Appendix A. Local Hydrology

Section Overview

The hydrologic cycle and interactions of groundwater and surface water comprise an important part of the hydrology of the Republican River Basin (Basin). Because water management is the primary focus of the Republican River Basin-Wide Plan (Plan), it is important to know the concepts of how water moves through the Basin. This section begins with a basic discussion of Basin hydrology and then discusses precipitation, supplies, and uses in greater detail.

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Basic Hydrological Principles of the Basin

Water moves between the sky, underground, and surface flows via a cycle known as the hydrologic (water) cycle (Figure A.1). A general understanding of basic water movement within the hydrologic cycle is needed to understand the Basin's hydrology.

Precipitation in the Basin can cycle in the following ways:

- Runoff into streams that feed into the Republican River
- Infiltration into the soil, eventually percolating into the aquifer
- Infiltration into the soil and returned as vapor through plant transpiration
- Evaporation from the soil
- Evaporation from open waterbodies
- Consumptively used and removed from the system (primarily via agricultural harvest)

Runoff into streams and rivers in the Basin directly supplies the Republican River. Runoff is the primary source of water for the Republican River, whereas other rivers can be primarily supplied by groundwater, snow melt, or springs. Different water sources lead to differing river characteristics. For example, the Republican River can display significant daily, seasonal, and annual variation because flows are significantly affected by recent rainfall.

Precipitation that infiltrates through the soil can reach the aquifer and be stored for long periods. This water, known as groundwater, is stored in interstitial spaces between sediment particles. Groundwater generally flows from areas of recharge (water moving into the aquifer) to areas of discharge (water moving out of the aquifer) via gravity. In locations where the water table (level of the "top" of the groundwater) is higher than stream elevation, water can flow from groundwater into surface water. Streams can lose surface water to groundwater recharge (losing stream) if the water table is lower than the stream elevation. If the water table is lower than the streambed (disconnected stream), declines in the water table no longer affect streamflow. This can occur naturally or because of aquifer overuse.

Precipitation that infiltrates the soil can be used by plants via root systems before the precipitation reaches the aquifer. Stomas on the outer layer of a plant must be open to photosynthesize. These pores lose water through a process known as transpiration.

Water can evaporate, and leave the system as vapor. Evaporation increases with temperature and wind speed, and with greater surface area.

Consumptive uses remove water from the local hydrologic system (Figure A.1). Consumptive use losses occur as evaporation from water bodies and land surfaces. In addition, evaporation and transpiration

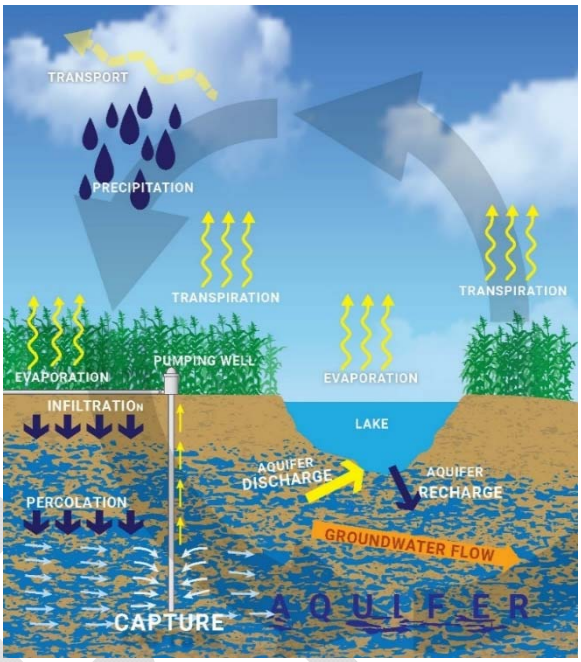

Figure A.1. A representation of the movement of water in a local hydrologic area. The movement of water (arrows) is driven by various above-ground and below-ground factors.

(evapotranspiration) by plants and the water contained in crops at the time they are removed from the field are considered other consumptive use losses.

Surface water in the Basin is hydrologically connected to the surrounding groundwater, but the interactions are difficult to observe and measure. To analyze the Basin hydrology, many variables need to be accounted for, including precipitation, soil type, land use, topography, water use, and geology. Computer models analyze and predict the influence of such variables.

Precipitation

Precipitation within the Basin is important to analyze because precipitation is a significant factor of groundwater replenishment and surface water flows. The majority of precipitation falls in the Basin during the months of May, June, and July. Precipitation can vary significantly among years (Figure A.2). The average annual precipitation varies across the Basin and increases from west to east. The lowest average annual precipitation, 19", occurs in Wauneta (west), and the greatest, 26", occurs in Superior (east) based on 1918 through 2016 records (Figures A.2 and A.3). Many factors influence recharge from precipitation including soil type, precipitation intensity, topography, and vegetative cover. Greater recharge occurs on coarse-textured soils compared with fine-textured soils given the same amount of precipitation, slope, and landuse.

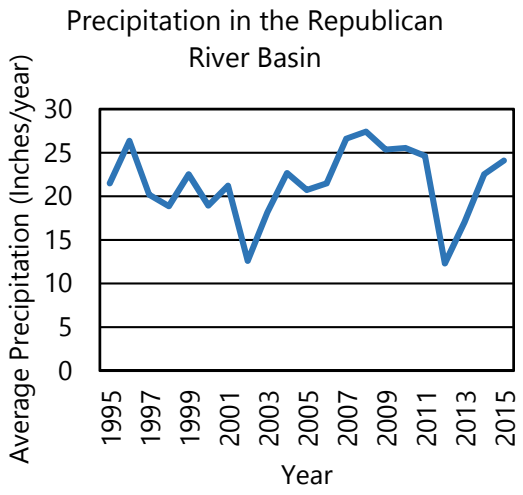

Figure A.2. Average annual precipitation for the Republican River Basin from weather stations used in the RRCA with a full 98 years of data (1918-2016). Precipitation varies significantly among years.

