THE HISTORICAL QUIVIRA ECOSYSTEM

GEOLOGY AND GEOMORPHOLOGY

Quivira NWR is within the Great Bend Sand Prairie physiographic province, and Rattlesnake Creek Basin, of south-central Kansas. Structurally, the region lies on the southwestern flank of the Central Kansas uplift (Barton arch) and the northern one-half of the Pratt anticline (Merriam 1963). Basement rocks are Permian and early Cretaceous in age. Permian rocks, consisting of the Ninnescah Shale, Stone Corral Formation, Harper Sandstone, Salt Plain Formation, Cedar Hills Sandstone, and undifferentiated strata in the Great Bend region are often referred to as "red beds" because they contain red to brown shale, siltstone, and sandstone with minor beds of limestone, dolomite, and anhydrite (Arbogast 1998). Overlying the Permian and Cretaceous bedrock are varying thicknesses of unconsolidated Tertiary and Quaternary deposits of silt and fine sand with interbedded caliche that were derived from the Rocky Mountains (Fader and Stullken 1978). Permian bedrock subcrops along an approximately north-south trend near U.S. Highway 281.

The surficial geology of the Quivira region is dominated by unconsolidated Quaternary deposits of eolian and alluvial origin (Arbogast 1998). Quaternary sediments of the region have a maximum thickness of about 360 feet. The kinds of material (e.g., quartz, feldspar, granite) found in these deposits suggests a Rocky Mountain origin with the ancestral Arkansas River serving as the primary source. The bend of the Arkansas River has apparently migrated laterally from the south to its current position via successive captures by its northern tributaries, leaving a thick deposit of sand, silt, and clay behind (Fent 1950). Most of the surficial geology of Quivira NWR is Post-Kansas Quaternary (Qal3) alluvial deposits from the more recent Rattlesnake Creek floodplain with smaller areas on the edge of the alluvial plain being comprised of Quaternary Dune eolian sand dunes hills (Qds on Fig. 3). The Great Bend Sand Prairie province is covered with a veneer of loess deposits and sand dunes that overlie the Pleistocene alluvium. The stratigraphy of the Quaternary alluvium at Quivira NWR in descending order is: 1) sand dunes, 2) relatively continuous near-surface silt-clay bed from a loess deposit, 3) alternating sequences of sandy silt-clay and sand and gravel lenses, 4) basal sand and gravel beds of fluvial origin, and 5) bedrock (Figs. 4,5 and http://www.ksda.gov/subbasin/content/201).

Pleistocene alluvium at Quivira NWR was deposited by the ancestral Arkansas River and a small number of local streams and is composed of undifferentiated early Pleistocene sediments (the Meade Formation, which consists of interbedded lenses of unconsolidated gravel, sand, and silt; caliche is common throughout the formation) and other late Pleistocene period sediments (the Sanborn Formation, which consists of silt, sandy silt, and fine sand that locally contains lenses of coarse sand and gravel) (Arbogast 1998). The alluvium in the Rattlesnake Creek Valley is relatively thin, probably < 20 feet deep everywhere. It is composed mainly of poorly sorted sand and gravel derived from the Meade Formation. The relatively flat depression areas of the Big and Little Salt Marshes are underlain by unconsolidated materials consisting of clay, silt, sand, and fine to medium gravel derived mostly from nearby sand dune sands with minor contribution from the Meade Formation and Kiowa Shale (Fig. 5). The thickness of these salt marsh depression deposits is < 15 deep; the upper 1-2 feet consist of fossiliferous sand, silt and clay. A ridge of beach sand derived from a large Wisconsin-age lake is up to 15 feet deep and occurs along the east and southeast sides of the intermittent lake in the center of the current Big Salt Marsh area

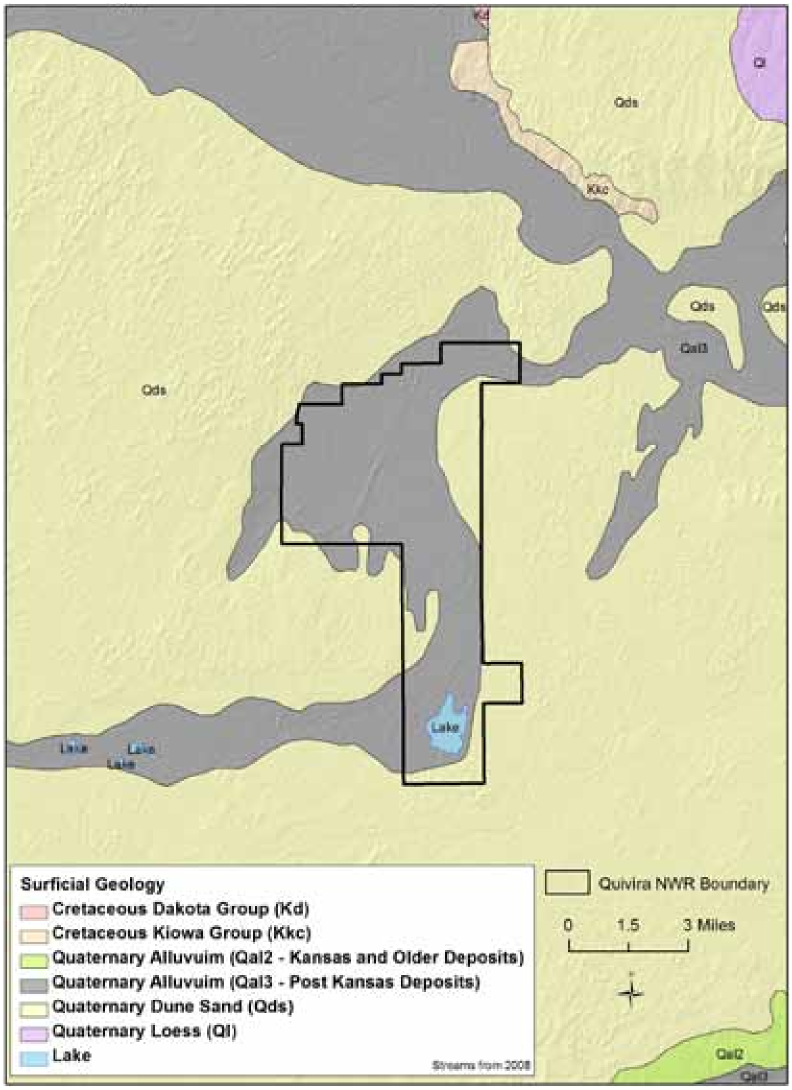


Figure 3. Surficial geology/geomorphology at Quivira NWR.

on Dillwyn-Tivin complex and Pratt-Tivoli fine sandy soils up to 20% slope (Fig. 6). The form, position, and soil characteristics of the beach ridge reflect the strong northwesterly winds that prevailed in this earlier late Wisconsin time. Choppy sand Dillwyn-Tivin complex beach-ridge sands also are present on the east and south sides of the Little Salt Marsh (Fig. 6). The beach sands are fine to medium sand and are lithologically similar to the dune sand.

Overlying silty sands in the Quivira region are eolian sands of varying thickness. Radiocarbon ages from the upper sands are late Wisconsin period, suggesting that overlying eolian sands accumulated during the Woodfordian time. In most areas, however, the upper silty sand dates from about 7,000 BP to 800 BP, indicating that overlying sand dunes are largely Holocene deposits. Landforms on uplands range from nearly flat sand sheets to parabolic dunes (Arbogast 1988). Dune sands are well sorted with a mean particle size of very fine to fine sand and imply a warmer climate during the Holocene period compared to the Woodfordian time. The orientation of parabolic dunes indicates a prevailing southwesterly wind. Dunes usually contain one to two weakly developed buried soils representing brief periods of landscape stability. Some dune soils are poorly developed, suggesting that they can be easily mobilized if increased aridity occurs in the region.

SOILS

Soils in the Great Bend Prairie include Mollisols, Alfisols, Entisols, and Inceptisols. Soil classification is based on landscape position and parent-material associations. The best developed soils in the Quivira NWR area are Typic Argiaquolls (Carwile Series), Udic Argiustolls (Naron Series), Pachic Argiustolls (Blanket and Farnum Series), and Vertic Argiustolls (Tabler Series). These soils are loamy, generally considered to have formed in old alluvium, and occur on the broad landscapes of relatively low relief between large dune fields (Figs. 6,7). Soils in the Tabler Series have the finest texture, generally occupy depression positions in upland areas, and are the least well drained. Carwile soils occur in similar topographic positions as Tabler soils but are more coarse textured and slighter better drained. Naron and Farnum soils contain the highest proportions of sand, occupy slightly higher landscape positions, and are better drained. Abbyville loam occur along the transition zone from sand hills to alluvium in the north-central part of the refuge

Soils that evolved in the complex, wind-modified dune topography consist of Psammentic Haplustalfs (Pratt Series), Typic Ustipsamments (Tivoli Series), and Aquic Ustipsamments (Dillwyn Series). Each has formed in sediments classified as loamy fine sand. Dillwyn soils are deep, somewhat poorly drained and subirrigated soils in interdunes where seasonal water tables are relatively high. Pratt soils are well drained and occupy the lowest, least erodible slopes on dunes. Tivoli and Tivin soils also are well drained, but are found on dune crests where eolian erosion is mostly likely to occur. These soils have the poorest development of any series in the region.

Soils that have formed in younger, fluvial landscapes are classified as Fluvaquentic Haplustolls (Plevna Series) and Leptic and Typic Natrustolls (Natrustolls). Natrustolls developed in loamy, calcareous alluvium that contains layers of sand or clay in places. They are somewhat poorly drained and often contain high concentrations of salt. Seasonal water tables are high in these sites. Plevna soils are often heavily gleyed and typically have developed in slight depressions on floodplains and on chaotic, channeled floodplains. Parent material is usually fine, sandy loam at the surface that is underlain by sandy and clayey alluvium (Dodge et al. 1978). Soils under the current flooded areas of Little Salt Marsh and Big Salt Marsh are mapped as water, marsh, or Aquolls (Fig. 6).

TOPOGRAPHY

USGS 7.5-minute quadrangle (Fig. 8) and 3-foot contour interval maps (Fig. 9) identify the gross-scale topographic heterogeneity of the refuge. Generally elevations slope from about 1,815 feet above mean sea level (amsl) in the south to 1,716 feet amsl in the northeast parts of the refuge. Also elevations slope from sandhills to the Rattlesnake Creek drainage and toward the salt marsh depressions. The bottom elevation of the Little Salt Marsh located at the south end of the refuge is 1,780 feet amsl and the bottom elevation of Big Salt Marsh located at the north end of the refuge is 1,736 feet amsl (Jian 1998).

CLIMATE AND HYDROLOGY

Climate data for Quivira NWR is available from the U.S. Historical Climatology Network (Menne et al. 2010) and are summarized in Striffler (2011). The climate of the Quivira NWR region is dry subhumid. The region lies along the transition boundary between the rain shadow of the Rocky Mountains and the warm moist air currents of the Gulf of Mexico. Average annual rainfall is about 24 inches, with about 75% of precipitation falling as rain between April and September. Snowfall averages less than 20 inches annually. Evaporation rates (ET) are high during summer and summer precipitation seldom exceeds ET rates. Average annual free-surface ET is

System	Epoch	Unit	Thickness feet
Quaternary	Holocene	Alluvium and Marsh	0-20
		Dune Sands	0-50+
	Pleistocene		
		Loess	0-40
		Mead Formation	50-200
Cretaceous		Dakota Formation	0-30
		Kiowa Shale	0-100
		Cheyenne Sandstone	0-80
Permian		Undifferentiated Redbeds	≤350
		Cedar Hills Sandstone	≤200
		Salt Plain Formation	≤300

Figure 4. Generalized stratigraphy of geological surfaces under Quivira NWR (from Fader and Stulken 1978).

