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The Role of Science in Managed Aquifer Recharge—the *Equus* Beds aquifer near Wichita, Kansas 1938–2015

Andy Ziegler, Brian Kelly, Mandy Stone, Brian Klager, Trudy Bennett, Wichita field staff and many more
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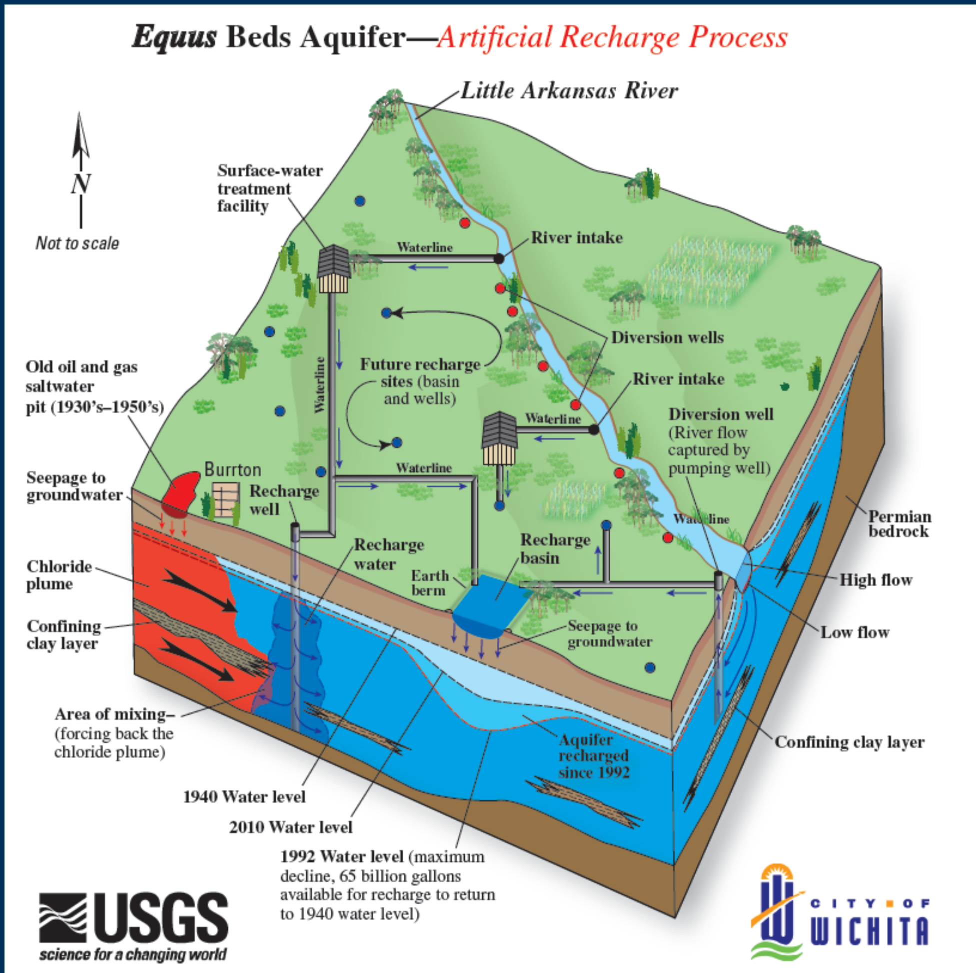
A collaborative study by the City of Wichita, Groundwater Management District #2, Burns and McDonnell, Professional Engineering Consultants, Mid- Kansas Engineering Consultants, Science Application International Corp., HDR Consultants, CDM, CH2M Hill, Kansas Water Office, Kansas Department of Agriculture- Division of Water Resources, Kansas Geological Survey, Kansas Department of Health and Environment, Kansas Department of Wildlife, Parks and Tourism, Kansas Corporation Commission, Kansas Universities and Extension, US Environmental Protection Agency, DOI Bureau of Reclamation, USGS, and others….