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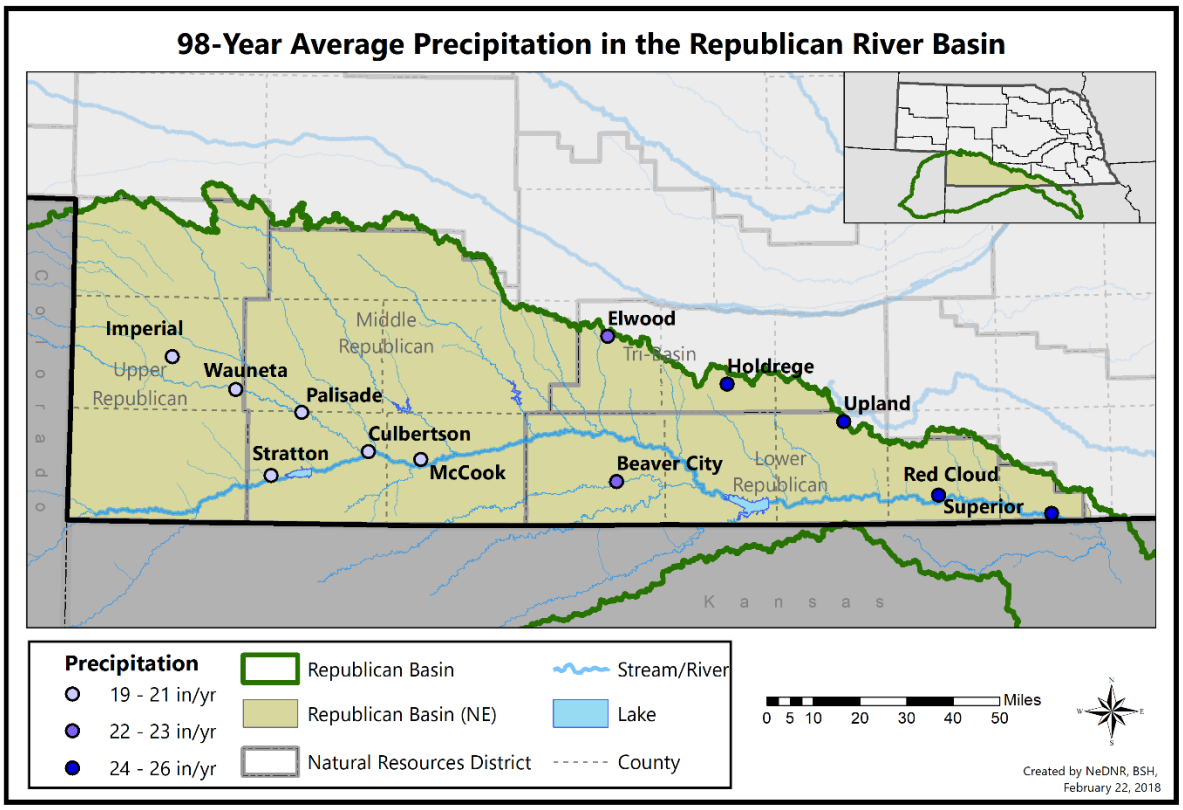

Figure A.3. Map of 98-year precipitation averages from weather stations in the Republican River Basin.

Surface Water Supplies

The mainstem of the Republican River forms at the junction of the North Fork of the Republican River and the Arikaree River near Haigler, Nebraska. The river flows in a generally eastern direction for approximately 445 miles before it joins the Smoky Hill River to form the Kansas River at Junction City, Kansas. The Basin encompasses approximately 24,900 square miles within its watershed, of which about 7,700 square miles are in Colorado, 7,500 square miles are in Kansas, and 9,700 square miles are in Nebraska (Figure A.4). Its gradient ranges from about four to ten feet per mile. The channel width varies considerably, gradually widening downstream. There are many stream and canal gages throughout the Basin (Table A.1 and Figure A.5).

Important tributaries to the Republican River include:

- Frenchman Creek (River),
- Driftwood Creek,
- Red Willow Creek,
- Medicine Creek.
- Rock Creek,
- Driftwood Creek,
- Sappa Creek,
- Beaver Creek, and
- Buffalo Creek.

Table A.1. Streamgages and measured canals within the Republican River Basin. Gages are monitored by either NeDNR (**bold)** or the US Geological Survey (USGS, *italics*)

Station Name - Owner	Station Number	Type
North Fork Republican River at CO-NE - USGS	06823000	Stream
Haigler Canal Spillback to Arikaree River - NeDNR	61500	Canal
Arikaree River at Haigler - USGS	06821500	Stream
Buffalo Creek near Haigler - USGS	06823500	Stream
Rock Creek at Parks - USGS	06824000	Stream
Republican River at Benkelman, NE - USGS	06824500	Stream
South Fork Republican River near Benkelman - USGS	06827500	Stream
Republican River at Stratton - USGS	06828500	Stream
Frenchman Creek near Imperial - NeDNR	6831500	Stream
Frenchman Creek near Enders - NeDNR	6832500	Stream
Frenchman Creek at Palisade - USGS	06834000	Stream
Stinking Water Creek near Palisade - NeDNR	6835000	Stream
Frenchman Creek at Culbertson - USGS	06835500	Stream
Driftwood Creek near McCook - USGS	06836500	Stream
Republican River at McCook - USGS	06837000	Stream
Red Willow Creek above Hugh Butler Lake - NeDNR	6837300	Stream
Red Willow Creek near Red Willow - USGS	06838000	Stream
Bartley Canal from Republican River - USGS	6000	Canal
Republican River at Hwy 47 Bridge, Cambridge, NE - NeDNR	6843400	Stream
Medicine Creek near Somerset - NeDNR	6838500	Stream

Station Name - Owner	Station Number	Type
Medicine Creek near Curtis - NeDNR	6839970	Stream
Fox Creek at Curtis - NeDNR	6840000	Stream
Medicine Creek above Harry Strunk Lake - NeDNR	6841000	Stream
Medicine Creek below Harry Strunk Lake - NeDNR	6842500	Stream
Republican River at Cambridge - USGS	06843500	Stream
Muddy Creek at Furnas-Gosper County Line - NeDNR	224600	Stream
Muddy Creek at Arapahoe - NeDNR	6844000	Stream
Turkey Creek at Furnas-Gosper Co. Line - NeDNR	231700	Stream
Turkey Creek at Edison - NeDNR	6844210	Stream
Republican River near Orleans - USGS	06844500	Stream
Beaver Creek near Beaver City - USGS	06847000	Stream
Prairie Dog Creek near Woodruff KS - USGS	06848500	Stream
Sappa Creek near Stamford - USGS	06847500	Stream
Turkey Creek at Naponee - NeDNR	6850000	Stream
Center Creek at Franklin - NeDNR	6851000	Stream
Republican River at Riverton - NeDNR	6851090	Stream
Thompson Creek at Riverton - NeDNR	6851500	Stream
Elm Creek at Amboy - NeDNR	6852000	Stream
Republican River at Guide Rock NE - USGS	06853020	Stream
Courtland Canal at Nebraska-Kansas Stateline - USGS	06852500	Canal
Republican River- Hardy NE - USGS	06853500	Stream

