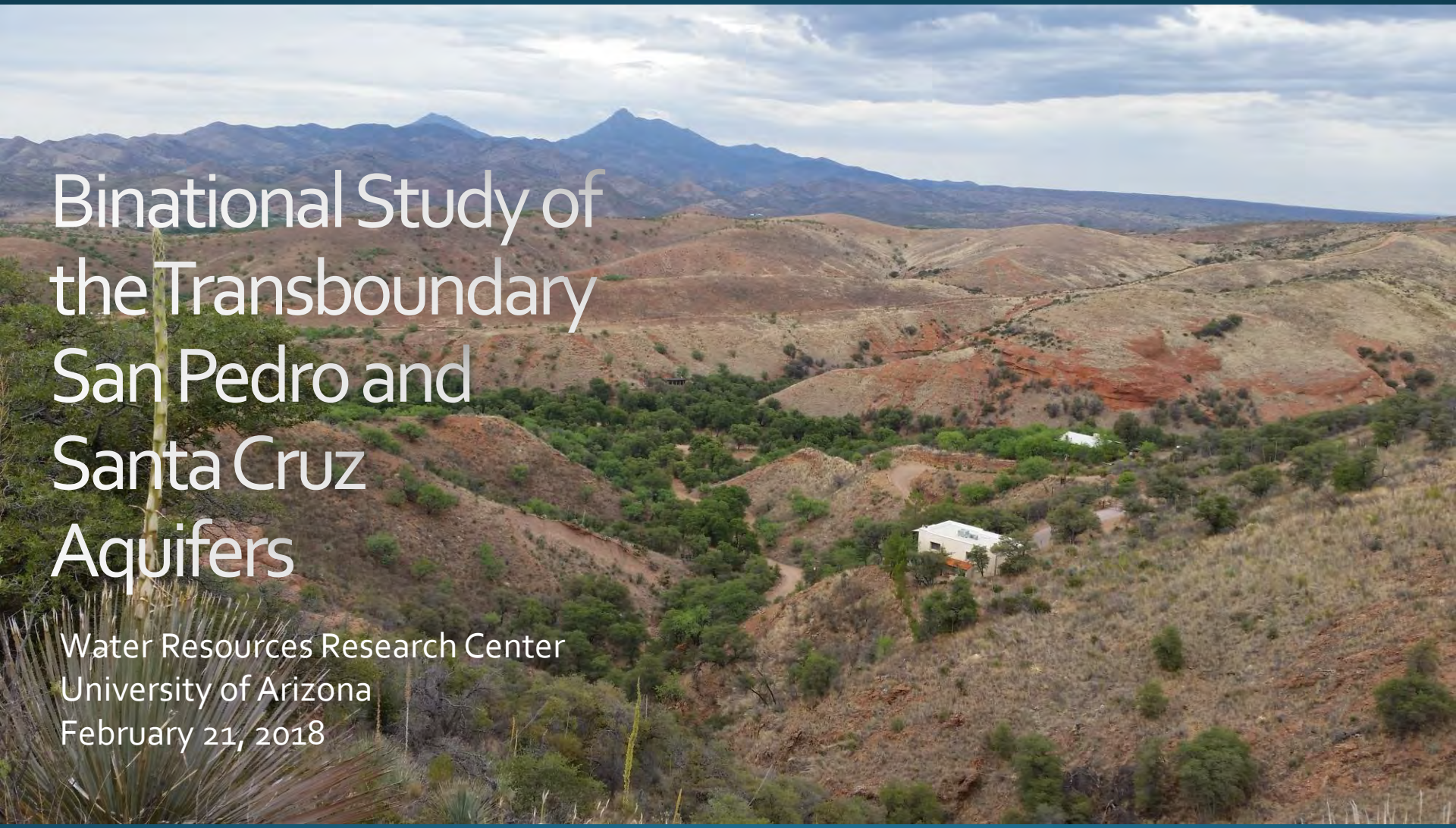

Binational Study of the Transboundary San Pedro and Santa Cruz Aquifers

Water Resources Research Center
University of Arizona
February 21, 2018

J.B. Callegary, I. Minjárez Sosa, E.M. Tapia Villaseñor, R. Monreal Saavedra, F.J. Grijalva Noriega, A.K. Huth, S.B. Megdal, F. Gray, J.D. Petersen-Perlman

Binational Reports – Informes Binacionales

- Written by binational team from US (USGS and UA) and Mexico (UNISON).
- Content:
  - Physical Geography
  - Surface-Water Hydrology and Hydrometeorology
  - Conceptual Geologic Model
  - Hydrogeology
  - Piezometry and Hydraulic Parameters
  - Hydrogeochemistry
  - Conceptual and Numerical Groundwater Models

- Escritos por un equipo binacional de México (UNISON) y de los Estados Unidos (USGS y UA).
- Contenidos:
  - Geografía Física
  - Hidrología de Agua Superficial y Hidrometeorología
  - Modelo Conceptual Geológico
  - Hidrogeología
  - Piezometría y Parámetros Hidraúlicos
  - Hidrogeoquímica
  - Modelos Conceptuales y Numéricos de Agua Subterránea

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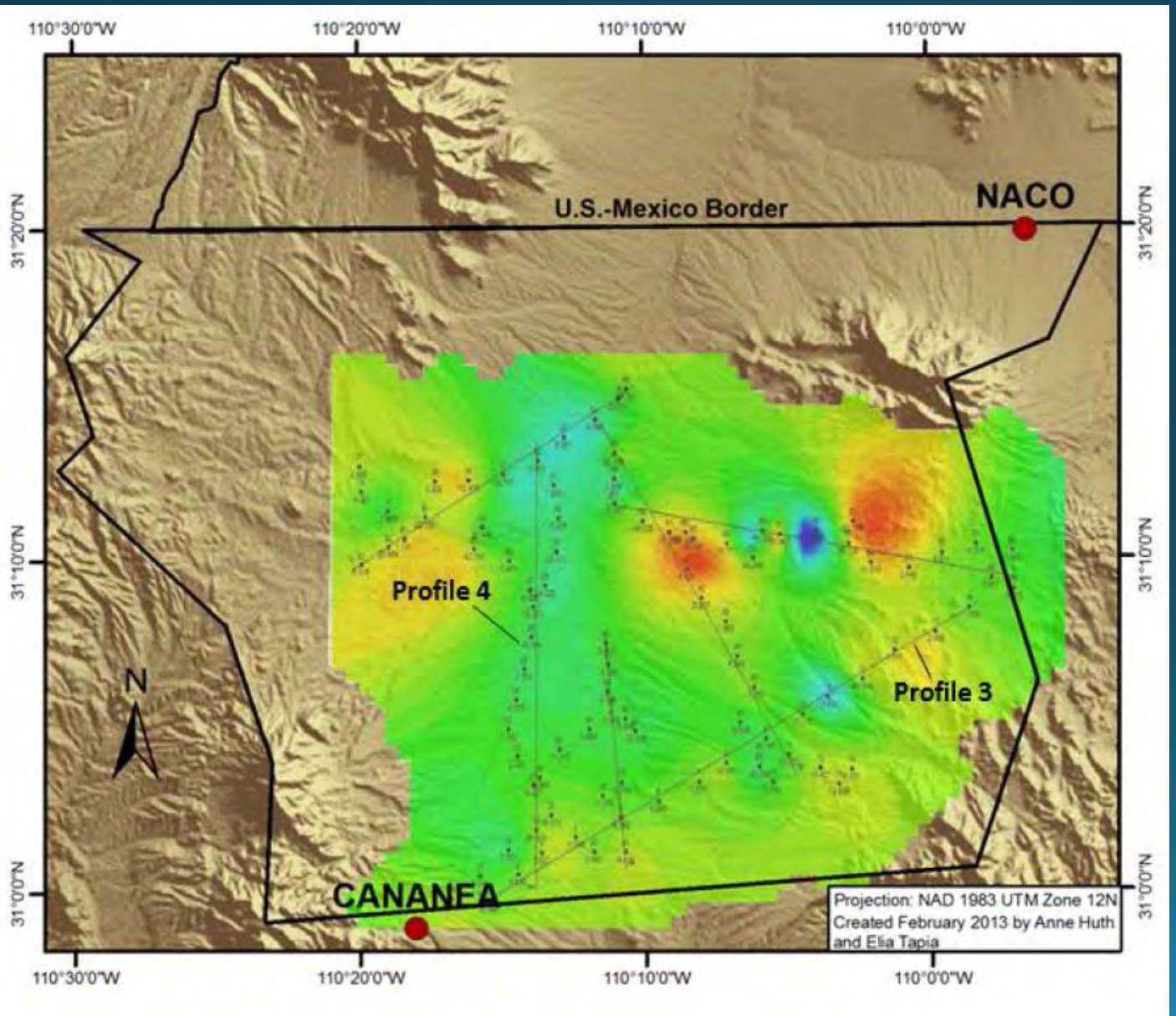
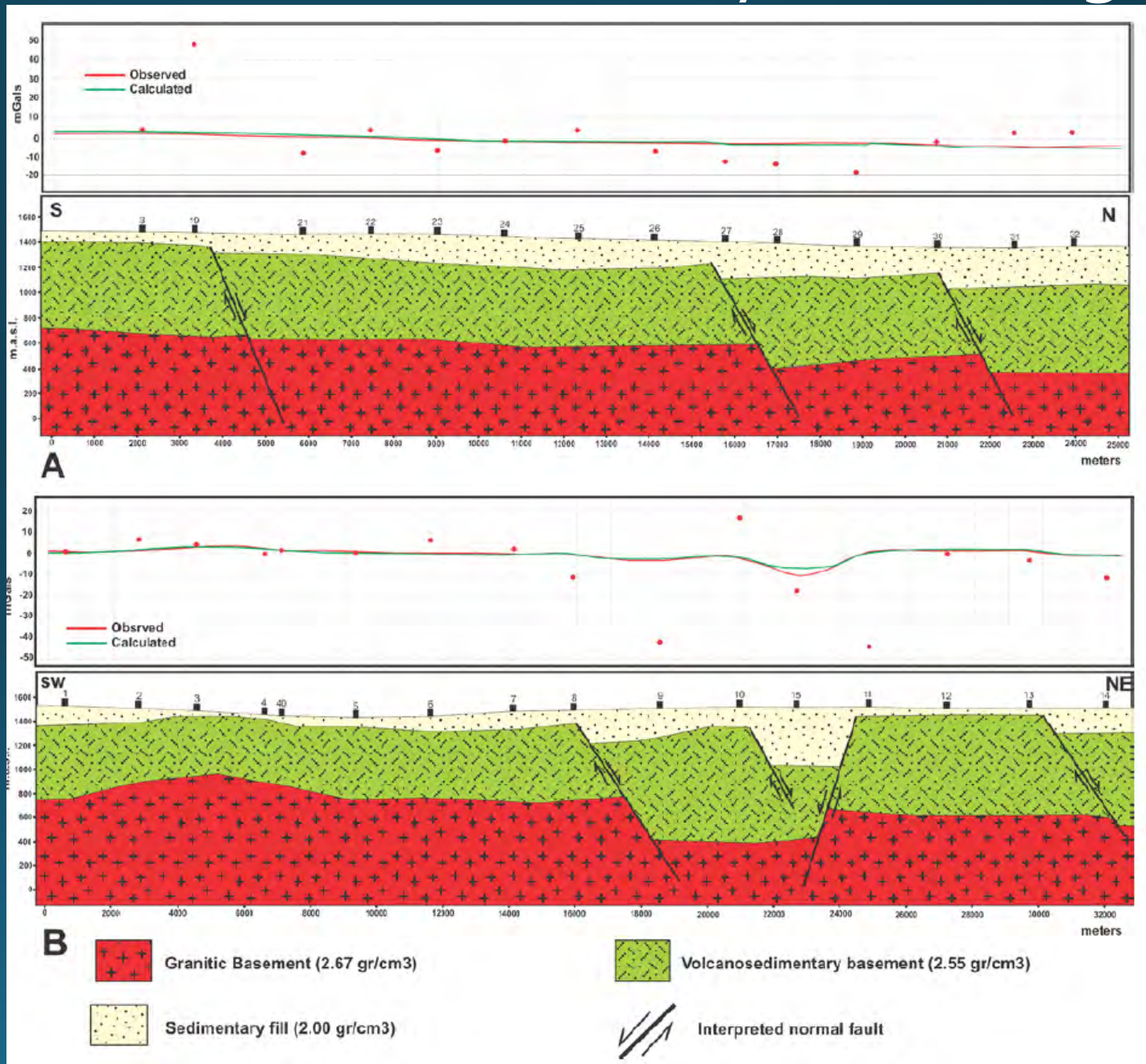
Depth to Basement



Gravity Modeling



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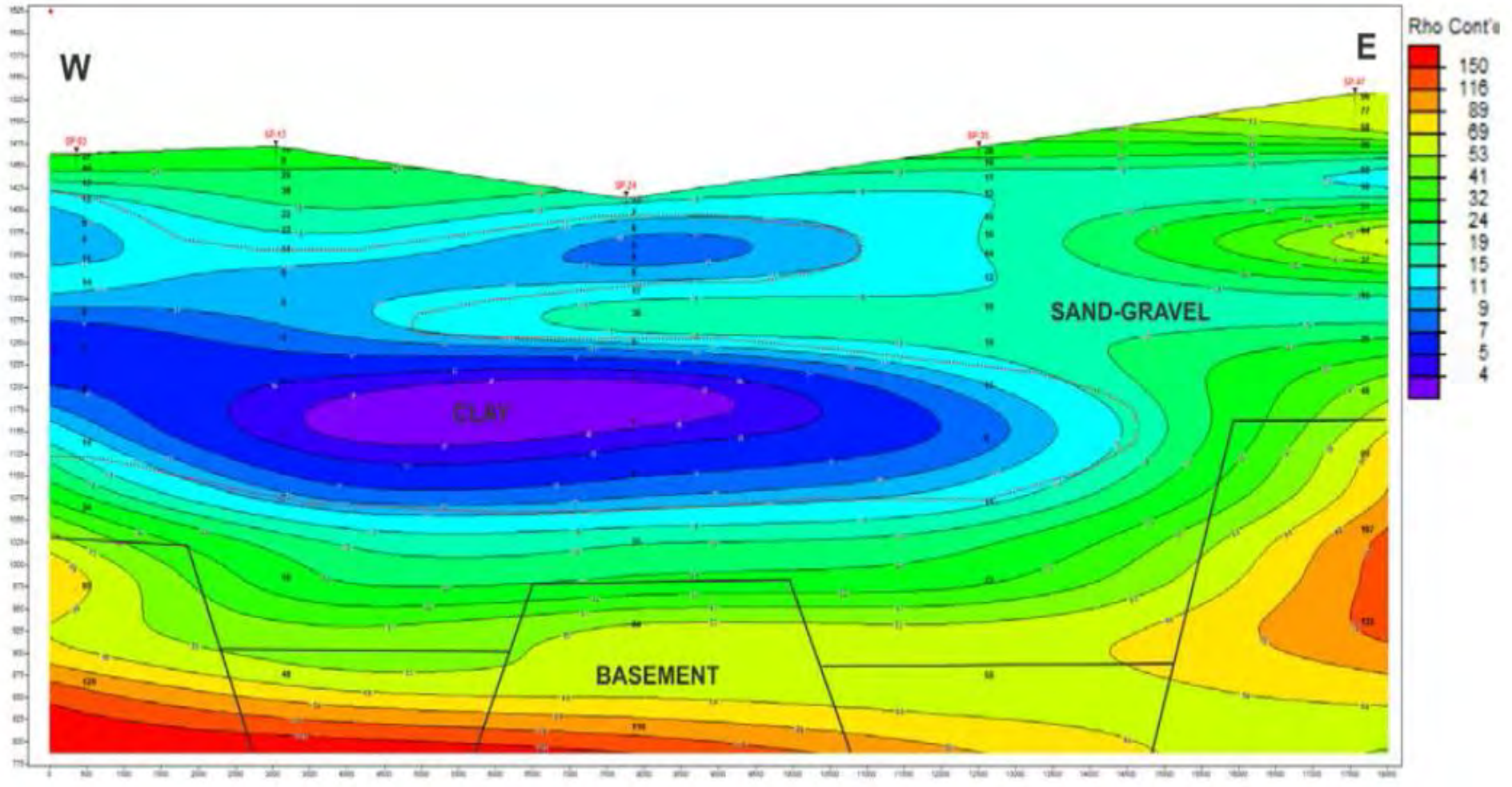
Transient Electromagnetics



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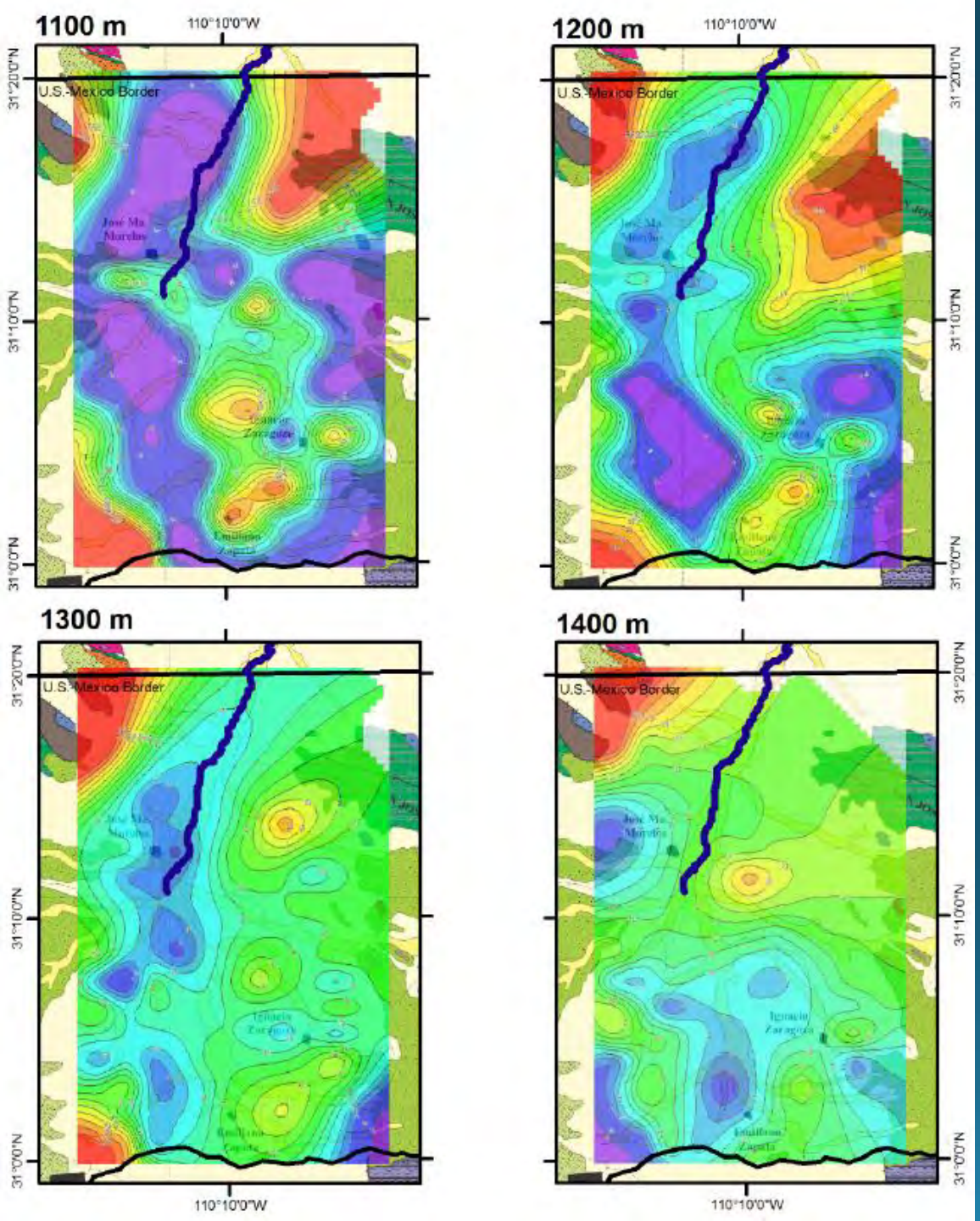

Resistivity at Different Elevations

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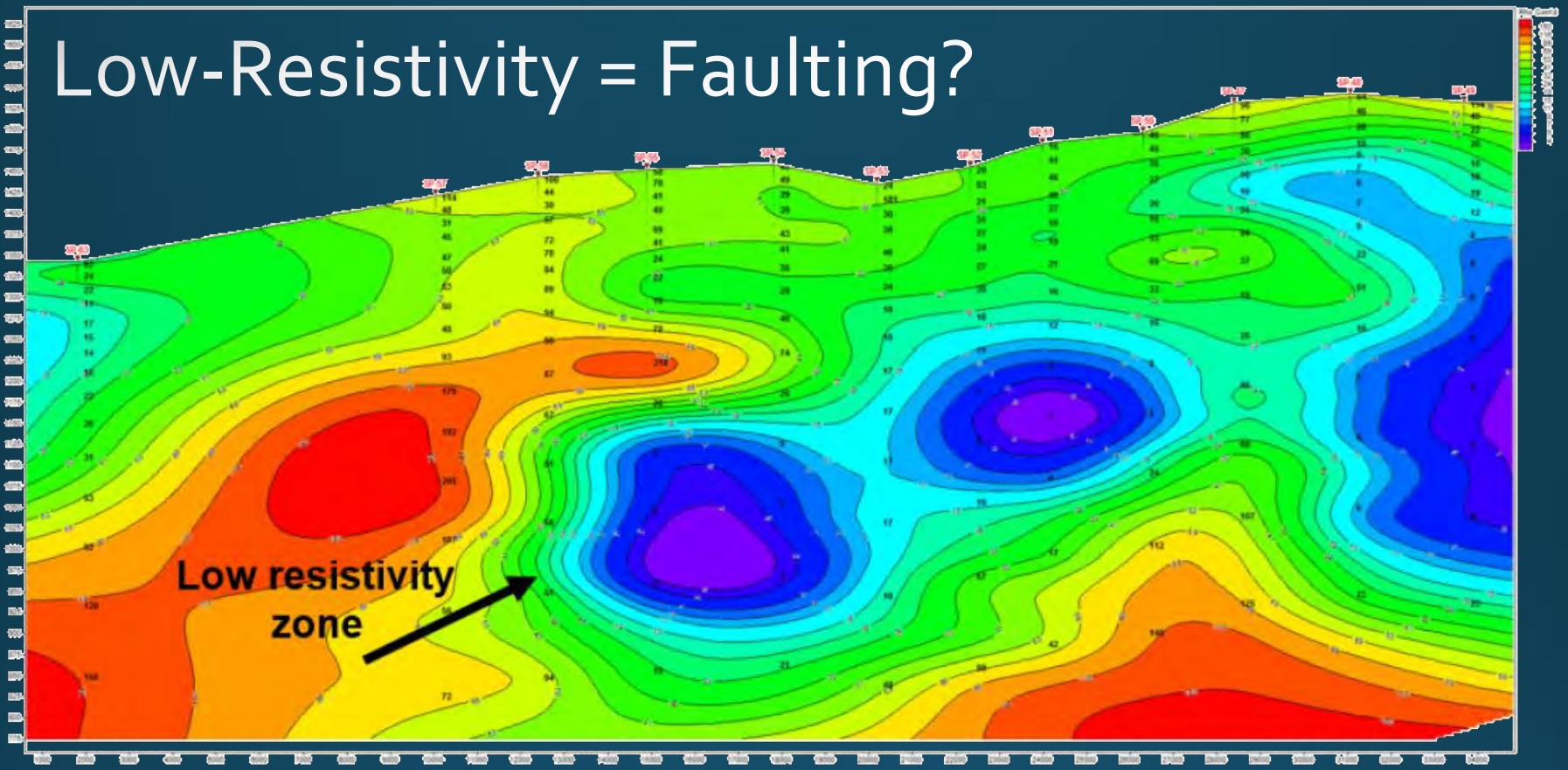
Low-Resistivity = Faulting?