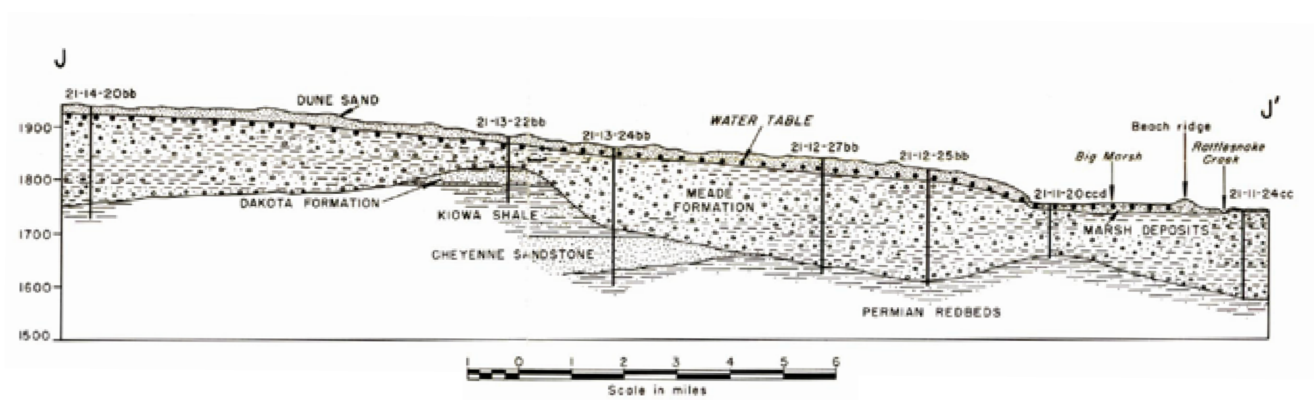
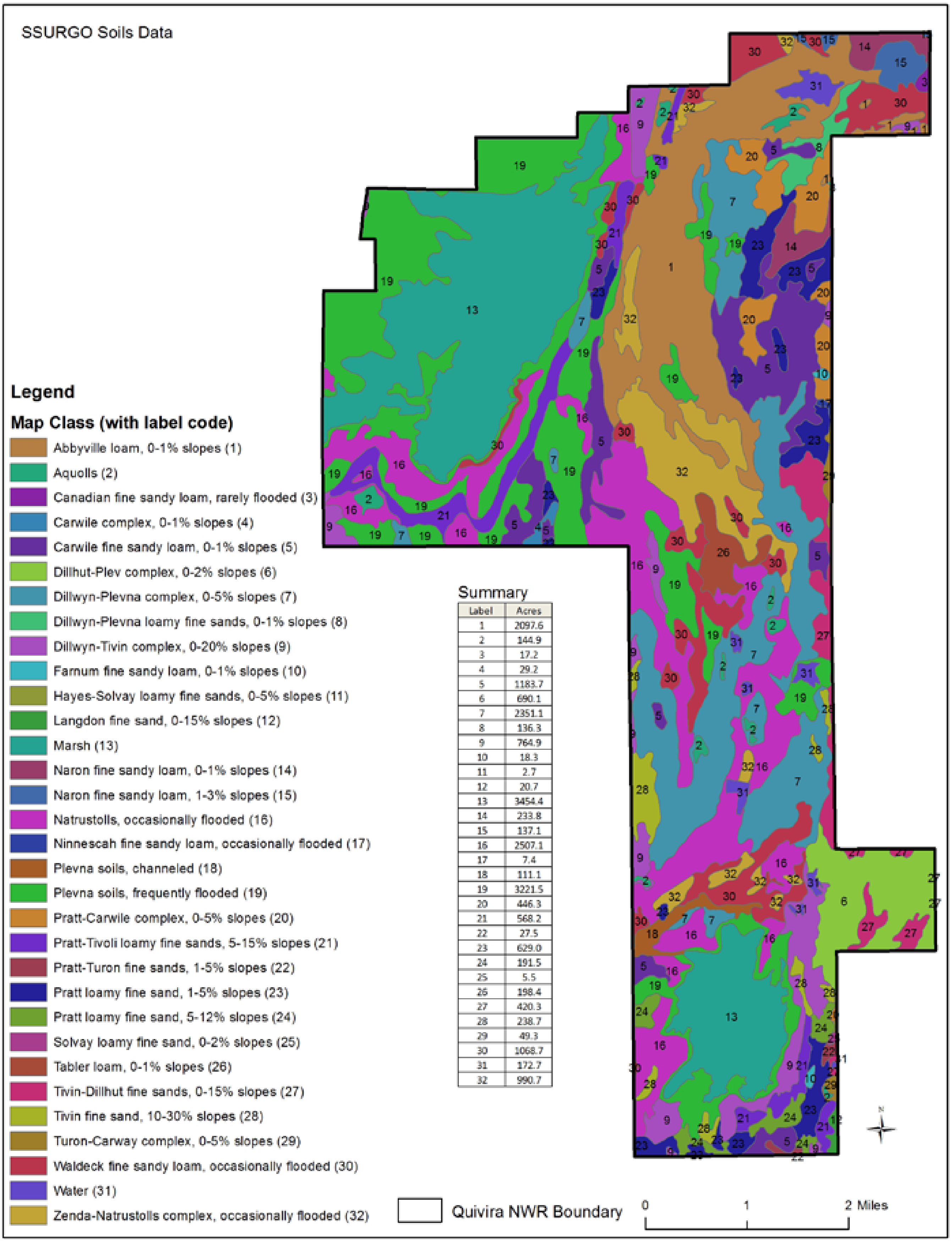


Figure 5. Geologic cross sections of Tertiary deposits in northeastern Stafford County, along line J-J' (from Latta 1950, http://www.kgs.ku.edu/General/Geology/Barton/index.html).



Label	Acres
1	2097.6
2	144.9
3	17.2
4	29.2
5	1183.7
6	690.1
7	2351.1
8	136.3
9	764.9
10	18.3
11	2.7
12	20.7
13	3454.4
14	233.8
15	137.1
16	2507.1
17	7.4
18	111.1
19	3221.5
20	446.3
21	568.2
22	27.5
23	629.0
24	191.5
25	5.5
26	198.4
27	420.3
28	238.7
29	49.3
30	1068.7
31	172.7
32	990.7

Figure 6. SSURGO soil types on Quivira NWR.

about 64 inches. With the exception of very wet years, rain and snow water does not pass through the soil into the zone of saturation. Long term precipitation records indicate relatively regular alternating high (> 30 inches) vs. low (< 20 inches) amounts of annual precipitation with occasional spikes of very high (1973) and very low (1939) precipitation (Fig. 10). Drought conditions have occurred in the Rattlesnake Creek Basin for extensive periods of time; perhaps the most extensive and notable period was the "Dirty Thirties" when very low annual rainfall and high winds created large dust storms. Drought periods of 3-4 years have been common, such as the extreme droughts in the late 1930s, mid 1950s, 1964-67, 1987-1990, and 1999-2002 (Fig. 10, Sophocleous and McAllister 1990). Mean annual temperature in the region is about 55° F and the growing season averages about 185 days. Prevailing wind direction is southerly, except during winter, and winds are strongest during March with average velocities of about 14 mph.

Rattlesnake Creek is a primary source of surface water at Quivira NWR. The creek meanders from the High Plains of Kansas northeast through the Great Bend Sand Prairie Ecoregion and Quivira NWR where it joins the Arkansas River. Average annual runoff of Rattlesnake Creek at Zenith, just upstream from the refuge, is about 34,000 acre-feet/year and average streamflow is about 47 cfs but varies significantly among seasons and years in relationship to regional precipitation (Fig. 11, Table 1). When Quivira NWR was established flow of Rattlesnake Creek into the refuge was estimated at about 100 cfs with greatest discharge occurring in April and May and a rarer high discharge in early fall; minimum summer flows were estimated at about 10 cfs (USFWS 1954). Local people living in the area in the mid-1900s, reported that this small meandering prairie stream could shallowly flood nearly a mile wide after large storm and precipitation events (USFWS 1962). Since 1938, the primary channel of Rattlesnake Creek has shifted locations several times in response to natural lateral creek migration and man-made diversions (Fig. 12).

The Rattlesnake Creek Basin contains about 1,047 mi^2, but the underlying groundwater basin is not a closed system; nearly half of the drainage area is considered noncontributing (Putnam et al. 2001). Regional groundwater flow is to the northeast and is impacted by groundwater levels outside the limits of the surface watershed. Rattlesnake Creek and its tributaries act as both sources and sinks of groundwater for the underlying Great Bend Prairie Aquifer system. Quivira NWR lies in a discharge zone for groundwater exiting the aquifer and the bedrock. This groundwater discharge subsequently becomes surface flow in Rattlesnake Creek and also contributes direct groundwater seepage into alluvial depressions, especially the Big Salt Marsh. Water enters the groundwater-driven system as underflow from outside the refuge area, as inflows from the bedrock, through infiltration of precipitation, and percolation of surface runoff through

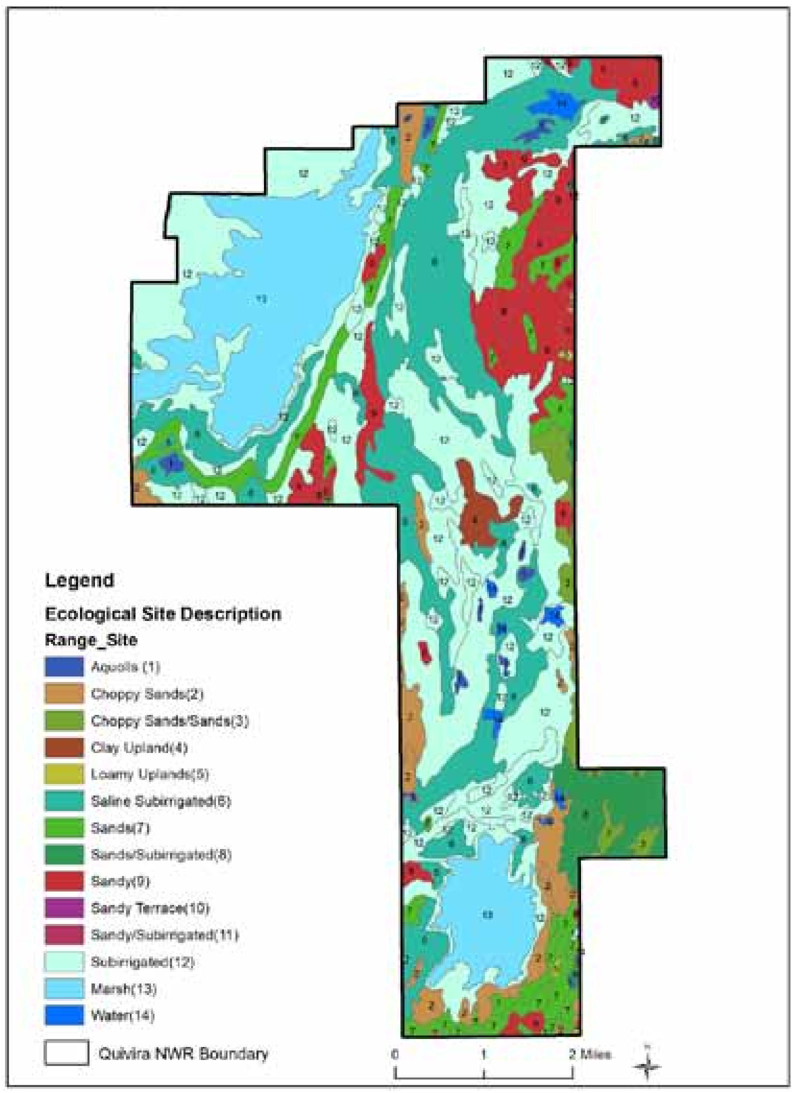


Figure 7. Soil grouping by taxon category and ecological site type on Quivira NWR (from NRCS 2010).

Rattlesnake Creek and its tributaries. Groundwater exits the study area as evaporation, underflow from the area, baseflow of streams and marshes, and now through groundwater well pumping. Discharge into the Quivira region, and depth to groundwater varies among years depending on precipitation in the basin and aquifer-source areas. Depth to water may be as little as one foot in wet seasons and up to 5 feet in dry seasons (Sophocleous and Perkins 1993).

The Great Bend Prairie Aquifer that underlies the Quivira region is part of the broader High Plains aquifer system and is a shallow (usually less than 300 feet thick from the land surface to bedrock) alluvial aquifer of Quaternary age. The hydraulic conductivity of the Great Bend Prairie Aquifer in the Quivira NWR region ranges from 11 to 230 feet/day with storage coefficients of 0.0007 to 0.18. In areas where the aquifer is thickest, wells can yield 1-2,000 gallons/minute. In the Quivira region the aquifer is overlain by a silt-clay bed that acts as a confining unit and causes artesian conditions in some areas, such as Boiling Springs, which discharges fresh water. Two artesian springs (wells) are located on the south side of the Big Salt Marsh and another artesian well is on the northwest side of the Little Salt Marsh (Fig. 13). These artesian springs are uniquely fresh, unlike many other surface water resources on the refuge that range from slightly brackish to saline.

Historically, most wetlands at Quivira were seasonally flooded by surface water runoff from local precipitation, overbank flow of Rattlesnake Creek, and discharge/seepage and springs originating from the Great Bend Prairie Aquifer. Historically, the Little Salt Marsh seems to have been recharged primarily by overbank flow from Rattlesnake Creek (e.g., unpublished Quivira NWR annual narratives), as the creek channel did not run through the marsh, but rather immediately to its north (Figs. 12, 14). In contrast, the Big Salt Marsh has historically received water mostly from groundwater seepage and discharge from springs (Sophocoleous 1992, Sophocleous and Perkins 1993). Based on a geologic cross-section passing through the Big Salt Marsh, a bedrock ridge trending roughly north-south beneath the marsh and the resulting thinning of the permeable water-bearing material was a major factor causing the discharge of saline groundwater at that location (Fig. 5). Models of groundwater leakage upward from the Great Bend Prairie Aquifer into the Big Salt Marsh area are about 98 acre-feet/day and seepage from the adjacent sand hills that flows overland to the marsh are only about one acre-foot/day (Sophocleous 1997, Jian 1998). Recent monitoring of groundwater discharge into the Big Salt Marsh indicates about 5,000 acre-feet of discharge /year (Jian 1998). In contrast, the Little Salt Marsh loses, or recharges, about 545 acre-feet/year to the underlying aquifer.