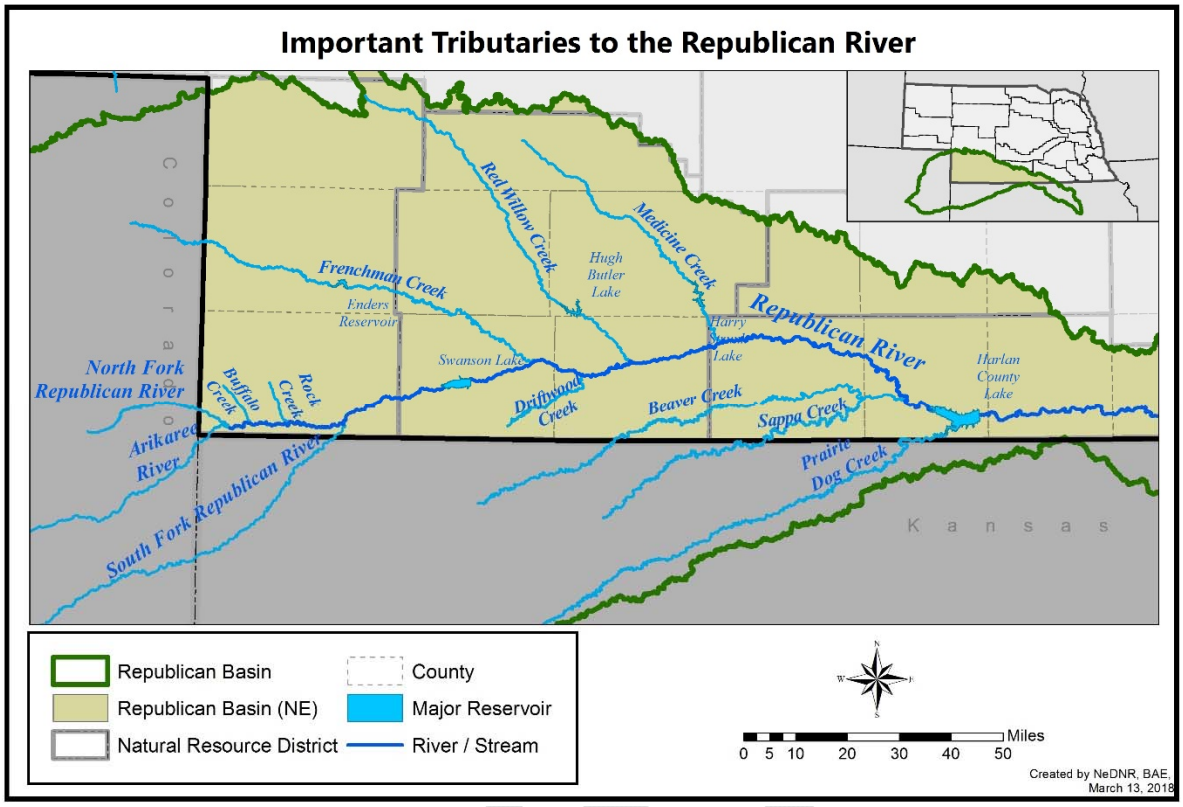

Figure A.4. Important tributaries and reservoirs to the Republican River.

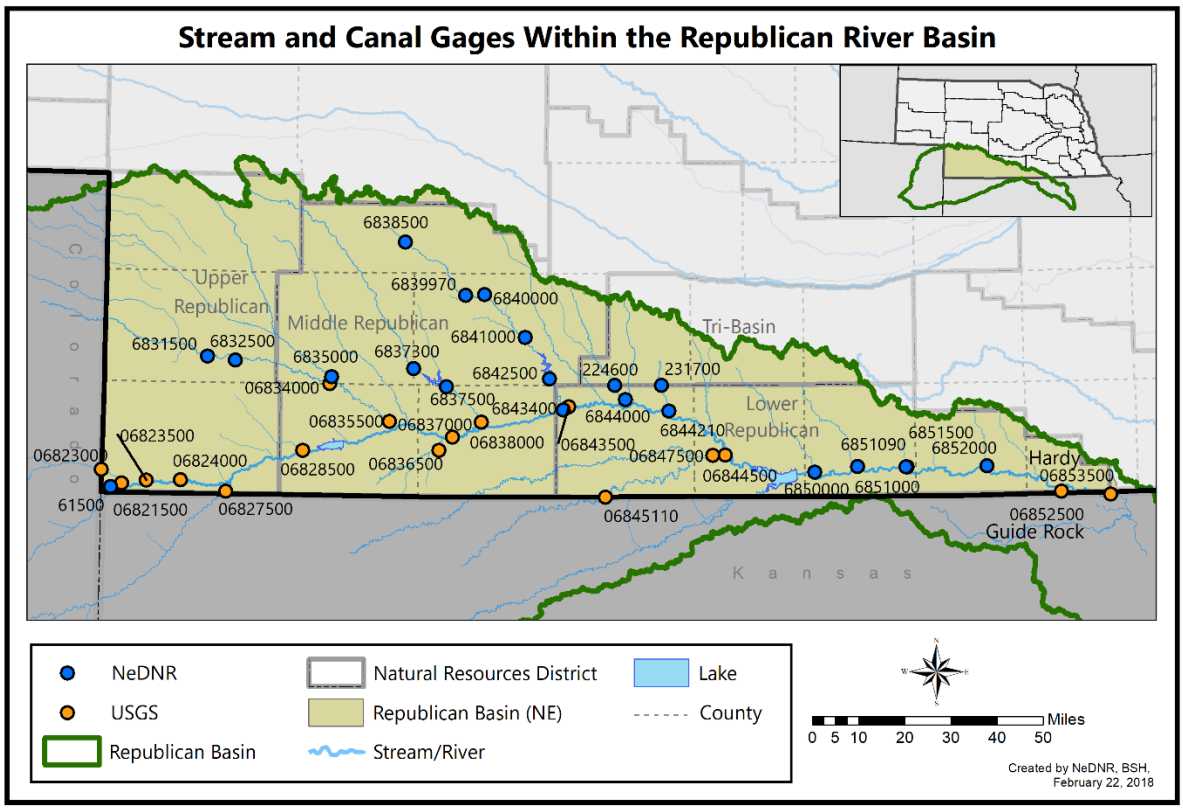

Figure A.5. Stream and canal gages within the Republican River Basin that collect data on surface water flows throughout the Basin.