U.S. Department of the Interior
U.S. Geological Survey

Briefing tour with OWRB and DEQ
June 1, 2016

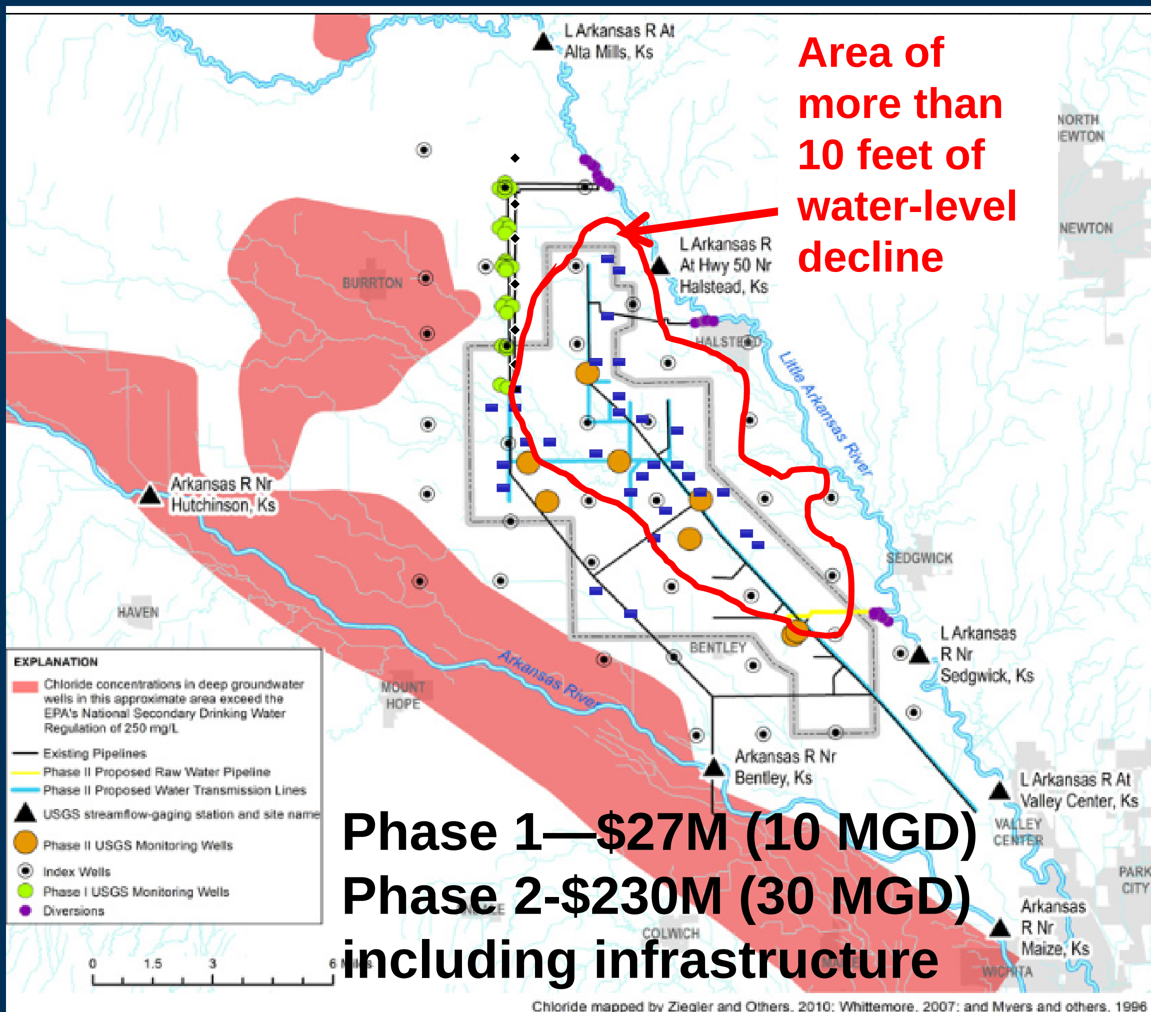
Water issues



http://ks.water.usgs.gov/equus-beds-recharge

- **Saltwater migration from Burrton and along the Arkansas River accelerated because of large water level declines from agricultural and city pumping. Current rate is about 0.8 ft per day (~0.5 miles per decade)**
- **Declines in water levels caused by agricultural and city pumping decrease storage and increase velocity of chloride movement**
- **Artificial Recharge and Aquifer Storage and Recovery Program began in 1995**
- **ASR will help preserve Wichita water supply through 2060+ and preserve agricultural supply**
- **Sustainability? 1% Drought?**

Equus Beds Aquifer Storage and Recovery– Wichita



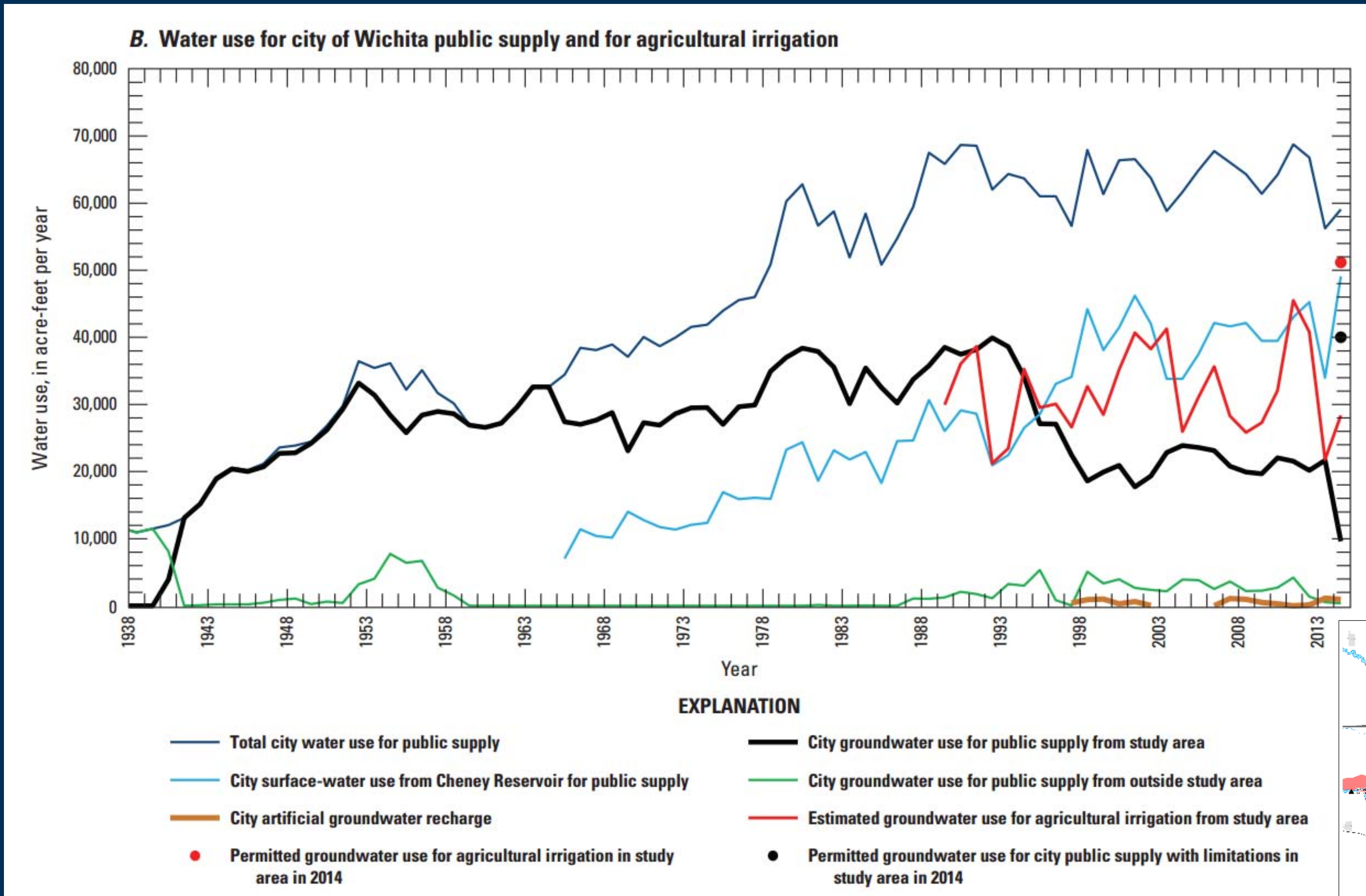
Phase 1—$27M (10 MGD)
Phase 2-$230M (30 MGD) including infrastructure

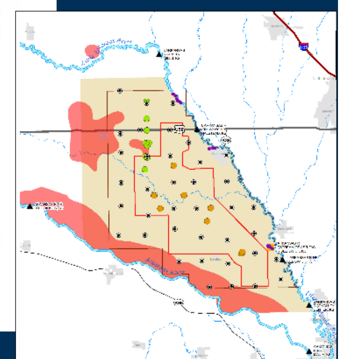
Map of Operations for Equus Beds Groundwater Recharge Project

USGS Role: FACTS

- **Define change in GW level storage and relation to water use and hydrologic factors, including ASR**
- **Define existing water quality and effects of ASR on aquifer water quality**
- **Report science to the public**
- **Example of USGS Cooperative Water matching $$**

In 1993, city increased Cheney use and decreased well field use 50%+
ILWSP (http://www.usbr.gov/gp/otao/equus/burns_mcdonnell.html)





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Whisnant and others, 2015
(https://pubs.er.usgs.gov/publication/sir20155121)

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Water-level declines led to concerns of increased chloride movement

