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Hydrogeologic Framework And Water Balance Investigation of Land near the Gothenburg Canal System

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CONSERVATION AND SURVEY DIVISION
School of Natural Resources

Acronyms:

NPPD – Nebraska Public Power District
CSD – Conservation and Survey Division
LiDAR - light detection and ranging
UNL - University of Nebraska - Lincoln
USGS – United States Geological Survey
CPNRD – Central Platte Natural Resources District
NeDNR – Nebraska Department of Natural Resources
DEM – digital elevation model
NRCS – Natural Resources Conservation Service
HUC – hydrologic unit code
NHD – National Hydrography dataset
NWI – National Wetlands Inventory
cfs – cubic feet per second
GIS - geographic information system

Introduction

The Nebraska Public Power District (NPPD) requested that Conservation and Survey Division (CSD) develop a local hydrogeologic framework and conceptual water budget for a parcel of land near a segment of canal in the Gothenburg Canal System to determine likely sources of ponded surface water that are ephemerally present on the parcel. The study seeks to assess the parcel scale water budget and to better understand the parcel-scale hydrology and hydrogeology. The object of this project is to provide reliable information to NPPD and its customers along a small portion of the canal. Information from this report may influence, or be incorporated into, NPPD's canal water accounting and operations tools. This publication also describes sources, methods, limitations, and recommendations for future work to improve rigor and/or limit uncertainties.

Executive Summary

Information from NPPD, the landowner, and public databases was mined and used to create a GIS, build a hydrogeologic framework, and analyze the water budget around a parcel of interest along Gothenburg Canal in northern Dawson County. New data identified possible subsurface channels capable of creating preferred flow paths to convey groundwater to the site from the west.

Key Conclusions

Bulleted here as a summary of findings relating to why there is sometimes standing water on the parcel.

- New data show that the parcel location is situated above a topographic high of a subsurface channel facies near the toe of an apparent northwest to southeast trending channel deposit that extends north of and to the east of the parcel. This may indicate that there are likely coarse grained conduits of channel sand and gravel conveying high head groundwater from the northwest. These coarse sediments may create preferred flow pathways for groundwater. Adjacent fine sediments may slow groundwater, creating a subtle hydraulic dam effect at the toe(s) of the channel sands and gravels.
- The parcel is concave, with a distinct low area and high potential for the water table to intersect the land surface at the lower elevations or for surface water (precipitation and/or applied irrigation water) to funnel into the low areas and accumulate on the surface.
- The surface of the ponded water in the ditch to the south of the parcel is a primary control on the elevation of the interface between the surface soils and saturated zone (Figure 24) beneath the parcel.
- Land cover change has likely contributed to increased water on the parcel. Historically, the land use on the parcel changed from hay to row crop. Changing crops on the parcel from hay to row crop likely represents a decrease in the evapotranspiration flux around 5 inches per season and potentially a decrease in percolation of precipitation through the root zone. A decrease in evapotranspiration flux will result in higher runoff, soil moisture, and perhaps recharge to groundwater, resulting in higher groundwater levels and/or standing surface water across the parcel.
- Canal seepage at the parcel may be similar in volume to applied irrigation water. Because of the potential of flow to the north and east, there are significant uncertainties relating to the proportion of canal seepage that becomes groundwater beneath the parcel. If the depth to groundwater interpolation and resulting water table configuration is spatially correct, the segment of canal along the parcel of interest should be the only location where seepage is likely to raise groundwater enough to intercept the land surface.

Key Recommendations

Recommendations are given in the order of priority, such that those listed earlier are expected to have the highest likelihood of making significant difference to remedy the standing water issue at the parcel. Thus, these recommendations come with the overall presumption that they be implemented sequentially as a workflow. If high priority recommendations are found to be less than satisfactorily effective to the parties after a range of seasonal conditions are tested, then subsequent recommendations should be implemented and tested.

1. Lower the elevation of standing water in the road ditch. A primary control on the level of groundwater under the parcel and its impact on standing surface water is the level of ponded water along the road south of the parcel. The largest benefit to minimize the extent and duration of ponded water on the parcel is actively maintaining the drain network to the south of the property.
2. Lower the amount of applied surface water and/or increase the consumptive use on the parcel. The simplest way to change consumptive use is to change from row crop to a higher consumptive use crop capable of sub-irrigation, such as hay or grass. Lowering applied surface water can be achieved by waiting for crop stress before watering during growth stages that are stress-tolerant or by deploying an observation network as described in recommendation #3.
3. Manage applied irrigation water with soil moisture measurements. Install soil moisture monitors in the ephemerally inundated area and restrict irrigation of this part of the field to times when soil moisture is insufficient to meet crop needs. Map the ambient soils moisture in the field over a few years to determine pre-irrigation season moisture distribution and minimize applied irrigation water, and/or install an irrigation system that will apply less water to the parts of the field that show consistently higher soil moisture. An alternative approach to this recommendation may be to furrow row crops along the land contours to avoid accumulation of applied irrigation water in the lower parts of the field.
4. Improve understanding of the local (parcel) water budget and hydrogeological framework. Drill new test holes within the parcel and construct observation wells and piezometers completed in and beneath the channel facies, as appropriate. Install water level recorders in the observation wells, the tile drain access box at the south end of the field, in the canal (or stilling well reflecting canal stage), and in the existing observation wells along the canal to document stage/head changes at a refined temporal resolution (hourly) and compare among the observations and to nearby precipitation.
5. Improve understanding of and mitigate canal seepage. Conduct flow measurements and/or geophysical mapping of the adjacent canal (and lateral) reach(s) to update synoptic study (2008) seepage numbers for segments of the canal near the parcel and to document potential changes in seepage rates resulting from previously conducted maintenance activities, such as the sheepsfoot roller compaction completed in 2017. Based on these results, line the section of canal immediately adjacent to the parcel or take additional engineering steps to minimize the amount of seepage in this section of canal.
6. Refine this study using modern remote sensing and borehole geophysics. Conduct spatially robust geophysical mapping supported by new test holes across the study area to better define the framework of channel facies and determine the presence, absence, and thickness of coarse

sand/gravel channels to the west, northwest, and northeast of the parcel, that are indicated by the groundwater contours and channel facies mapping conducted herein.

Methods

Several public data sets were qualitatively reviewed in the study area with some selected for analysis. Public information was queried and gathered from the NeDNR well registration database, NRCS 2011 LiDAR collection project served online by NeDNR (2012), USGS surface water data for the nation, USGS Topography maps from the USGS Earth Science Information Center at the UNL School of Natural Resources (1971), and the USDA Web Soil Survey (Soil Survey Staff, 2019).

CSD gathered public and limited proprietary information into a common directory and created a GIS project in ArcMAP. Data included registered wells (NeDNR, 2019), water rights (NeDNR, 2013), NeDNR and USGS stream gages, National Hydrography datasets for streams and canals, roads, the parcel boundary, watersheds, sections, townships, National Wetlands Inventory wetlands, images/maps provided by the landowner, historical Farm Service Agency (FSA) aerial photographs from 1938, 1951, 1957, 1963, 1969 and 2014, the USGS topographic map of the area (USGS Earth Science Information Center, 1971), the 2-meter digital elevation model from a 2011 LiDAR collection, NRD boundaries, precipitation data and topographic regions.

Previous work was also reviewed, including HDR Engineering’s (2015) study “Irrigation Canal Water Budget Analysis, Nebraska Public Power District: Gothenburg, Dawson County, and Kearney Canals, NeDNR’s (2013) COHYST 2010 model documentation, and Conservation and Survey Division data and publications (2017, undated).

For this work, an area of approximately 293 square kilometers (113 square miles) was selected as a study area. The study area is about 8 miles west to east (range 23 west and part of range 22 west) and 13 miles north to south (township 12, 11 and part of 10 north); it was digitized to provide sufficient context for the local scale analysis. The study area includes two local 12-digit HUCs of interest for this work; the upper portion of Middle Buffalo Creek and Upper Spring Creek (102001010807 and 102001010702 respectively). A fifty eight square kilometer watershed upstream of the Upper Spring Creek HUC, Headwaters Spring Creek (102001010701), was not included in this analysis. The parcel of interest is near the westernmost headwall of the Middle Buffalo Creek watershed, immediately adjacent to the Upper Spring Creek watershed, with about half of the Upper Spring Creek watershed hydraulically above the parcel of interest, and about half of that watershed hydraulically below the parcel of interest.

Some data were incorporated into an excel workbook included with project deliverables, and selected datasets (wells, wetlands and topography) were clipped to the study area boundary and resulting GIS data was stored in the project directory.

There were 1070 registered wells in the study area, 147 of those were removed from the data for lack of a static water level record, resulting in a dataset of 923 registered wells for this project area. Of those wells in the project area, 343 wells are within the Upper Spring Creek watershed, and 42 wells are within the Middle Buffalo Creek Watershed. Most of the registered wells are in the low plain along the Platte River and its sub-parallel tributaries. Wells in the study area were assigned land surface elevation from the 2-meter digital elevation model using the “extract values to points” function. The raster value assigned to each well was converted from meters to feet, to be consistent with the units in the well registration database. Groundwater elevation was calculated at each well by subtracting the static water level from the land surface elevation. There are seven CSD test holes in the study area, five of which recorded the depth to groundwater. The water elevation was calculated in each of the test hole locations by subtracting the depth to groundwater from the land surface elevation.

Five CSD test holes along the west boundary of the parcel were used to examine south to north trends of subsurface strata. Data showed channel facies (unsorted fine to coarse sands and/or gravel) found at varying depths beneath the land surface. A surface representing the top of the uppermost channel facies in the study area was modeled using 923 drillers’ logs from the Nebraska Department of Natural Resources’ well registration database. Logs were analyzed individually and depth measurements recording the top of the uppermost channel facies were manually populated in a new field added to the database and normalized to a common datum using the 2-meter digital elevation model by subtracting the sand depth from the elevation at the well location. Of the 923 logs analyzed, 678 contained descriptions sufficient to assign channel facies from the logs. The top of channel facies was interpolated/extrapolated across the study area to a raster cell size of 6.56 feet (to correlate 1:1 with the 2 meter DEM) using the Topo to Raster function in the Spatial Analyst toolbox of ArcMAP. The interpolated sand surface was then compared to the land surface by subtracting it from the 2-meter DEM on a pixel-by-pixel basis using the “Minus” tool in the Spatial Analyst toolbox of ArcGIS, resulting in a 2-meter raster dataset illustrating the depth to channel facies in each pixel of the DEM. Negative values in this calculation represent areas where the sand body will likely be at or very near the land surface. The depth to channel facies from the modeled surface was compared back to the CSD test holes facies depths described in the test hole database, resulting in a reasonable comparison.

Groundwater elevation was also interpolated/extrapolated across the study area to a raster cell size of 6.56 feet (to correlate with the 2 meter digital elevation model) using the Topo to Raster function in the Spatial Analyst toolbox of ArcMAP. The interpolated groundwater surface was then compared to the land surface by subtracting it from the 2-meter DEM on a pixel-by-pixel basis using the “Minus” tool in Spatial Analyst toolbox of ArcGIS, resulting in a 2-meter raster dataset illustrating the depth to groundwater in each pixel of the DEM. Negative values in this calculation represent areas where the study area head distribution of groundwater indicates that groundwater should likely be at or very near the land surface.

A qualitative analysis of historical aerial photography in the GIS was conducted to understand the long-term changes at the parcel, augment the hydraulic analysis, and inform the development of a conceptual water budget for the parcel. A hydraulic analysis of the land surface at the parcel was conducted, and calculations were made in ArcGIS using the Fill function to eliminate much of the noise in the topographic DEM, and to use the resulting DEM to determine flow direction, flow accumulation, slope and aspect of each DEM pixel in the study area. The data and analyses described above were used to conceptualize a water budget for the parcel of interest.

Physical Setting, Site Geology and Soils

The study site is in Dawson County, NE within the Central Platte Natural Resources District (Figure 1), along the northern margin of the broad Platte River valley, in the valley topographic region corresponding to the Platte River mainstem as well as the dissected plains just north of the valley, (Figure 2) and lies in the west part of the Buffalo Creek watershed just east of the Spring Creek watershed (Figure 3). The distinct low/flat area in the valley makes up more than the southern half of the study area (Figure 4).

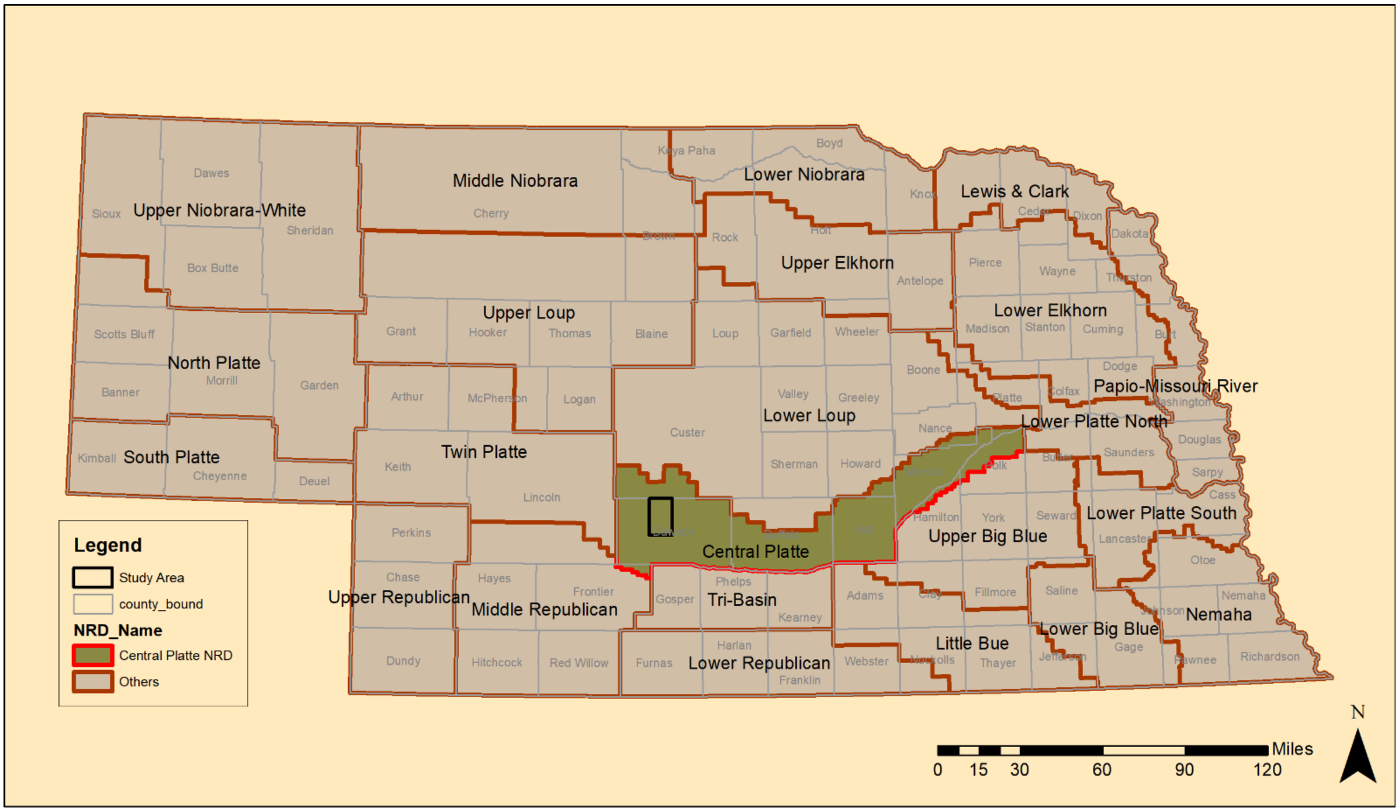

Figure 1. Map showing the study location, study area, Nebraska Natural Resources District, and county boundaries.

