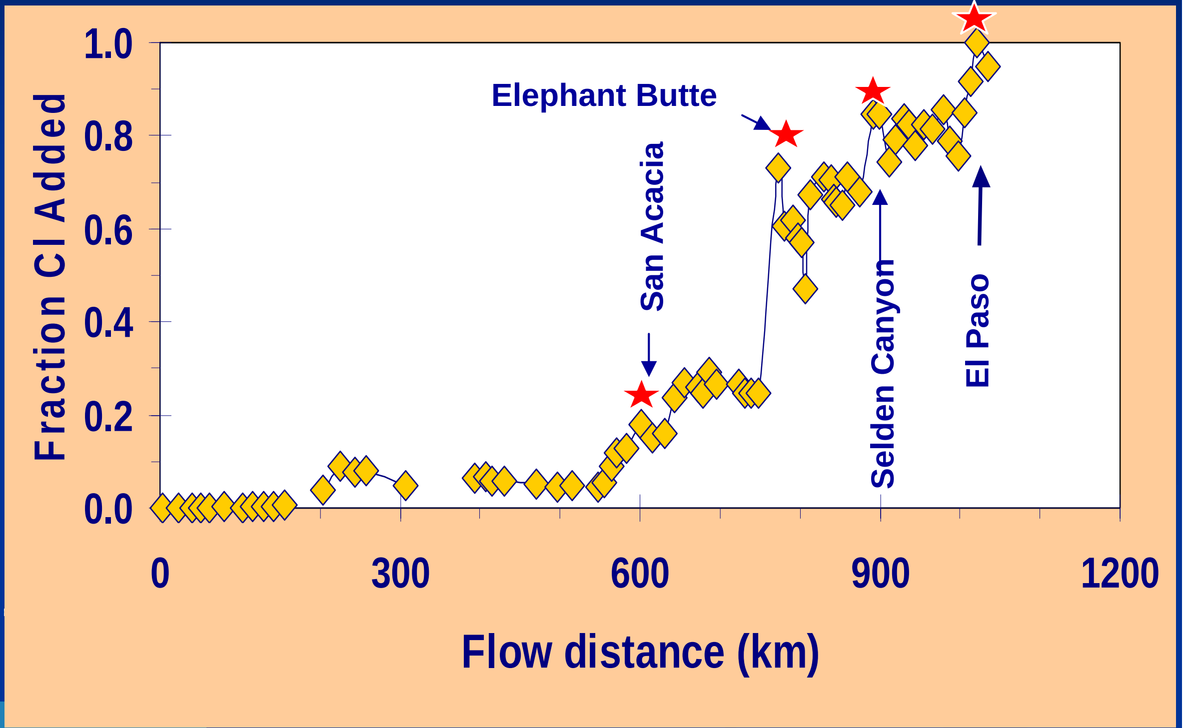
Patterns of Salt Addition cont'd: Cl/Br in the Rio Grande



Points of Salt Addition

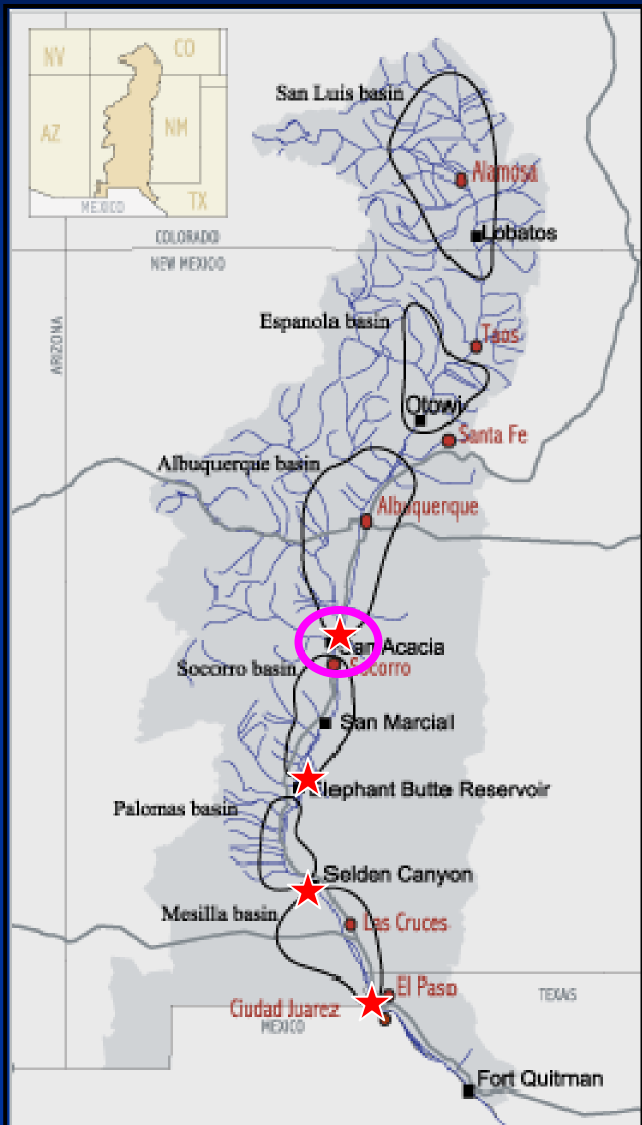


Fraction Cl Added vs. flow distance

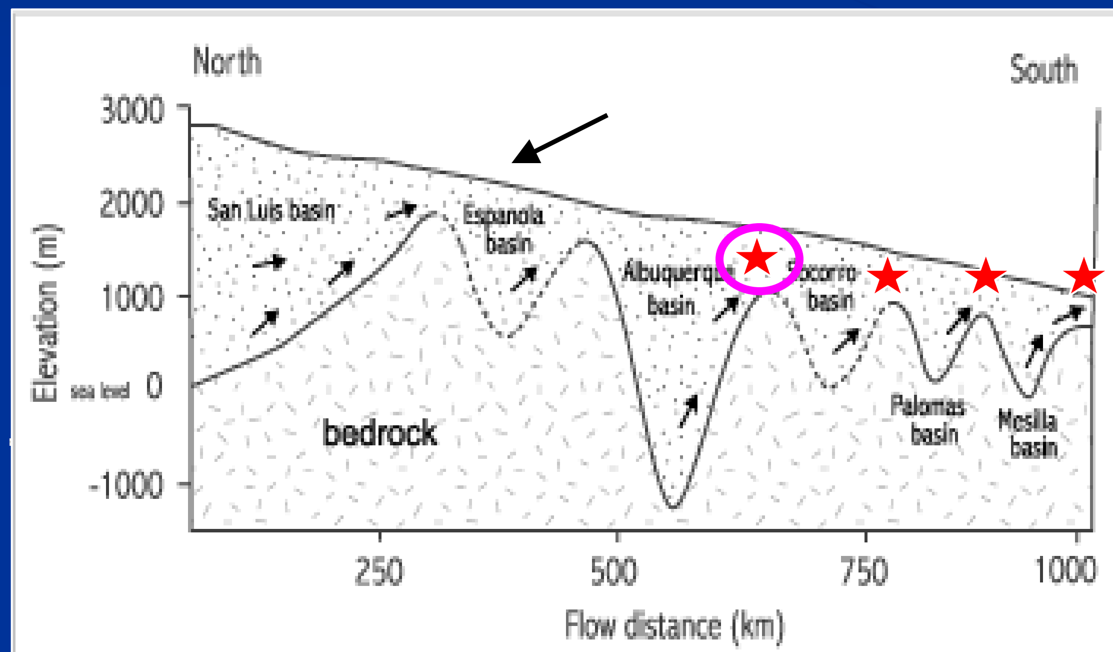


★ = basin terminus

Basin Groundwater Systems



Schematic Hydrogeologic Cross-Section, Parallel to River Path



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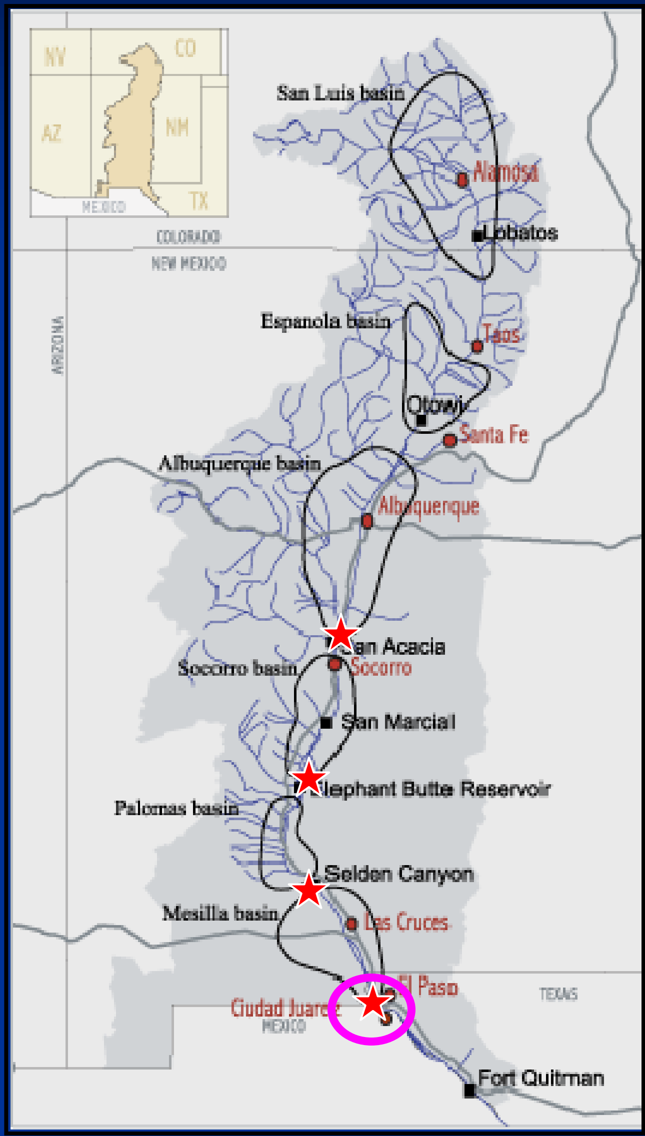
Saline input: San Acacia pool

[Cl^-] = 32,300 mg L^{-1}

salt-encrusted tree stumps

Basin Groundwater Systems



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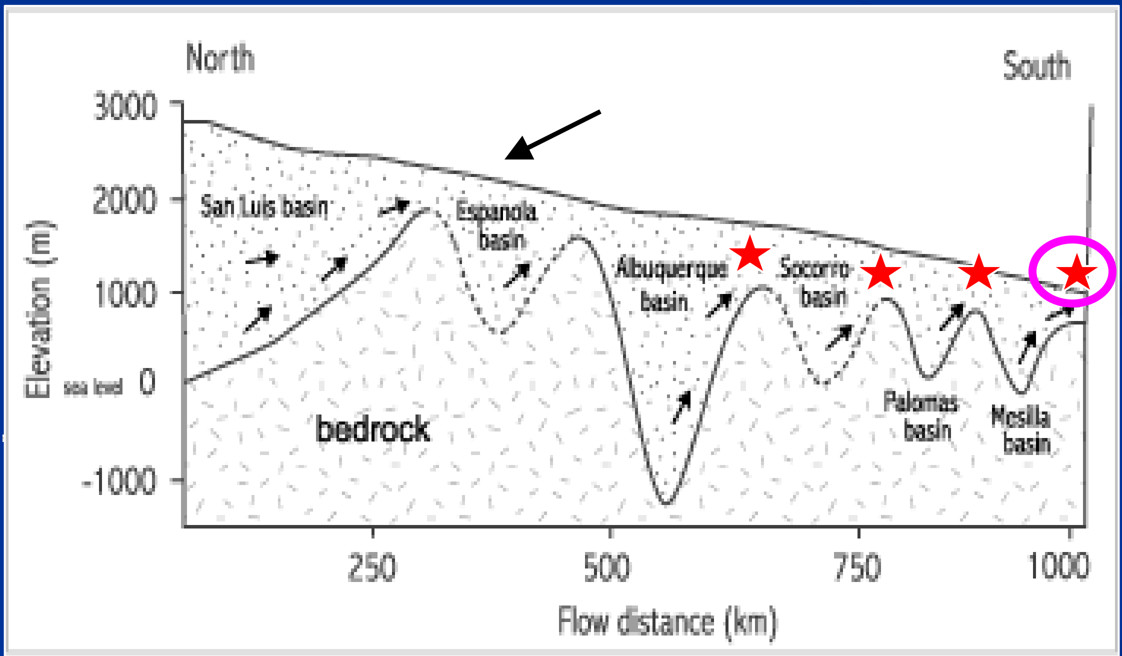
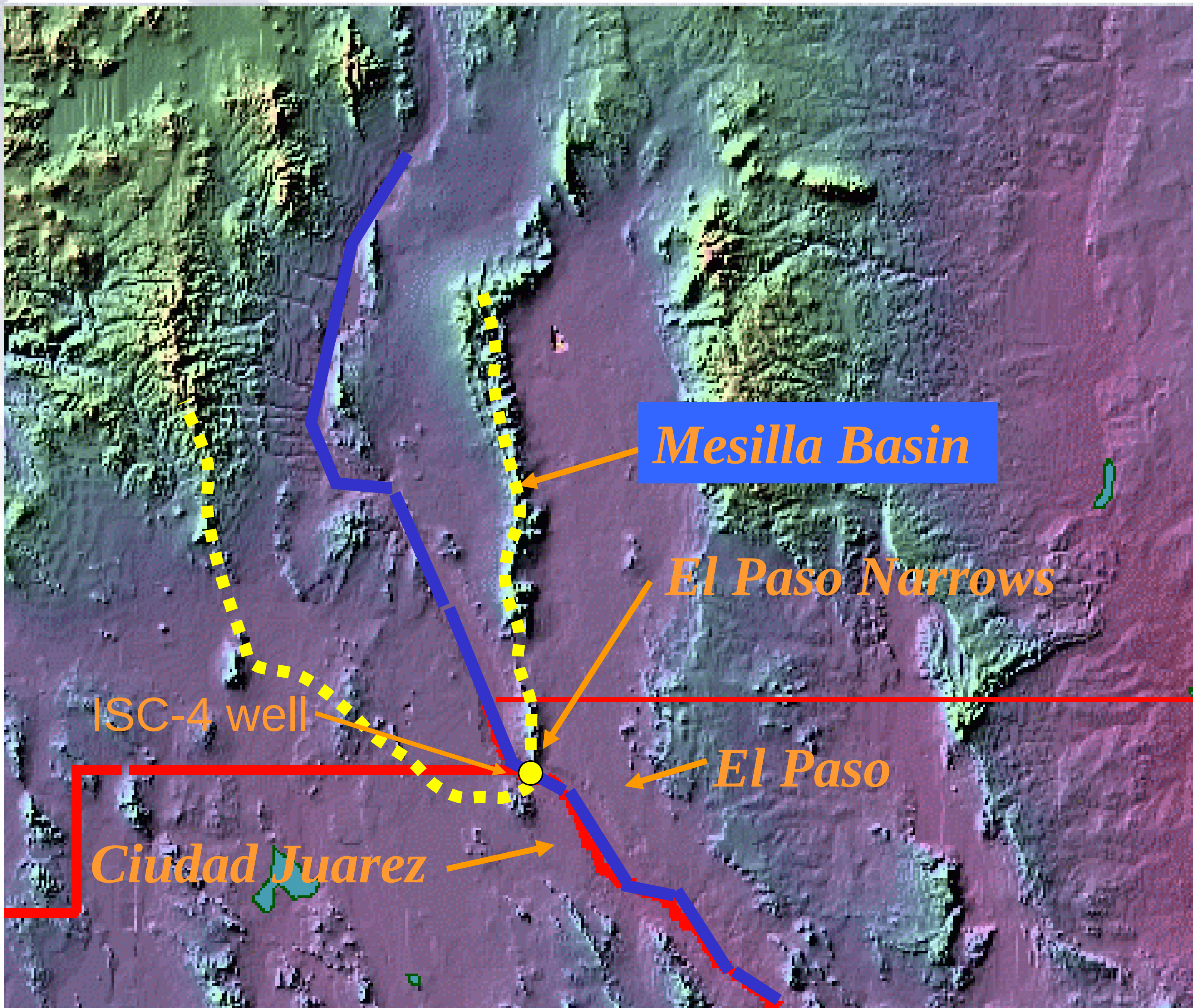
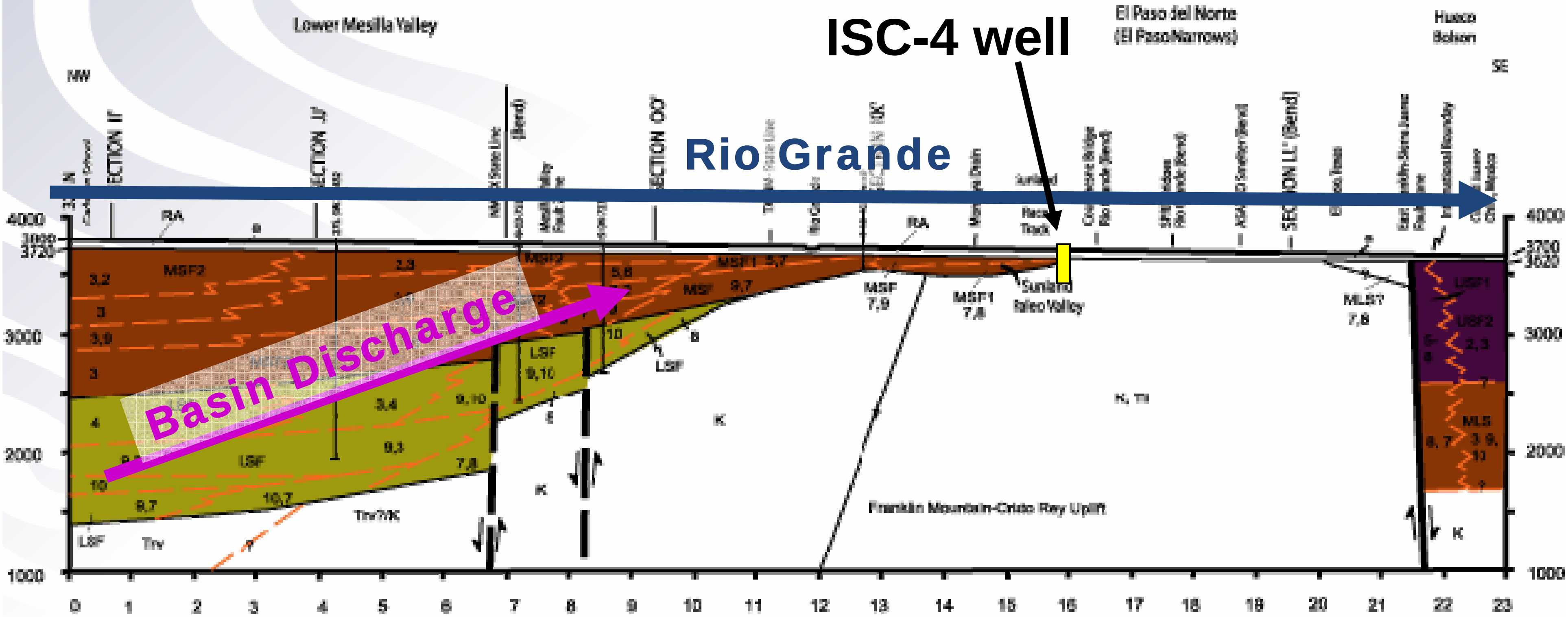