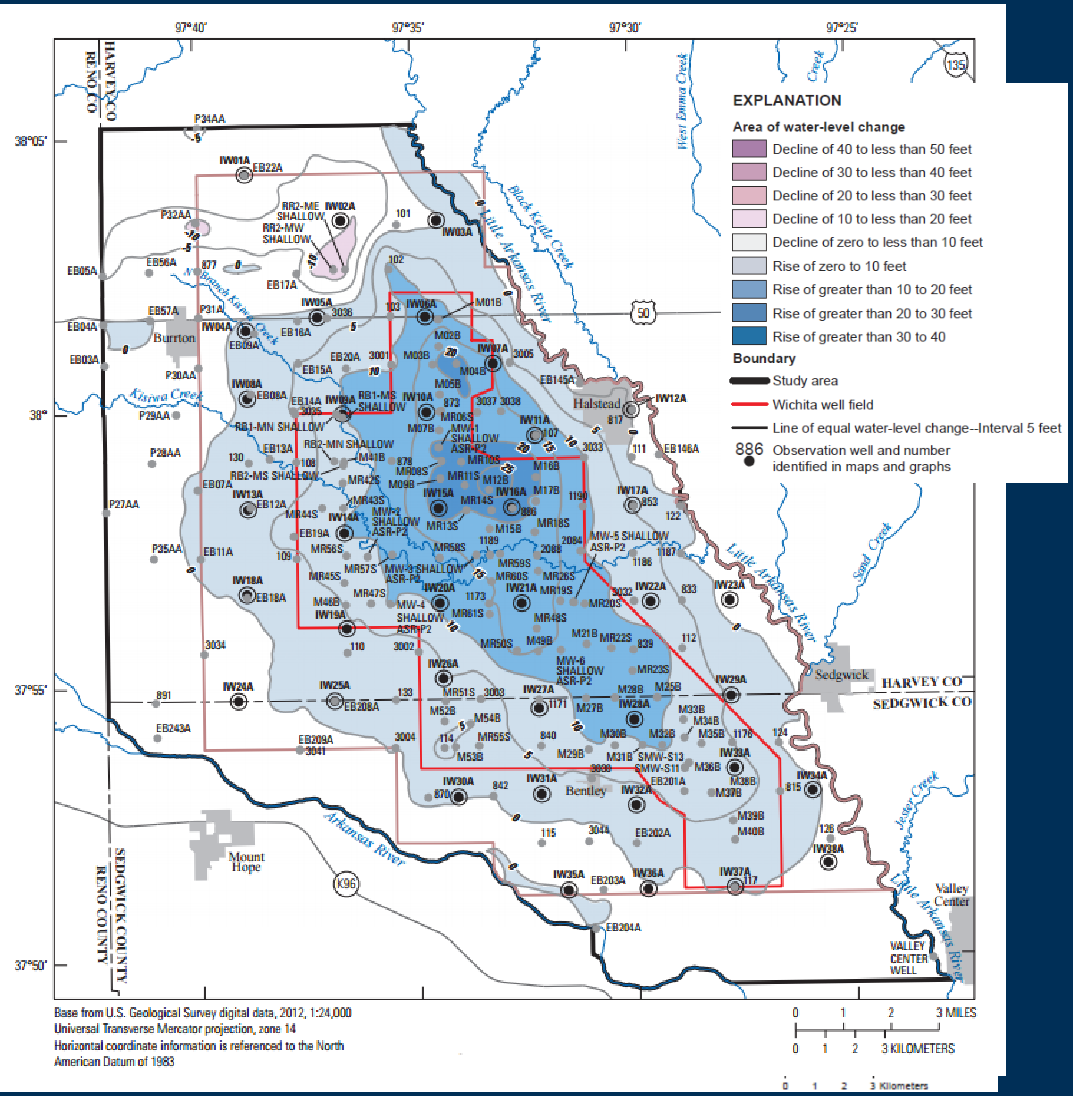
1 → **In 1993, water levels in the Wichita well field area were as much as 40 ft lower than predevelopment levels. Gradient 12 ft per mile.**

2 → **Wichita increased use from Cheney Reservoir and decreased withdrawals from well-field. Beginning in 1993, city well field use was eventually decreased by about 40%.**

3 → **In winter 2014, water levels in the Wichita well field area recovered 20 ft, but remain 20 ft lower than predevelopment levels. Gradient about 8 ft per mile.**

4 → **Increased withdrawals outside well field area decrease recoveries?**

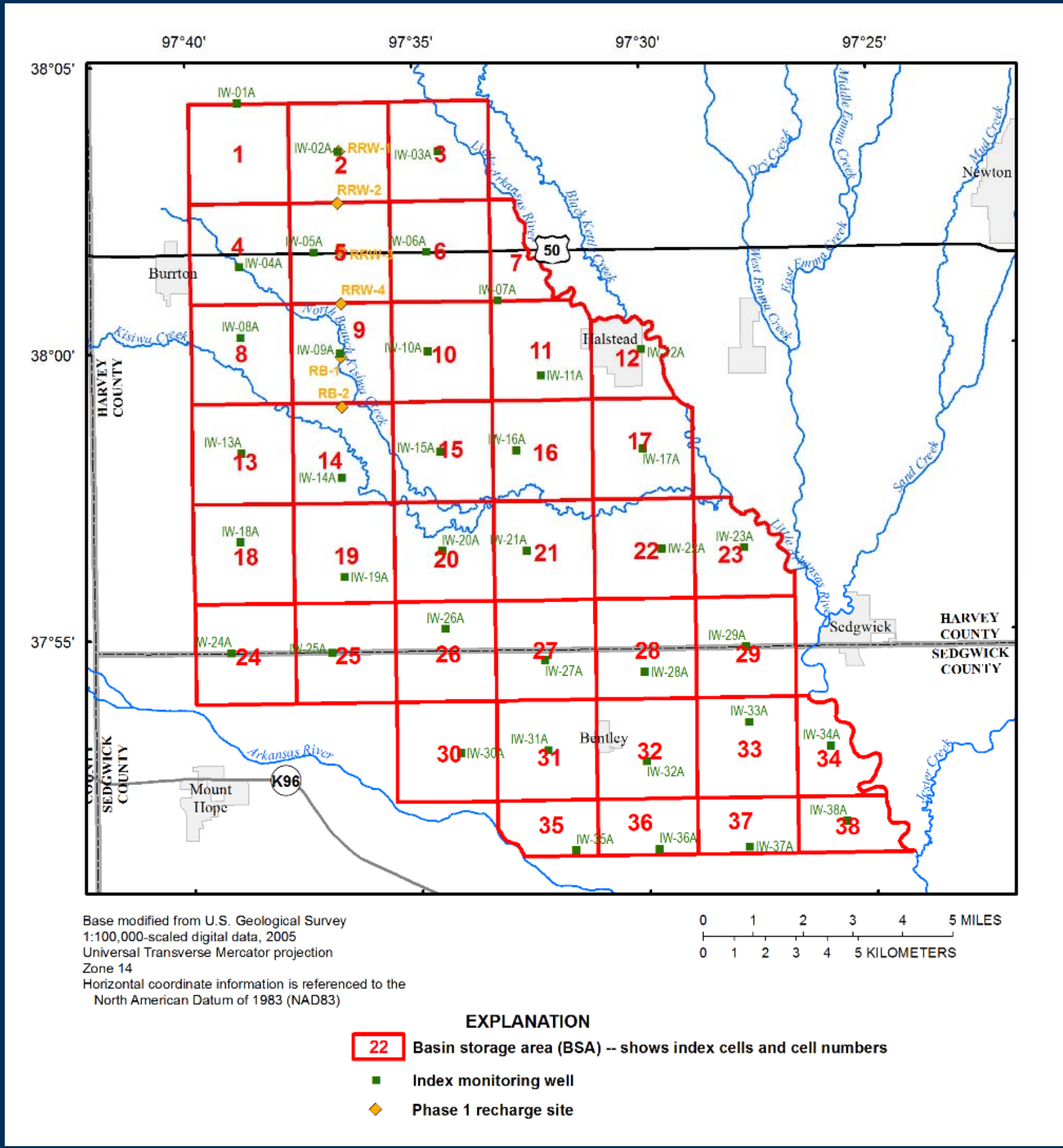
1993 to winter 2015



Hansen and others, 2014 (http://pubs.usgs.gov/sir/2014/5185/)
Whisnant and others, 2015 (https://pubs.er.usgs.gov/publication/sir20155121)