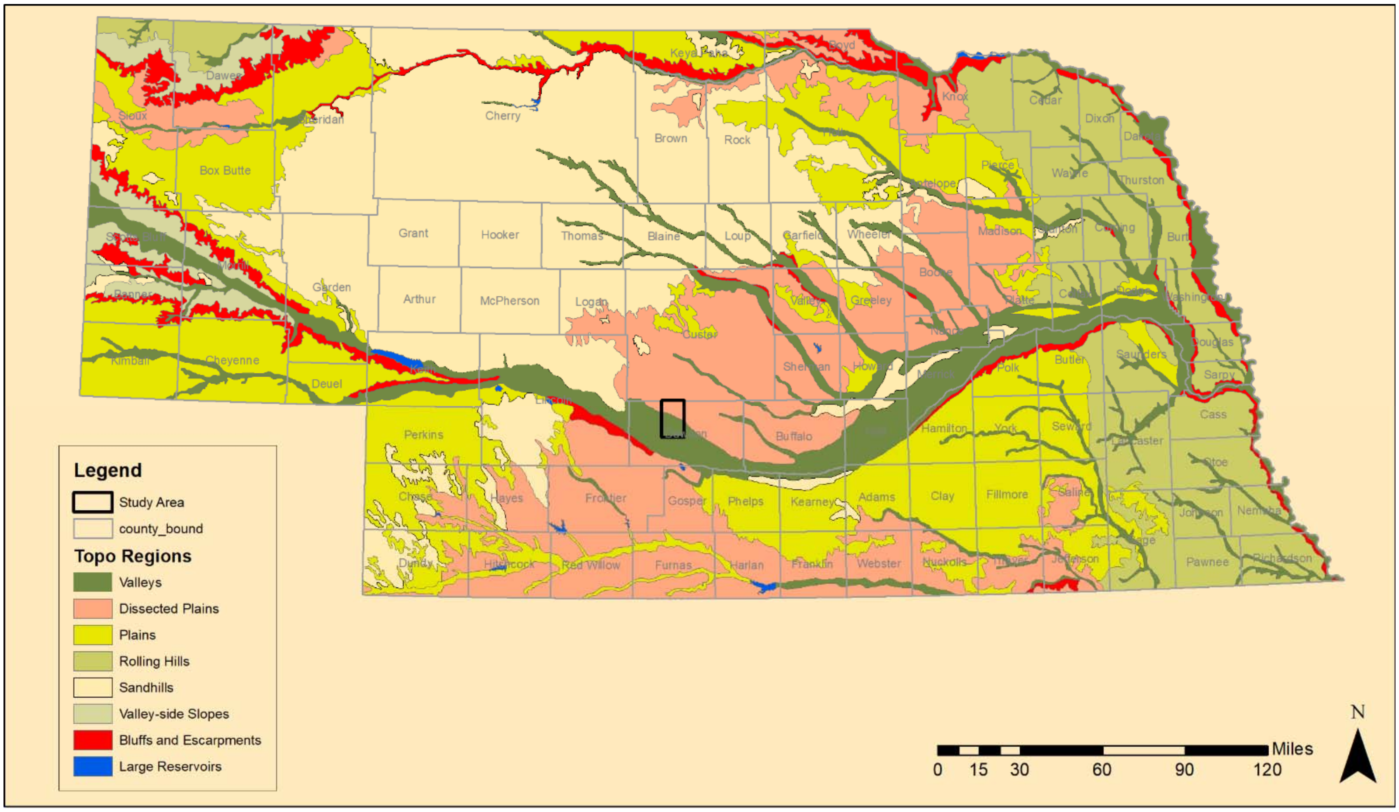

Figure 2. Map of Nebraska showing the study location and study area with respect to topographic regions.

The parcel of interest lies roughly centered in the study area along the margin of the Platte River terrace and dissected plains. The Gothenburg Canal is cut along the transition between river terrace and dissected upland, bisecting the parcel. Hay and/or row crops have been grown on the portion of the parcel south of the canal. The dissected upland part of the parcel was and is maintained as pasture.

Surface materials in the region are undifferentiated Quaternary age sediments, mostly silt and clay of varying thickness over alluvial silt, sand, or sand and gravel. Bedrock is Miocene age Ogallala group strata. The Ogallala Group is highly variable vertically and horizontally and includes unconsolidated silt, sand, and gravel, as well as cemented siltstone, sandstone and conglomerate. Lower bedrock units may include Arikaree and/or White River Group sands, silts and clays. The Cretaceous Pierre shale underlies the region (CSD, undated). A chart showing the general geologic framework in the study area is illustrated in Figure 5.

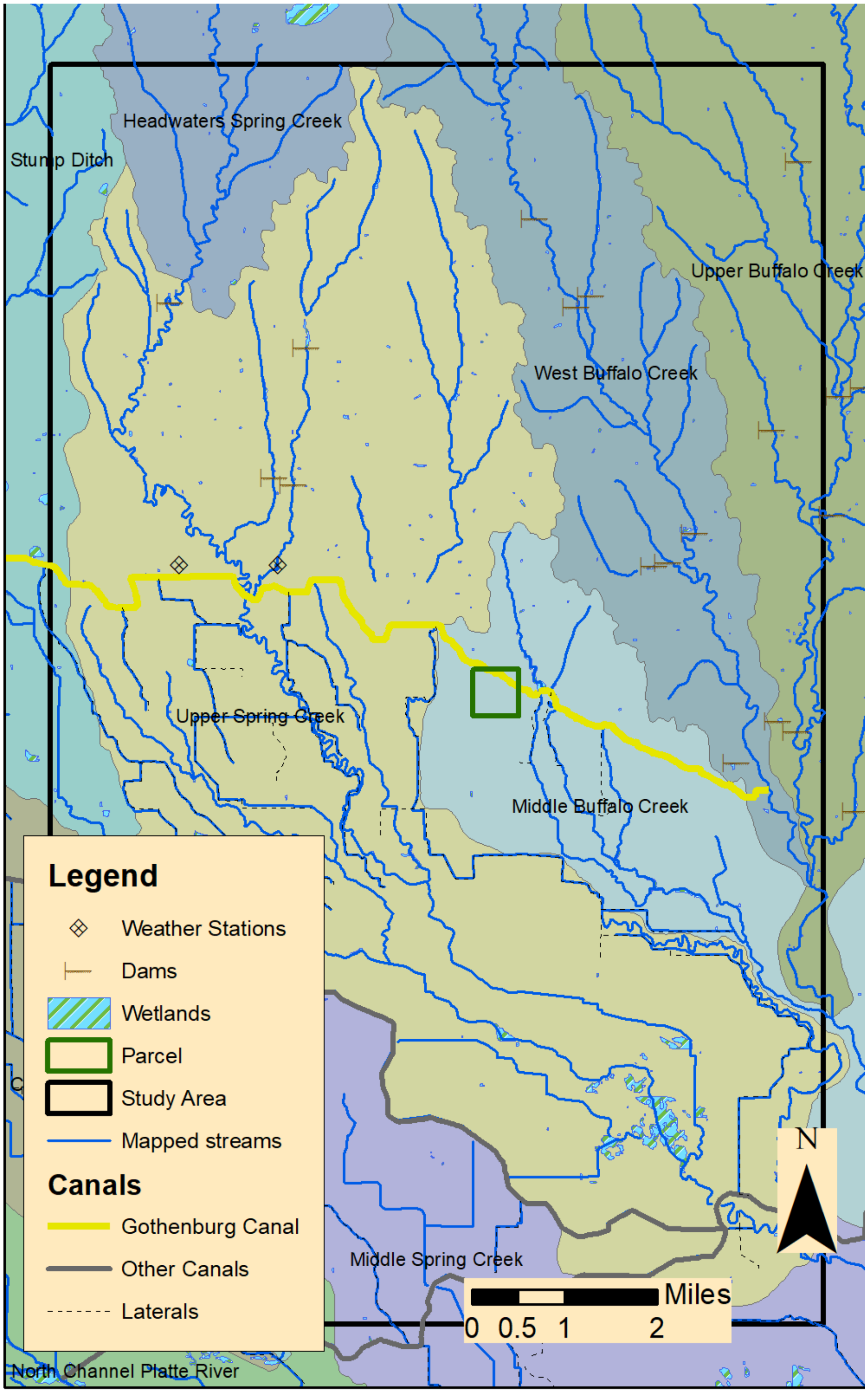

Figure 3. Map showing the study area and location of the parcel of interest. HUC 12 digit watersheds are colored and labeled. NHD major steams, NWI wetlands, canals, laterals, and dams and weather stations are symbolized as shown in the legend.

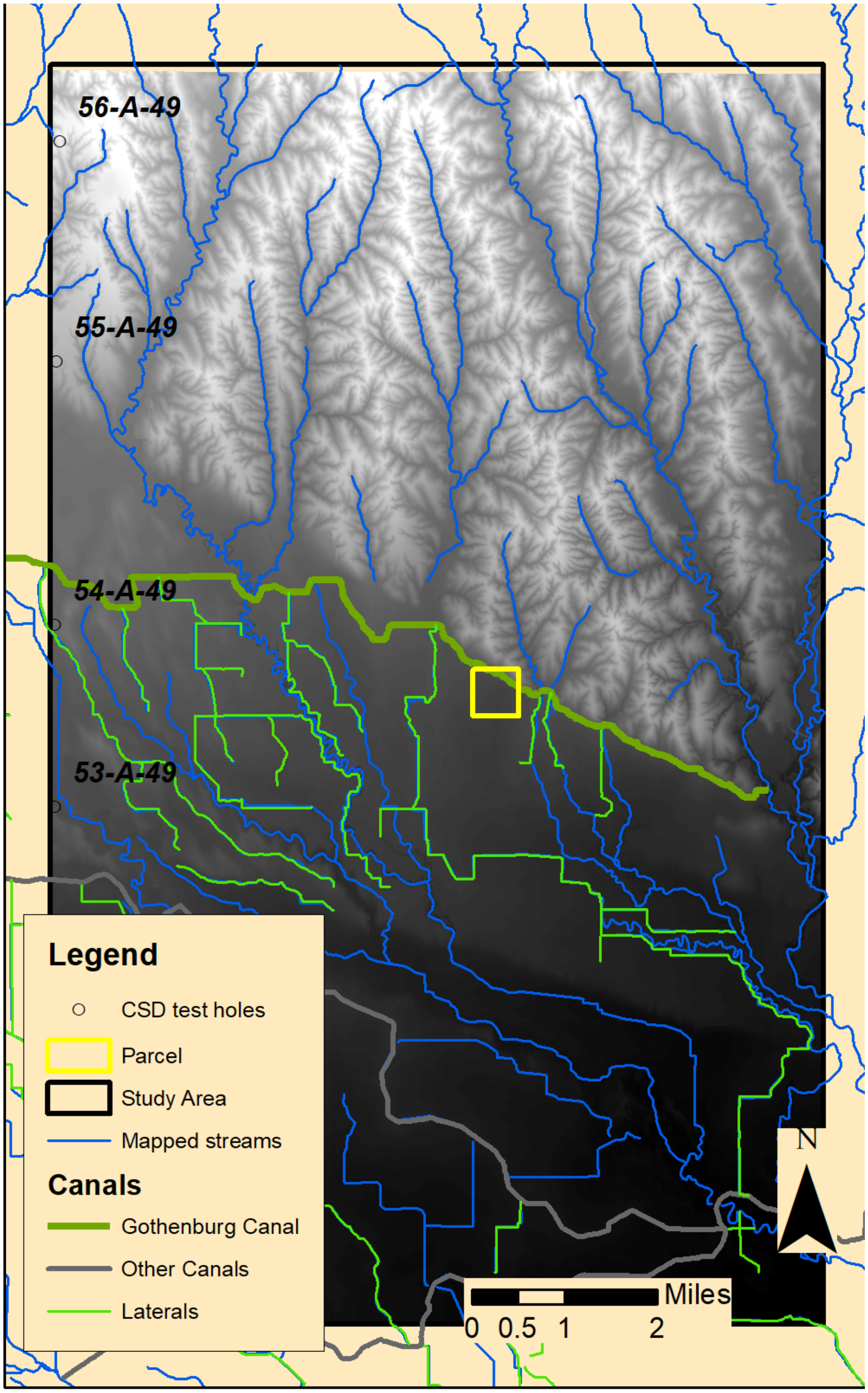

Figure 4. Map showing test holes used to build geologic framework of the study area and the DEM used to define the land surface elevation.

PERIOD	EPOCH	GROUP	FORMATION
QUATERNARY	Holocene and Pleistocene		Undifferentiated
NEOGENE	Miocene	Ogallala	Ash Hollow
			Valentine
			Sheep Creek
			Runningwater
		Arikaree	Harrison
			Monroe Creek
PALEOGENE	Oligocene		Gering
		White River	Brule
			Chadron
	Eocene		Chamberlain Pass
CRETACEOUS	Late Cretaceous		Laramie
			Fox Hills
		Montana	Pierre Shale

Figure 5: Chart illustrating a generalized geologic framework of central Nebraska. Undifferentiated quaternary strata are found at the land surface, and Ogallala Group strata subcrop in the study area. Strata below the Ogallala Group are undifferentiated herein.

All of the CSD test holes and many of the registered well logs have a relatively shallow channel facies (unsorted medium to coarse sand and gravel) noted in them. The configuration of the top surface of this sand and gravel body, and its relationship to the land surface may be of significance to water movement onto, or away from the land surface, and may influence the ephemeral distribution of surface water. The degree of connectedness spatially may influence whether groundwater will drain away from or toward any given location in the study area. The interpolated/extrapolated surface created to represent the upper limit of channel sands/gravels was compared to actual observations made in the CSD test holes, and the results showing a favorable comparison are shown in Figure 6.

Location	Interpolated Channel Facies Prediction (registered wells model)	Top of Shallowest Channel Facies Described (test hole database)
51-A-49	7	7
52-A-49	16	22
53-A-49	74	63
54-A-49	83	88
55-A-49	127	156
56-A-49	252	236

Figure 6: Chart showing the estimated depth to the top of channel facies at CSD test hole locations from the interpolation/ extrapolation of drillers' logs (left) compared to the top of channel facies documented in the CSD test hole logs (right).

Figure 7 shows that while channel facies slope generally to the east-southeast, sub-parallel to the Platte River, the parcel location is situated above a topographic high of the channel facies near the toe of an apparent northwest to southeast trending channel deposit. Southeast of the parcel there is a rather abrupt step downward in the surface. This may indicate that there are likely coarse grained conduits of channel sand and gravel conveying groundwater from the northwest, with finer grained overbank or windblown facies (fine sand, silt and clay) to the southeast of the parcel. The coarse sediments sloping to the east may create preferred flow pathways for groundwater. Several data points east-northeast of the parcel show a relative topographic high of the top of channel facies, a possible continuation of the coarse grained conduit from the northwest of the parcel. Over distances on the east sloping land surface of the High Plains, similar configurations of sediments have been known to create discharges of groundwater at the land surface, like the Blue Hole on the Dismal River (Goeke, 2009). Finer sediments to the east may slow groundwater flowing eastward, creating a subtle hydraulic dam effect at the toe of the channel sands and gravels.

The interpolated sand surface was then compared to the land surface by subtracting it from the 2-meter DEM on a pixel-by-pixel basis using the “Minus” tool in 3D Analyst toolbox of ArcGIS, resulting in a 2-meter raster dataset illustrating the depth to sand in each pixel of the DEM. Negative values in this calculation represent areas where the sand body will likely be at or very near the land surface. Figure 8 shows the map resulting from these calculations. This map indicates that the parcel location is unique when compared to nearby parcels, inasmuch as the calculated depth to channel facies is much smaller than surrounding parcels. Interestingly, another location northwest of the parcel of interest also has channel facies very near the land surface, and may make an interesting case study if further analysis were conducted by pairing the two parcels and examining similarities and differences. Figure 9 shows the calculated depth to channel facies at the parcel scale.

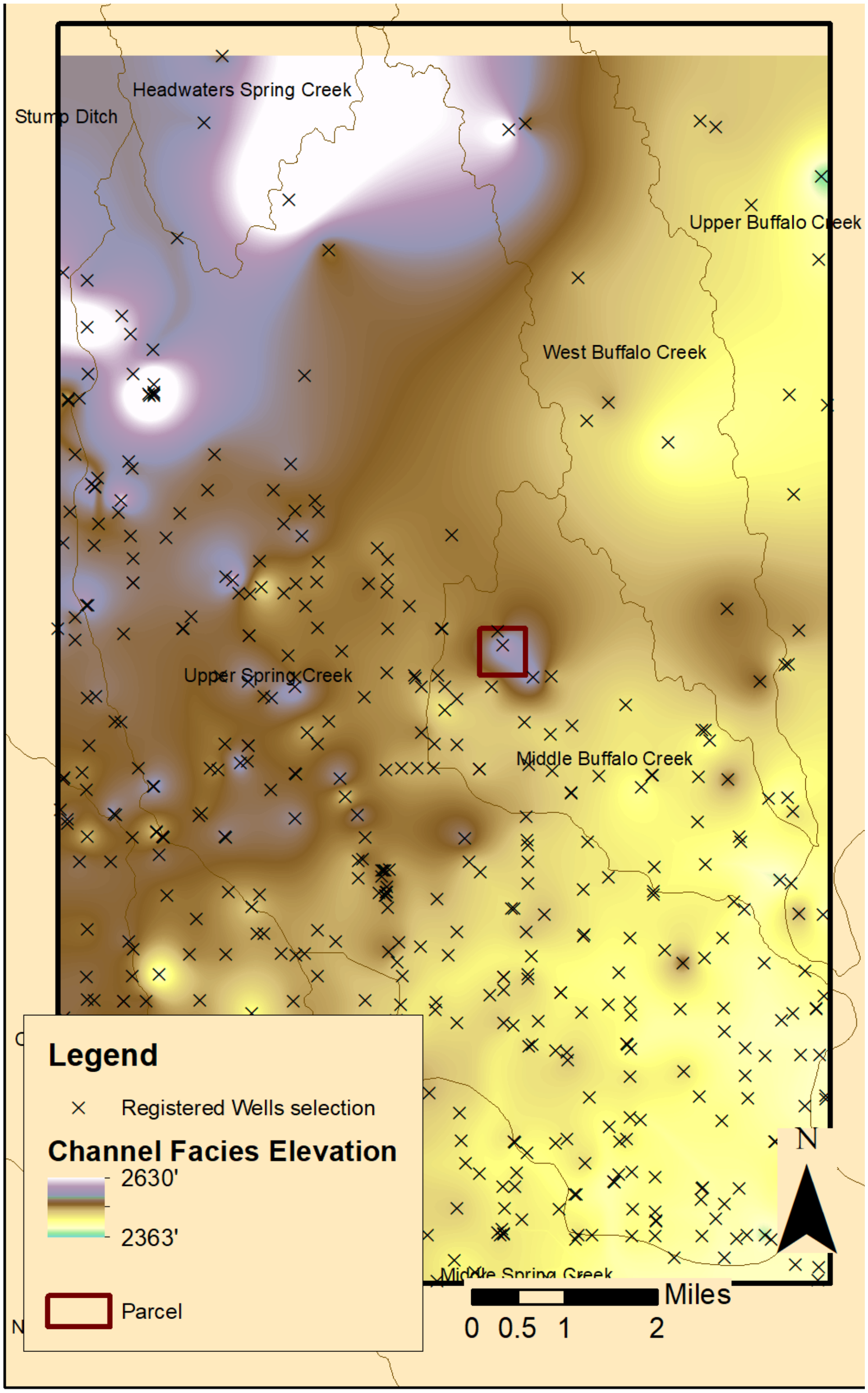

Figure 7: Map illustrating the interpolated/extrapolated elevation of the top of documented channel facies in the study area.