★ = basin terminus

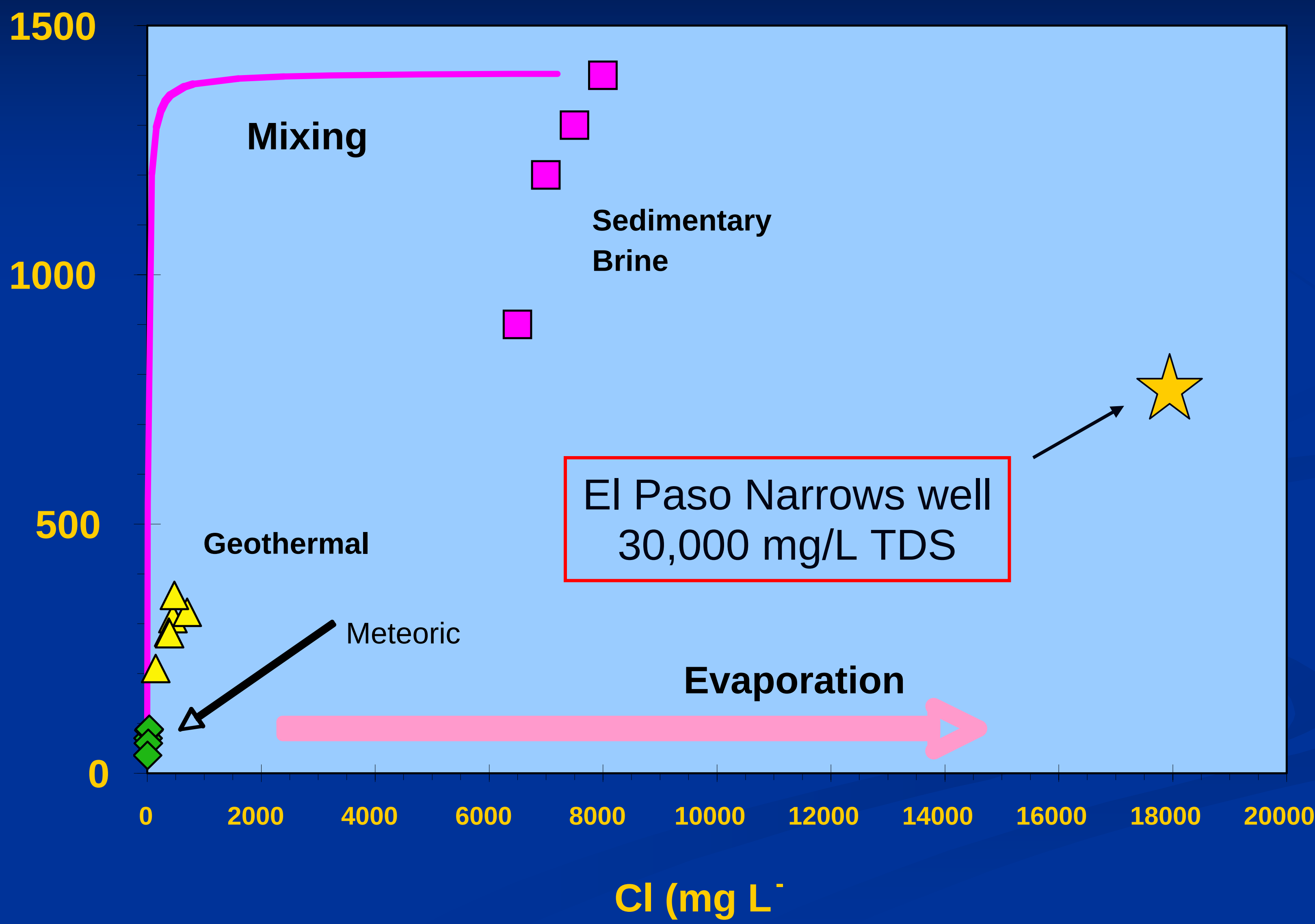

Mesilla Basin
El Paso Narrows
ISC-4 well
El Paso
Ciudad Juarez

El Paso del Norte



- Cross section through Paso del Norte along Rio Grande
- Basin flow from Mesilla basin forced up
- Recharge when entering the Hueco Bolson

El Paso Narrows well results

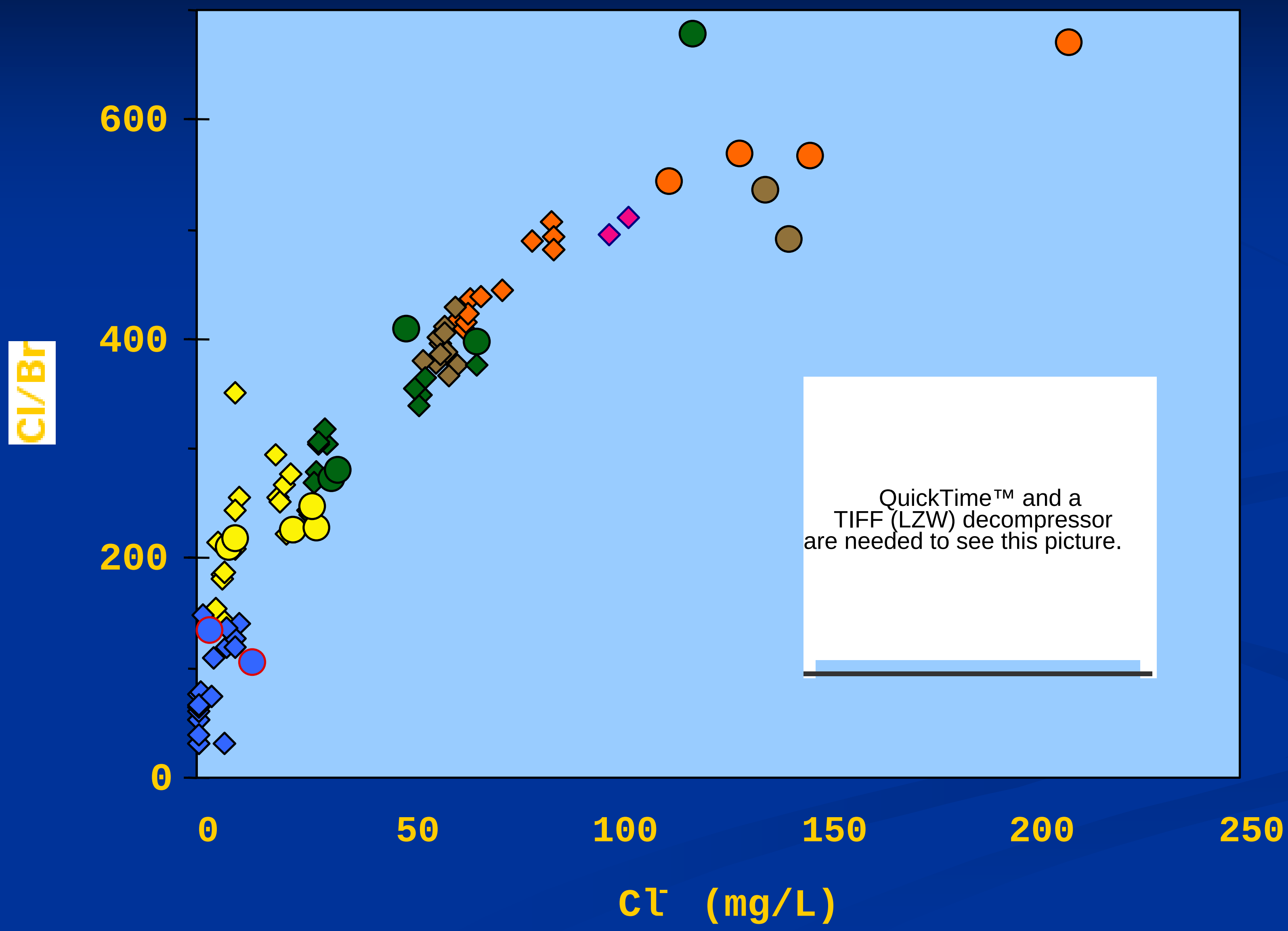


Findings from subsurface investigations

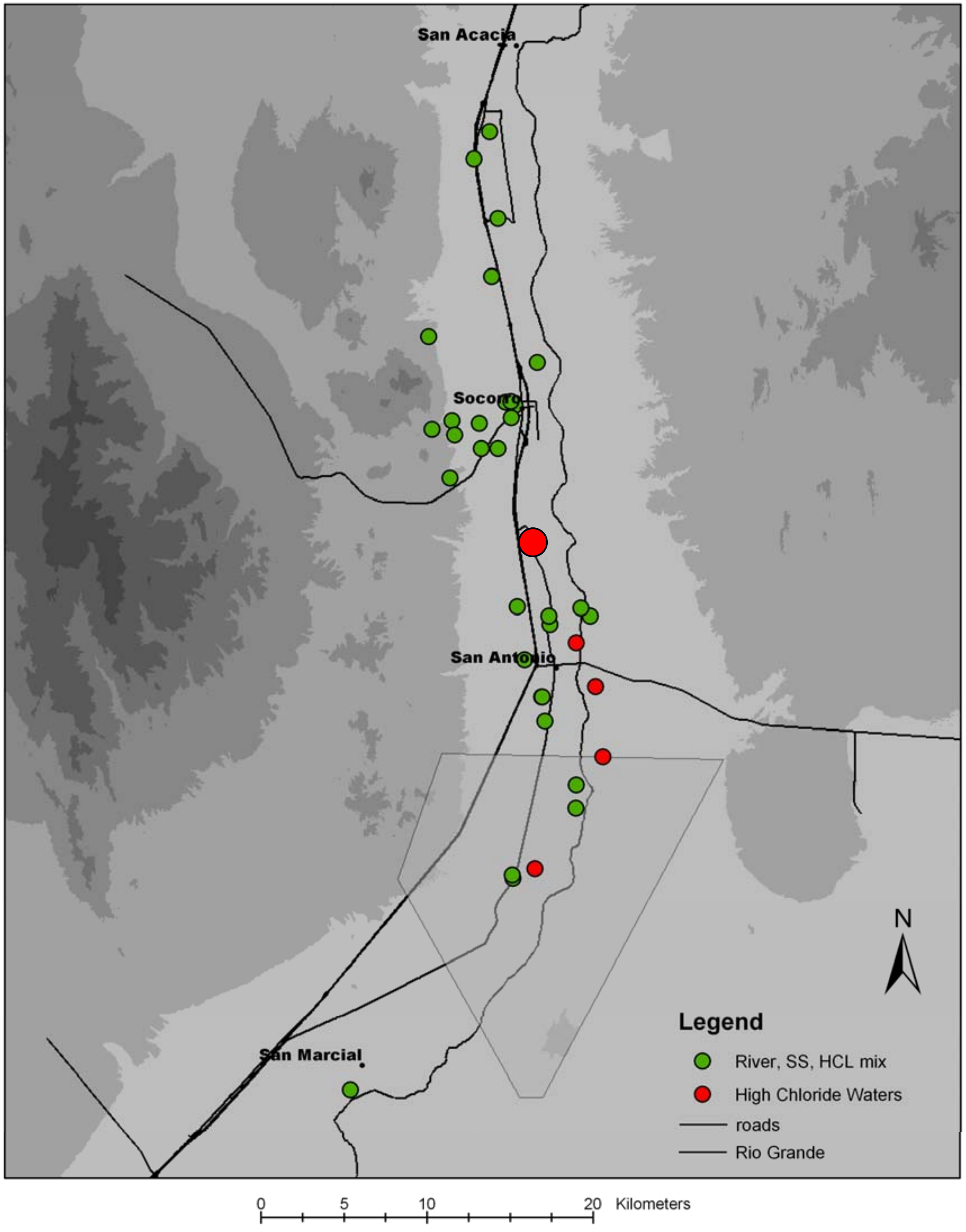
Sites of brine leakage along structurally-controlled pathways can be clearly identified in the field

Role of agriculture?

