Aquifer Storage and Recovery and the **Lower Republican River Valley, Kansas**

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KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

Presentation Outline

- Introduction to Aquifer Recharge and Recovery, better known as **Aquifer Storage & Recovery (ASR)**
- Outline of Equus Beds ASR
- Outline of hydrogeology of Lower Republican R. basin relevant to ASR
- Concluding Statement

What is ASR?

- ASR (Aquifer Storage & Recovery) is the purposeful recharge and temporary storage of water in an aquifer with the intent to recover all or a portion of the water from the same aquifer in the future
- Other equivalent names are:
- MAR—Managed Aquifer Recharge
- MUS– Managed Underground Storage of Recoverable Water

Motivation

- Need for temporary detention and storage of water during times of abundance and recovery of that water in times of scarcity
- Critical to sustainable water management

Ingredients of ASR

- Aquifer of suitable characteristics
- Source water of good quality
- Means to transmit source water into aquifer
- Means to recover it

Advantages of ASR

- Large volumes of water can be stored at a fraction of the cost of other storage options
- ASR systems do not experience the evaporative losses of surface reservoirs
- ASR systems have minimal surface footprints (and thus land requirements)
- ASR systems are less vulnerable to contamination from surface activities

Uses of ASR

- In support of potable water supply projects
- In support of agriculture in the form of irrigation supply
- In support of environmental water supply to support in-stream uses (Everglades Restoration)

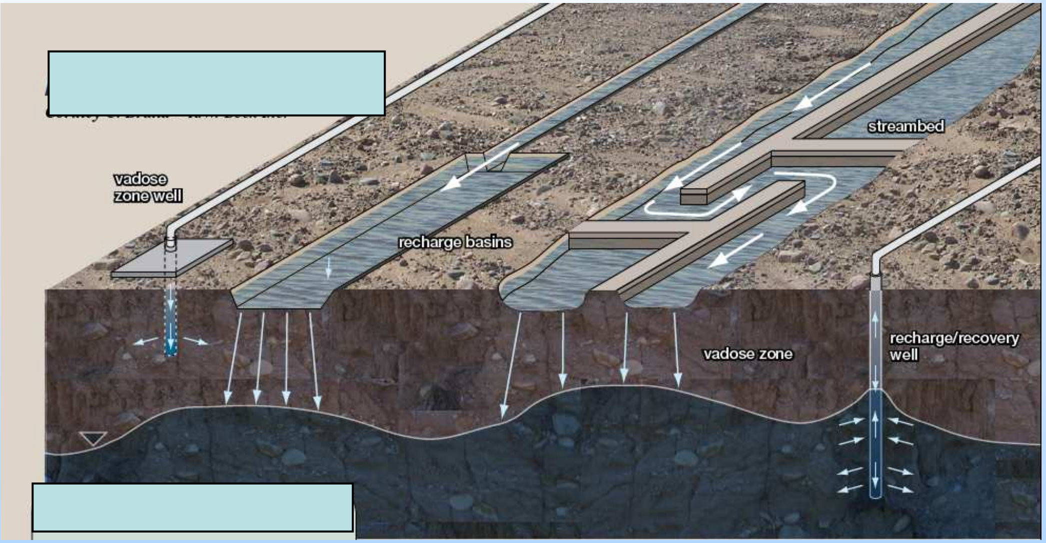
ASR not a panacea

Factors precluding ASR are:

- Low available water storage
- Low hydraulic conductivity
- High probability of clogging during recharge
- Anticipated loss of recharge water
- Anticipated degradation of water quality due to physical, chemical, or biological processes
- Anticipated changes in patterns of hydraulic gradients that would adversely affect existing water supplies

Methods of ASR

- **Source waters**: surface water from streams; stormwater runoff; remediated groundwater; reclaimed water; industrial water
- **Means of recharge**: natural drainages; impoundments; spreading basins; trenches; injection wells; vadose zone wells
- **Water recovery**: wells; natural discharge of GW to streams



ASR Challenges (1)

- **Water quality**: Mixing dissimilar waters underground and exposing aquifer materials to non-native water can drive geochemical reactions that alter water chemistry. Potential impacts include dissolution of trace elements such as *As* compounds, precipitation of clays, introduction of organics, nutrients, and pathogens.
- Plugging and clogging problems

ASR Challenges (2)

- **Water recovery**: Full recovery is not always feasible due to aquifer characteristics and the practical placements of wells. Issues can also be legal or political in origin as with imposed limitations on the rate or volume of water to be recovered.

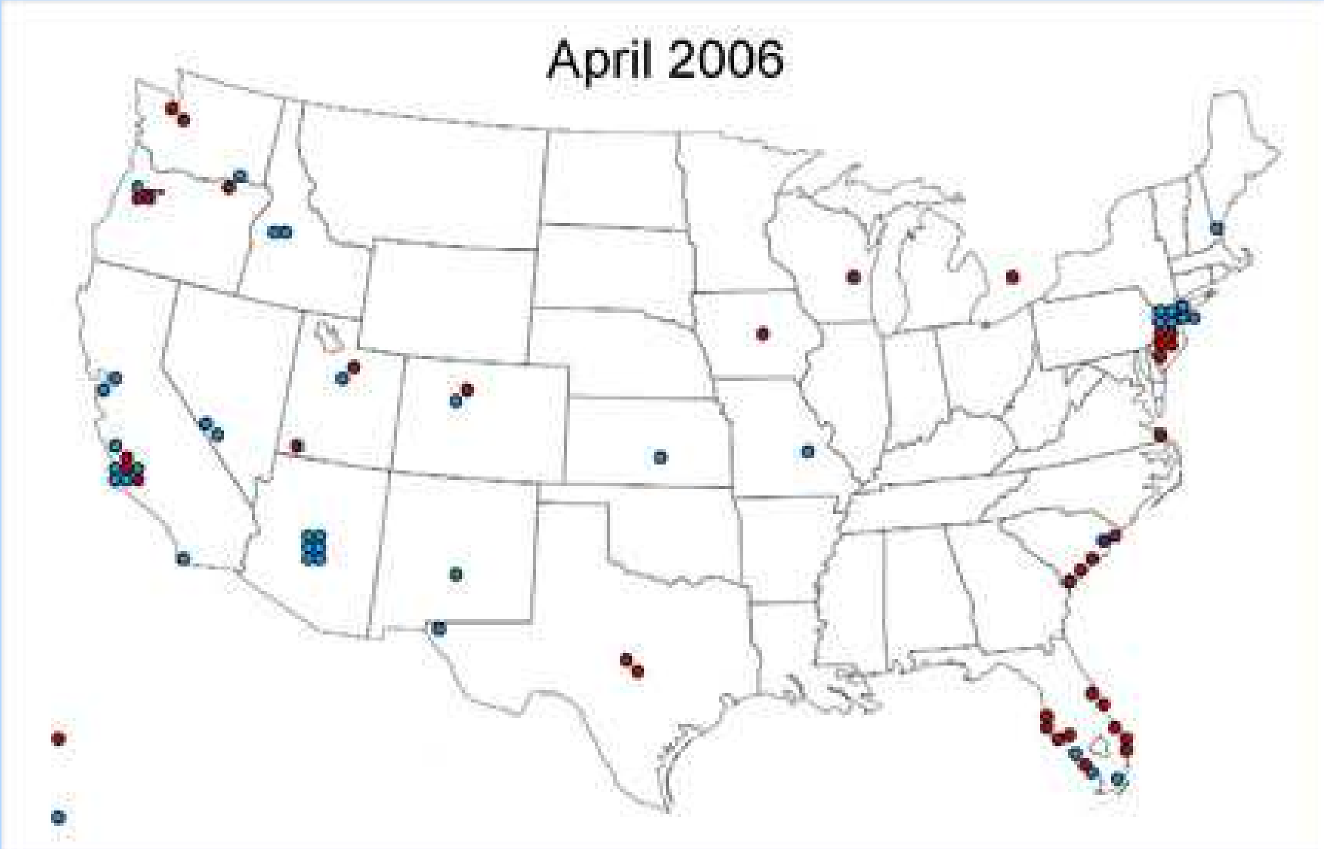
ASR Challenges (3)

- **Management, monitoring & accounting of recharged water**: GW is not visible. Computer models, monitoring wells, and sophisticated accounting systems are employed.

ASR Challenges (4)

- **Water rights**: Protection of senior WR can represent significant barriers to ASR projects.
- **Source of water availability**: Can be a limiting factor for some entities. Can engender creative solutions.

ASR Projects



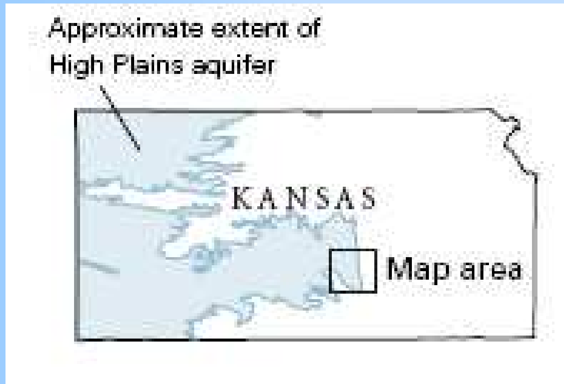
Modified after Pyne, R. D. G., 2005. Aquifer Storage Recovery: A Guide to Groundwater Recharge Through Wells. Second Edition.

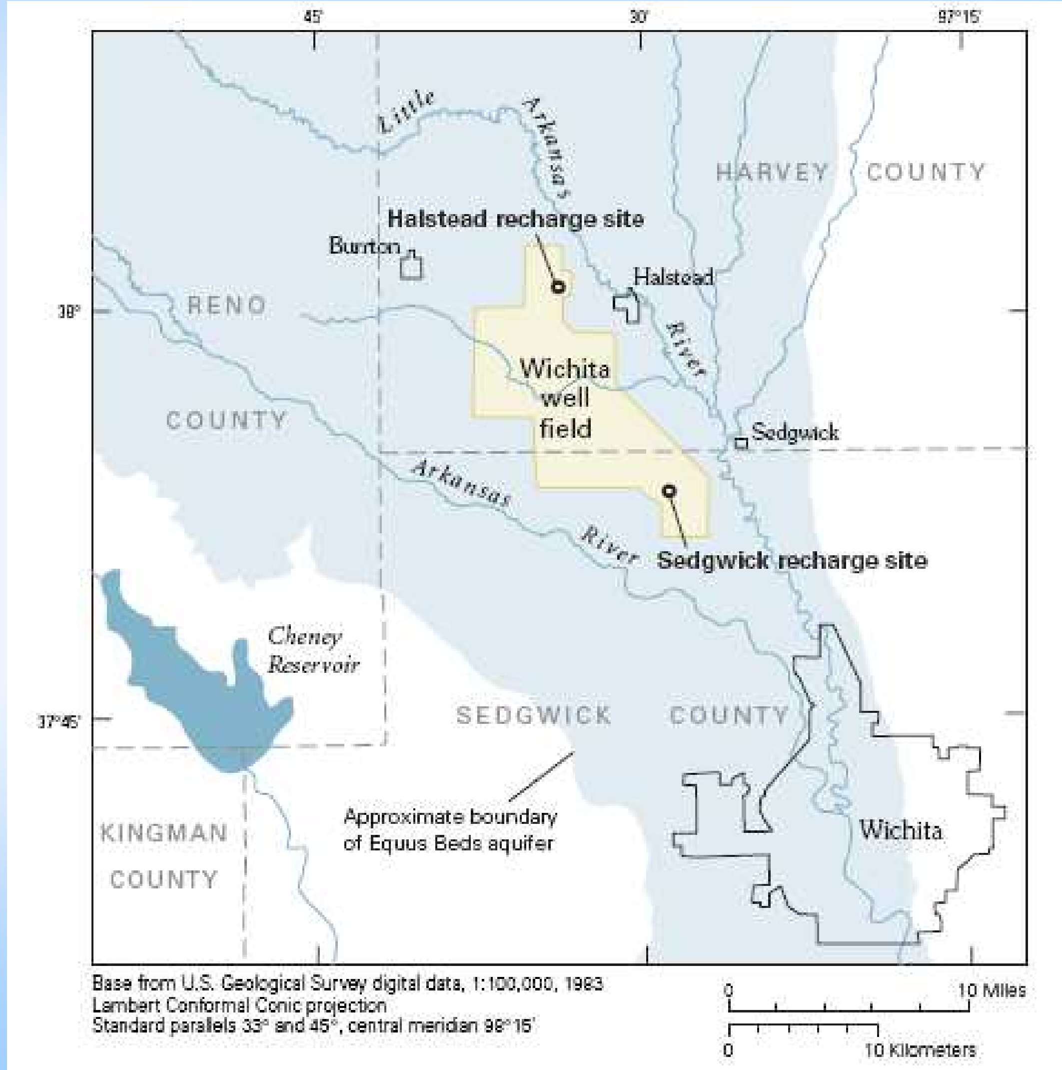
Examples of ASR projects in Western US

Entity / Project	Objective	Water Source	Aquifer Type	Recharge Method	Recovery Method
Arizona					
City of Scottsdale	store excess surface water and stormwater runoff	treated CAP water, reclaimed water	alluvial basin	direct injection wells, vadose zone wells	production and dual-use wells
Salt River Project	store excess surface water	CAP water, surface water (Salt and Verde rivers), reclaimed water	Salt River alluvium	basins	to be determined
Central Arizona Project (CAP)	store excess surface water	CAP water	alluvial basin	basins	to be determined
Tucson Water	treat and store surface water and reclaimed water	CAP water, reclaimed water	alluvial basin	basins	production wells
Vidler Recharge Facility	store surface water	CAP water	alluvial basin	basins, vadose zone wells	to be determined
California					
Orange County Water District	long-term storage, groundwater replenishment	surface water (from MWD), stormwater runoff, reclaimed water	alluvial basin	direct injection wells, in-lieu, basins	production wells
Coachella Valley	long-term storage, groundwater replenishment	surface water (from MWD), All-American Canal	alluvial basin	in-lieu, basins	production wells, water transfer
Texas					
City of El Paso	recharge aquifer and store water	reclaimed water	alluvial basin	direct injection wells, basins	production wells
City of San Antonio	store seasonally available Edwards Aquifer water	groundwater	alluvial basin	direct injection wells	production wells
Wintergarden Groundwater Conservation District	enhance recharge to the Carrizo aquifer	stormwater runoff	sandstone	impoundments, passive wells	production wells
Colorado					
Centennial Water & Sanitation District	store excess surface water	surface water (S. Platte River)	sandstone	direct injection wells	production and dual-use wells
Colorado Springs Utilities	store excess surface water	surface water (Colorado River)	sandstone	direct injection wells	dual-use wells
Lower South Platte Water Conservancy District	streamflow augmentation, wildlife recovery	surface water (S. Platte River) and alluvial wells	S. Platte River alluvium	basins and ditches	accretion to river
Nevada					
Las Vegas Valley Water District	store excess surface water	surface water (Colorado River)	alluvial basin	direct injection wells	production and dual-use wells

(from Southwest Hydrology, May/June 2008 issue)

