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Guidebook for Omaha's Urban Geology and Anthropocene Nebraska Well Drillers 2022 Field Trip

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Field trip August 31st, 2022

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Omaha 2015 skyline looking south from the Missouri River

<u>Field trip introduction</u>: The sub-discipline of urban geology looks at surface and near surface geologic processes, landscapes and deposits and considers how they have been modified by human activity in urban environments and how they influence design of the built environment. With a > 60-year record of associated publications, the field of urban geology is aligned with engineering, public health, emergency management, planning and much more. This one-day field trip will focus on examples of Omaha's urban geology and place it in the even larger discussions on the Anthropocene (a proposed addition to the geologic time scale).

Guidebook Contents:

Introduction to the concepts of urban geology and the Anthropocene

This geologic field trip focus is somewhat atypical but arguably reflects an ongoing evolution within the geosciences. Instead of traveling out into rural settings to look at outcrops and the stratigraphy exposed, or rural landforms and their geologic history, this field trip is focused on built and engineered environments in the Omaha area and the 'modified' associated geologic processes such as surface and groundwater flow, weathering, and soil formation. The ongoing evolution includes an increase in a multidisciplinary system science approach and is driven by a need to address environmental and resource management challenges using new tools and conceptual frameworks. One example is the concept of the **critical zone**, the zone encompassing the vegetation canopy down to groundwater. This framework is crucial to understanding endeavors at Glacier Creek Preserve and provides an example of an application of a system science approach and the role that technology plays. These topics are also part of the environmental geology courses we teach at UNO where we explore the interplay between geologic knowledge and human endeavors.

McGill (1964) provided a relatively early articulation of the concept of urban geology using the Los Angeles area as an example. Legget (1973) provides an often-referenced compendium focused on urban geology. Culshaw and Price (2012) draw on Legget's legacy to suggest the following definition for urban geology: "The study of the interaction of human and natural processes with the geological environment in urbanized areas, and the resulting impacts, and the provision of the necessary geo-information to enable sustainable development, regeneration, and conservation." Wilson & Jackson (2016) define **urban geology** as "the application of the earth sciences to problems arising at the nexus of the geosphere, hydrosphere and biosphere within urban and urbanizing areas." Aiming for brevity we suggest that urban geology is geoscience applied to an urban setting.

What is different about an urban setting that sets urban geology aside from other more traditional geologic endeavors? One obvious answer is the greater role of human activity in shaping the landscape and associated processes. Examples are numerous. That impermeable surfaces increase runoff and flooding is well known (Konrad, accessed 8/5/2022). Old cemeteries become sources of groundwater arsenic contamination because of past embalming practices (e.g. Brennan et al. 2015). The ASARCO related lead superfund site is Omaha's example of how human activities influence urban geochemistry. Slope stability for ubiquitous retaining walls becomes a function of engineering practice. Rip rap deposits designed to stabilize straightened stream channels become flood-mobilized sediment that collects to produce pools and riffles. Concrete, asphalt, and garbage, including durable plastics, become a significant part of the sediment load in urban streams. Streams disappear into the subsurface, to reemerge downstream, all part of a vast constructed subsurface drainage network. Drainage is filled in for construction purposes, with the new sediment load causing differential compaction, as exemplified by UNO's library. Old landfills are encompassed by the expanding city. Ornate building stone from around the world is incorporated into public buildings and spaces. Lakes and ponds in public parks and spaces that add greatly to urban livability become sediment traps that need to be dredged. Created wetlands become features that provide environmental services, such as storm water storage and water quality improvement. Salvage archeology and paleontology attempt to preserve valuable scientific deposits from being destroyed during construction. Compared with Los Angeles or New Orleans, Omaha's urban geology may seem tame, but we hope this guidebook can help convince you that every city has significant urban geology associated with it, and Omaha provides plenty of local examples.

Urban geology is perhaps a conceptual predecessor linked to the **Anthropocene**, which is currently proposed as a new Epoch (following the Holocene Epoch) to the geologic time scale (reviewed in Zalasiewicz, J. et al. 2017). Perhaps more significant in the context of this field trip is the core concept underlying the Anthropocene: humanity has become a global geologic force too significant to be ignored. The more obvious influence of humanity in reshaping geologic processes, landforms and deposits in cities led to the earlier development of urban geology framework. That this was the case beyond cities, was the case globally, albeit often more subtlety than in cities, became more apparent as humanities geologic influence and our understanding continued to grow. The Missouri River that flows by Omaha is one example of many large river systems where water and sediment flow is strongly influenced by dams and other engineering structures, and by land-use in the drainage basin. Farming in the Great Plains has severely altered soils, changed groundwater levels and chemistry, and altered the morphology of hillsides through terracing. On the technical side, debate about the Anthropocene as an Epoch centers on when it started and what the stratigraphic marker used to identify it in the record should be (Corcoran et al. 2014), as well as the need for a new Epoch (Autin 2012, Finnery & Edwards (2016). Microplastics and distinctive isotopes released from nuclear testing are two of a suite of proposed Anthropocene markers, with the isotopes as the chosen option at the moment. The advent of agriculture has also been proposed as an earlier starting point.