Groundwater Supplies

Eighty-seven percent of the Basin overlies the High Plains aquifer (Figure A.6). The Ogallala geologic formation underlies all but the extreme southeastern edge of the Basin in Kansas. Water thickness in the Basin's portion of the aquifer ranges in thickness from a matter of inches to more than 400 feet.

The Ogallala Formation consists of beds of silt, sand, gravel, caliche, and clay, with considerable variability in the character of the formation within short vertical or horizontal distances. These variations are consistent with the fluvial environment in which the Ogallala was deposited. This environment was characterized by a series of braided streams carrying sediment eastward. Some of the sand and gravel deposits are weakly cemented into rocks by calcium carbonate, ranging from friable sandstone to relatively hard, ledge-forming mortar beds.

The High Plains Aquifer consists of the saturated parts of the Quaternary deposits and the underlying Ogallala Formation. Depth to groundwater in the Republican Valley ranges from about two feet near the river to about 40 feet adjacent to the bluffs along the edge of the valley. In the

Frenchman River valley, the depth to water ranges from less than 10 feet to about 60 feet. The aquifer has defined bottom and lateral limits, but usually has no confining upper boundary. This is known as an unconfined aquifer. Consequently, any change in the volume of the stored water coresponds to a change in the elevation of the water table.

Changes in the aquifer's water level result from an imbalance between discharge and recharge. Water-level declines can affect groundwater availability, surface water flow, and near-stream (riparian) habitat areas[i]. Seasonal water level fluctuations are due to variations in the amount and distribution of precipitation, temperature changes, and other factors that affect the amounts of ground-water recharge and discharge.

Discharge from the High Plains aquifer in the Basin primarily consists of groundwater withdrawals for irrigation but also includes groundwater withdrawals for public water supply and other uses; evapotranspiration where the water table is near land surface; and seepage to streams, springs, and other surface-water bodies where the watertable intersects the land surface[ii].

In general, the direction of groundwater flow in the Basin is west to east except in the vicinity of the Republican River and in the north-central portion of the Basin. Average groundwater flow velocities range from less than 50 to more than 200 feet per year.

In the extreme north-central portion of the Basin in Nebraska, there is a small amount of groundwater flow from the Republican River Basin north toward the Platte River Basin. In the northeast portion of the Republican River Basin, groundwater migrates south from the Platte River Basin via canal seepage in an area referred to as the "mound area" because of artificially higher water elevations (Figure A.7).

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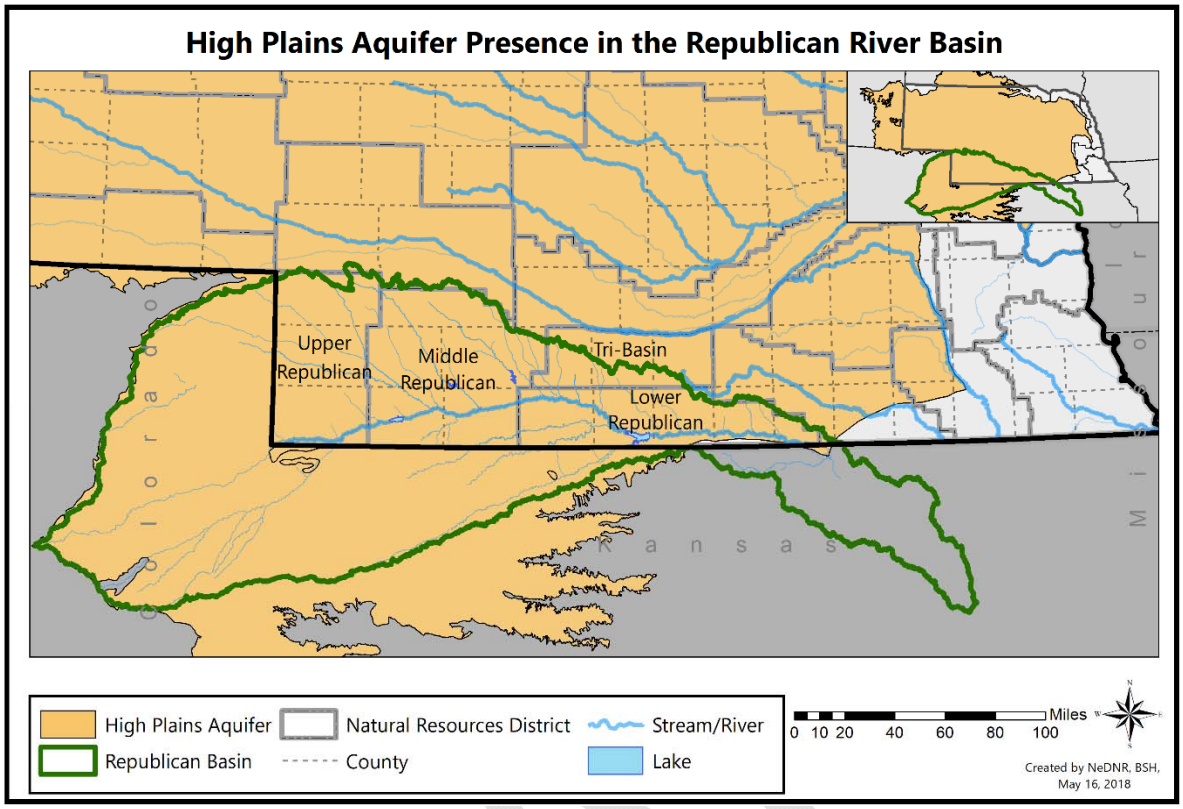

Figure A.6. Map of the High Plains Aquifer in the vicinity of the Republican River Basin. The majority of the Basin within Nebraska overlies the High Plains Aquifer. Other, local aquifers exist throughout Nebraska and the Republican River Basin.