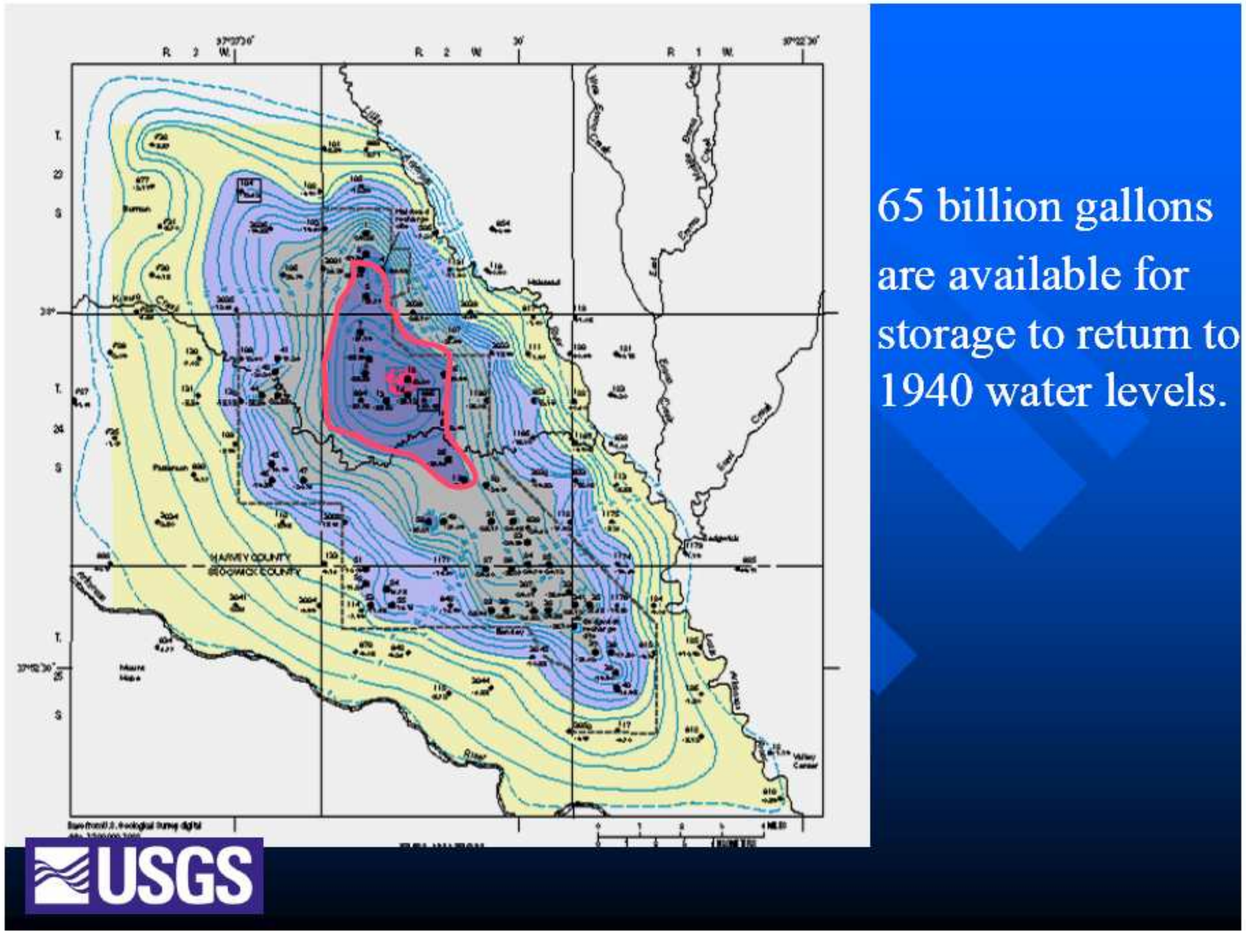
Equus Beds ASR Project





Equus Beds aquifer problems

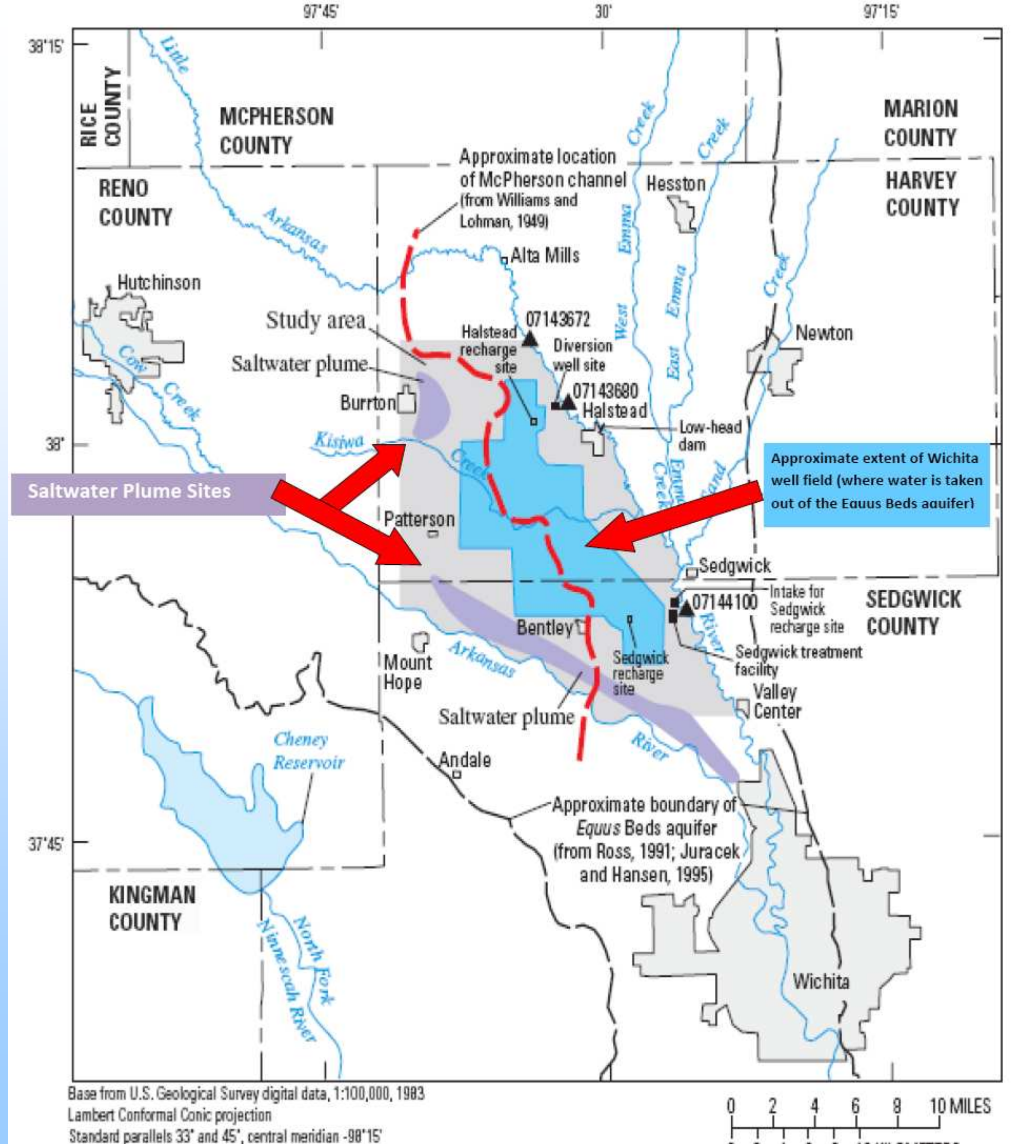
Since the 40s & 50s, water levels in the aquifer have dropped up to 40 ft. As a result, the Equus Beds is being threatened by saltwater from the Ark. R. in the SW, and by oil-field brine from the NW.



Equus Beds Aquifer

In 1965, the City of Wichita began using surface water from Cheney Reservoir to supplement Wichita's public supply. As a result, water use from the Equus Beds aquifer was not as great as it would have been without the availability of water from the reservoir.

However, by the late 70s to early 80s water pumped out from the aquifer increased as a result of the growing needs in the region with the consequence that GW levels resumed their general decline.



Wichita's 1993 Integrated Local Water Supply (ILWS) Plan to meet City's water needs through year 2050

- Greater use of Cheney Reservoir
- Conservation (15%)
- Use of ASR system in the Equus Beds aquifer (100 mgd recharge capacity)
- Re-development of the Bentley Wellfield (10 mgd)
- Expansion of Local Wellfield (45 mgd)
- Additional raw water pipelines
- An additional water treatment plant (65 mgd)

Equus Beds ASR Project

- Capture above base-flow water from Little Arkansas River.
- Use both diversion wells and surface water intake.
- Treat the water to drinking water quality standards.
- Recharge that water through recharge wells and recharge basins.

ILWS Plan is considered a Win-Win Project

- The City gets a water supply source that meets needs through 2050
- Water quality is protected from salt water contamination because the recharged fresh water forms a hydraulic barrier to saltwater contamination
- No requirement to curtail irrigation
- Irrigators have lower pumping costs
- Improves low flows in Little Arkansas River
- Project uses less land than any other surface water development project

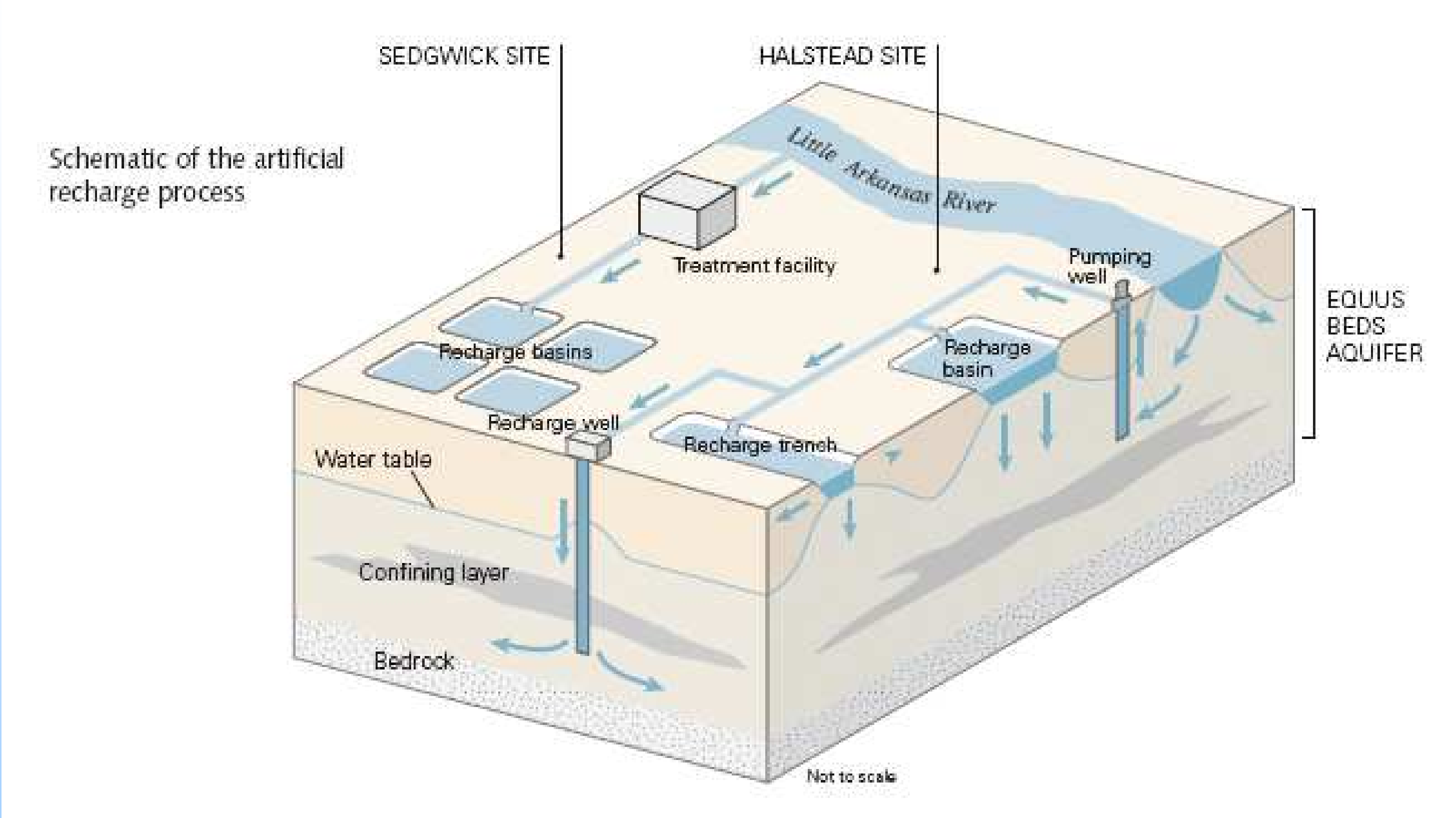
Demonstration Project

- To address concerns about the ASR project, the City did a 5-year demonstration project to validate primary components of the project

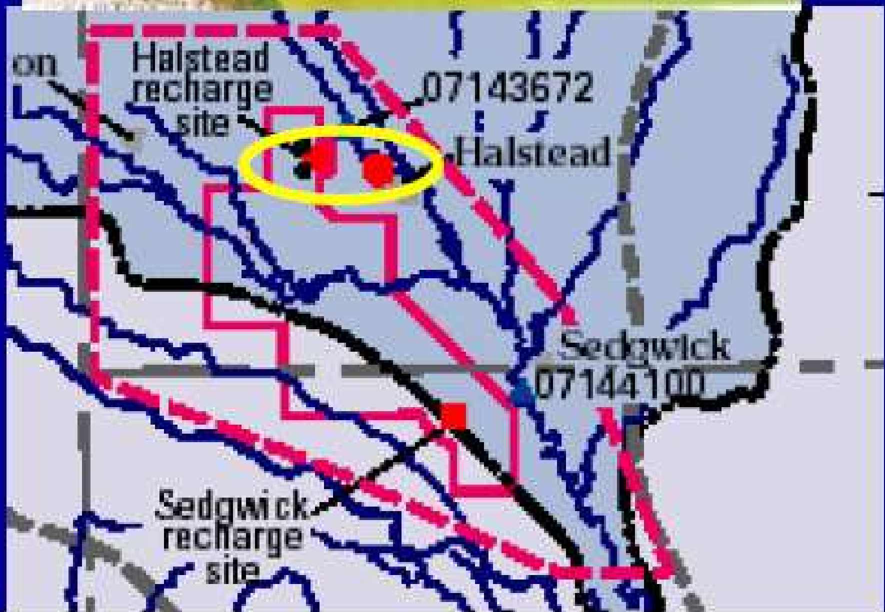
ASR Phase I

- Capacity to divert and recharge up to 10 MGD
- 3 River Diversion Wells
- One 7 MGD River Diversion
- One 7 MGD Surface Water Treatment Plant (Ballasted Flocculation)
- 4 Recharge Wells
- 2 Recharge Basins
- 14 Miles of Overhead Power Lines
- Phase I completed in September 2006

Equus Beds Aquifer Storage & Recovery schematic

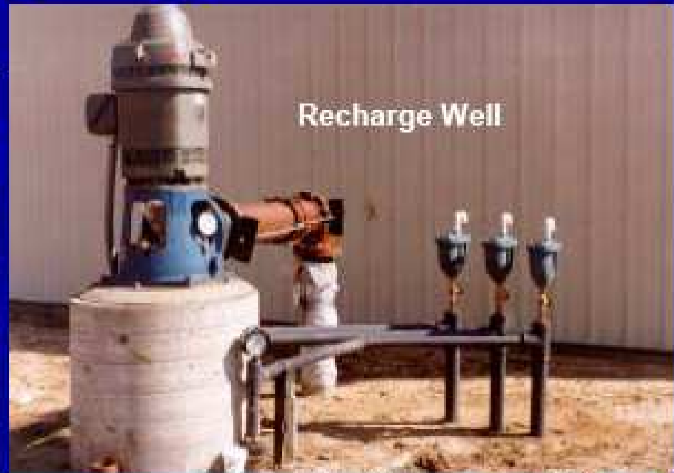


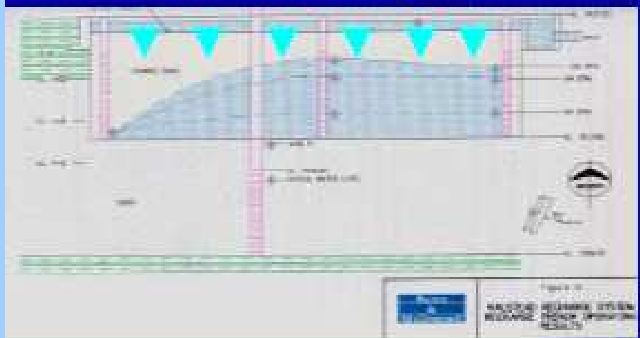
Halstead Recharge System



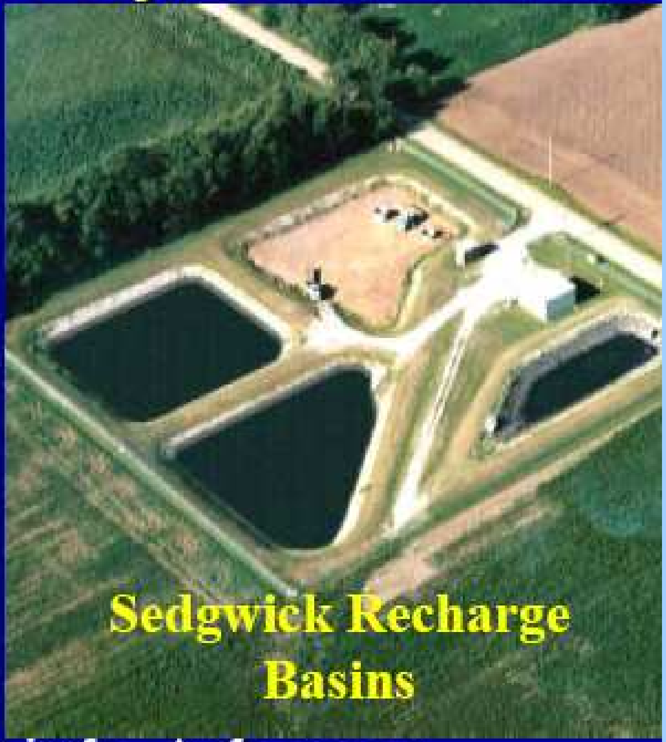
- Large capacity well induces streamflow into the well
- Water is pumped 3 miles to the west and recharged through either a trench, basins, or recharge well

Halstead Recharge System



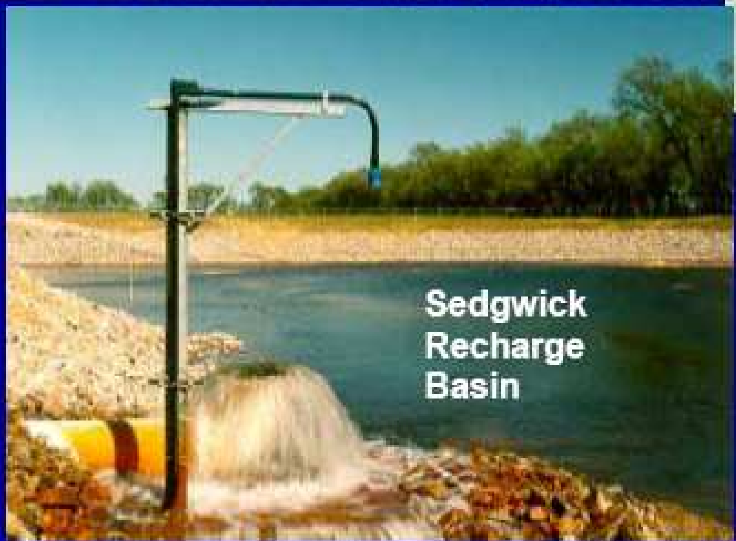


Sedgwick Recharge System



Water is withdrawn from the Little Arkansas River, treated to remove sediment and pesticides, and then piped 2 miles and recharged through surface basins

Sedgwick Recharge System



Demonstration Project

- Demonstration Project recharged over 1 billion gallons and confirmed that project would be successful

Water Quality

All water recharged must be below the Maximum Contaminate Level (MCL) established for drinking water.