In turn, one can link the concept of the Anthropocene to that of **geoengineering**, a concept usually associated with addressing anthropogenic-induced global climate change, and specifically to forms of carbon management, including sequestration (e.g. Oxford Geoengineering Program, accessed 8/5/2022). However, more than global or regional temperatures must be considered in such endeavors, especially given how such geoengineering may influence geochemical systems connected to ecosystem and human health. Therefore, here we consider geoengineering to include the regional to global scale manipulation of hydrologic, geochemical, biologic and sedimentologic systems for the purposes of human sustainability. In this context, the multi-billion-dollar proposal to create a control structure to allow controlled flooding and siltation of part of the Mississippi to protect New Orleans, known as the Mid-Barataria Project (described in detail in the USACE environmental impact statement, G.E.C. 2021), is one of many projects that exemplify the scale of what can be considered as geoengineering efforts. The Anthropocene and geoengineering are perhaps terms trying to capture an ongoing evolution driven by population and technologic growth, where environmental and resource management must be coordinated at a larger scale for to ensure sustainability. In these endeavors geologic investigation of the surface and subsurface will only become more critical. Omaha provides our local example, and the stops highlighted in this guidebook and on this one-day field trip are the briefest of introductions.

Field Trip Itinerary, 8/31/2022

Each field trip stop is described in greater detail in sections after this itinerary.

Meet at Walmart parking lot 8:30 AM.

Arrive at Glacier Creek Preserve at 9 AM
Dr. Dere and her colleagues and students have created a critical zone observatory on the periphery of Omaha, with semi-continuous soil-gas, moisture and temperature monitoring at various depths, an array of observation water wells, and local weather stations. Cores and geophysical work have characterized the subsurface. Research on wind-blown dust, the influence of prescribed burns on soil development, on the difference between restored prairie versus farmed soils and more has been conducted. Monitoring sites exist in both agricultural and restored prairie soils.

Lunch 11:30 AM-12:30 PM

Drive to Heflinger Park 12:30-1:00 PM

Heflinger Park 1:00-1:30 PM
Perched above Papillion Creek, this old landfill was engulfed by Omaha's western urban growth and is an example of a legacy environmental site. Differential subsidence has required the road to be repaired many times, and wells installed to release methane and monitor downslope water conditions. It is now a dog park. Short walks to the various points in the park illustrate the nature of concerns and remediation efforts.

Drive to Heron Haven (across the street from Heflinger Park) 1:30-1:45 PM

Heron Haven 1:45-2:30 PM
This old 'dump' site is an example of habitat reconstruction within the city. Fed by vigorous springs sourced in glacial outwash gravels, the human-created wetlands not only provide habitat and a recreational opportunity for city dwellers to connect with nature, but enhances water quality and helps a small bit with flood water storage. The substrate for some of the site is waste fill material. The site is managed by volunteers.

Drive to Carter Lake 2:30 to 3:00 PM

Carter Lake 3:00-3:30 PM
This lake is the site of a well-known ox-bow lake that left a bit of Iowa on Nebraska's side of the river. It is highly managed for water quality and recreational purposes. Research using lake sediments and diatoms as a record of environmental change and sedimentation and water quality challenges will be shared. How the airport was threatened by the 2011 flood, and the response that saved it can be considered here.

Drive to Bob Kerry Bridge (nearby) 3:30- 3:45 PM

3:45 - 4:45 PM Bob Kerry Bridge
This stop focuses on Missouri River flood control efforts including wing dikes, levees, and bank armoring, and their response during the 2011 flood. The pre-engineered character of the Missouri River will be contrasted with the present character as an example of why the concept of the Anthropocene has developed. In addition, the buried contamination site associated with the ASARCO smelting operations, and the associated lead superfund site in Omaha, can be reviewed.

4:30 PM Return to initiation point and participants cars

Alternate stops for those interested in further investigating Omaha's urban geology at some other time have been included. The Thompson Creek site is an example of an integrated watershed restoration and flood control project. The Little Papillion – Keystone Trail stop is an example of a highly engineered urban stream that has evolved significantly over the decades since it was modified. Urban flood response, bank stabilization efforts, plastics in the sediment, and channel evolution are topics that can be addressed.

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Field trip leaders and contributors include Drs. Dere, Luethje, and Maher of the University of Nebraska (UNO) at Omaha Department of Geography and Geology. Dr. Dere has experience in researching soils and critical zone processes, and the Glacier Creek Preserve is one of her primary research sites. Dr. Luethje researches paleoclimate and environmental change of lakes using diatoms and other tools. Dr. Maher researches Great Plains geology with a focus on structural processes and sedimentation. The UNO Geography and Geology Department offers undergraduate degrees in Geology, Geography and Environmental Science (Earth Science option and planning option), and a M.S. degree in Geography.