Permian bedrock outcrops in the Quivira NWR region are saline and salt water intrudes into the Great Bend Prairie Aquifer where the shallow alluvial aquifer is in contact with the

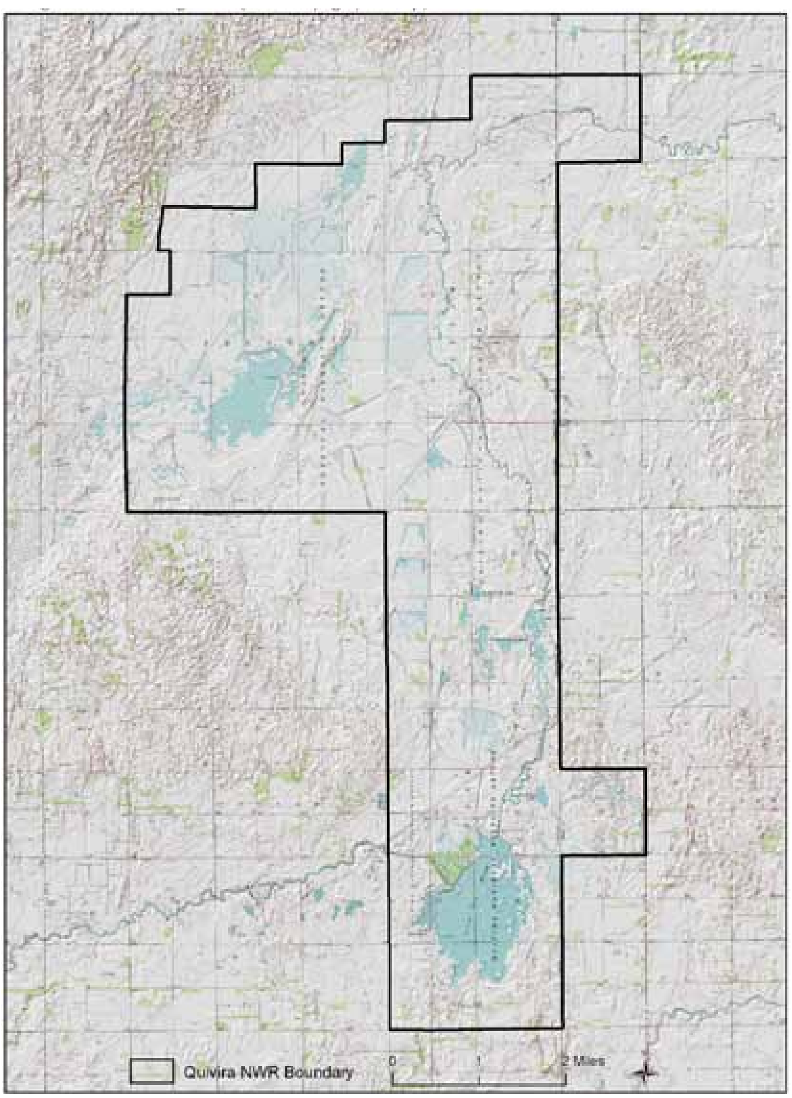


Figure 8. USGS 7.5-minute topographic quadrangle of Quivira NWR and surrounding lands.

bedrock formations. Permian "red bed" subcrops increase the salinity of the water in the unconsolidated aquifer in the lower reaches of Rattlesnake Creek. The average chloride load of flow in Rattlesnake Creek at its mouth is about 130 ton/d. Water near the salt marshes, especially Big Salt Marsh reflects the occurrence of artesian saltwater encountered deeper to the west. The salt water flows from the edges of the bedrock formation into the overlying sediments and then rises to the surface in low areas primarily along Rattlesnake Creek. The upper reaches of Rattlesnake Creek have low chloride levels but abrupt increases in conductivity occur in the 3 mile reach about one mile east of where Rattlesnake Creek crosses US Highway 281 with values of about 3-4,000 uS/cm. Where the creek exits Quivira NWR, another rise in conductivity occurs up to > 20,000 uS/cm, but by the time it discharges into the Arkansas River the creek's conductivity drops to about 3,100 uS/cm (Fig. 15).

Rattlesnake Creek historically flowed through the prairie grasslands of the Great Bend Sand Prairie Province from southwest to northeast on what is now Quivira NWR and did not directly flow into, or through, either the Big or Little Salt Marsh (see Fig. 2). Likely, the Little Salt Marsh received annually variable inputs of surface water from local runoff, modest seepage from the underlying aquifer, and seasonal overbank flooding from Rattlesnake Creek. The size of the historical Little Salt Marsh basin was much smaller than the current developed marsh area (Figs. 2, 14) and likely had annually variable amounts of open water surrounded by moderately brackish concentric bands of persistent emergent and seasonal herbaceous marsh plant species. The historical Little Salt Marsh apparently did not have a natural drainage outlet, and consequently, saline conditions occurred because of evaporation of surface

PLANT AND ANIMAL COMMUNITIES

The Quivira NWR region historically was dominated by mixed-grass prairie, the Rattlesnake Creek stream corridor, scattered small wetland depressions, and the unique Big and Little Salt Marsh basins. GLO surveys and maps from 1871 (Fig. 14), Santé Fe Railroad Field Notes in the mid 1870s (Fig. 16), and the Stafford County Township Map from 1886 (Fig. 17) provide descriptions of topography, geography, hydrological features, and plant communities prior to major alteration by European settlers. Other sources of information about vegetation and communities in the region are accounts of early explorers (e.g., Nathan Boone's journal from 1843, Fessler 1929), county history documents (e.g., Cutler 1883), early soil surveys, physiography (e.g., Adams 1903) and botanical investigations (e.g., Ungar 1961 and references cited). Aerial photographs of the refuge area from 1938 (Fig. 18) also provide evidence of general landscape features and communities prior to major alterations of land and water.

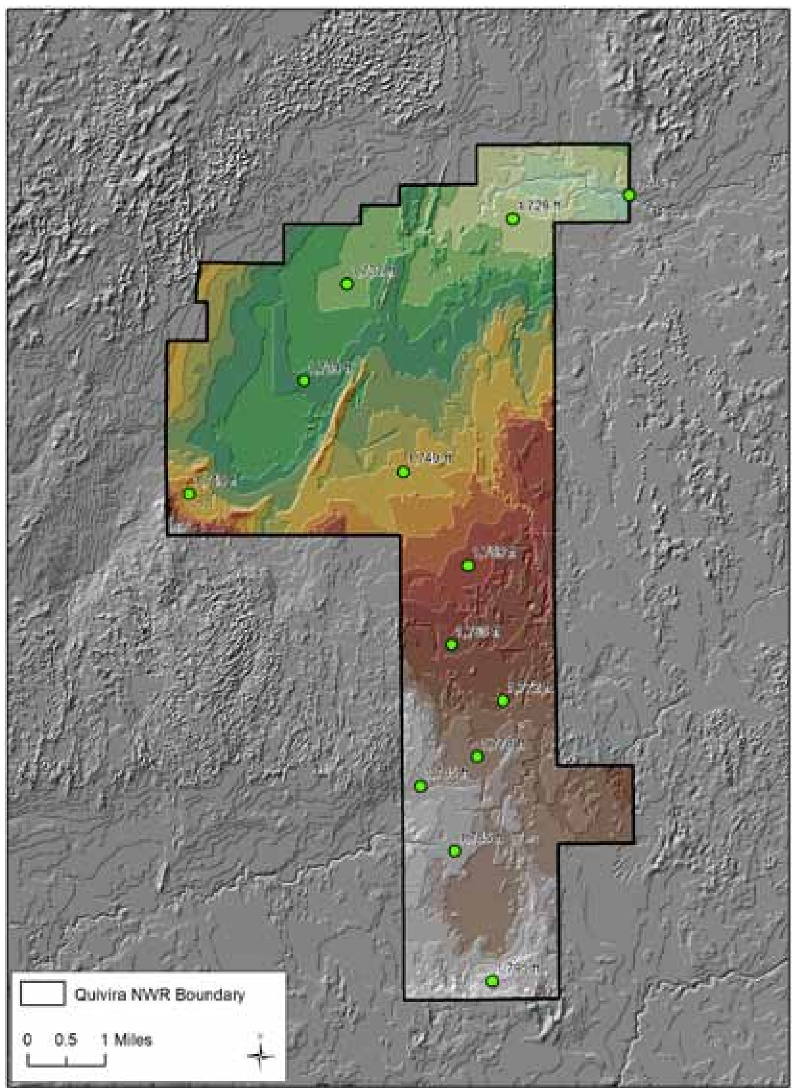


Figure 9. Elevation map (3 foot contours) of Quivira NWR.

water. In contrast, the Big Salt Marsh basin received more regular, albeit typically low pulsed amounts, of highly saline surface water from groundwater seepage and springs on the southwest side of the marsh. The highly saline groundwater and overland flow of this water across the Big Salt Marsh created wide areas of some open water surrounded by alkaline flats, salt grass assemblages, and alkaline herbaceous marsh vegetation. Surface water exited the Big Salt Marsh via Salt Creek, a tributary flowing into Rattlesnake Creek and eventually to the Arkansas River (Figs. 14, 17).

The historical Rattlesnake Creek corridor, including its relict, now abandoned, meandering channels (Fig. 12) and small natural levees contained mostly grass, wetland, and narrow riparian vegetation depending on topography, source and quality of water, and soil types. Early accounts of the Rattlesnake Creek channel do not mention trees bordering the creek channel, and only occasionally refer to scattered willows (*Salix* spp.) in riparian areas (e.g., Fessler 1929). The majority of upland non-wetland areas on the refuge were mixed-grass prairie, with type and diversity of grass communities determined by the type and extent of seasonal flooding or soil saturation, salinity, and soil type. Sand dunes occurred on the upland edges of the Rattlesnake Creek valley and supported more xeric vegetation communities with some scattered Chickasaw plum (*Prunus angustifolia*).

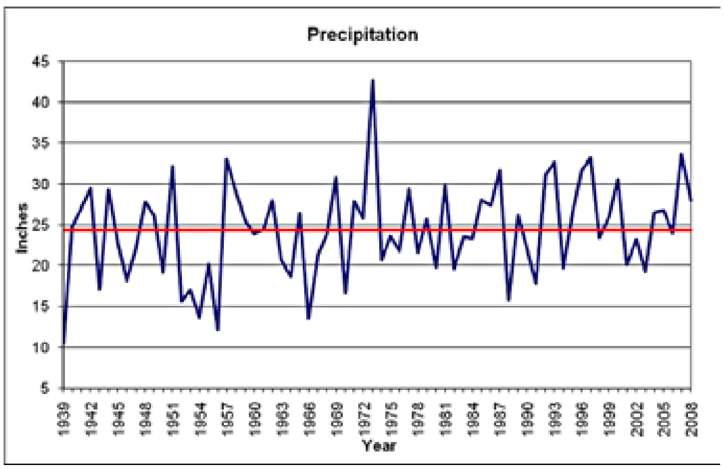


Figure 10. Mean annual precipitation at Zenith, KS 1939-2008.

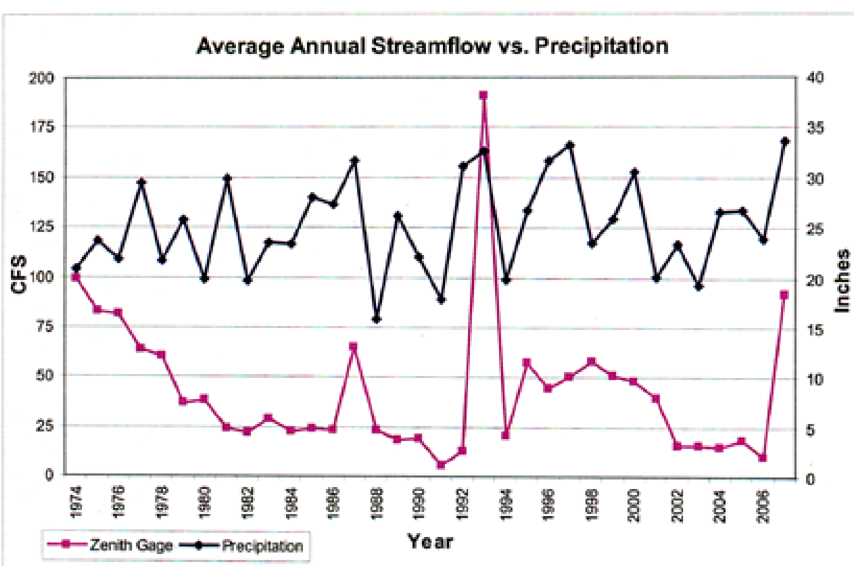


Figure 11. Average annual streamflow in Rattlesnake Creek compared to annual precipitation at Zenith, KS.