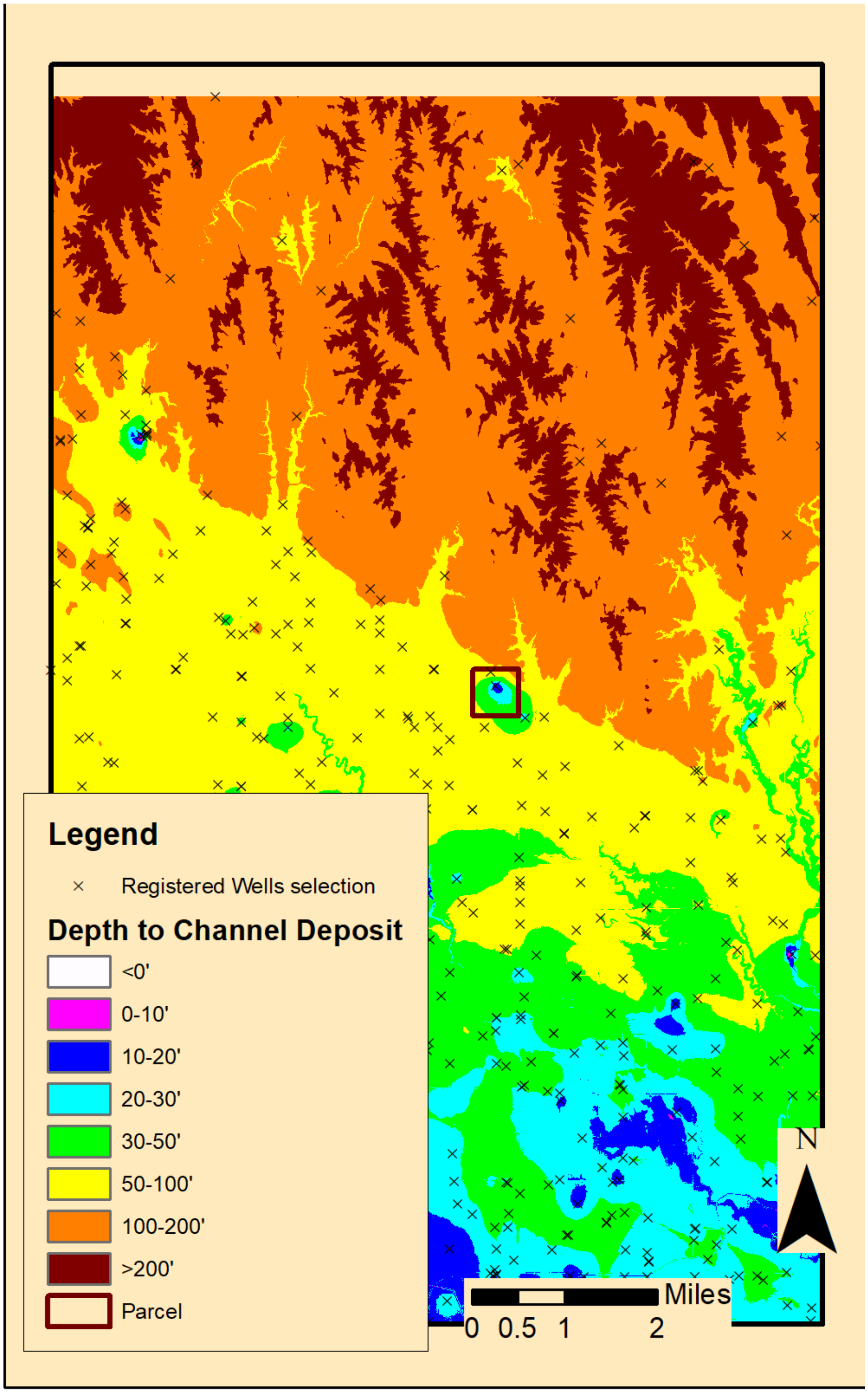

Figure 8: Map showing the modeled depth to channel facies in the study area. Note that a much shallower depth to channel facies corresponds with the parcel location when compared with the surrounding area.

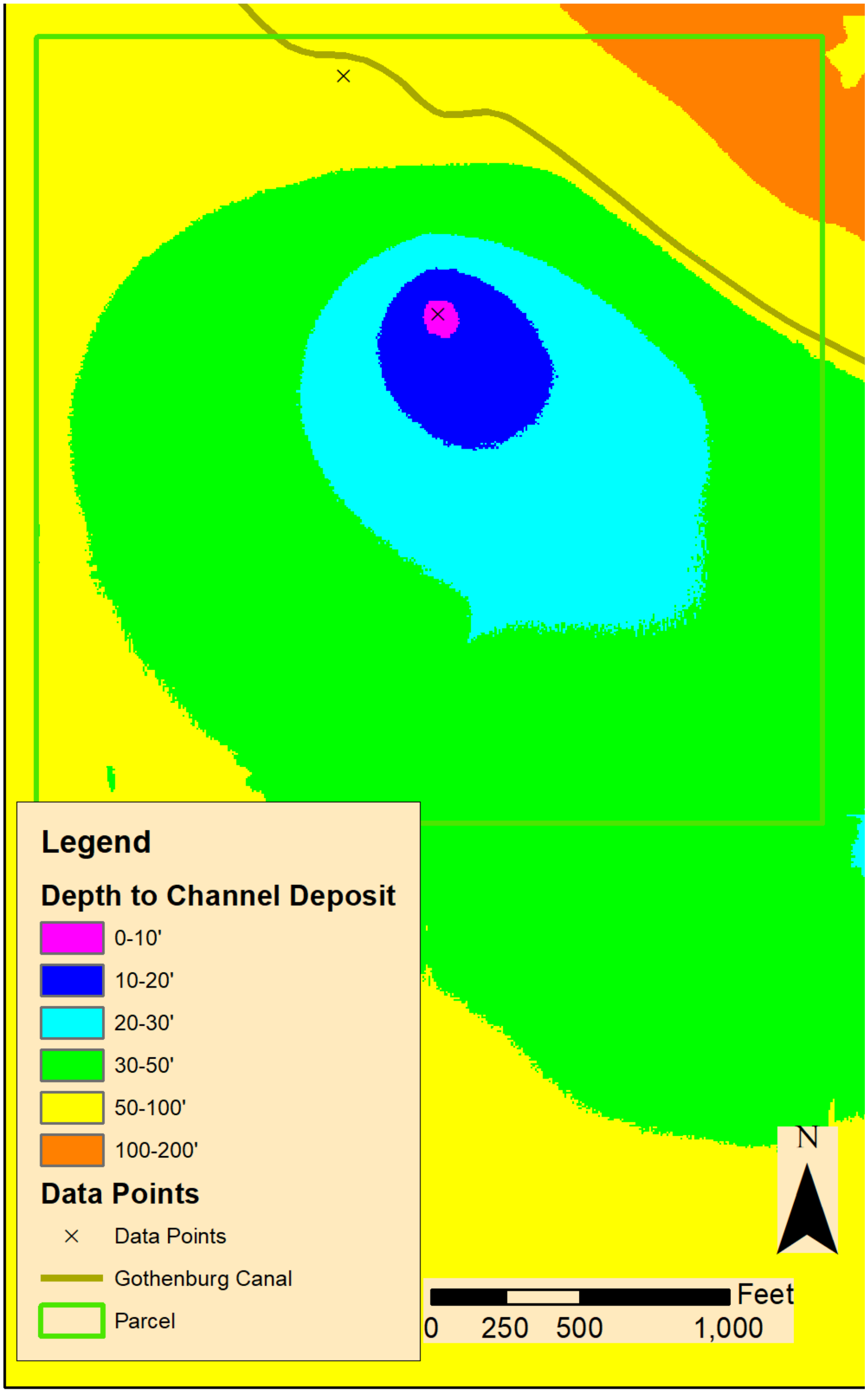

Figure 9: Map detailing the interpolated depth to channel facies at the parcel of interest.

Precipitation, Hydrology and Hydrogeology

The strata described above are all comprised of sediments deposited in marine (Pierre Shale), dominantly fluvial (Ogallala Group), and dominantly subaerial (White River Group, Arikaree Group, and Quaternary loess) settings (Bleed and Flowerday, 1998). Sediments deposited by water (marine and fluvial) generally reflect a direct relationship between the amount of energy in the environment and grain size and an inverse relationship between the distance from the sediment source and the depositional environment, thus sediments transported into a basin (marine) tend to be dominated by fine grain sizes, such as clays with silt, while those on slopes and in fluvial (river) settings tend to be dominated by coarser grain sizes, such as sands and gravels. Subaerially deposited sediment grain size is limited to fine sand, because wind can move sand along the land surface by saltation (bouncing), or silt and clay size particles can be suspended in the air for varying lengths of time, depending on the direction and speed of air movement. Generally, coarser sediments have higher hydraulic conductivity than finer sediments because of the generally larger pore sizes. Clays are sufficiently fine that they provide little sufficiently connected pore space through which water can move, and have electrical properties that can bind the polar water molecules in a way that retards the movement of water. Compaction of sediments can limit hydraulic conductivity of all grain sizes, but likely affects the finer silts and clays disproportionately, greatly reducing their ability to transmit water. Generally, this means that the coarser fluvial sediments may provide preferred flow pathways for water in the subsurface. Unfortunately. Fluvial systems can be very complex so mapping their distribution in the subsurface is limited by the spatial density and distribution of data points.

Over the long term, groundwater levels in the study area are within 5 feet of their predevelopment level, but just to the west in the northwest corner of Dawson County, and further east along the Dawson/Buffalo County line, significant historical declines up to 20 feet have been recorded (Young et. al. 2018). Over shorter timeframes (20, 10, 5 and 1-year), changes in the study area are mixed (Young et. al. 2018), and correlate very generally with average precipitation over corresponding timeframes. Aquifer saturated thickness in and near the study area should be about average for the Nebraska portion of the High Plains Aquifer, at around 400 feet (Korus et.al. 2013).

There are no USGS or NeDNR stream gages in the study area. There is one cancelled water right in the Middle Buffalo Creek watershed, downstream of the parcel of interest. There are nine water rights in the Upper Spring Creek watershed, two are active storage rights that are hydraulically above the parcel location associated with two dams; Reservoir 9-A and 9-B, located together almost three and one-half miles northwest of the parcel as shown in Figure 3. They are permitted for 55.7 and 62.8 acre-feet of storage, respectively (NeDNR, 2013). Interestingly, the water table elevation near the dams does not seem to be significantly affected by the presence of the dams and their storage water on the land surface. The active storage appropriations held for Reservoirs 9-A and 9-B may influence the groundwater head in the Upper Spring Creek watershed, possibly influencing groundwater levels slightly in the upper portions of the Middle Buffalo Creek watershed, particularly hydraulically above the Gothenburg Canal. The seven remaining rights are all downgradient of the parcel, and are expected to have negligible impact on the hydrogeology at the parcel: one is an active natural flow irrigation right, five are cancelled natural flow irrigation rights, and one is a denied application (NeDNR, 2013).

The USGS 7.5-minute topography map (1971) symbolizes Middle Buffalo Creek just northeast of the parcel as an ephemeral stream, and maps Peden Lake as a wetland along an ephemeral stream, consistent with the National Wetlands Inventory map (US Fish and Wildlife Service, 2011). About 4 miles west of the parcel, Spring Creek is mapped as a perennial stream (USGS, 1971). Stream discharge records for Buffalo Creek, just east of the study area, were collected from 1947 to 1969, representing the closest and best surface water data we have for the study area. The maximum flow over that period occurred on June 22, 1947, when local flooding occurred and discharge was recorded at nearly 5,000cfs. Much of the period saw no flow in the stream, such that mean flow over the period of record is 4.2cfs, which is fairly heavily influenced by the flood event in 1947. Decadal mean flows are 8.3cfs in the 1940s, 3.3cfs in the 1950s and 3.8cfs in the 1960s, further demonstrating the significant influence of the 1947 flood on the mean flow over the decade. A qualitative view of the data plotted by date demonstrates no distinct trend (Figure 10). While the data do not cover recent conditions, they may be indicative of the ephemeral nature of surface water in the study area, as well as illustrating that when water is found to flow on the land surface, the flows tend to be in excess of what the Gothenburg Canal is capable of seeping, and are often in excess of the amounts the canal is capable of conveying.

The B-1 reservoir east of the study area gets its water supply from the Gothenburg Canal, and this data may be considered a proxy for times when surface water is plentiful and there is extra water in the canal. Figure 11 shows data from 1983 to 2019. The linear trend of the data shows a slightly decreasing trend. The trend is likely driven by the relative lack of water delivery from 1996 to 2013, as recent deliveries have been more frequent.

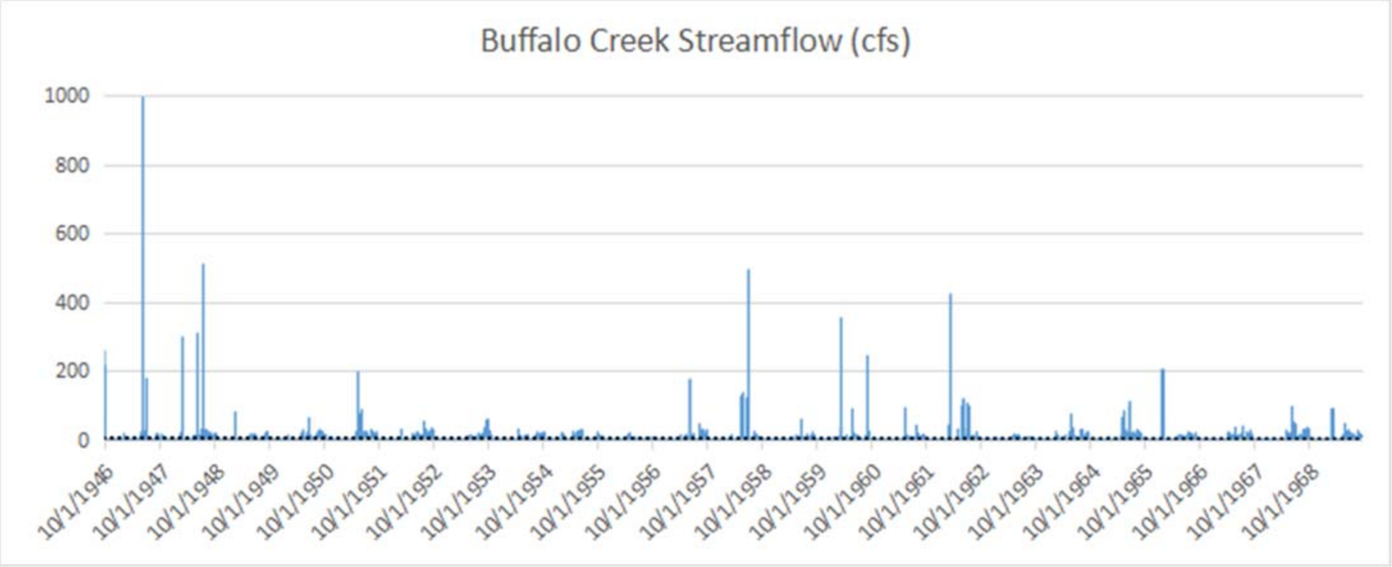

Figure 10: Chart showing stream discharge of the Buffalo Creek, downstream of the study area, between 1947 and 1969. The black dotted line shows the linear trend of the data over the time period, which is flat along the horizontal zero axis. The June 22, 1947 data is off scale, representing a single discharge of almost 5,000cfs.