Broad geologic framework for the Omaha area

Miller (1964) provides an early, in-depth, and easily available summary of the geology of the Omaha area. In broad brush, geologic units from most recent to oldest are : soil and recent alluvium and colluvium that mainly overlies locally thick and significantly eroded loess deposits, which transition down into glacial outwash and fluvial deposits above or withing deformed pre-Illinoian glacial tills, with Mesozoic (Dakota Formation (sandstones and shales) and Paleozoic 'basement' rocks (mostly limestones, marls, and shales) below. The character of the sediments above the 'basement' rocks is far from layer cake, with significant paleo-topography, erosional surfaces, and quick facies changes. Korus et al. (2012) provides a detailed N-S cross section through western Douglas County, W of Omaha, that demonstrates well the nature of the paleo-topography and facies changes.

From an urban geology perspective to this traditional 'natural' stratigraphy can be added the detritus of human activity. In the Omaha area this includes landfills, construction fill, levees, and remediated soils (e.g., from the lead superfund activity described at the Bob Kerry Bridge stop). The inclusion of such anthropogenic deposits in the stratigraphic code that governs the designation of stratigraphic units is being explored (Howard 2014). The inclusion of such units in geologic maps and databases is perhaps in its infancy.

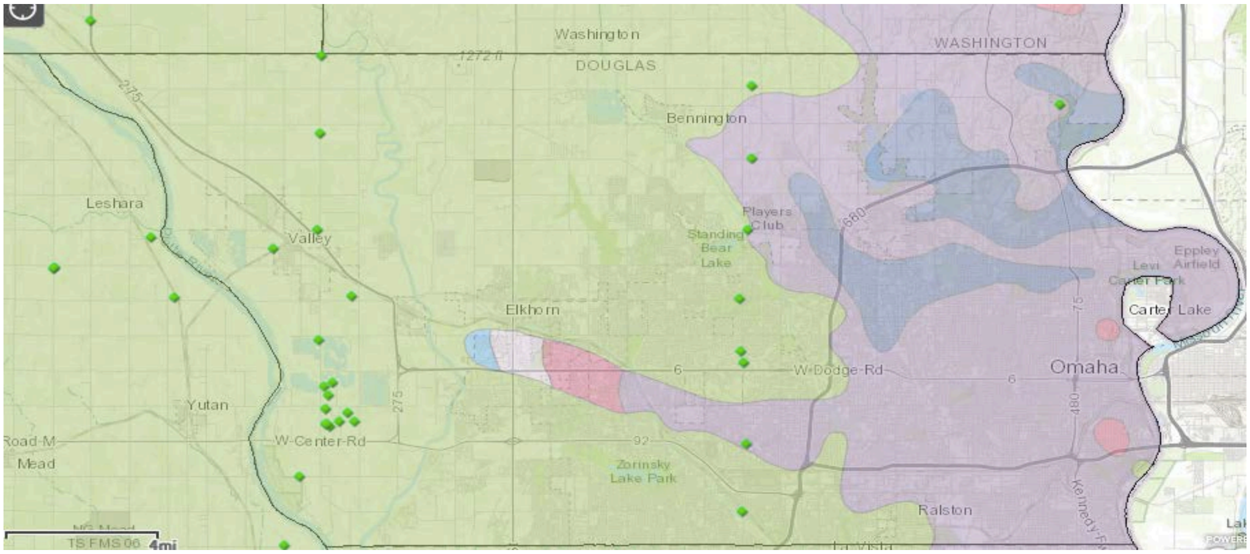


Figure 1: Map obtained from Nebraska Conservation and Survey website showing bedrock geology of Douglas County and the Omaha area. The green is the Dakota Formation, and aquifer, and the other colors are underlying Paleozoic units (blue is Marmaton Group, purple is the Kansas City Group, the pink is the Lansing Group, lighter blue to W is the Shawnee Group and the lightest is the Douglas Group), comprised primarily of limestones and shales). The green diamonds are Conservation Survey geologic test hole sites and more information about the stratigraphy encountered in those cores can be obtained at the website (a simple click on the symbol brings it up) Website: https://universityofne.maps.arcgis.com/apps/webappviewer/index.html

One of the more important geologic units in the Omaha area is loess. These wind-blown 'dust' deposits form a good bit of Omaha's near surface geology (Schroba et al, 2001; Figures 2 and 3), and have unique engineering and geomorphic properties (e.g., Brice 1964). A weak carbonate cement bonds the silt sized grains just enough that characteristic steep-sided gullies and bluffs form. Bluff exposures are sometime columnar due to subvertical fractures. One good exposure is along the front road for Hummel Park, and is known as Devil's Slide (Figure 2, 41.369° -95.555°). Hikes through Hummel Park, Neale Woods, or Fontenelle Forest provide a good introduction to a distinct steep loess geomorphology.