The primary ecological "drivers" that sustained natural vegetation communities at Quivira NWR were annually- and seasonally-variable inputs of surface and ground water of varying salinity and periodic physical disturbance events of fire, herbivory, wind, and other climate factors such as hail and dust storms. Occasional fire removed thatch residue and recycled and released nutrients and stimulated new growth in grasslands. Grazing by large ungulates and herbivory by small mammals, invertebrates, and some waterfowl species such as geese and wigeon (*Anas americana*) also helped sustain the long-term productivity and sustainability of grass and salt flat communities. The distribution and extent of historical plant communities on Quivira NWR were influenced by geomorphic position, soils, topography, and associated surface and groundwater hydrology. Specific, ecologically distinct, communities included: 1) sand hills, 2) choppy sand beach-ridge grassland, 3) salt marsh, 4) saltgrass flats, 5) creek channels with narrow riparian corridors, 6) seasonal herbaceous wetland, 7) subirrigated saline grassland, 8) subirrigated nonsaline grassland, 9) upland sandy grassland, and 10) upland loess-loam grassland (Ungar 1961, NRCS 2010). Information on these communities, including relationships with ecosystem attributes (e.g., soil texture and salinity, hydroperiods, disturbance events, etc.) is provided in the following

Table 1. USGS surface water monthly statistics for Rattlesnake Creek near Zenith, KS, 1973-2010.

YEAR	00060, Discharge, cubic feet per second, Monthly mean in cfs (Calculation Period: 1973-10-01 -> 2010-09-30)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973										690.6	184.8	269.8
1974	191.6	140.6	173.5	160.6	105.2	79.8	38.9	45.5	51.6	53.4	66.5	82.4
1975	80.7	86.3	82.1	83	65.2	177.1	131.5	79.5	60.8	32.9	54	57.6
1976	52.4	65.3	55.8	271.9	189.4	69.7	79.1	22.9	33.1	33.2	43.9	61.9
1977	38.1	47.8	52.6	59.7	160.2	146.2	46.2	32.7	43.7	39.2	44.5	49
1978	50.8	57.9	92.2	52.1	120.6	222.7	30.5	11	9.07	11.9	28.2	33.1
1979	27.8	46.1	75.1	57.6	48.7	33.1	24.6	32.6	6.87	6.51	44.3	35.9
1980	40	59.7	93.2	99.1	59.5	49.7	15.2	7.92	2.78	2.37	9.08	23.5
1981	22	21.5	26.7	21.2	46.9	46.2	20.4	8.42	5.48	7.2	34.9	25.2
1982	25.1	47.7	38	26.1	36.2	35.8	21.9	6.5	4.28	5.46	8.53	11.3
1983	14.7	29.1	29	75.5	68.5	88.7	16.7	2.99	2.29	3.04	9.04	8.46
1984	17.3	21.1	61.3	72.5	47.9	20	6.24	1.51	0.855	3.42	3.27	15.7
1985	8.58	23.6	25.9	31.3	46.1	23.9	8.39	9.94	6.01	59.4	22.4	25.9
1986	27.7	28.5	24.6	23.4	16.4	16.4	45.5	14.2	17.9	21.6	20.1	23.4
1987	22.6	29.9	207.4	132.1	61.5	40.3	108	53.5	28.7	23.6	32.4	40.7
1988	46.8	41.2	44.2	60.4	34.4	21.8	9.46	2.65	1.47	2.65	6.61	7.86
1989	11.4	9.3	15.5	11.3	40.4	39.9	27.8	13.8	24.7	8.32	9.07	8.79
1990	16.2	19.9	28.7	34.5	56.1	44	6.35	3.8	2.16	4.17	7.4	6.78
1991	8.28	9.5	11.3	11.2	8.12	10.2	1.54	0.875	0.091	0.046	3.64	5.56
1992	6.48	6.64	7.78	6.47	5.24	37.3	22.2	18.1	4.53	5.44	10.2	21.5
1993	31.8	57.4	86.4	48.2	177.8	595.9	1,099	49.6	30.6	30.5	39	43
1994	41.4	41.7	37.5	40.8	35.3	11.7	7.24	3.65	1.35	5.83	7.16	12.1
1995	14.4	15	18.1	21.5	370.9	100.2	84.7	19.6	6.42	8.05	13	18.6
1996	22.1	22.9	26.9	31	55.1	57.7	10.2	29.8	93.3	70.4	60.4	50.3
1997	45	59.5	54.2	60.4	42.2	49.5	40.3	63.9	35	41.9	49.7	63.3
1998	71	81.5	135.5	131.1	66.2	36.6	28	18.2	4.9	22.9	62.7	37.8
1999	45	71.4	70.1	93.9	64	50.6	110.5	17.2	13.9	17.6	23.1	30.5
2000	37.5	45.6	159.5	80.3	64.5	33.1	56.4	21	4.32	14.4	36.9	25.2
2001	34.3	68.2	65.5	45.5	70	129.4	14.3	6.9	7.45	7.13	11.8	14.7
2002	17.8	23.8	22.9	22.3	18.6	21	6.07	6.32	3.76	14.7	12	13.1
2003	14.7	17.2	48.1	29.5	31.4	14.1	4.51	3	3.26	7.29	6.48	8.71
2004	9.13	8.8	24.5	13.2	15.8	8.85	20.7	21	6.75	11.6	16.5	17.6
2005	15.3	27.9	19.2	20.4	19.6	30	22.4	26.8	9.97	5.81	9.02	12
2006	13.4	16.9	17.6	14.4	9.81	7.7	4.25	8.13	3.04	5.39	6.64	10.4
2007	14.9	13.5	23.8	152.6	399.9	133.1	218.7	30	19	18.1	23.5	53.4
2008	47.8	45.6	40.7	75.3	131.9	46.1	20	18.4	13.9	82.4	40.2	35.5
2009	34.6	37	38.7	187.8	179.9	191.9	38.7	25.7	21.2	26.8	33.2	30
2010	40.7	55.9	55.9	43.9	38	68.6	76.2	61	21.9			
Mean of monthly Discharge	34	41	56	65	81	75	68	22	16	38	30	35

** No Incomplete data have been used for statistical calculation

paragraphs and in NRCS (2010) ecological site descriptions. The NRCS site descriptions also include detailed lists of plant species in each community type.

Sandhills and choppy sand beach-ridge grassland at Quivira NWR occurs on Quaternary dune sand surfaces (Fig. 3) with deep sandy soils that absorbed inputs of surface water from local precipitation and runoff rapidly (see NRCS 2010). Dune surfaces with up to 30% slopes typically have Tivin fine sand soils and sparse grassland vegetation; these dune areas support "sandhill" habitats. Sandy dune areas with up to 15-20% slopes historically had denser, more complete, land cover of grasses and were on Dillwyn-Tivin complex, Langdon fine sand, and Tivin-Dillhunt fine sand soils. Sand beach-ridge habitats are dominated by warm-season grasses including sand bluestem (*Andropogon hallii*), switchgrass (*Panicum virgatum*), Indiangrass (*Sorghastrum nutans*), and

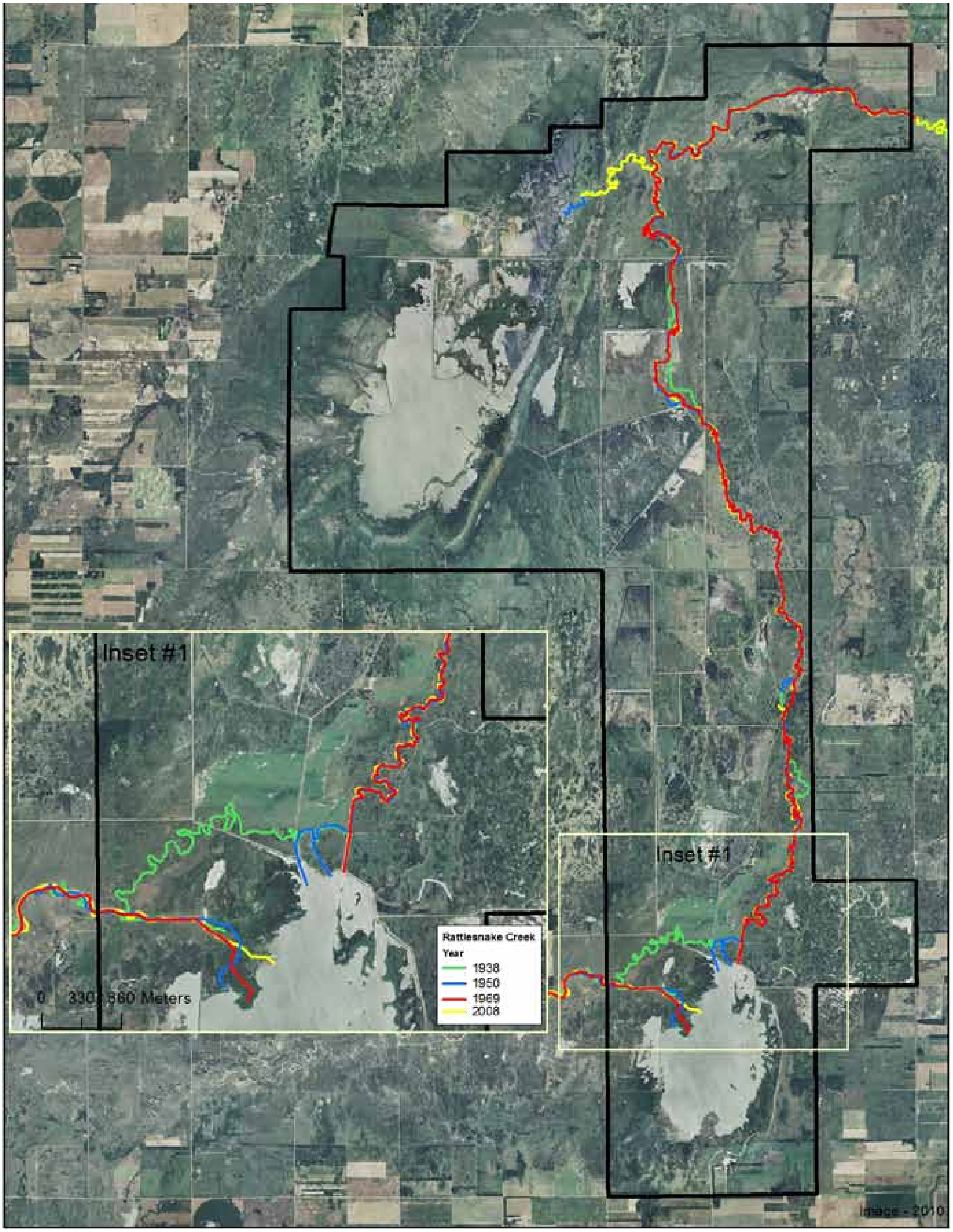


Figure 12. Movement of Rattlesnake Creek from 1938 through 2008 on Quivira NWR as mapped from sequential aerial photographs.

giant sandreed (*Calamovilfa gigantean*) (NRCS 2010). Little bluestem (*Schizachyrium scoparium*) historically was common in sand hills and beach-ridge areas as was Canada wildrye (*Elymus canadensis*), sand lovegrass (*Eragrostis trichodes*), composite dropseed (*Sporobolus composites*), and purple sandgrass (*Triplasis purpurea*). Scattered minor amounts of blue grama (*Bouteloua gracilis*), hairy grama (*Bouteloua hirsute*), thin paspalum (*Paspalum seteceum*), and sand dropseed (*Sporobolus cryptandrus*) also occur in these sand habitats along with a few legume species. A few small clumps of Chickasaw plum and skunkbrush sumac (*Rhus trilobata*) often are present on steeper dune and beach-ridge slopes. Soils in dune areas are susceptible to wind erosion and grasses that evolved in this community have deep root systems capable of utilizing moisture throughout the loose soil profile where almost no surface water runoff occurs. Fire was an important ecological process that sustained dune and beach-ridge communities; most fires occurred in spring and early summer when thunderstorms and lightning were most prevalent. All of the dominant grasses in dune and beach-ridge areas are rhizomatous, which helps them to survive intense wildfires. Trees and shrubs in dune and beach-ridge were suppressed by fires. This community also evolved under periodic grazing by large herds of bison that while intense at times, was usually of short duration. Dune areas cannot sustain prolonged heavy grazing because of sparse vegetation and highly erodible soils.