Influence of Drains

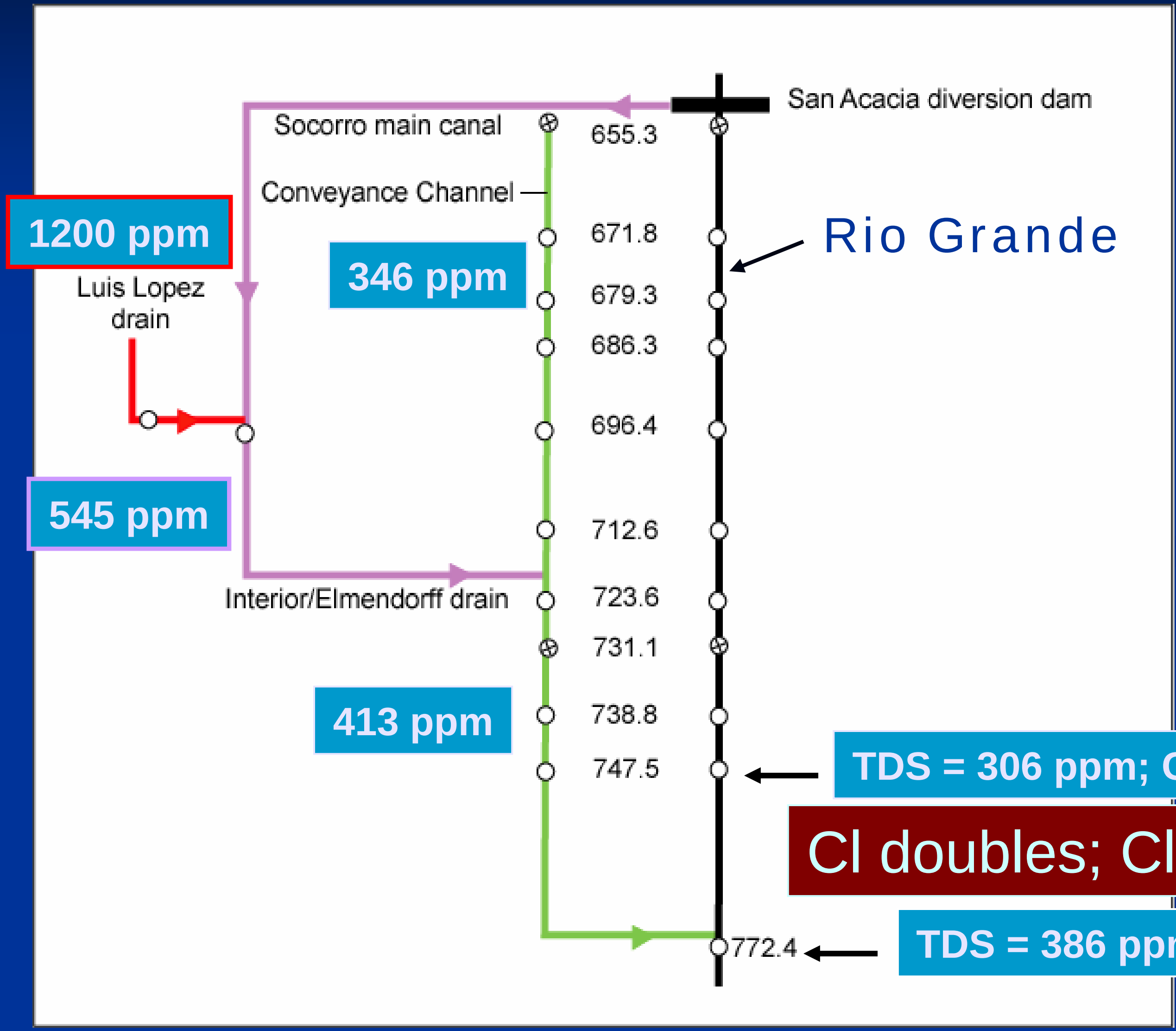


Location of high chloride waters



Talon Newton, M.S. Thesis, 2004

Drains pick up deep-basin salts



TDS = 306 ppm; Cl = 30 ppm; Cl/Br = 306

Cl doubles; Cl/Br increases 30%

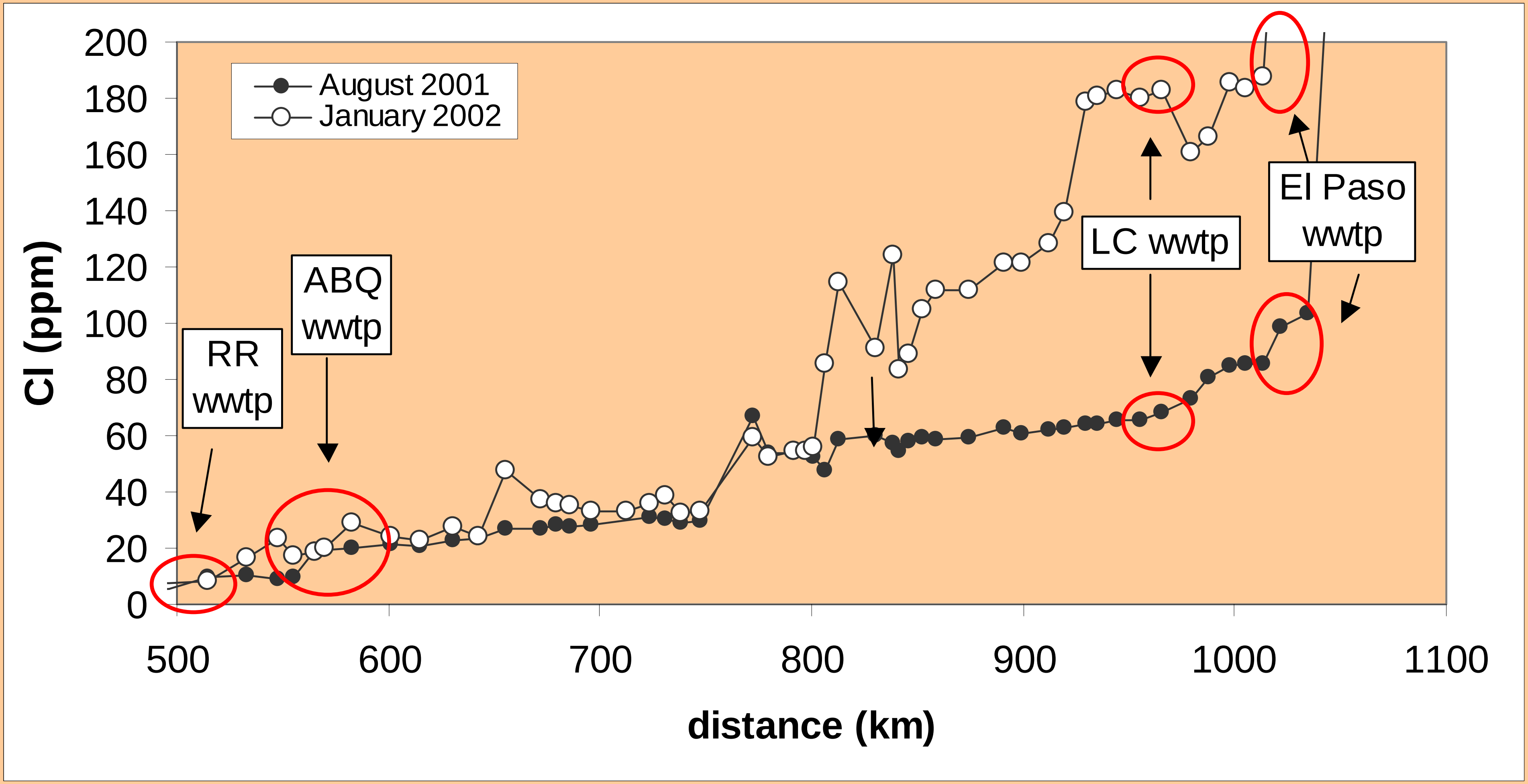
TDS = 386 ppm; Cl = 66 ppm; Cl/Br = 376

Summary of Findings

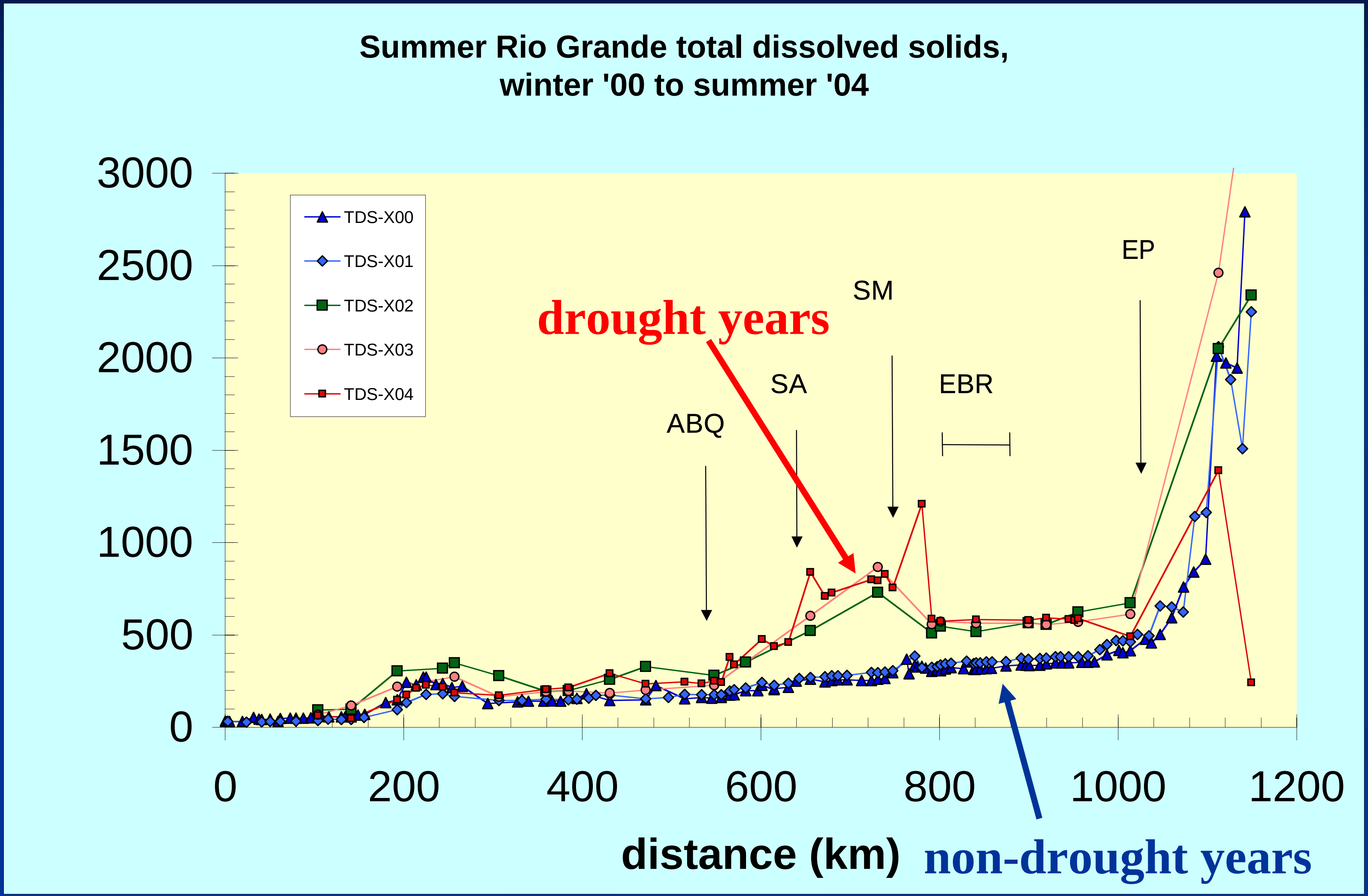
- Salt addition to the Rio Grande occurs in a stepwise pattern
- Salt is added at San Acacia, Elephant Butte, Selden Canyon, and the El Paso narrows (and T or C)
- Salt is either connate or from long-term rock/water interaction

Influence of wastewater

The Rio Rancho, Albuquerque, Las Cruces, and El Paso (Northwest WWTP) wastewater effluents all increase Cl^- and Cl/Br in the river.



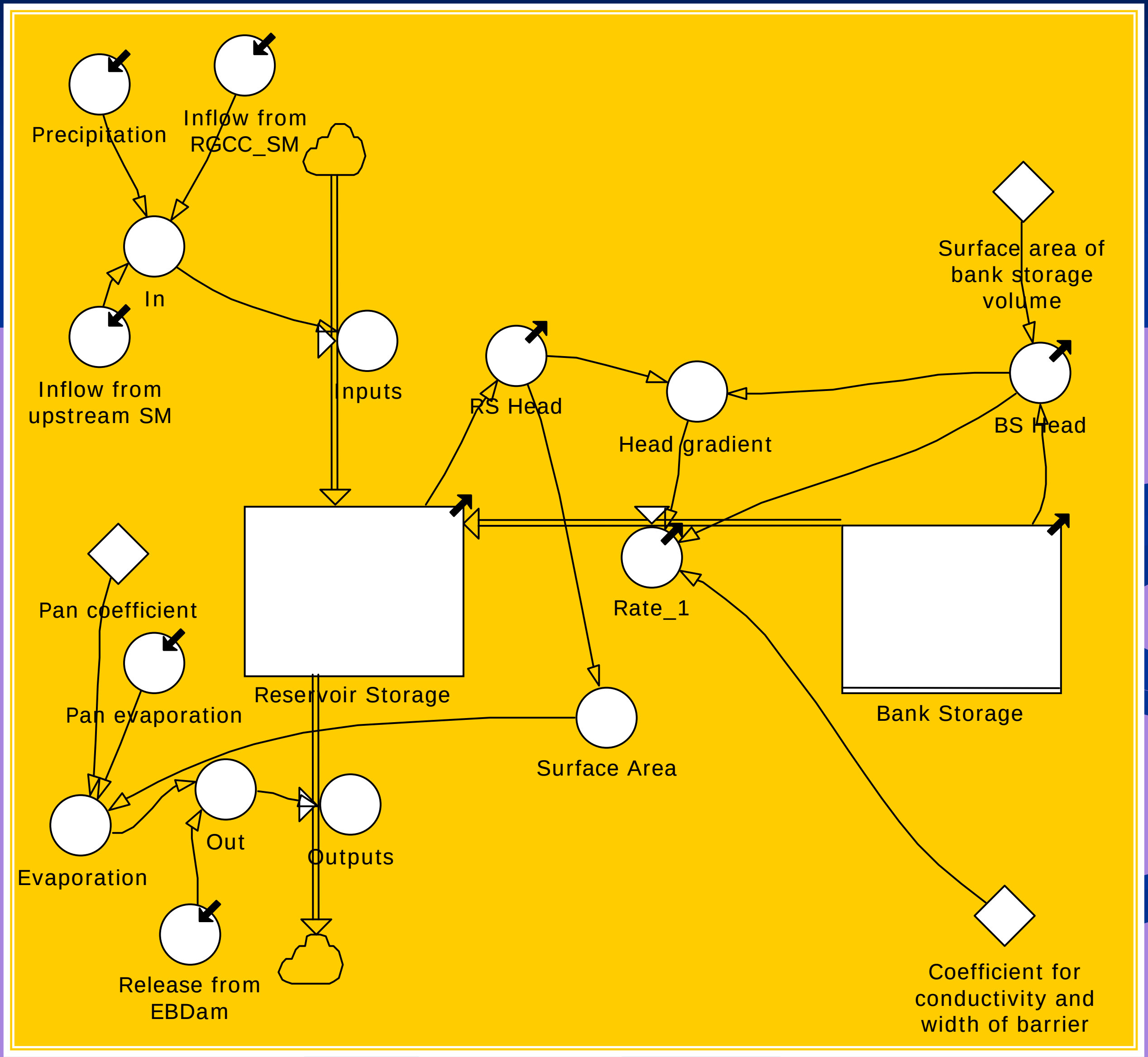
Response to drought



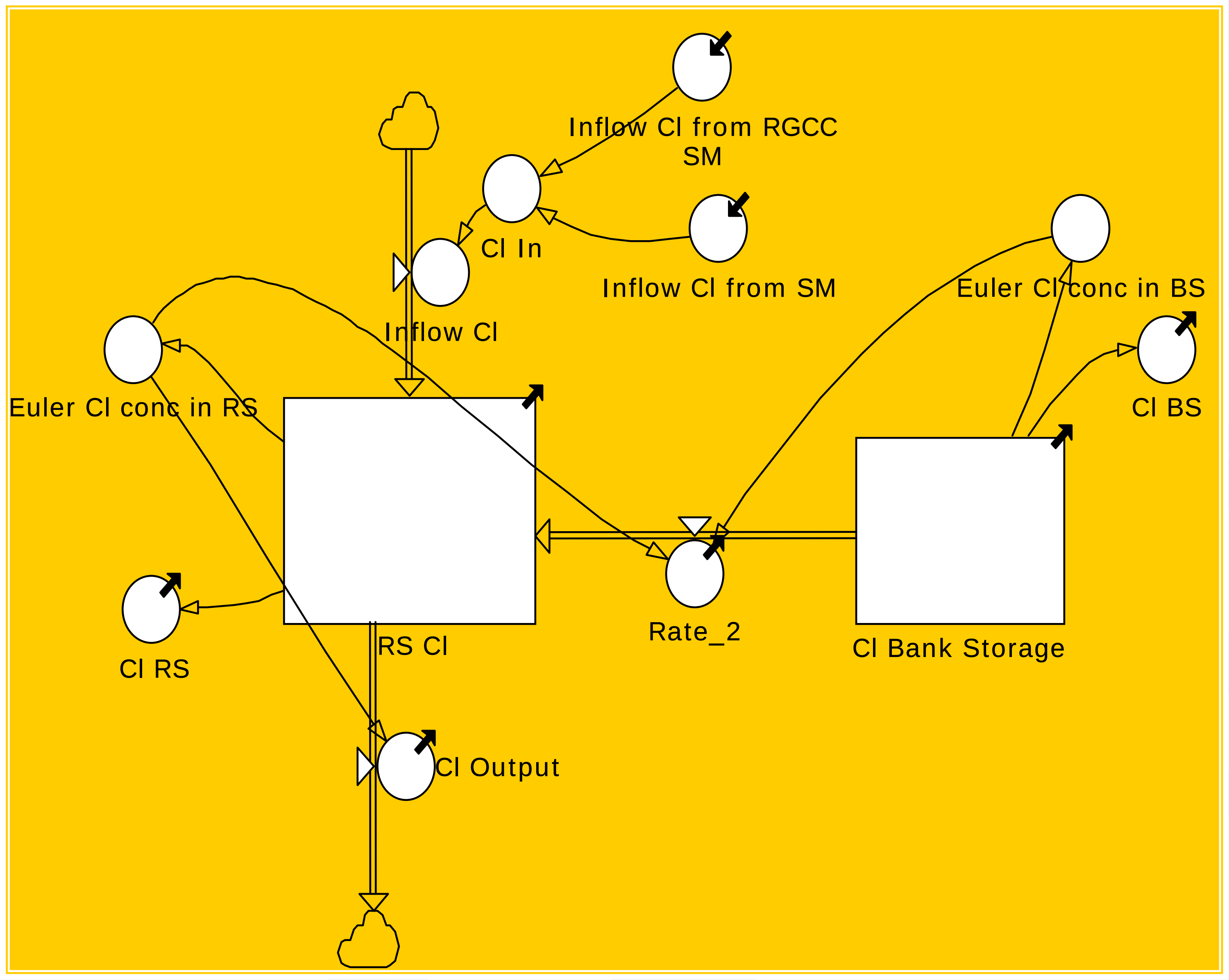
Chloride concentrations and loads are highly variable in time and location