Two extensive and thicker loess units are the Late Wisconsinin Peoria Loess and the Illinoian Loveland Loess, with the intervening Sangamon paleosol horizon. Muhs et al. (2008) provide an in-depth description of the loess stratigraphy and traits throughout Nebraska. In a guidebook Mason et al. (2004) provide a more detailed description of loesses in the Omaha area and on the Iowa side. Numerous additional paleosols within the loess sequence are identified, representing wetter climatic conditions where dust supply and accumulation was significantly decreased, and soil formation accelerated. The loess deposits and internal paleosols reflect changing climatic conditions in the region.

Figure 2: Left - view of loess exposures at Devil's Slide in Hummel Park with the columnar fracturing on display. The deposits are fairly massive, likely due grassland related bioturbation, but laminated or bedded loess does occur. Right - outcrop of till and overlying loess along the road south of Hummel Park. The orange layer midway in the cliff is an iron oxide rich paleosol developed on top of a distinctly weathered till with overlying loess. When freshly exposed the till can be medium grey in color.

Mason et al. (2004) specifically explores the subsurface borehole log signatures (single point resistivity and natural gamma) of the loess units in the area north of Omaha. The contact with underlying tills was often quite apparent in the logs as an increase in resistivity and a decrease in gamma levels. Some of the paleosols were associated with high resistivity values. Why is unclear, but it could reflect preserved pedogenic structure. Interestingly, for such visually homogenous material significant variation exists in the logs.

Engineering traits of the loess are distinctive. If the cement bonds between the loessal silt grains are mechanically broken (e.g. by construction) or dissolved, the reworked silt is easily transported and has little strength. This results in piping (Bernatek-Jakiel & Poesen, 2018), which is the shallow subsurface erosion of the loess along roots or pipelines. Piping contributes to gullying and landscape development. The crushing strength of loess is also such that the load from larger buildings several stories tall can break the cement bonds and cause silt grain rearrangement or breakage that produces settling. Thus, piers are used to support larger buildings located on loess in the Omaha area. Within the loess are the previously mentioned paleosols that are clay rich and stronger, such as the Sangamon paleosol between the Peoria and Loveland loess units. These can be the subsurface level at which such piers are resting.

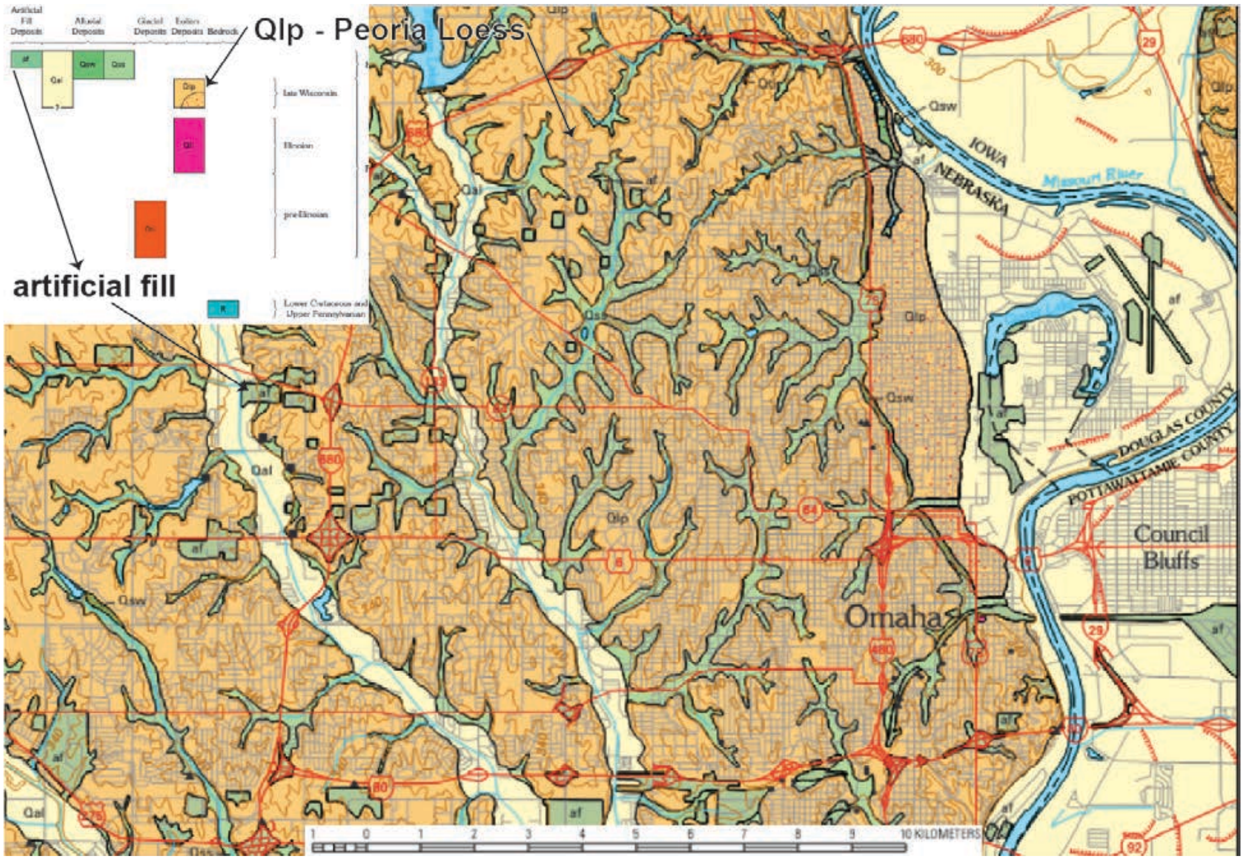


Figure 3: Modified portion of Shrobo et al. (2001) surficial geology map for the Omaha area. Note the dominance of Qlp, the Peoria Loess, and the mapping of artificial fill deposits as a geologic unit. A map some 20 years later would show significant new areas of fill due to construction and other activities. In the future artificial fill could be subdivided into distinct types.