Water-level data: GMD2, city of Wichita, KGS, and USGS

Groundwater-flow model for ASR accounting



Kelly and others, 2014 (https://pubs.usgs.gov/sir/2013/5042/)

ASR Accounting

Index Cell 01

	With ASR	Without ASR
Flow to IC-05	0.0	0.0
Flow from IC-05	0.0	0.0

Difference with ASR
Flow to IC-05 0.0
Flow from IC-05 0.0

Index Cell 02

	With ASR	Without ASR
Flow to IC-05	1734.7	1735.9
Flow from IC-05	2060.2	1991.8

Difference with ASR
Flow to IC-05 -1.2
Flow from IC-05 68.5

Index Cell 03

	With ASR	Without ASR
Flow to IC-05	0.0	0.0
Flow from IC-05	0.0	0.0

Difference with ASR
Flow to IC-05 0.0
Flow from IC-05 0.0

Index Cell 04

	With ASR	Without ASR
Flow to IC-05	4200.3	4240.1
Flow from IC-05	0.0	0.0

Difference with ASR
Flow to IC-05 -39.8
Flow from IC-05 0.0

Index Cell 05

2010 Recharge Credit
39.7

Metered Recharge 2010
146.7
Metered Recovery 2010
1.0
Change in Amount Withdrawn from Aquifer Storage
-15.0

Index Cell 06

	With ASR	Without ASR
Flow to IC-05	0.0	0.0
Flow from IC-05	4238.2	4149.5

Difference with ASR
Flow to IC-05 0.0
Flow from IC-05 88.7

Index Cell 08

	With ASR	Without ASR
Flow to IC-05	0.0	0.0
Flow from IC-05	0.0	0.0

Difference with ASR
Flow to IC-05 0.0
Flow from IC-05 0.0

Index Cell 09

	With ASR	Without ASR
Flow to IC-05	1791.7	1754.4
Flow from IC-05	1718.9	1719.1

Difference with ASR
Flow to IC-05 37.3
Flow from IC-05 -0.1

Index Cell 10

	With ASR	Without ASR
Flow to IC-05	0.0	0.0
Flow from IC-05	0.0	0.0

Difference with ASR
Flow to IC-05 0.0
Flow from IC-05 0.0

Units are Acre-feet per year

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Source: Burns and McDonnell, 2011, ASR Project 2010 Accounting Report

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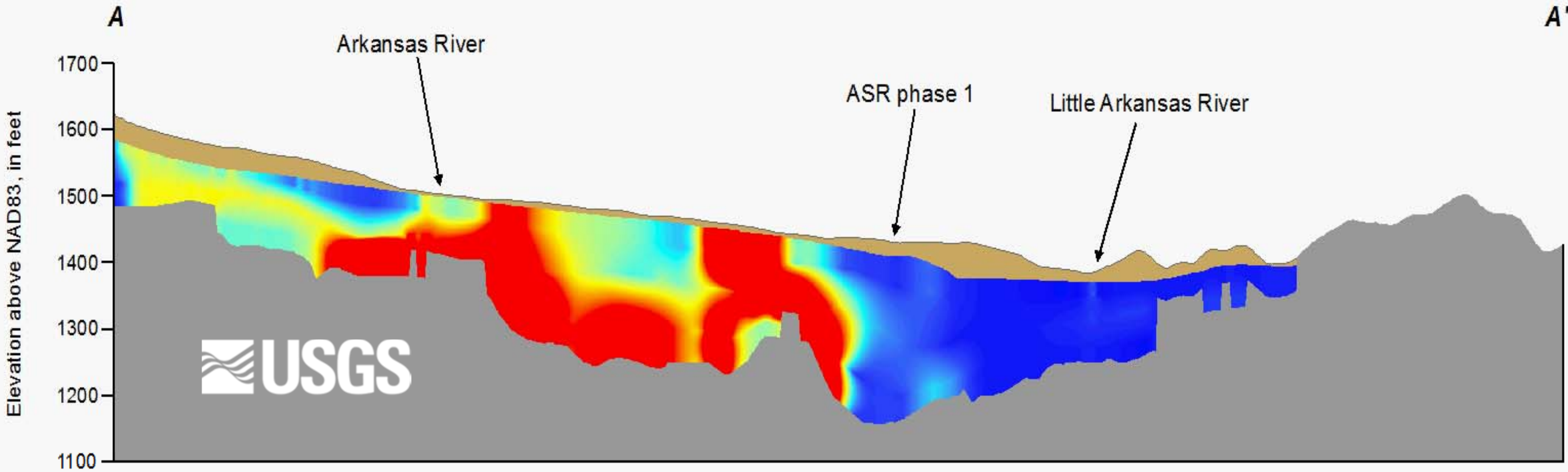
Equus Beds aquifer model cross section (row 195), simulated chloride concentration, 1990