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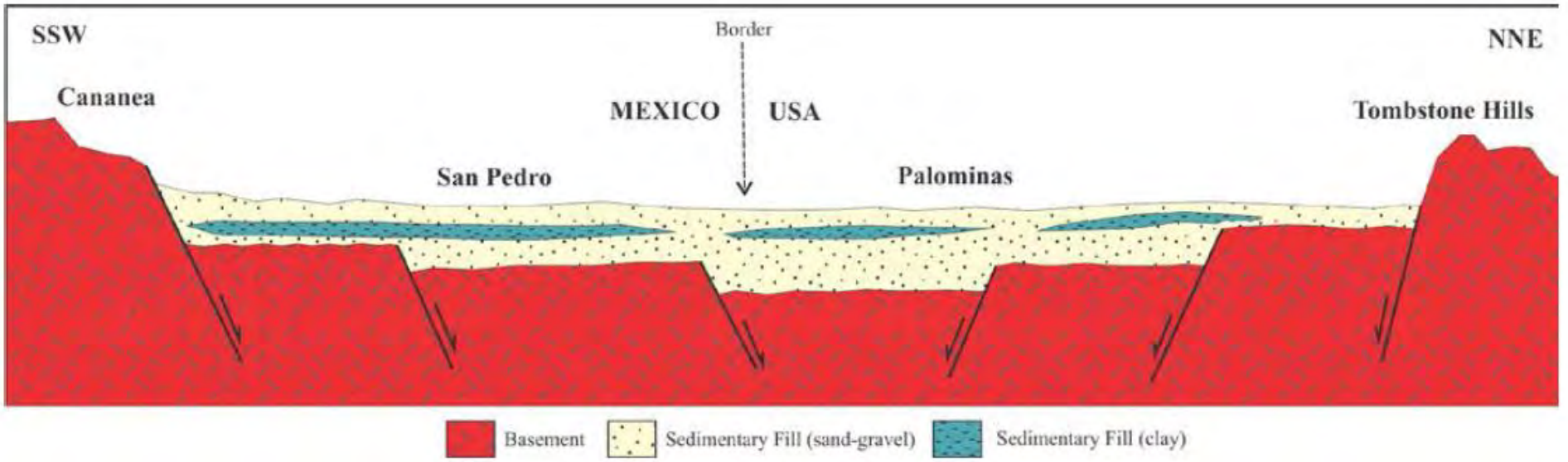
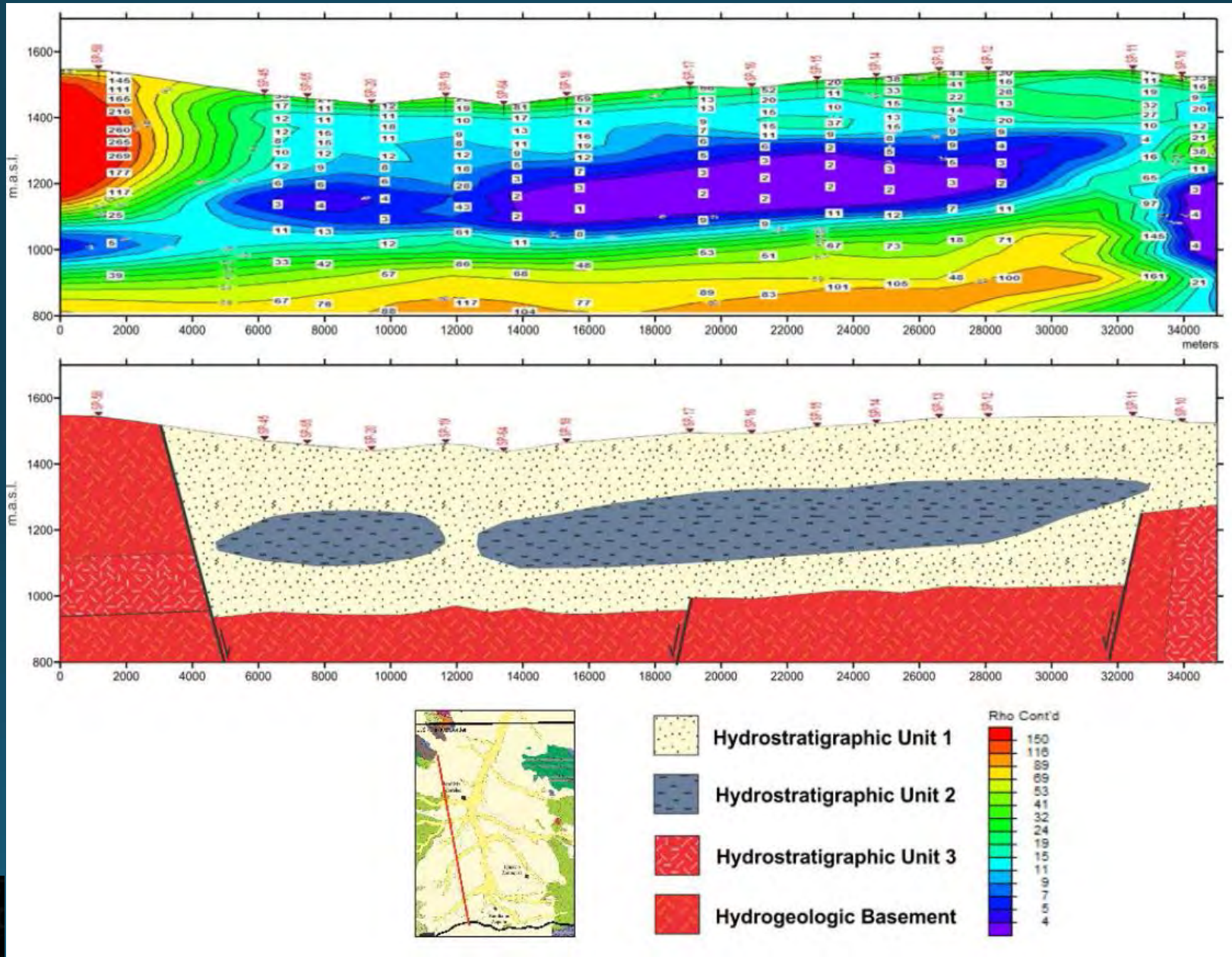
Schematic Interpretation of the Binational San Pedro Basin



Hydrogeologic Interpretation



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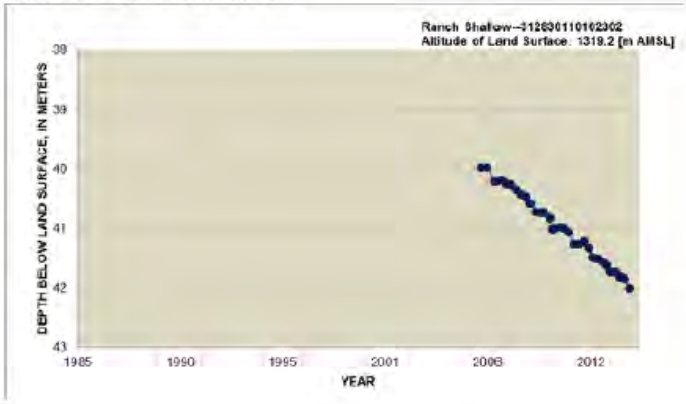
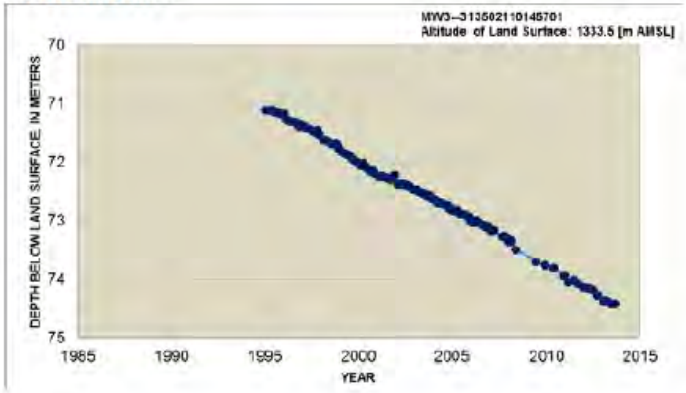
Well Hydrographs

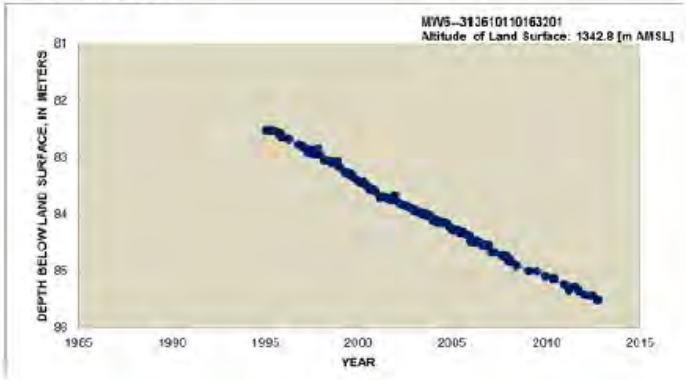
A.Ranch Shallow Well



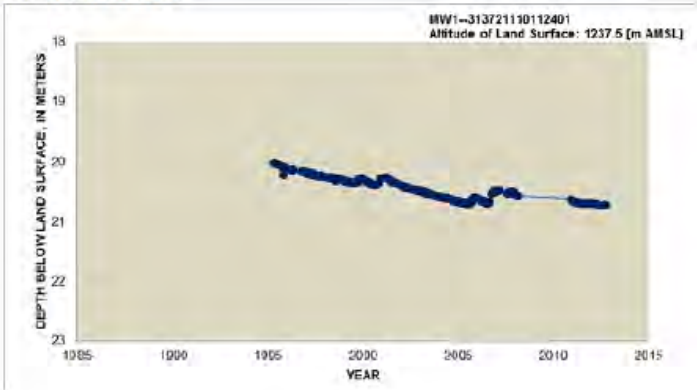
B. Well MW3



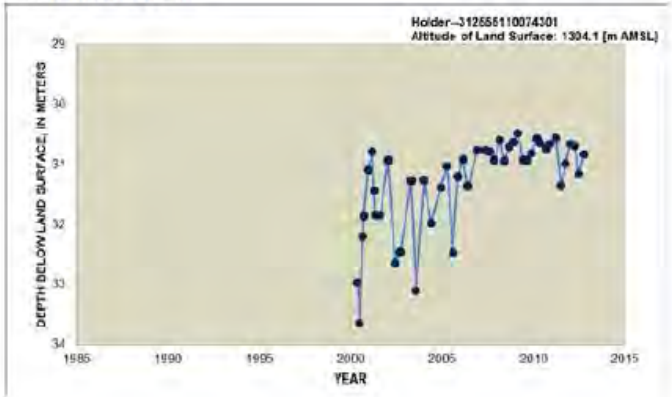
C. Well MW6



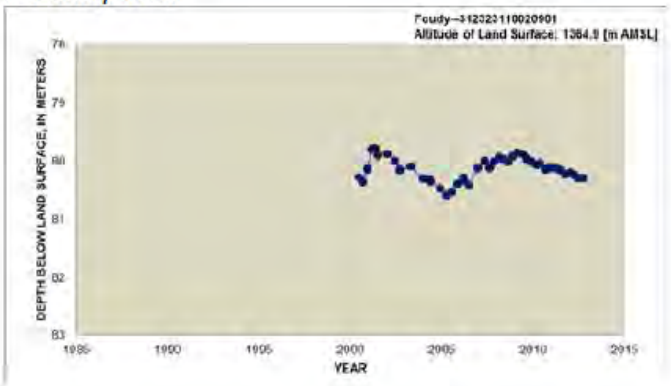
D. Well MW1



E. Holder Well



F. Foudy Well



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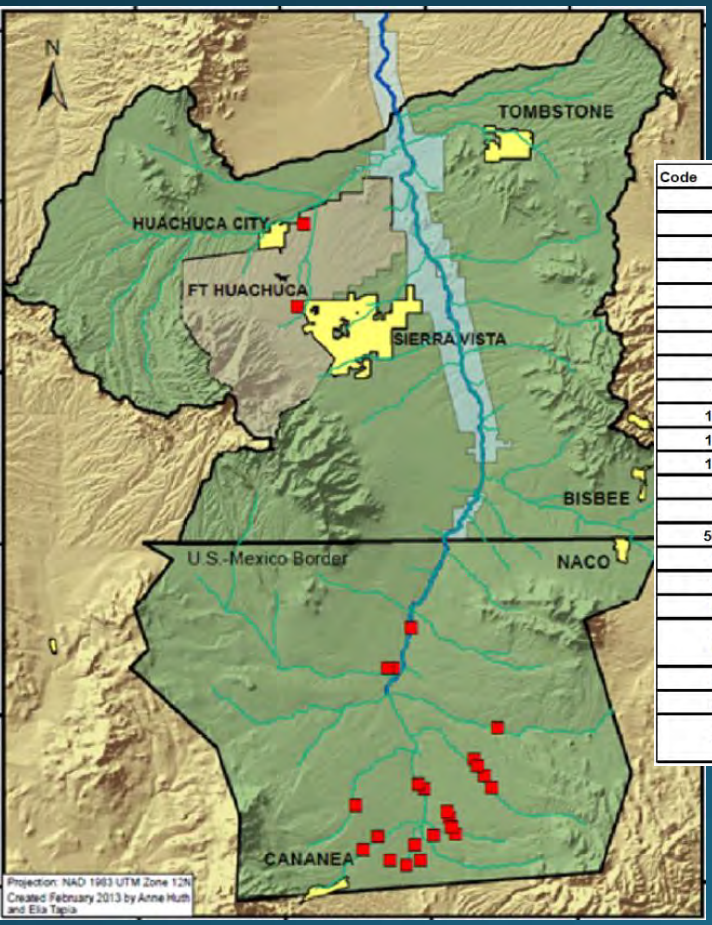
Annual Concession Volume - Sonora

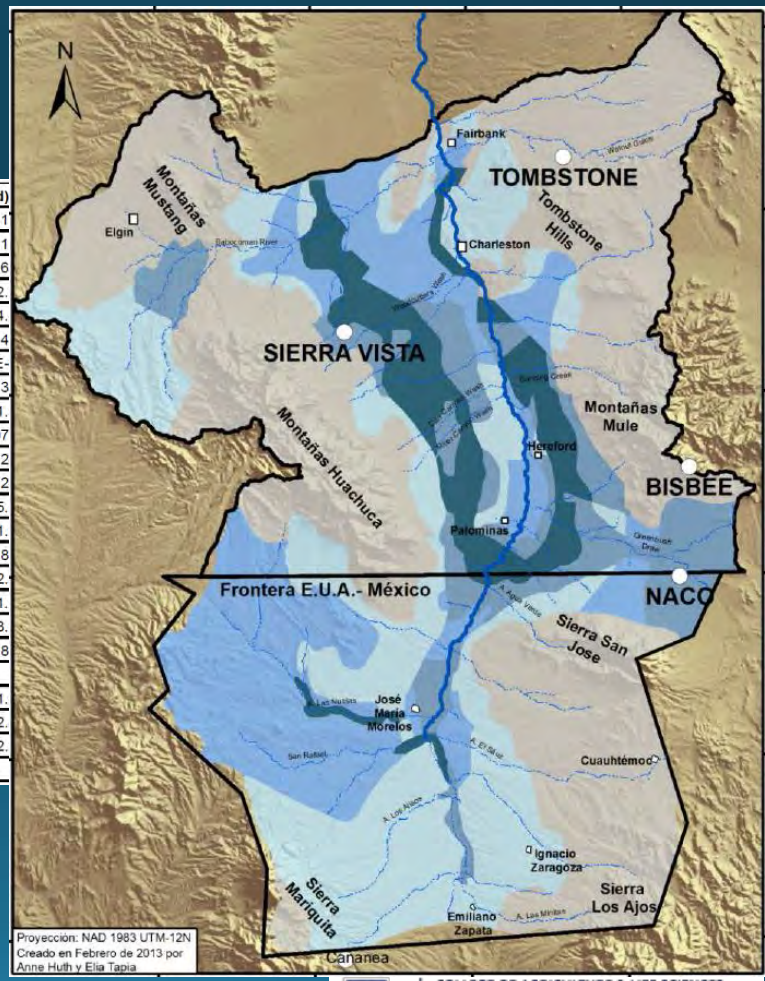
Use	Number of Wells	Volume (hm^3)	Volume (acre-ft)
Agricultural	41	8.2	6600
Domestic	4	9.7	7900
Livestock	86	0.53	430
Public Urban	21	1.8	1500
Industrial	51	13.8	11000
Total	203	24.3	27000

Table 6.1 Annual Concession Volume for the San Pedro River aquifer in Mexico (REPDA, 2012). Concessions for groundwater pumping are granted to users (individuals, municipalities, etc.) for a fixed time period by CONAGUA.

Aquifer Tests → Transmissivity



Code	Phase	Coord. X	Coord. Y	Q (lps)	T (ft2/d)	K (m/d)
3	Drawdown	578820	3439956	19.69	319	0.1
4	Drawdown	578163	3440450	41.1	335	0.1
14	Drawdown	579837	3434918	33	1370	0.6
27	Drawdown	576849	3431730	57	6830	2.
28	Drawdown	584235	3443171	50	21400	4.
29	Drawdown	577795	3433957	40.1	2350	0.4
73	Recovery	585313	3441409	20.24	-	8.35E-
87	Drawdown	582222	3435070	16.71	406	0.3
95	Drawdown	586811	3446573	9.08	7730	1.
126	Drawdown	577348	3457302	19	11500	0.07
147	Drawdown	575377	3452973	24.7	885	0.2
148	Drawdown	574825	3452912	24.05	1190	0.2
30	Recovery	575114	3432194	51	8270	5.
34	Recovery	578426	3432287	28	6350	1.
50a	Recovery	581554	3436863	33	2670	0.8
51	Recovery	581802	3435905	24	3710	2.
53	Recovery	581265	3437451	33	3620	1.
62	Recovery	572170	3433400	51	10900	3.
66	Drawdown	573773	3434823	50	5670	0.8
	Recovery	573773	3434823	54.39	6170	-
68	Recovery	571302	3438109	76.96	4520	1.
71	Recovery	586154	3440141	46	12800	2.
75	Drawdown	584629	3442429	32.5	13600	2.
	Recovery	584629	3442429	43.41	8690	-



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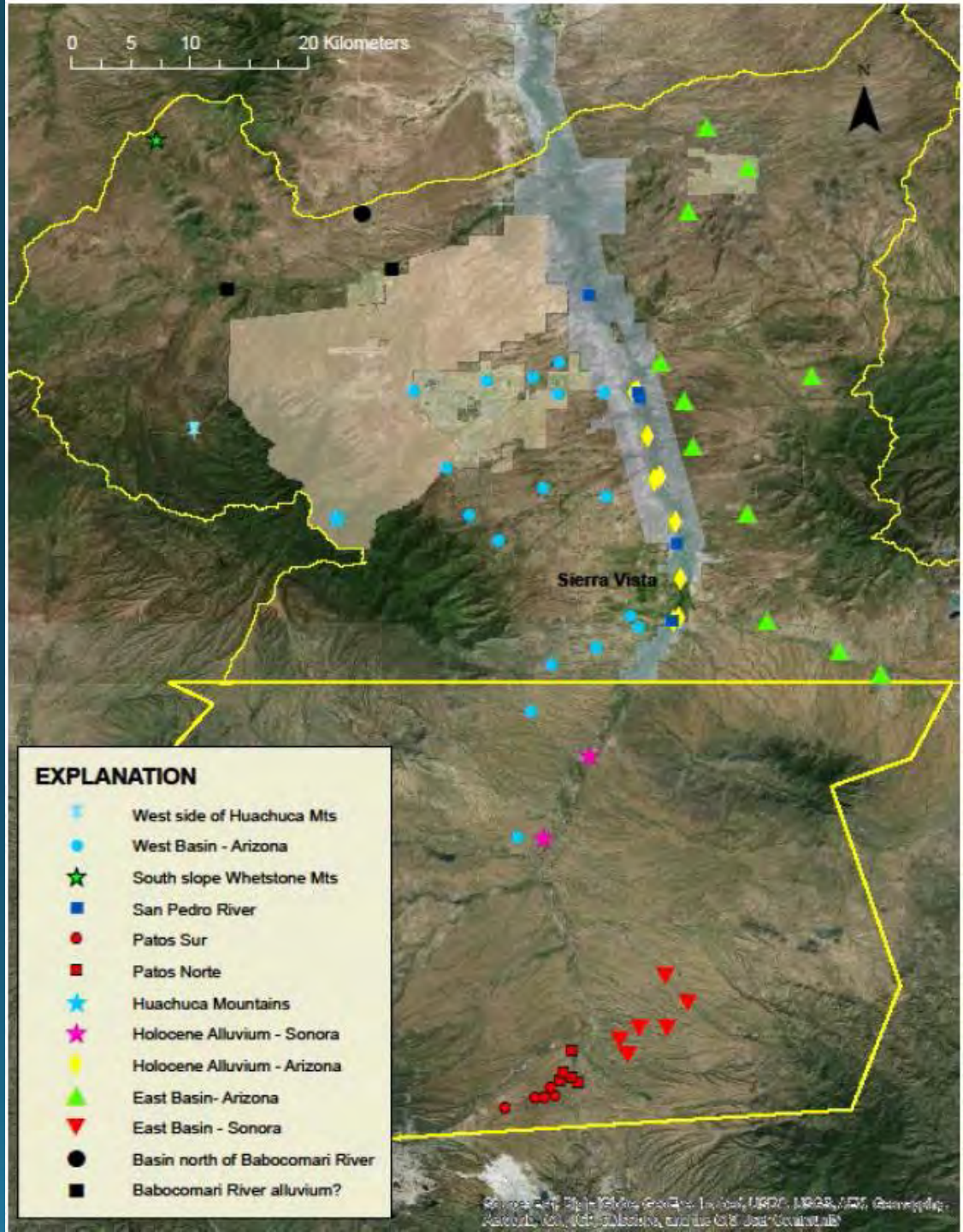
Piper Diagram: Water Chemistry Families