The underlying tills are locally exposed (e.g. Figure 2) and significantly influence the hydrogeology, acting as an aquitard that perches groundwater and produces springs and/or seeps. Where the tills are better exposed outwash gravels are commonly folded into deformed tills, and/or reside on top. The till is often highly altered by paleo-weathering with sub-vertical fractures that can have $CaCO_3$ and iron oxide growth along them. The influence of such fractures on the till and loess permeability is largely unknown, but potentially significant.

Two geologic units of economic and construction significance to the city are alluvial gravels and the Paleozoic limestones, both used mainly for aggregate purposes. Relatively shallow alluvial gravels of the Platte River are actively extracted at several localities, including near the juncture with the Missouri River. Gravels associated with the Missouri River are too deep to be economically extracted in this area. Limestone is quarried at several local quarries including the Schildberg quarry near Crescent Iowa, and the Martin Marietta quarries near Fort Calhoun to the north (which is now being continued underground) and their Springfield Quarry to the south along the edge of the Platte River valley. Several abandoned quarries can be found along the Plate River corridor south of Omaha. Larger limestone blocks are used as riprap for erosion control purposes throughout much of the city, including along the Missouri River and the Papillion Creek drainage.

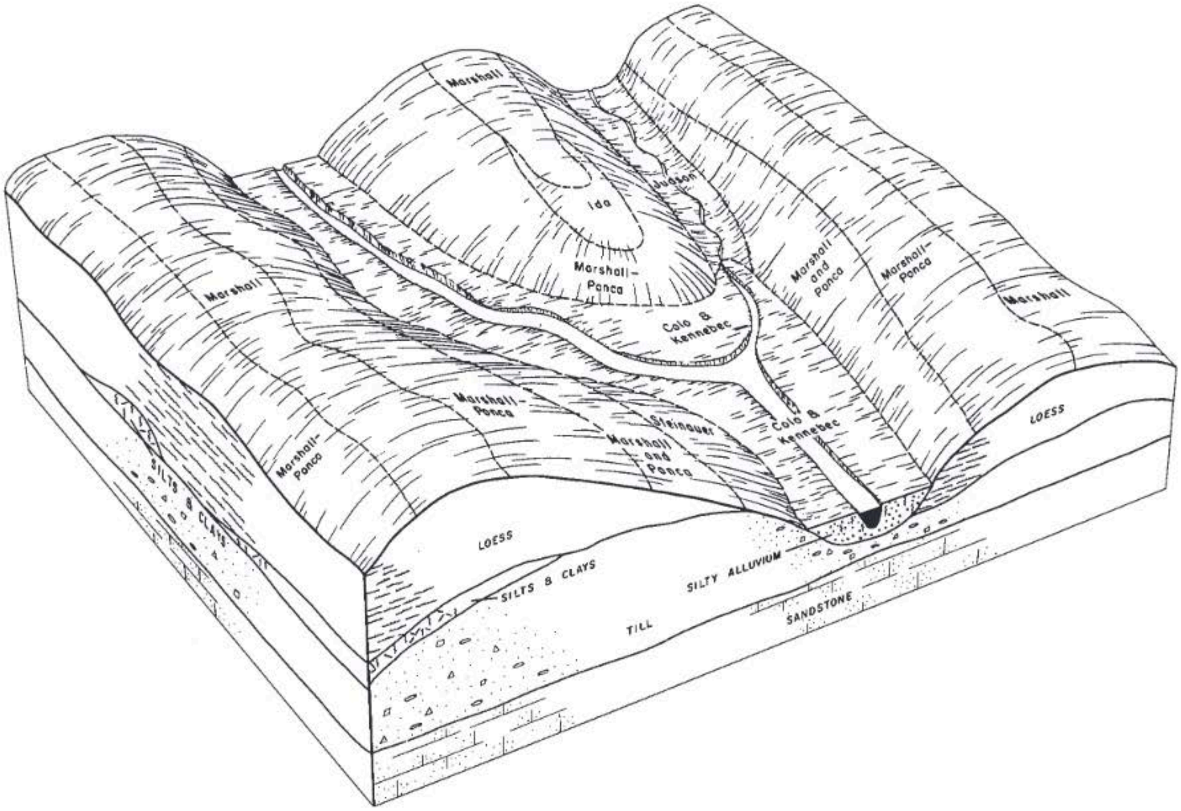


Figure 3.—Typical pattern of soils and underlying material in Marshall-Ponca association.