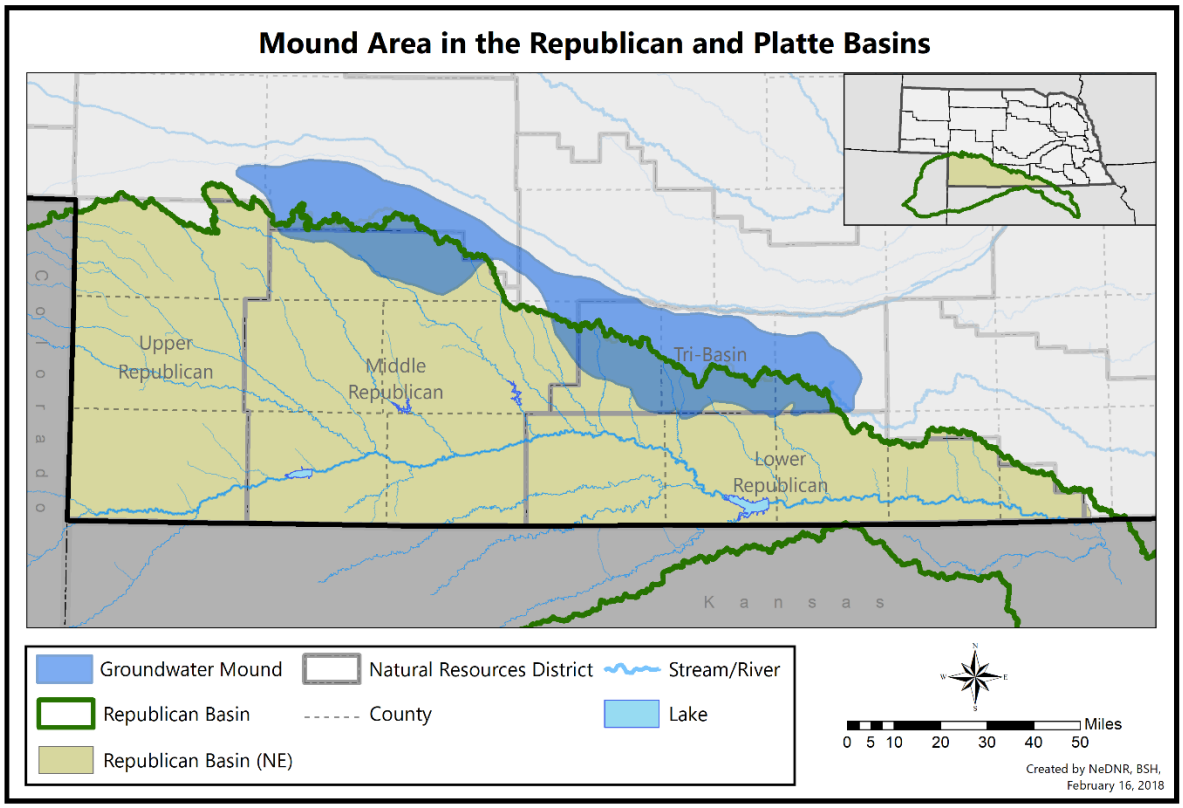

Figure A.7. Groundwater accretions, known as the Mound, originate from CNPPID and NPPD canals and cover much of the Middle Republican and Tri-Basin NRDs. In addition to providing groundwater for irrigation, accretions flow into the Republican and Platte Rivers.

Human Activities Relating to Basin Hydrology

The variability in precipitation within the Basin has long been a barrier to living and farming within the Basin. A disastrous flood in the Basin in 1935 took the lives of 110 persons, damaged 274,615 acres of cropland, and killed over 20,500 livestock[iii]. A devastating drought in the late 1930's caused economic hardship for the region. Two large flood events in June of 1947 and 1948, one of which crested at 27 feet above normal at the Medicine Creek dam site, caused significant damage (Figure A.8).

Figure A.8. June 24, 1947, flood of the Republican River on the border of Jewell County, KS, and Republic County, KS, near Hardy, Nebraska and Webber, Kansas, just south of Nebraska NE-8 on Kansas 1 Rd/CR-1 bridge over the Republican River. The normal flood state for the river is at the tree line in the foreground. By J.G. Connor (submitted to USGS by Steve Blanchard, OSW). USGS surface water photo gallery item 18, 09, Public Domain.

Following the drought of the 1930's and floods of the 1930's and 1940's, the Bureau of Reclamation and U.S. Army Corps of Engineers began constructing a series of dams and surface water irrigation networks intended to reduce flooding and to provide water for agriculture. The large Federal surface water irrigation projects came into use in the 1950's and 1960's.

By 1957, the Nebraska part of the projects was essentially complete, and the structures in Kansas were nearing completion.

The primary use of water in the Basin is for irrigation of agricultural crops. The primary crops grown are corn and soybeans, along with wheat and other small grains. Alfalfa and potatoes are also grown in the Basin. Most irrigable lands in the Basin are scattered on ridgetops throughout the Basin, along the Republican River valley, or on tablelands in Kearney, Phelps, Perkins and Chase Counties. There are several active irrigation districts in the Basin. The two largest are Frenchman-Cambridge Irrigation District, with 45,669 irrigated acres, and the Nebraska Bostwick Irrigation District, with 22,446 irrigated acres. Including the irrigation districts, there are approximately 112,000 acres that may be irrigated with surface water in the Basin. Groundwater use is extensive, and groundwater pumping in the Basin removes water that might otherwise have flowed into the Republican River or its tributaries. The effect of the depletions is muted with distance (Figure A.9.).

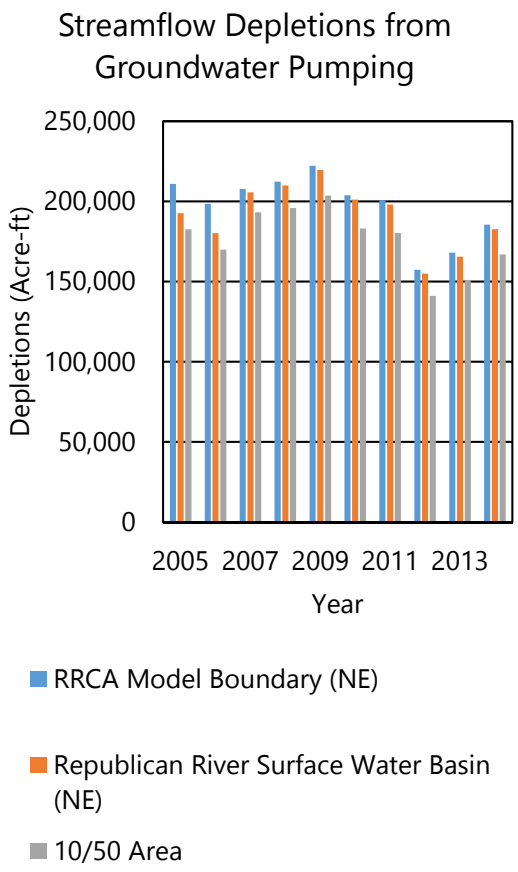

Figure A.9. Modeled depletions from groundwater pumping within three different boundaries of the Basin: the RRCA model boundary, the surface water basin, and the 10/50 area.