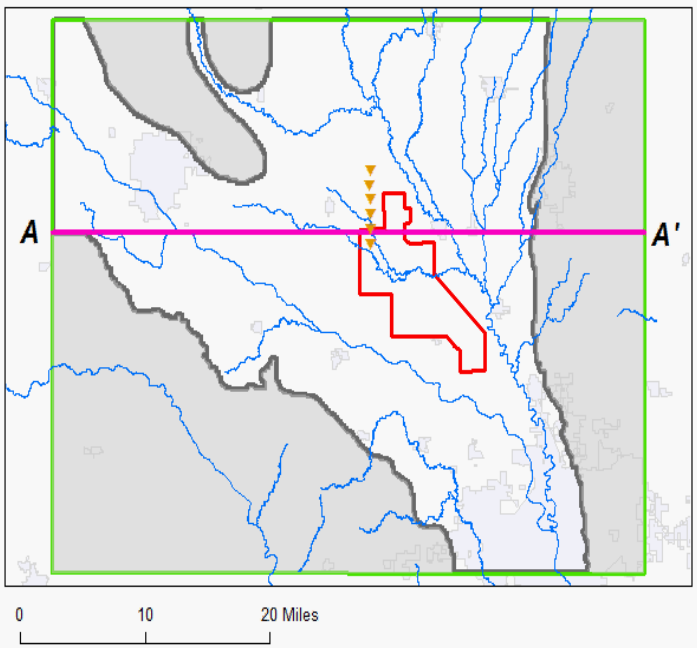
Vertical exaggeration x100

EXPLANATION

Chloride concentration

in milligrams per liter

500
400
300
200
100
0



Demonstration project 1994-2002

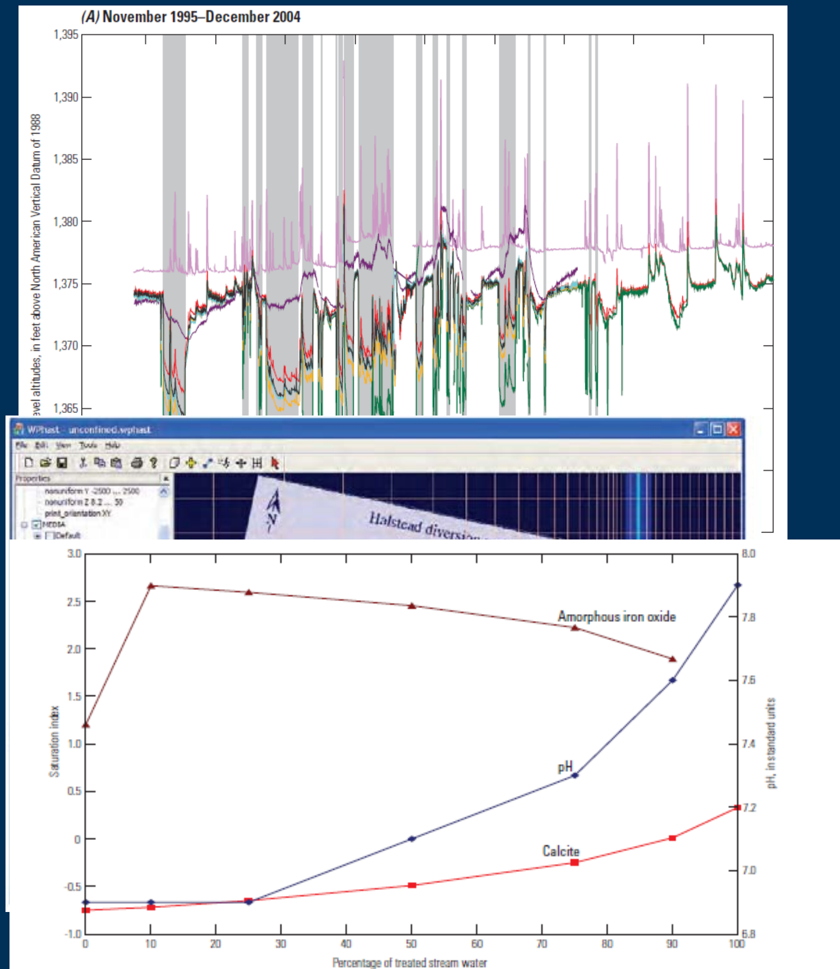


Figure 33. Saturation indices for calcite, amorphous iron oxide, and modeled pH for the theoretical mixing model of artificial recharge by injection of treated stream water into the *Equus* Beds aquifer.

- **Bank storage is real**
- **Constituents of concern are Cl, SO_4, NO_3, As, Fe, Mn, Na, atrazine, and indicator bacteria**
- **Water can be treated and artificially recharged.**
- **Bank storage water 75% surface water after long-term continuous pumping (PHAST and simple mixing modeling)**
- **Water-quality is compatible**
  - **injected water little geochemical affect if bank storage water,**
  - **injection of oxygenated water (treated surface water) oversaturated for metal hydroxides in groundwater and calcium carbonate (PHREEQC)**

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Schmidt, H.C.Ross, Ziegler, A.C., and Parkhurst, D.L., 2007, Geochemical effects of induced stream-water and artificial recharge on the Equus Beds aquifer, south-central Kansas 1995-2004; U.S.Geological Survey Scientific Investigations Report 2007-5025, 58p.

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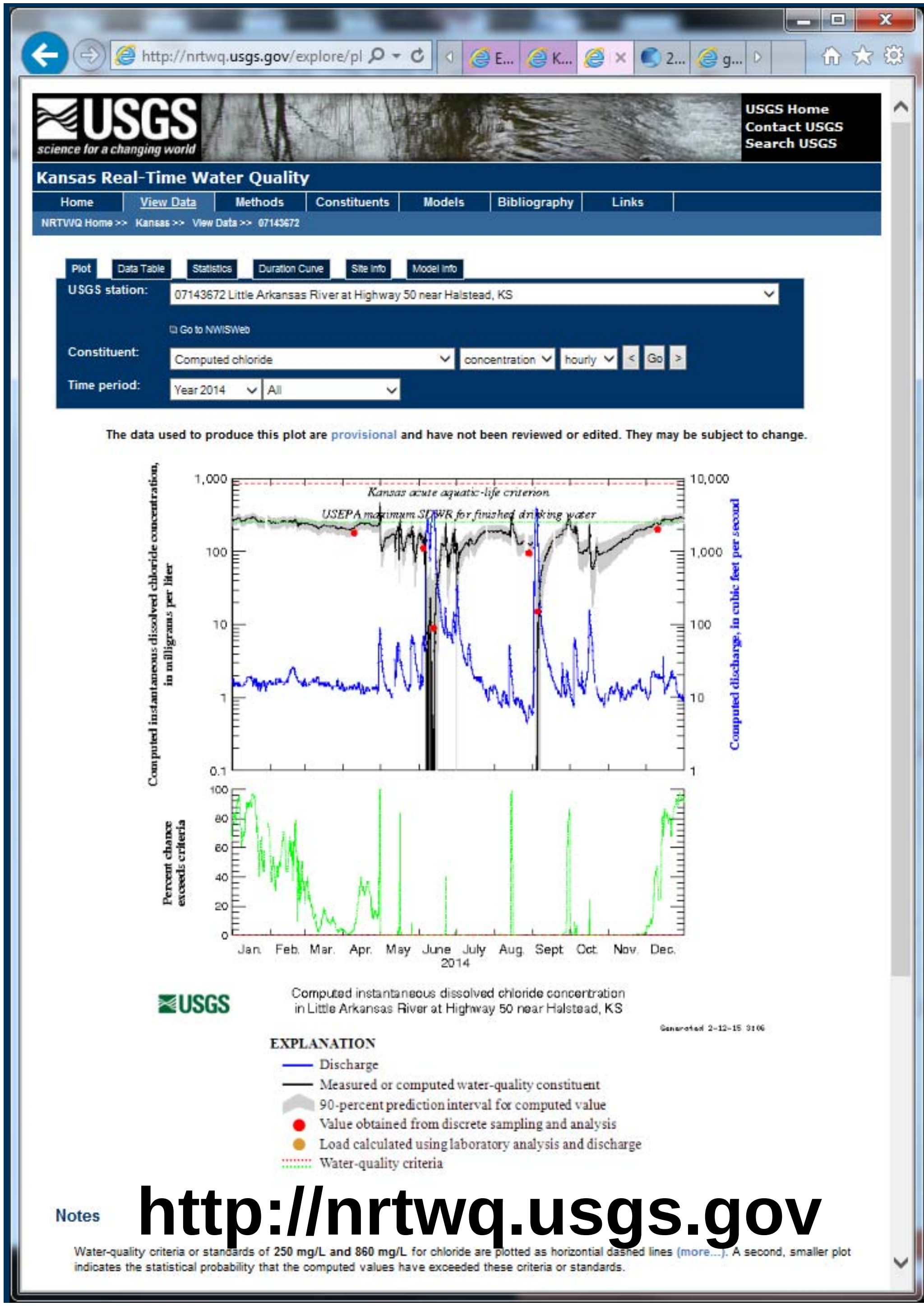

http://nrtwq.usgs.gov

- **Statistical surrogate models developed with in-stream continuous sensor measurements and discrete samples for estimates of concentrations of constituents of concern with defined uncertainty**

- **Used for real time treatment/management of recharge**

Christensen, V.G., Jian, Xiaodong, Ziegler, A.C., 2000, Regression analysis and real-time water-quality monitoring to estimate constituent concentrations, loads, and yields in the Little Arkansas River, south-central Kansas, 1995-99: U.S. Geological Survey Water-Resources Investigations Report 00-4126, 36 p.