Figure 4: Diagram taken from Bartlett (1975) showing one of the six soil associations described and how they are related to topography and the underlying geology. This association which makes up about 50% of the survey area is described as “deep, well drained, nearly level to moderately steep silty soils on loess uplands”.

Bartlett (1975) provides an in-depth description of the soils of Douglas and Sarpy County (e.g., Figure 4). The report also includes a section and table on the engineering properties of the soils. As would be expected the parent material is often loess or reworked loess, which influences soil development. Typically, loess soils developed into Mollisols, a category of soils common in grasslands where significant organic matter has accumulated in surface soil horizons. More soil information for the Omaha area can also be found online at the interactive map database at https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx and at https://dnr.nebraska.gov/data/soils-data .

A look at Omaha area soils from an anthropogenic viewpoint is yet to be done. Given that much of Omaha expanded over land previously farmed, natural associations have been altered by tilling, and erosion likely removed some of the topsoil (the zonation is truncated). With all the subsequent urban related changes (e.g., construction related erosion or emplacement, addition of topsoil and mulch) the soil type and character as described by the Bartlett soil maps (1975) may bear little or no resemblance to what surface material presently exists in the Omaha area. The distinction between an engineering and scientific perspective and classification of soils is of importance in such discussions. A general framework has been developed for classifying such ‘anthropogenic’ soils (Galbraith and Shaw, accessed 8/5/2022).

Notes

Glacier Creek Preserve

Location: 14810 State St, Bennington, NE 68007; N 41.33886° W -96.14702°.

Parking: Limited parking is available at The Barn, a donated and restored building now used as an educational center. The Barn and preserve open space can be reserved for events (more info at https://www.unomaha.edu/college-of-arts-and-sciences/nature-preserves/preserves/index.php#use).

Background: Glacier Creek Preserve is a "a unique metropolitan area preserve available for education, research, and appreciation of our natural heritage" (UNO website) that is managed by the University of Nebraska at Omaha and has a multi-stage history of development. In 1959 the Glen Haven Farm was donated to the UNO Biology Department as a wildlife refuge. The area had been farmed since the 1870s. In 1970, 130 acres were seeded to reestablish a tall and mixed grass prairie, named the Allwine Prairie Preserve. Additional substantial donations and expansion led to the development of the Glacier Creek Preserve which includes the Allwine Prairie Preserve. In addition to research in grassland ecology and management, the site has also been developed into a highly instrumented **critical zone observatory**. As mentioned, the **critical zone** is defined as the area from the top of the vegetative canopy, through the soil, and into the shallow groundwater (e.g., NSF, retrieved 7/22/22). This zone comprises what might be considered the living 'skin' of the earth. Critical zone science requires an integrated earth system science approach to understand the dynamics of that zone, a zone critical to human and ecosystem well-being (Minor et al. 2019). Critical zone observatories are heavily instrumented and monitored sites where research is focused (Brantley et al. 2017). Nine such observatories were initially funded in the U.S. by the National Science Foundation, and a network has expanded beyond those (https://www.criticalzone.org). Counterpart observatories exist elsewhere globally, and a Critical Zone Exploration Network organization facilitates international research collaboration (https://www.czen.org/).

A striking example of the influence of humanity at regional and global scales is the present rarity of prairies in the Great Plains, which, because of their rich soils, have been overwhelmingly recast into farmland. Only 4% of tall grass prairie is estimated to still exist (Anon, retrieved 2/23/22). Thick prairie soils dominated by a high biodiversity, with recycling of nutrients, and shaped by fire have been replaced with farmland soil with high-yield monocultures, where nutrients must be reintroduced, where fire is prevented, and which are prone to and thinned by erosion. Processes of soil formation, surface water infiltration, groundwater geochemistry, and the transport of windblown dust have all been changed significantly in ways we are only beginning to understand. This human modification of the very extensive grassland biome is one reason that the Anthropocene has been proposed and is one reason that Glacier Creek is a fitting first stop for the field trip.

Some of the specific critical zone research questions being pursued at Glacier Creek Preserve include the following. How quickly do disturbed and depleted soils regenerate once restored to prairie? How do actively farmed soils differ from the restored prairie soils, and why do they differ? How does microbial activity contribute to prairie soil development? How does the prescribed prairie management burns influence soil mineralogy? What are groundwater and mineral interactions at this site (Figure 5). How is carbon sequestered or released from the soil and how much? Other research questions are evolving as critical zone research at observatories and elsewhere provides detailed data on what is occurring. Answers may help us better manage soils, a precious resource.