Surface Water

Surface water is stored, and may be released for irrigation projects, in seven federal reservoirs that are within the Basin upstream of where the Republican River crosses into Kansas. Within the State of Nebraska, the five Federal reservoirs (Swanson, Enders, Hugh Butler, Harry Strunk, and Harlan County Lake) are managed by the US Bureau of Reclamation, and hold water rights that are administered by the NeDNR (Figure A.4). The reservoirs, in addition to providing flood control, provide storage water to multiple irrigation districts including Frenchman-Valley, Hitchcock & Red Willow (H&RW), Frenchman Cambridge, and Nebraska Bostwick

The reservoirs and associated tributary streams across which they are constructed are as follows, listed in downstream order:

1. Bonny Reservoir, South Fork of the Republican River, Colorado (In 2011, Colorado modified the dam so that it no longer stores water)
2. Swanson Lake, Mainstem of the Republican River, Nebraska
3. Enders Reservoir, Frenchman Creek, Nebraska
4. Hugh Butler Lake, Red Willow Creek, Nebraska
5. Harry Strunk Lake, Medicine Creek, Nebraska
6. Keith Sebelius Lake, Prairie Dog Creek, Kansas
7. Harlan County Lake, Mainstem of the Republican River, Nebraska
8. Lovewell Reservoir, Norway Creek, Kansas
9. Milford Lake, Mainstem of the Republican River, Kansas

Surface water irrigation projects (Figure A.10) that use both flowing surface water and water stored within the US Bureau of Reclamation's reservoirs are summarized in Table A.2. Other surface water permits not held by an irrigation district are summarized in Table A.3.

Table A.2. Number of acres irrigated by irrigation districts within the Republican River Basin.

Surface Water Acres in the Republican River Basin	
Irrigation Districts	**Acres Permitted for Irrigation**
Frenchman Cambridge	45,669
Bostwick	22,446
H & RW	11,915
Frenchman Valley	9,323
Pioneer	1,900
Riverside	672
Total	**91,925**

Table A.3. Number of privately held appropriations and associated acres, by use, within the Republican River Basin.

Surface Water Permits Not Held by an Irrigation District		
Use	**Number of Permits**	**Acres Permitted for Irrigation**
Irrigation	429	111,000
Power	1	-
Irrigation from Reservoir Only	12	700
Storage	115	-
Total	**557**	**111,700**

Surface water use grew at a steady pace until about 1956, when, at its peak, over 370,000 acre-feet (af) per year of surface water was applied for irrigation. Surface water acres fell from this peak and remained stable until the early 2000's when they began to drop again.

There are three surface water augmentation projects in the Basin: Nebraska Cooperative Republican Platte Enhance (N-CORPE), Rock Creek augmentation project, and the Turkey Creek augmentation project (Figure A.11). These projects were created in response to inconsistent surface water supplies in the Republican River in recent dry years, and help Nebraska meet its requirements under the Republican River Compact. N-CORPE was created from a purchase by four NRDs of 19,500 acres (15,800 previously irrigated) along the Republican/Platte watershed divide in 2012. Rock Creek augmentation project is operated by the Upper Republican NRD (URNRD) and augments surface flows to the Republican River to offset URNRD's depletions. The Rock Creek augmentation project was completed in early 2013. The Turkey Creek augmentation project was completed in early 2016 by Tri-Basin NRD (TBNRD). The Turkey Creek augmentation project is a tool to limit net depletions to streamflow in TBNRD's IMP for the Republican River Basin. It has not yet been pumped for surface water augmentation.

Groundwater

Groundwater is the primary source of irrigation in the Nebraska portion of the Basin (Figure A.12.). Groundwater irrigation via wells in the Basin increased significantly from just over 300 wells in 1950 to over 12,500 wells in 2014 (Figure A.13.). Most growth occurred between 1970 and 2000, when the numbers of registered wells

increased 343% from about 3,600 to over 12,500. In conjunction with the increase in registered wells, groundwater and commingled pumping increased from 2,056 af in 1950 to 415,944 af in 2014, with a peak of 913,270 af in 2002 within the RRCA groundwater model area. Groundwater levels in the Basin have responded to pumping with significant variation. Water-level changes from 2002 to 2015 in the High Plains aquifer within the Basin, by well, ranged from a rise of 9.4 feet to a decline of 43.2 feet. The area-weighted, average water-level change from 2002 to 2015 in the Basin was a decline of 4.5 feet.

The natural resources districts in the Basin collect local data on acres irrigated by groundwater and set allocation limits on groundwater pumping.

Table A.4, below, summarizes acres by NRD.

Table A.4. Acres certified for irrigation, by NRD, in the Republican River Basin *[the values shown in the table are currently placeholders using 2015 actual irrigated acres. These placeholder numbers will be replaced with Certified Acres for 2017, instead, once those values are available, before the Plan is finalized]*.