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Small increasing concentrations of most constituents of concern in study area during 2007–2012 compared to 2001–2006

2007-2012 Index Well Avg. Increases

- Arsenic (1%)
- Iron (8%)
- Manganese (3%)
- Nitrate (7%)
- Sulfate (9%)
- Spec. Conductance (3%)

2007-2012 Index Well Avg. Decreases

- Oxidation-Reduction Potential (18%, bad– means more metals are mobilizing)
- Chloride (3%)

Largest increases (Fe & SO_4^{2-}) likely a result of the oxidation of aquifer material during drawdown, specifically pyrite (FeS_2), before recovery. Decreased ORP caused partially by 2010–2012 drought conditions and lack of oxygenated water infiltrating to the water table.

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Tappa and others, 2015

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Hydrobiological Monitoring Program (HBMP): Purpose and Objectives

Document baseline and post-operational conditions upstream and downstream from the Phase II facility (15 MGD capacity)

Describe effects of aquifer recharge on surface and groundwater quality

Evaluate changes that may be related to the ASR project

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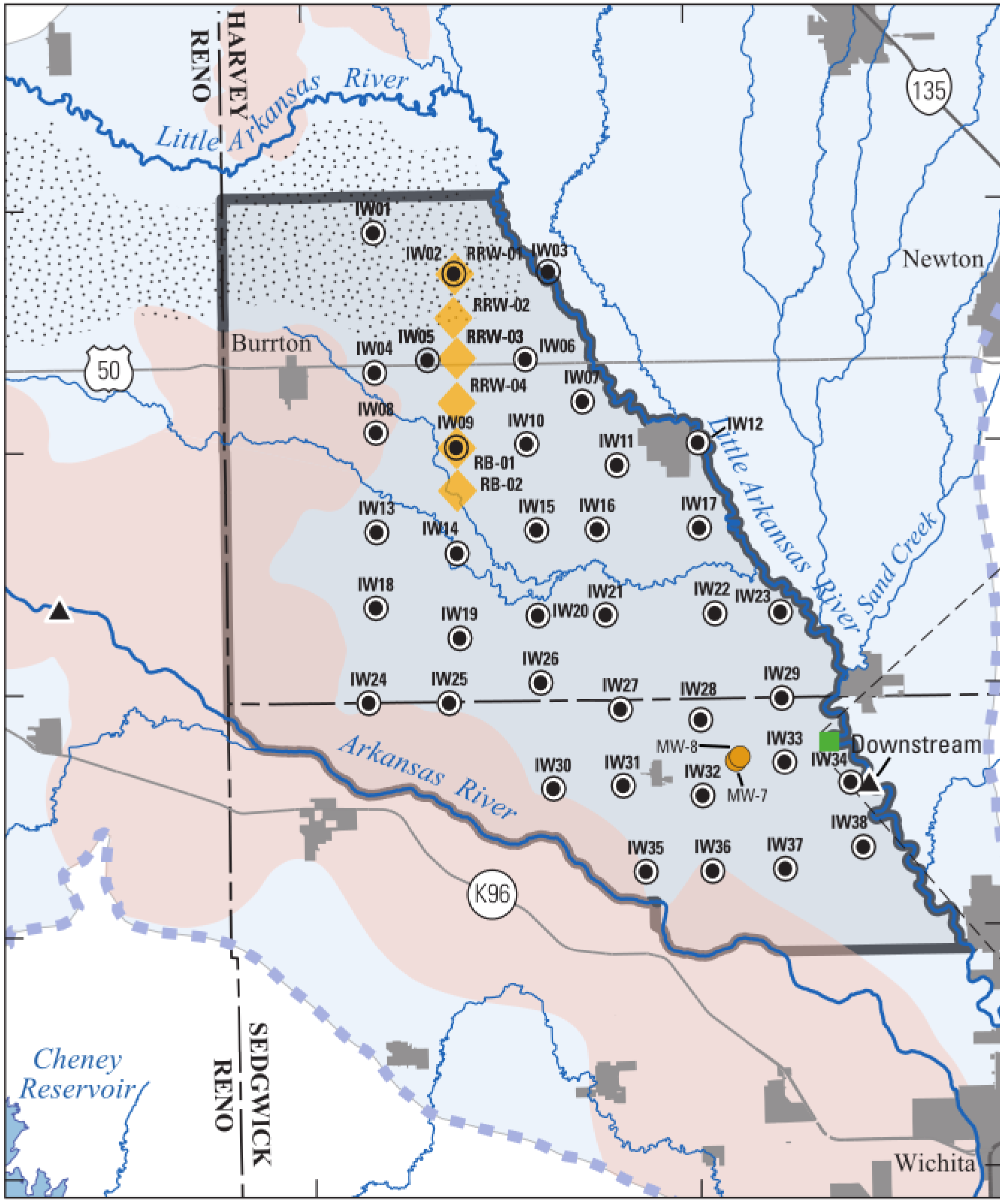
Background and Study Area



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HBMP: Data Collection

Surface water:

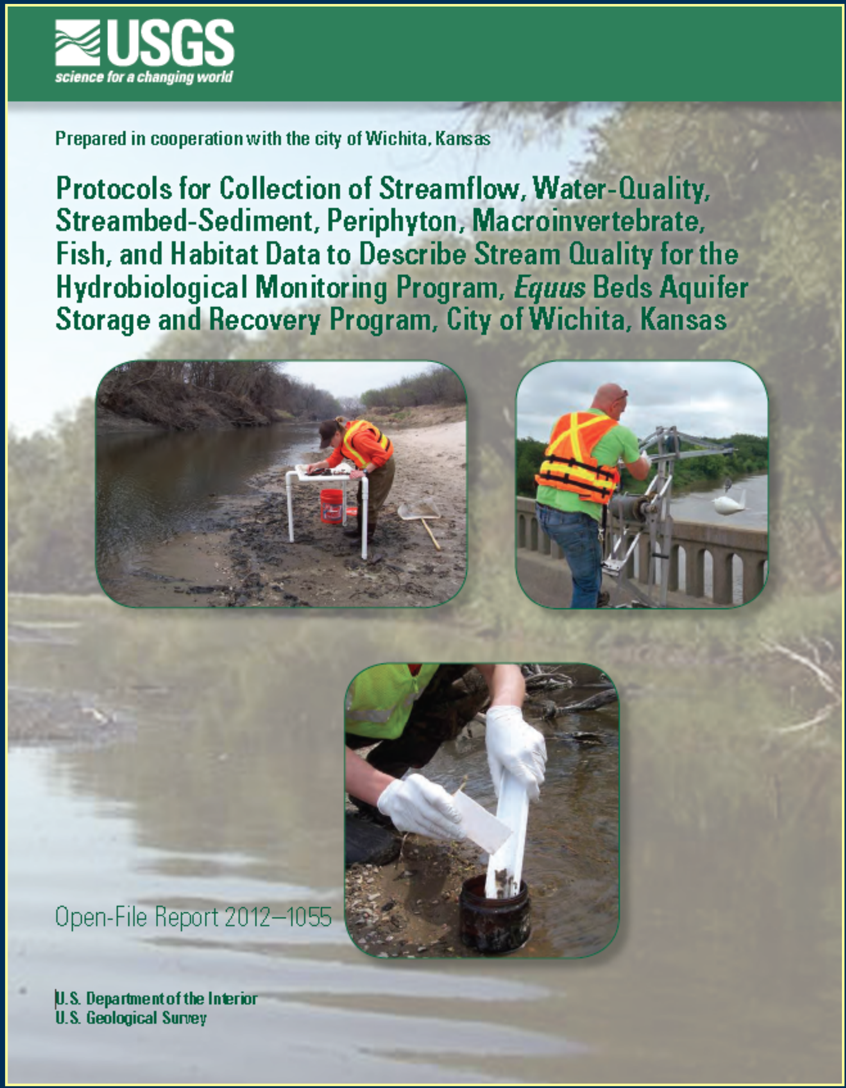
Jan 2011-Apr 2013: Pre-ASR
May 2013-Dec 2014: Post-ASR