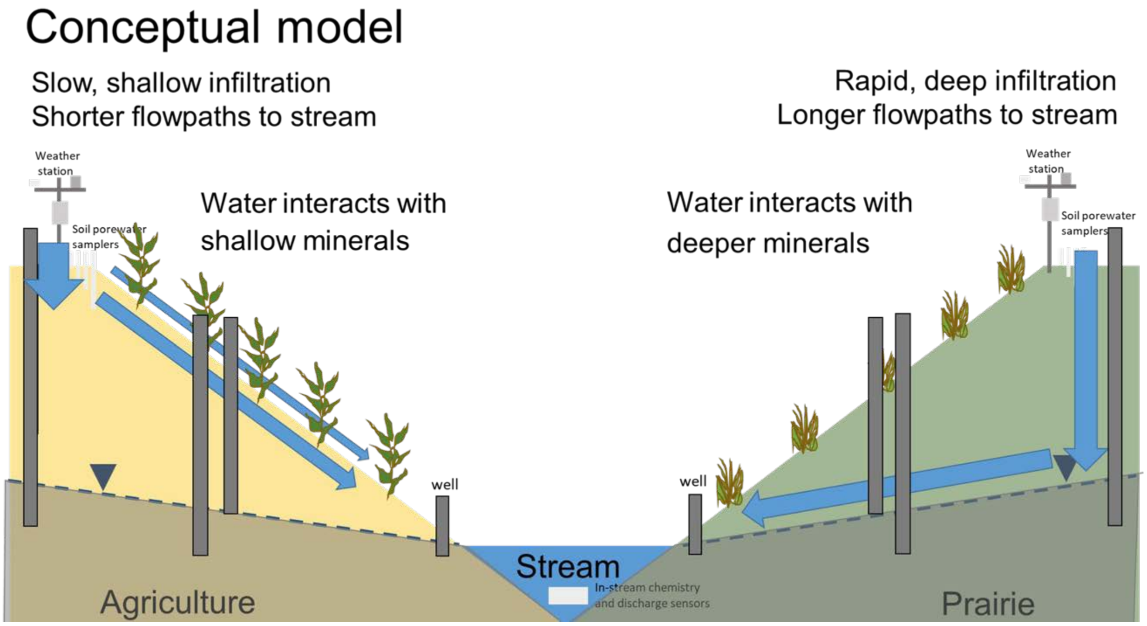


Figure 5: This conceptual model of Glacier Creek Preserve addresses the overarching question: How do intensive agriculture and restored prairie land management influence geochemical and hydrologic fluxes from soils to stream? Grey bars indicate groundwater well locations across the hillslopes, weather stations and soil porewater samplers are located on ridgetop topographic positions in both restored prairie and agriculture land uses, and blue arrows indicate hypothesized hydrologic flow paths through the different hillslopes. Figure modified from Dere et al. (2019a).

Monitoring facilities at Glacier Creek include 7 groundwater wells (Figure 6), two weather stations that provide continuous local meteorological data, and two sites where buried sensors with data loggers record soil moisture, O_2 and CO_2 soil gas concentrations, temperature, and soil conductivity at four different depths (20, 60, 110 and 180 cm) (Figures 5, 6). In addition, soil water and soil gas samples are sampled manually every two weeks and analyzed for their geochemistry. One of the sites is in the restored prairie (restored from agriculture in 1970) and the other in the actively farmed area (corn-soybean rotation), allowing for comparison of soils, solutes, and gases under different land management. The weather stations were installed in 2015, soil porewater samplers were initially installed in 2018, and gas sampling cups and sensors were installed in fall 2021 (prairie) and spring 2022 (agriculture). In addition, direct push cores, bucket auger samples and geophysical surveys have allowed subsurface characterization. Much of this work is currently funded by a collaborative National Science Foundation grant to Dr. Dere. A parallel set of facilities and research supported by the grant exists in an agricultural site and younger restored prairie in Illinois to facilitate both comparison and generalization across the Midwest. A tremendous amount of data has already been collected and will support substantial future analysis.

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, and the GIS User Community
Map Created 14 January 2020

Figure 6: Air photo of Glacier Creek Preserve. The educational barn and other UNO buildings associated with the preserve can be seen in the lower left. The green dots are the positions of groundwater observation wells. The main roughly E-W drainage is Glacier Creek (solid blue line) which feeds into the Papillion Creek; dashed blue lines are natural drainage features. The northern portion of the watershed is where active farming is occurring, and the southern portion of the watershed is the restored Allwine Prairie. The relict terraces created for erosion control when Allwine Prairie was being formed are quite evident. Plans are to create wetlands in the portion of Glacier Creek to the east of where it crosses the dashed yellow line.

The Glacier Creek Preserve site geology consists of loess mantling glacial till, with local but discontinuous outwash sands and gravels encountered in the subsurface (Figure 9), a stratigraphy widespread in the Omaha area. The till is near surface in the lower portions of the creek, where wetlands, and in the past small ponds have existed, but is mantled by soil and vegetation. Because of the till acting as an aquitard, groundwater is likely perched and feeds Glacier Creek. Push cores show significant heterogeneity in glacial materials below the thick loess mantle in the northern portion of the watershed, but these sand lenses were not observed in the mid-slope cores. Ridgetop and mid-slope cores on the southern prairie portion of the watershed did not have any sand lenses within the upper 23 m of core. It seems likely the ridgetop groundwater well on the agricultural northern side if the preserve is screened within one of the sand lenses, as the well is rapidly pumped dry but also recharges quickly. On the prairie ridgetop, however, recovery time after pumping can be several weeks, indicating very slow recharge through the dense till.