.	**Acres Certified for Irrigation in the Republican River Basin, by NRD, in 2017**		
NRD	**Acres Certified for Groundwater Irrigation (af)**	**Acres Certified for Commingled Irrigation (af)**	**Acres Certified for Surface Water Irrigation (af)**
Upper Republican	*[431,988]*	*[731]*	*[3,685]*
Middle Republican	*[261,013]*	*[24,115]*	*[23,226]*
Lower Republican	*[282,440]*	*[23,105]*	*[33,312]*
Tri-Basin	*[181,607]*	*[659]*	*[2,429]*

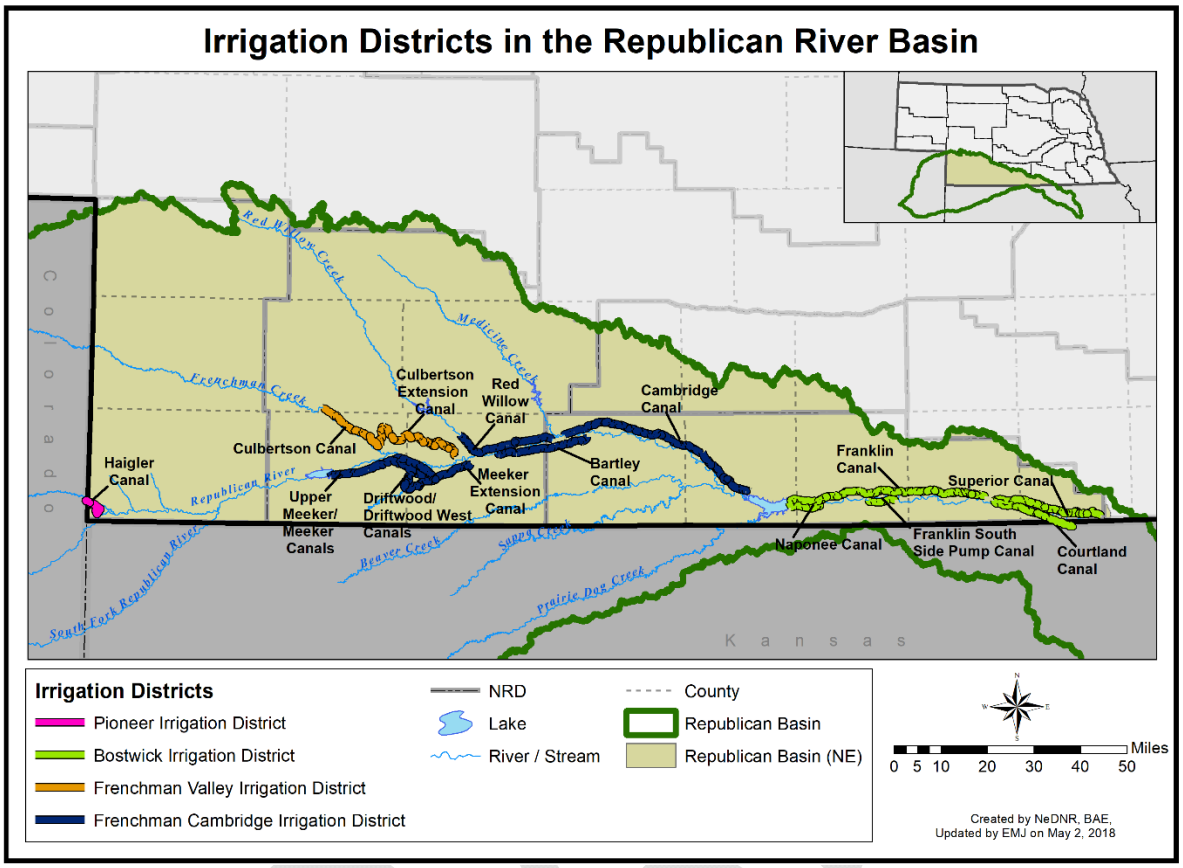

Figure A.10. Canals within the Nebraska portion of the Republican River Basin.

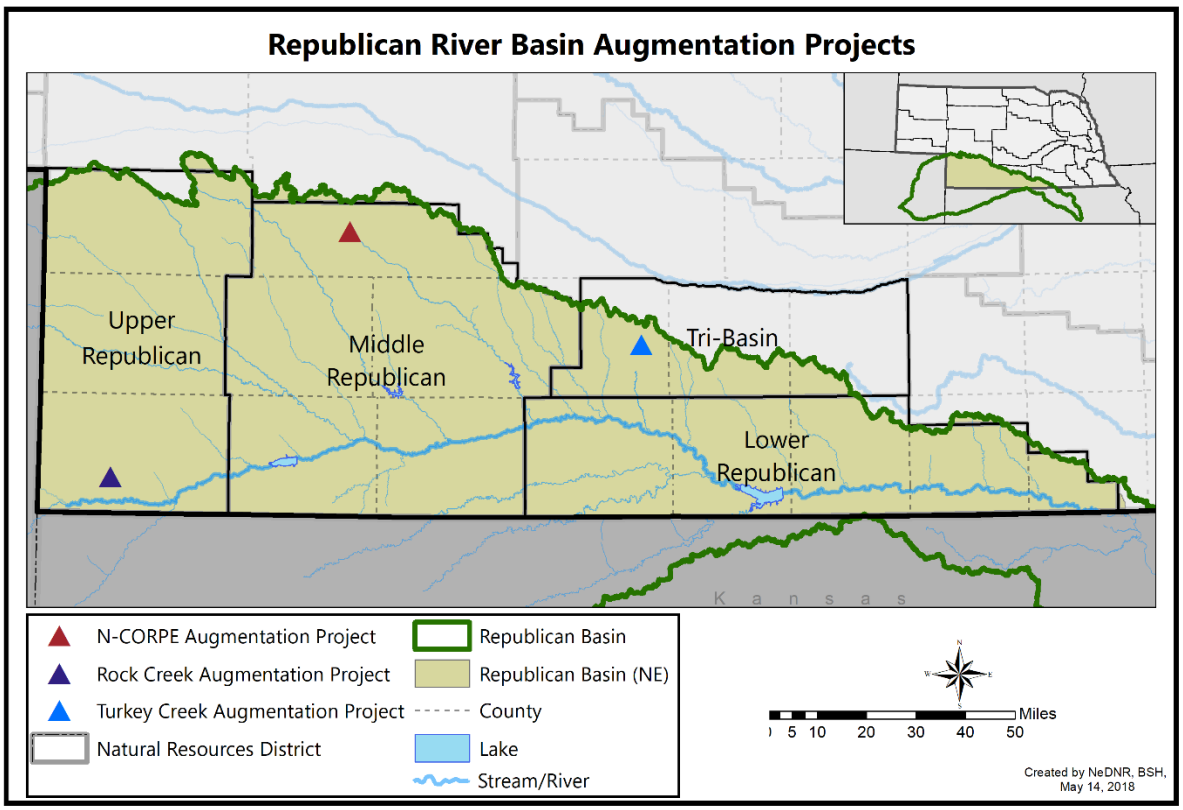

Figure A.11. Augmentation Projects within the Nebraska portion of the Republican River Basin.