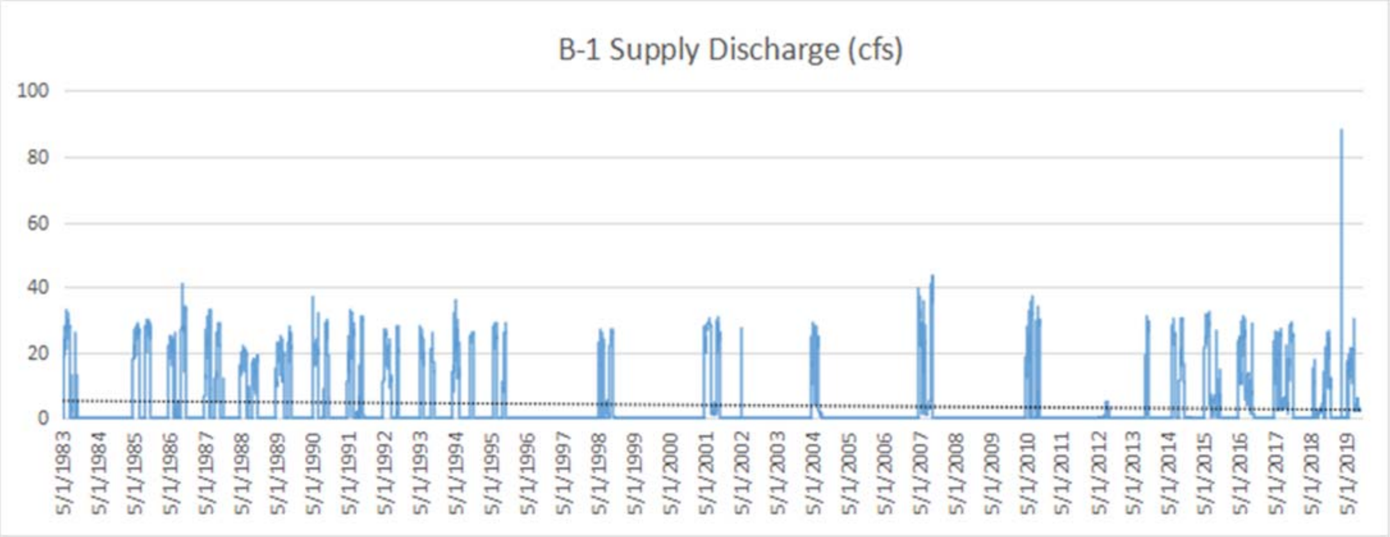

Figure 11: Chart showing canal discharge to B-1 reservoir, downstream of the study area, between 1983 and 2019. The black dotted line shows the linear trend of the data over the time period. The downward slope of the linear trend is likely heavily impacted by the relative lack of discharge between 1996 and 2013.

Precipitation data was collected from the High Plains Regional Climate Center (2019) by NPPD, and consists of two sets of records, Cozad 2S and Cozad 8N. Both weather stations are mapped northwest of the parcel as shown in Figure 3. The record for Cozad 2S begins in 1996 and ends in 2019, and includes precipitation and snowfall components. The record for Cozad 8N begins in 2004 and ends in 2019, and includes only precipitation. Daily data are illustrated in Figure 12 and annual data are illustrated in Figure 13. Linear trends of the data over the periods of record shows no distinct trends. The annual 5-year moving averages in Figure 13 vary from approximately 18 to 28 inches per year, with the wettest period between 2007-2011 and a slightly wet period from 2017-2019. The 180-day moving averages in Figure 12 show little year-to-year departure from normal for the entire period of record, except respecting snowfall data from 2017-2019 that shows a significant increase from previous data.

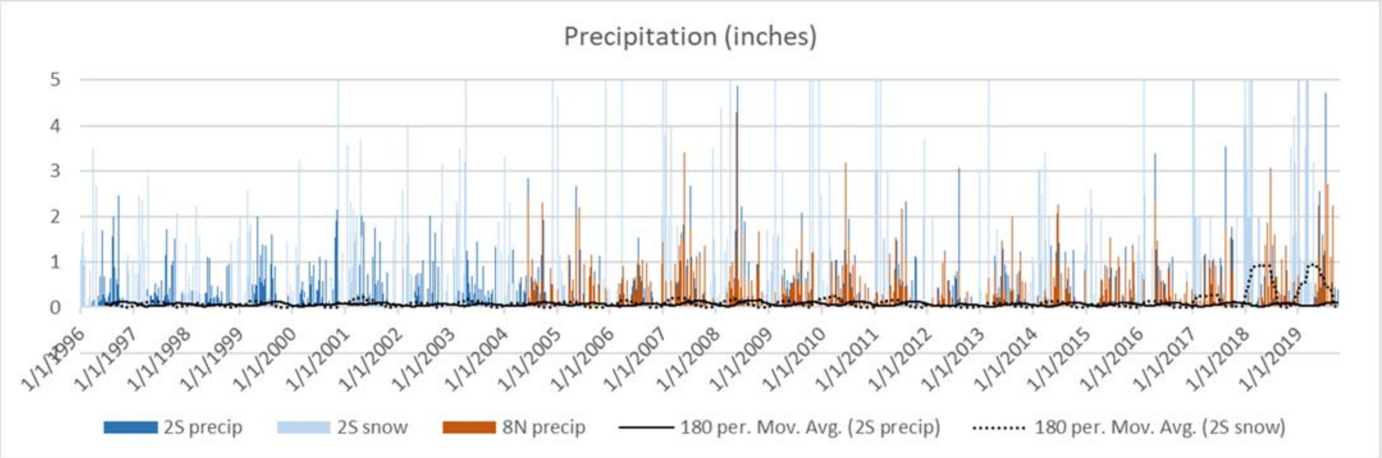

Figure 12: Chart showing daily precipitation data and moving averages between 1996 and 2019. The solid black line shows a 180-day moving average of the daily "2S" precipitation data over the time period and the dotted black line shows a 180-day moving average of the daily "2s" snowfall data. While the moving average of precipitation data do not indicate a trend, the snowfall data is showing a significant upward departure since 2017.

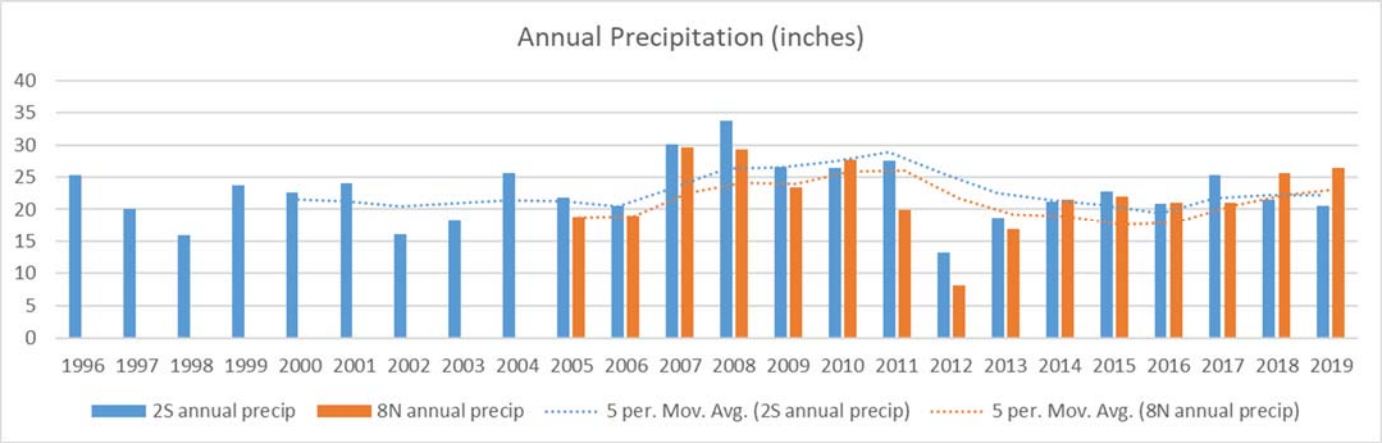

Figure 13: Chart showing annual precipitation data between 1996 and 2019. The blue dotted line shows the 5-year moving average of the annual “2S” precipitation data and the orange dotted line shows the 5-year moving average of the annual “8N” precipitation data over their respective time periods. While the moving averages vary, they are relatively flat over the period of record.

The water table surface was calculated using CSD test holes and registered wells in the study area (Figure 14), and interpolated/extrapolated at a 2-meter resolution to the extent of available data within the study area (Figure 15). Based on the calculated water table configuration, groundwater flow direction at the parcel of interest may be north (then immediately east), east and/or south. The complex contours near the parcel may be an indication of subsurface channels of coarse material that represent preferential flow pathways for groundwater. These preferential pathways should have the effect of causing lower that normal gradients (widely spaced contours). A regionally generalized map of the area surrounding the parcel would show a dominant flow to the east-southeast, sub-parallel to the Gothenburg Canal at the parcel location. The water table configuration shown in Figure 15 gives little indication of influence from the Gothenburg Canal or its laterals, though determining a relationship between groundwater and canal water from data collected over decades of well drilling for this purpose is uncertain. A map of the expected depth to groundwater is shown in Figure 16. Interestingly, data at the parcel shows that the expected depth to groundwater at the parcel (Figure 17) is significantly shallower than the surrounding area, and could be as shallow as five feet below land surface according to the interpolation. The shape of the expected shallow groundwater is only generally consistent with lower than normal crop yields from 2014 and 2016, while it also correlates generally with higher than normal crop yields in 2015 and 2017, and demonstrates little correlation with yield patterns from 2012 and 2018. The crop yield data was provided as hardcopy by the landowner and is included as Appendix A.

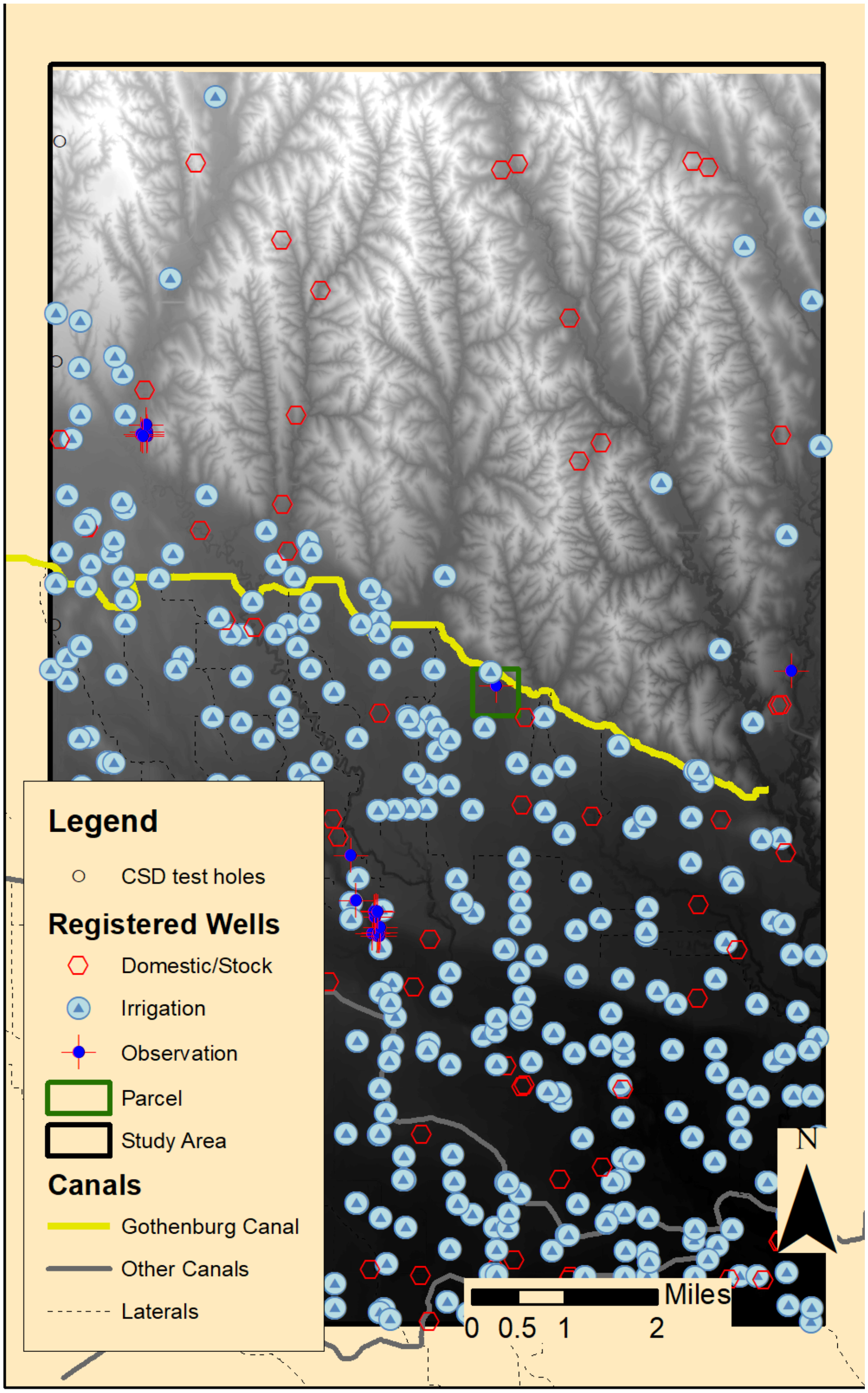

Figure 14. Map showing registered wells and CSD test holes in the study area that were used to calculate the water table elevation.

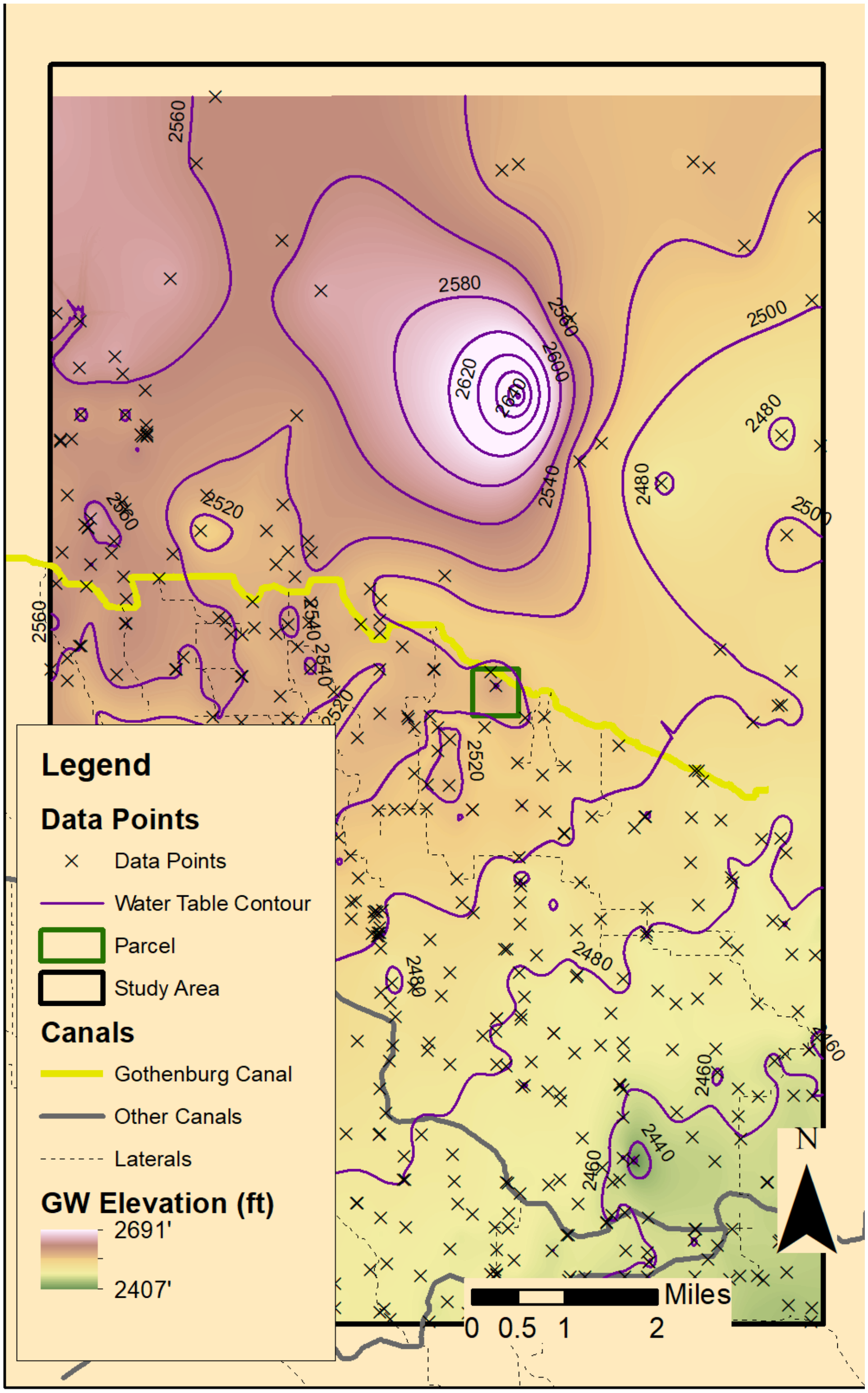

Figure 15. Map showing calculated groundwater elevation and resulting 20-foot contours in the study area; as well as data points used in the calculation. The low elevation trough just north of the parcel may be an indication of a high hydraulic conductivity zone with a west-northwest to east-southeast trend parallel with the Gothenburg Canal.