Salt marsh and saltgrass communities historically were present in areas within and immediately surrounding the Little Salt Marsh and Big Salt Marsh depressions (see descriptions in Ungar 1961). The deeper parts of the historic salt marshes had more prolonged flooding regimes with variable salinity and duration based on water source, topography, and inter-annual flooding dynamics related to regional precipitation and subsequent seepage of groundwater from the Rattlesnake Creek Basin. Occasional drought alternating with periodic high precipitation years and events created a dynamic balance of amount and extent of surface water and its relative salinity. This dynamic caused marsh and alkaline flat communities to contract or expand among years, mainly in the Big and Little Salt Marsh areas, depending on water inputs. Occasional drought was important to rejuvenate marsh and flat areas by releasing and recycling nutrients, consolidating sediments, volatilizing salts and minerals, and providing substrates for germination of some species. The Big Salt Marsh received relatively regular small amounts of groundwater discharge, of high saline content, throughout the year. This groundwater seepage, supplemented by rainfall and local groundwater runoff flowed into and across the marsh area and created a mosaic of salt marsh and salt flat habitats dominated by salt tolerant wetland plants such as alkali sacaton (*Sporobolus airoides*), saltgrass (*Distichlis spicata*), Pursch seepweed (*Suaeda depressa*), and alkali bulrush (*Scirpus paludosus*). Deeper, more permanently flooded parts of the Big Salt Marsh contain submergent aquatic plants such as wigeongrass (*Ruppia*

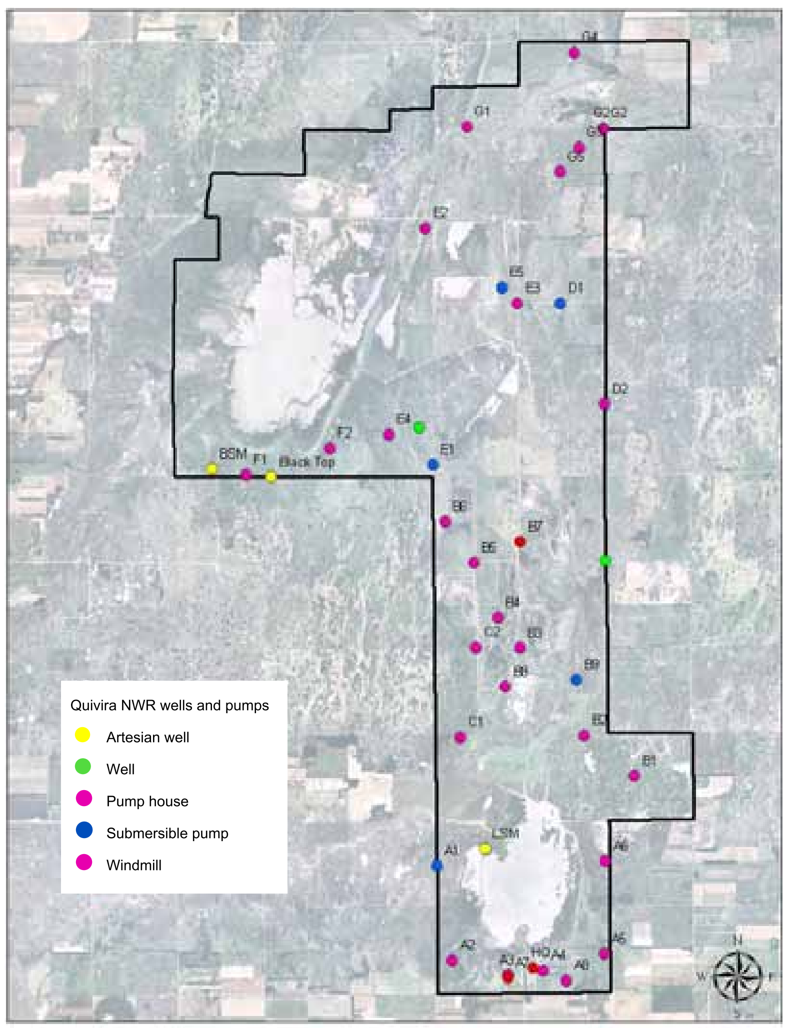


Figure 13. Map of hydrologic features on Quivira NWR.

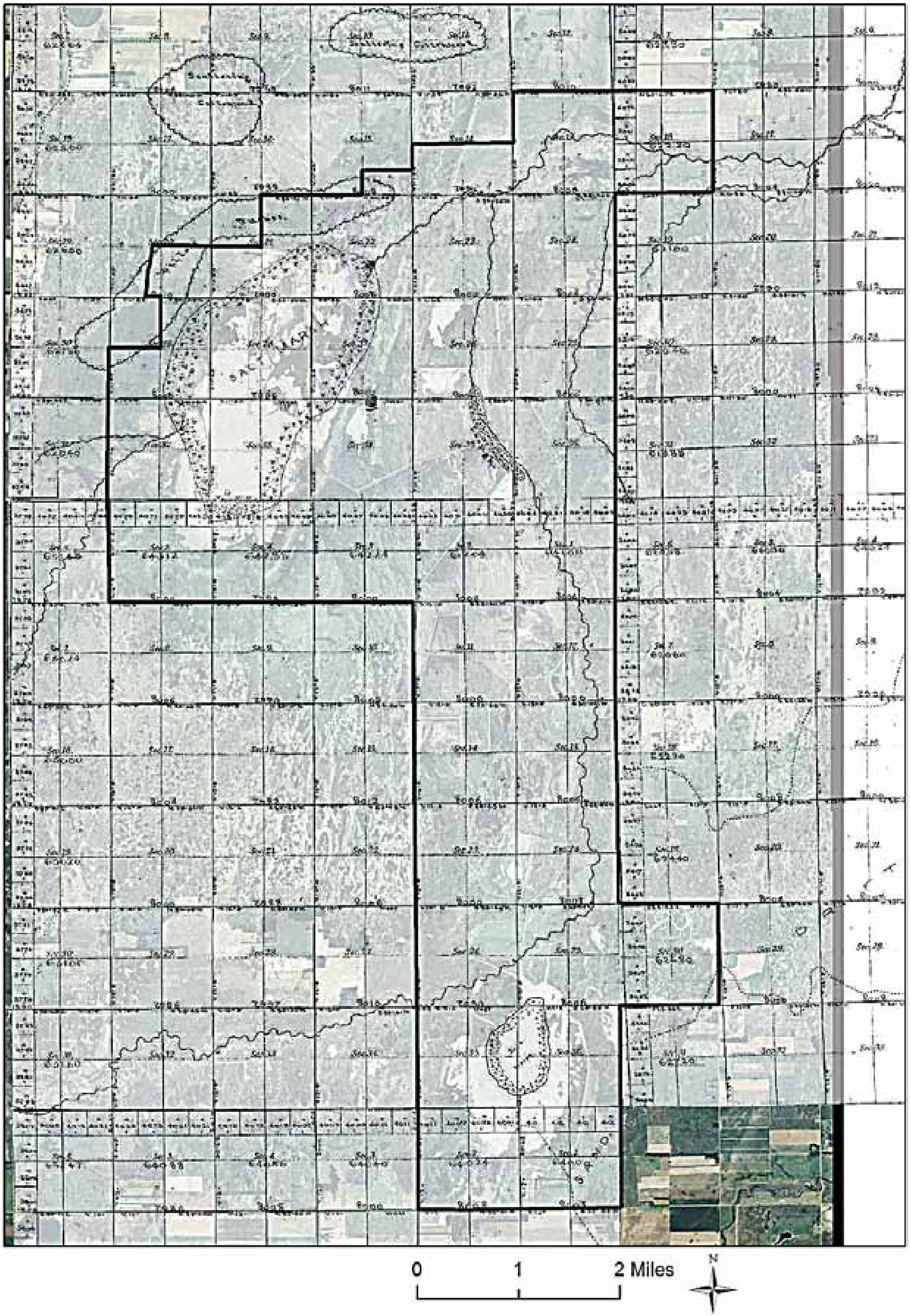


Figure 14. General Land Office map from 1871 overlain on 2010 NAIP photography.

maritime), muskgrass (*Chara* spp.), and pondweeds (*Potamogeton* spp.) while semipermanently flooded areas contain alkali bulrush, spikerush (*Eleocharis* spp.), and scattered American bulrush (*Scirpus americanus*). Areas along the edges of the Big Salt Marsh that seldom have surface flooding, but are subirrigated by high groundwater tables, support often wide saltgrass flats with some prairie cordgrass (*Spartina pectinata*) (Ungar 1961). These upper elevation edges of salt marsh typically have Plevna soils (Fig. 6).

Less is known about the historic vegetation composition of the Little Salt Marsh, however, the extent of the marsh and its naturally flooded area was much smaller than the present larger flooded area created by diversion and storage of Rattlesnake Creek water into the Little Salt Marsh basin (e.g., Fig. 14). It appears that most annual flooding of the Little Salt Marsh area historically was from periodic overbank flows from Rattlesnake Creek during high discharge events and seasons, direct rainfall, and local surface runoff with relatively small amounts of groundwater discharge/seepage (see above hydrology section). These sources of water were less regular and less saline than the groundwater seepage that flowed into and across the Big Salt Marsh. In wet years, more of the historic Little Salt Marsh was flooded for longer periods than in dry years, and likely water was fresher and open water areas in the center of the basin was surrounded by bands of persistent emergent and sedge/rush communities. Open water areas likely supported extensive submergent communities in wet years. During drier years, water area in the Little Salt Marsh likely was reduced and high evapotranspiration rates probably caused the wetland to be more saline. Bands of saltgrass occur on the edges of the Little Salt Marsh (usually on Plevna soils) and historically were less extensive and narrower than in the Big Salt Marsh.

Rattlesnake Creek flows through Quivira NWR and historically contained open water habitats in the creek channel and persistent emergent and seasonal herbaceous wetland vegetation along the channel edges. Only limited evidence suggests that scattered willows were present along the creek; apparently other trees were not present (Fessler 1929). Recently abandoned channels of Rattlesnake Creek (e.g., Fig. 12) probably had relatively regular connectivity with the active channel and may have had semipermanent water regimes. Older Rattlesnake Creek channel depressions (and other small drainages) likely had less, if any, regular connectivity with high flows of Rattlesnake Creek, and appear to have been sustained by combined surface runoff from seasonal rainfall and local runoff and groundwater discharge including the current wetland units 22 and 23 and Unit 57 (McCandless Lake or East Lake). Wetland vegetation in these smaller wetland sumps appears to have been diverse mixtures of seasonal herbaceous plants dominated by alkali sacaton, sedges and rushes, and some more water tolerant grasses, such as prairie cordgrass. A few larger, and deeper, depressions may have been flooded for longer periods at least in wet years. Wetland depressions in grasslands on Quivira NWR typically occur on Aquoll and Waldeck sandy loam soils (Fig. 6).

Grasslands dominated the Quivira NWR landscape where surface water does not seasonally or permanently flood areas. Areas that are subirrigated by high groundwater levels and that also have short duration sheetflow of surface water runoff from uplands are dominated by warm season grasses. Subirrigated grasslands occur on both saline and nonsaline soils and species composition depends on, and can be ecologically separated, by soil salinity. In both soil types, grassland vegetation evolved on broad, nearly level alluvium with high water tables, under a diverse and fluctuating climate, grazing by herds of large herbivores, and periodic intense wildfires. The major influence for plant adaptation and growth is the presence of a relatively high permanent water

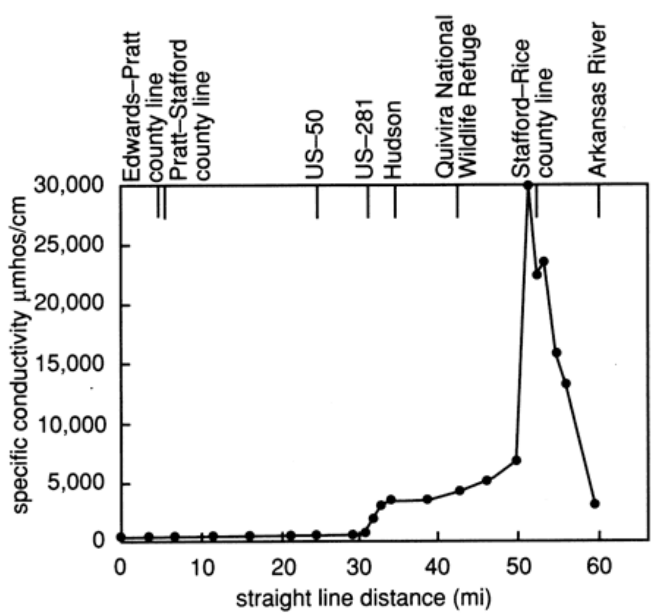


Figure 15. Relative salinity of Rattlesnake Creek at various locations including Quivira NWR (from Sophocleous and McAllister 1990, http://www.kgs.ku.edu/Publications/Bulletins/GW11).