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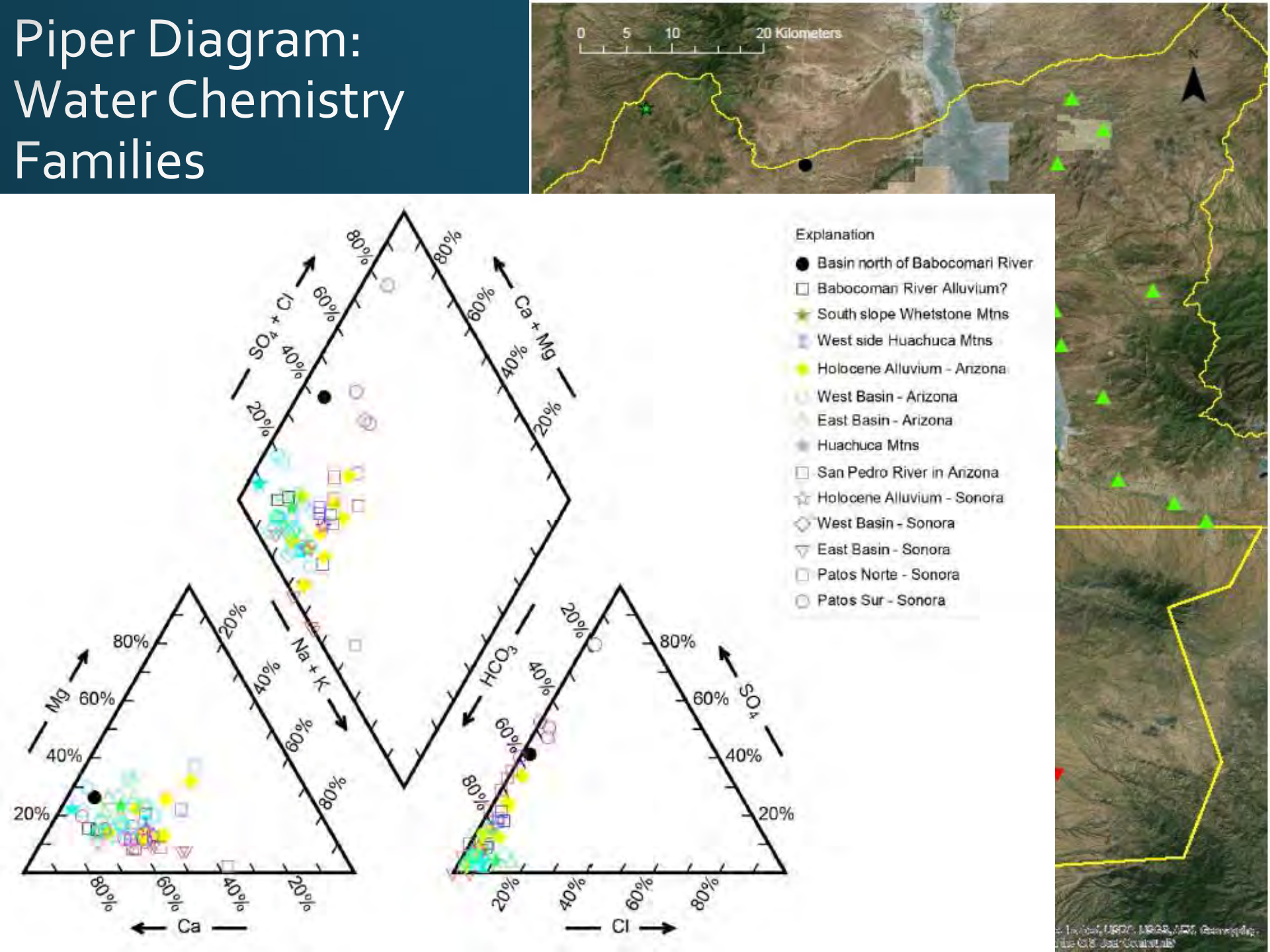
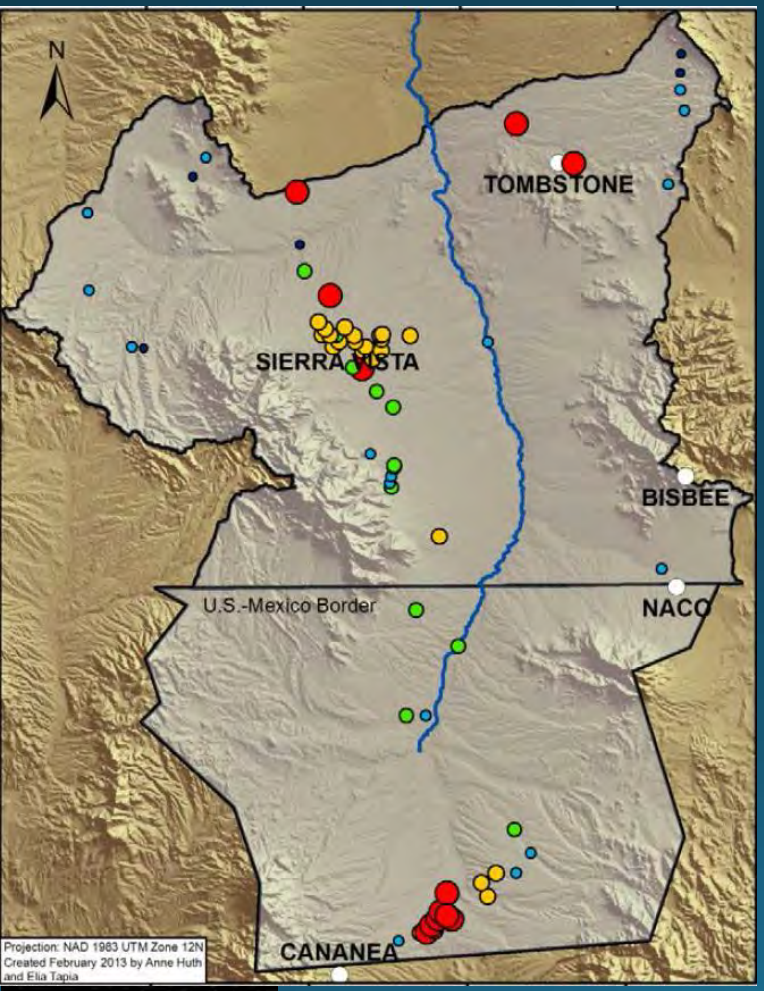
Piper Diagram: Water Chemistry Families

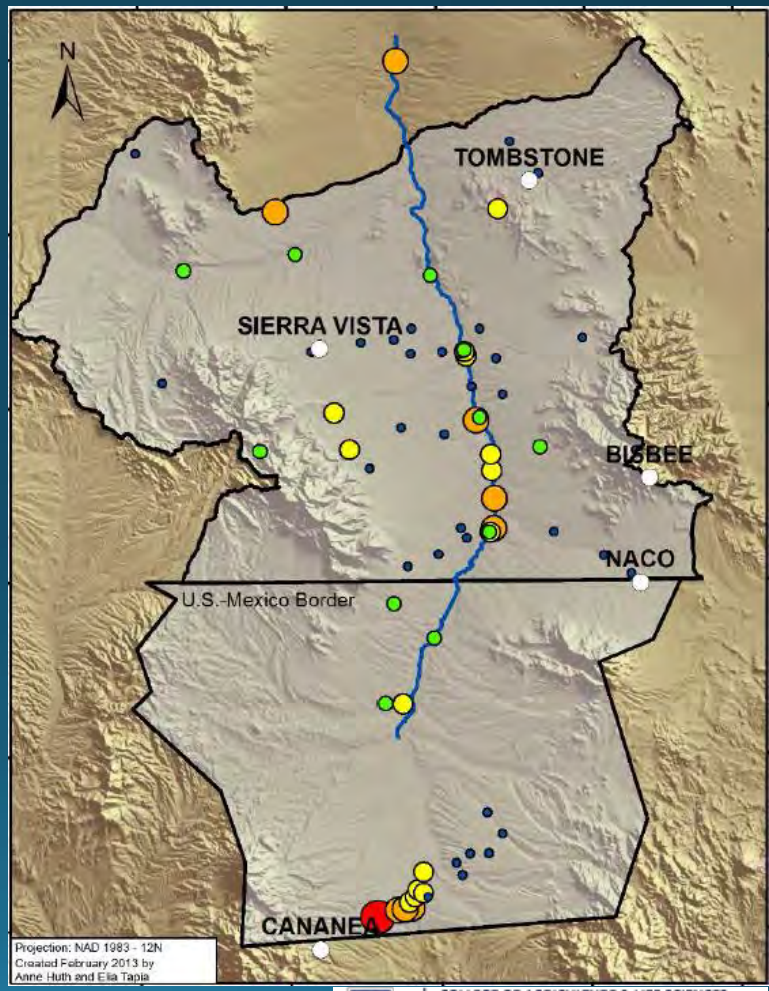


Ions, pH, EC, Alkalinity, and Temperature

Temperature



Sulfate



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Progress – Avances
Santa Cruz Basin – Cuenca Santa Cruz

- *Geochemical Database*
- *Sampling surface and groundwater for compounds of emerging concern – pesticides, pharmaceutical and personal care products*
- *Preliminary transport modeling - nitrate*
- *Installation of a streamgage in Nogales Wash the main tributary to the Santa Cruz River which originates in the twin cities of Nogales*

- *Base de datos geoquímicos*
- *Muestreo de contaminantes emergentes – pesticidios, farmaceúticos, productos de cuidado personal*
- *Modelación preliminario – transporte de nitratos*
- *Instalación fluviómetro en el Arroyo Nogales, el tributario principal del Río Santa Cruz que fluye desde las ciudades de Ambos Nogales*

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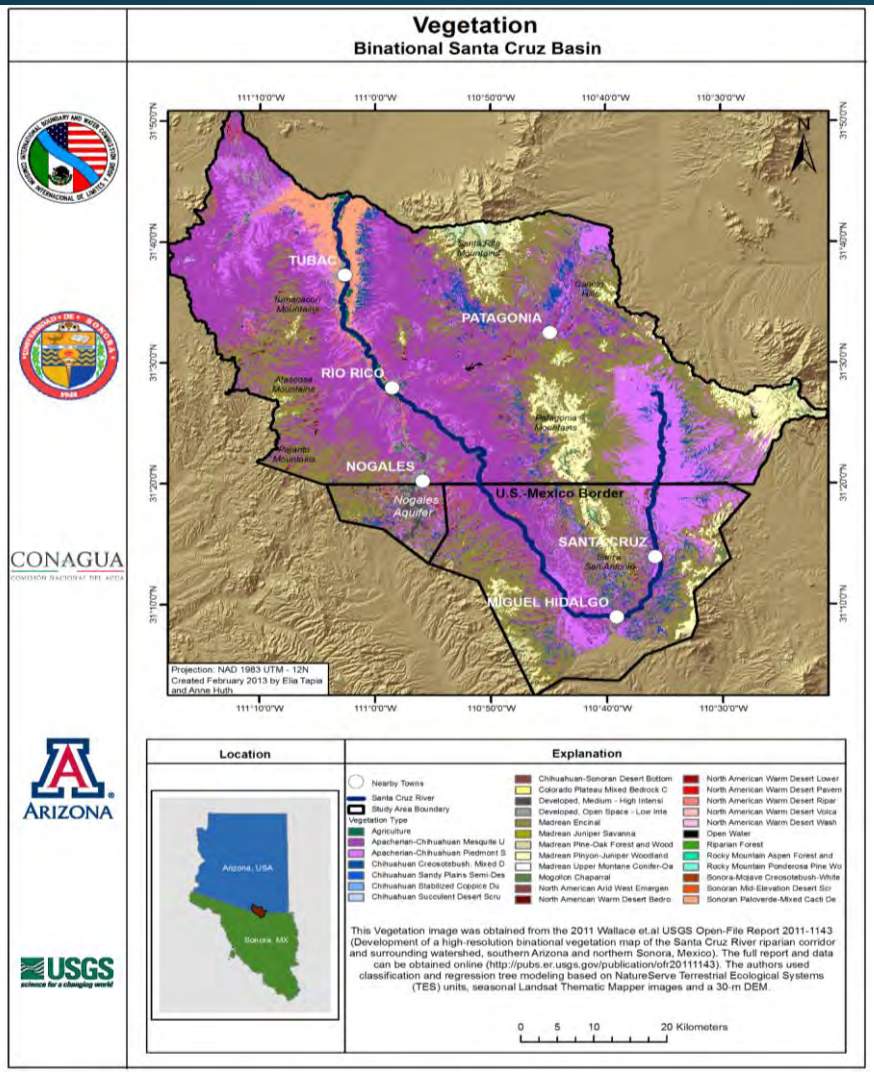
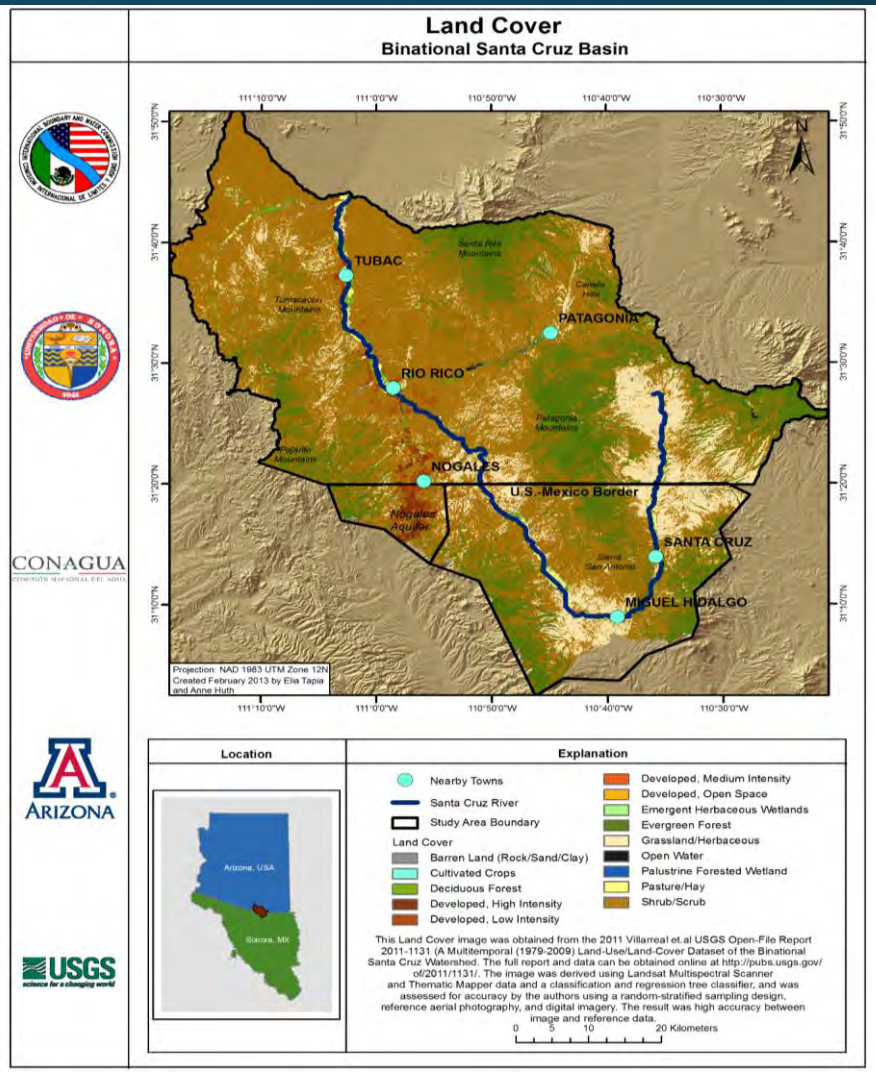
Vegetation and Land Cover





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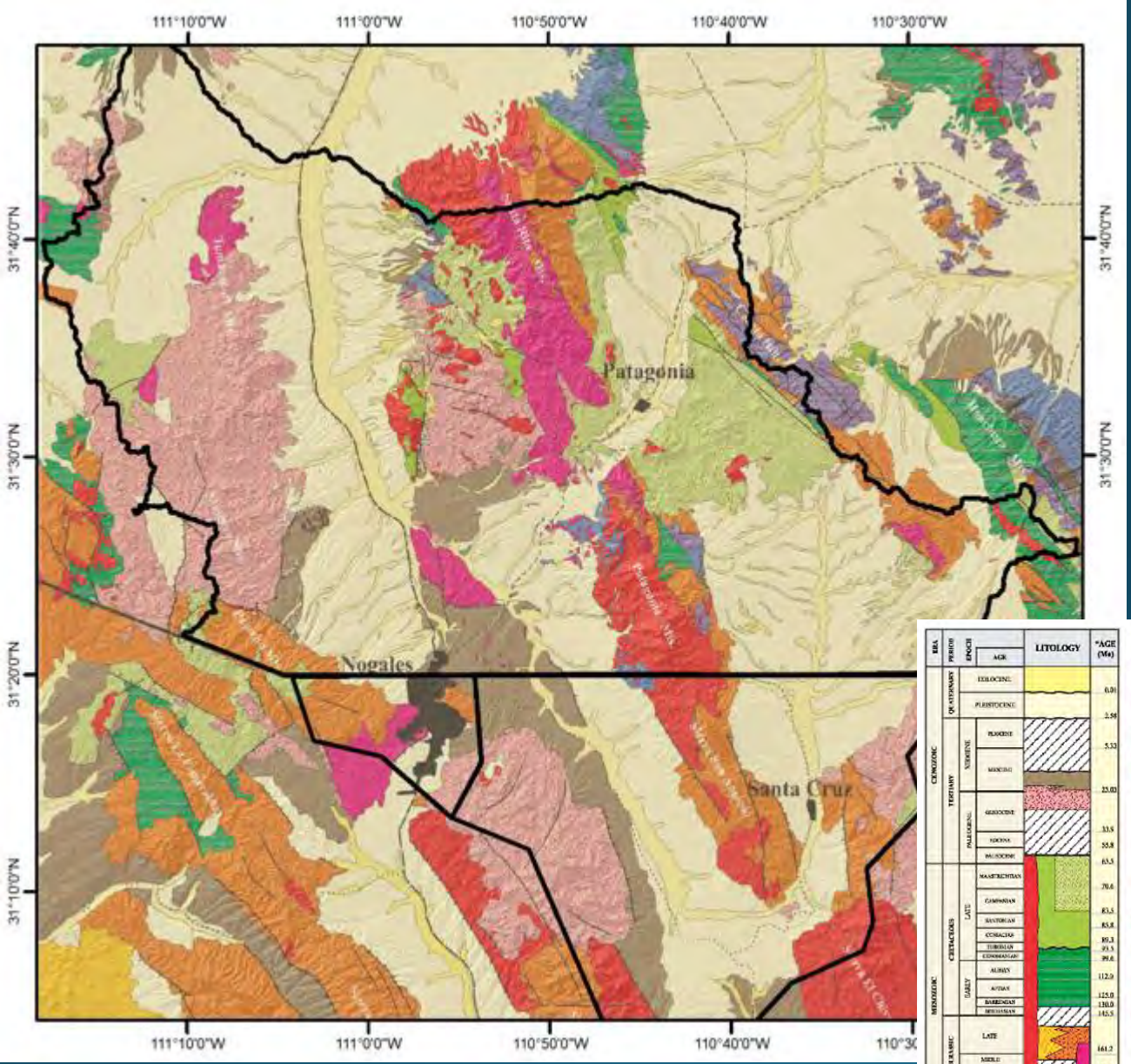
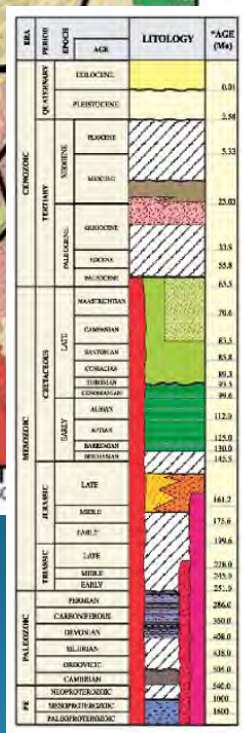
GEOLOGY





- Alluvium (Qal, Qg, Qhoal)
- Plio-Quaternary Sedimentary Unit (QTg, QptCgp)
- Tertiary Volcanosedimentary Unit (Tuc, Tc, Tm Cgp, Tm Ar-B, Tm Cgp-Ar,TmCgp-B, Tm Ar-Lu)
- Tertiary Volcanic Unit (TmTR-R,Tv, Tva, Tva?)
- Tertiary Intrusive Complex (Kd,Ti,Tlg, Tpa Gr-Gd, Tg, Kq,Tkp, TKg)
- Cretaceous-Paleocene Volcanosedimentary Unit (Klvs, Kr, Ka, KsA-TA, TLv?)
- Late Cretaceous Sedimentary Unit (Ks, Kus, KsVs)
- Early Cretaceous Sedimentary Unit (Kbu, Kb?, JsKiAr-Cgp)
- Jurassic Intrusive Complex (Jg, JmGr)
- Jurassic Metavolcanic Unit (JMe-MV)
- Jurassic Felsic Volcano-Sedimentary Unit (JTRvs, TRvs, JimR-Ar)
- Triassic Intrusive Complex (TRm)
- Late Paleozoic Sedimentary Unit (Ps, PPs Ph, Mds)
- Early Paleozoic Sedimentary Unit (Cs)
- Precambrian Igneous-Metamorphic Complex (€TmGr,Yg, Xp)

Discordancia
Sin exposición estratigráfica

Falla Normal
Falla Inversa

Poblaciones
Caminos

*Ages of ICS (2009)

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GEOLOGY: Generalization and Integration

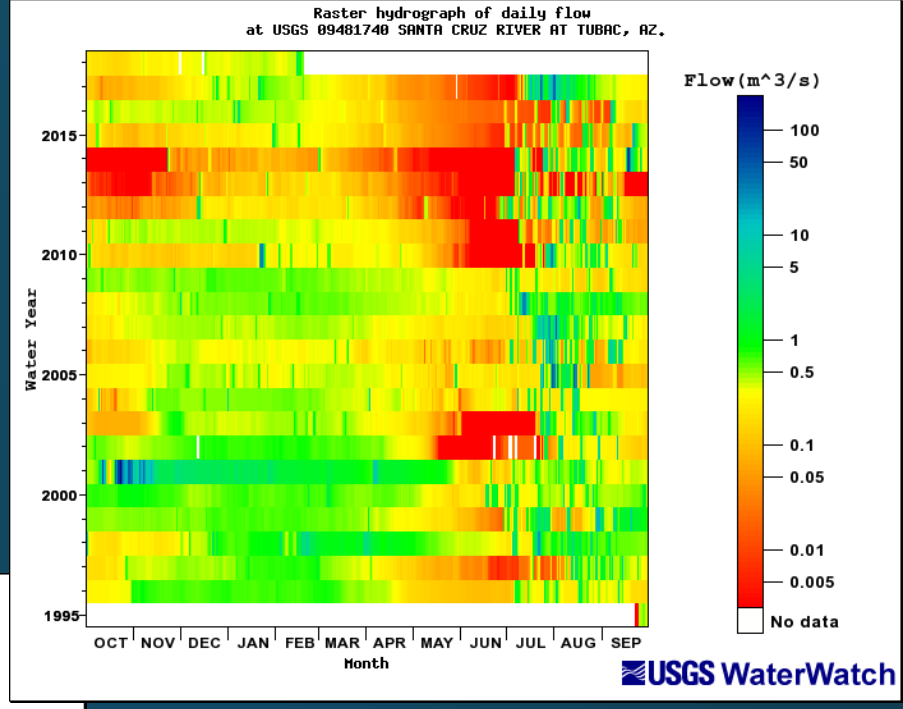
Precambrian Igneous-Metamorphic Complex

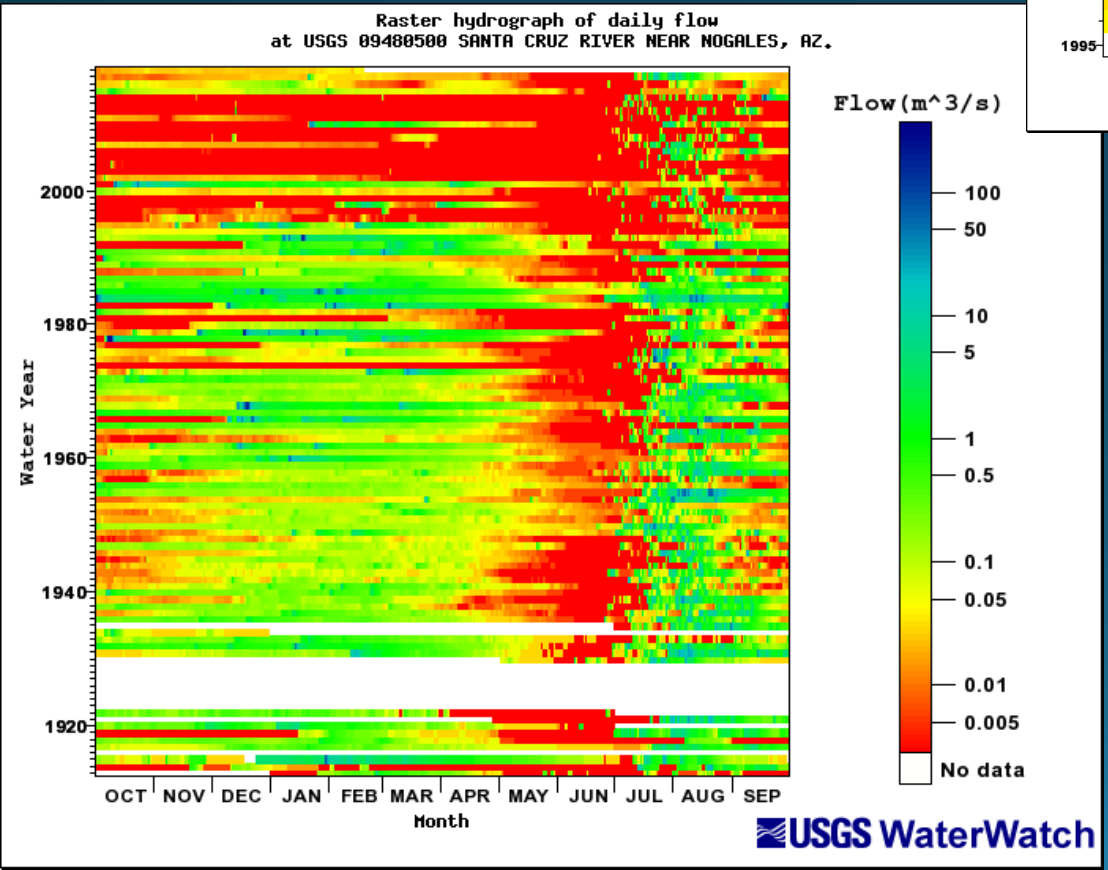
- Outcrops of igneous and metamorphic rocks of Precambrian age that occur within the Binational San Pedro Aquifer.