We need a dynamic modeling tool to adequately understand budgets and variability of solutes in the Rio Grande

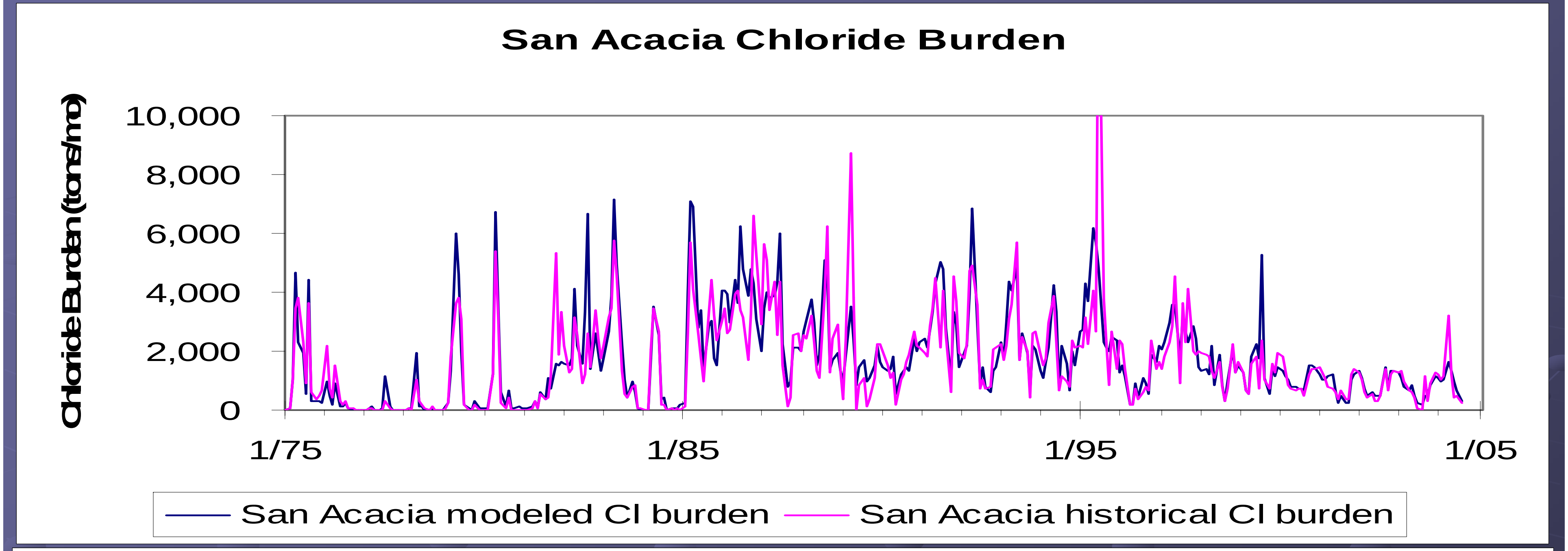
Powersim modeling - water model

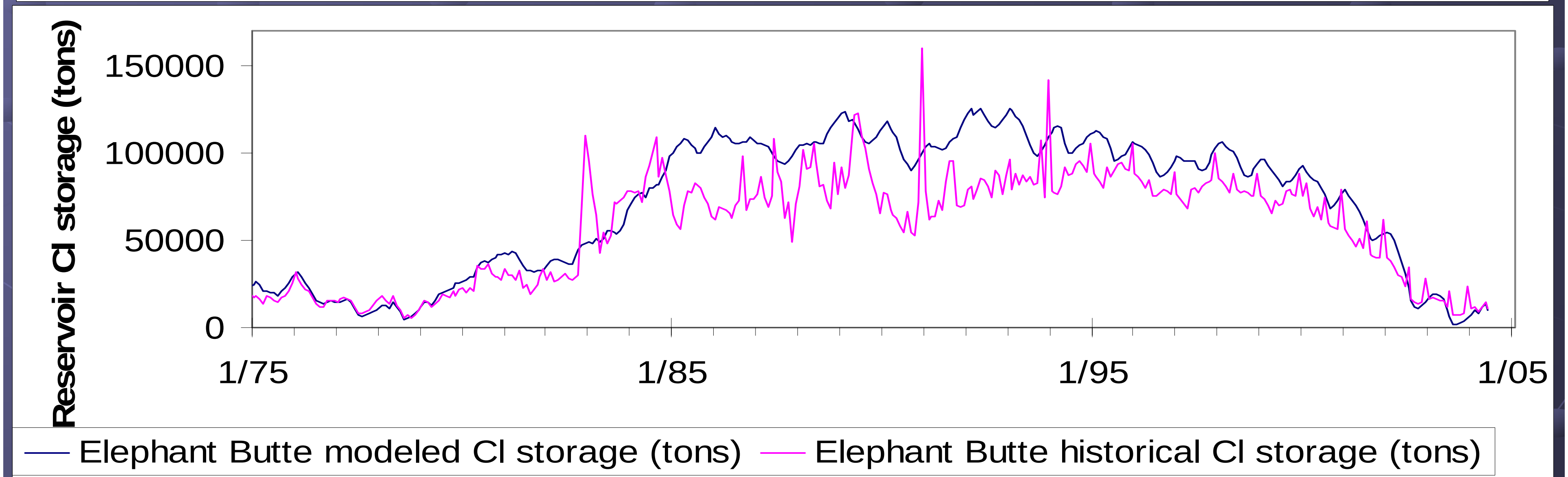


Powersim modeling - chloride model

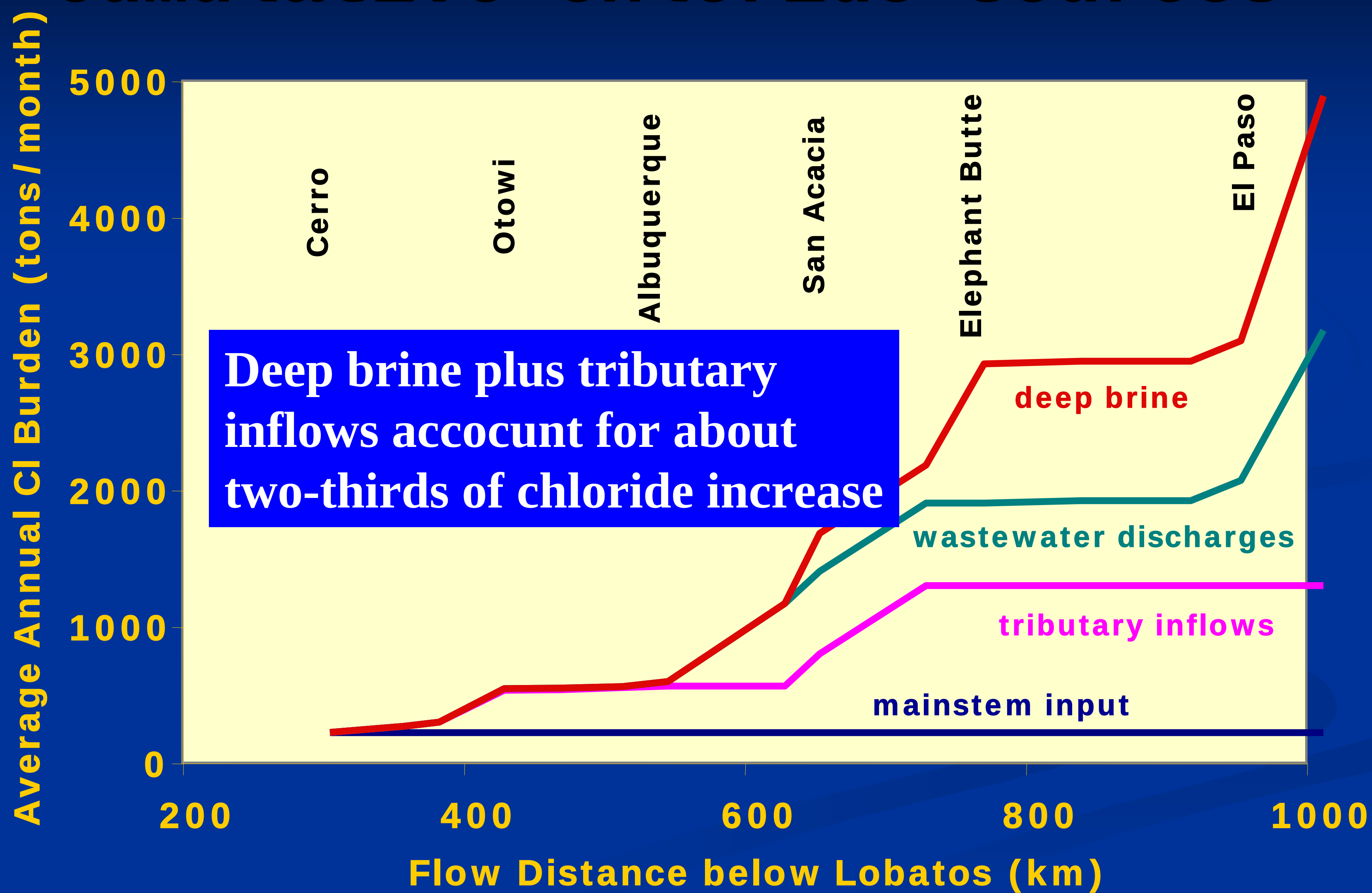


Model Results w/brine inflows: Cl burden





Cumulative Chloride Sources



Historical Perspective

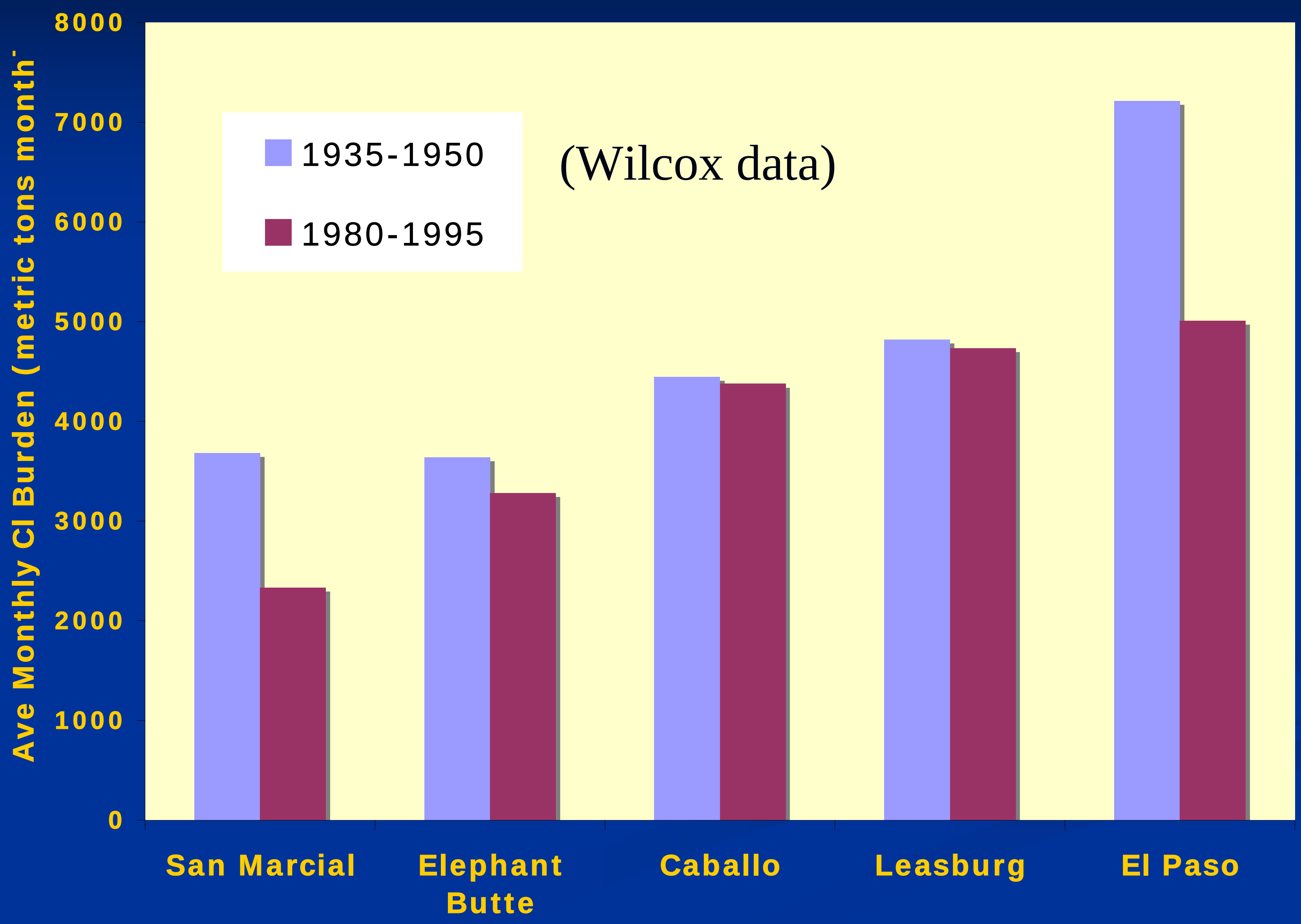
Are modern practices responsible for worsening water quality? (perhaps by increasing brine inflows?)