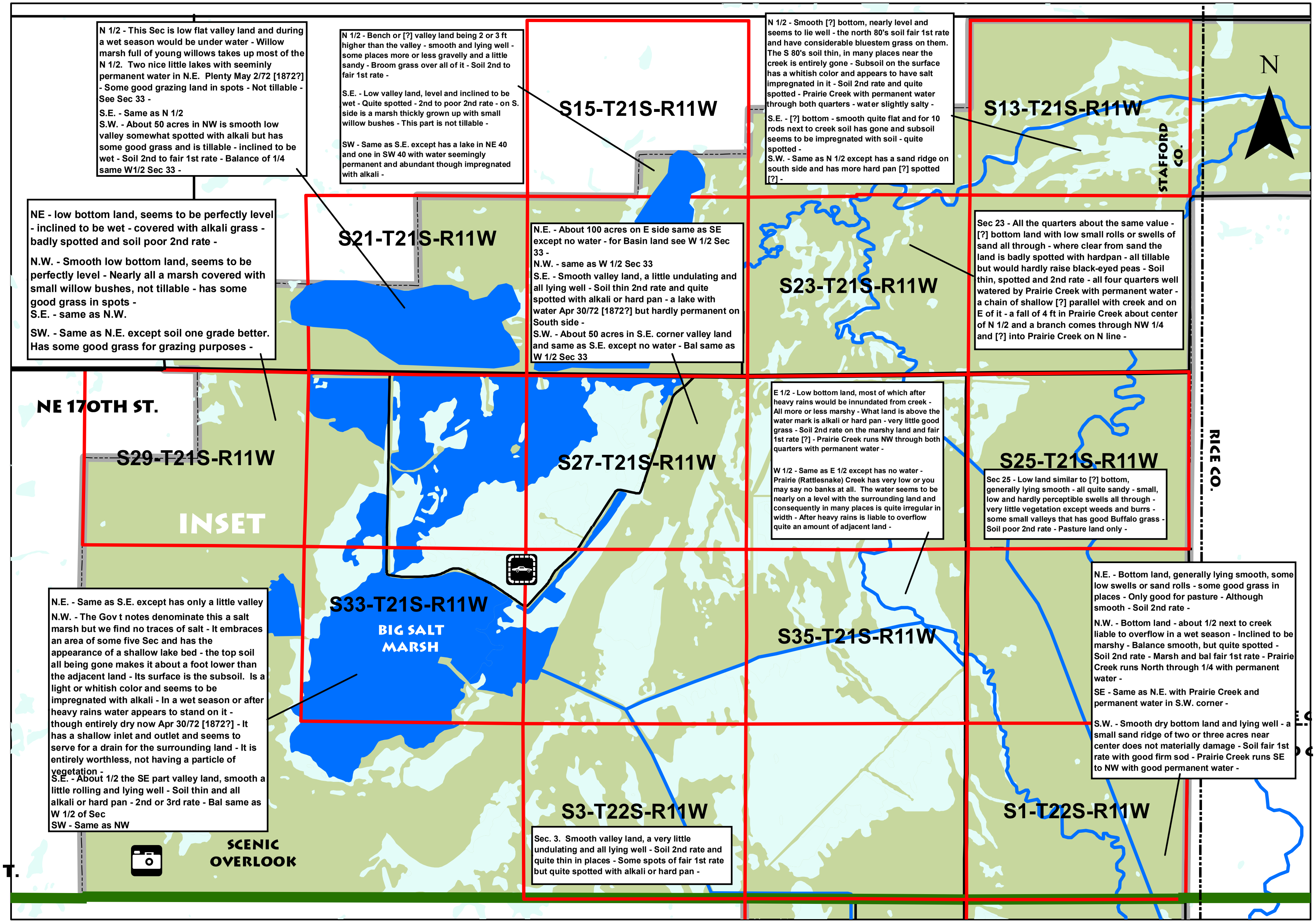


Figure 16a. Map of Quivira NWR with field notes from the Santa Fe Railroad surveys in the 1870s(north section).

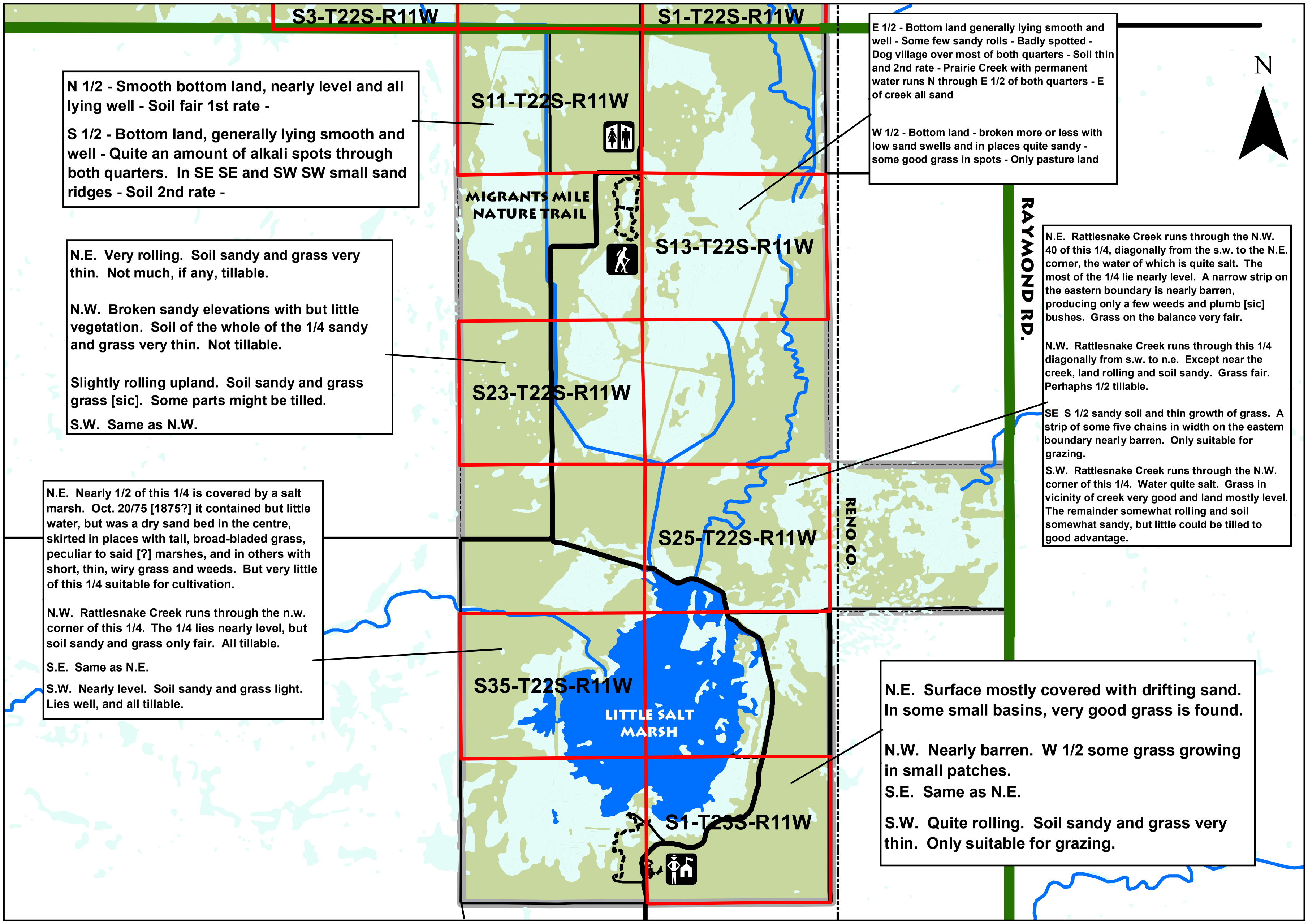


Figure 16b. Map of Quivira NWR with field notes from the Santa Fe Railroad surveys in the 1870s(south section).

table that generally varies from a few inches from the surface to a depth of two to four feet. The rhizomatous grasses and subirrigated saturated soils allow grasses to survive intense, regular wildfires. Trees and shrubs historically were suppressed in subirrigated grasslands by occasional fires and the few trees and shrubs that did occur in these areas probably survived only on wet protected sites such as along stream banks. Grazing history has a major impact on the dynamics of grasslands (NRCS 2010) and native herbivores included large ungulates, rabbits, insects, and numerous burrowing rodents. Nonsaline subirrigated sites at Quivira NWR occur on Dillhunt-Pleva complex, Dillwyn Plevna complex, Hayes-Solvay, Ninnescah, Solvay, Turon-Caraway complex, and Zenda-Natrustolls complex soils (Fig. 6). These habitats typically are dominated by big bluestem, Indiangrass, eastern gammagrass (*Tripsacum dactyloides*), and prairie cordgrass (NRCS 2010). Other prevalent grasses include Canada wildrye, little bluestem, sideoats grama (*Bouteloua curtipendula*), buffalograss (*Bouteloua dactyloides*), and marsh bristlegrass (*Setaria parviflora*). Common forbs interspersed with grasses in nonsaline subirrigated habitats include Maximillian sunflower (*Helianthus maximiliani*), golden tickseed (*Coreopsis tinctoria*), prairie acacia (*Acacia angustissima*), and many others. Desert false indigo (*Amorpha fruticosa*), buttonbush (*Cephalanthus occidentalis*), and roughleaf dogwood (*Cornus drummondii*) occasionally are present in nonsaline subirrigated sites. The fresher subirrigated grasslands at Quivira NWR were often sites of native "hay" production and cutting, and are sometimes referred to as "prairie hay" habitats in older literature and historical accounts of the region (e.g., Fig. 16).

Saline subirrigated grassland communities have similar physical attributes as fresher subirrigated grassland habitats, but occur on moderately tight alkaline or saline soils that are poorly drained. These saline subirrigated sites usually are located on low terraces bordering floodplains. Major soil types in alluvial subirrigated saline grassland include Abbyville and Natrustolls types. Subirrigated saline grassland soil-plant moisture relationships are dictated by the relative salt or sodium concentrations, and are typically have high annual biomass production. Dominant grass species are similar to alluvial subirrigated nonsaline grassland, but more alkali sacaton and composite

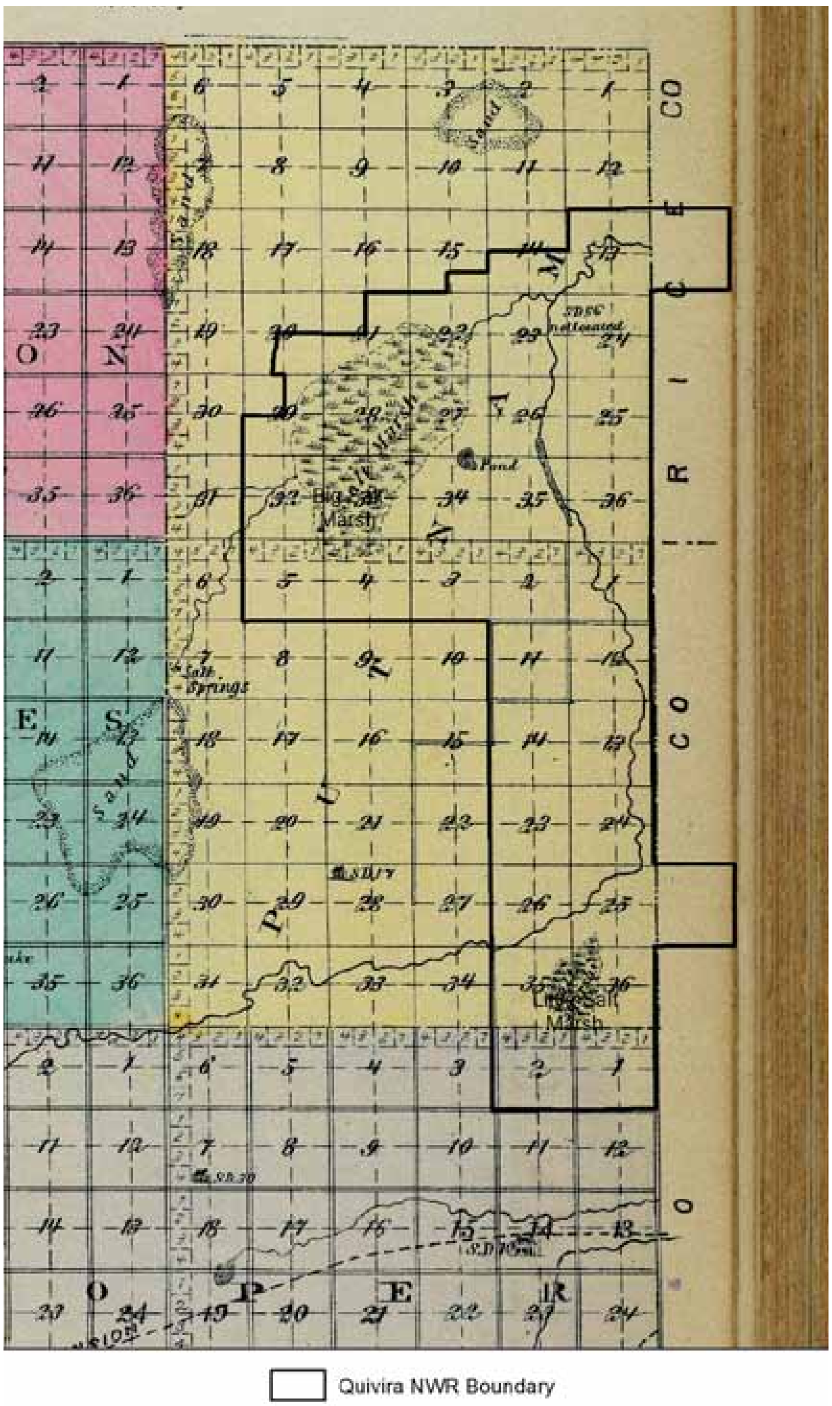


Figure 17. Stafford County, KS township map from 1886.

dropseed are present (NRCS 2010). Eastern gamma-grass, big bluestem, and little bluestem occur on more neutral pH soil inclusions.