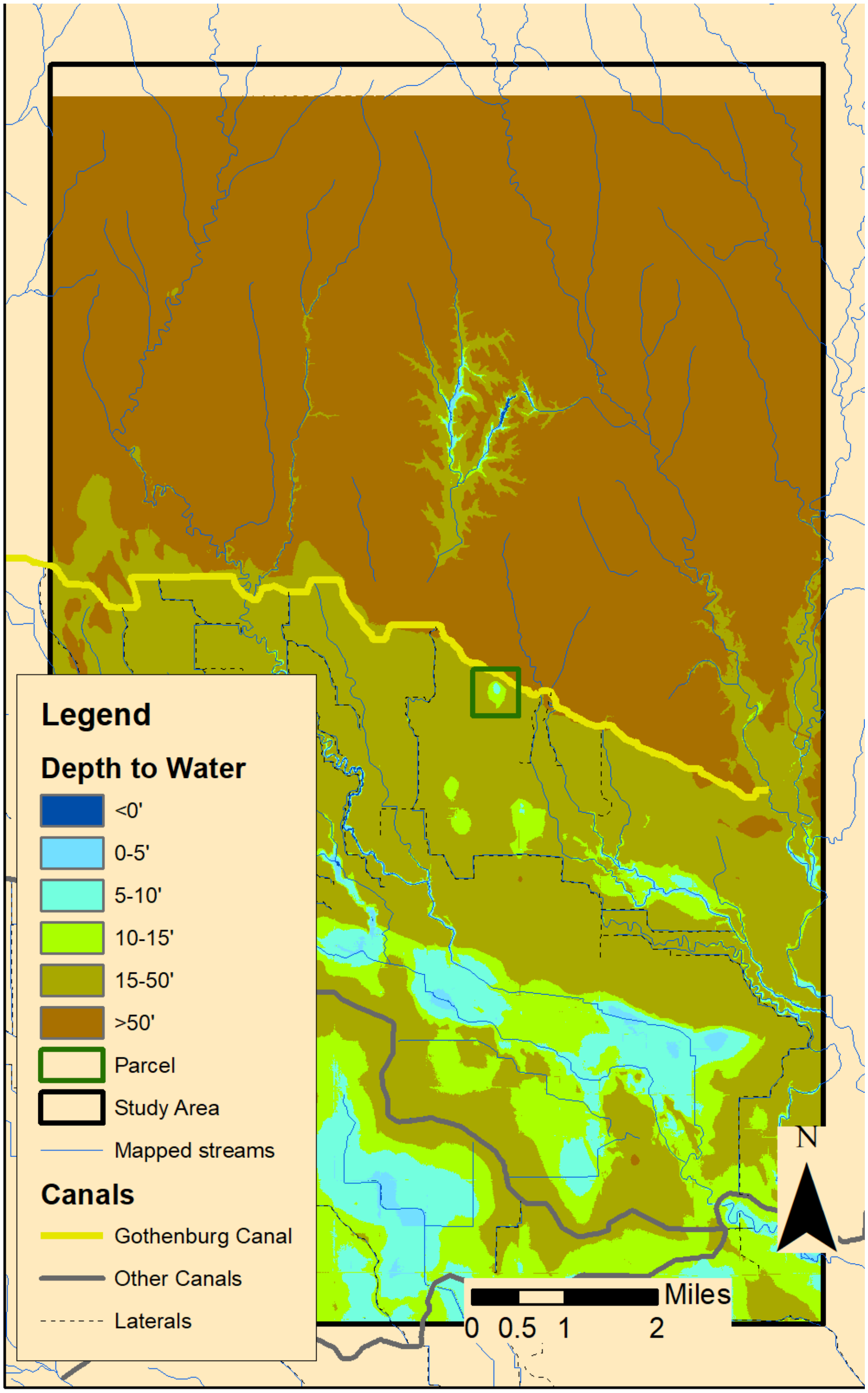

Figure 16. Map showing calculated (modeled) depth to groundwater in the study area.

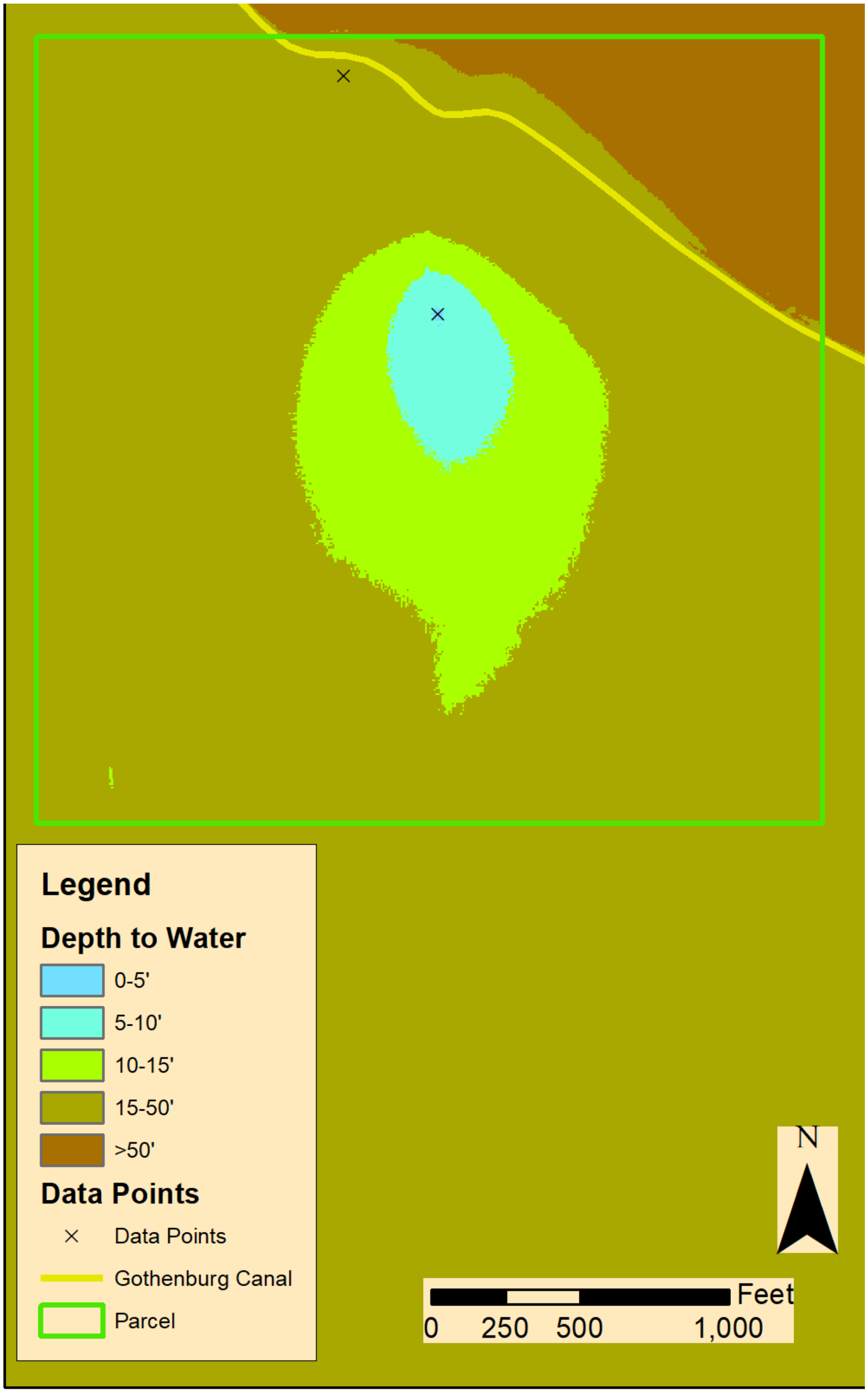

Figure 17. Map showing calculated (modeled) depth to groundwater in the parcel area.

Historical aerial photography from 1938 and 1951 (Figure 18), 1957 and 1963 (Figure 19) show varying field configurations within the parcel, many showing evidence of haystacks, indicating that the landuse category for the fields was irrigated hay in those years. The image from 1969 (Figure 20) may have haystacks in the northeast quadrant of the parcel, but much of the parcel may have been planted to row crop if the image was collected after hay cutting. The USGS topographic map reflects the parcel condition of 1969, and none of the images provide reliable information relating to historical yield that indicate a pattern similar to those produced in the modern yield maps. Even recent aerial photography (Figure 21) gives little indication of yield varying across the parcel.

Figure 18. Aerial images of the study parcel collected in 1938 (left) and 1951 (right). Note that the 1938 image shows a natural channel beginning in the south-central part of the parcel of interest that drains water across the road bisecting the adjacent parcel to the south. Subsequent images show that the natural drain was farmed in and straightened. The LiDAR elevation model in Figure 21 indicates that the drain may have filled with sediment.

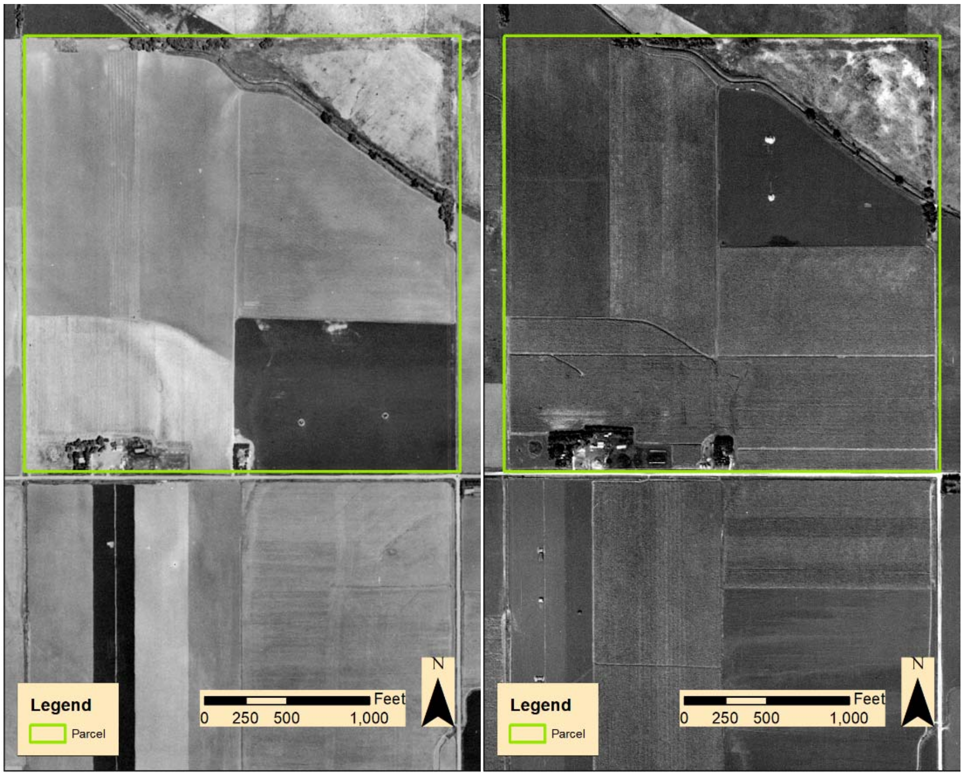

Figure 19. Aerial images of the study parcel collected in 1957 (left) and 1963 (right).

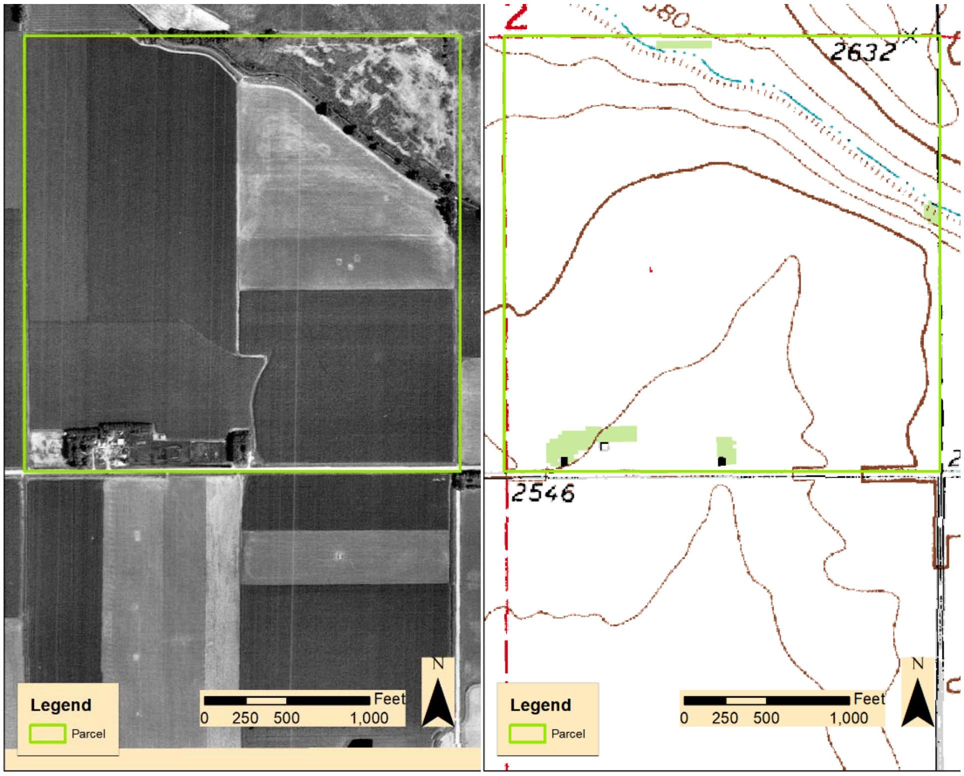

Figure 20. Aerial image of the study parcel collected in 1969 on the left and USGS topographic map published in 1971 on the right.

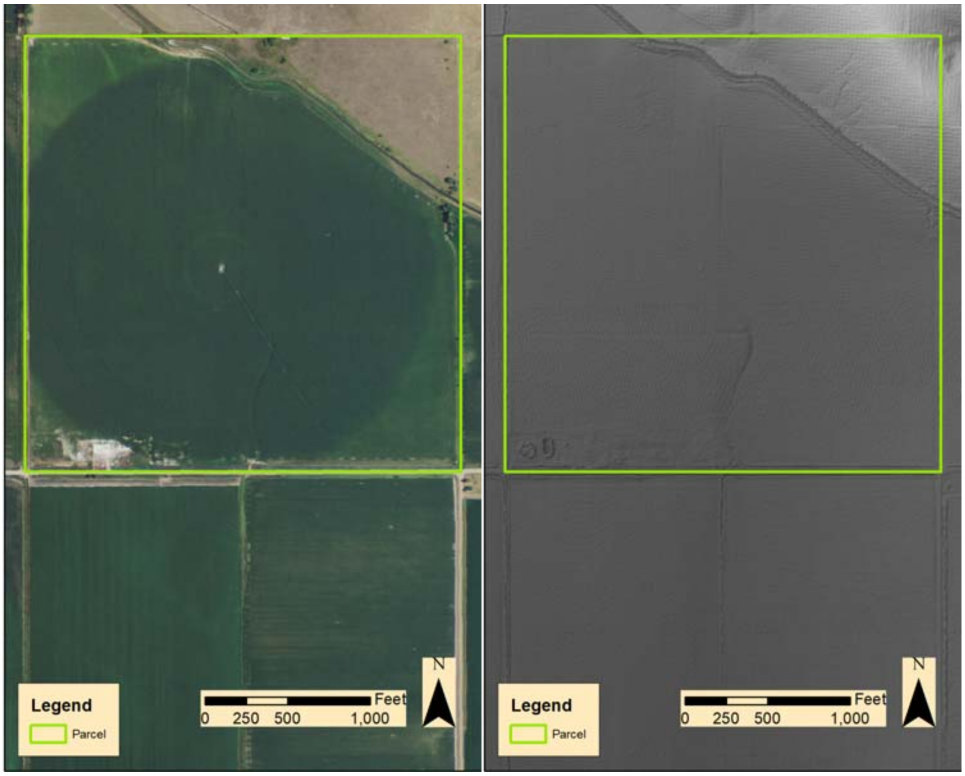

Figure 21. Maps of parcel location showing recent FSA aerial image (left), as well as a hillshade of 2-meter digital elevation model (right) from LiDAR data collected in 2011 showing the morphological configuration of the study location.

Borings on and near the parcel indicate that there is a mantle of silt and/or clay above sandy/gravely strata. Fine grained sediments such as silt and clay will tend to retard the percolation of water into the subsurface, so a hydraulic analysis of the land surface was conducted to better determine how water may move around the parcel on or near the land surface. Pixel by pixel calculations were made for flow direction, flow accumulation, slope and aspect. Aspect and flow direction are essentially the same, but flow direction assigns a code to each pixel to make subsequent calculations more efficient. The slope function calculate the pixel-to-pixel slope in percent. Flow accumulation counts the number of pixels that flow toward each pixel, providing a measure of the "watershed" size above each pixel. Figure 22 shows the parcel hillshade beside the flow accumulation, and Figure 23 shows the slope and aspect.