Two important past studies:

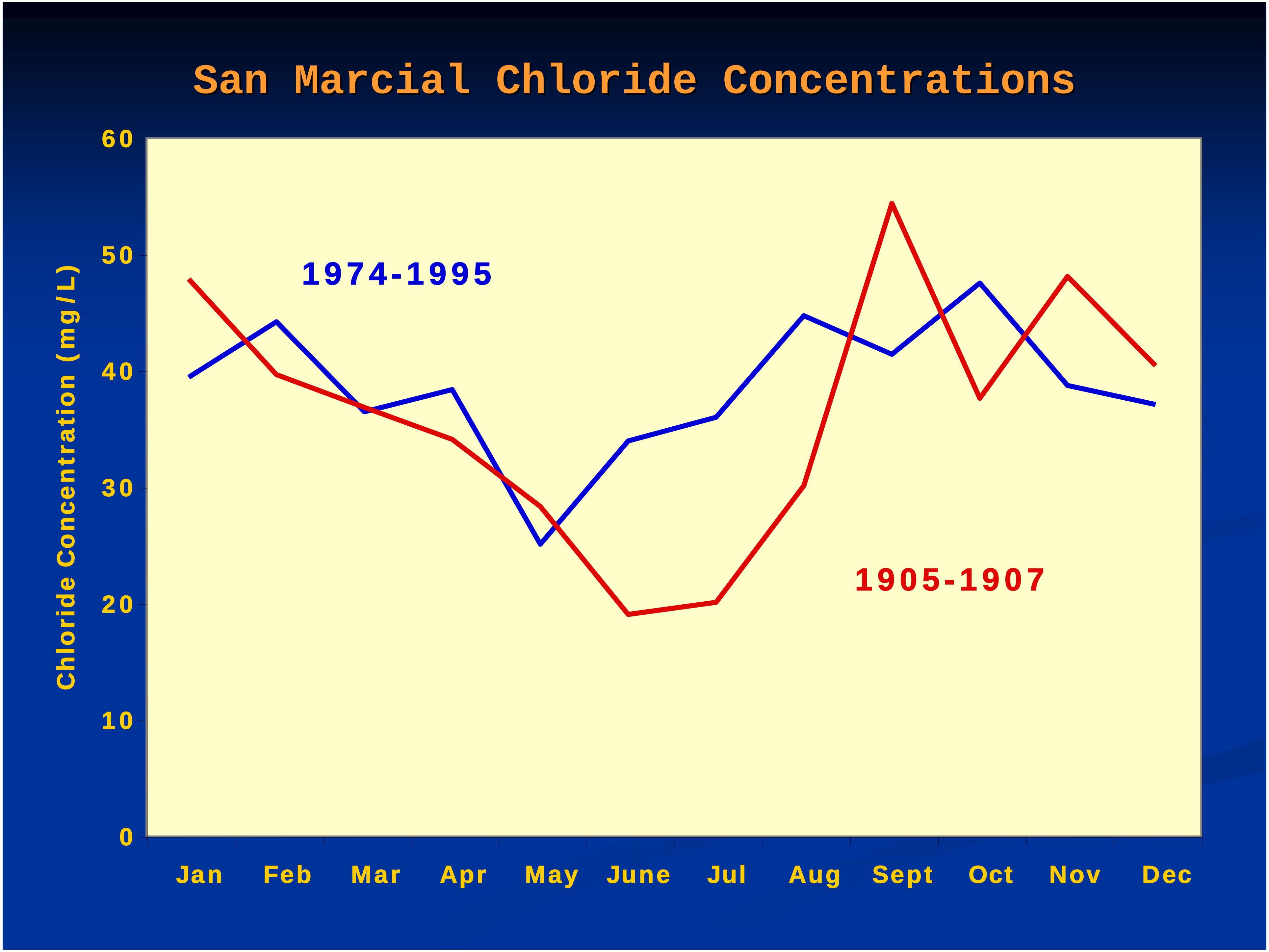
- **Wilcox 1934-1950 at many gauging stations**
- **Stabler 1905-1907 at San Marcial and El Paso**

Comparison with Wilcox (1934-1950) data set

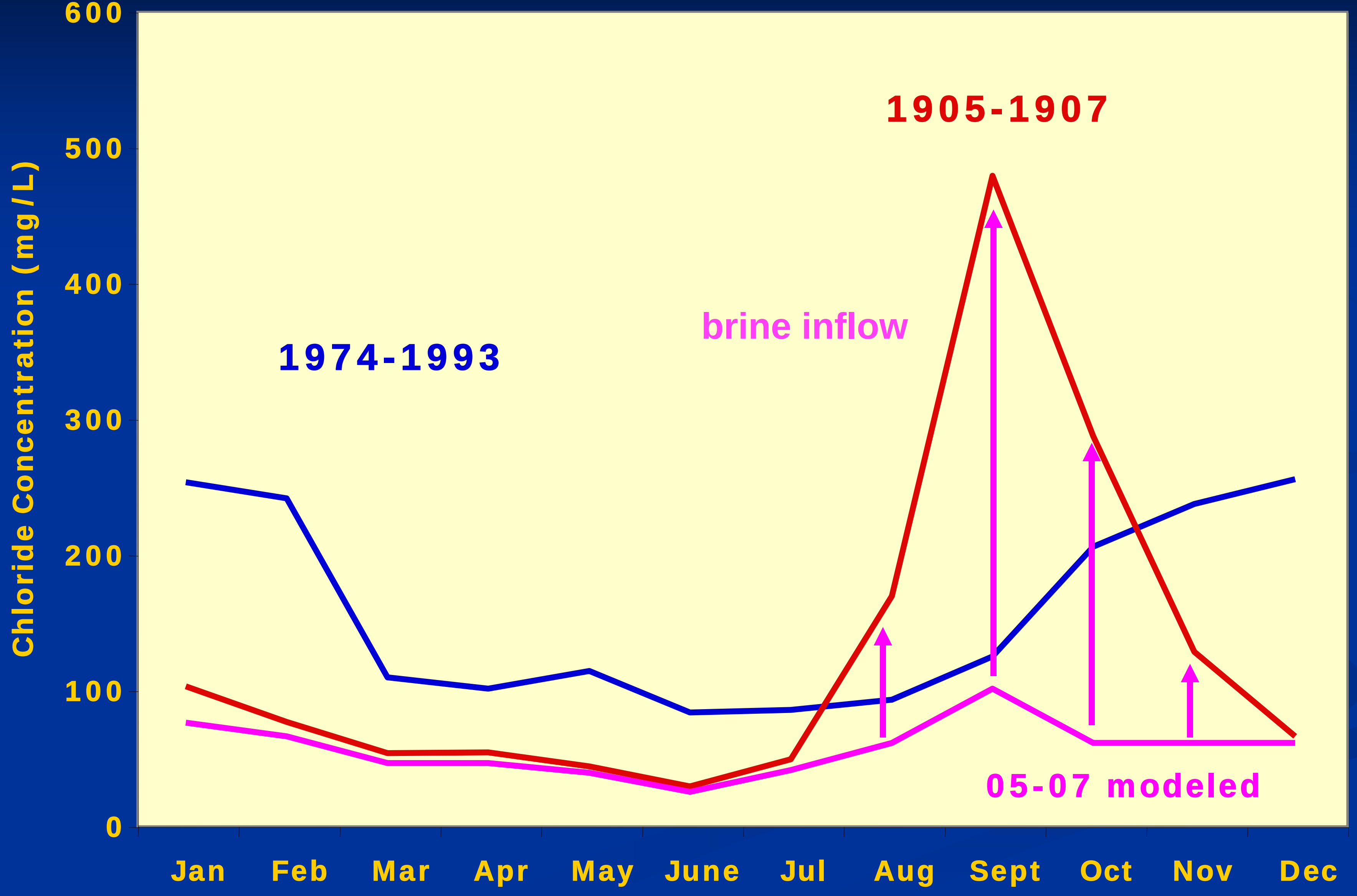
Monthly Chloride Burden



Comparison with Stabler (1905-1907) data set (before Elephant Butte Dam!)


San Marcial Chloride Concentrations
Chloride Concentration (mg/L)
60
50
40
30
20
10
0
1974-1995
1905-1907
Jan
Feb
Mar
Apr
May
June
Jul
Aug
Sept
Oct
Nov
Dec

El Paso chloride



Conclusions

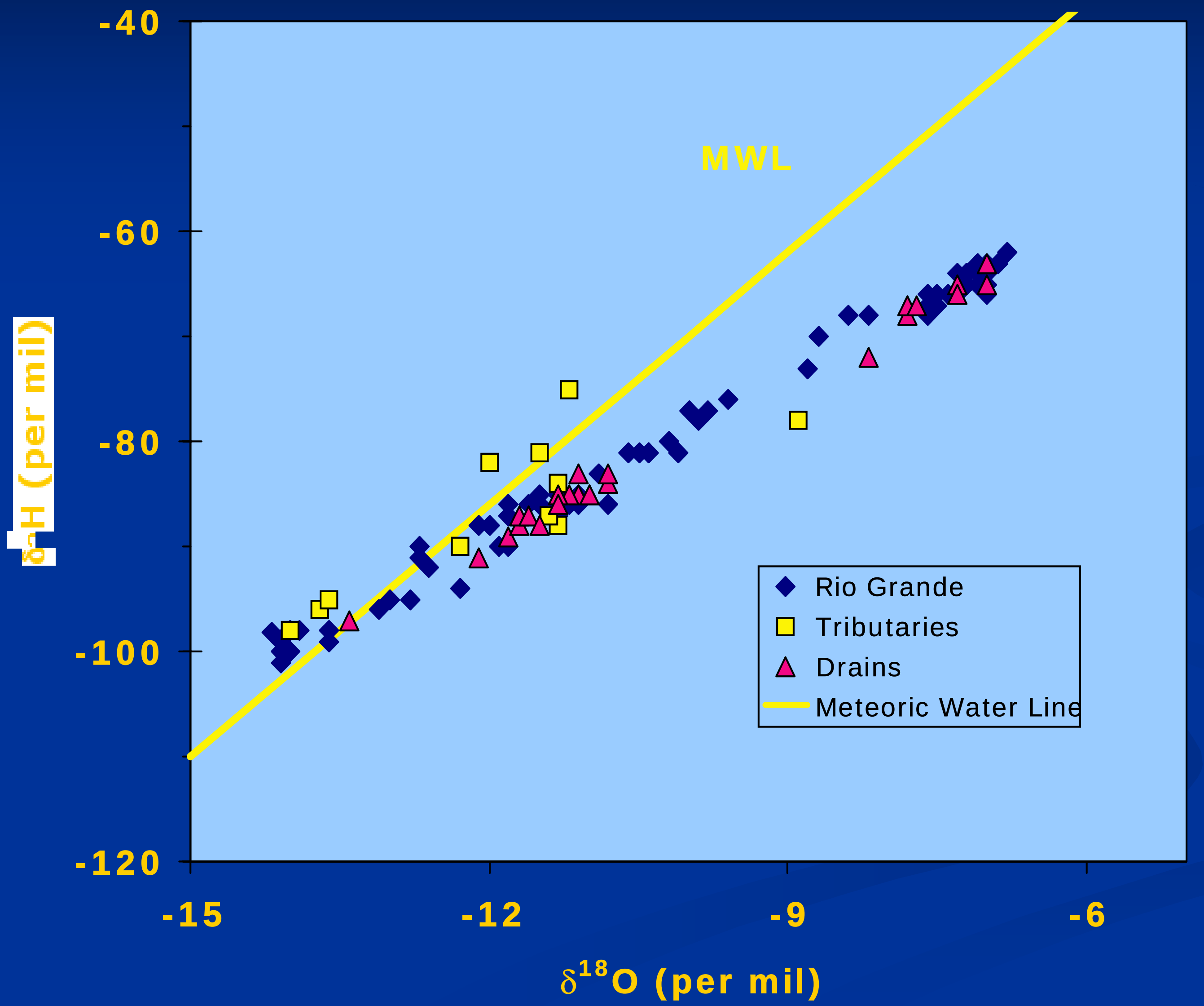
- About 2/3 of the chloride increase of the Rio Grande is from “geological salt”, either from brine leakage or tributaries
- The brine leakage is along structural features (mostly faults) and might be intercepted and pumped

Conclusions

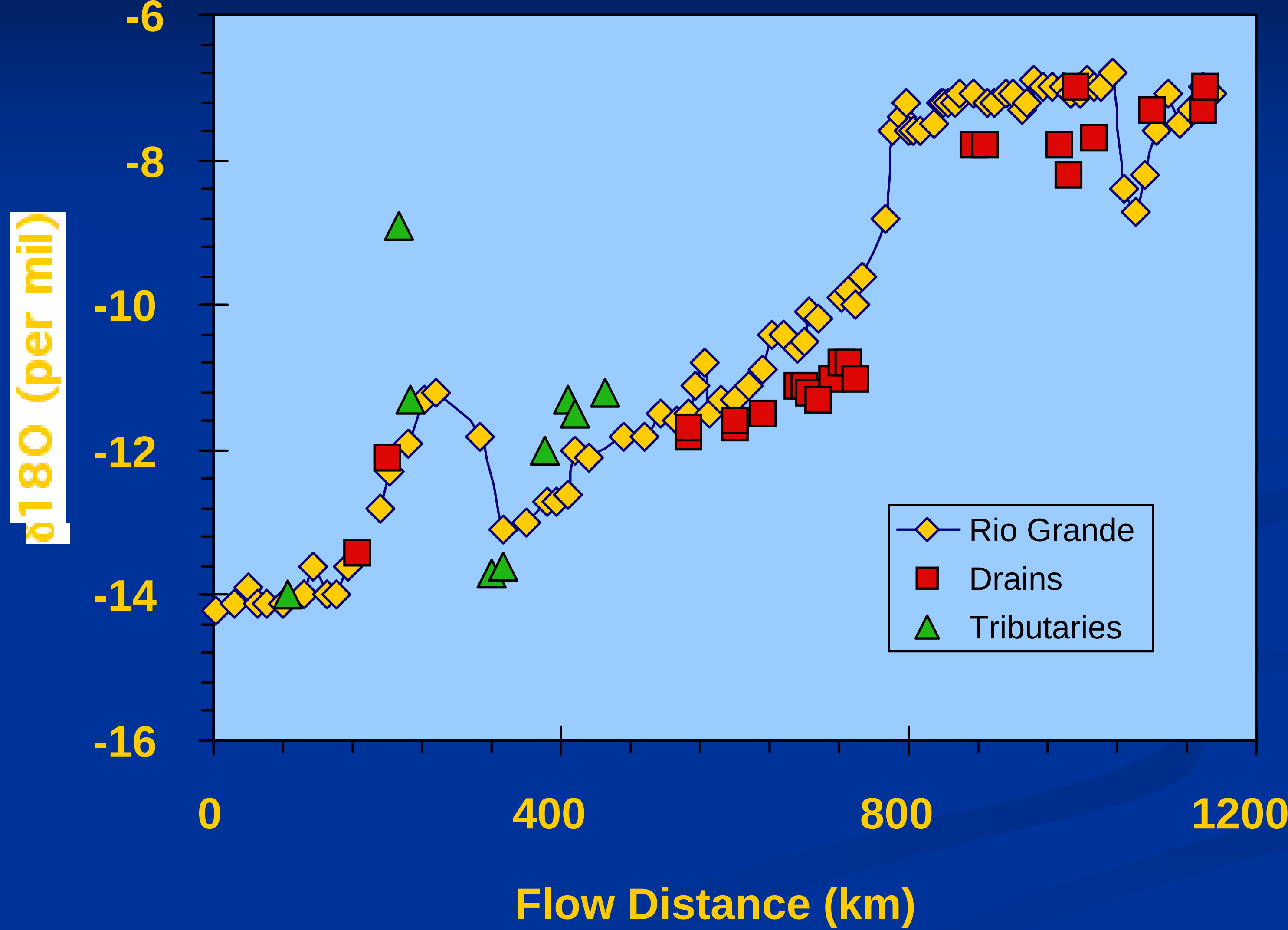
- The brine leakage predates development of the river and may have actually decreased over the 20th Century
- Agriculture contributes to the salinization of the Rio Grande but probably plays only a secondary role

Water and Salt Dynamics of the Rio Grande

$\delta^{18}O$ vs $\delta^{2}H$ (Summer '01)



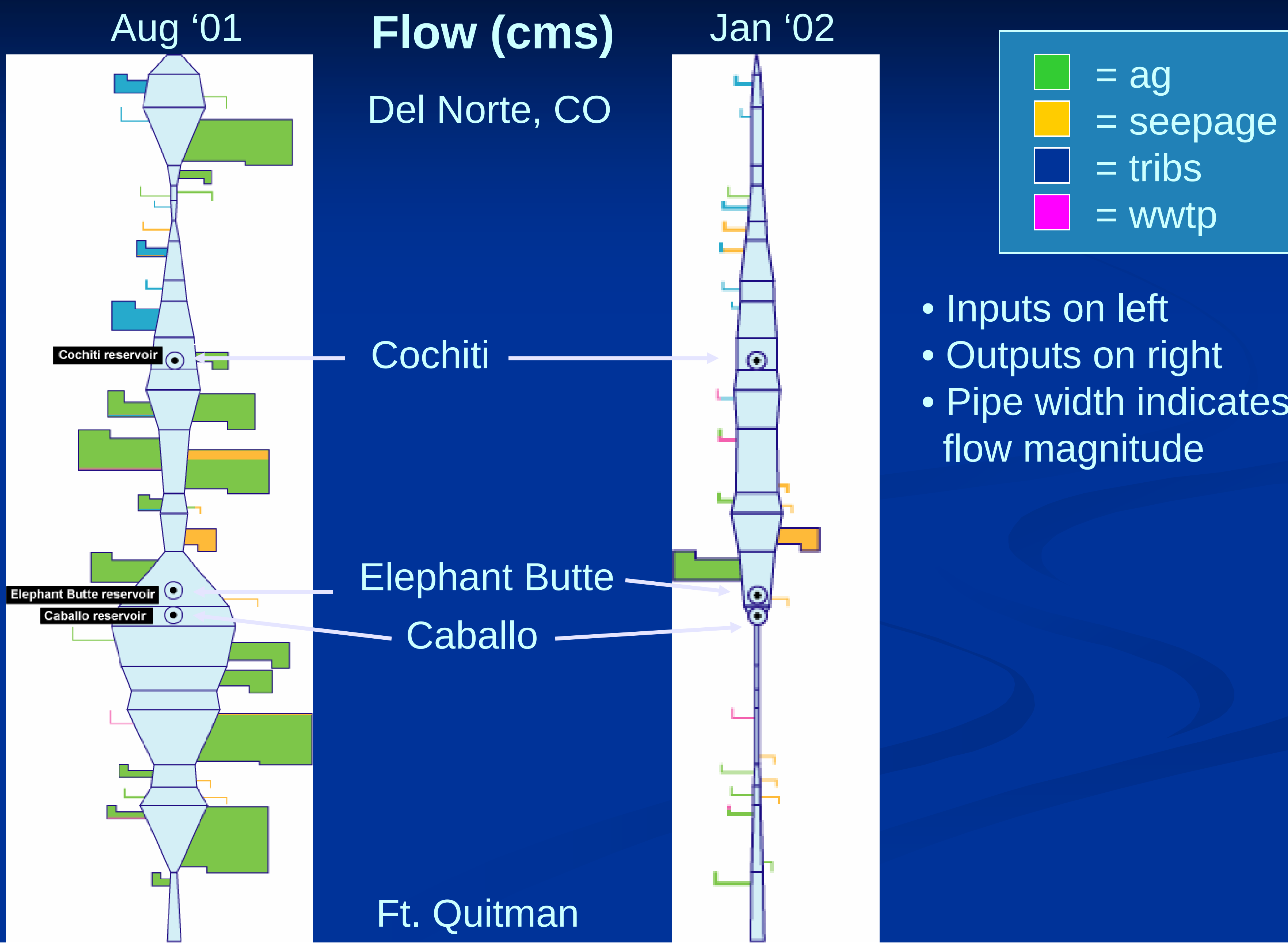
$\delta^{18}O$ vs Flow Distance (Summer '01)