- For the Mexican portion: outcrops occur on the NE flank of El Caloso Peak, west of Cananea… called the Cananea Granite by Emmons (1910) and Valentine (1936), characterized by light gray to pink, phaneritic texture, dominated by quartz, feldspar, biotite, muscovite…

- For the U.S. portion: outcrops of this unit are represented by two dominant lithologies. The first is a hornblende-biotite granodiorite exposed in the Tombstone hills, and more widely in the eastern portion of the Huachuaca Mountains. The second is a sequence of schists and slates from the Pinal Schist …

Raster Hydrographs





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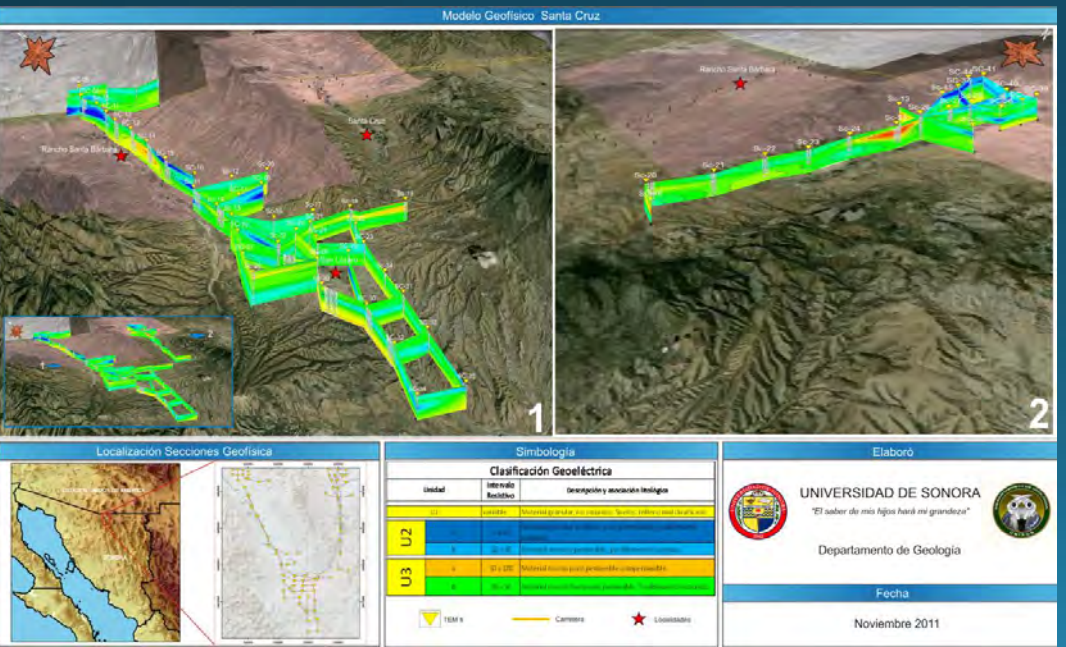
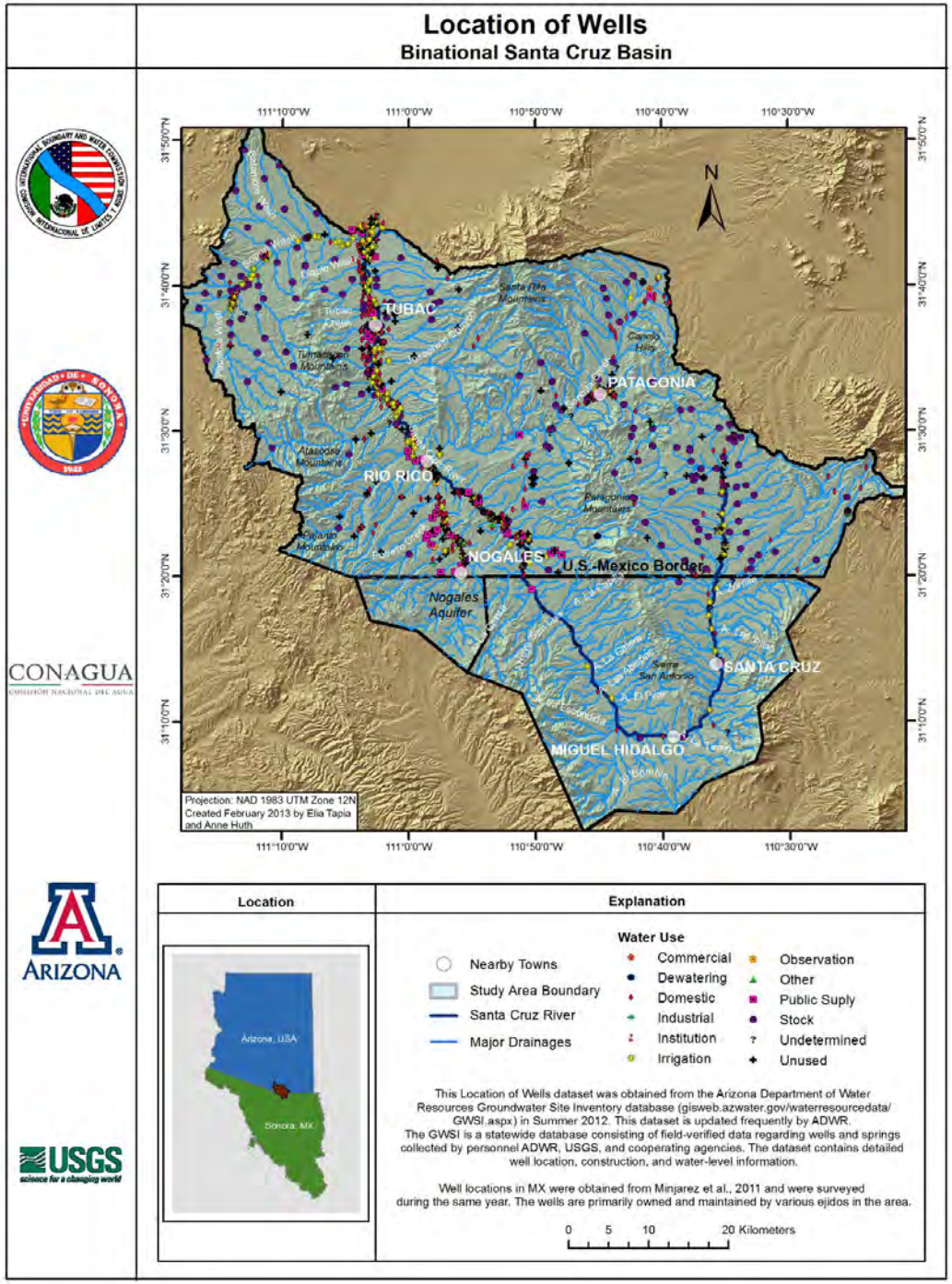
Progress – Avances
Santa Cruz Basin – Cuenca Santa Cruz

- Work on hydrogeologic framework model for Upper Santa Cruz Basin (AZWSC, GMEG, UNISON)
- Development of wells database with geologic log information.

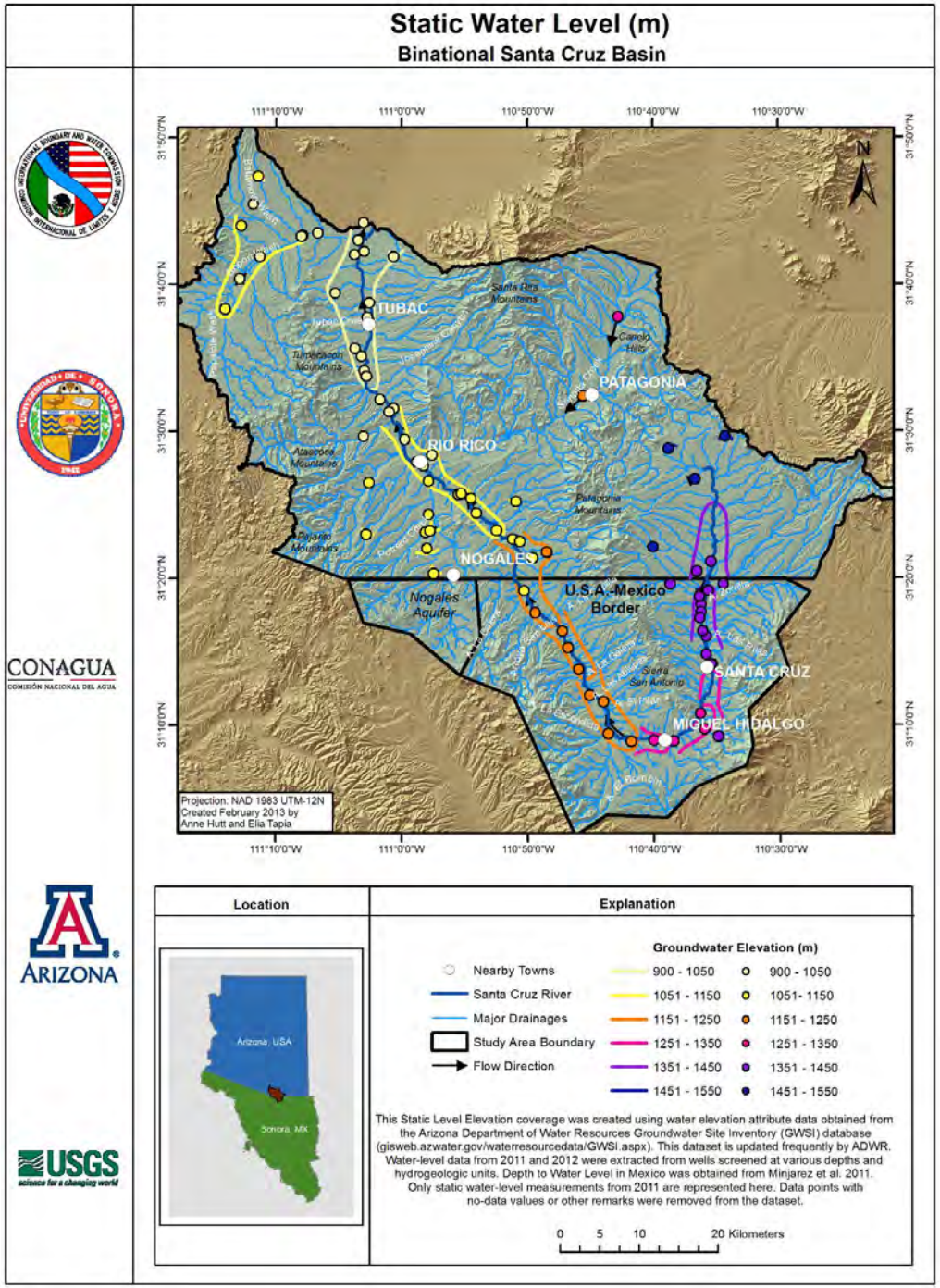
- Esfuerzo en el marco hidrogeológico de la Cuenca Alta Santa Cruz (AZWSC, GMEG, UNISON)
- Elaboración de una base de datos de pozos con información sobre cortes geológicos.





Well Locations

Water Table Altitude



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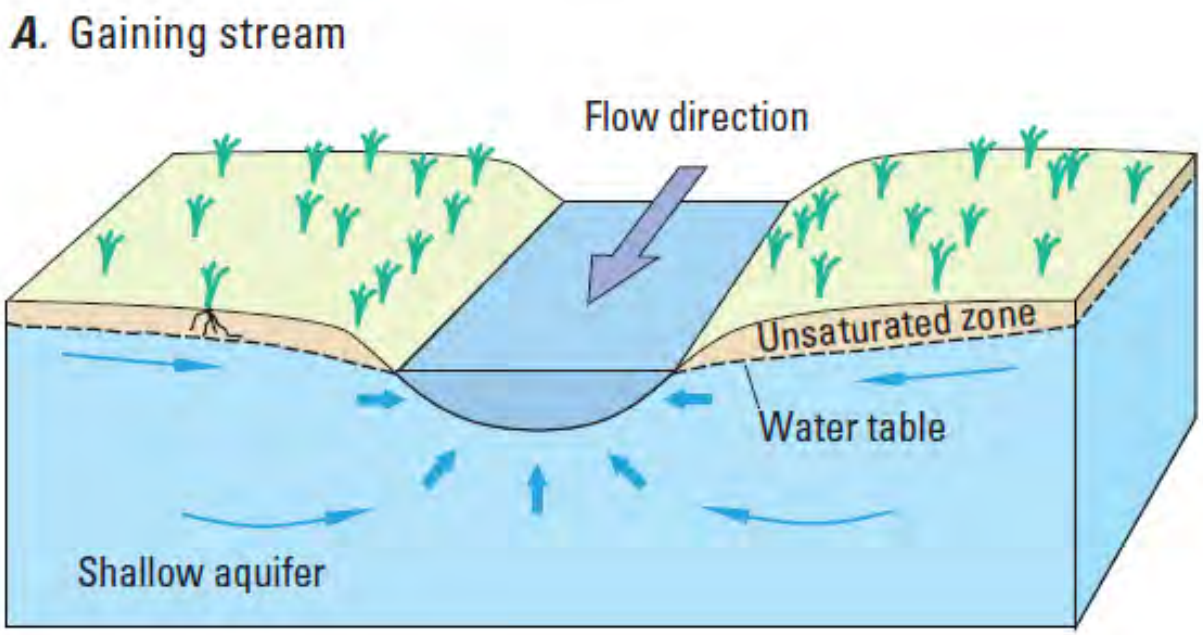
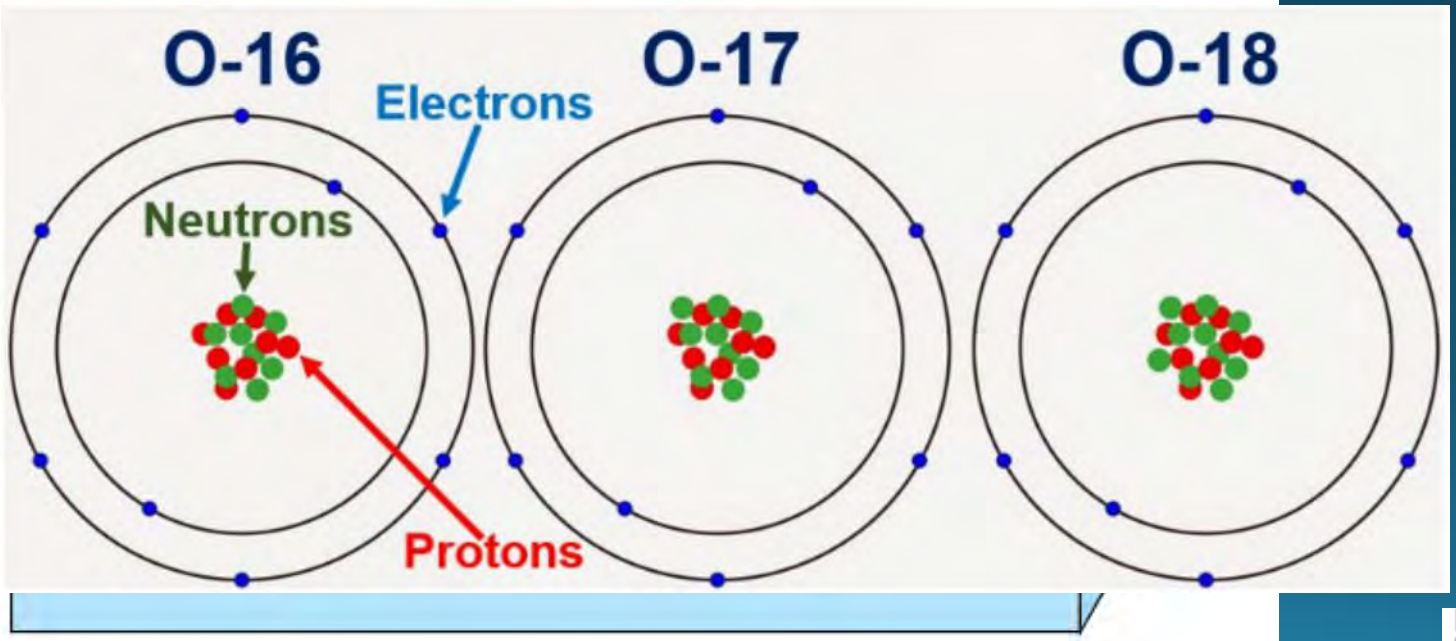
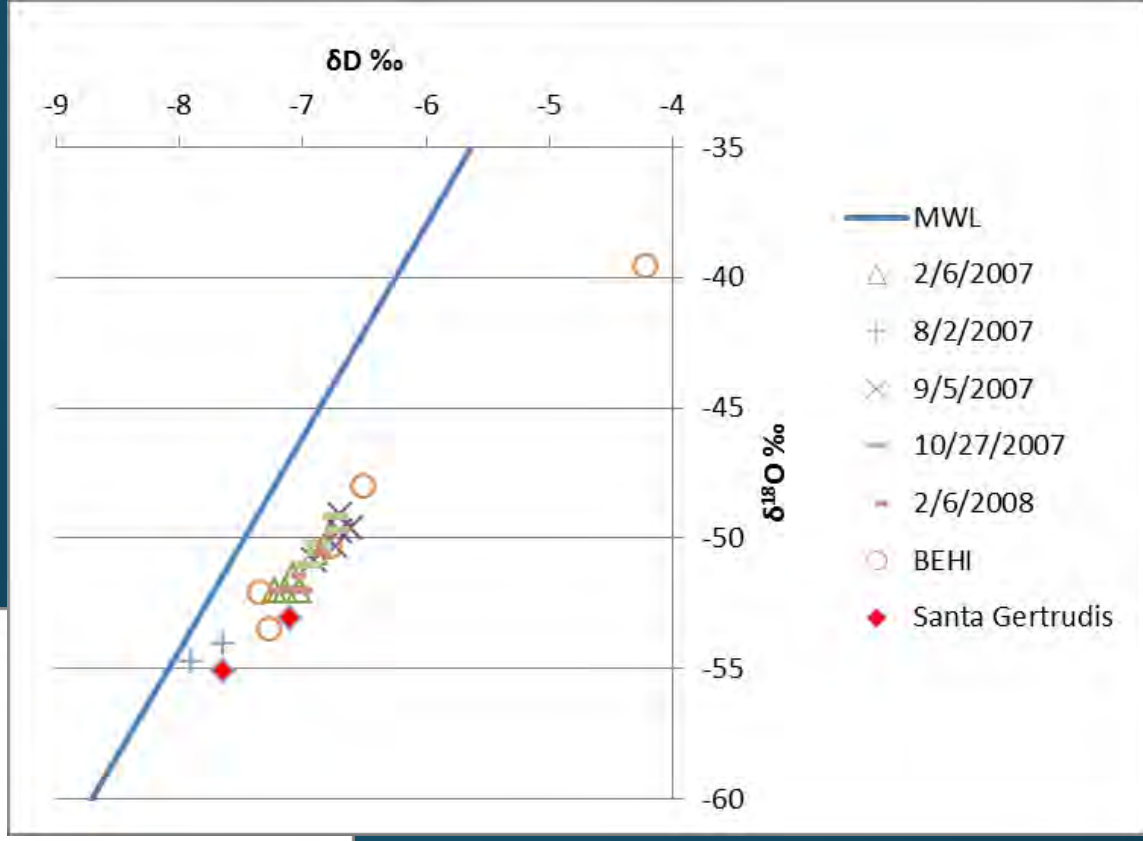
Stable Isotopes