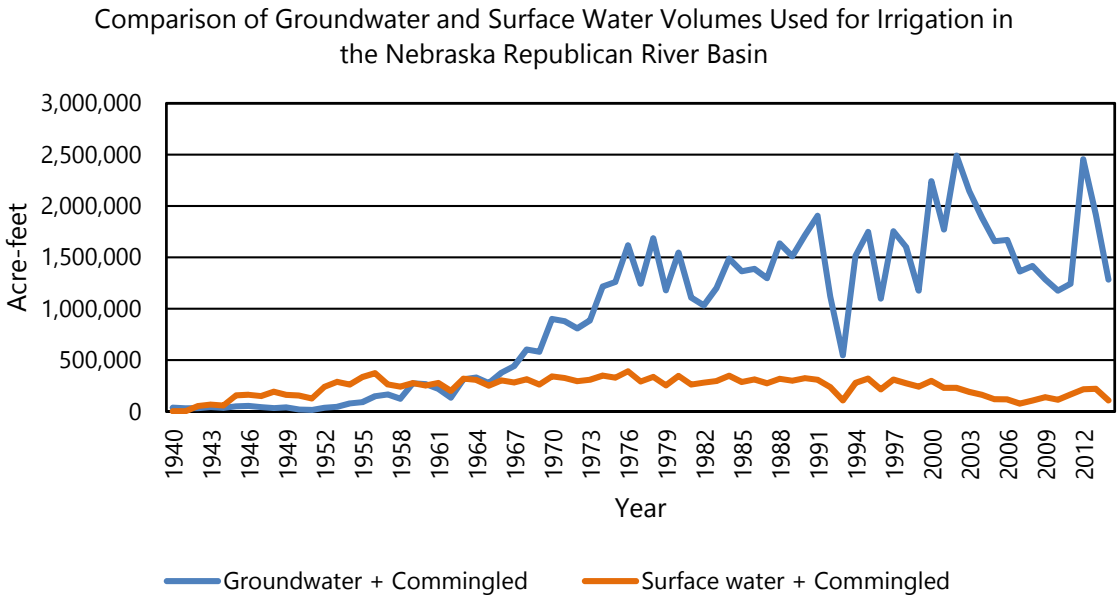

Figure A.12. Comparison of groundwater and surface water irrigation through time in the Republican River Basin. Since the early 1960's, groundwater has been the primary water source for irrigation in the Republican River Basin. Data for this figure was provided by the Flatwater Group and encompasses the Republican River Compact Administration groundwater model area for Nebraska.

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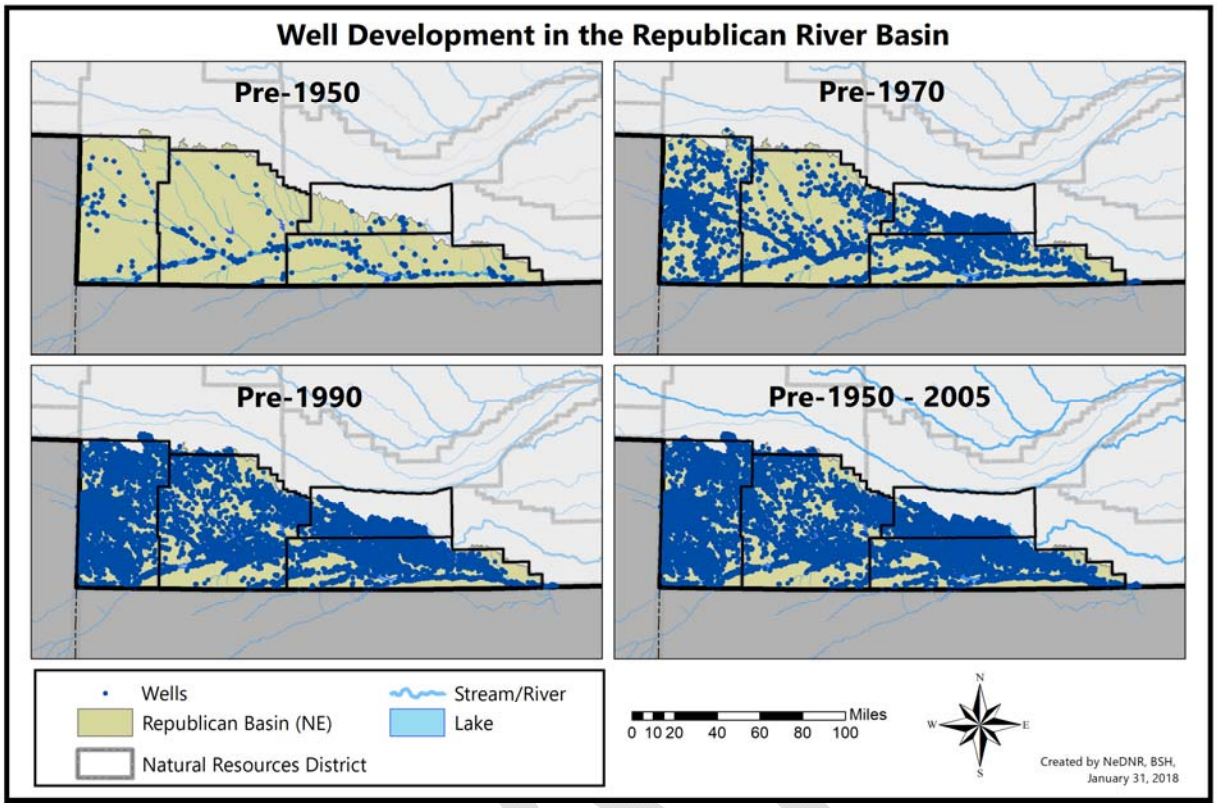

Figure A.13. Well development in the Republican Basin. Wells developed rapidly from 1950- 2005, from just over 300 wells in 1950 to over 12,500 wells in 2005.

References Cited

[i] Alley, W.M., Reilly, T.E., and Franke, O.L. 1999. Sustainability of ground-water resources: U.S. Geological Survey Circular 1186, 79 p. [Also available at http://pubs.usgs.gov/circ/circ1186/].

[ii] Maupin, M.A., and Barber, N.L., 2005, Estimated withdrawals from principal aquifers in the United States, 2000: U.S. Geological Survey Circular 1279, 46 p. [Also available at http://pubs.usgs.gov/circ/2005/1279/.

[iii] http://www.weather.gov/gld/1935flood-aftermath. U.S. National Oceanic and Atmospheric Administration.