Significance of Stable Isotopes

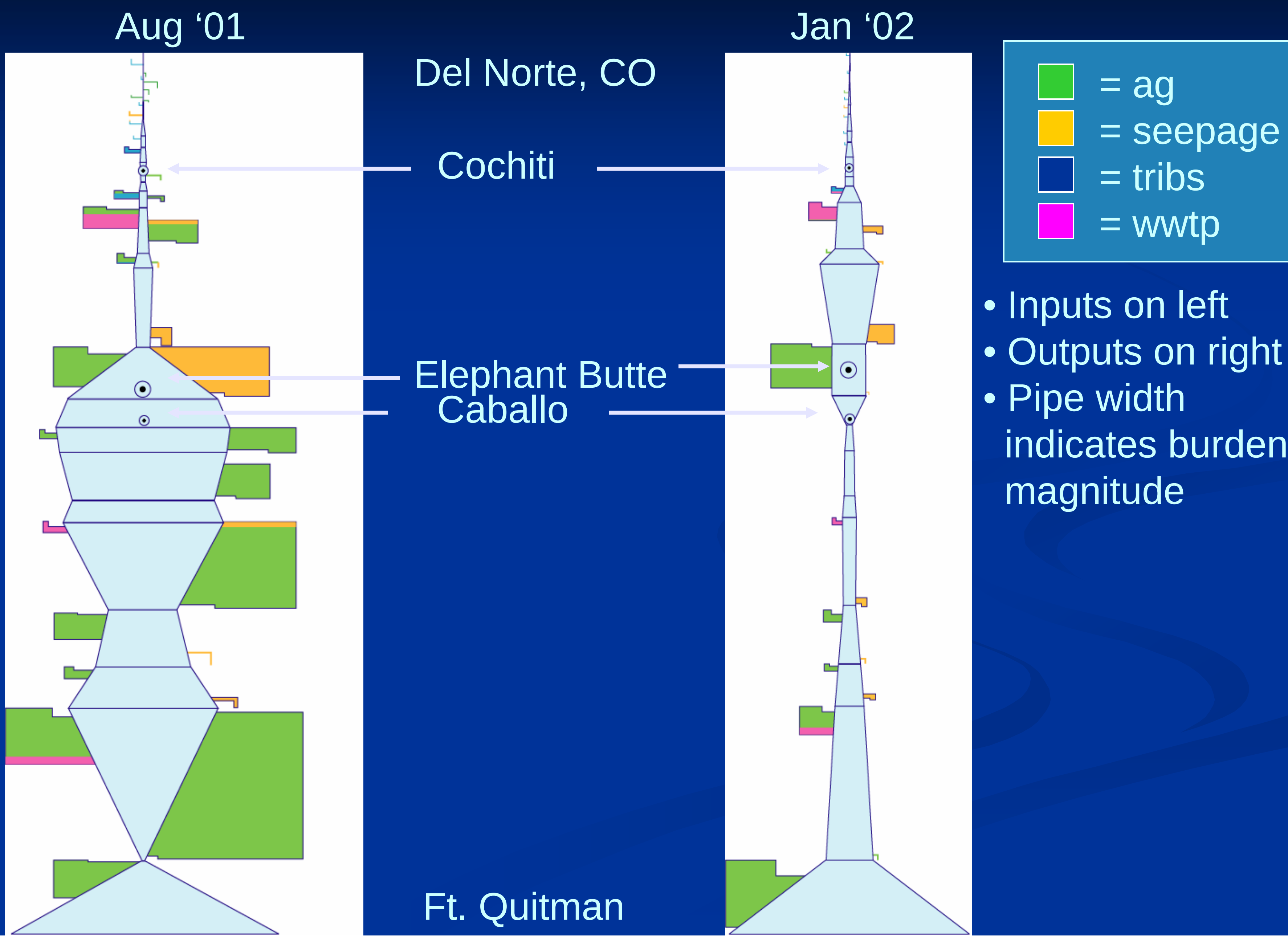
- Water source is mnt. snowmelt
- Strong enrichment = much evaporation
- Simple Rayleigh distillation model indicates ~35% of inflow is evaporated
- ~1/3 of evaporation occurs from Elephant Butte Reservoir
- River gauging indicates ~75% lost to ET
- Loss is ~1/2 evap. and ~1/2 transp.

Where is water going?



- Inputs on left
- Outputs on right
- Pipe width indicates flow magnitude

Where is salt going?