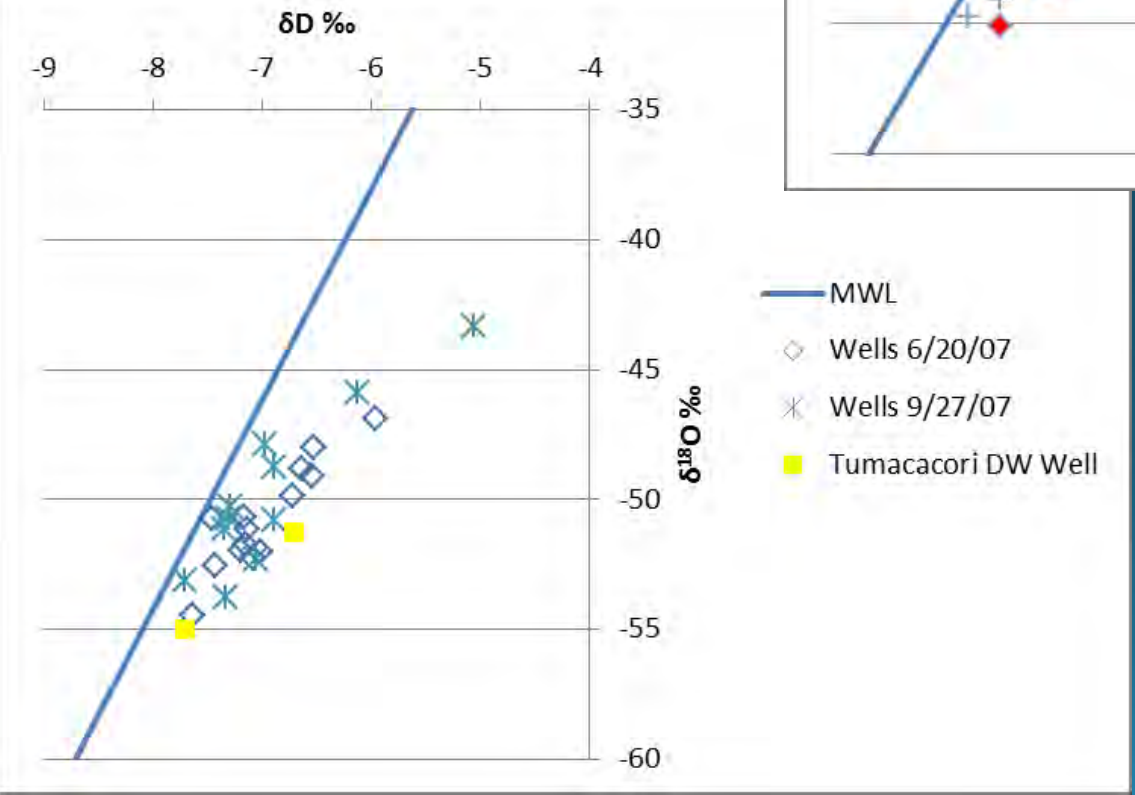




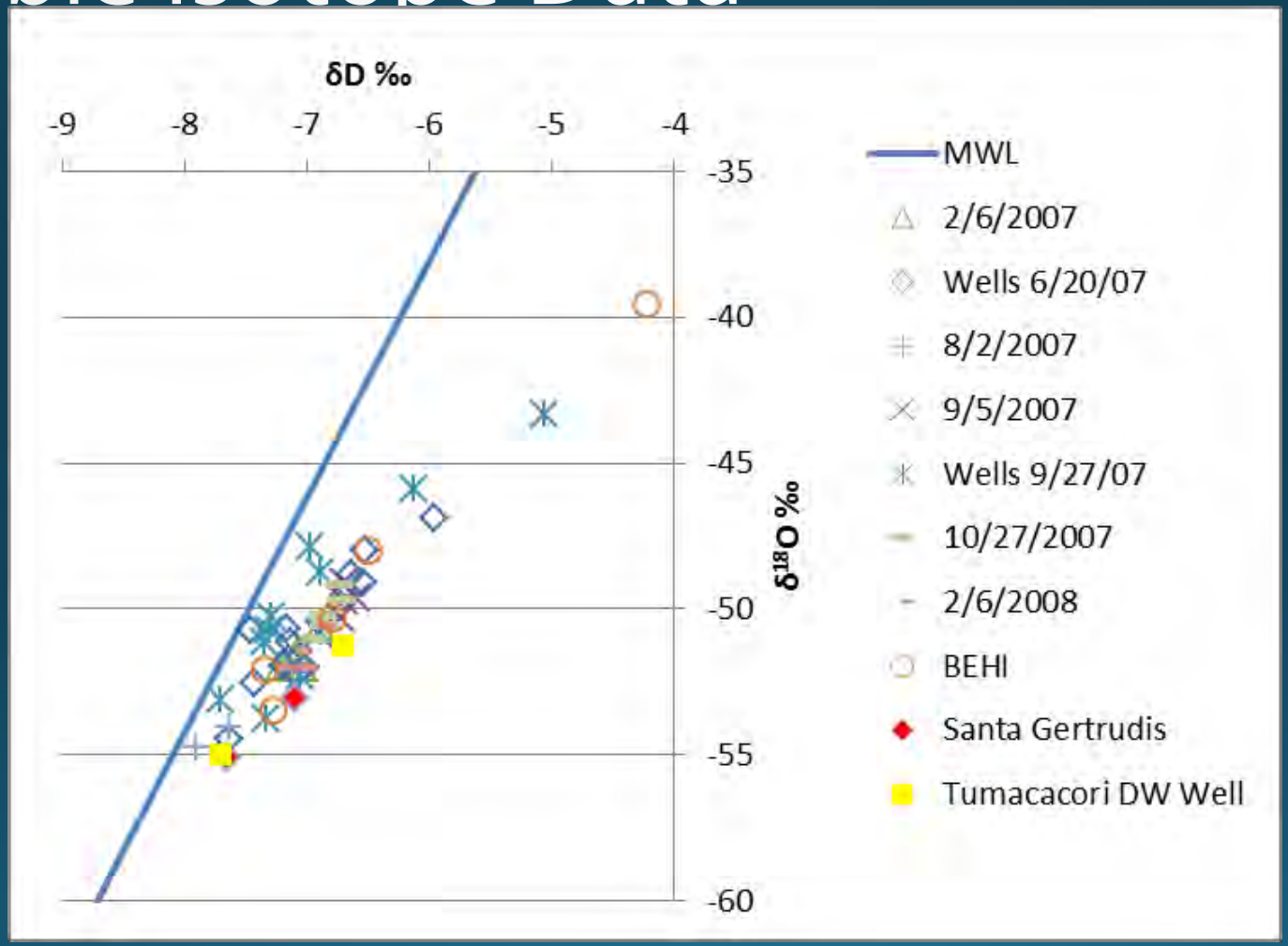
Barlow and Leake, 2012

Stable Isotope Data





Stable Isotope Data



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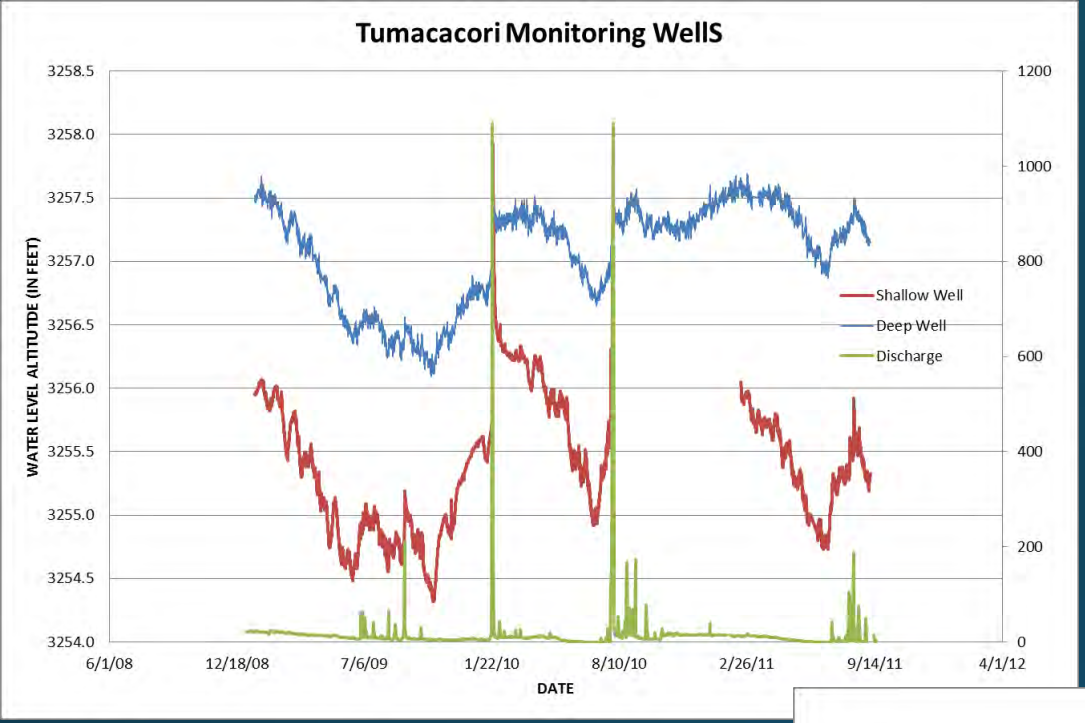
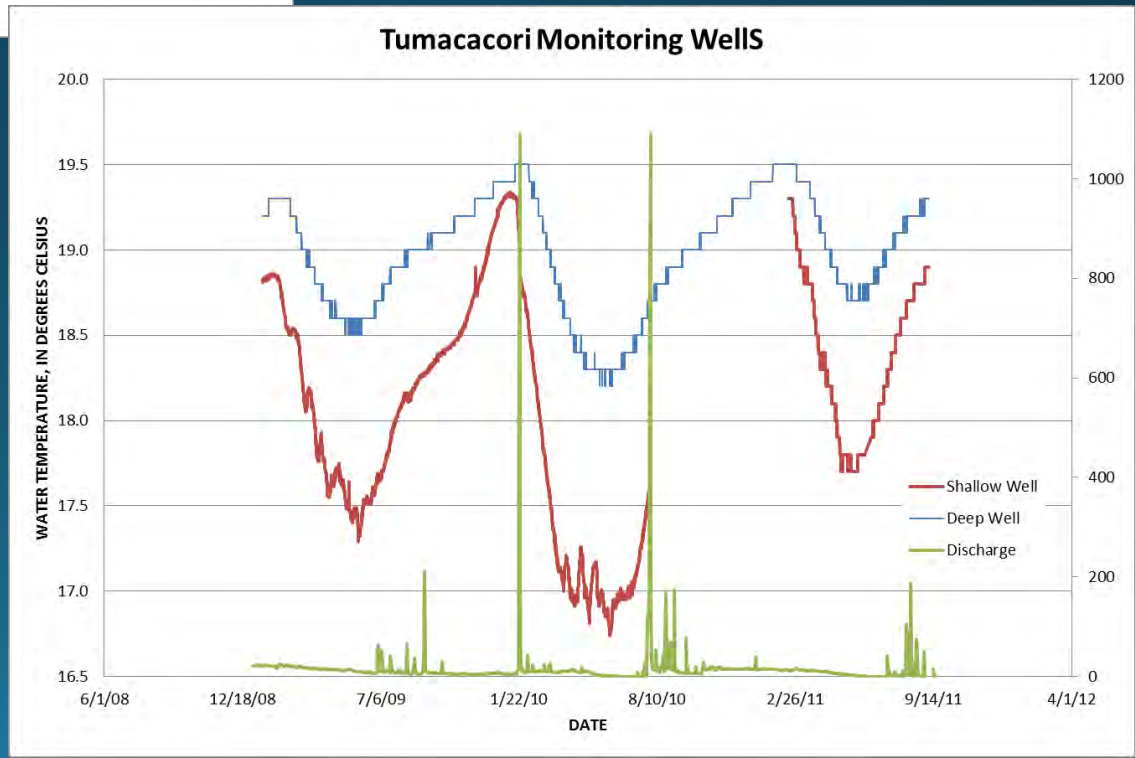


Water Levels and Streamgage Data

Temperature and Streamgage Data



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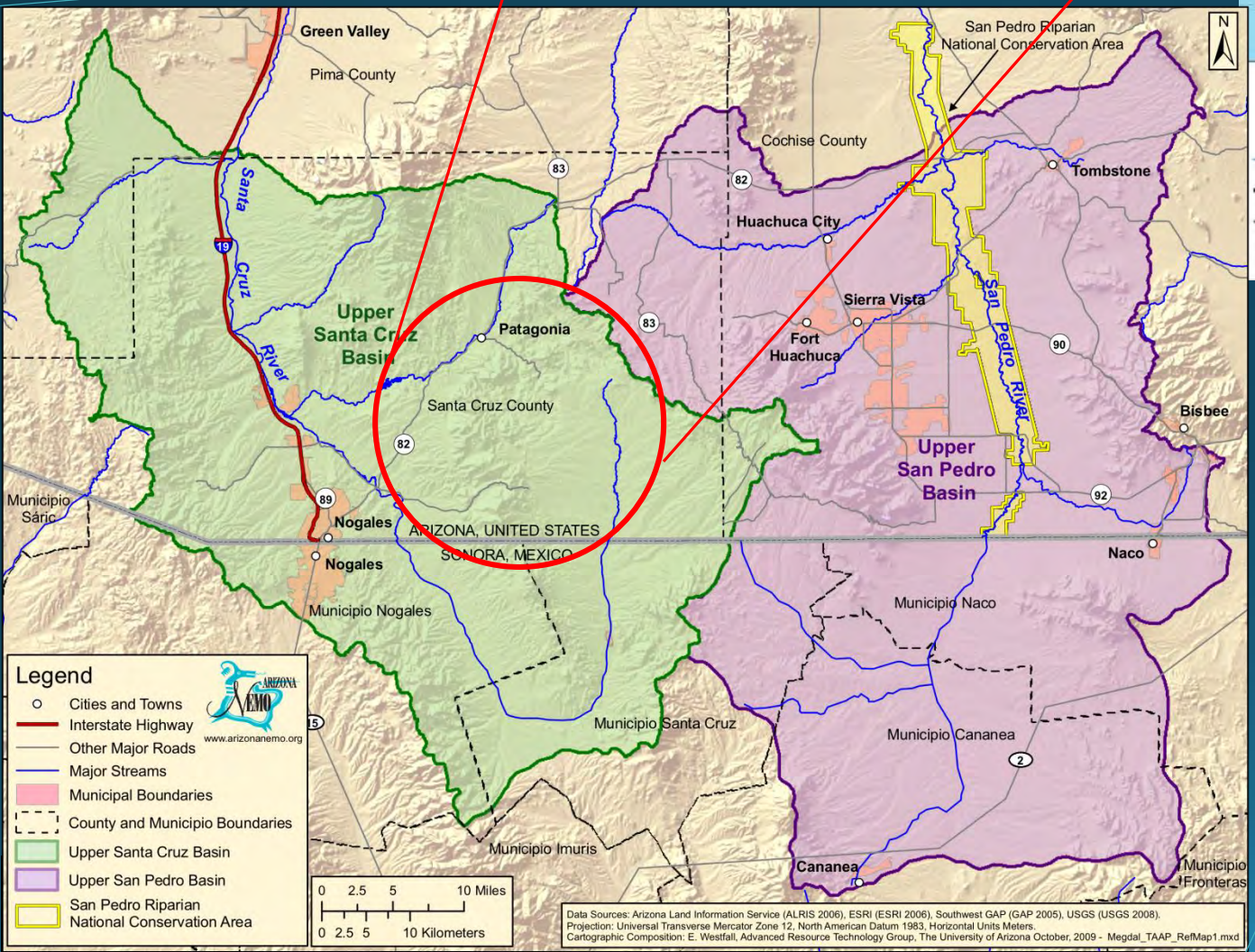
Study Area: Patagonia Mtns



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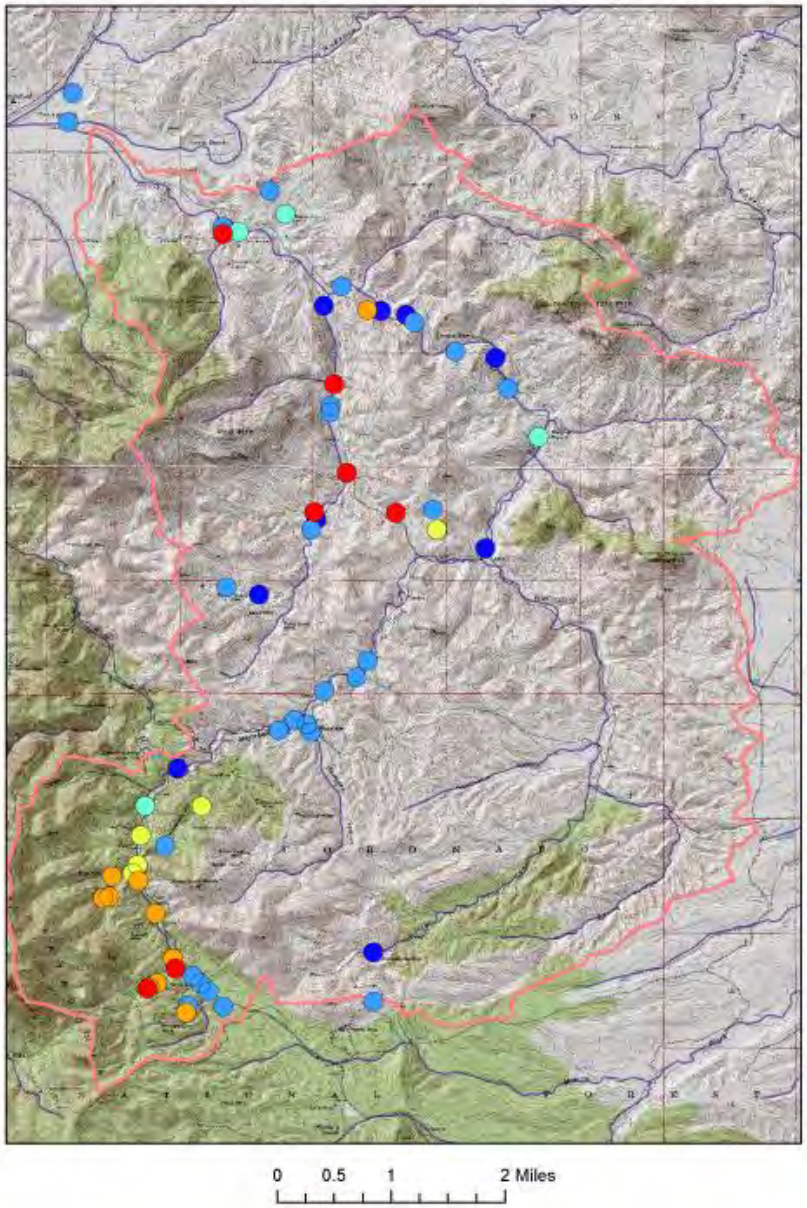
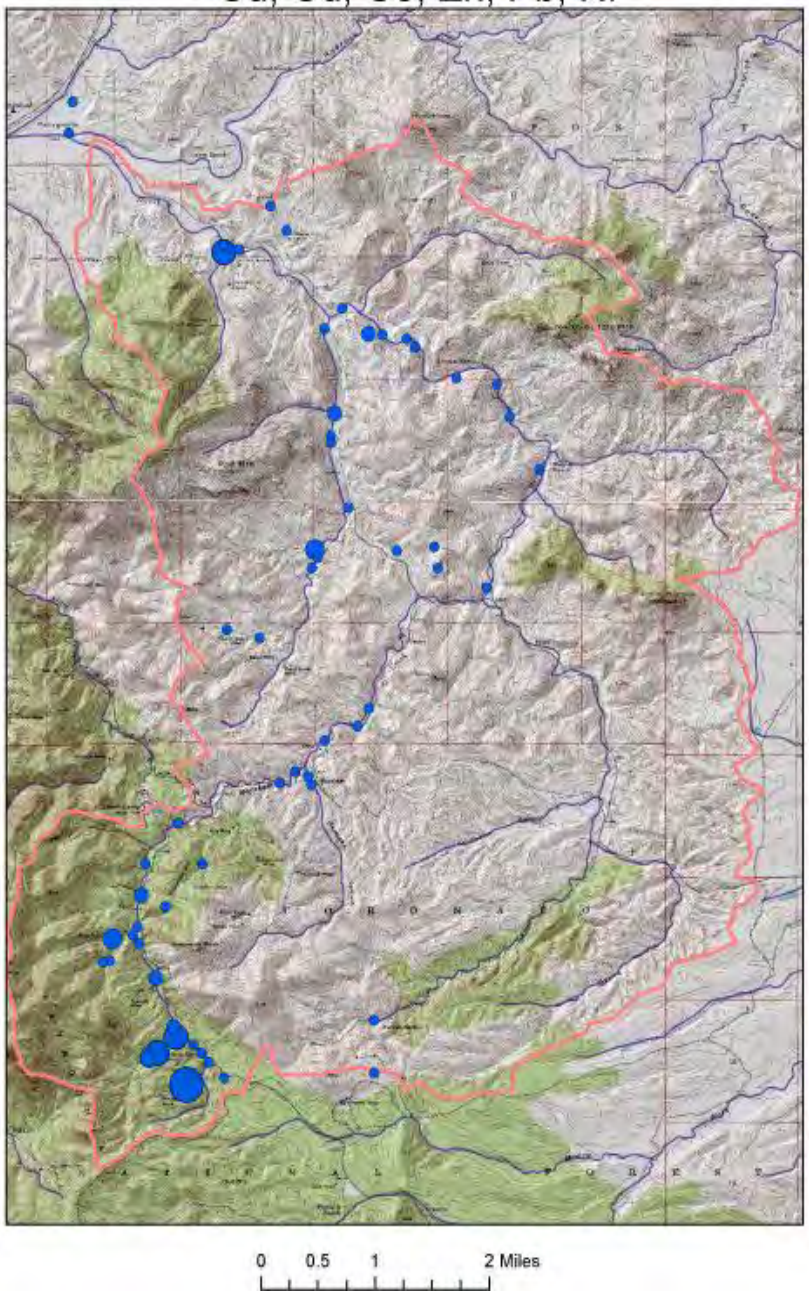
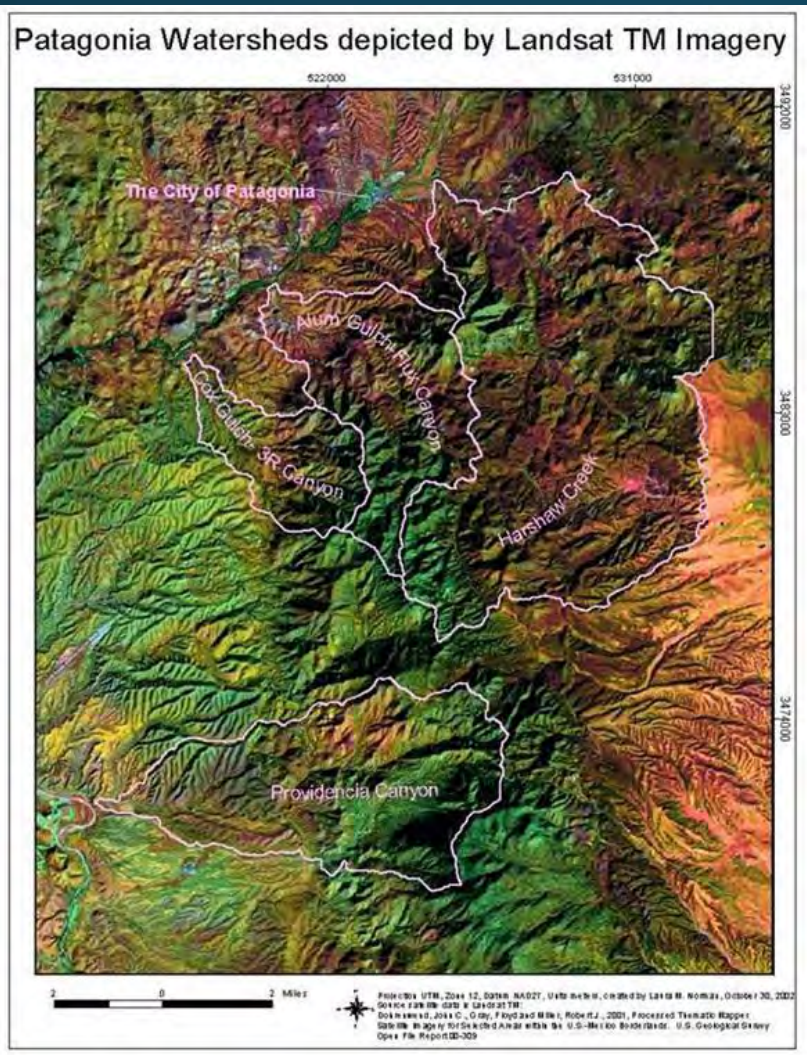
Harshaw Watershed Samples by pH

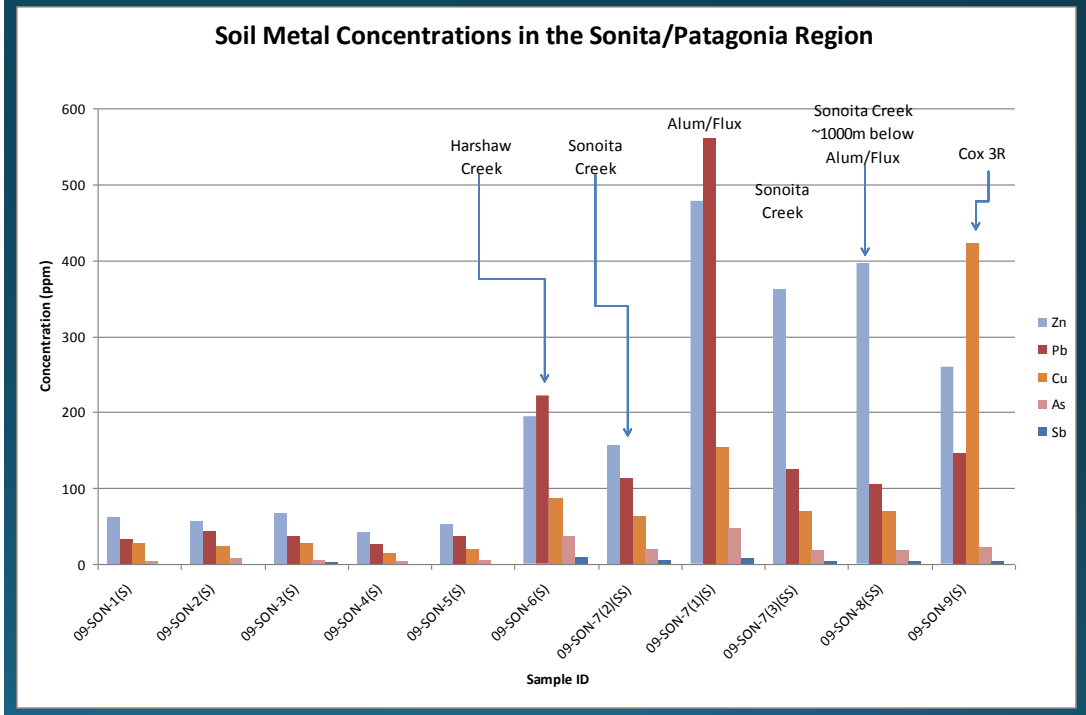


Harshaw Watershed Combined Metals
Cu, Cd, Co, Zn, Pb, Ni



Metals in Soils and Sediments

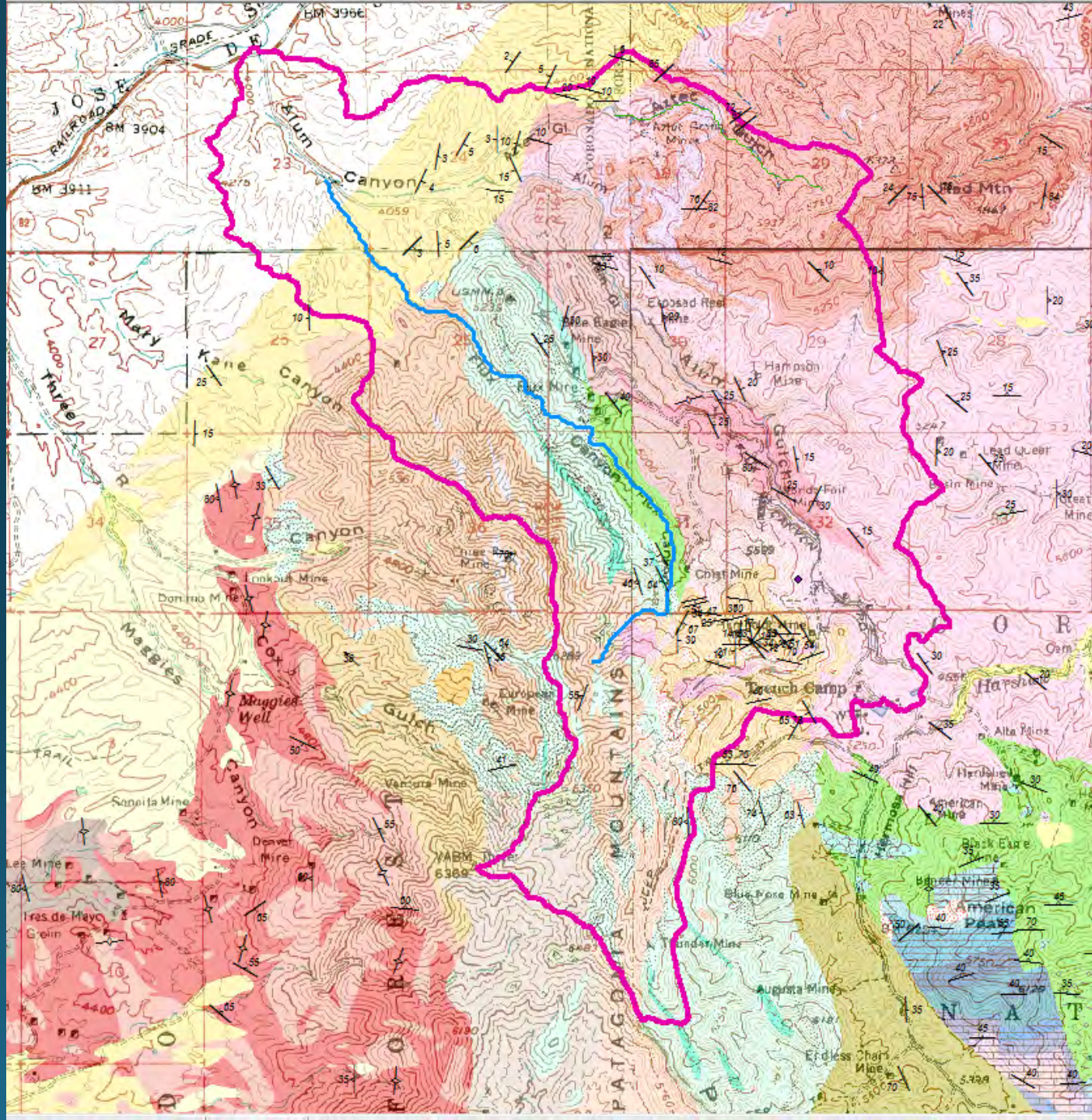




Geology

(Graybeal and others, 2015)