	Recharge Wells	Recharge Basins	Drinking Water Standard
Atrazine	N/D	1.6 ppb	3 ppb
Arsenic	8.6 ppb	N/D	10 ppb
Hardness	135 ppm	123 ppm	NA
Chlorides	5.5 ppm	42.8 ppm	250 ppm
Nitrates	N/D	0.3 ppm	10 ppm

(from http://www.wichita.gov/CityOffices/WaterAndSewer/ProductionAndPumping/Maps.htm)

Phase II (1)

- Will capture and recharge up to 30 MGD
- Will only use surface water
- Will have treatment plant that will treat the water adequately to go directly into recharge wells
- Includes replacement of approximately 17 miles of existing raw water pipeline

Phase II (2)

- Will include 26 recharge/recovery wells, most at sites with existing municipal supply wells
- Water quality established by KDHE – as safe as municipal water supply
- Design started in 2008
- Construction to begin in 2009, complete by 2012

Phases III & IV

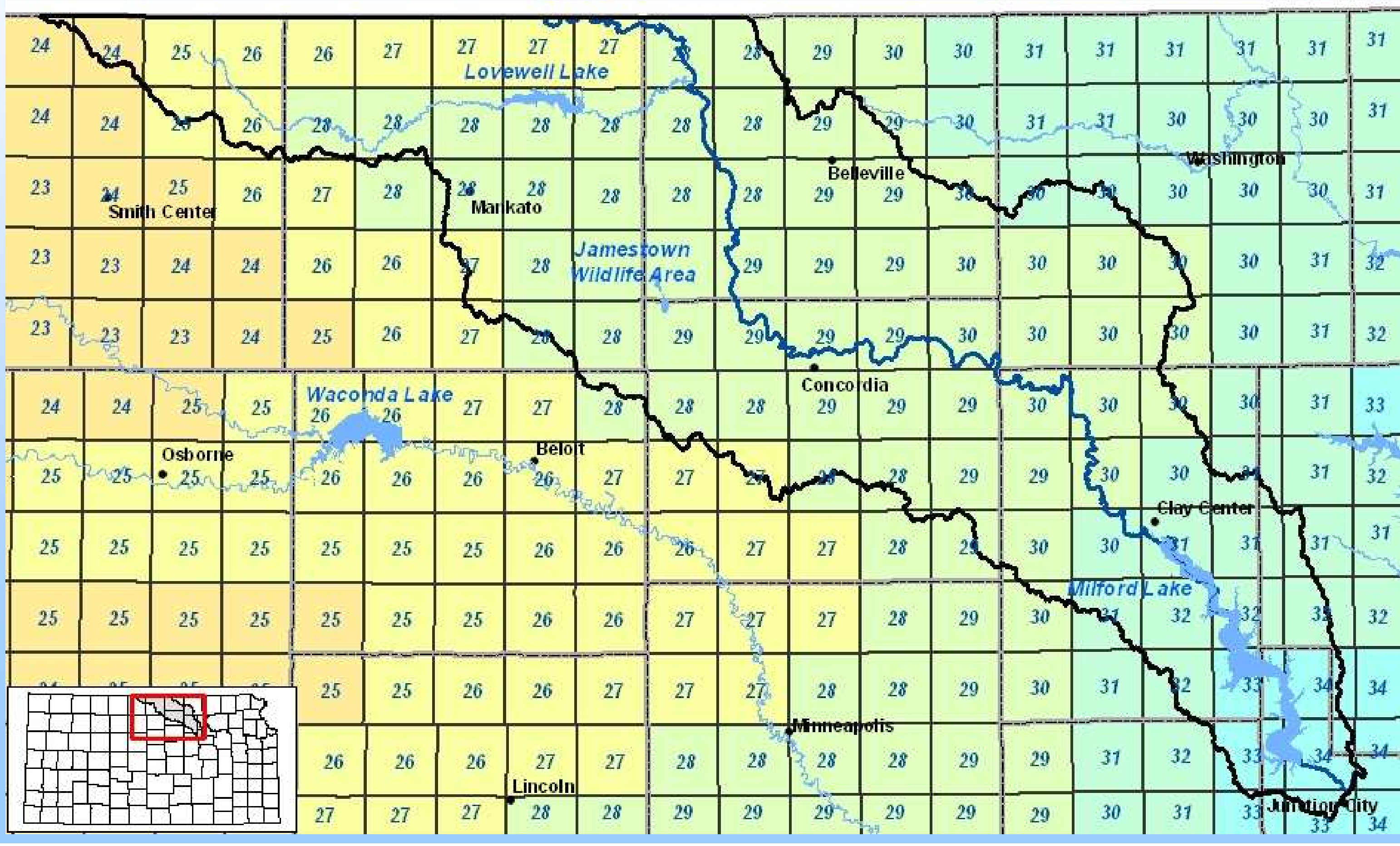
- Will include further expansion of treatment and water storage capacity

Introduction to the Hydrogeology of the Lower Republican River basin

Milford Dam - Corps of Engineers photo

Water Climatology (1)

- Climate is subhumid. Average annual precipitation generally increases from west to east, ranging from 27 in/yr in the NW to 31 in/yr in the SE

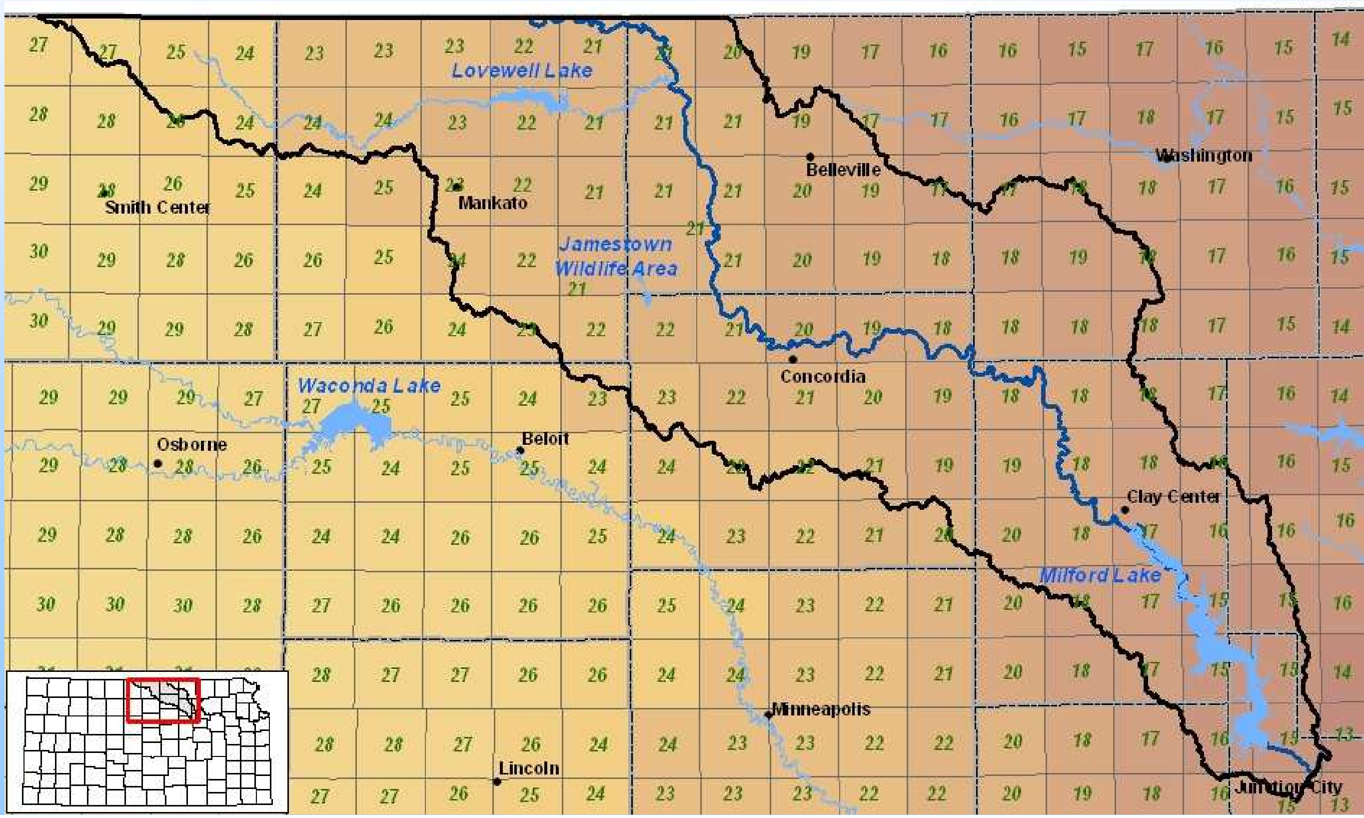


Water Climatology (2)

- The basin has high evaporation potential. Annual lake evaporation ranges from about 55 in/yr along the SC part of the basin and gradually decreases to ~49 in/yr along the W, N, and E edges of the basin, resulting in a large annual moisture deficit in all parts of the basin

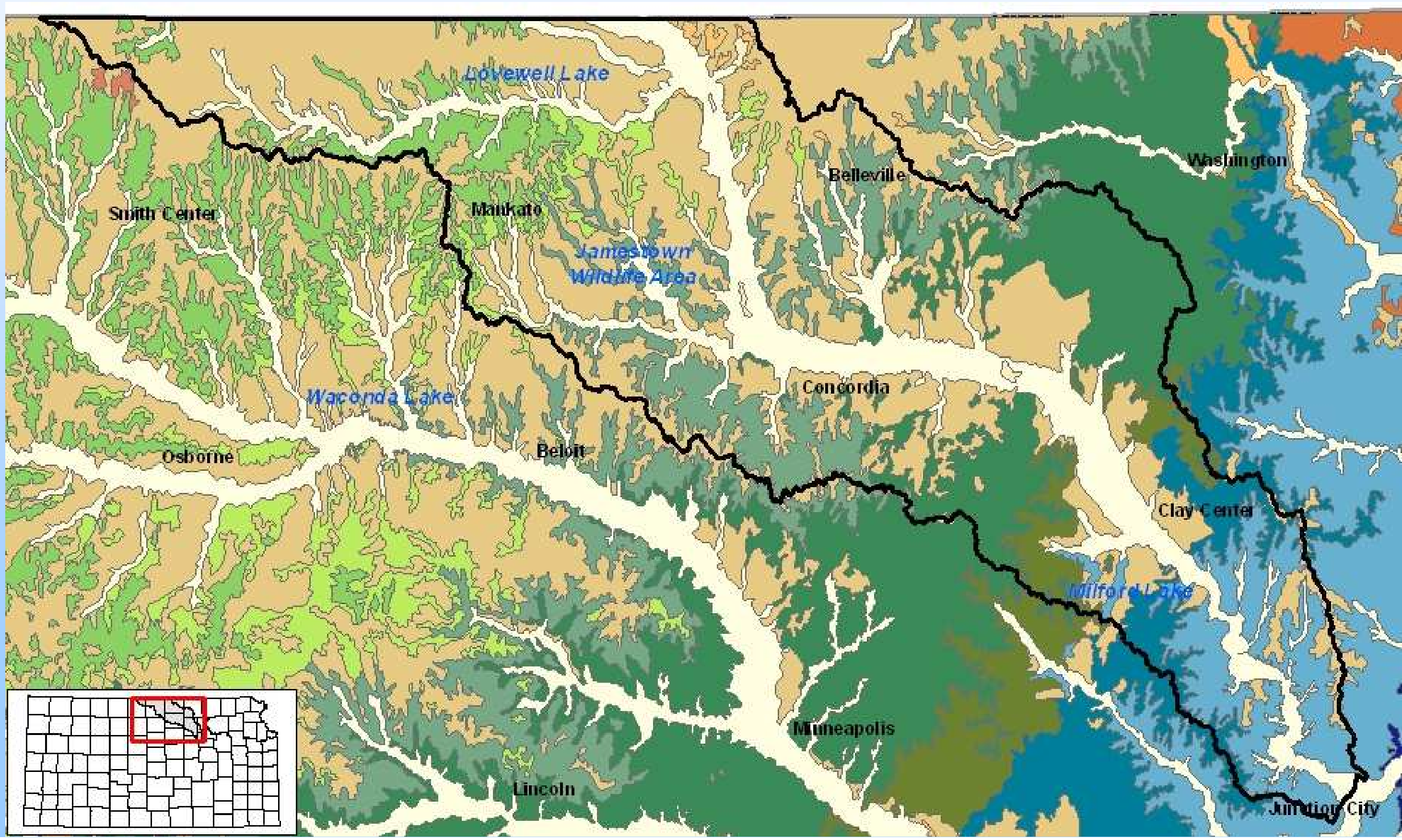
Potential Net Evaporation =

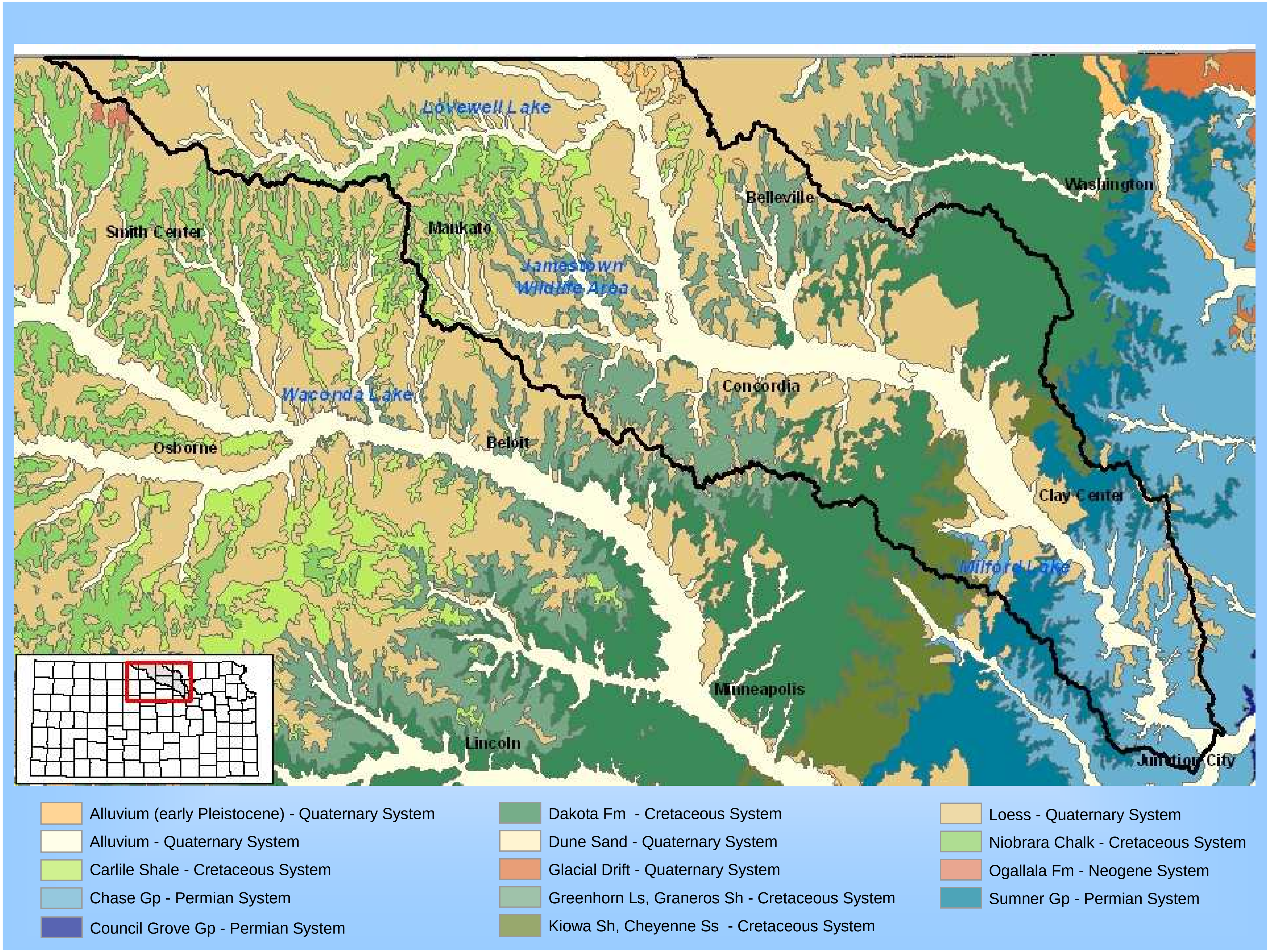
(Pot. Evap.) − (Precipitation)



Surficial Geology

- Rocks that crop out at the surface are mostly shale, sandstone, and limestone formations of Cretaceous (*green*) and Permian (*blue*) age. The major stream valleys are underlain by Quaternary alluvium and terrace deposits.