Upstream
Downstream
Residuals return line
- -Continuous & discrete water quality
- -Streambed sediment
- -Habitat
- -Macroinvertebrates
- -Fish

Groundwater:

Jan 2011-Apr 2013: Before recharge
May-Sept 2013 & May-July 2014: During recharge
Oct 2013-Apr 2014 & Aug-Dec 2014: After recharge

Groundwater wells (ea. w/ shallow and deep)
- -Continuous & discrete water quality



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No Significant Differences in Post-ASR Constituents

	Upstream from ASR		Downstream from ASR		Residuals Return Line
	Pre-ASR (Mar '11-Apr '13)	Post-ASR (May '13-Dec '14)	Pre-ASR (Mar '11-Apr '13)	Post-ASR (May '13-Dec'14)	(May '13-Dec '14)
Chloride (mg/L)	79	51	58	54	44
Chlorine (total residual; µg/L)	12*	--*	19*	48*	50*
Copper, total (µg/L)*	--*	--*	--*	--*	39
Arsenic (µg/L)	10.5	8.5	8.8	8.2	5.1
Sulfate (mg/L)	59	44	55	49	40
Iron (µg/L)	--*	102*	17	115*	140
Manganese (µg/L)	252	51	170	94	56
Total suspended solids (mg/L)	70	78	74	57	858

Median values
*Datasets ≥50% left-censored

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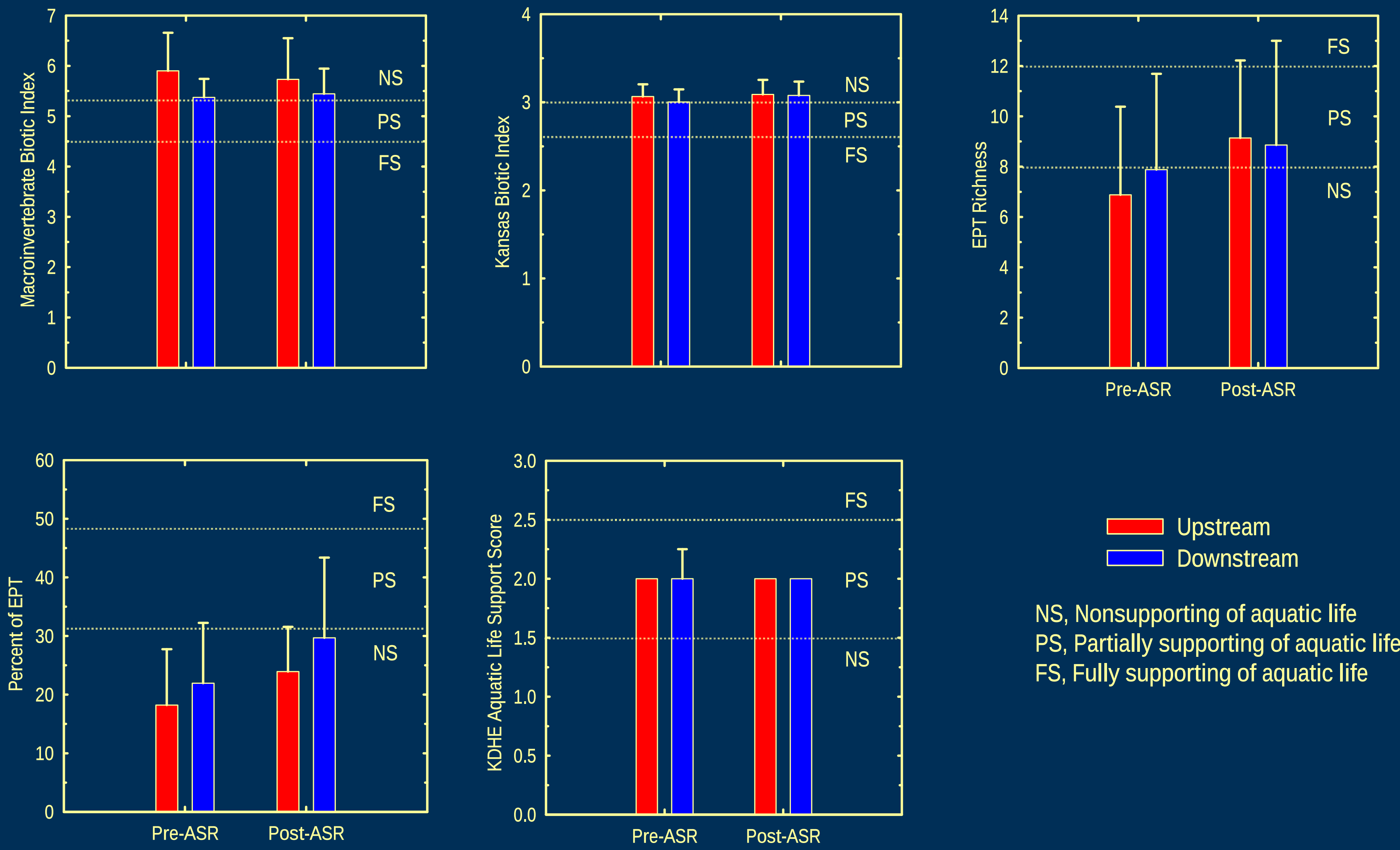
Both Sites Partially-Supporting of Aquatic Life Throughout Study Period