- Inputs on left
- Outputs on right
- Pipe width indicates burden magnitude

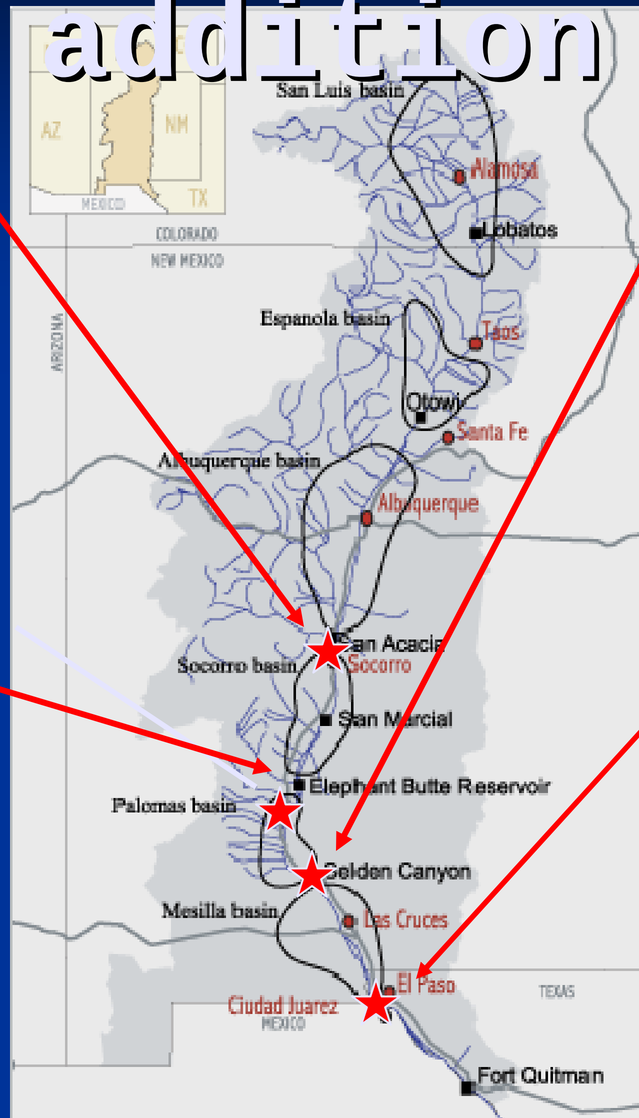
Deep groundwater addition

San Acacia: **1800 (summer) – 26,000 (winter) kg/dy**

Selden canyon: **300-6,000 kg/dy (winter only)**

T or C: **30,000 – 60,000 kg/dy**

El Paso narrows: **18,000 – 30,000 kg/dy**

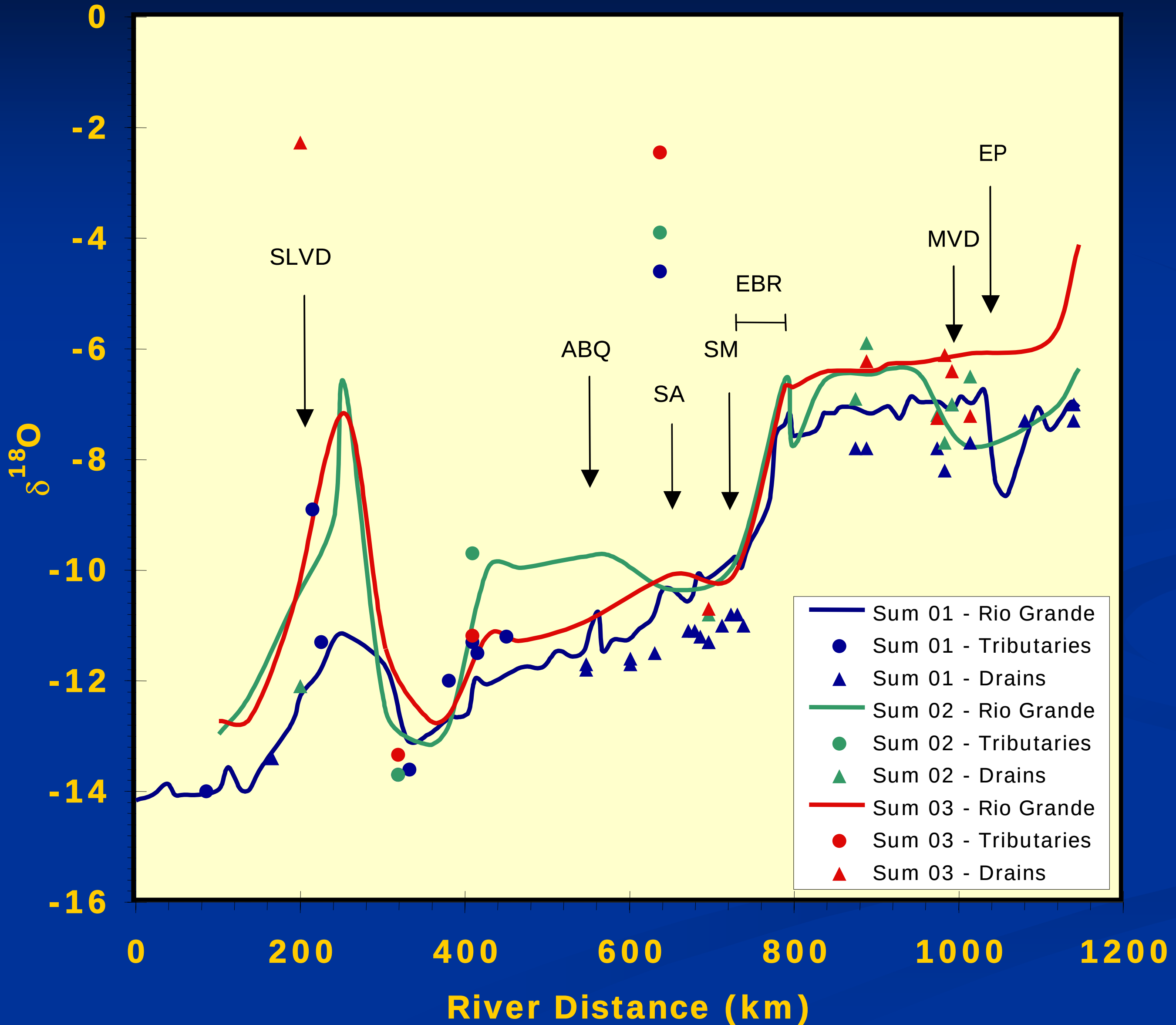


Rio Chama: **4,000 kg/dy**

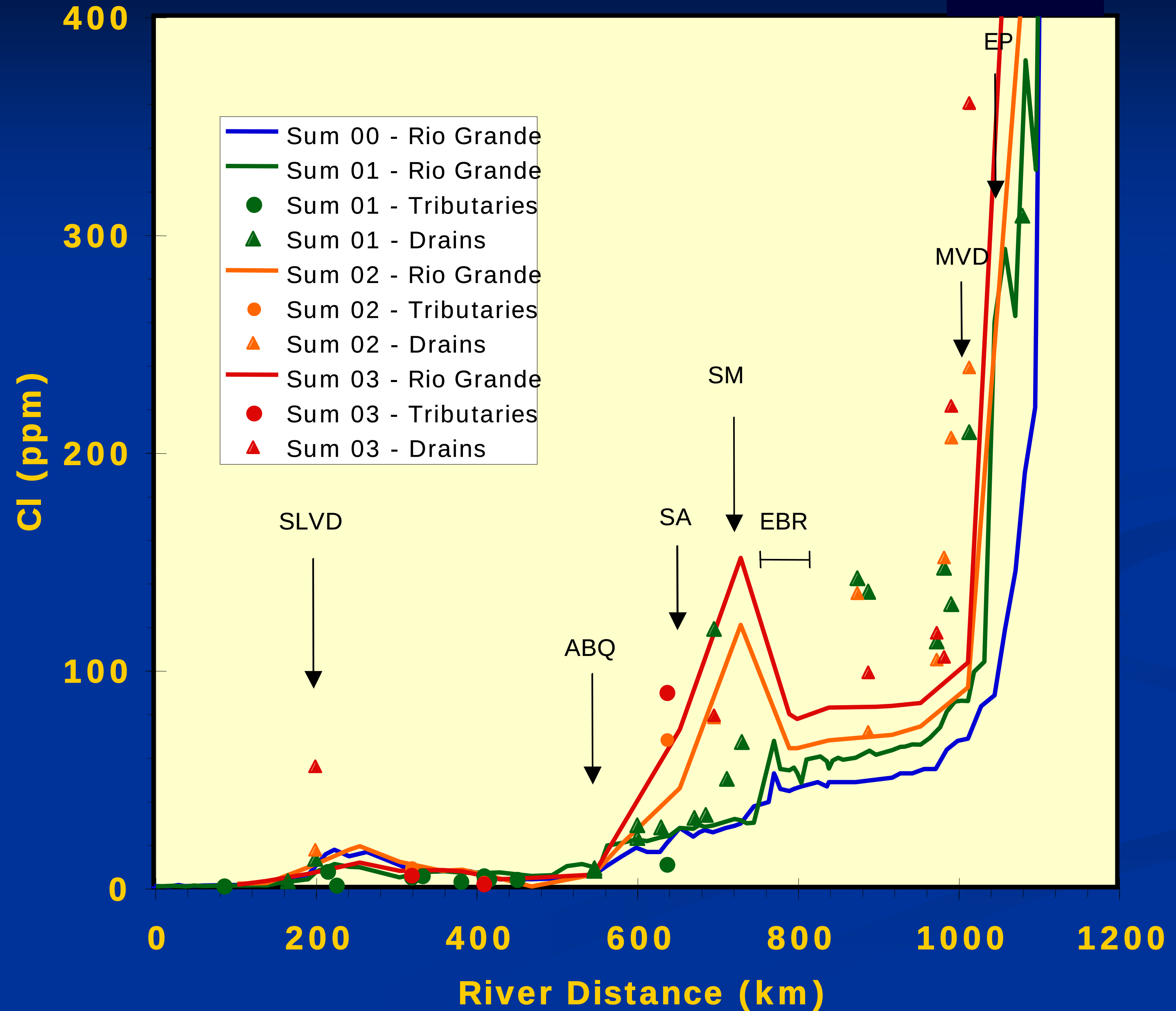
ABQ wwtp: **18,800 kg/dy**

Solute Dynamics Under Worsening Drought

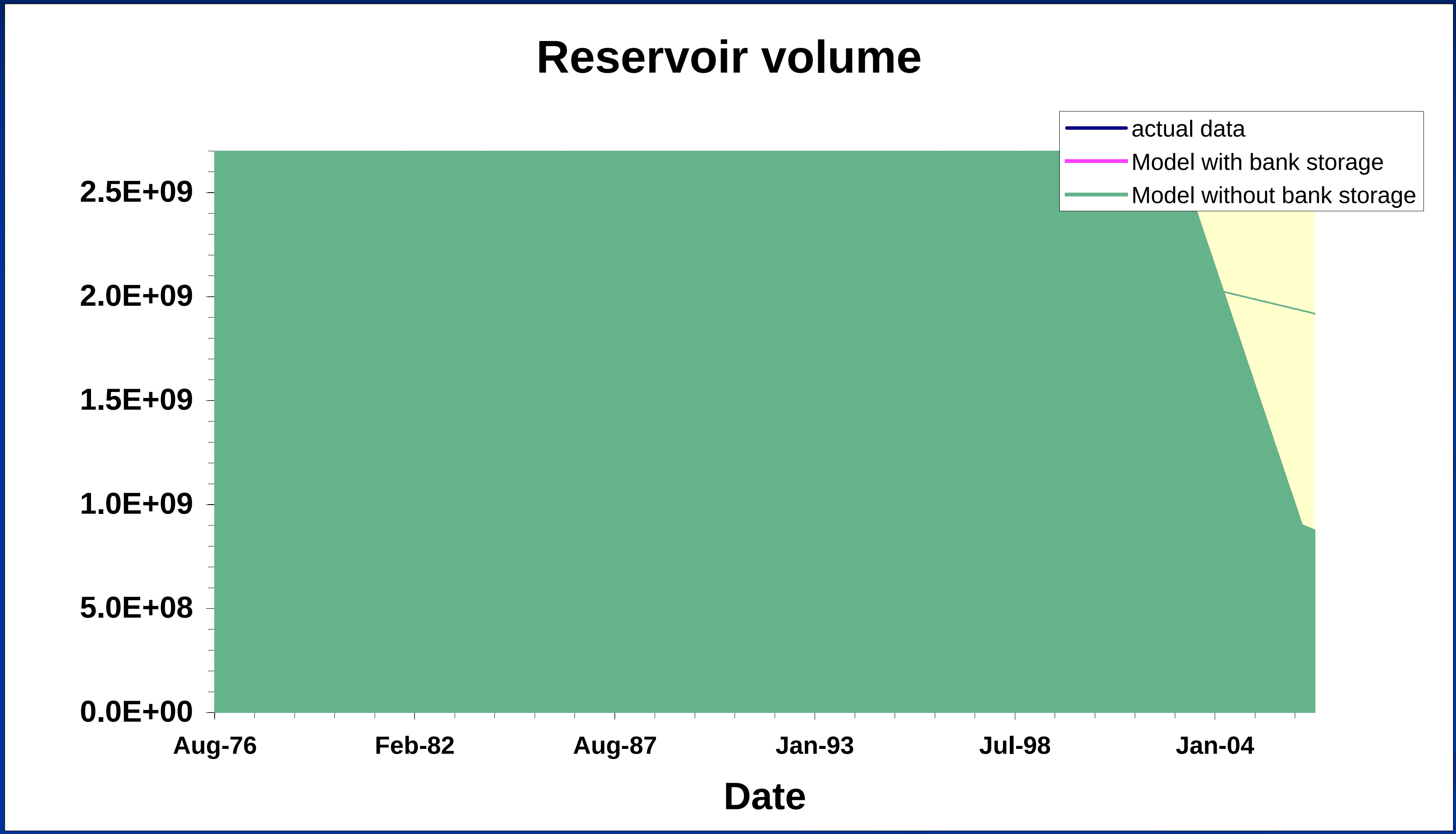
δ18O in Summer



Cl in summer

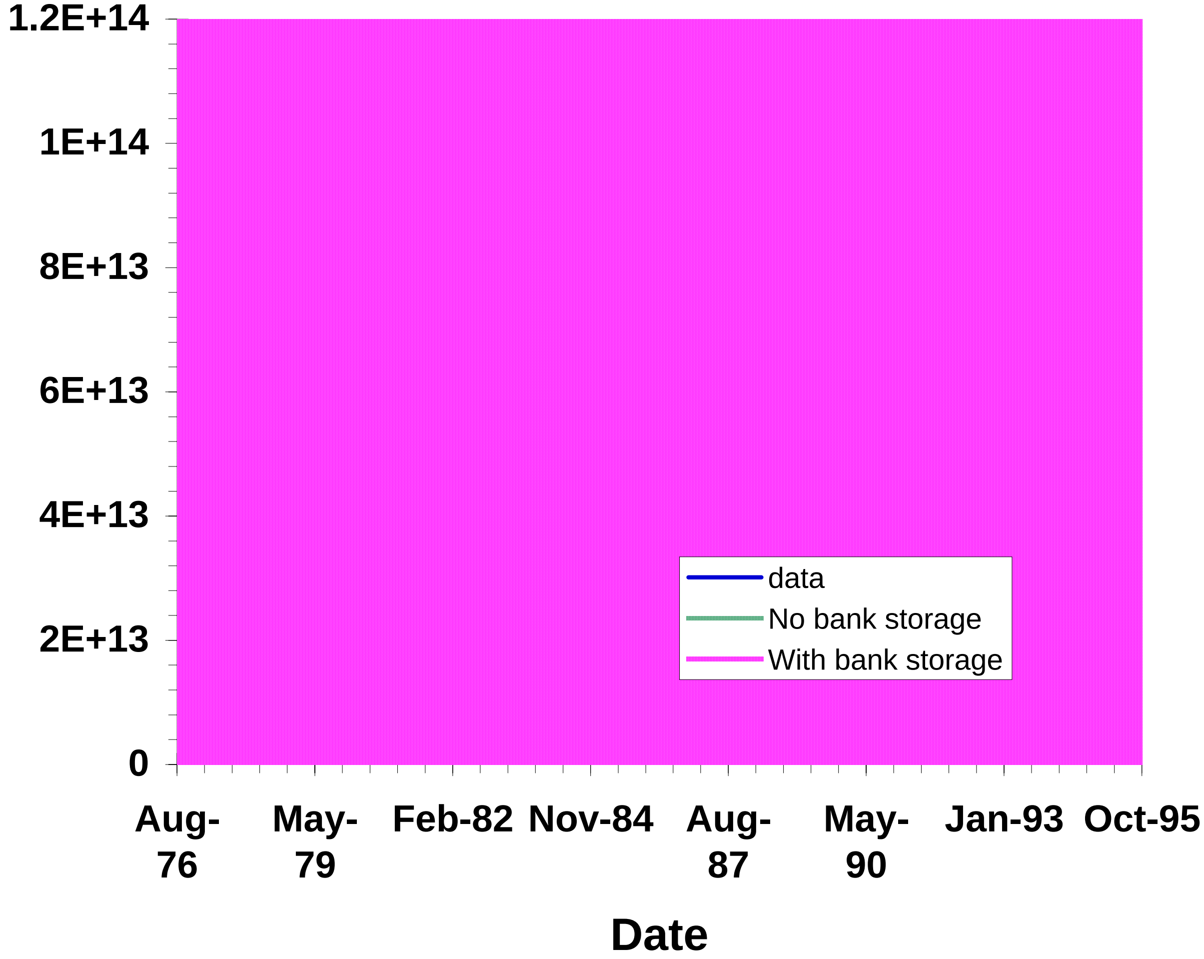


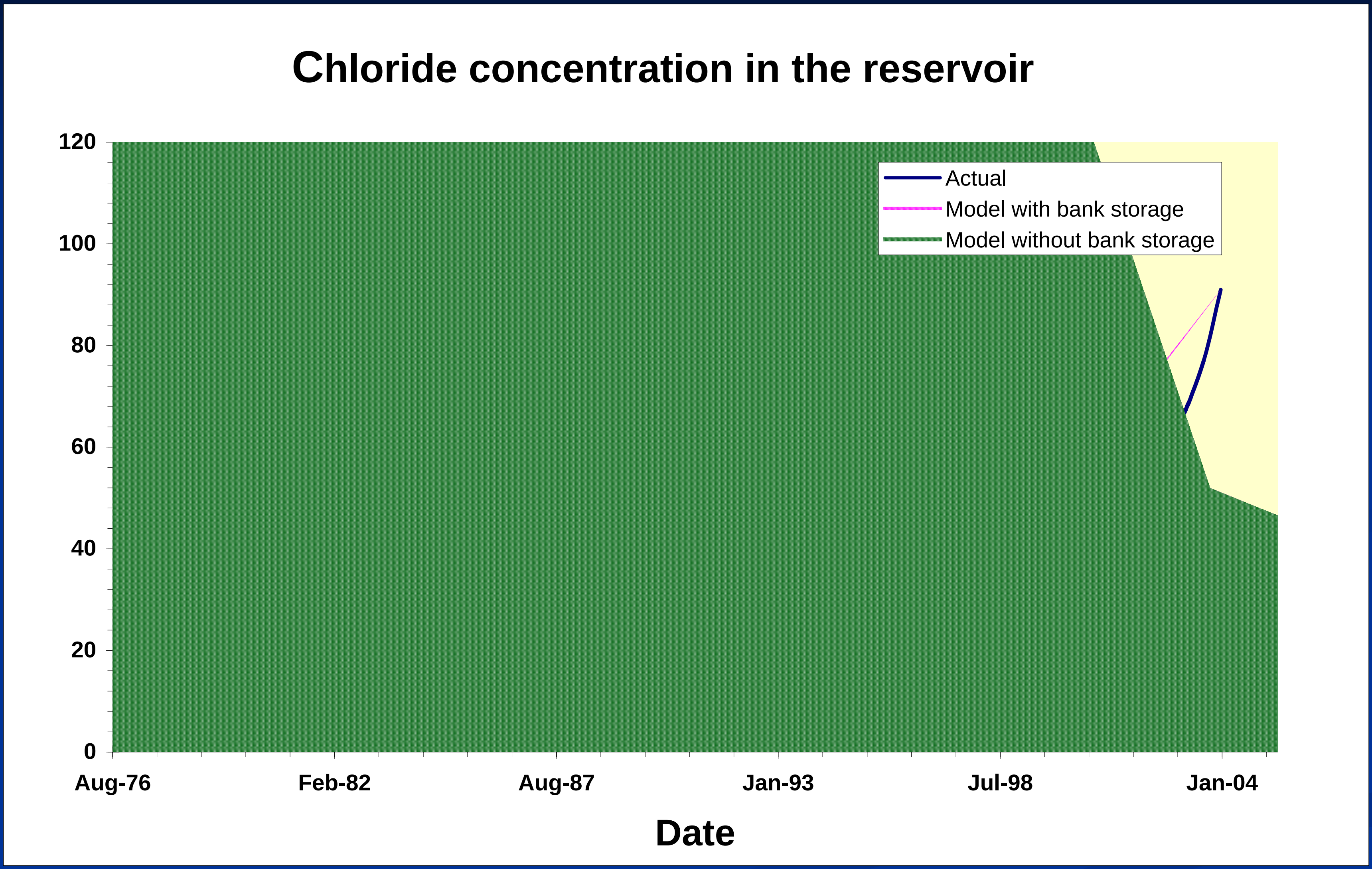
Sum 00 - Rio Grande
Sum 01 - Rio Grande
Sum 01 - Tributaries
Sum 01 - Drains
Sum 02 - Rio Grande
Sum 02 - Tributaries
Sum 02 - Drains
Sum 03 - Rio Grande
Sum 03 - Tributaries
Sum 03 - Drains
EP
MVD
SM
SA
EBR
SLVD
ABQ
Cl (ppm)
400
300
200
100
0
0
200
400
600
800
1000
1200
River Distance (km)



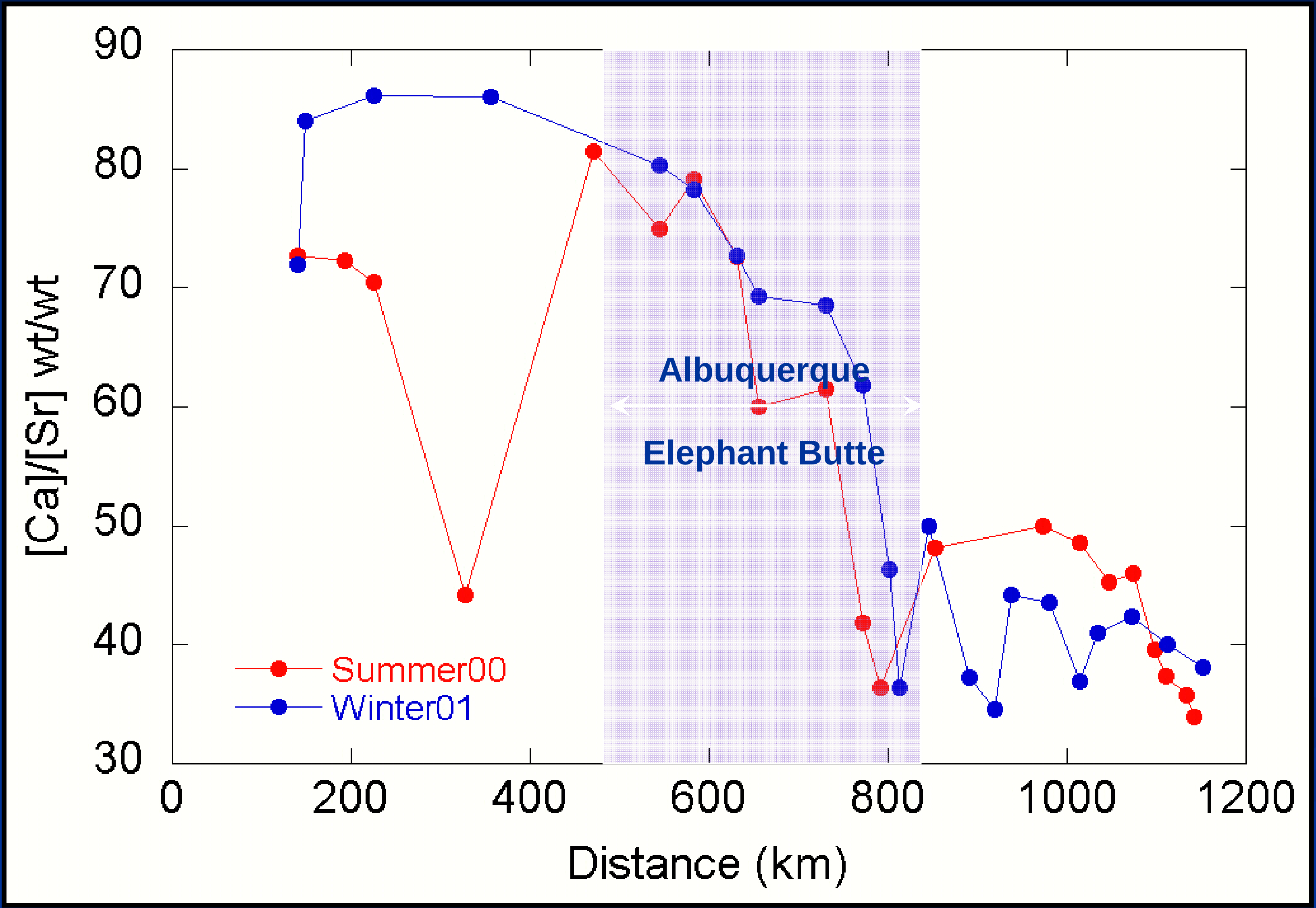
Reservoir volume
actual data
Model with bank storage
Model without bank storage
2.5E+09
2.0E+09
1.5E+09
1.0E+09
5.0E+08
0.0E+00
Aug-76
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Date