- Geologic Units
- Strike and Dip: Foliations, Faults, Bedding



USGS
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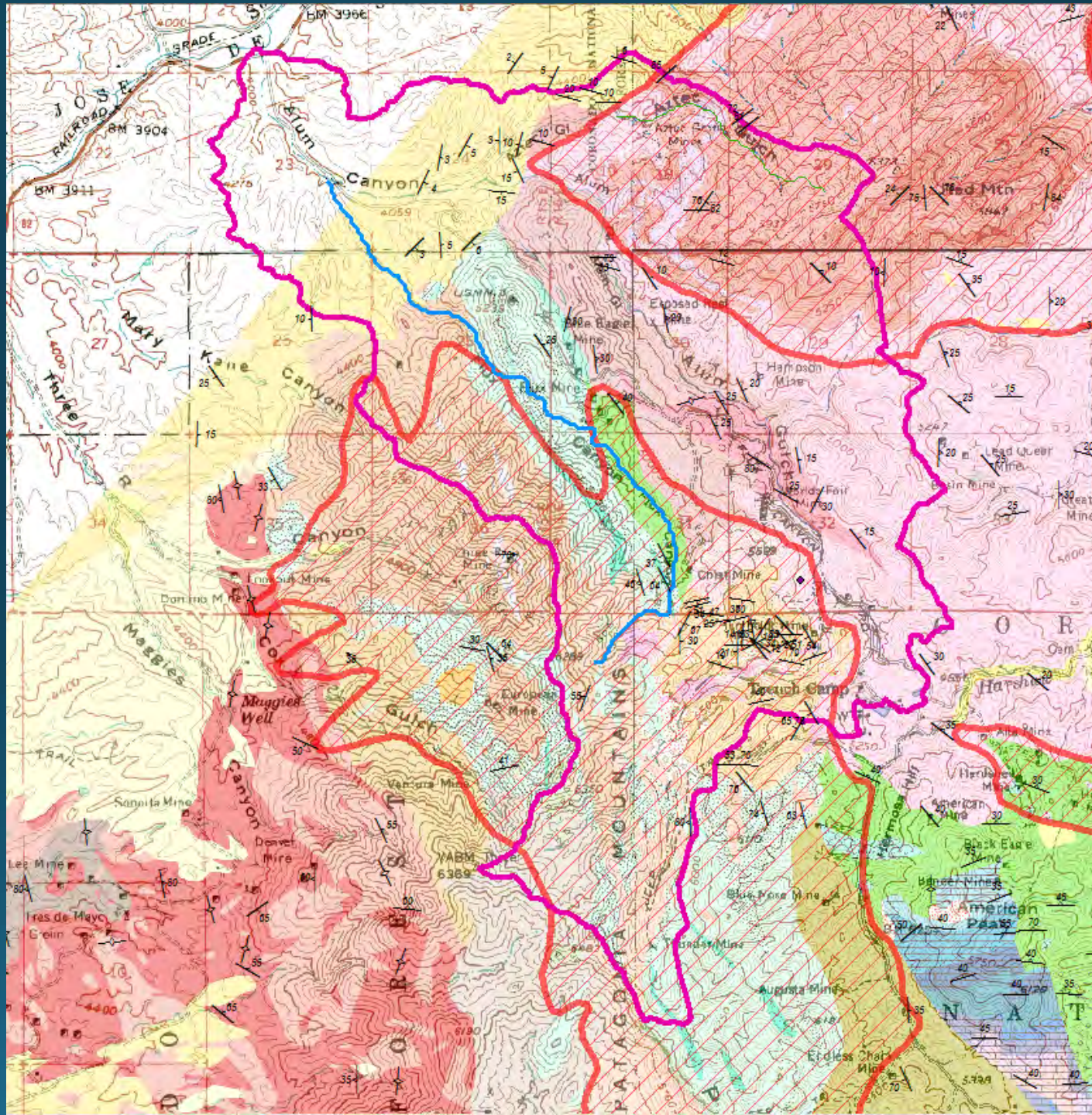
Geology

(Graybeal and others, 2015)

- Geologic Units
- Strike and Dip: Foliations, Faults, Bedding
- Pyritized Zones

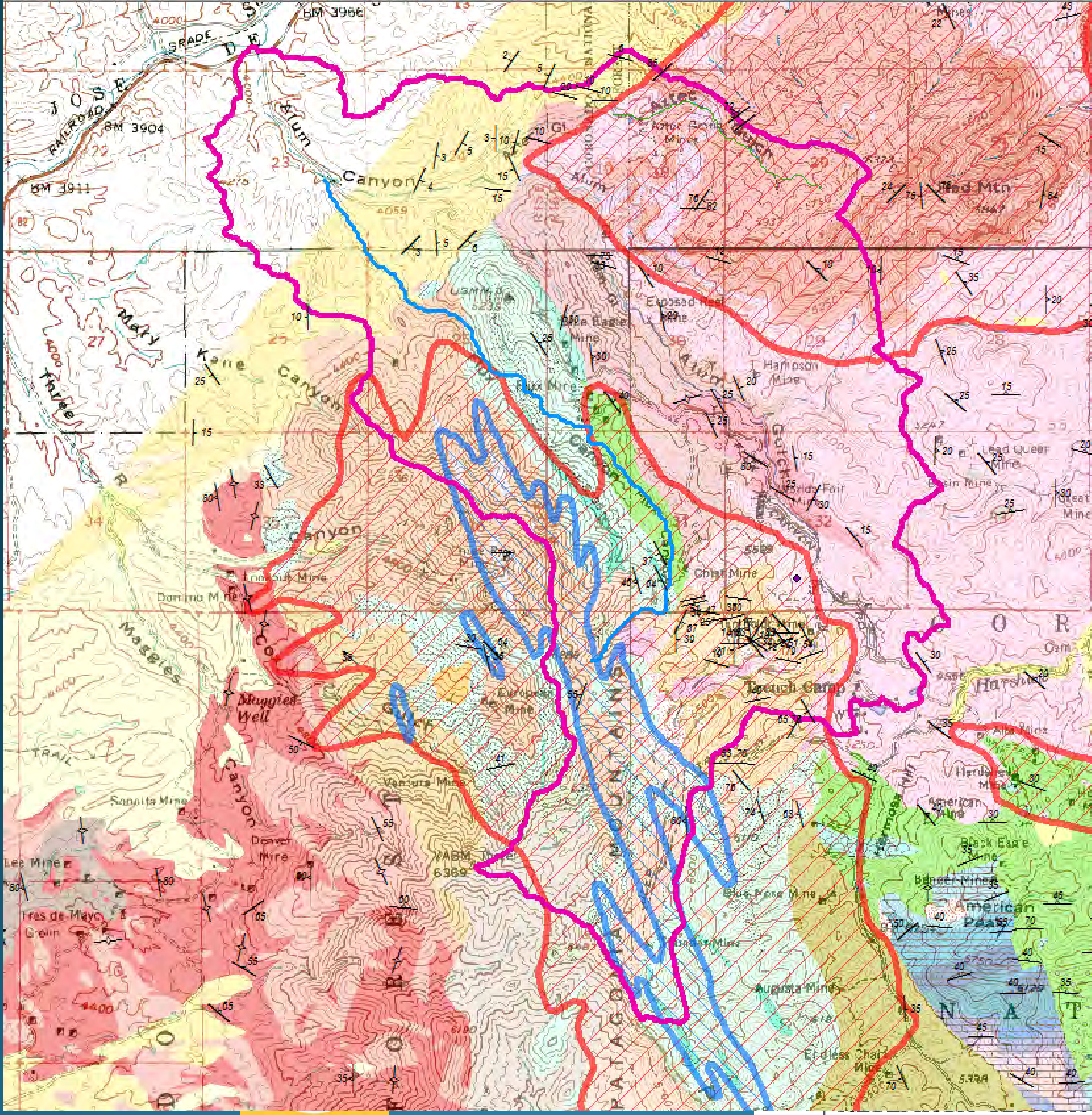


USGS
science for a changing world

Geology

(Graybeal and others, 2015)

- Geologic Units
- Strike and Dip: Foliations, Faults, Bedding
- Pyrtized Zones
- Shear Zones

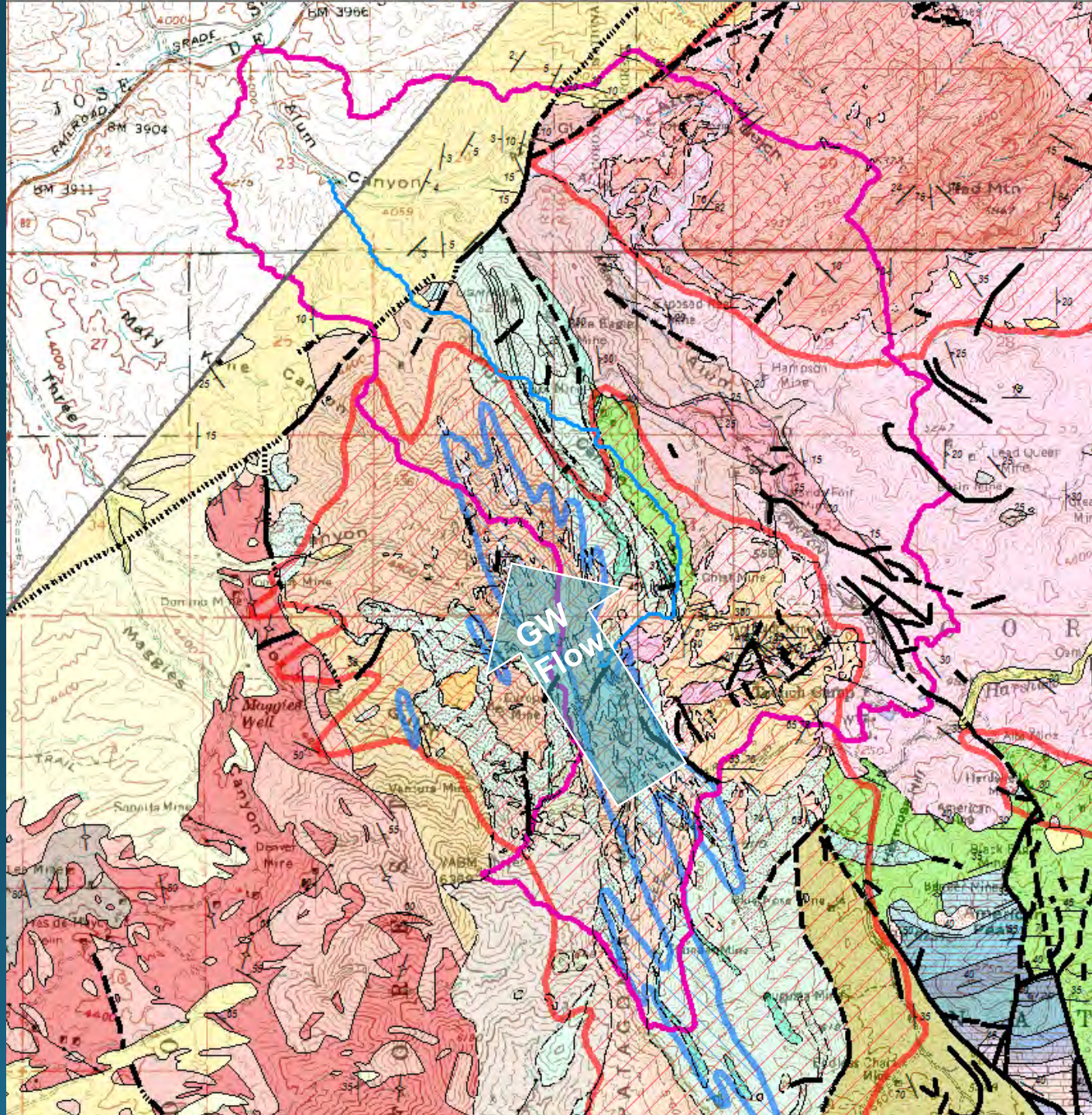


USGS
science for a changing world

Geology

(Graybeal and others, 2015)

- Geologic Units
- Strike and Dip: Foliations, Faults, Bedding
- Pyritized Zones
- Shear Zones
- Faults

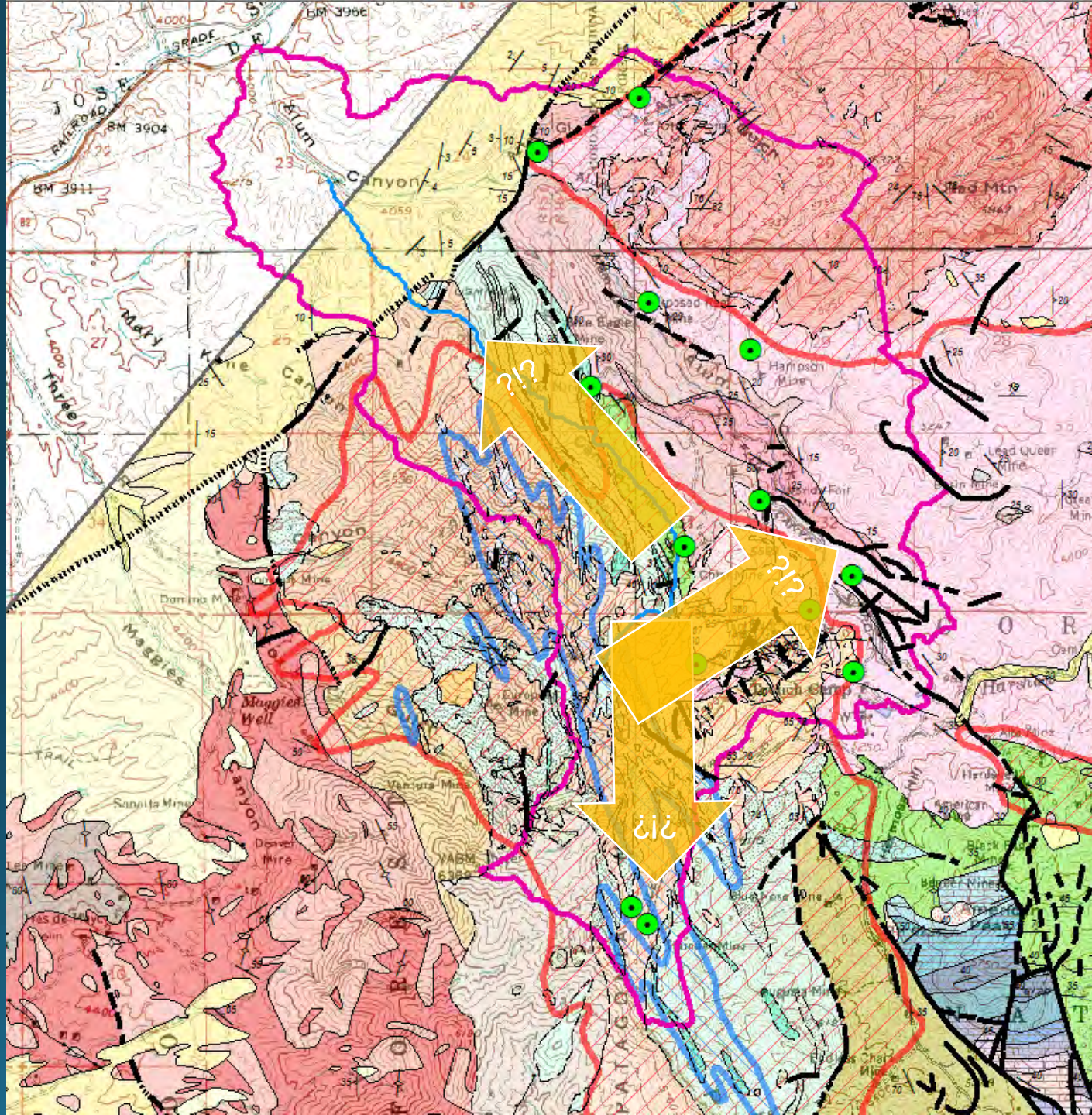


USGS
science for a changing world

Geology

(Graybeal and others, 2015)

- Geologic Units
- Strike and Dip: Foliations, Faults, Bedding
- Pyrtized Zones
- Shear Zones
- Faults



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Recommendations for Future Work

- Water Budget Components (with caution!)
- Water Use and Groundwater Extraction
- Water Levels
- Stream and River Discharge
- Weather Observations
- Evapotranspiration and Vegetation Change

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COOPERATIVE EXTENSION
WATER RESOURCES RESEARCH CENTER

Recommendations for Future Work

- Water Quality and Stable Isotope Sampling
- Geophysical and Remote Sensing Methods
- Research Drilling
- Binational Soils Map
- Database Standardization
- Groundwater-Surface-Water Interactions
- Numerical Modeling

Gracias
Thank you

For further information, contact
James Callegary
jcallega@usgs.gov

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COOPERATIVE EXTENSION

WATER RESOURCES RESEARCH CENTER

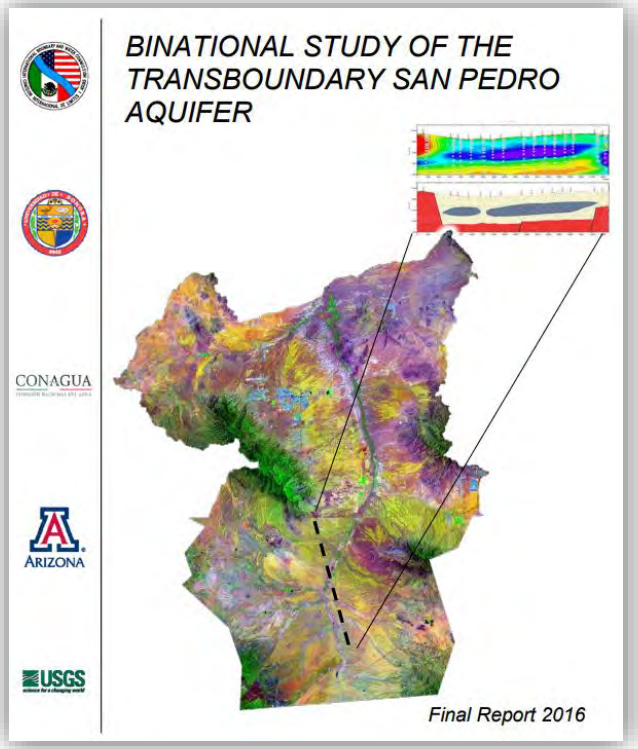
Collaborations on the San Pedro-Santa Cruz Transboundary Studies and Current TAAP efforts

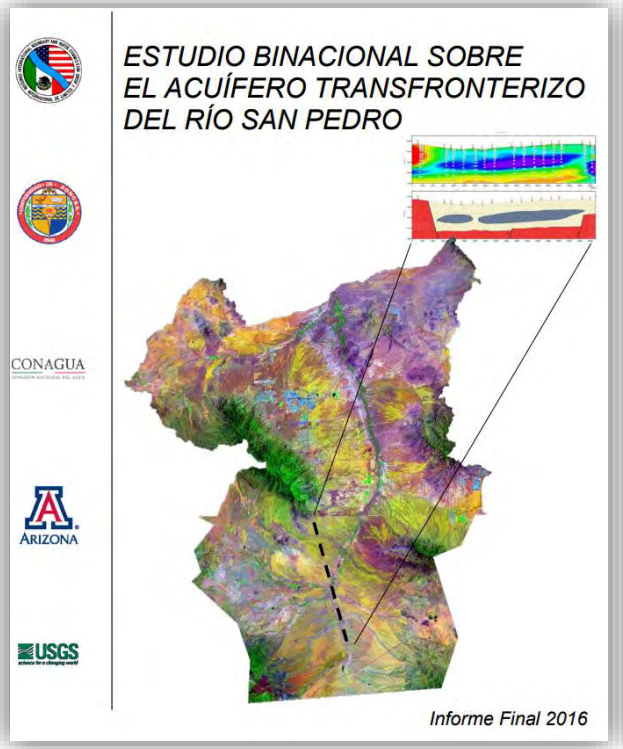
Elia M. Tapia
Water Resources Research Center, University of Arizona