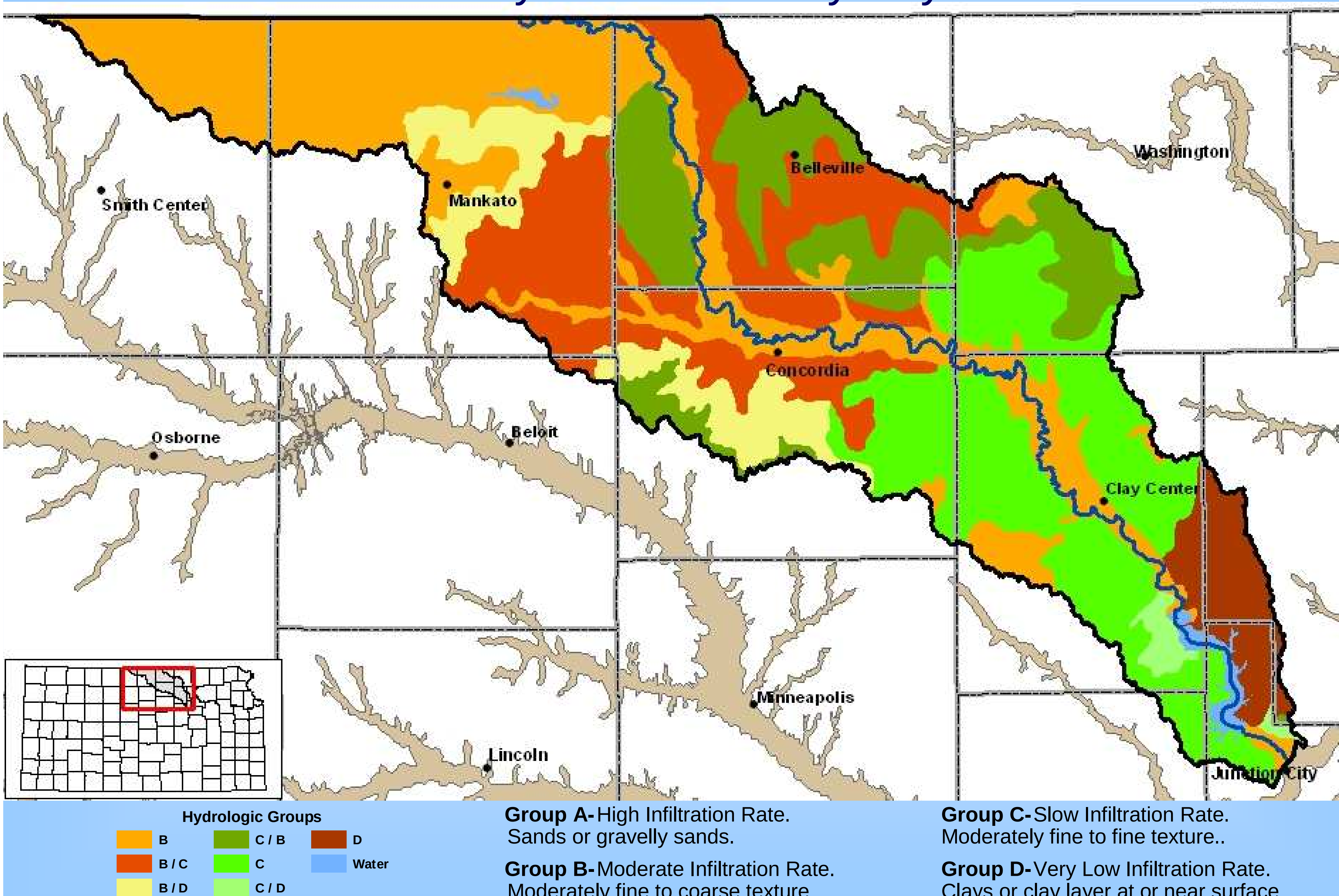




Lovewell Lake
Washington
Belleville
Smith Center
Mankato
Jamestown Wildlife Area
Concordia
Waconda Lake
Osborne
Beloit
Clay Center
Milford Lake
Minneapolis
Lincoln
Junction City
Alluvium (early Pleistocene) - Quaternary System
Alluvium - Quaternary System
Carlile Shale - Cretaceous System
Chase Gp - Permian System
Council Grove Gp - Permian System
Dakota Fm - Cretaceous System
Dune Sand - Quaternary System
Glacial Drift - Quaternary System
Greenhorn Ls, Graneros Sh - Cretaceous System
Kiowa Sh, Cheyenne Ss - Cretaceous System
Loess - Quaternary System
Niobrara Chalk - Cretaceous System
Ogallala Fm - Neogene System
Sumner Gp - Permian System

STATSGO Regional Soils, Hydrologic Groups

Soils: silty loams and silty clay loams



Group A- High Infiltration Rate.
Sands or gravelly sands.

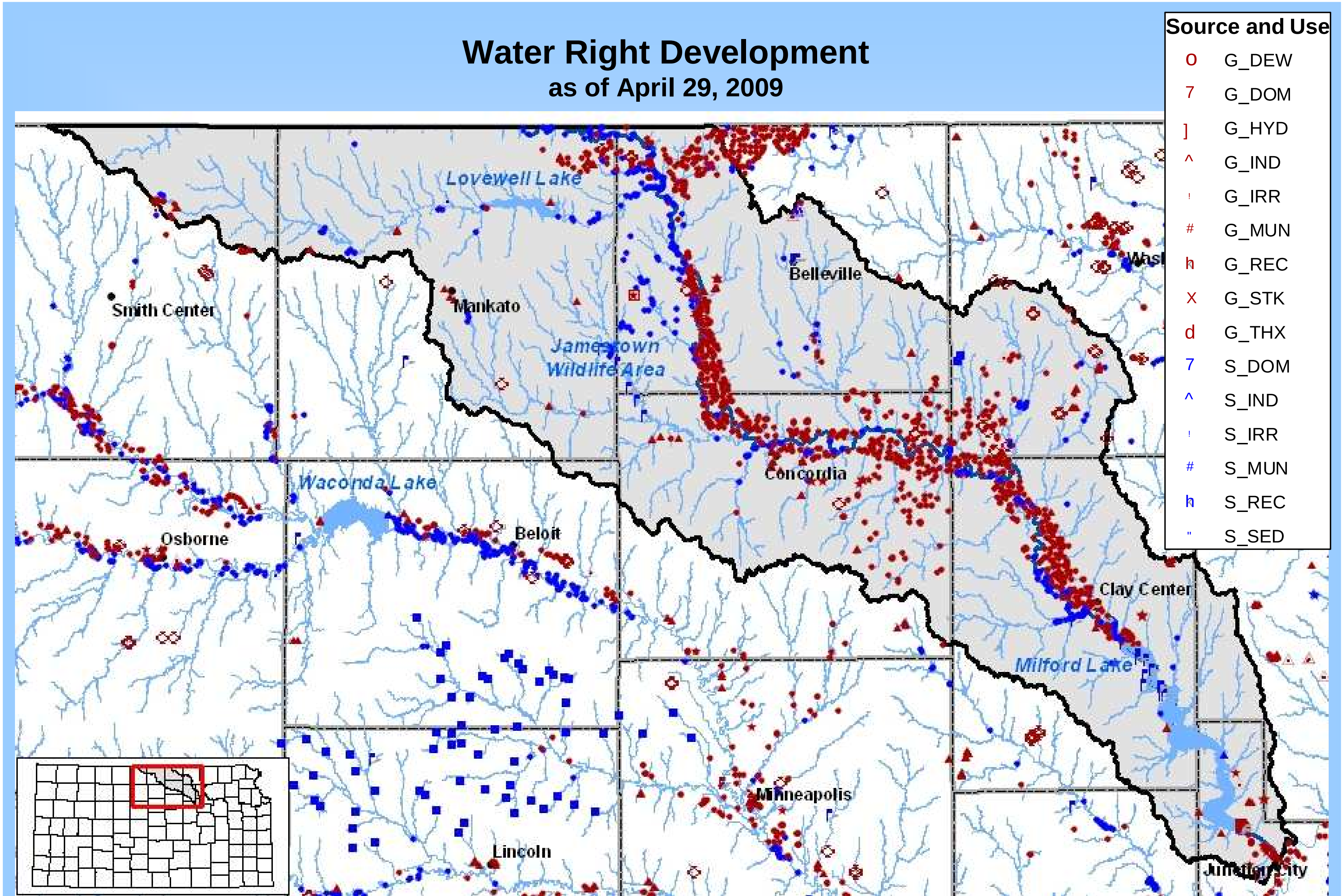
Group B- Moderate Infiltration Rate.
Moderately fine to coarse texture.

Group C- Slow Infiltration Rate.
Moderately fine to fine texture..

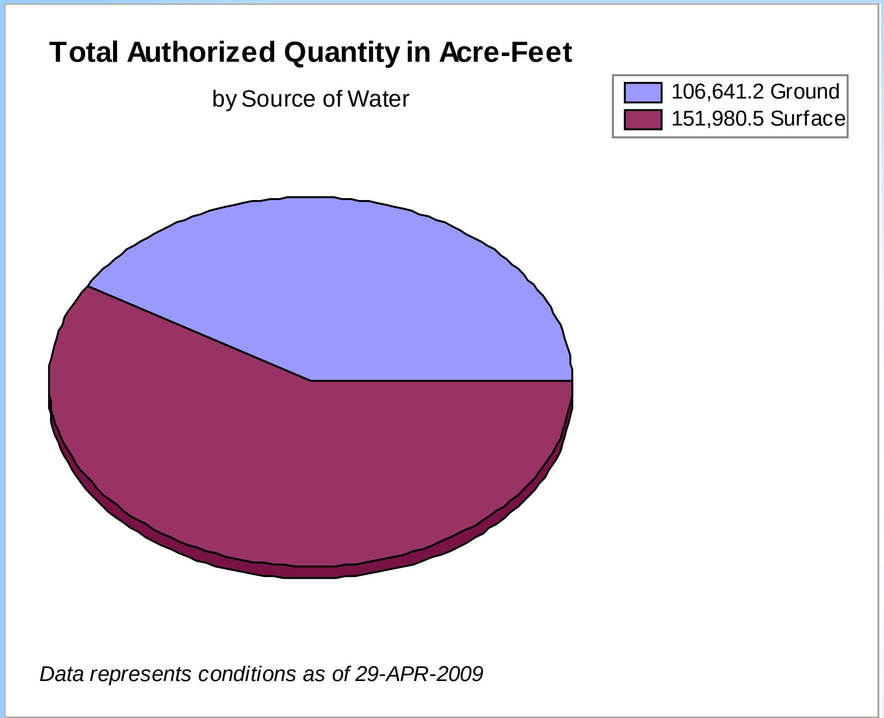
Group D- Very Low Infiltration Rate.
Clays or clay layer at or near surface.

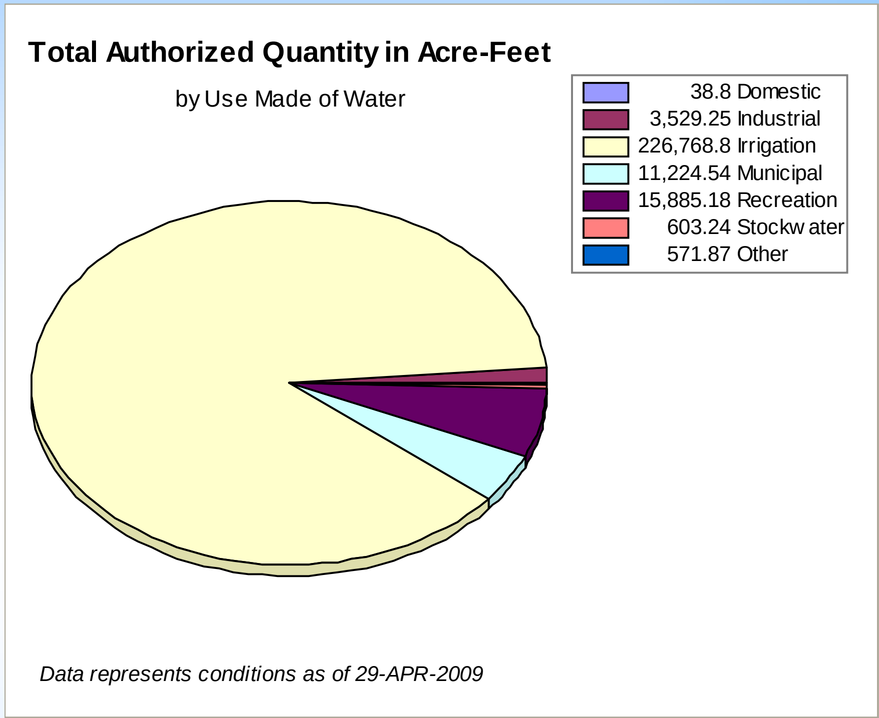
Water Right Development

as of April 29, 2009



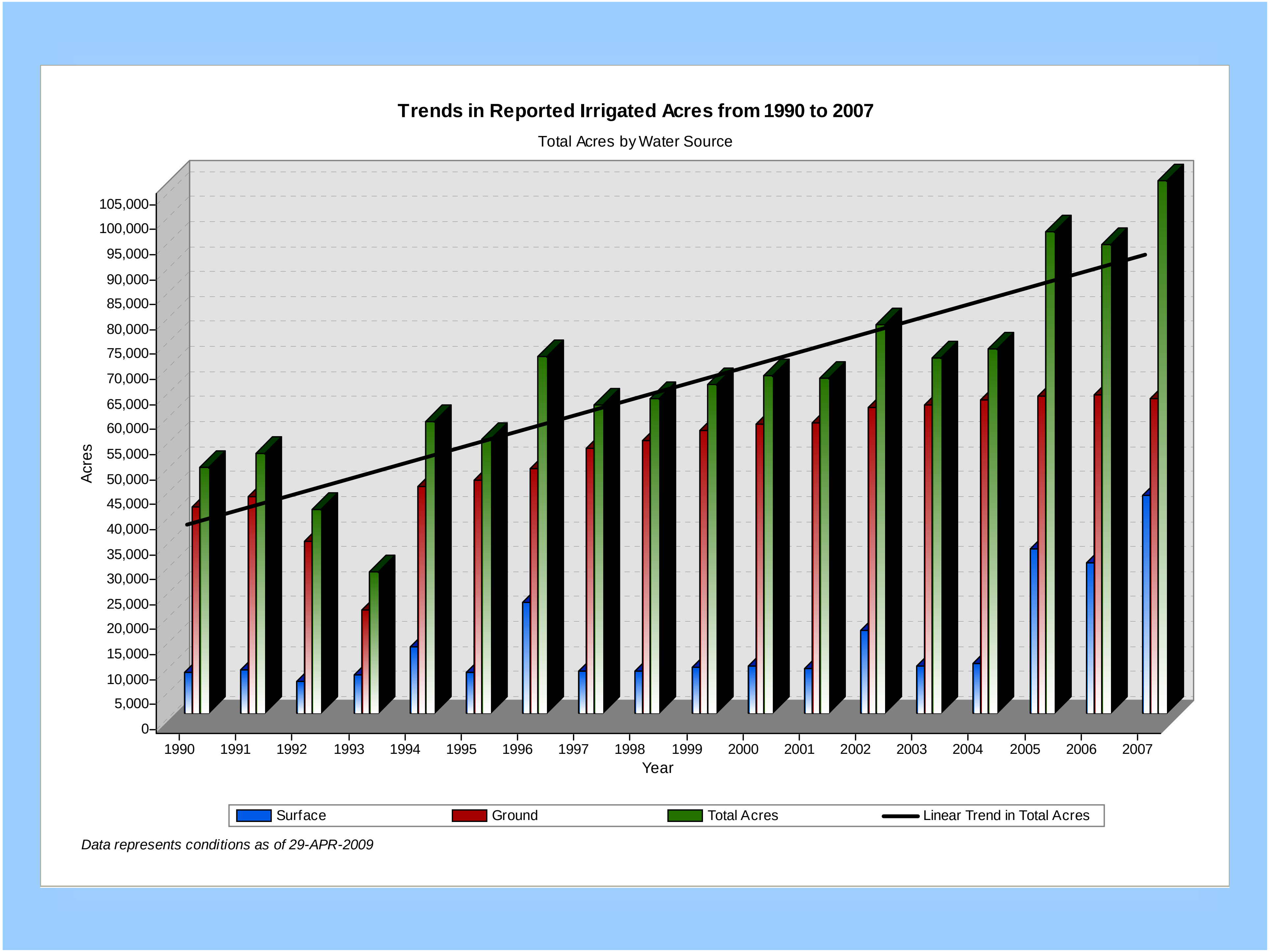
Total Authorized Quantities
as of April 29, 2009