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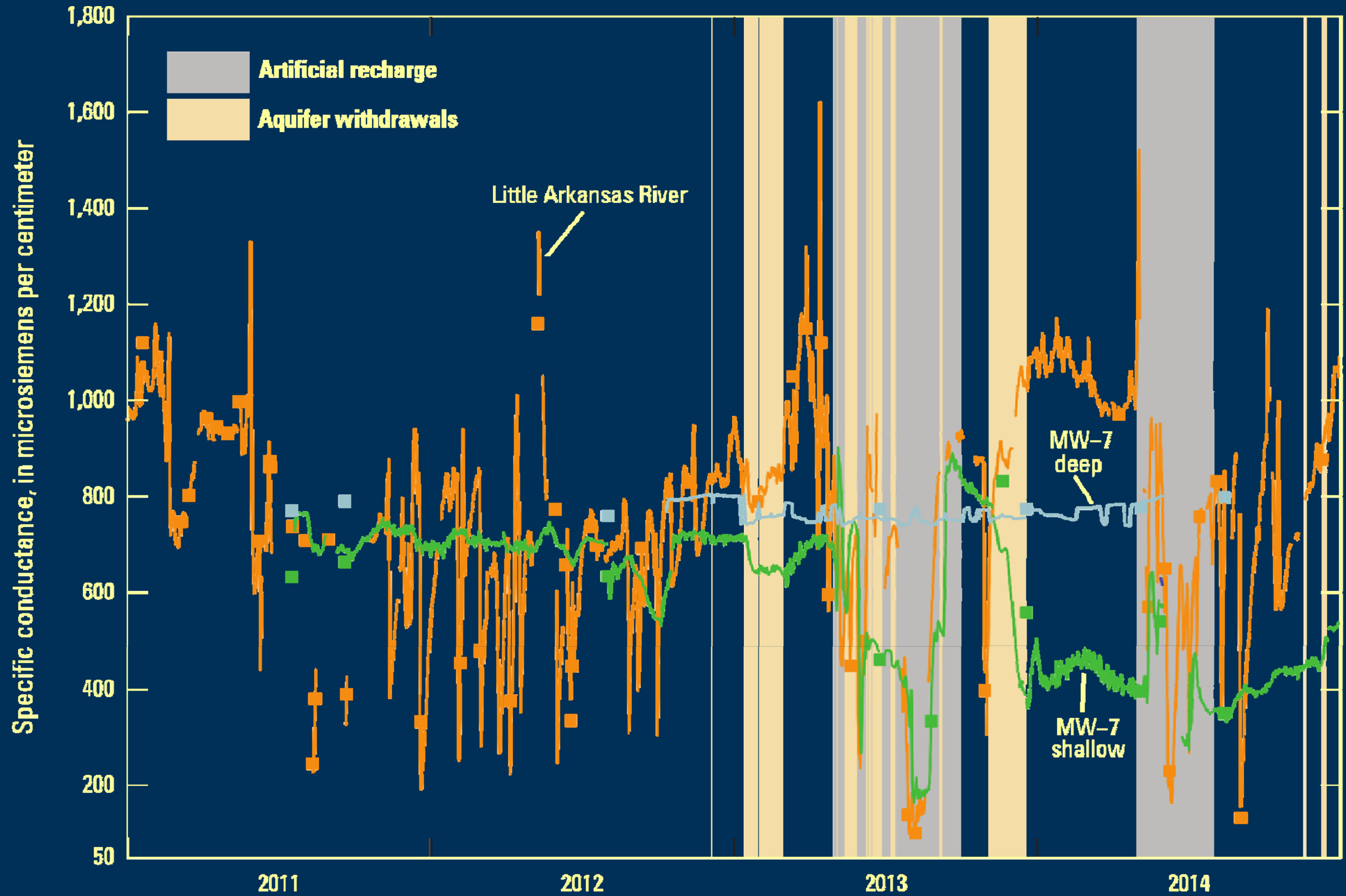
Water-Quality Changes Return to Background Conditions



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Study Conclusions

- **Decreased reliance on aquifer by Wichita helped to maintain aquifer water storage in central part of study area during 2012 drought. Declines in storage affected by other withdrawals.**
- **Concentrations of water-quality constituents of concern haven't changed substantially during ASR Phase 1 & 2, likely more influenced by climate and drawdown and recovery.**
- **Chloride plume is moving toward Wichita well-field regardless of pumping rates, but plume moves slower with lower pumping rates and increased artificial recharge.**
- **Minimal water quality and macroinvertebrate (indicators of water quality) differences between upstream and downstream of Sedgwick Little Arkansas diversion site. Continuous water quality data are useful for operational and monitoring effects.**

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Role of science in Managed Aquifer Recharge:

- Data and interpretation for unbiased, objective water quantity and quality information provide a scientific foundation for water-management decisions.

- Development of tools that can be used in variety of applications/approaches ranging from real-time operations to long-term projections and resource management are necessary.

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Selected publications:

Burrton Task force report and DWR Chief Engineer order issued on June 1, 1984. https://agriculture.ks.gov/docs/default-source/igucas/burrton198406.pdf?sfvrsn=2 and correctional order issued on July 24, 1984 https://agriculture.ks.gov/docs/default-source/igucas/burrtoncorrection198407.pdf?sfvrsn=2

Christensen, V.G., Jian, Xiaodong, Ziegler, A.C., 2000, Regression analysis and real-time water-quality monitoring to estimate constituent concentrations, loads, and yields in the Little Arkansas River, south-central Kansas, 1995-99: U.S. Geological Survey Water-Resources Investigations Report 00-4126, 36 p.

Klager, B.J., Kelly, B.P., and Ziegler, A.C., 2014, Preliminary simulation of chloride transport in the Equus Beds aquifer and simulated effects of well pumping and artificial recharge on groundwater flow and chloride transport near the city of Wichita, Kansas, 1990 through 2008: U.S. Geological Survey Open-File Report 2014–1162, 76 p., http://dx.doi.org/10.3133/ofr20141162

Kelly, B.P., Pickett, L.L., Hansen, C.V., Ziegler, A.C., 2013, Simulation of groundwater flow, effects of artificial recharge, and storage volume changes in the Equus Beds aquifer near the city of Wichita, Kansas well field, 1935–2008: U.S. Geological Survey Scientific Investigations Report 2013–5042, 90 p.

Hansen, C.V., Whisnant, J.A., and Lanning-Rush, J.L., 2014, Status of groundwater levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, 2012 to 2014: U.S. Geological Survey Scientific Investigations Report 2014-5185, 39 p.

Hansen, C.V., Lanning-Rush, J.L., Ziegler, A.C., 2013, Revised shallow and deep water-level and storage-volume changes in the Equus Beds Aquifer near Wichita, Kansas, predevelopment to 1993: U.S. Geological Survey Scientific Investigations Report 2013-5170, 18 p.

Heidari, M., Sadeghipour, J. and Drict, O., 1987, Velocity Control as a tool for optimal plume containment in the Equus Beds Aquifer, Kansas, Water Resources Bulletin, Journal of American Water Resources Association, volume 23, no.2, 11 pp.

Schmidt, H.C.Ross, Ziegler, A.C., and Parkhurst, D.L., 2007, Geochemical effects of induced stream-water and artificial recharge on the Equus Beds aquifer, south-central Kansas 1995-2004; U.S.Geological Survey Scientific Investigations Report 2007-5025, 58p.

Whittemore, D.O., 2007, Fate and identification of oil-brine contamination in different hydrogeologic settings: Applied Geochemistry, v. 22, no. 10, p. 2,099–2,114.

Whittemore, 2012, Distribution and Change in Salinity in the Equus Beds Aquifer in the Burrton Intensive Groundwater Use Control Area, Kansas Geological Survey Open-file Report 2012-1, 35 pp.

Williams, C.C., Lohman, S.W., 1949. Geology and ground-water resources of a part of south-central Kansas. Kansas Geol. Surv. Bull. 79.

Ziegler, A.C., Hansen, C.V., Finn, D.A., 2010, Water quality in the Equus Beds aquifer and the Little Arkansas River before implementation of large-scale artificial recharge, south-central Kansas, 1995-2005: U.S. Geological Survey Scientific Investigations Report 2010-5023, 143 p.

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Questions?

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For more information
http://ks.water.usgs.gov/equus-beds-recharge

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