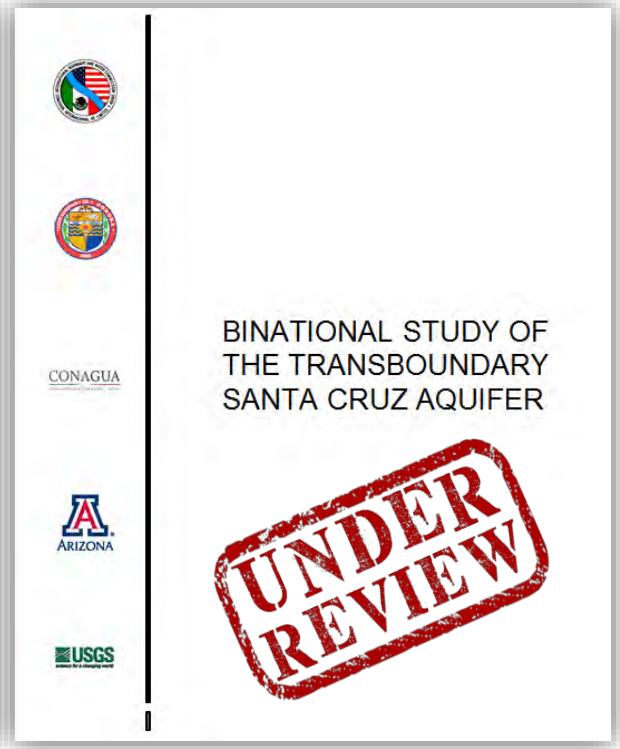
TAAP Brown Bag Presentation
February 21, 2018

wrrc.arizona.edu

The Binational Studies of the Transboundary San Pedro and Santa Cruz Aquifers





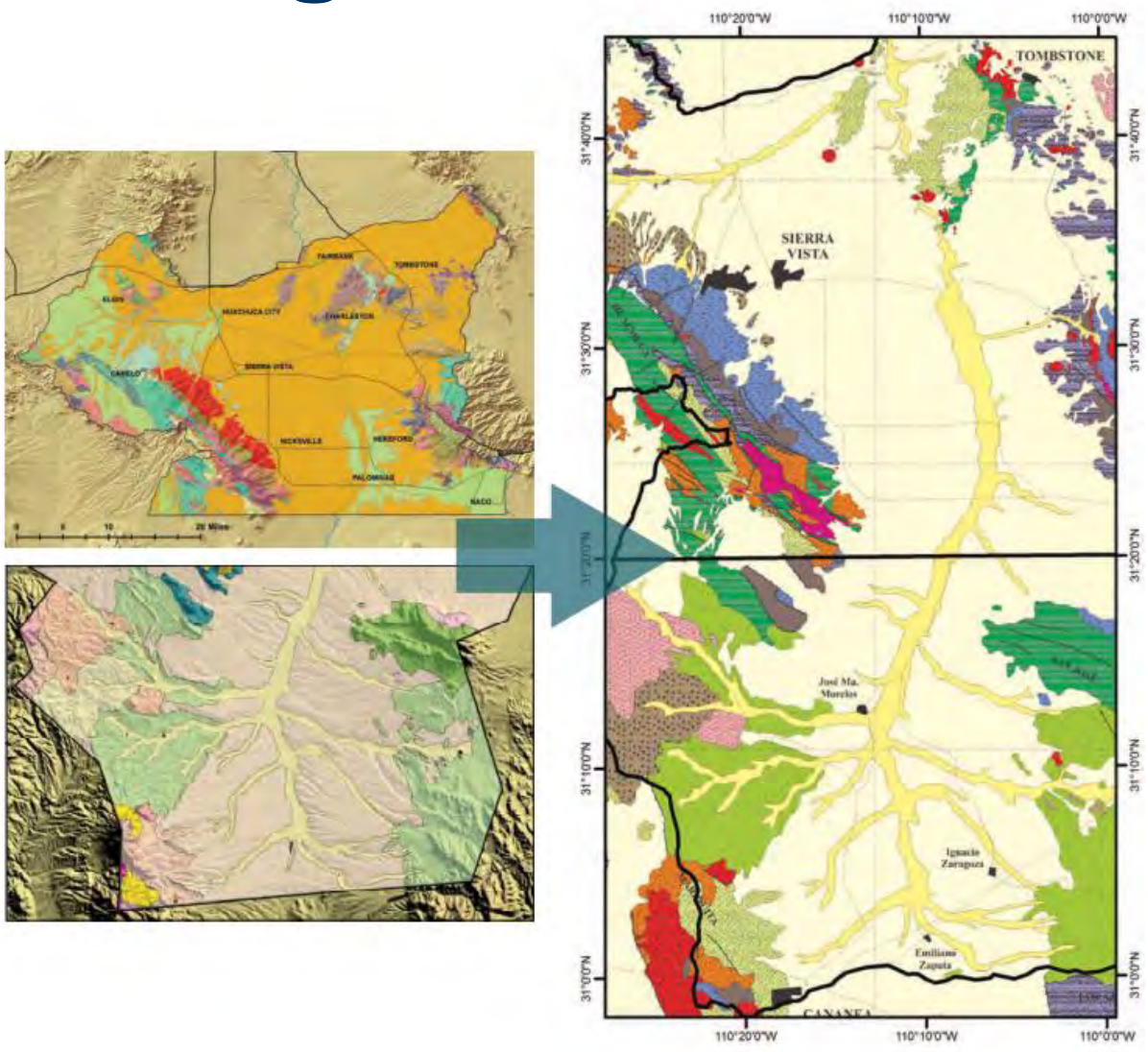


Mapping Efforts

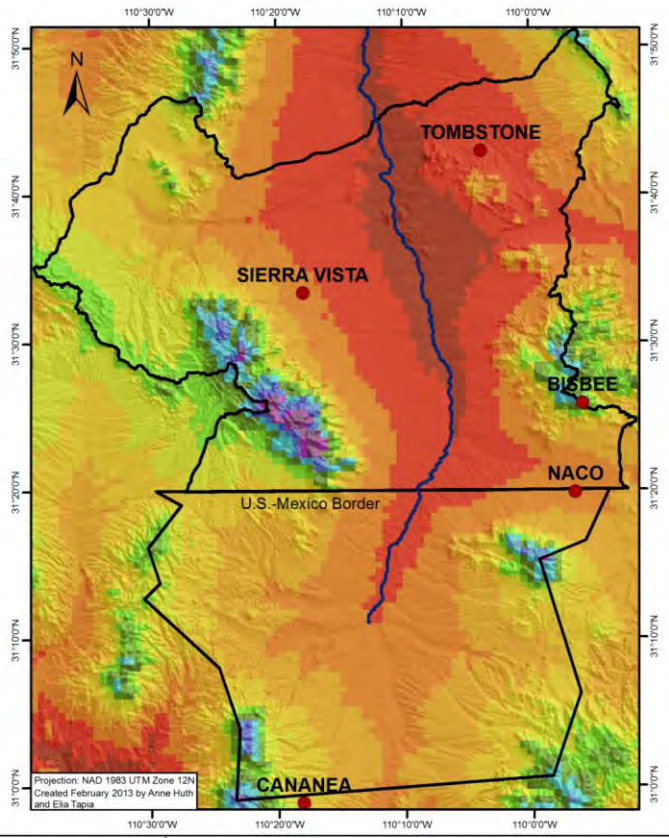
- 40 binational maps about climate, hydrology, geology, land use, soil distribution, vegetation, etc.
- 23 binational water quality maps.
- 4 binational maps with information on depth to groundwater level for the year 2011.

Mapping Challenges

- Merging different classification systems.
- Harmonization of measurement units.
- Different cartographic preferences.



Mean Annual Temperature (°C)
San Pedro Basin



CONAGUA
COMISIÓN NACIONAL DEL AGUA

ARIZONA

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Location

Explanation

- Nearby Towns (> Pop. 1000)
- San Pedro River
- Study Area Boundary

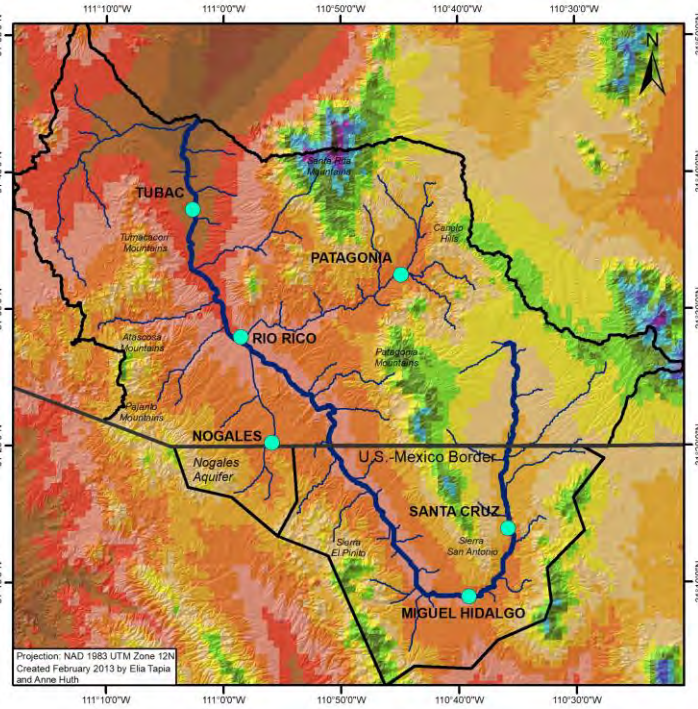
Mean Annual Temperature, ° C

9.0 - 9.5	10.1 - 10.5	13.1 - 13.5	16.1 - 16.5
9.6 - 10.0	10.6 - 11.0	13.6 - 14.0	16.6 - 17.0
	11.1 - 11.5	14.1 - 14.5	17.1 - 17.5
	11.6 - 12.0	14.6 - 15.0	17.6 - 18.0
	12.1 - 12.5	15.1 - 15.5	
	12.6 - 13.0	15.6 - 16.0	

This interpolated grid was produced by WorldClim (www.worldclim.org) and was created from the integration of monthly temperature data from weather stations around the globe and from a large number of sources, including GHCN, WMO, FAOCLIM, CIAT, and other regional databases. Data records were numerous and restricted to a period of 1950 - 2000, where possible. Data were compared with previous studies, including PRISM and Daymet for accuracy assessment. Gridded temperature data are originally represented in units of ° C * 10 to reduce file size, but on this map they are represented as ° Celsius. A thin-plane smoothing spline algorithm was used to interpolate the data.

0 5 10 20 Kilometers

Mean Annual Temperature (°C)
Binational Santa Cruz Basin



CONAGUA
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Location

Explanation

- Towns
- U.S.-Mexico Border
- Santa Cruz River
- Major Streams and Tributaries
- Study Area Boundary

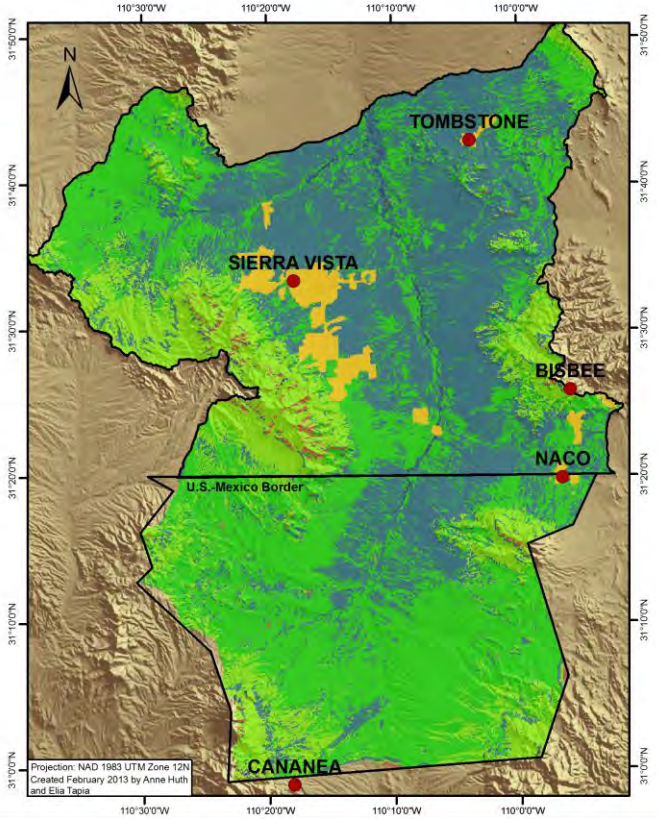
Mean Annual Temperature, ° C

8.6 - 9.0	12.1 - 12.5	15.6 - 16.0	
9.1 - 9.5	12.6 - 13.0	16.1 - 16.5	
9.6 - 10.0	13.1 - 13.5	16.6 - 17.0	
10.1 - 10.5	13.6 - 14.0	17.1 - 17.5	
10.6 - 11.0	14.1 - 14.5	17.6 - 18.0	
11.1 - 11.5	14.6 - 15.0	18.1 - 18.5	
11.6 - 12.0	15.1 - 15.5	18.6 - 19.0	

This interpolated grid was produced by WorldClim (www.worldclim.org) and was created from the integration of monthly temperature data from weather stations around the globe and from a large number of sources, including GHCN, WMO, FAOCLIM, CIAT, and other regional databases. Data records were numerous and restricted to a period of 1950 - 2000, where possible. Data were compared with previous studies, including PRISM and Daymet for accuracy assessment. Gridded temperature data are originally represented in units of ° C * 10 to reduce file size, but on this map they are represented as ° Celsius. A thin-plane smoothing spline algorithm was used to interpolate the data.

0 5 10 20 Kilometers

Land Cover
San Pedro Basin



Location

Explanation

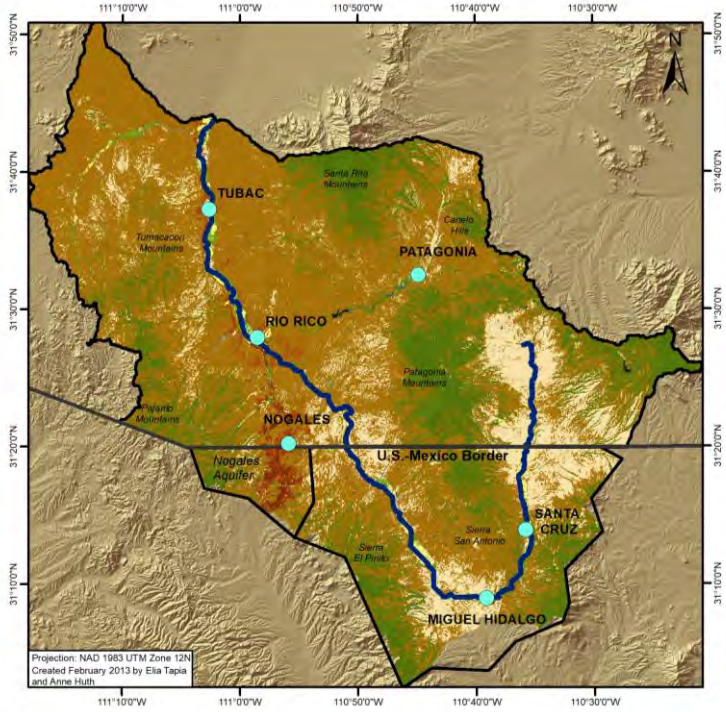
- Nearby Towns (> Pop. 1000)
- Study Area Boundary

Land Cover
- Barren Lands
- Deciduous Forest
- Developed or Agriculture
- Developed or Agriculture
- Emergent Herbaceous Wetland
- Evergreen Forest
- Grassland/Herbaceous
- Mixed Forest
- Other Cover Types
- Shrub/Scrub
- Woody Wetland

This Land Cover grid was obtained from the Boykin et al. updated San Pedro River Basin Data Browser and report (fwscase12.nmsu.edu/SanPedro/data/SPCART_Landcover2.htm). The 2008 grid was derived by the New Mexico Cooperative Fish and Wildlife Research Unit using classification and regression tree analysis to create a land cover dataset of ecological systems for the San Pedro Study Area. Multi-temporal (spring, summer, and fall) ETM+ satellite imagery and tasselled-cap datasets coupled with elevation and elevation derived derivatives (landform) were used.

0 5 10 20 Kilometers

Land Cover
Transboundary Santa Cruz Basin



Location

Explanation

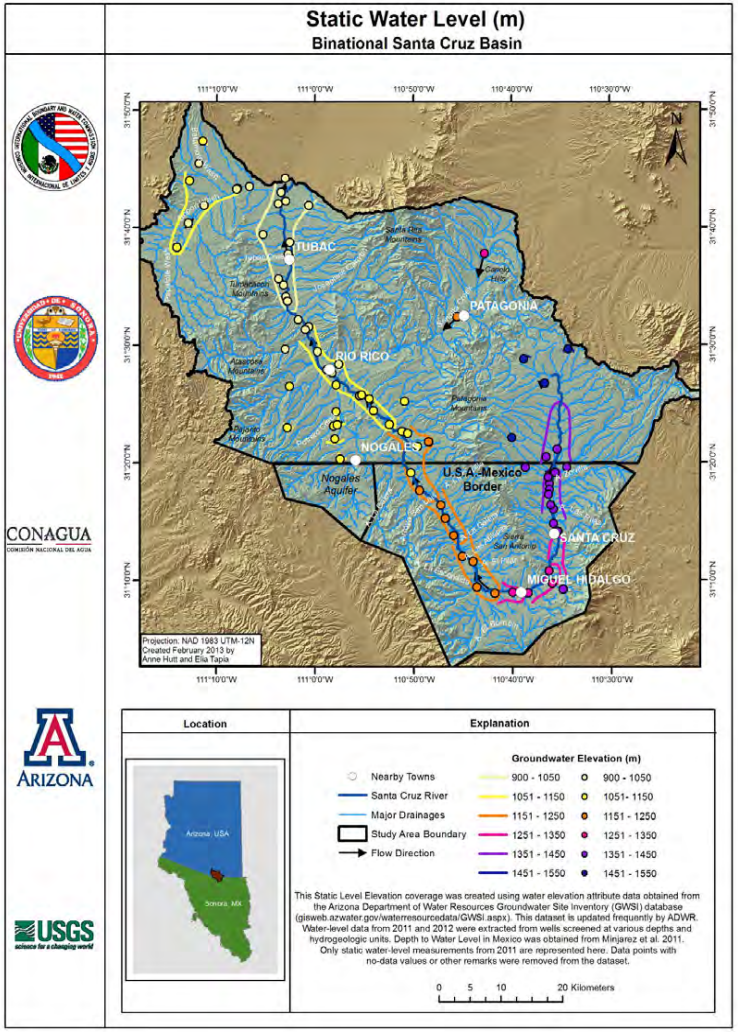
- Towns
- U.S.-Mexico Border
- Santa Cruz River
- Study Area Boundary

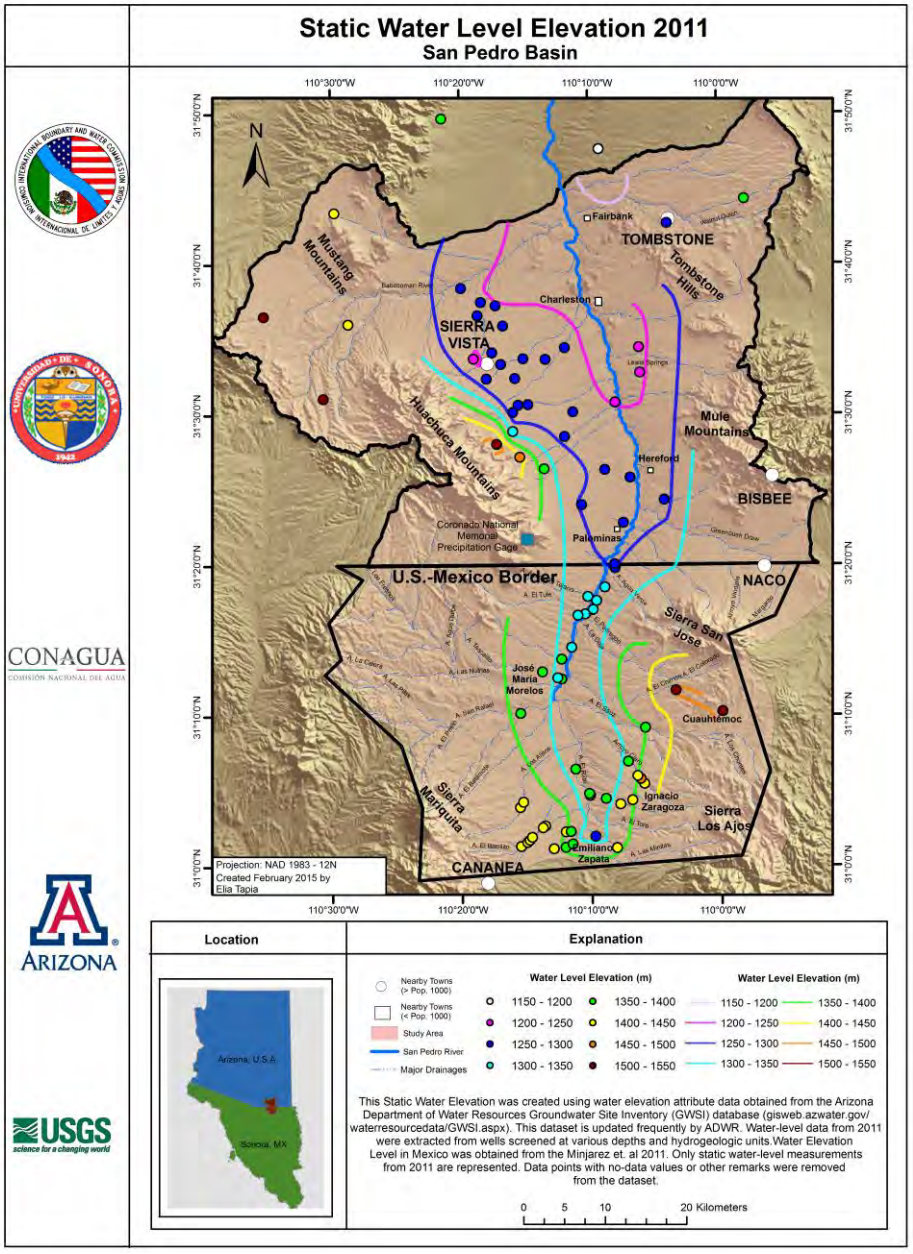
Land Cover
- Barren Land (Rock/Sand/Clay)
- Cultivated Crops
- Deciduous Forest
- Developed, High Intensity
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, Open Space
- Emergent Herbaceous Wetlands
- Evergreen Forest
- Grassland/Herbaceous
- Open Water
- Palustrine Forested Wetland
- Pasture/Hay
- Shrub/Scrub

This Land Cover image was obtained from the 2011 Villarreal et al USGS Open-File Report 2011-1131 (A Multitemporal (1979-2009) Land-Use/Land-Cover Dataset of the Binational Santa Cruz Watershed. The full report and data can be obtained online at http://pubs.usgs.gov/of/2011/1131/. The image was derived using Landsat Multispectral Scanner and Thematic Mapper data and a classification and regression tree classifier, and was assessed for accuracy by the authors using a random-stratified sampling design, reference aerial photography, and digital imagery. The result was high accuracy between image and reference data.