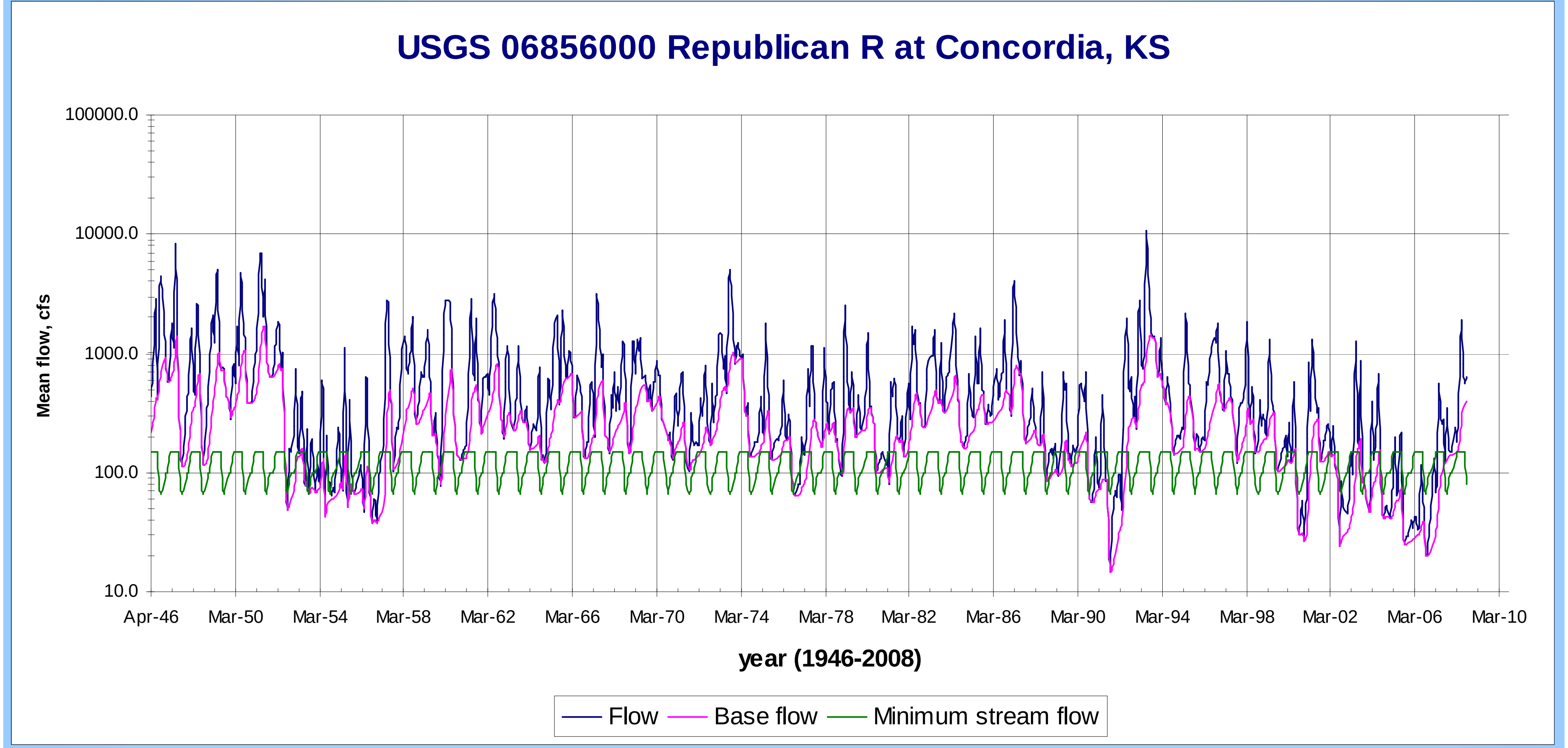


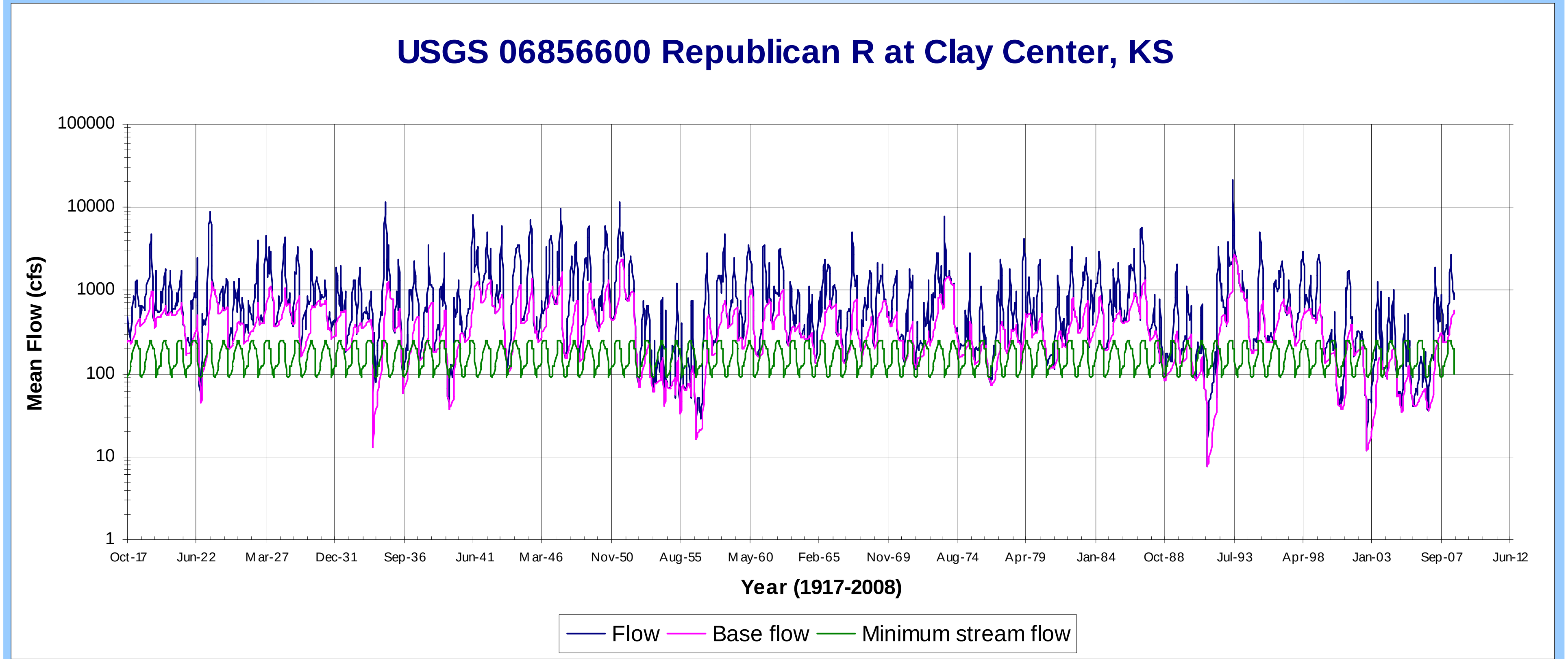


Total number of water rights.

	DOM	IND	IRR	MUN	REC	STK	OTHER	**Total**
Surface	6	0	228	2	22	0	1	259
Ground	8	31	808	86	8	20	2	960
Total	14	31	1,036	88	30	20	3	1,219


Trends in Reported Irrigated Acres from 1990 to 2007
Total Acres by Water Source
Acres
105,000
100,000
95,000
90,000
85,000
80,000
75,000
70,000
65,000
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year
Surface
Ground
Total Acres
Linear Trend in Total Acres
Data represents conditions as of 29-APR-2009


USGS 06856000 Republican R at Concordia, KS
Mean flow, cfs
100000.0
10000.0
1000.0
100.0
10.0
Apr-46
Mar-50
Mar-54
Mar-58
Mar-62
Mar-66
Mar-70
Mar-74
Mar-78
Mar-82
Mar-86
Mar-90
Mar-94
Mar-98
Mar-02
Mar-06
Mar-10
year (1946-2008)
Flow
Base flow
Minimum stream flow



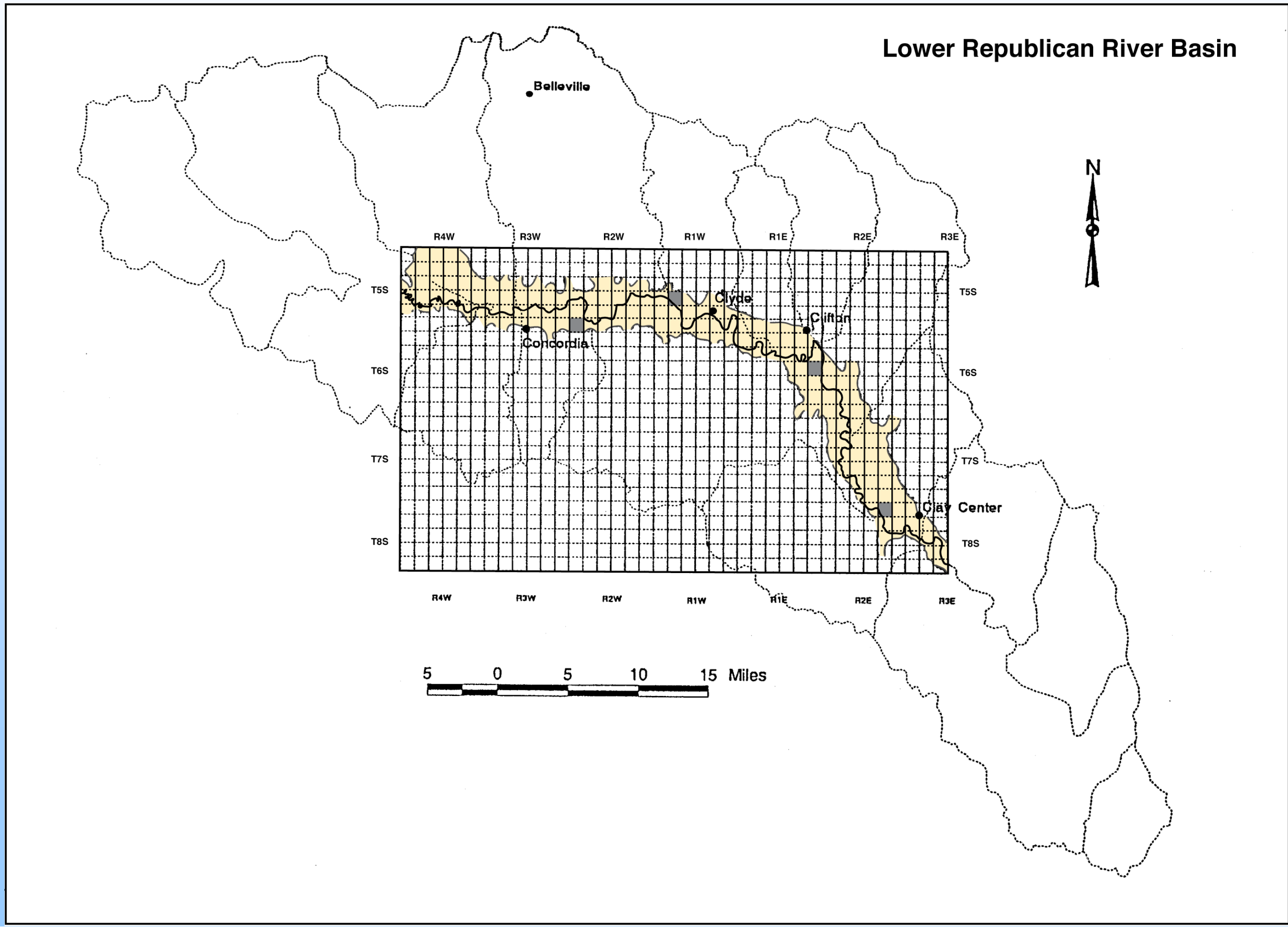
USGS 06856600 Republican R at Clay Center, KS
Mean Flow (cfs)
100000
10000
1000
100
10
1
Oct-17
Jun-22
Mar-27
Dec-31
Sep-36
Jun-41
Mar-46
Nov-50
Aug-55
May-60
Feb-65
Nov-69
Aug-74
Apr-79
Jan-84
Oct-88
Jul-93
Apr-98
Jan-03
Sep-07
Jun-12
Year (1917-2008)
Flow
Base flow
Minimum stream flow

Aquifer Hydrogeologic Properties

- The avg *K* for Cloud Co. based on 31 field tests was 422 ft/day (Fader, 1968). One pumping test in the Rep. R. valley of Clay Co. resulted in a *K*=300 ft/day (Walters and Bayne, 1959)
- Such testing indicates that the Rep. R alluvium is highly permeable

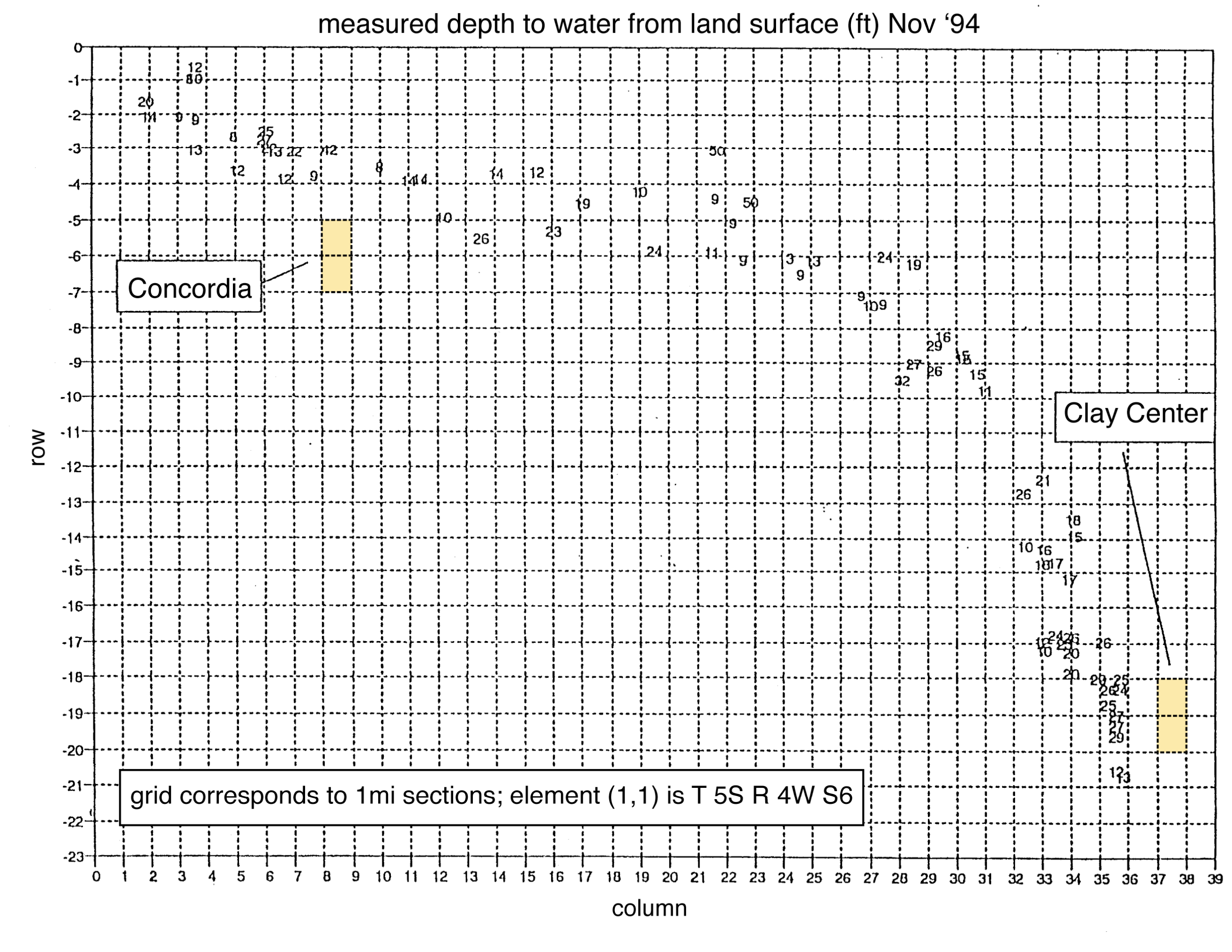
Depth to Water Table

- During November 1994 KGS conducted a water-level survey of 80 wells in the Rep. R. valley from Clay Center to west of Concordia