Higher elevation non-floodplain, and non-subirrigated, upland grasslands historically were extensive on Quivira NWR and contained sandy and clay/loam mixed grass assemblages (NRCS 2010). Sandy upland-type grassland at Quivira NWR is present on deep sandy Canadian, Carwile, Naron, and Pratt soils (Fig. 6) that have moderate water retention capability. Occasional fire was an integral ecological driver of upland grasslands and fires occurred mostly during spring and summer lightning events and perhaps some intentional burning by native people. Grazing by native ungulates, rodents, and insects also was an important influence on plant composition and structure in upland grasslands. Upland sandy grasslands were essentially free of trees and large shrubs and were dominated by warm season grasses such as sand bluestem, switchgrass, and Indiangrass. Other common species in these sandy uplands include Canada wildrye, sideoats grama, sand lovegrass, purple lovegrass (*Eragrostis spectabilis*), and sand dropseed. Short grasses including blue grama, hairy grama, thin paspalum (*Paspalum setaceum*), and sideoats grama are scattered in sandy grassland sites. Many legumes are present in sandy grasslands including Nuttall's sensitive-briar (*Mimosa nuttallii*), roundhead lespedeza (*Lespedeza capitata*), sessileleaf tick trefoil (*Desmodium sessilifolium*), golden prairie clover (*Dalea aurea*), silky sophora (*Sophora nuttalliana*), and prairie bundleflower. Common forbs include scaly blazing star (*Liatris squarrosa*), downy ragged goldenrod (*Solidago* petiolaris), and pitcher sage (*Salvia azurea*). Small seasonal and temporary wetland depressions are common in some sandy grassland areas, e.g., the Unit 10 and 11 areas (Fig. 19). These small depressions receive annually variable inputs of surface water from onsite precipitation and runoff and support unique vegetation including many wet meadow species such as spikerush, sedges (*Carex* spp.), herbaceous species, and wetland grasses.

Loamy–clay uplands at Quivira NWR contain extensive mixed warm season grass species and endemic grasses have root systems capable of using often low amounts of water that slowly percolates through soil profiles (NRCS 2010). Loamy-clay soils in these assemblages usually are Farnum and Tabler types (Fig. 6). Dominant grass species in upland loamy-clay areas include big bluestem, switchgrass, and Indiangrass; the major mid-height grass species is little bluestem. Scattered short stature grasses

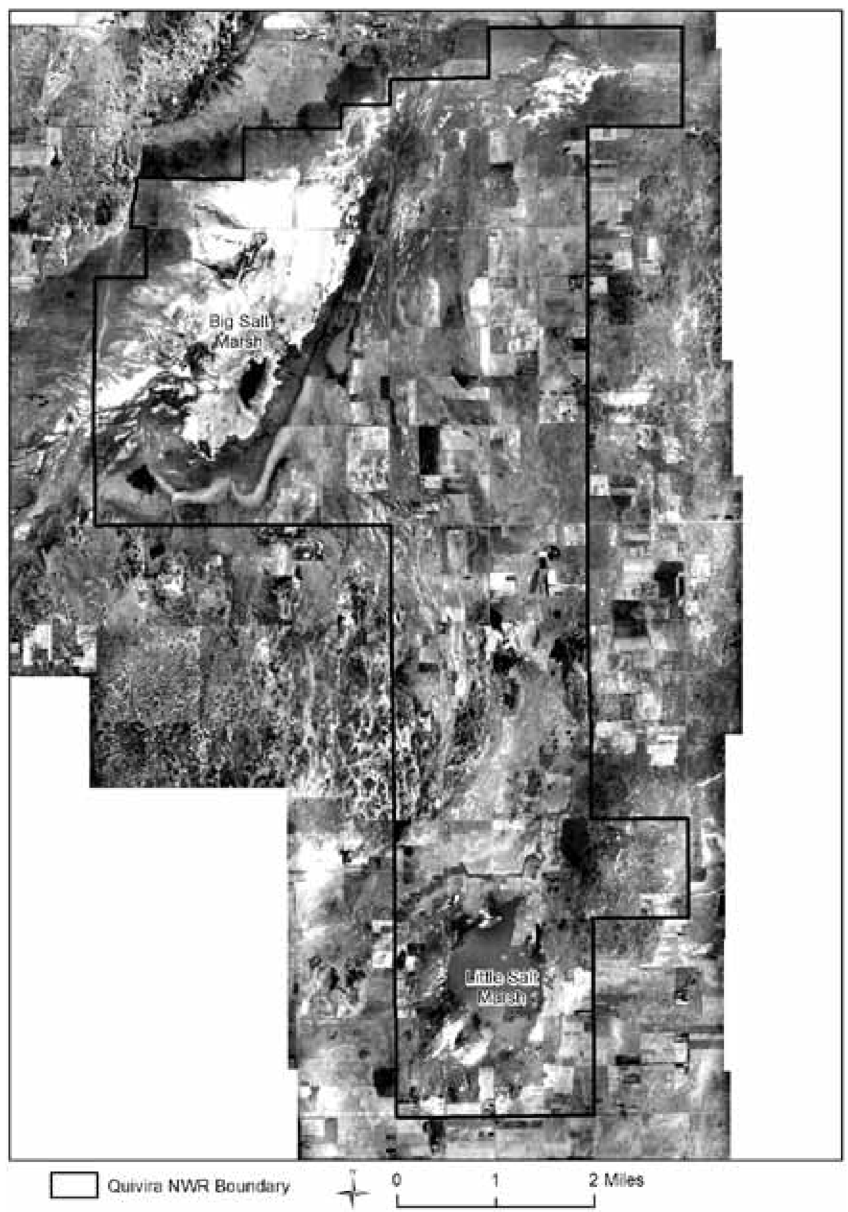


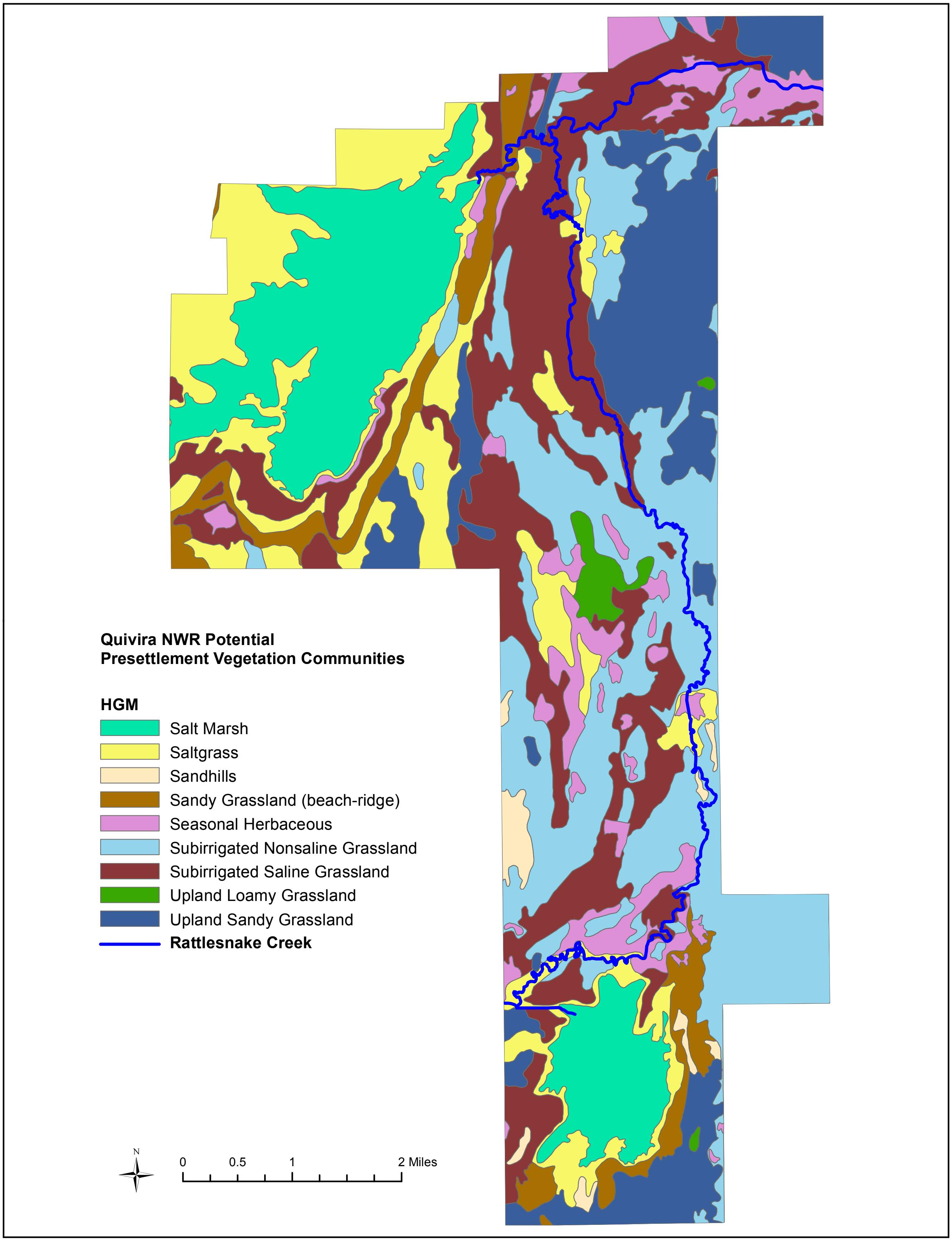
Figure 18. 1938 aerial photograph of the Quivira NWR region.

Figure 19. Photograph of small ephemeral wetland depressions in upland grasslands on Quivira NWR.

include blue grama and buffalograss. These upland sites support a wide variety of native legumes interspersed throughout the grass sward. Common legume species include groundplum milkvetch (*Astragalus crassicarpus*), purple prairie clover, slimflower scrufpea (*Psoralea tenuiflora*), and prairie bundleflower. Leadplant (*Amorpha canescens*) and Jersey tea (*Ceanothus herbaceous*) are common low-growing shrubs that are tolerant to fire, and clumps of smooth (*Rhus* glabra) and fragrant sumac (*Rhus aromatic*) occur in areas that partially escape fires. Because these shrub areas often occur on ridgetops and other high elevations, they are often used by grazing animals during the hot days of late summer to gain relief from heat and insects.

A HGM matrix of relationships of the above major plant communities to geomorphic surface, soil, general topographic position, and hydrology was developed (Table 2) to map potential distribution of historic communities on Quivira NWR (Fig. 20). The hydrogeomorphic matrix of understanding, and prediction of, potential historic vegetation communities was developed from plant associations described in published literature, vegetation community reference sites, and state-of-the-art understanding of plant species relationships (i.e., botanical correlation) to geomorphology, soil, topography and elevation, hydrological regimes, and ecosystem disturbances (e.g., Ungar 1961, Nelson 2005, NRCS 2010). These plant-abiotic correlations are in effect the basis of plant biogeography and physiography whereby information is sought on where plant species, and community assemblages, occur throughout the world relative to geology and geomorphic setting, soils, topographic and aspect position, and hydrology (e.g., Barbour and Billings 1991). The hydrogeomorphic matrix provides a way to map the potential historic vegetation communities at Quivira NWR in an objective manner based on the botanical correlations that identify community type and distribution, juxtaposition, and "driving" ecological processes that are most influential in community formation and sustainability. Obviously, the predictions of type and historic distribution of communities are only as accurate as the understanding and documentation of plant-abiotic relationships and the geospatial data for the abiotic variables for a location and period of interest, such as Presettlement period. For example, the precise delineation of salt marsh vegetation zones and shallow small wetland depressions in upland grassland areas, is limited by the gross-scale topographic information available when this report was prepared. When recently completed LIDAR topography survey data are available and processed for Quivira NWR, then analyses of topographical/hydrological relationships of these specific wetland vegetation zones can be conducted.

At Quivira NWR, the major vegetation communities that were present during the Presettlement period are known (e.g., discussion in NRCS 2010) and the botanical relationships of these communities with at least some abiotic factors are documented (e.g., Ungar 1961). The interrelationships among abiotic factors at Quivira NWR generally are understood and documented. For example, the type and spatial position of soils generally are closely related to geomorphic surface and formation. As a specific example, Plevna sub-order soils are present in frequently flooded, depressions in alluvial floodplains and abandoned channel areas. These soils are formed in loamy alluvium and are underlain



Blue Heron Conservation Design || 2012

Figure 20. A model of potential Presettlement vegetation communities on Quivira NWR.