Historical field boundaries (Figures 18-20) within the parcel are preserved in the lineaments illustrated by the flow accumulation data, although the parcel generally funnels surface water radially into its center and then to the south parcel boundary. The crest of the Gothenburg Canal is easily discernible in the northeast quadrant, and it is evident that the canal intercepts runoff from land topographically above the parcel, preventing some "run-on". The data indicate a couple of points where flow accumulates from the canal and onto the parcel; this is likely the result of bridges or control structures on the canal, and not a reflection of the actual physical flow accumulation at the site, which is expected to discharge to the east once it is contained within the canal.

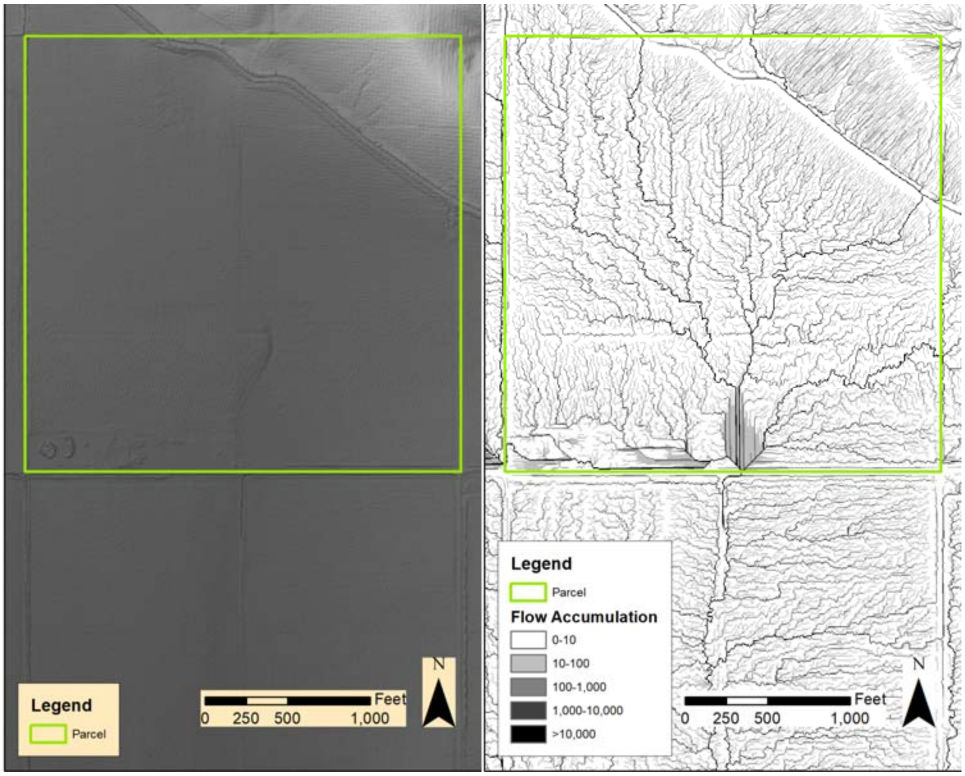

Figure 22. Map of parcel location showing parcel hillshade (left) and flow accumulation (right).

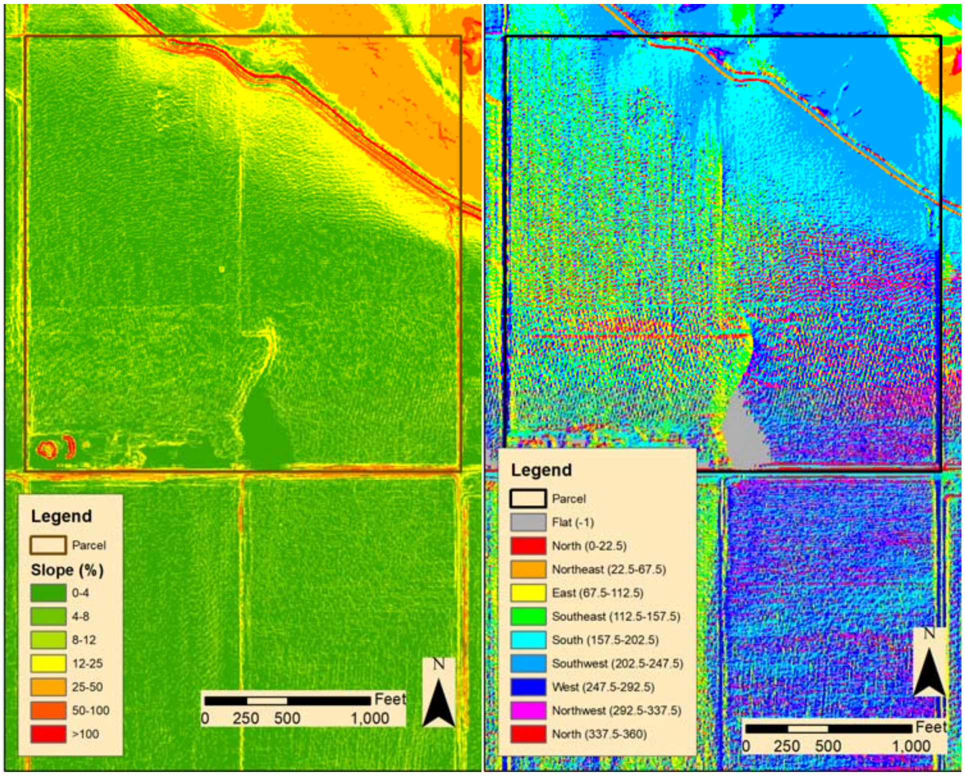

Figure 23. Map of parcel location showing parcel slope (left) and aspect (right).

Parcel Water Budget and Discussion

Possible water inflows at the parcel location include precipitation, applied irrigation water, overland runoff flowing onto the parcel; or “run-on”, percolation of canal water, and groundwater flow. Water outflows include groundwater flow, tile drain discharge, runoff, and evaporation and transpiration [together “evapotranspiration”] (Figure 24). A finite amount of groundwater storage exists beneath the parcel, and there is sometimes a small amount of surface water stored on the parcel [the impetus for this work].

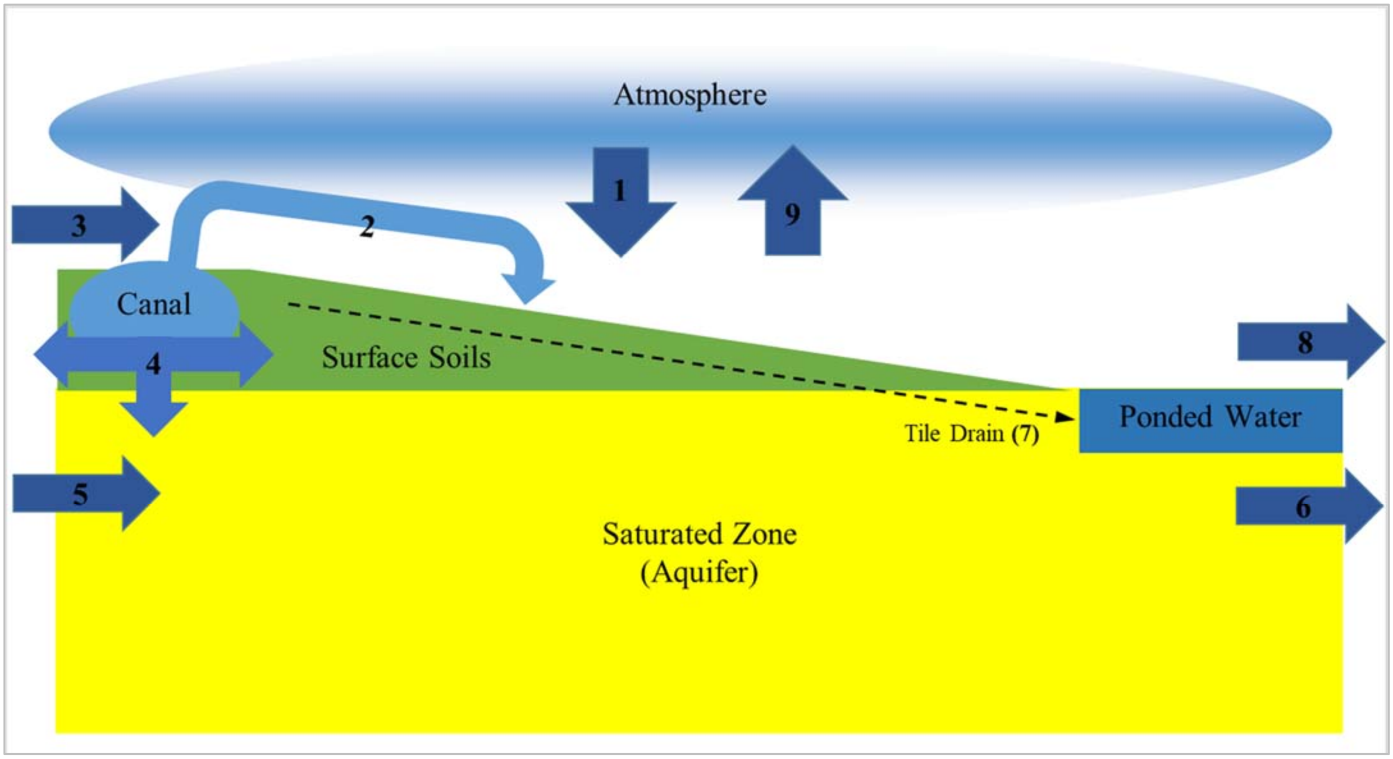

Figure 24. Chart illustrating the conceptual water budget for the parcel of interest. Sinks are spatial volumes capable of storing variable amounts of water, and are represented by labeled shapes, including: atmosphere, soils, saturated zone (groundwater), canal, and ponded water (surface water). Flow of water between sinks are represented by numbered arrows that represent various fluxes in the water budget including: precipitation (1), applied irrigation water (2), overland runoff flowing onto the parcel; or “run-on” (3), percolation of canal water (4), and groundwater flow (5). Water outflows include groundwater flow (6), tile drain discharge (7), runoff (8), and evaporation and transpiration [together “evapotranspiration”] (9). Together, the sinks and fluxes illustrate the parcel water budget.

Long term precipitation (over multiple decades) lacks a distinct trend and that short term (the recent decade) precipitation may be increasing slightly. Annually, the weather station near the parcel receives about 22 inches of rainfall on average, and ~95% of the time, rainfall will be between 13 and 32 inches per year. Recent data show that the average of precipitation data collected and mapped statewide from 2000 to 2009 for the study area is between 22 and 24 inches annually (Korus et. al., 2013). Water level measurements with notations regarding precipitation collected in the mid-1990s indicate that groundwater responds quickly to significant (>1inch) rainfall events, indicating a reasonably good hydraulic connection between the land surface and groundwater (NPPD, 1995, NPPD, 1994, Czarnick, 1994). Interestingly, the 180-day moving average of the snowfall data shows significant increase from 2017-2019 (Figure 12). The impacts of increased snowfall on the parcel water budget are uncertain, but may indicate that excess soil moisture and higher than normal groundwater levels are present in the spring, meaning that in years following significant snowpack, the parcel is starting the irrigation season from a higher than normal "baseline" or that surface soils are nearer to field capacity with respect to moisture, thus requiring much smaller precipitation events to induce recharge to groundwater and/or runoff. Both high groundwater and runoff can result in ponded surface water on the parcel.

A synoptic study contracted by NPPD indicates that the segment adjacent to the parcel seeps 1.3 cubic feet per second per mile of canal based on measurements collected on August 18 and 19, 2008 (Aqua Engineering, 2008). The length of canal adjacent to the parcel of interest is approximately 2,150', or about four tenths of a mile. If canal seepage is relatively uniform along the length of the measured segment, the reach adjacent to the parcel of interest will percolate about 0.52cfs, almost 12 inches when distributed across the parcel, or a little more than half an inch per week. Figure 15 shows the calculated groundwater gradient along the canal that indicates a potential for some (most?) of the canal seepage along the north parcel boundary to flow to the north (away from the parcel) under the upland and then to the east in a inferred high hydraulic conductivity channel deposit. If this interpretation is true, then the canal seepage affecting the parcel groundwater should be reduced by at least half. Additional efforts to minimize seepage near the parcel, such as bank compaction conducted by NPPD in 2017, have NOT been quantified herein, yet may reduce the total amount of water seeping from the canal. Data collected for the T.C. Engineering study in the mid-1990s also shows water levels in wells (#1 and #4) that are greater than ten feet lower than the canal stage (Werblow, 1995) and significantly below the thalweg of the canal, indicating a potential hydraulic disconnect between surface water in the canal and groundwater beneath it. A hydraulic disconnect beneath the canal is consistent with the modeled water table shown in Figure 15. The consequence of a disconnect between canal water and groundwater would be that there is a vertical hydraulic flux that is relatively insensitive to the stage of canal water, and therefore the effect of canal seepage on the groundwater beneath the parcel (and surface water on the parcel) should be fairly constant during times when the canal is wet. In other words, we would expect the canal to effect standing water on the parcel shortly after the canal begins diversions, and cease shortly after canal diversions cease, and significant changes in this condition should not be experienced during the irrigation season except to the extent they are controlled by other factors.

Upslope runoff (parcel "run-on") was largely intercepted by the Gothenburg Canal when it was built, with only a small portion of the northwest corner of the parcel accumulating water from upslope land (Figure 22). Downslope runoff is conveyed in the shallow drain bisecting the south half of the parcel to the road ditch that forms the south boundary of the parcel. The drain appears as though it may have been more distinct (incised) historically than currently, based on a qualitative assessment of the historical imagery that seems to show a narrower channel with uniform crop cover across the parcel. The road ditch is hydraulically connected with the road ditch on the south side of the road through a pair of culverts, and both ditches contained water during a site visit in October 2019 and appear capable of storing additional water due to significant vegetation and presumably silt in the drain running south from the area. Runoff and run-on are likely small, but can be highly variable and uncertain from year to year and season to season.

The tile drain recently installed in the field also discharges to the road ditch, and was partly submerged by water in the road ditch during the site visit. Groundwater inflow is unknown at the parcel, but over days to weeks, is likely to be equivalent to or perhaps slightly less than groundwater outflow. Groundwater is likely influenced by surface water at the site, such that surface water in the ditch south of the parcel will create a hydraulic dam that will slow the outflow of groundwater and raise the groundwater head beneath the parcel. A downgradient hydraulic dam will also slow groundwater inflow by changing the groundwater gradient across the parcel. Canal seepage may connect canal water with groundwater upgradient of the parcel, potentially affecting groundwater flow by increasing the gradient across the parcel, increasing the groundwater flux. It is not clear the canal seepage rate discussed above is sufficient to hydraulically connect water in the canal to the groundwater, so further investigation of this question may be warranted.

Evapotranspiration is a significant flux that can be close to or greater than the precipitation flux, though its measurement is difficult and often has significant uncertainties. Satellite-based remote sensing work completed by Szilagyi and Jozsa in 2012 indicate that the study area probably has evapotranspiration that is greater than recharge (percolation of rainfall into the groundwater system), resulting in a negative net recharge to the groundwater system in the area (Korus et. al., 2013). It is unknown if the varying crop yields on the parcel are sufficient to cause significant variability in the evapotranspiration. The historical imagery (Figures 18-20) shows that hay was the dominant crop into the 1960s. The long term change in land use (conversion from hay to row crops) may result in consumptive use reduction of nearly 5 inches (Yonts, 2002). The net irrigation requirement for corn in the study area is estimated between 11 and 12 inches (NeDNR, 2017). Changing crops on the parcel from hay to row crop likely represents a decrease in the evapotranspiration flux. A decrease in evapotranspiration flux will result in higher runoff, soil moisture, and recharge to groundwater, resulting in higher groundwater levels and ponded water across the parcel.

The final flux to consider is applied irrigation water. Irrigation water may be applied by flood or furrow irrigation, or through center pivot irrigation system. A center pivot sprinkler has been installed on the parcel, and during the site visit, furrows between rows of corn and berms to support gated pipe were observed in the northwest quadrant of the parcel. Presumably irrigation water was applied by sprinkler and furrow in 2019. Since 2009, deliveries have averaged 10 inches per acre and ranged between 3 and 24 inches. Excess water delivered by furrow irrigation will saturate surface soils and percolate into the groundwater or flow into pools on the land surface.

The widely spaced 2500’ water table contour east of the parcel and the 2520’ water table contours around the parcel (Figure 15) are consistent with the relatively high top of channel facies elevation trend to the east of the parcel. High hydraulic conductivity in a preferred groundwater flow path could be expected to have this type of an appearance in map view (Figure 25). To visualize the relationship between the land surface, channel facies, and water table, two cross sections were created corresponding to the lines A-A’ and B-B’ in Figure 25, and are presented here as Figures 26 and 27 respectively. Cross section A-A’ connects two prominent channel facies highs; one at the parcel of interest, and another along the west bound of the study area northwest of the parcel. This cross section illustrates the groundwater table sloping generally up to the northwest, and the complex channel facies surface beneath it, except at its highest elevations to the west. This configuration may show a recharge area (groundwater flowing down within the aquifer) to the west and a discharge area (groundwater flowing up within the aquifer) at the parcel location. Figure 27 illustrates a similar pattern, yet the high groundwater between the north end (B) and the parcel may indicate some unknown local complexity in that part of the study area.