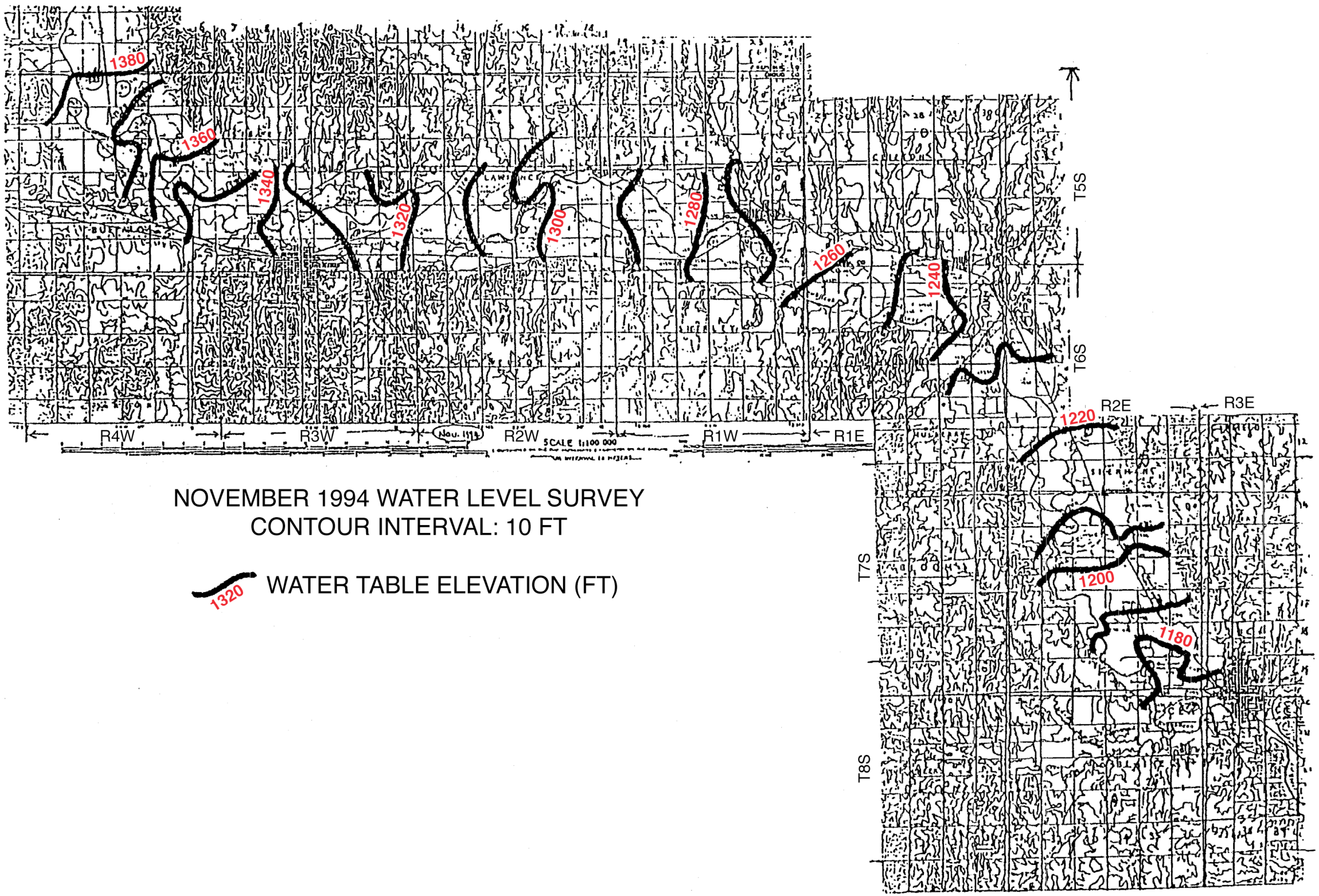


Depth to Water Table

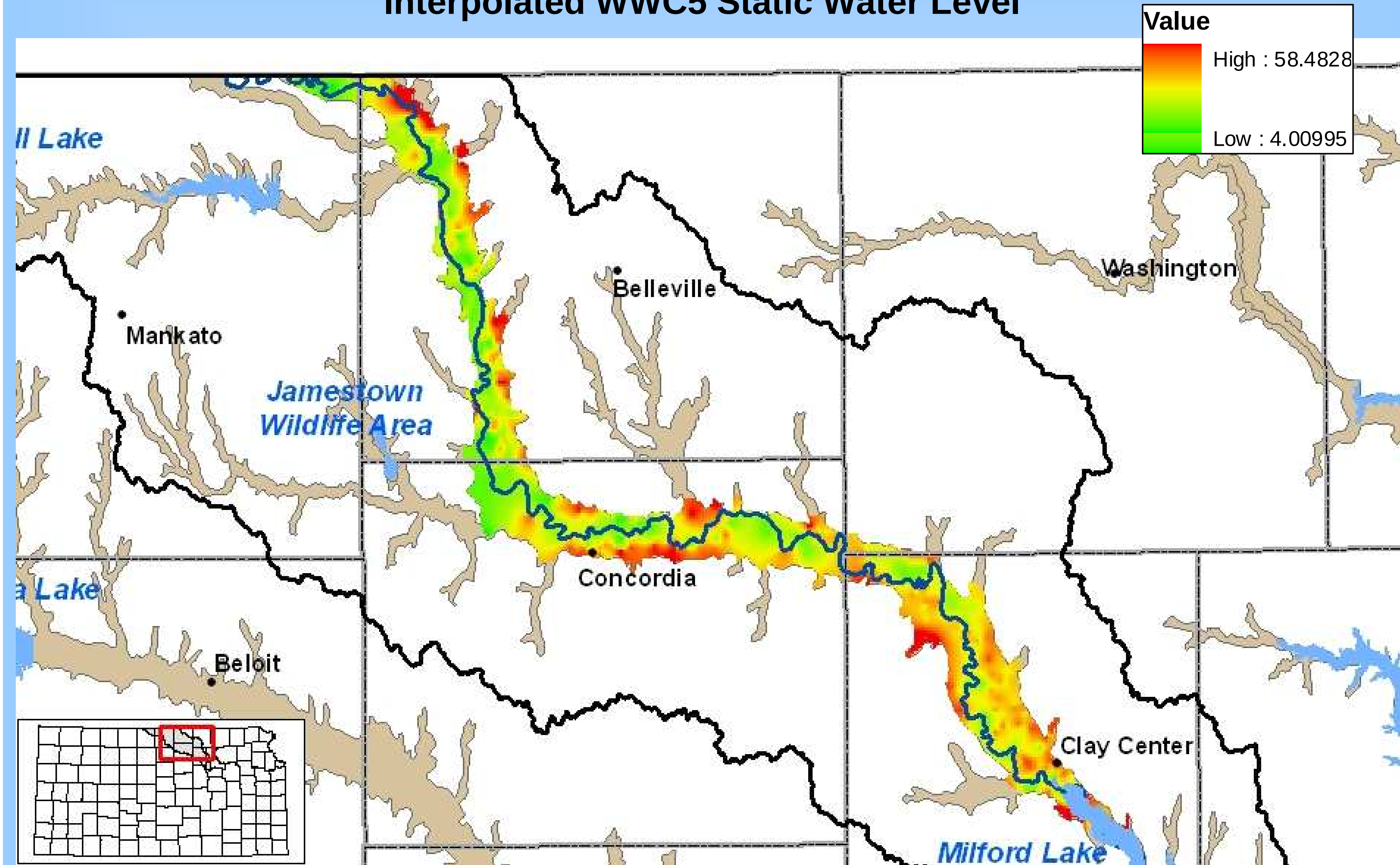
- Depths to the WT ranged from 7.5 ft to 50 ft but the avg depth to WT was less than 20 ft



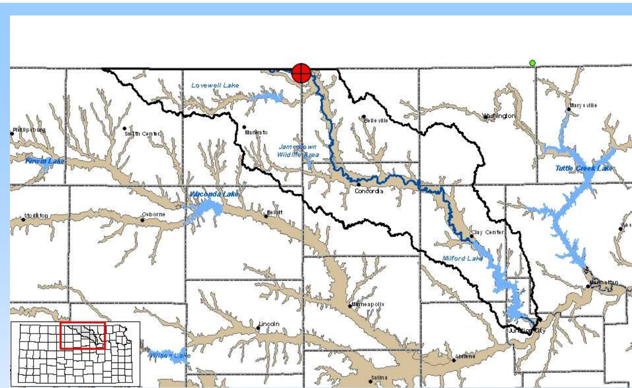
November 1994 water-table contours along the Lower Republican R. valley from Clay Center to west of Concordia

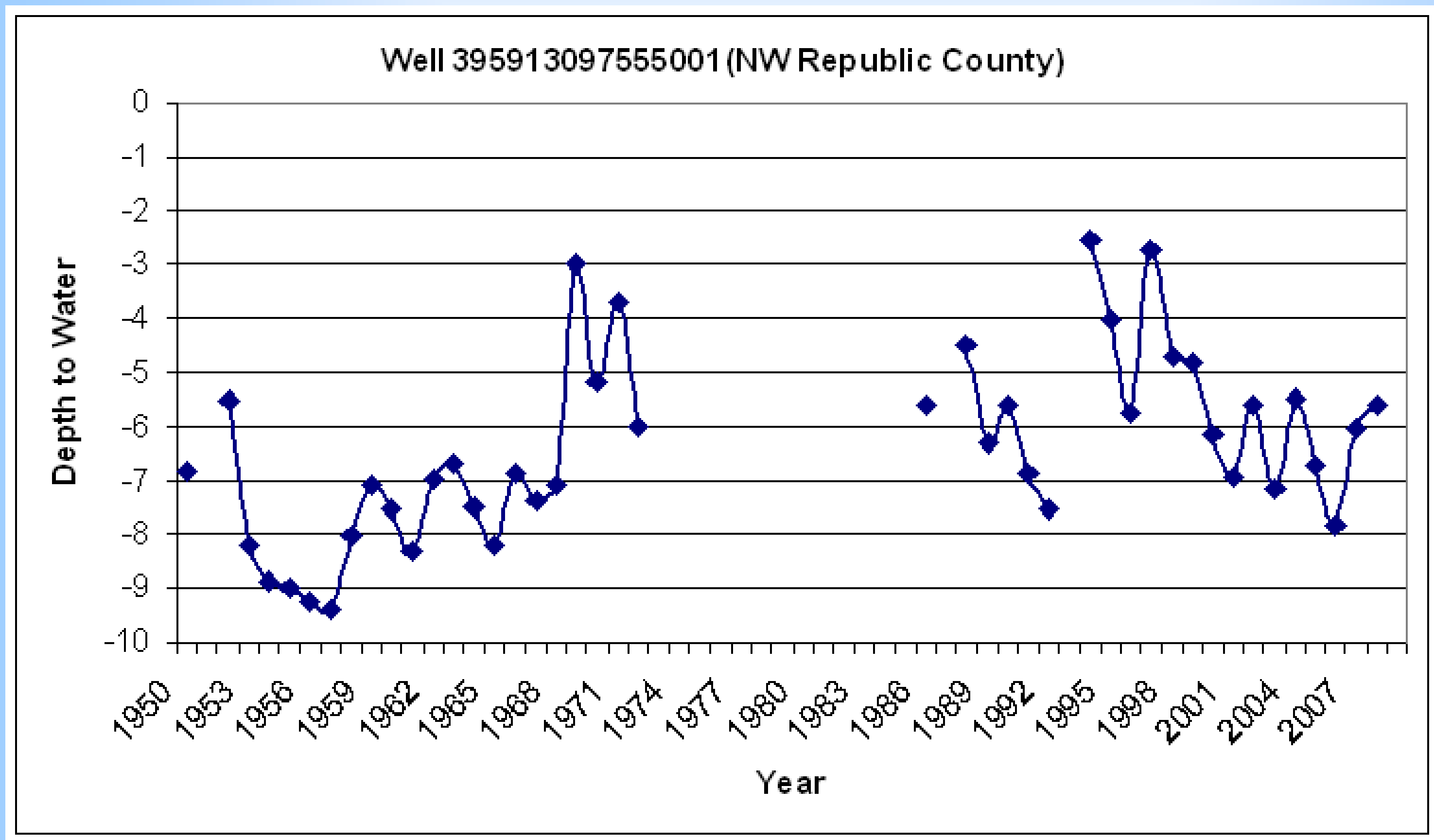


Interpolated WWC5 Static Water Level



“Winter” Depth-to-Water Measurements (December to mid-April)





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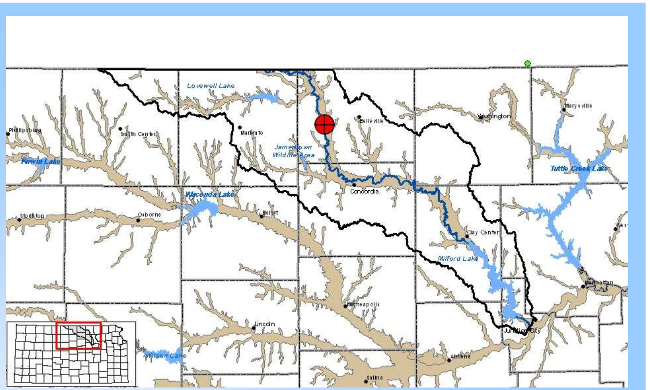

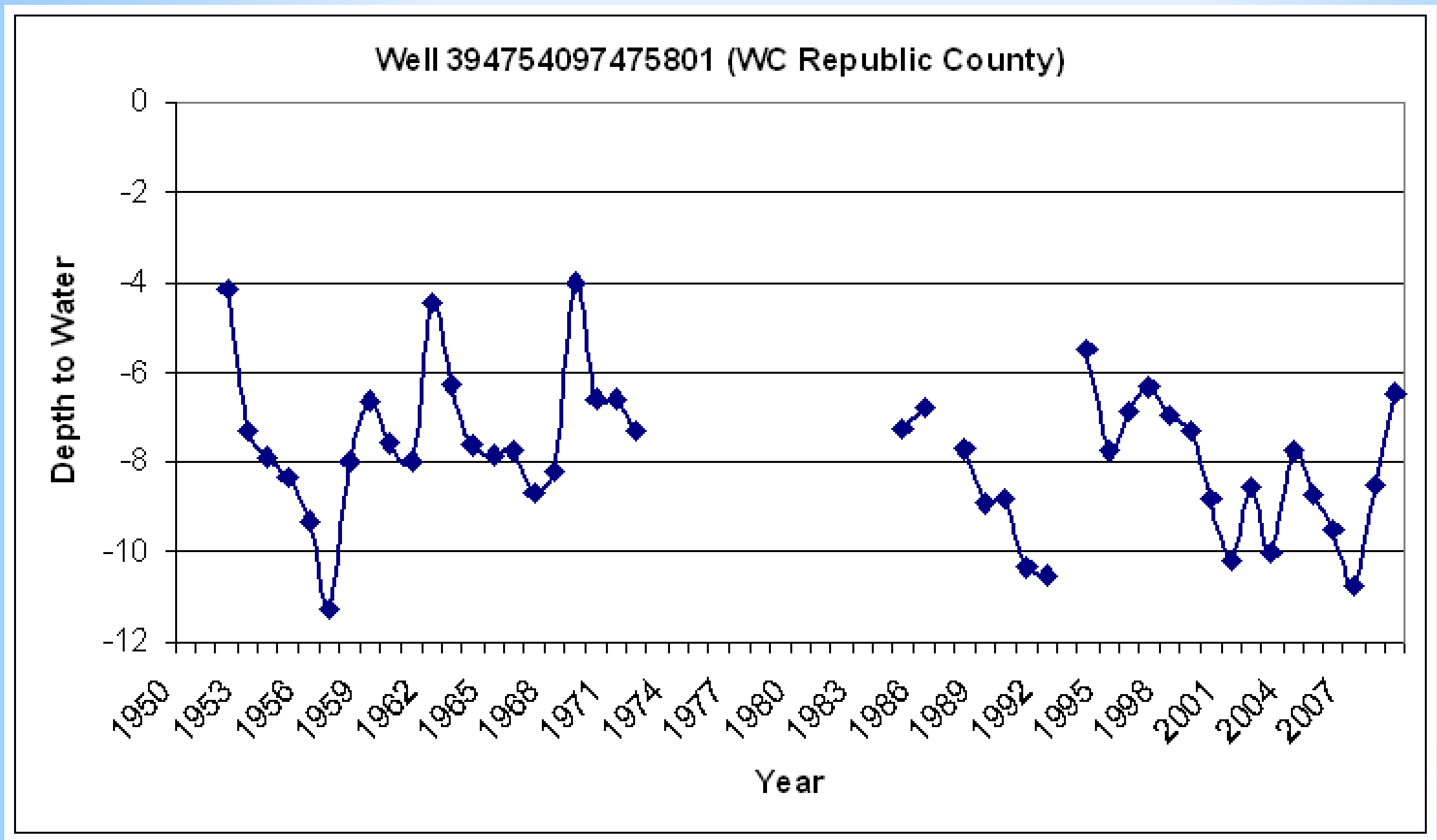

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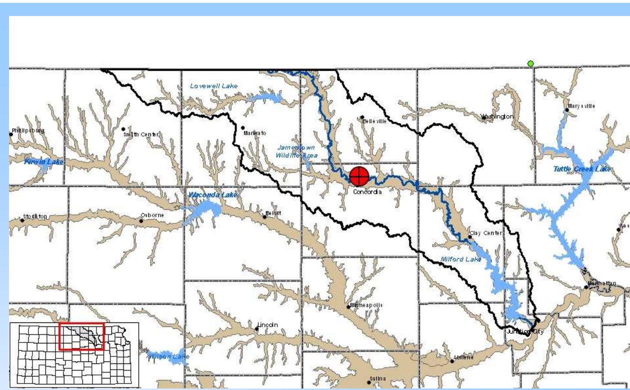