Table 2. Hydrogeomorphic (HGM) matrix of historical distribution of major vegetation communities/habitat types in the Quivira NWR region in relationship to geomorphic surface, soils, and hydrological regime. Relationships were determined from land cover maps prepared for the Government Land Office survey notes taken in the late 1800s, historic maps and photographs (e.g., Fig. 16), current and historic USDA soil maps (Dodge et al. 1978, NRCS 2010), geomorphology maps (Fig. 3), region-specific hydrology data (e.g., Fader et al. 1978, Sophocleous 1997, Jian 1998, Estep 2000, Striffler 2011), and various botanical accounts and literature (e.g., NRCS 2010, Ungar 1961).

Habitat type	Geomorphic surface	Major soil types	Flood frequency[a]
Sand hills	Dune sands	Tivin	OP
Sandy grassland (Beach ridge)	Beach ridge	Pratt-Tivoli	OP
Salt marsh	Alluvial/lacustrine depressions	SSURGO marsh	SGD, ROB
Saltgrass	Depression fringes	Plevna	SGD, ROB
Seasonal Herbaceous	Alluvium depressions	Aquoll, Waldeck	Seasonal surface
Riparian Creek Corridors	Rattlesnake Creek corridor	Varied, sand	Continual creek flow
Subirrigated saline grassland	Alluvium	Abbyville, Natrisols	SGD, OP
Subirrigated nonsaline grassland	Alluvium	Dillhut-Plevna, Hayes-Solweg, Dillwyn, Zenda	GD, OP
Upland sandy grassland	Dune sands	Canadian, Carwille, Naron, Pratt, Tivin-Dillhut	OP
Upland clay/loam Grassland	Dune loess, loam	Farnum, Tabler	OP

[a] OP - predominantly onsite precipitation; SGD- saline groundwater discharge; GD – groundwater discharge, with low salinity; ROB – Rattlesnake Creek overbank and backwater surface flows; Seasonal surface - predominantly seasonal surface water runoff and minor creek overbank flooding, relatively fresh or slightly brackish water; Continual creek flow – sustained flows in Rattlesnake Creek.

by clay material (Striffler 2011). Detailed maps of the geomorphology (Fig. 3), soils (Figs. 6,7), and hydrology (see reviews in Striffler 2011) at Quivira NWR are available.

The major factors influencing the type and distribution of historical vegetation communities at Quivira NWR are:

1. The geomorphic surface of either Quaternary alluvium or Quaternary upland dune sands (Fig. 3).
2. Soil type and salinity (Fig. 6).
3. The historic basin boundaries of the Big and Little Salt Marsh depressions (Fig. 14).
4. On-site hydrology that is affected by type and input of at least seasonal surface water (such as in topographic depressions in both alluvium and sand dune surfaces) and whether the site is subirrigated by high ground water tables (Fig. 7).

These ecosystem attributes were used to make the HGM matrix (Table 2) and subsequent map of potential historical vegetation community distribution (Fig. 20). The first step in this process was to determine the distribution of major vegetation/ community types from GLO surveys (Fig. 14), early explorer/naturalist accounts (Fig. 16 and various journal and literature accounts), and Stafford County Township plat maps (Fig. 17). This information defines the locations of "water" areas in the Big and Little Salt Marshes at the time of the map or account, larger alluvial floodplain wetland depressions, the historic channel of Rattlesnake Creek, sand hills and dunes, and the extensive grasslands in the area. The presence of these major landscape and vegetation features was overlaid on contemporary geomorphology, soil, and topography maps to determine correspondence. While older maps and accounts have limitations and may not be completely georeferenced, they do provide the opportunity to specifically define some areas, such as the general water and marsh areas of the Big and Little Salt Marsh, the location of possible narrow riparian areas along the historical channel of Rattlesnake Creek, sand hills on Tivin-associated soils, and larger alluvial wetland depressions in Aquoll and Waldeck soils. Further, the narrow linear relict "beach ridge" along the east side of the Big Salt Marsh is tightly aligned with Pratt-Tivoli, Pratt, and Carwile fine sandy loam soils. These soil types also are present on the southeast side of the Little Salt Marsh, and while it is unknown if some type of beach ridge existed there, the similarity of soils adjacent to a salt marsh suggests similar communities.

The historically extensive grasslands at Quivira NWR contained diverse assemblages of grass and forb species in relationship to soil salinity, textural material (i.e., sand, loam, loess), and soil-surface saturation (NRCS 2010). Recent vegetation mapping (Fig. 21) and description of ecological land types (NRCS 2010) provides a means to separate grassland types based on whether soils were alluvium or upland loess/dune derived, saline or nonsaline, and subirrigated or nonsubirrigated (Fig. 7). This classification is helpful because it by default integrates geomorphology, soil type and salinity, and hydrology, which can define grassland assemblages. Consequently, grasslands at Quivira NWR were separated into four categories (subirrigated nonsaline, subirrigated saline, upland loamy, and upland sandy) in addition to the previously mentioned "beach-ridge" sandy grassland association. Soil types associated with these four categories are provided in Table 2.

The final distinction of major historical vegetation communities at Quivira NWR was to separate the unique saltgrass community from the historical salt marsh complex of diverse herbaceous and aquatic wetland species along with more barren salt "flats" and hummocks. The best information on historical vegetation communities associated with and near Quivira NWR salt marshes is the 1954 vegetation maps (Fig. 21) and botanical descriptions provided in Ungar (1961) for the Big Salt Marsh. This botanical information separates the saltgrass assemblage, where saltgrass is the most dominant species, from other salt marsh and grassland categories, and generally correlates saltgrass with Plevna frequently flooded soil types (Fig. 6). It is important to note that saltgrass occurs in other vegetation communities, such as subirrigated saline grassland, but it is not the dominant species present. For lack of any other defining information, we mapped Plevna soils as the location of the historical saltgrass-dominated community. Further, a generic salt marsh community was mapped as the boundary of the current "marsh" soil type. This generic salt marsh boundary reflects not only the historical maps showing the smaller water area of the Big and Little Salt marshes (e.g., Fig 14), but also the associated marsh basin areas that had annually and seasonally variable flooding, but not permanent water, depending on water inputs within and among years. Consequently, this mapping attempts to delineate the possible extent of the salt marsh during the wettest years, while understanding that during dry periods the actual flooded areas of the Big and Little Salt Marsh would be much smaller. We acknowledge that the mapping of saltgrass and salt marsh communities is generic and hopefully can be refined when more detailed topographic information becomes available and can be correlated with seasonal and annual hydroperiods. For example, one-foot elevation differences in the Big Salt Marsh flats can cause specific sites to be either moderately covered with saltgrass or Suaeda vs. nearly barren salt flats.

As with all attempts to model the distribution of historical vegetation for a site, the potential vegetation map is only as good as the information available to prepare it. As such, Fig. 20 should be seen as a "hypothesis" of community distribution that hopefully will be refined when more detailed information, such as topography, becomes available.

Collectively, the Quivira NWR ecosystem historically was dominated by sandy, mixed warm season grasslands, essentially no trees or large shrubs, and the unique large Big Salt Marsh basin and the smaller, fresher, Little Salt Marsh basin.

Rattlesnake Creek was the primary source of slightly saline water moving through the Quivira ecosystem and provided periodic flooding of the Little Salt Marsh and subirrigation of alluvial grasslands and herbaceous wetland depressions. Saline groundwater discharge was the primary ecological driver causing regular sustained low flow surface water inputs into and through the Big Salt Marsh wetland complex and exiting via Salt Creek that merged with Rattlesnake Creek and ultimately flowed to the Arkansas River. Upland grasslands were dependent on local rainfall and surface water percolation into soils. These grasslands also historically had relatively regular fire and herbivory occurrences.

The heterogeneity of grassland communities coupled with unique salt marsh and diverse wetland habitats provided important resources used by varied and abundant animal species at Quivira NWR under past and present conditions. Among the more obvious differences between past (prior to refuge establishment) and present wildlife communities on the refuge are increasing populations of white-tailed deer (*Odocoileus virginanus*) and eastern wild turkey (*Meleagris gallopavo*) and the introduction of

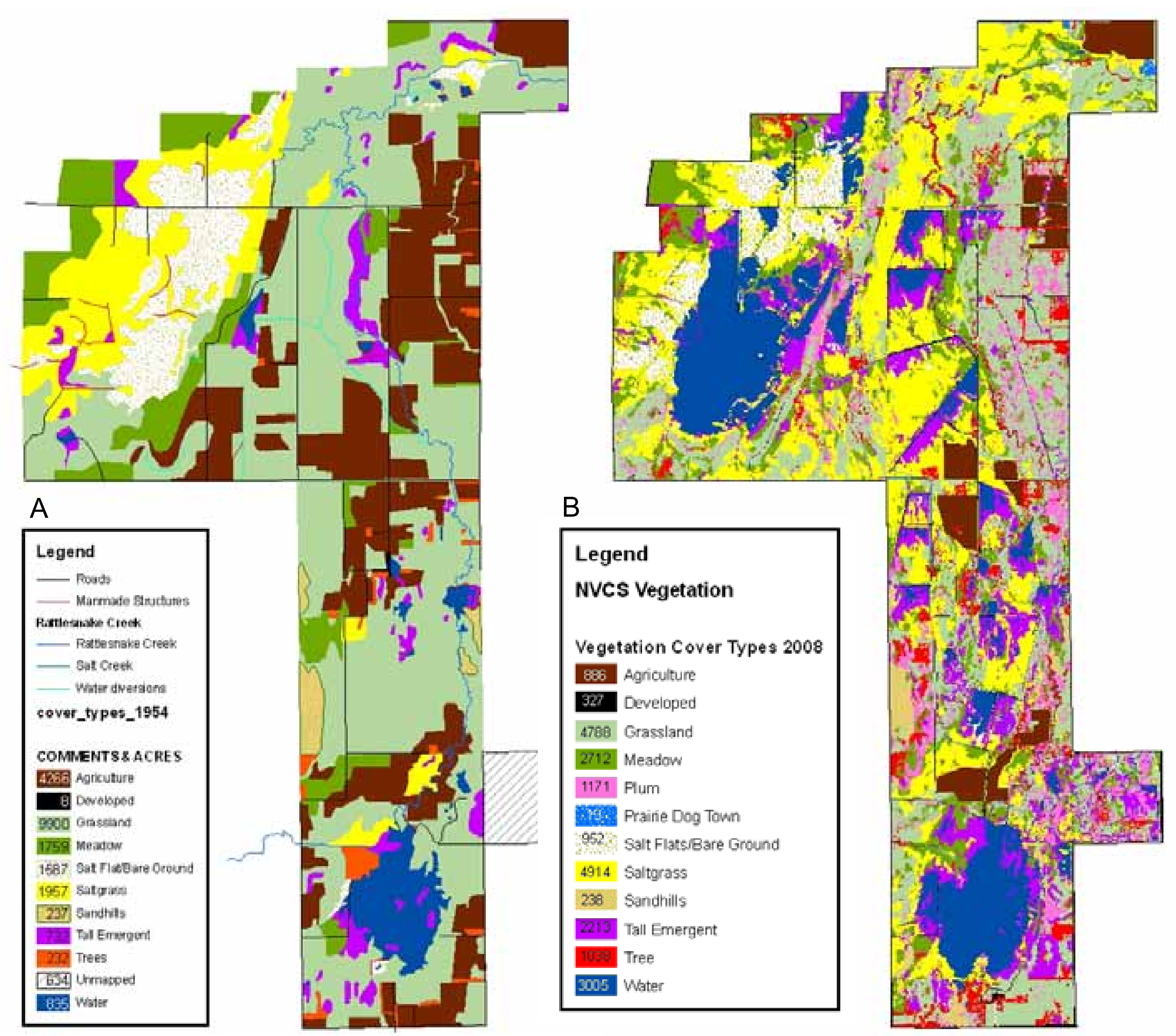


Figure 21. Vegetation land cover on Quivira a) in 1954 adapted from aerial photographs and b) field mapping and interpretation conducted 2008-2011.

common carp (*Cyprinus carpio*) into a largely flow-through surface water system. Major changes in wildlife abundance and habitat use on Quivira NWR are related to alterations in habitat types and conditions at various spatial and temporal scales. General habitat associations and life history characteristics of animal species currently present at Quivira NWR are provided in Appendices A-C).

The critical inputs of ground and surface water to the Quivira NWR ecosystem occurred mainly in spring and summer each year and caused pulses of resource availability that was used by both migrant and resident animals. In spring, increases in discharge of Rattlesnake Creek and some seepage of groundwater recharged wetlands and greatly increased wetland resources used by migrant waterbirds. This water subsequently dried through summer, but more regular inputs of groundwater and high flows in some years created variable amounts of wetland area used by breeding waterbirds, especially those species adapted to using salt flats and saline marshes such as snowy plover (*Charadrius alexandrines*) and least tern (*Sterna antillarum*). The larger salt marsh habitats provided important stopover habitats for spring and fall migrant waterbirds in an otherwise relatively dry prairie landscape in the Great Bend Sand Prairie Region. Grassland habitats supported many mammal and bird species (Appendices A,B).

Rachel Laubhan, USFWS

Cary Aloia

Bob Gress