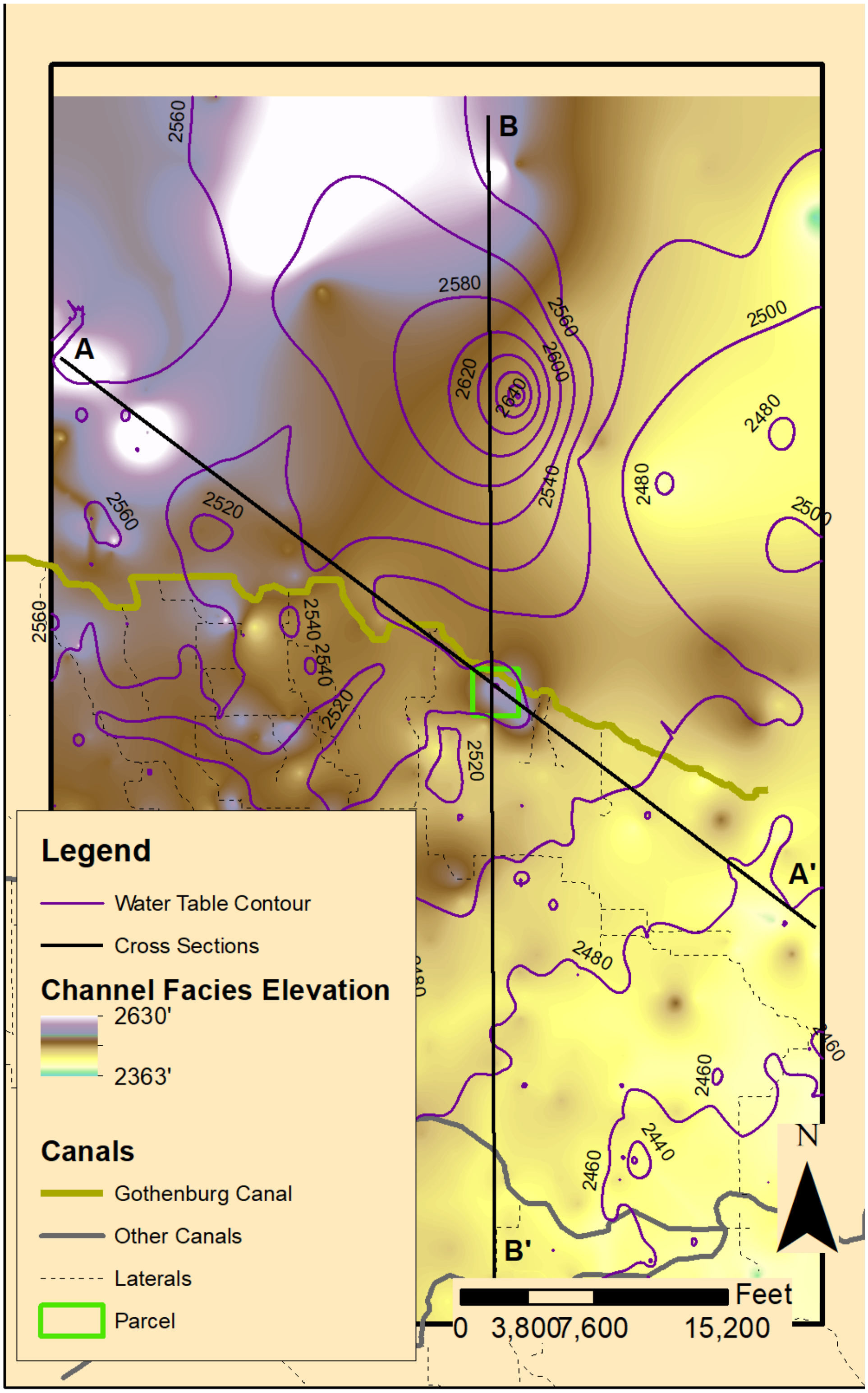

Figure 25. Map showing a color-wash of the channel facies elevation and groundwater contours with two cross section locations that intersect in the parcel of interest. Cross section labeled A-A' is illustrated by Figure 26, and B-B' is illustrated by Figure 27.

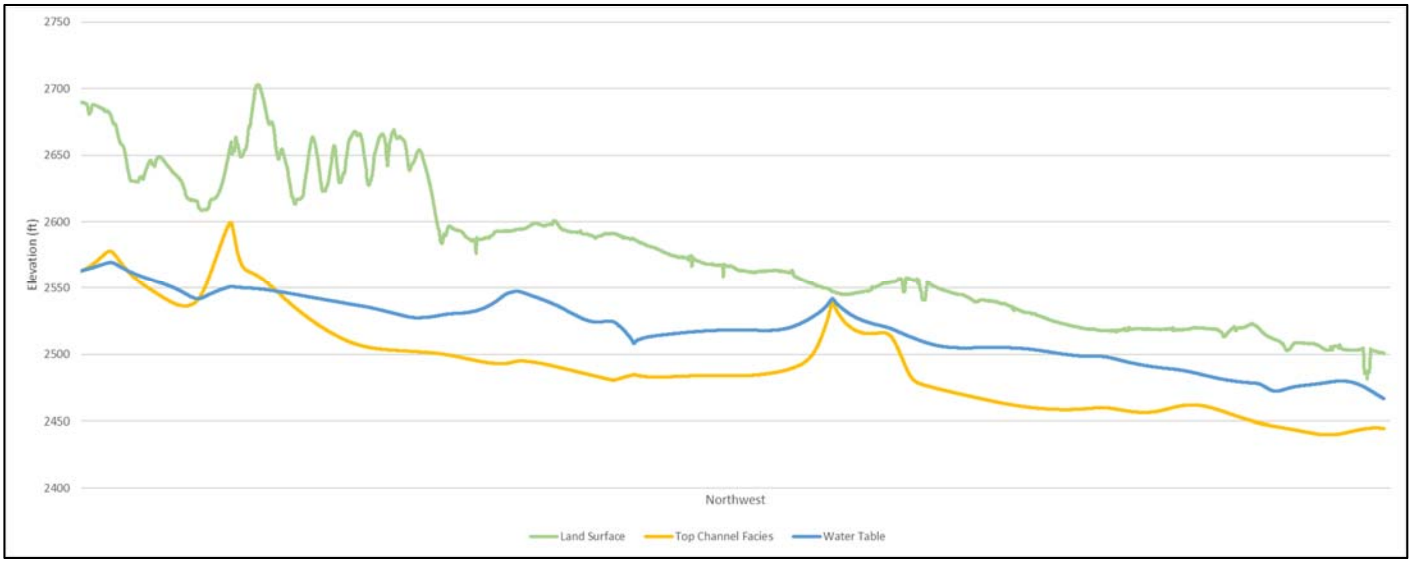

Figure 26. Cross section through the parcel on interest illustrating the northwest (A) to southeast (A') configuration of the landsurface (green), water table (blue), and top of the channel facies (yellow).

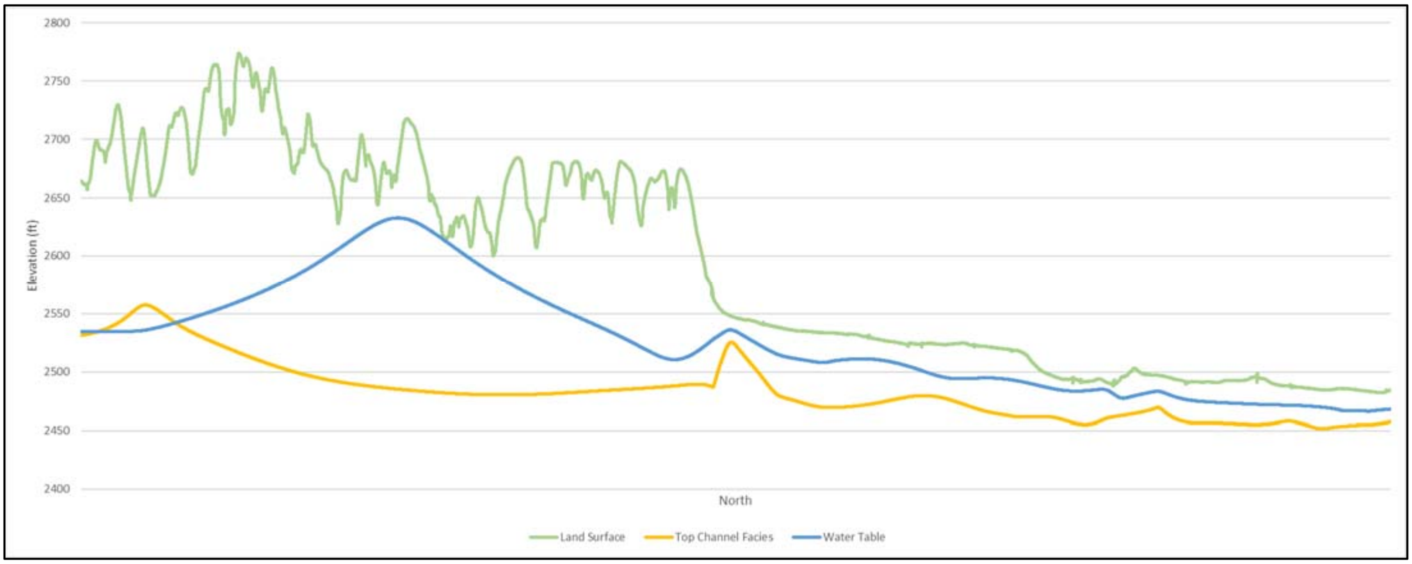

Figure 27. Cross section through the parcel on interest illustrating the north (B) to south (B') configuration of the landsurface (green), water table (blue), and top of the channel facies (yellow).

Limitations and Uncertainties

The work completed herein, along with newly acquired data vastly improves our understanding of the aquifer framework and relationships between surface and ground water in and near the parcel of interest. This work has also significantly reduced uncertainties relating to conceptions of the hydrogeology locally. Nevertheless, limitations and uncertainties are significant to this study. They include:

- The locations of registered wells in the NeDNR database are in some cases inaccurate. Therefore, some data points used in the water table and sand body modeling may be assigned elevation values based on incorrect locations, resulting in erroneous elevation values.

- Topography data (LiDAR) at the site was remotely sensed from a fixed wing aircraft, and may not reflect a perfect hydraulic model of the land surface, particularly in locations where vegetation bridges and/or other structures obscure the overhead view of channel thalwegs or where there is standing water that absorbs the laser pulse or tall grass that provides a poor reflection, confounding measurement.
- Water levels from the registered wells database were collected when each well was registered, these collections represent different years and/or seasons, thus different hydrogeologic conditions. Consequently, variance in the data is expected to be high because of seasonal, wet/dry, and climactic variability in the conditions under which the levels were collected.
- Fluvial systems can be spatially detailed and complex so mapping the distribution of their deposits in the subsurface is limited by the spatial density of data points.
- Given uncertainty in the groundwater table contours, it is uncertain what proportion of the canal seepage is affecting groundwater elevation at the parcel of interest (and surface water associated with high groundwater) when at least some of the canal seepage is expected to flow north and then east in a likely high hydraulic conductivity zone (Figure 24, flux #4).
- The above noted water table contours from this work and the T.C. Engineering study (Werblow, 1995) assume that subsurface soils are vertically and horizontally uniform in composition and compaction. If this assumption is in error, then the assumed vertical connection of high groundwater level along the canal with the canal water in the Werblow (1995) may be incorrect if compaction beneath the canal has created a "hard pan" upon which shallow groundwater is pooling, resulting in the high groundwater observations.

Future work

The GIS model could be improved through new data collection, more in-depth data mining (such as developing a 3D model of channel facies in the subsurface), and further modeling (recommendation #6). The author has also recently learned of a swath of newly acquired aerial electromagnetic remote sensing data in the region. If this data includes the study area and channel and overbank facies are sufficiently distinct with respect to their electrical properties in the study area, comparing the results of the remote sensing work to the results of this study may be beneficial in validating the conceptual model proposed herein.

Disclaimer

The views, conclusions, and/or opinions expressed in this work are solely those of the author and not the University of Nebraska, State of Nebraska, or the Nebraska Public Power District.

Acknowledgements

The NPPD staff has been very helpful gathering information and providing numerous datasets. The landowner, Matt Lauer, was instrumental to understand the water management and cropping systems employed on the parcel. Both parties deserve gratitude for their willingness to sit down and inform the author about operational practices and available information.

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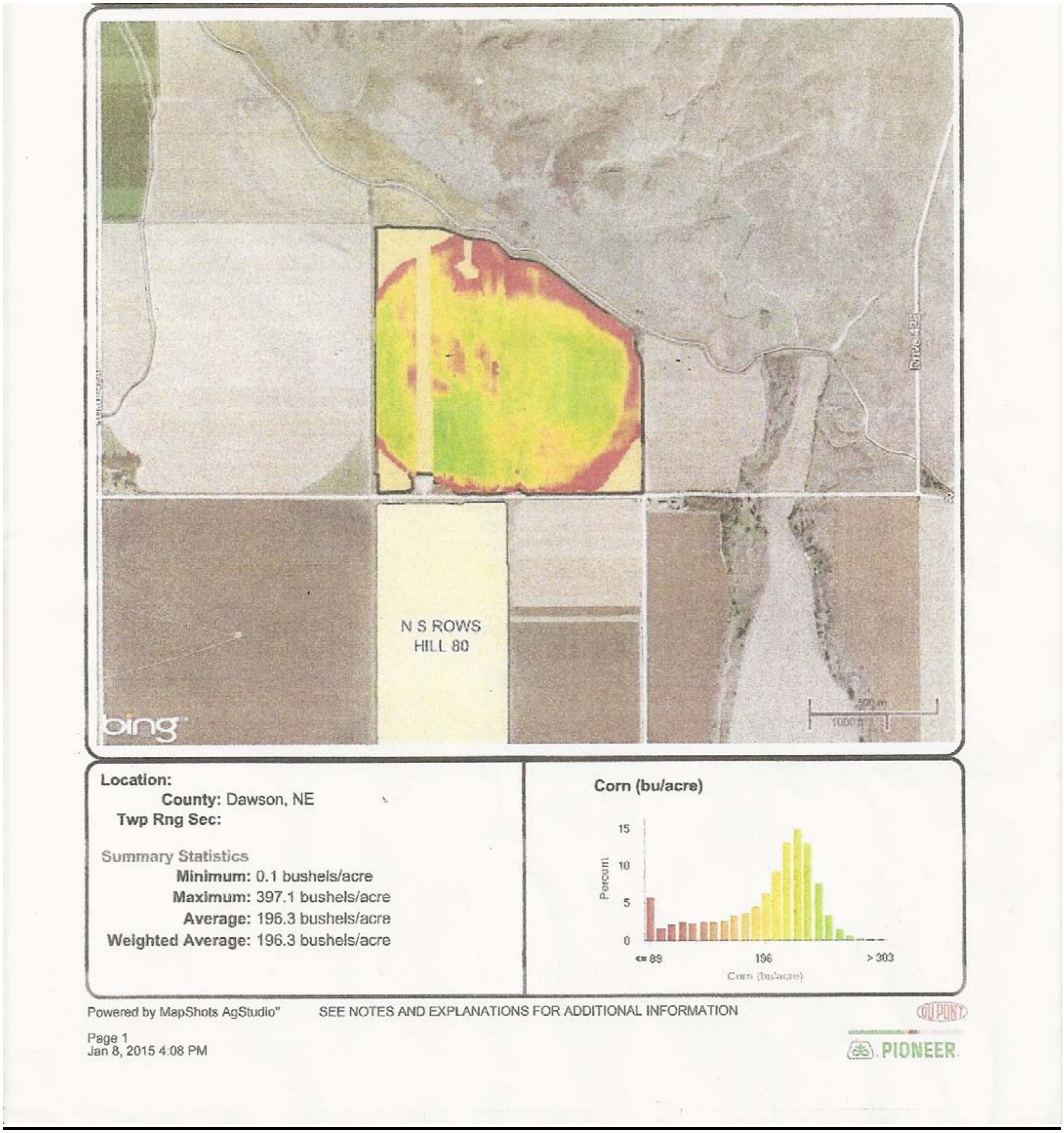
Number 86, Conservation and Survey Division, School of Natural Resources, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln

Appendix A – Yield Maps

Crop year: 2012



Location:
County: Dawson, NE
Twp Rng Sec:

Summary Statistics
Minimum: 0.1 bushels/acre
Maximum: 397.1 bushels/acre
Average: 196.3 bushels/acre
Weighted Average: 196.3 bushels/acre

Corn (bu/acre)