Accumulation of chloride in the reservoir system



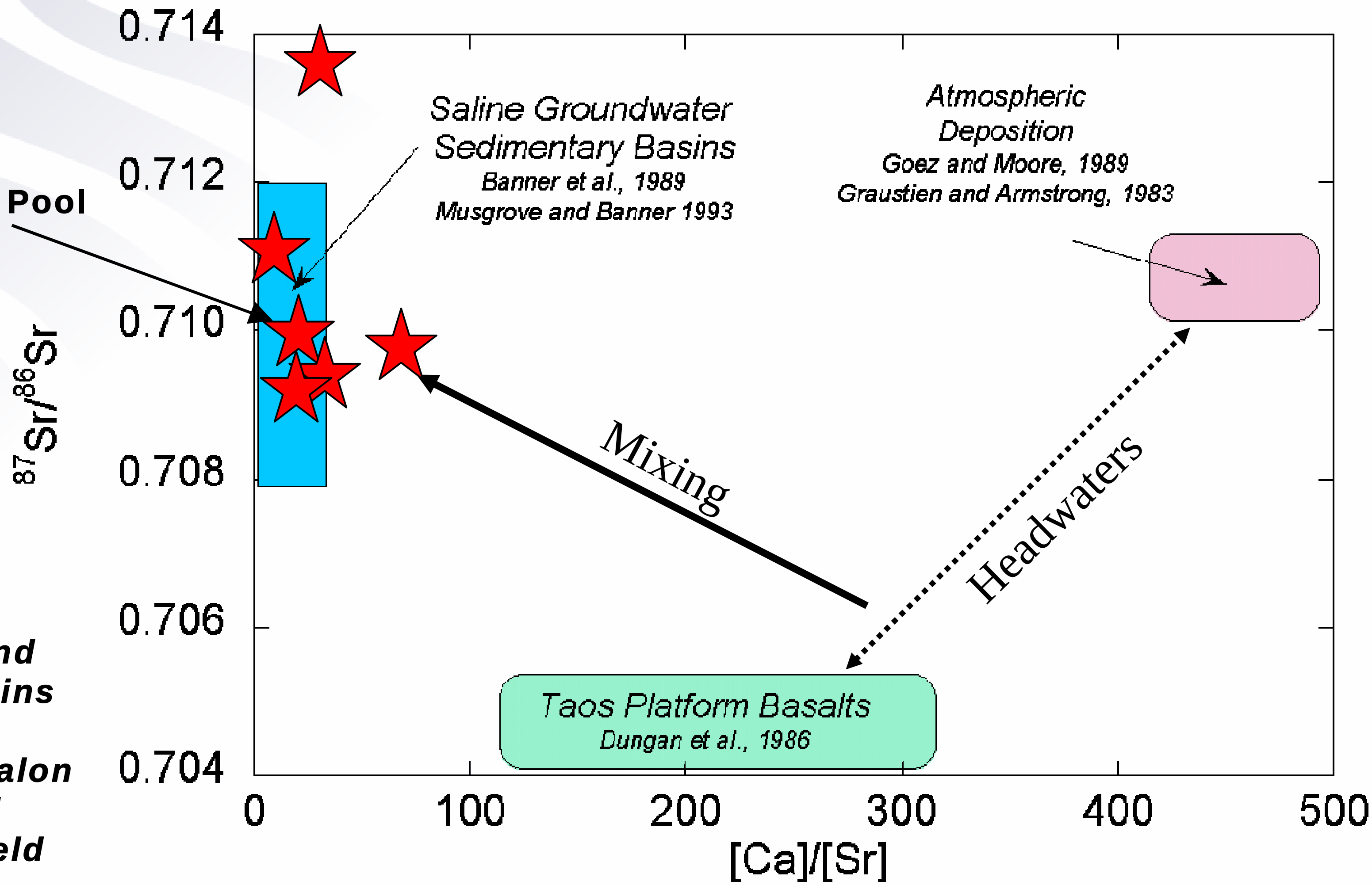

Chloride concentration in the reservoir
Actual
Model with bank storage
Model without bank storage
120
100
80
60
40
20
0
Aug-76
Feb-82
Aug-87
Jan-93
Jul-98
Jan-04
Date

Tracing GW inputs …



Sr End Members

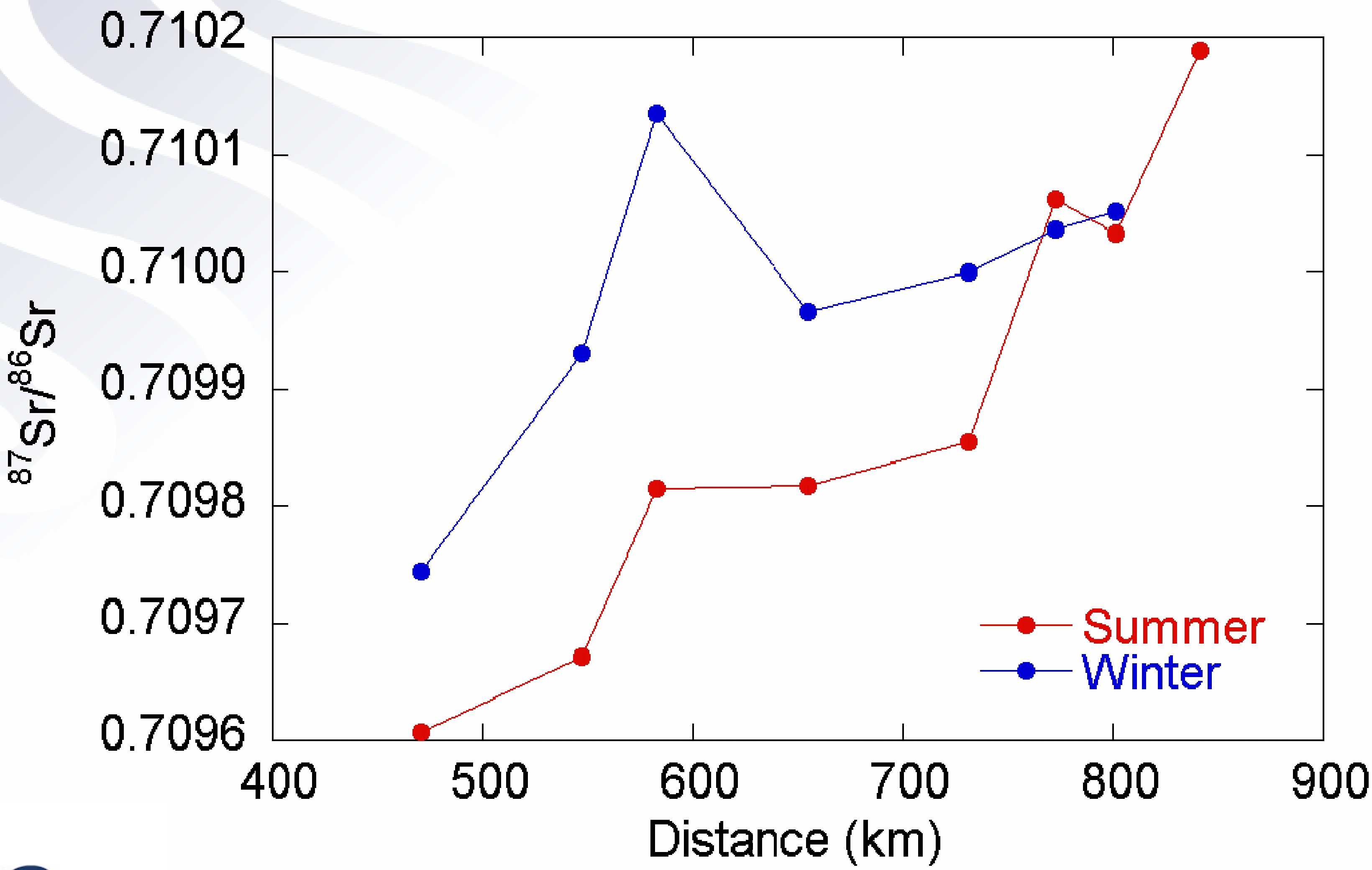
San Acacia Pool



"Shallow" Saline GW's from ABQ and Socorro Basins

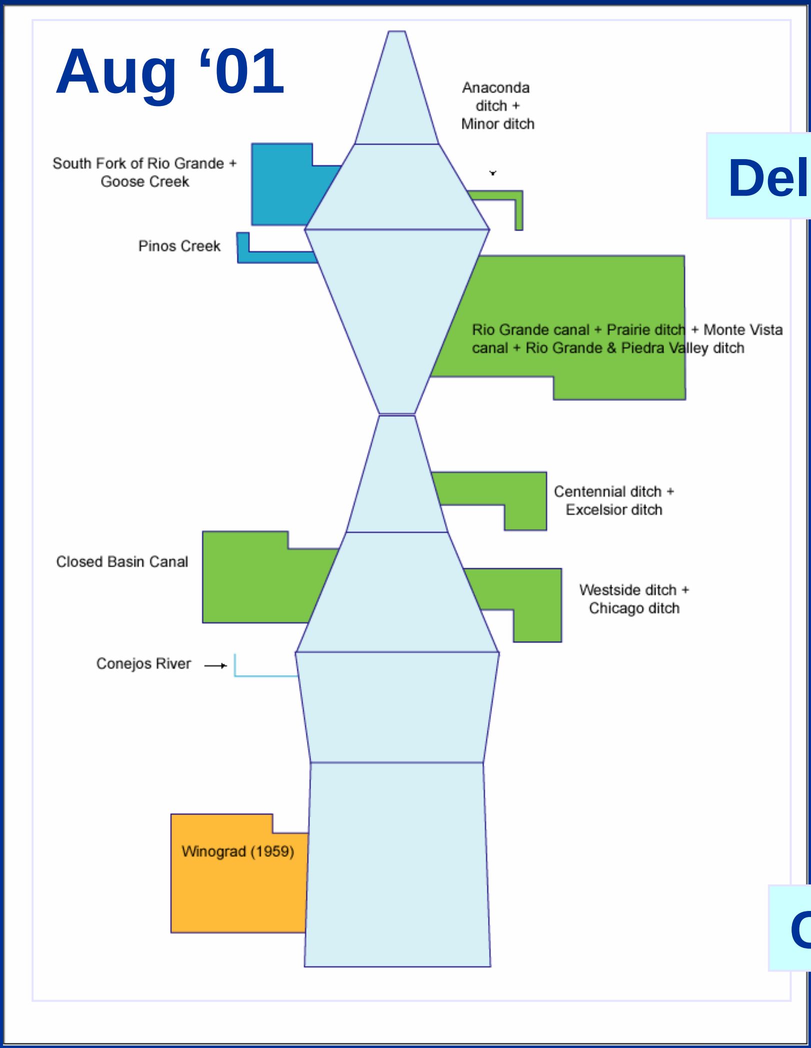
Thanks to Talon Newton and Laura Bexfield

Strontium Isotopes



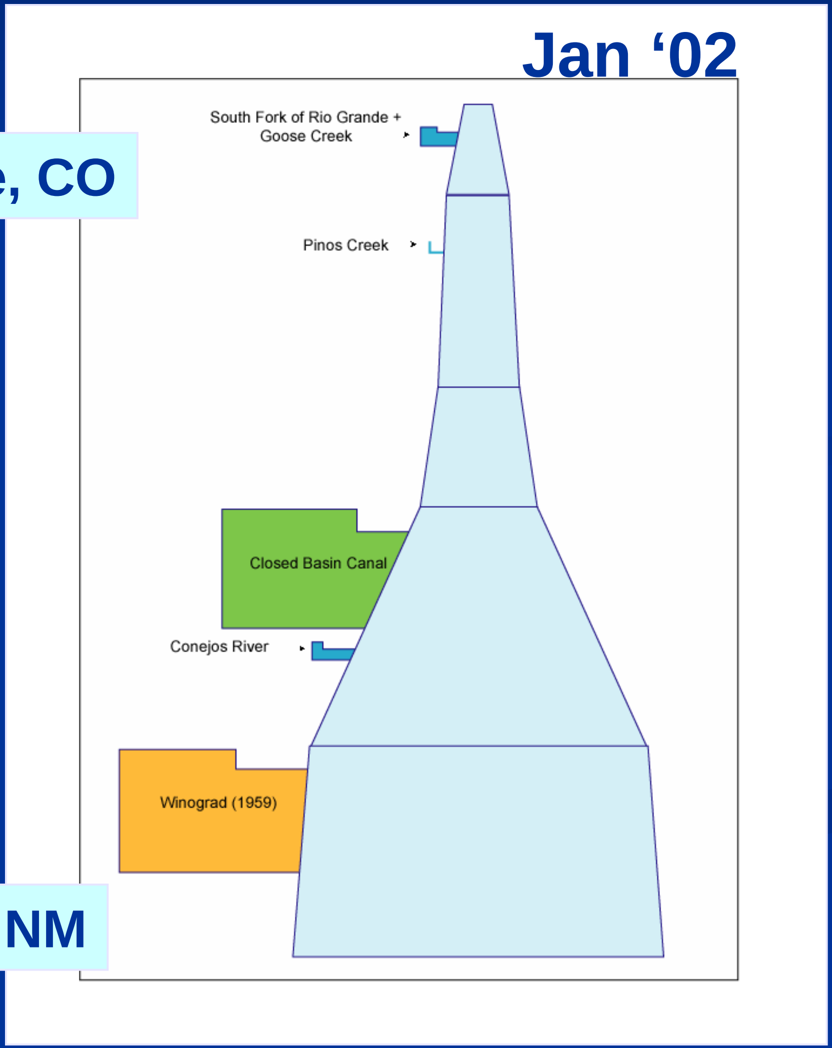
Influence of tributaries

Natural tributaries add most chloride in the headwaters (as well as the Closed Basin Canal).



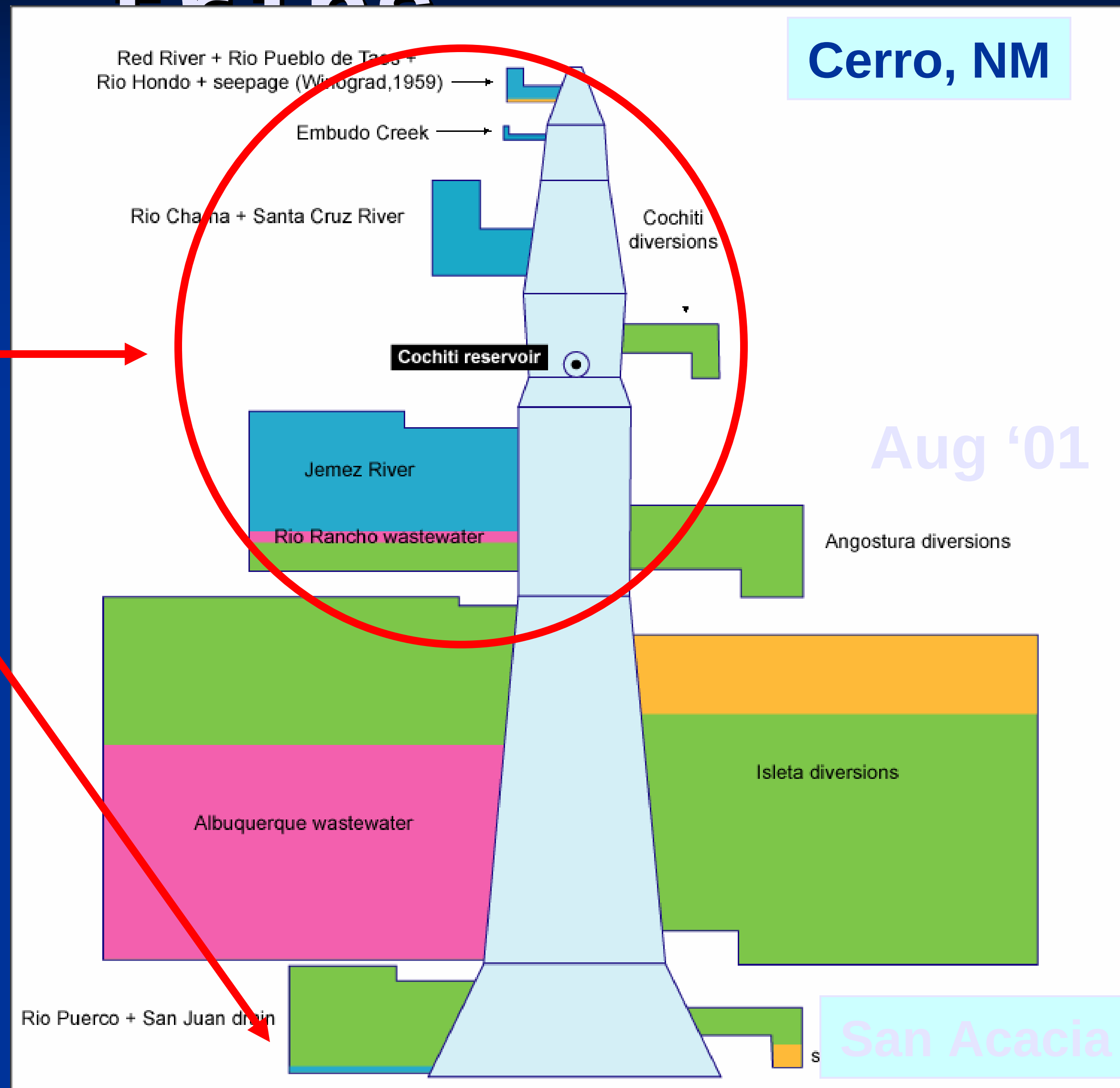
Del Norte, CO

Cerro, NM



Further input of natural tribs

Chloride enters the river with natural tributaries.



Influence of wastewater

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