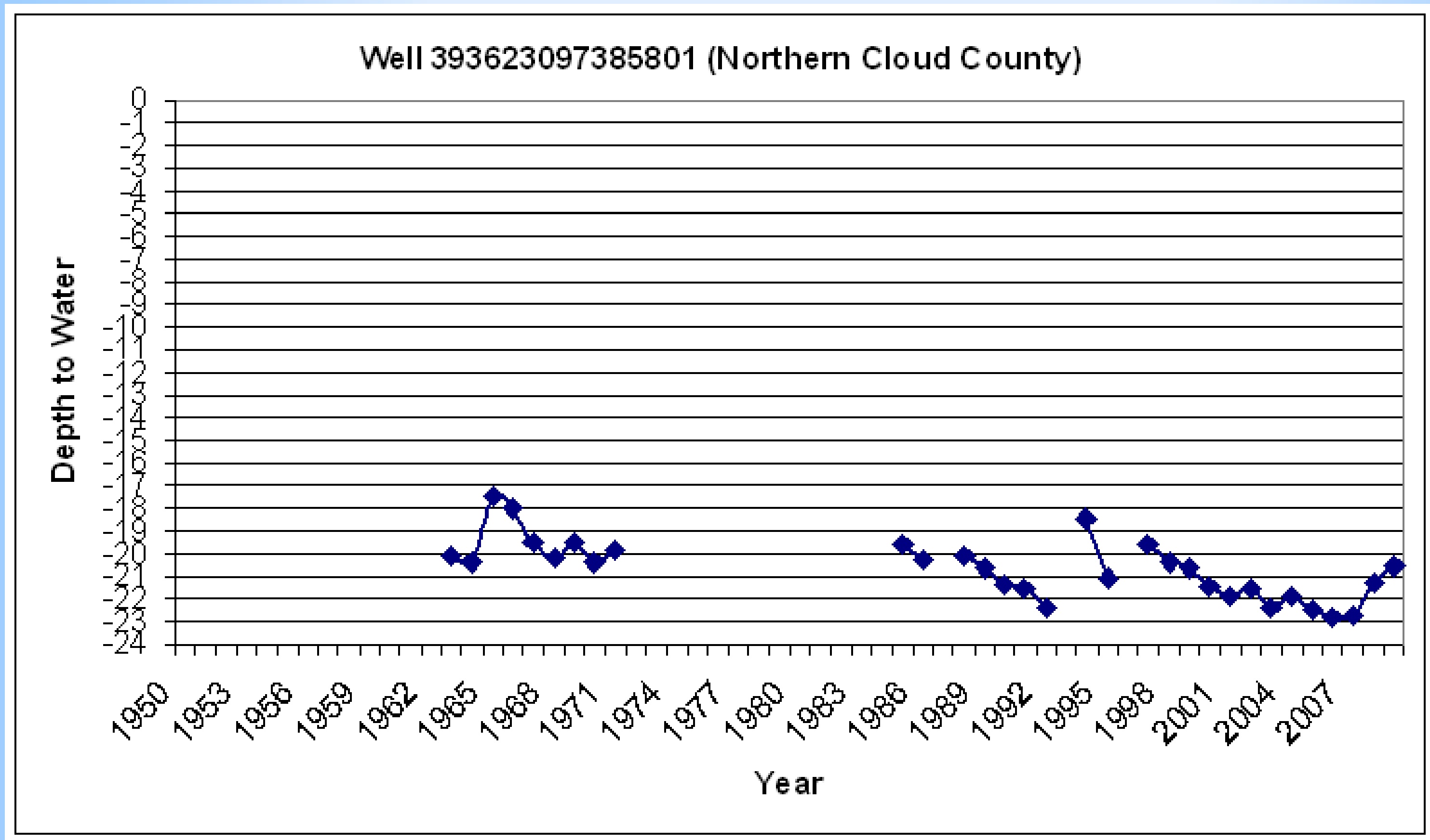

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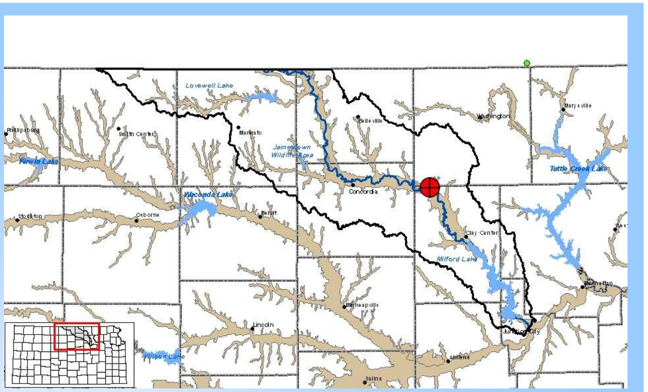

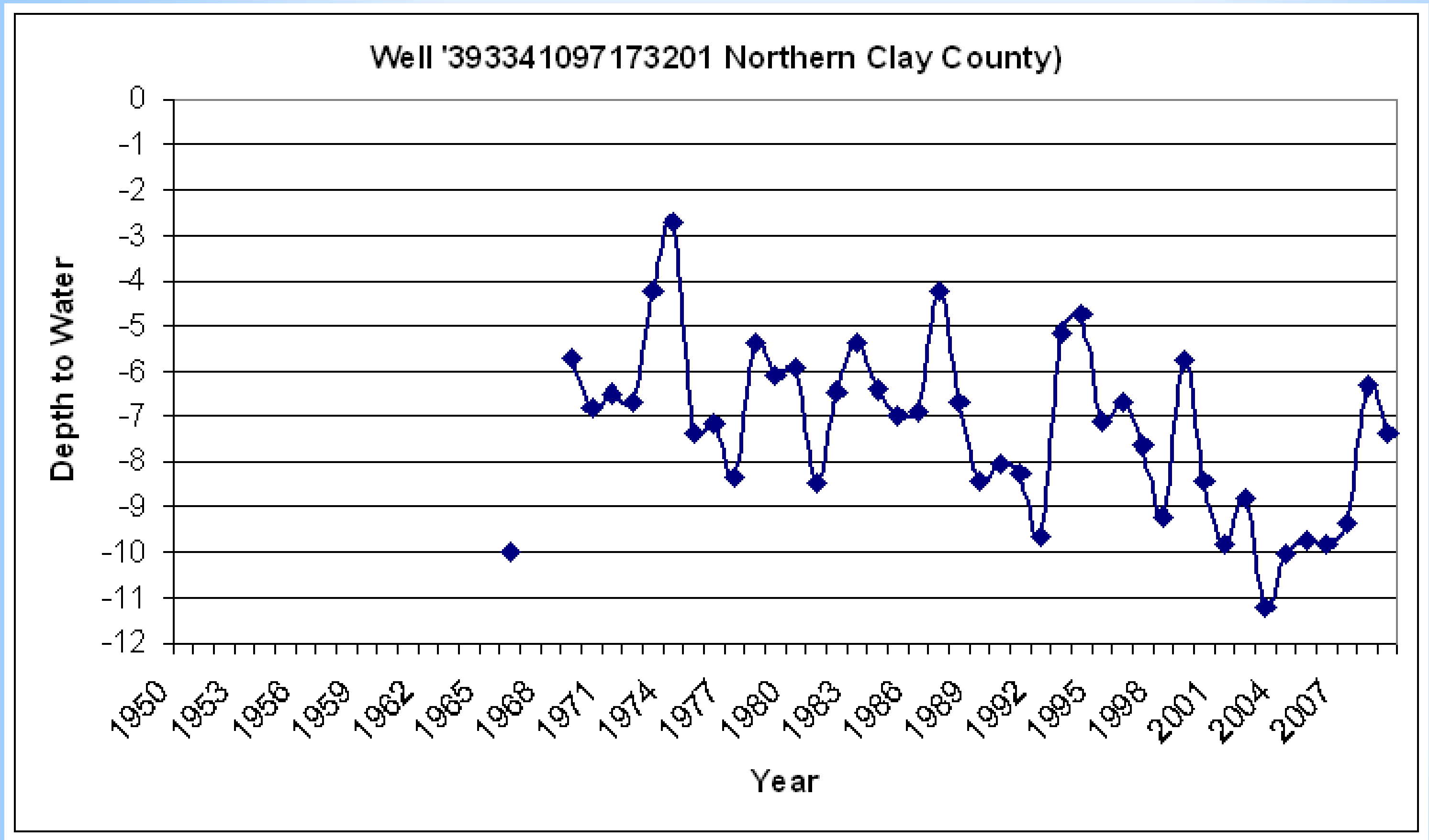

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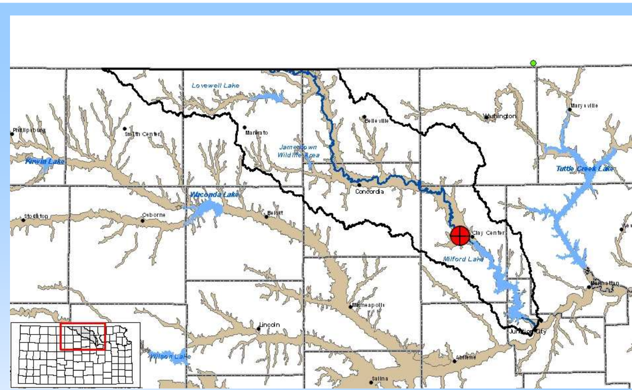
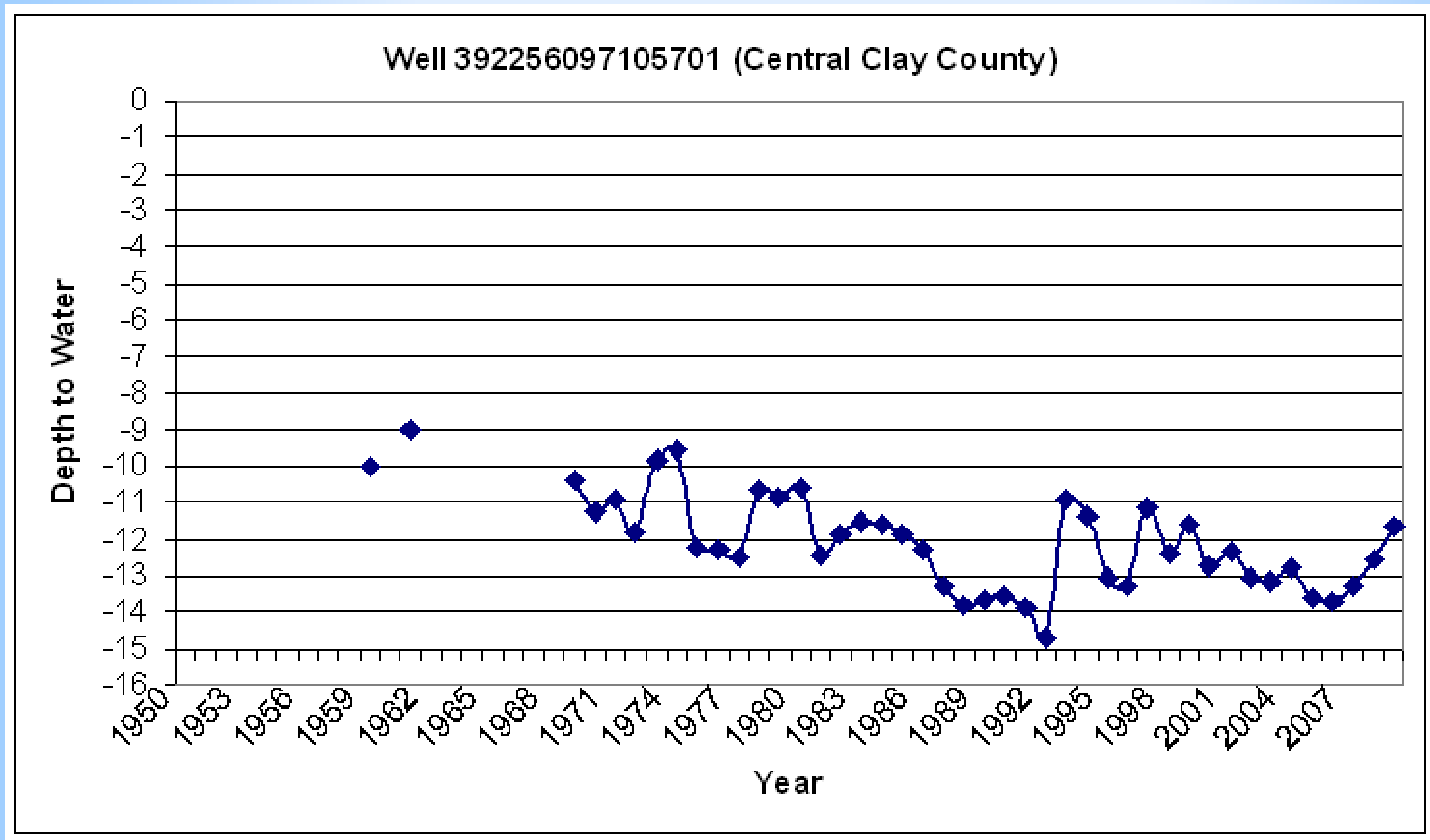
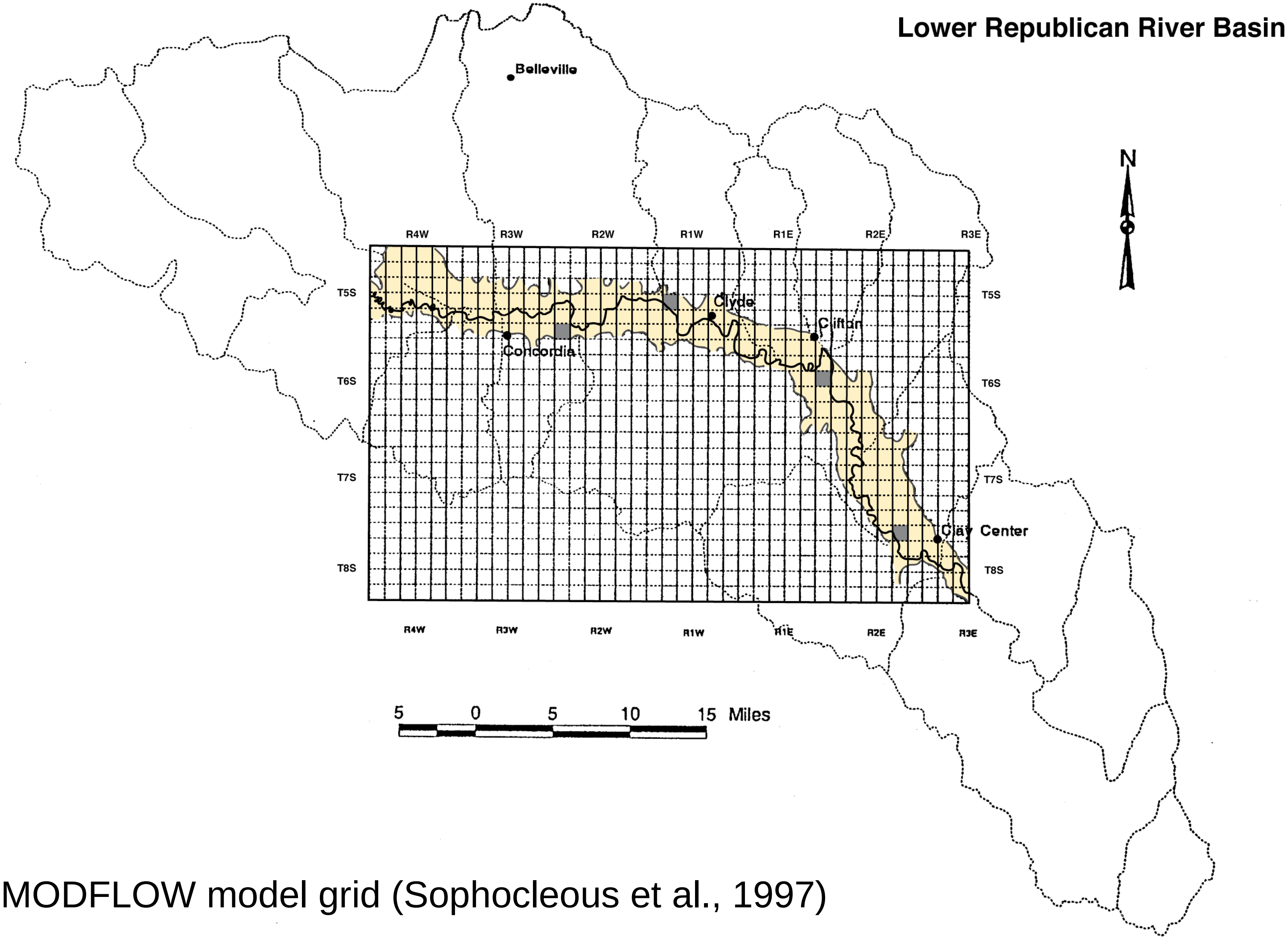