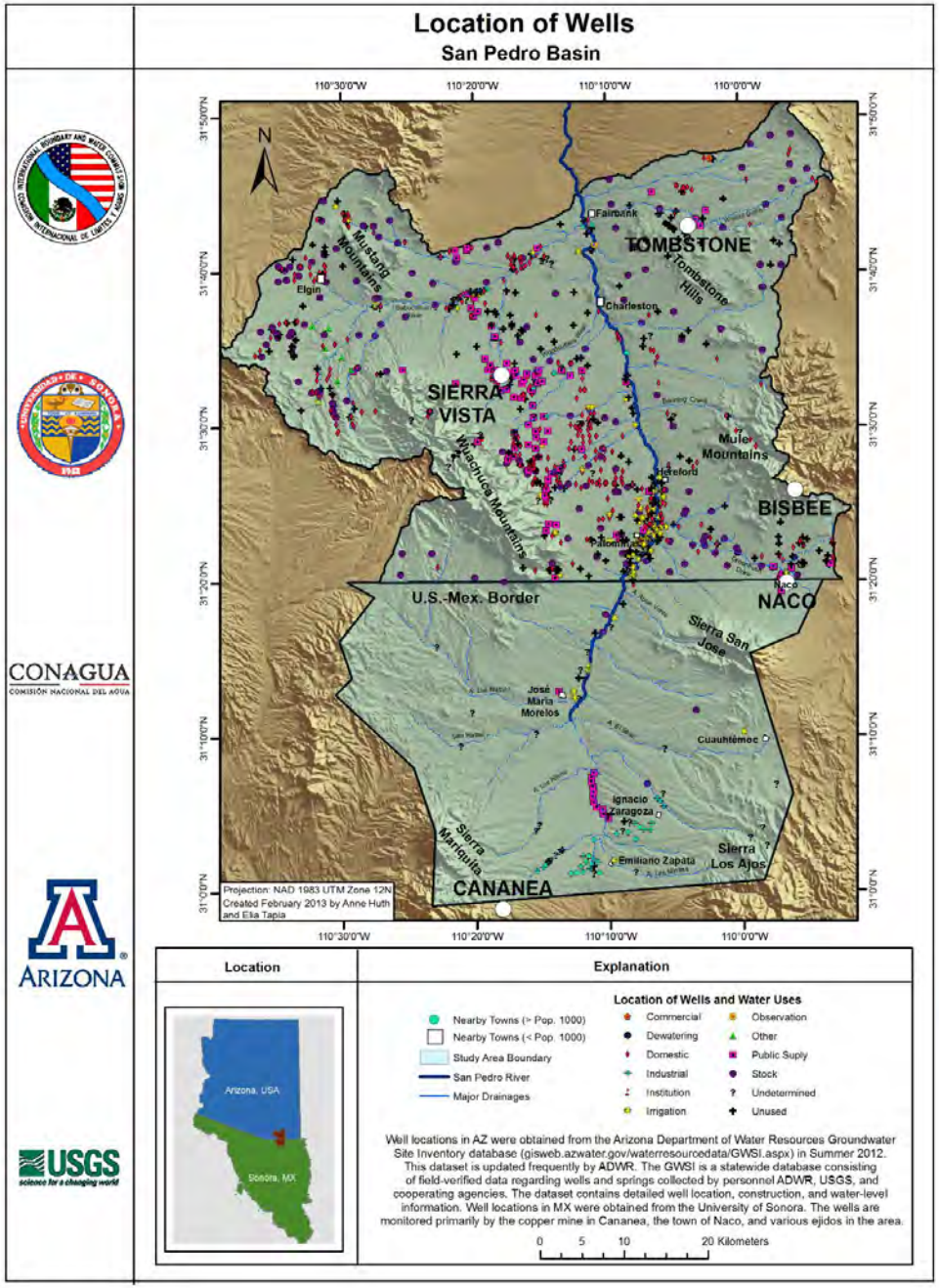
0 5 10 20 Kilometers

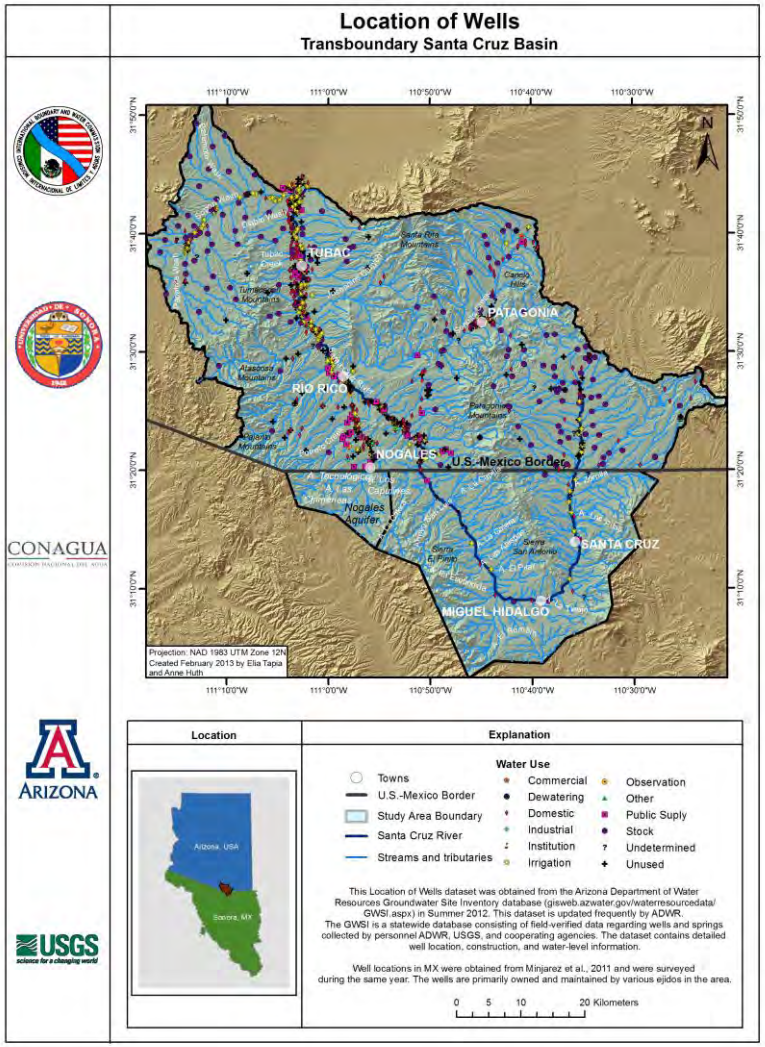
Groundwater Levels 2011





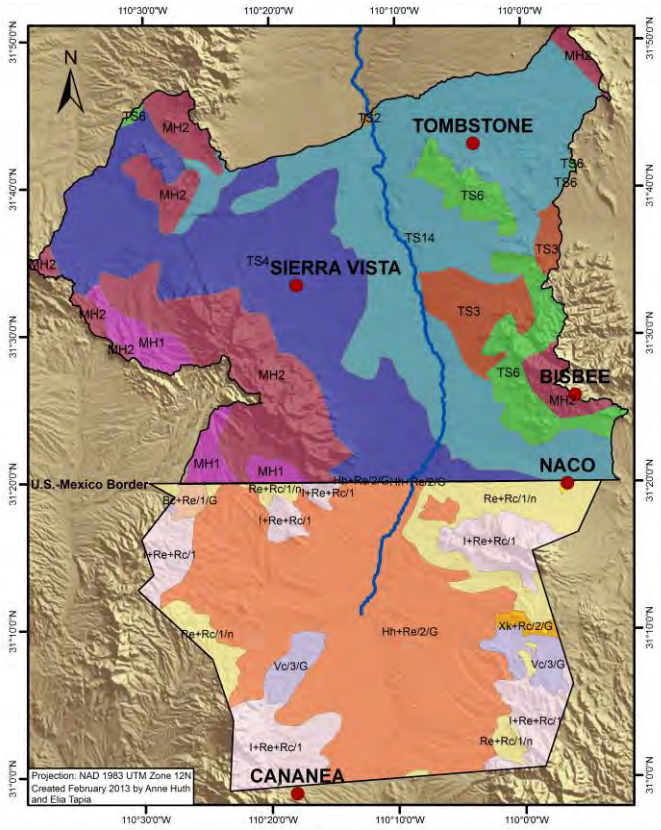
Water Uses


Location of Wells
San Pedro Basin
110°30'0"W
110°20'0"W
110°10'0"W
110°0'0"W
31°50'0"N
31°40'0"N
31°30'0"N
31°20'0"N
31°10'0"N
31°0'0"N
N
Fairbank
TOMBSTONE
Tombstone Hills
Mustang Mountains
Elgin
Charleston
SIERRA VISTA
Mule Mountains
Huachuca Mountains
Hereford
BISBEE
Palominas
Naco
NACO
U.S.-Mex. Border
Sierra San Jose
José María Morelos
Cuauhtémoc
Ignacio Zaragoza
Sierra Mariquita
Emiliano Zapata
Sierra Los Ajos
CANANEA
Projection: NAD 1983 UTM Zone 12N
Created February 2013 by Anne Huth and Elia Tapia
Location
Arizona, USA
Sonora, MX
Explanation
Location of Wells and Water Uses
Nearby Towns (> Pop. 1000)
Nearby Towns (< Pop. 1000)
Study Area Boundary
San Pedro River
Major Drainages
Commercial
Dewatering
Domestic
Industrial
Institution
Irrigation
Observation
Other
Public Suply
Stock
Undetermined
Unused
Well locations in AZ were obtained from the Arizona Department of Water Resources Groundwater Site Inventory database (gisweb.azwater.gov/waterresourcedata/GWSI.aspx) in Summer 2012. This dataset is updated frequently by ADWR. The GWSI is a statewide database consisting of field-verified data regarding wells and springs collected by personnel ADWR, USGS, and cooperating agencies. The dataset contains detailed well location, construction, and water-level information. Well locations in MX were obtained from the University of Sonora. The wells are monitored primarily by the copper mine in Cananea, the town of Naco, and various ejidos in the area.
0 5 10 20 Kilometers


Location of Wells
Transboundary Santa Cruz Basin
111°10'0"W
111°0'0"W
110°50'0"W
110°40'0"W
110°30'0"W
31°50'0"N
31°40'0"N
31°30'0"N
31°20'0"N
31°10'0"N
N
TUBAC
PATAGONIA
RIO RICO
NOGALES
U.S.-Mexico Border
Nogales Aquifer
SANTA CRUZ
MIGUEL HIDALGO
Projection: NAD 1983 UTM Zone 12N
Created February 2013 by Ella Tapia and Anne Huth
Location
Arizona, USA
Sonora, MX
Explanation
Water Use
Towns
U.S.-Mexico Border
Study Area Boundary
Santa Cruz River
Streams and tributaries
Commercial
Dewatering
Domestic
Industrial
Institution
Irrigation
Observation
Other
Public Suply
Stock
Undetermined
Unused
This Location of Wells dataset was obtained from the Arizona Department of Water Resources Groundwater Site Inventory database (gisweb.azwater.gov/waterresourcedata/GWSI.aspx) in Summer 2012. This dataset is updated frequently by ADWR. The GWSI is a statewide database consisting of field-verified data regarding wells and springs collected by personnel ADWR, USGS, and cooperating agencies. The dataset contains detailed well location, construction, and water-level information.
Well locations in MX were obtained from Minjarez et al., 2011 and were surveyed during the same year. The wells are primarily owned and maintained by various ejidos in the area.
0 5 10 20 Kilometers

Soil Characterization

San Pedro Basin



Location

Explanation

- Nearby Towns (> Pop. 1000)
- San Pedro River
- Study Area Boundary

Soil Classes, AZ
- CASTO-MARTINEZ-CANELO
- LITHIC HAPLUSTOLLS-LITHIC ARGIUSTOLLS-ROCK OUTCROP
- LITHIC TORRIOTHENTS-LITHIC HAPLUSTOLLS-ROCK OUTCROP
- TORRIFLUVENTS
- TORRIFLUVENTS-TORRIPSAMMENTS
- TUBAC-SONOITA-GRABE
- WHITE HOUSE-BERNARDINO-HATHAWAY

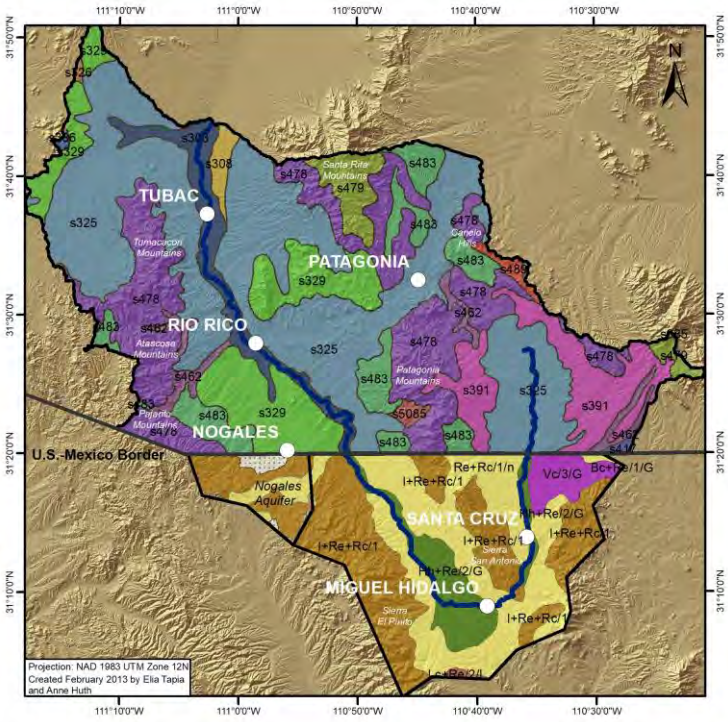
Soil Classes, MX
- Cambisol
- Cuerpo de agua
- Feozem
- Litosol
- Luvisol
- Planosol
- Regosol
- Rendzina
- Vertisol
- Xerosol
- ZU

This Soils coverage for AZ was obtained from the EPA San Pedro River Geo-data Browser (www.epa.gov/nerlesd1/land-sci/san_pedro). The coverage was derived from the digitization of the USDA's General Soil Map of Arizona (1975). The Soils coverage for MX was obtained from the University of Sonora.

0 5 10 20 Kilometers

Soil Characterization

Transboundary Santa Cruz Basin



Location

Explanation

- Towns
- U.S.-Mexico Border
- Santa Cruz River
- Study Area Boundary

Soils, SC Aquifer, MX
- Cambisol
- Feozem
- Litosol
- Luvisol
- Regosol
- Vertisol

Soils, Nog. Aquifer, MX
- Litosol
- Regosol
- Unidentified

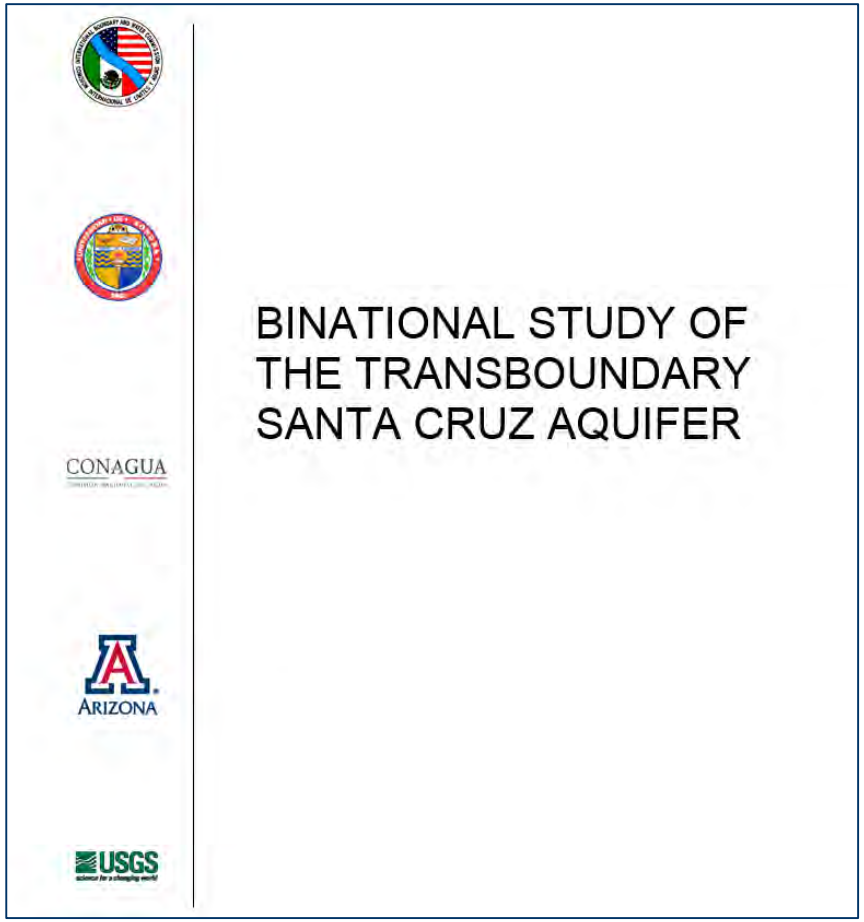
Soils, AZ
- Riveroad-Comoro-Arizo
- Rock outcrop-Lithic Haplustolls
- Rock outcrop-Lithic Ustochrepts
- Romero-Rock outcrop-Lampshire
- Sahuarita-Mohave-Cave
- Spudrock-Elledge-Docdee
- Telephone-Rock outcrop-Overgaard-Elledge
- Timhus-Quintana-Flugle
- Tombstone-Stronghold-Jerag
- Typic Dystrochrepts-Rock outcrop-Lithic Ustochrepts
- Typic Haplustalfs-Lithic Haplustalfs
- Typic Ustifluvents-Fluventic Ustochrepts
- Typic Ustorthents-Typic Ustochrepts-Typic Udorthents-Rock outcrop
- White House-Hathaway-Bernardino
- Wineg-Quintana-Amos

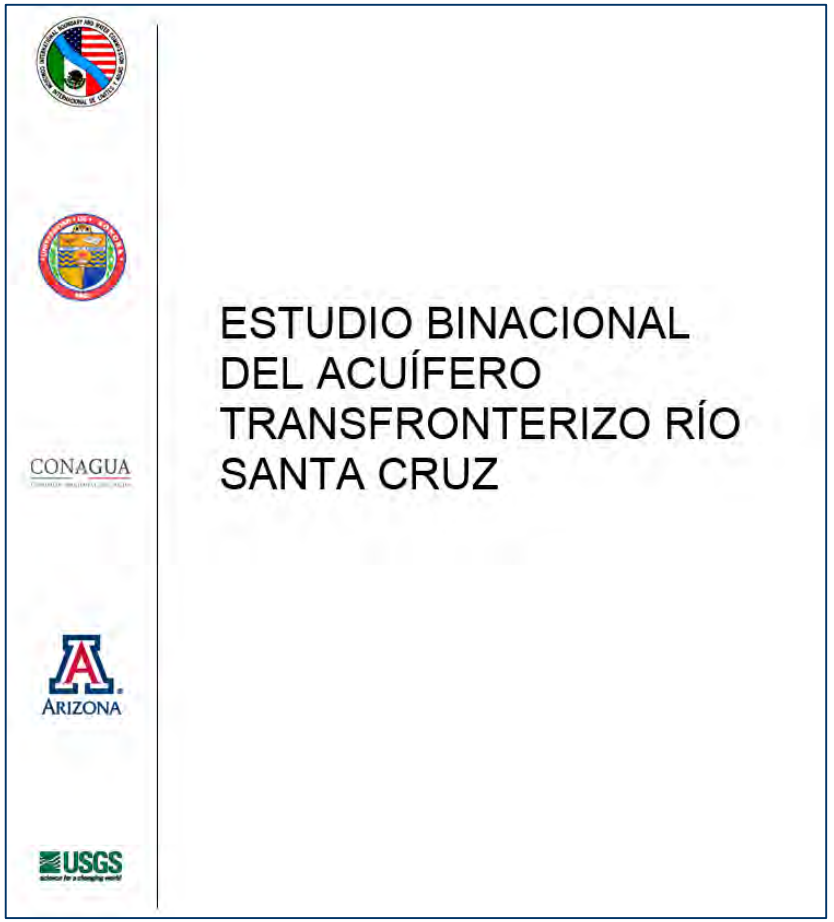
The Soils coverages for Arizona and within the confines of the Nogales Aquifer limits were obtained from L. Norman (USGS Tucson, Arizona office). Soils from the U.S. side are STATSGO soils clipped from the U.S. General Soil Map, available from the Natural Resources Conservation Service (http://soildatamart.nrcs.usda.gov/). The Soils coverage within the confines of the Santa Cruz Aquifer limits in MX were obtained from the University of Sonora.

0 5 10 20 Kilometers

Current TAAP Efforts

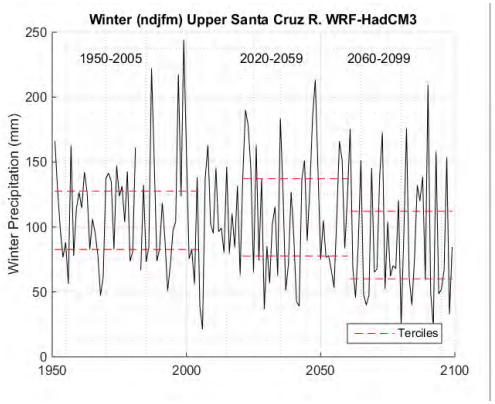
Task 1: Completing the Binational Study of the Transboundary Santa Cruz Aquifer

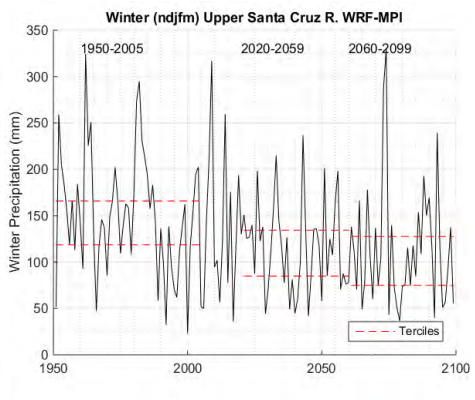


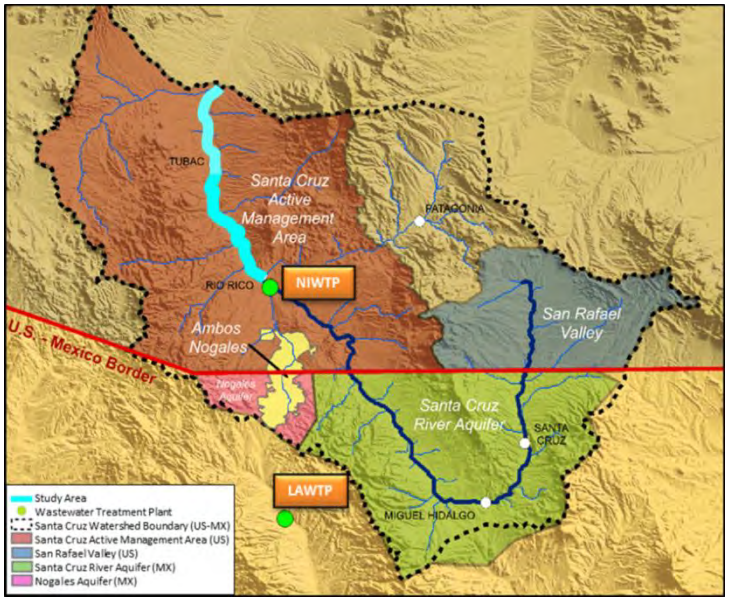


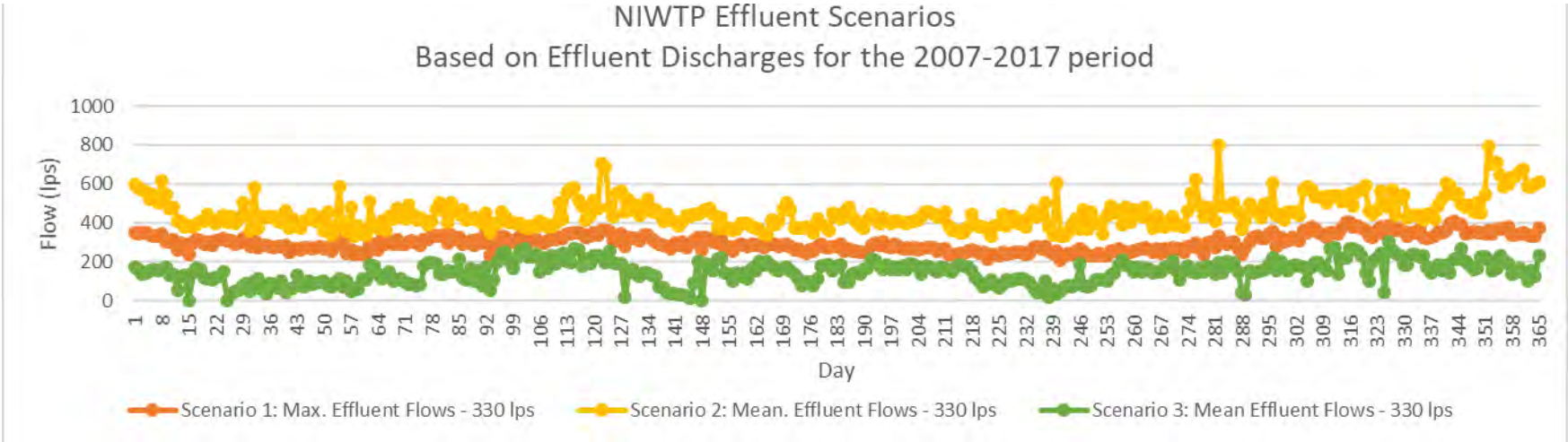
Task 2: Climate Change Assessment in the Upper Santa Cruz River Basin

- Implications of variabilities of climate and effluent discharges downstream of the Nogales International Wastewater Treatment Plant.



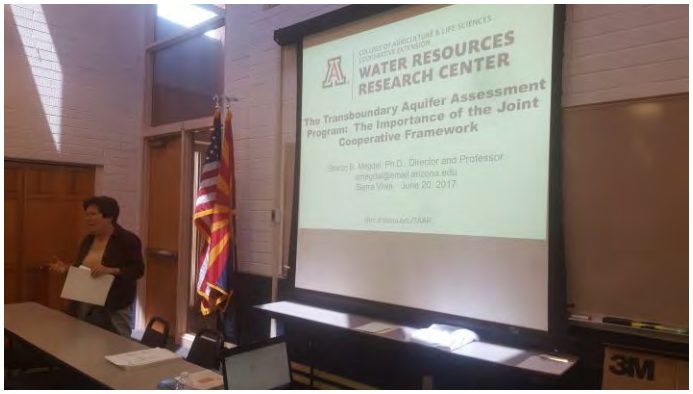






Task 3: Transboundary Stakeholder Engagement

Introduce the TAAP and its associated products to communities in the U.S. and Mexico.



Sierra Vista Forum. June 20, 2017.

World Water Congress. Cancun, Mexico. June 2017.

AMC Environment & Water Committee Meeting.
Puerto Peñasco, Mexico. November 30, 2017

June 13-15, 2017.
Fort Collins, CO.

Thank you!

Elia M. Tapia

emtapia@email.arizona.edu

For more information see wrrc.arizona.edu/TAAP