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Page 1
Jan 8, 2015 4:08 PM

Crop year: 2014

Harvest Summary

Total Yield (dry): 23,721.66 bu
Harvested Area: 129.71 acre
Crop Zone Area: 128.81 acre
Average Moisture: 15.21 %
Average Yield: 182.89 bu/acre
Avg Yld by Crp Zn Area: 184.16 bu/acre
Harvest Ended Date: Oct 31, 2014

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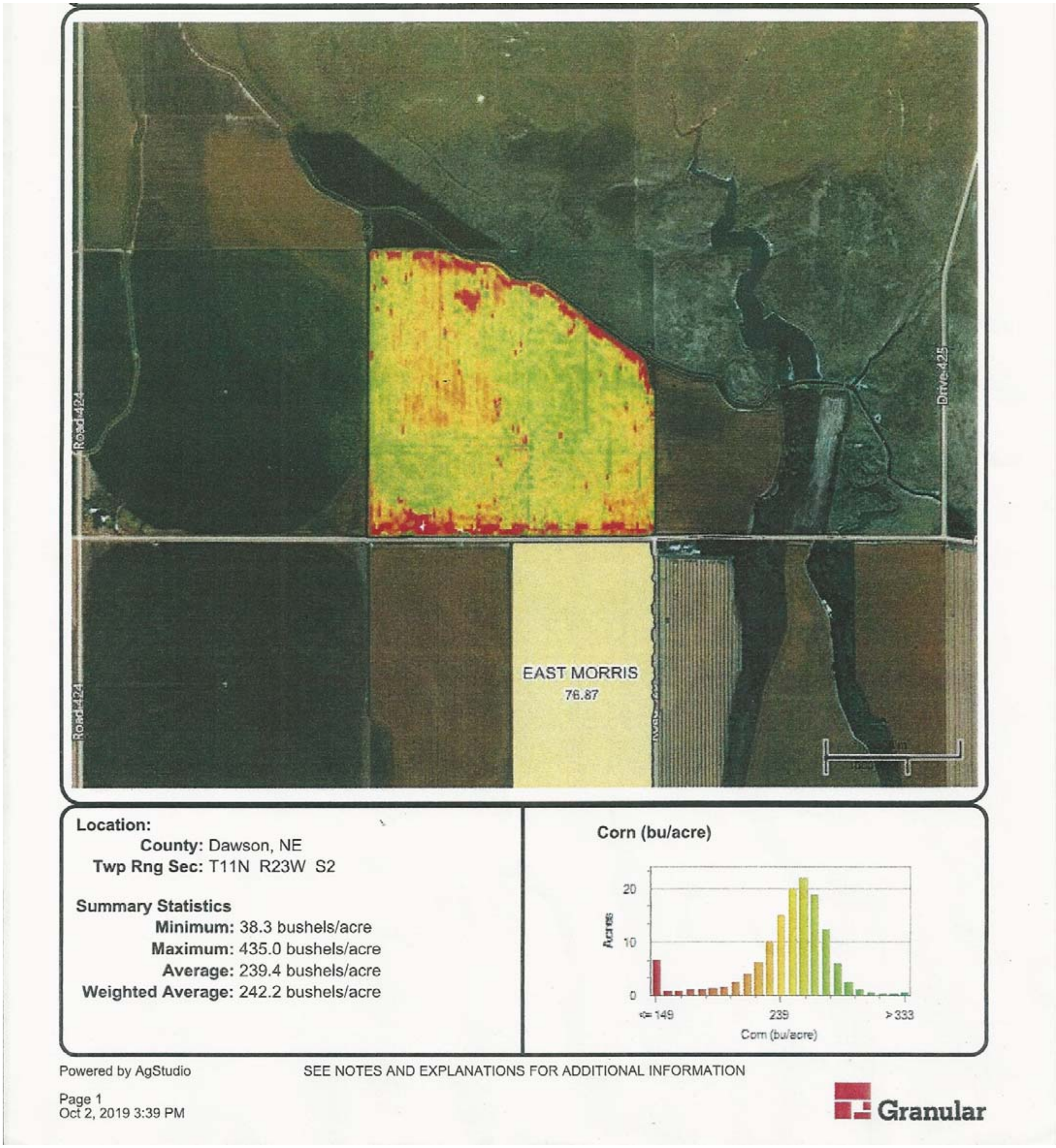
Page 5 of 32
Jan 8, 2015 5:34 PM

DUPONT PIONEER

Crop year: 2015



Location:
County: Dawson, NE
Twp Rng Sec: T11N R23W S2

Corn (bu/acre)

Summary Statistics
Minimum: 38.3 bushels/acre
Maximum: 435.0 bushels/acre
Average: 239.4 bushels/acre
Weighted Average: 242.2 bushels/acre

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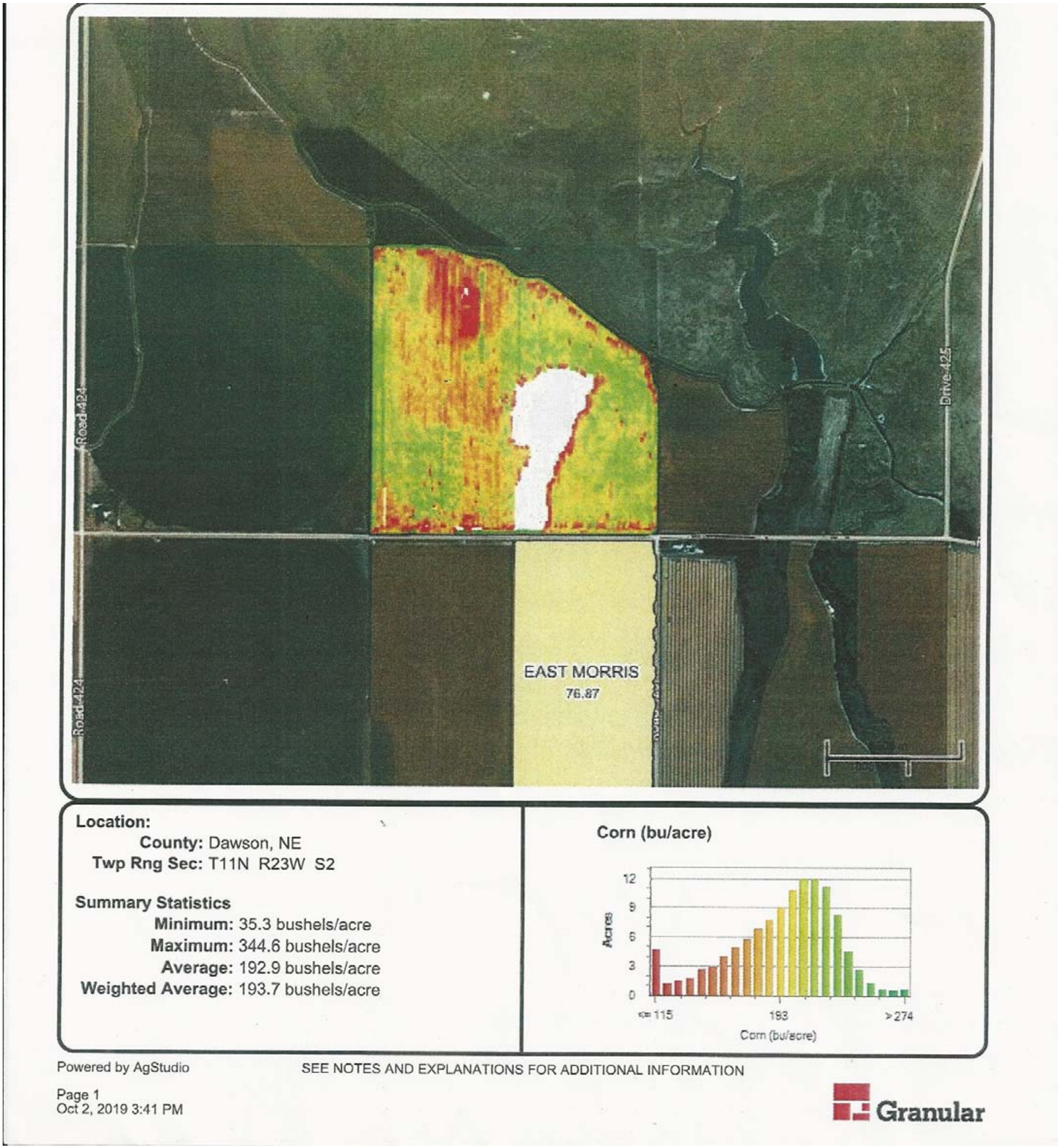
Page 1
Oct 2, 2019 3:39 PM

Granular

Crop year: 2016



Location:

County: Dawson, NE
Twp Rng Sec: T11N R23W S2

Summary Statistics

Minimum: 35.3 bushels/acre
Maximum: 344.6 bushels/acre
Average: 192.9 bushels/acre
Weighted Average: 193.7 bushels/acre

Corn (bu/acre)

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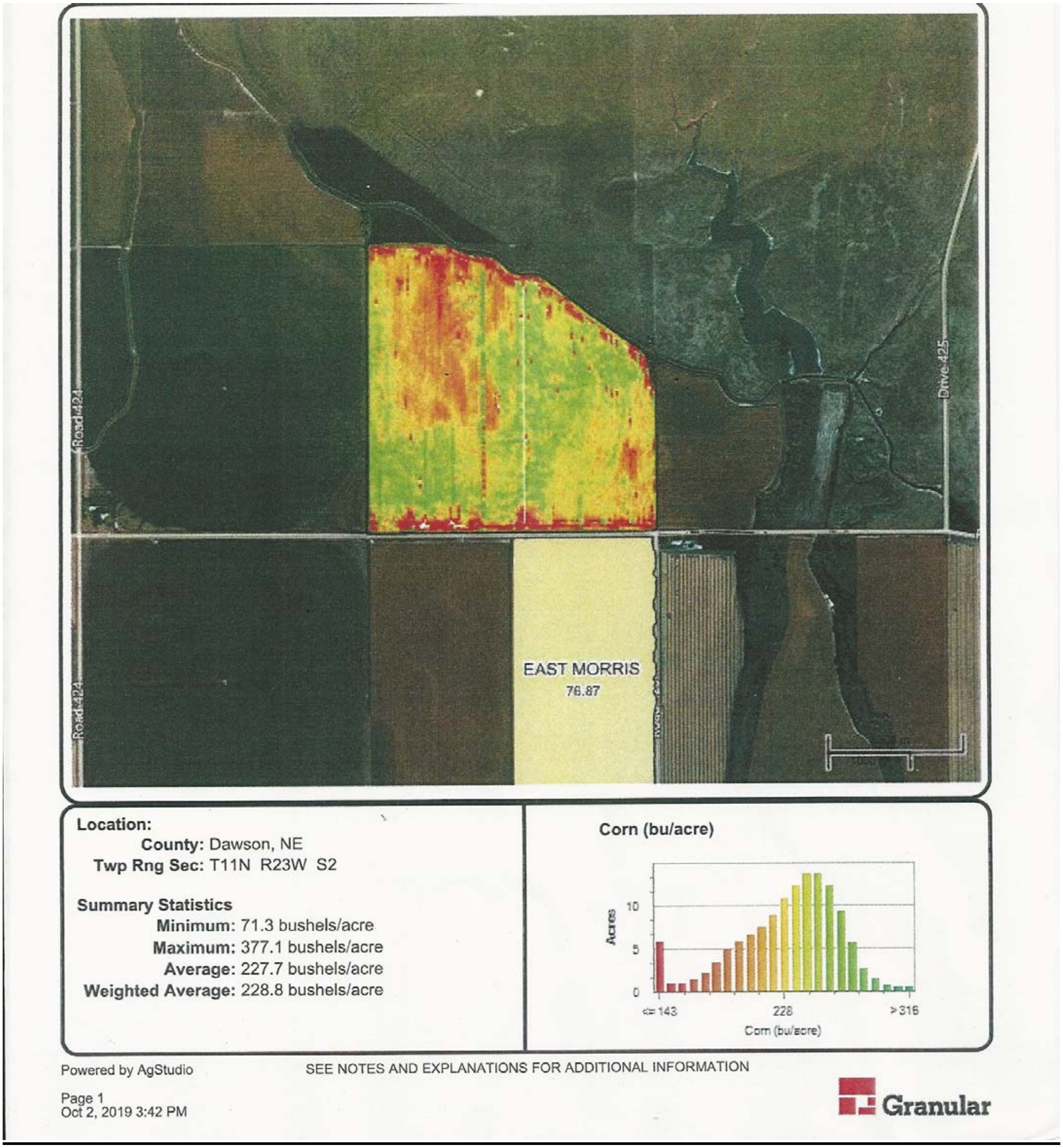
Page 1
Oct 2, 2019 3:41 PM

Granular

Crop year: 2017



Location:
County: Dawson, NE
Twp Rng Sec: T11N R23W S2

Summary Statistics
Minimum: 71.3 bushels/acre
Maximum: 377.1 bushels/acre
Average: 227.7 bushels/acre
Weighted Average: 228.8 bushels/acre

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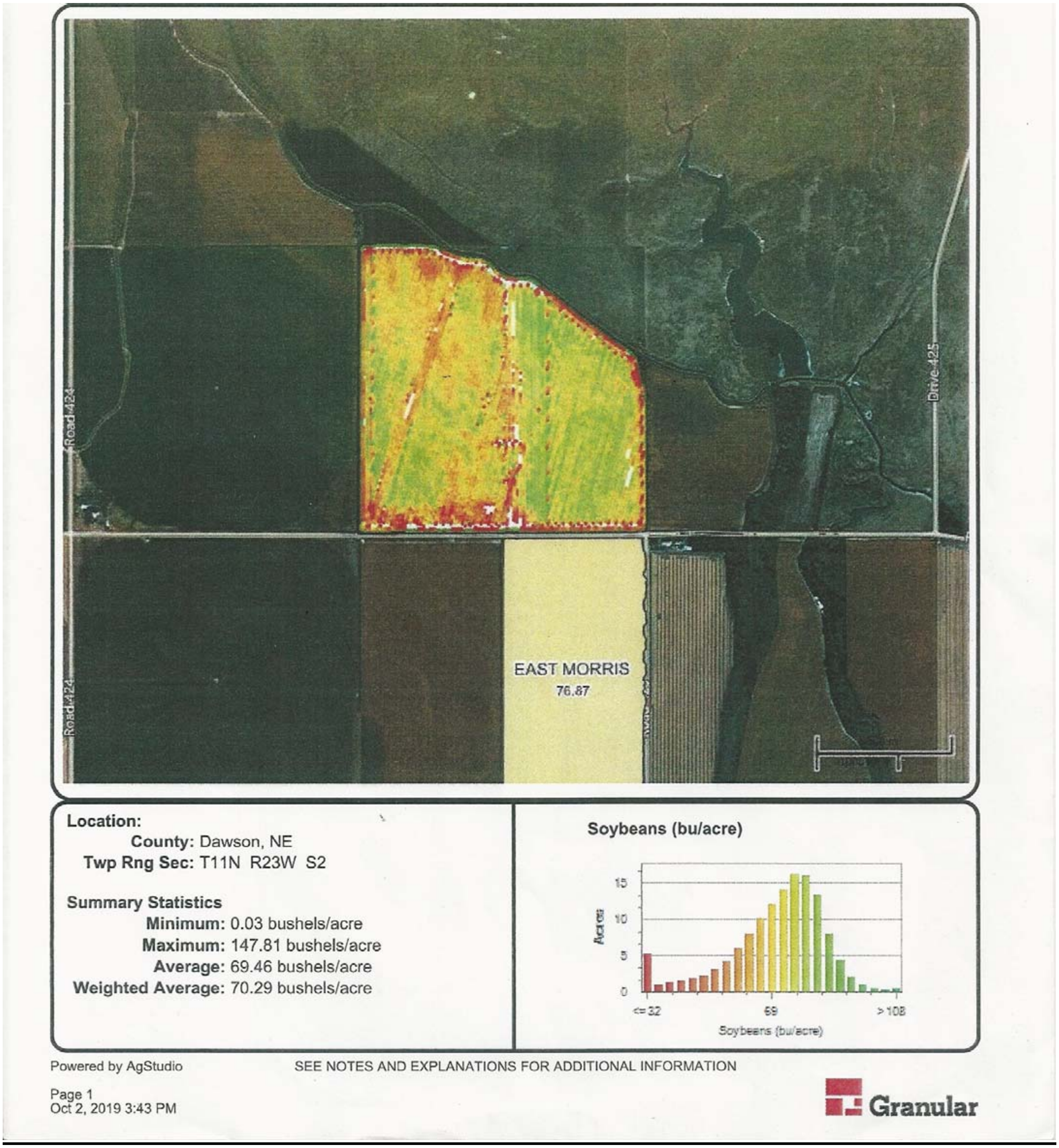
Page 1
Oct 2, 2019 3:42 PM

Granular

Crop year: 2018



Location:
County: Dawson, NE
Twp Rng Sec: T11N R23W S2

Summary Statistics
Minimum: 0.03 bushels/acre
Maximum: 147.81 bushels/acre
Average: 69.46 bushels/acre
Weighted Average: 70.29 bushels/acre

Soybeans (bu/acre)

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SEE NOTES AND EXPLANATIONS FOR ADDITIONAL INFORMATION

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