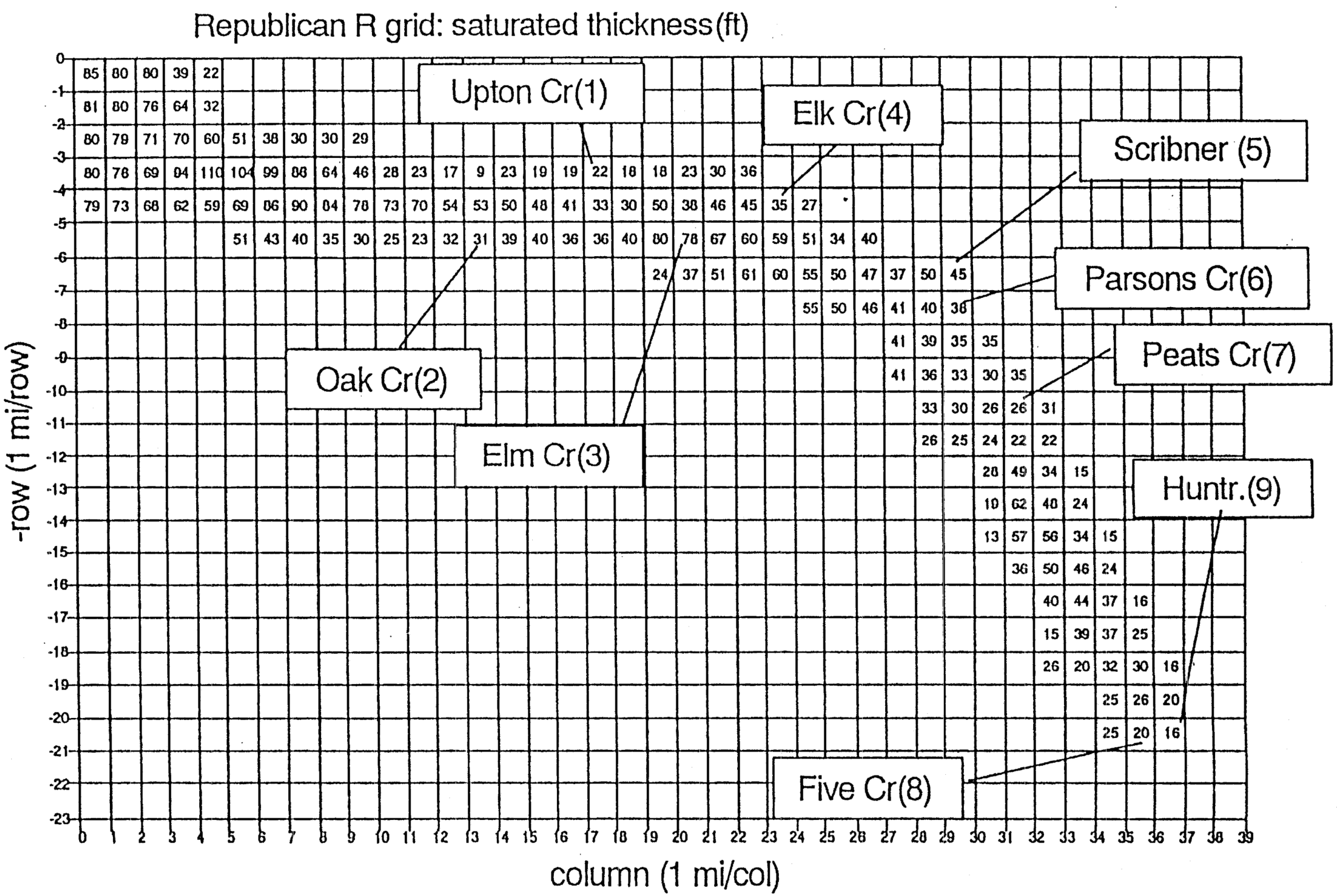


Aquifer saturated thickness

- The saturated thickness is higher in the valley W-NW of Concordia, with thicknesses of the order of 70-80 ft, and thins as one moves E-SE down to 15-30 ft near Clay Center

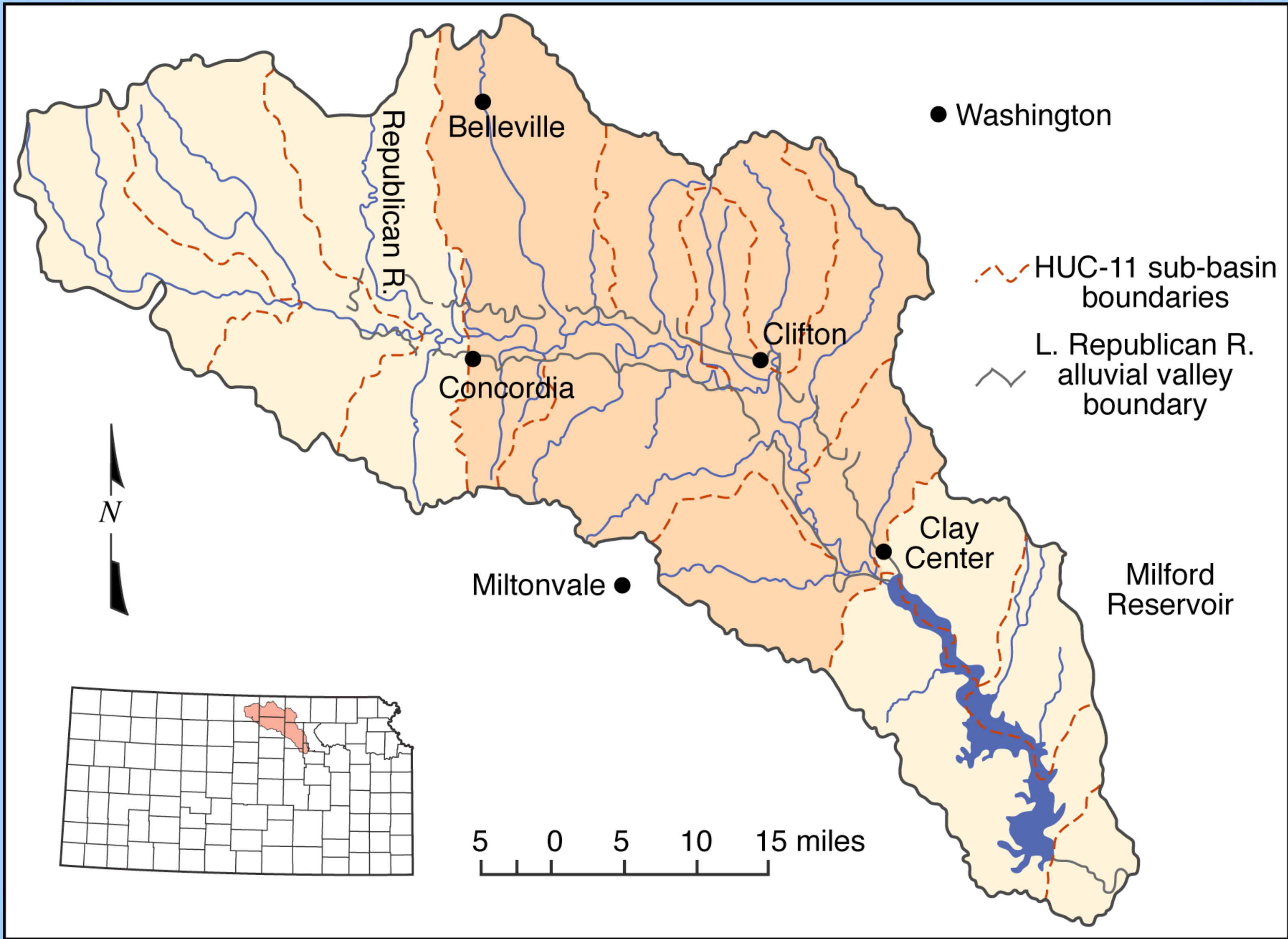


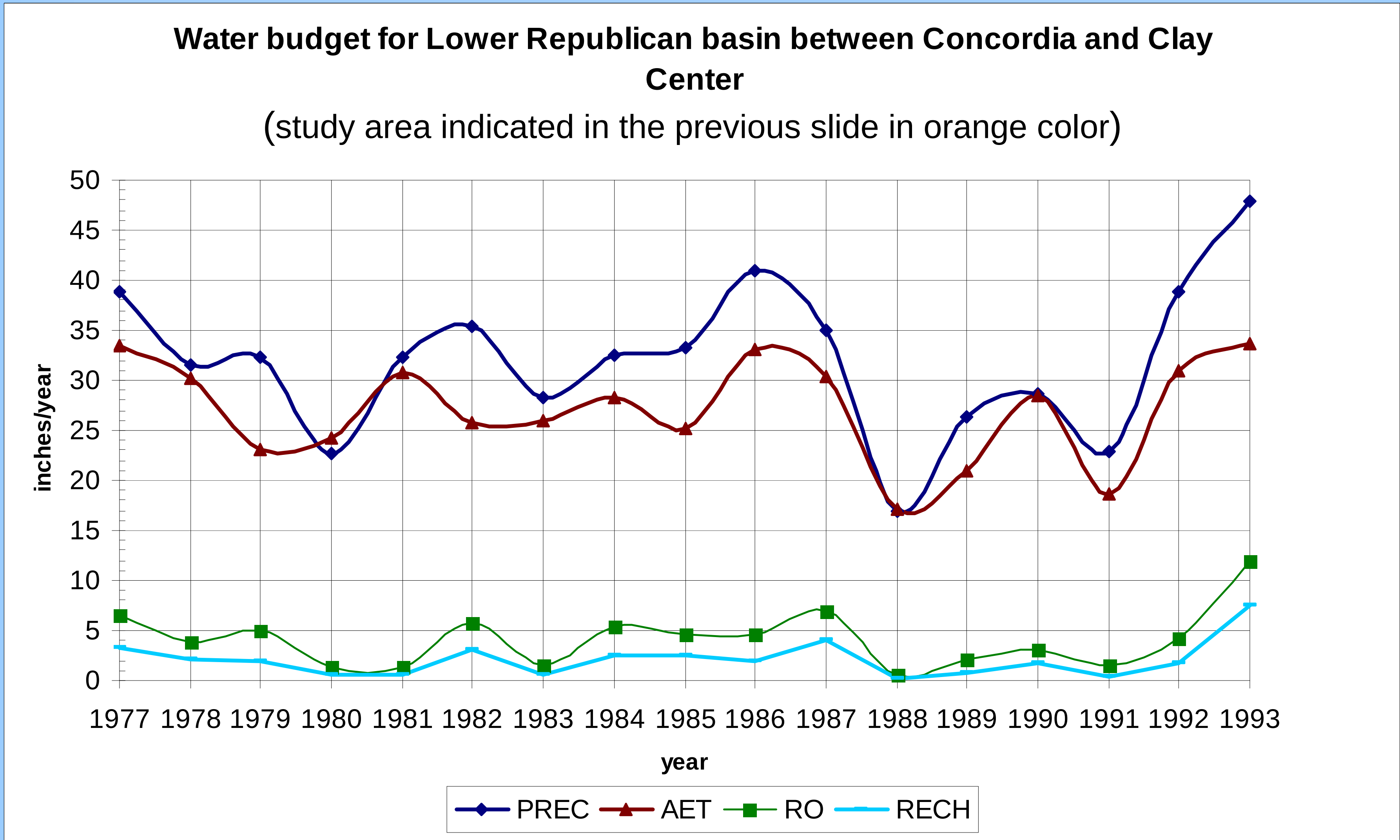
MODFLOW model grid (Sophocleous et al., 1997)



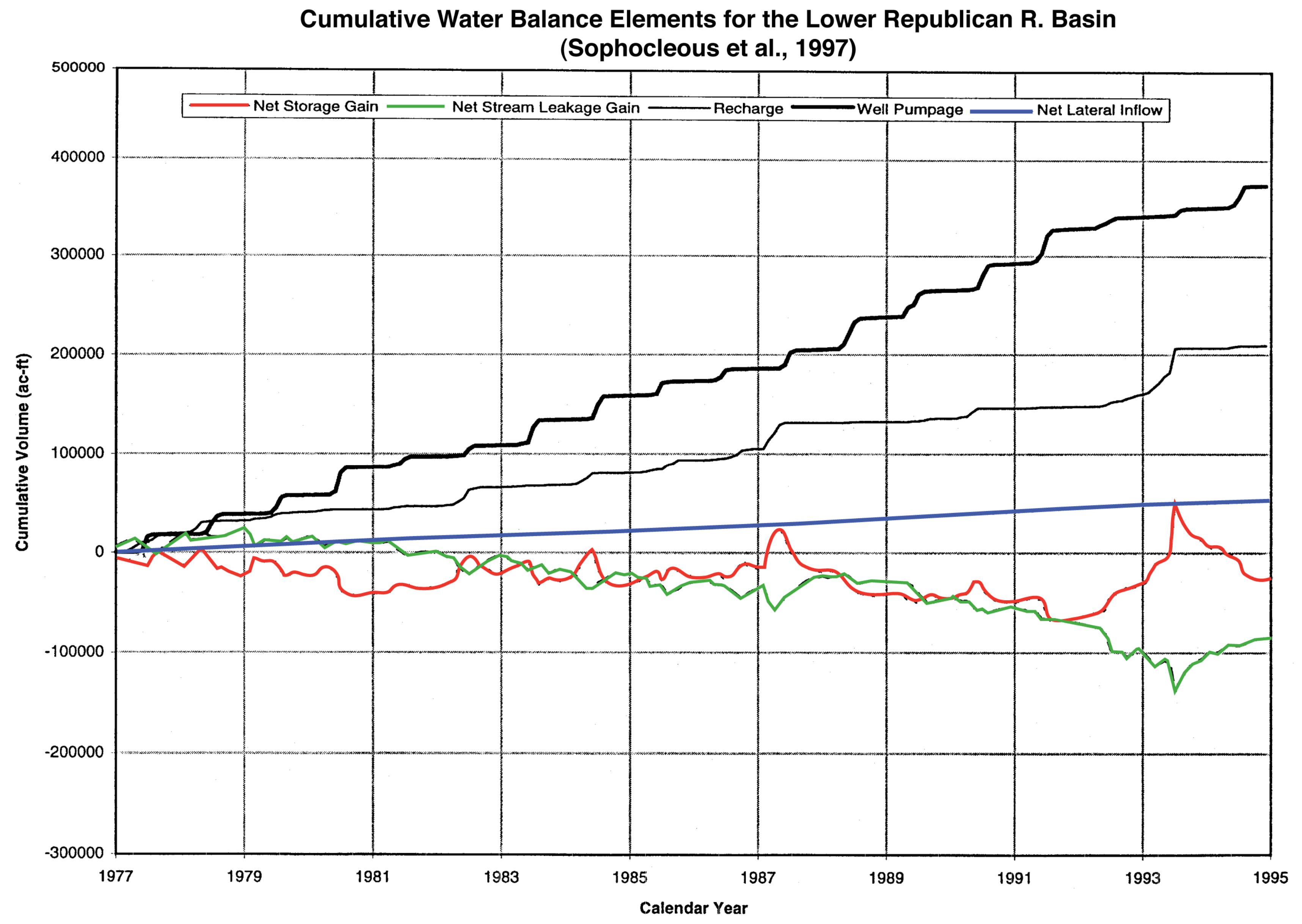
Republican R grid: saturated thickness(ft)
Upton Cr(1)
Oak Cr(2)
Elm Cr(3)
Elk Cr(4)
Scribner (5)
Parsons Cr(6)
Peats Cr(7)
Five Cr(8)
Huntr.(9)
85 80 80 39 22
81 80 76 64 32
80 79 71 70 60 51 38 30 30 29
80 78 69 94 110 104 99 88 64 46 28 23 17 9 23 19 19 22 18 18 23 30 36
79 73 68 62 59 69 86 90 84 78 73 70 54 53 50 48 41 33 30 50 38 46 45 35 27
51 43 40 35 30 25 23 32 31 39 40 36 36 40 80 78 67 60 59 51 34 40
24 37 51 61 60 55 50 47 37 50 45
55 50 46 41 40 38
41 39 35 35
41 36 33 30 35
33 30 26 26 31
26 25 24 22 22
28 49 34 15
10 62 40 24
13 57 56 34 15
36 50 46 24
40 44 37 16
15 39 37 25
26 20 32 30 16
25 26 20
25 20 16
-row (1 mi/row)
column (1 mi/col)

SWAT-MODFLOW Integrated Model Application Area (Sophocleous et al., 1997)





1977-93 AVG: PREC=32.04”; **RECH=2.06”;** AET=27.08”; RO=4.16”; POTET=54.2”



Net GW Storage Gain = GW Storage Accumulation − GW Storage Depletion

Net Stream-leakage Gain = Baseflow − Stream-leakage loss

ASR-related features of the Republican River valley aquifer

- Shallow depth to water table (DTW)
- Small saturated thickness/shallow bedrock
- Low water-table declines
- High hydraulic conductivity (*K*), thus relatively high GW velocities
- Conditions may be favorable for baseflow augmentation only as the shallow DTW and high *K* do not provide secure storage for ASR

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