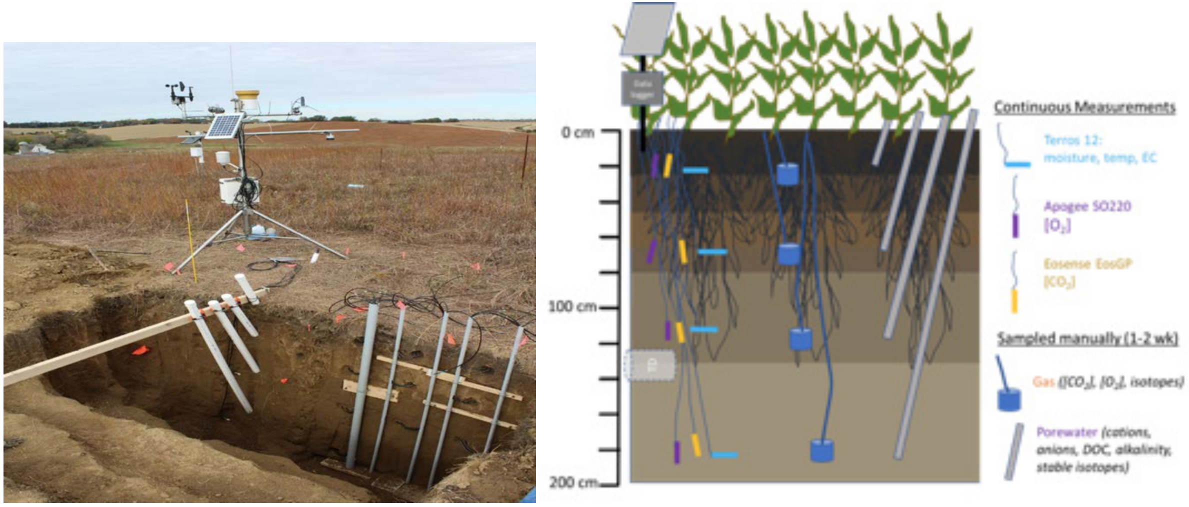


Figure 7: (left) Soil monitoring site being installed in the restored prairie on the top of the hill to the south of Glacier Creek. The preserve Barn can be seen in the distance in the upper left corner. The parent loess material and organic matter-enriched prairie soil are evident in the soil pit. The weather station sits aboveground and the far-left PVC pipes house soil CO2 and O2 sensors; all sensors record data every hour. The grey tubes on the right house flexible tubing that allows soil gas concentrations to be manually sampled and analyzed. A white tube directly under the weather station is one of four samplers that extracts soil porewater by applying a vaccum. (right) Schematic of sensor installations showing various measurements both in and below the rooting zone. Instrumentation is identical between restored prairie and agricultural sites here in Nebraska and in Central Illinois. Modified from Dere et al. (2022).

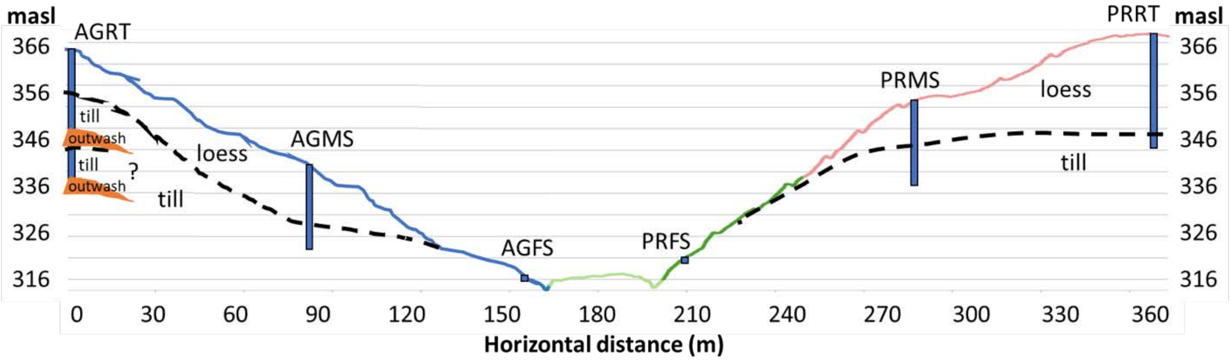


Figure 8: Geologic cross section of the Glacier Creek valley. Topography is from lidar data and is vertically exaggerated. Blue bars indicate groundwater wells and dashed lines are inferred geologic boundaries from dill core logs and push core samples. Figure from Deureling et al. (2021).

Closer to the surface, loess dominates the watershed (13 – 18 m deep at the ridgetop). Distinct soils have formed after 52 years of restoration from agriculture to prairie: surface soils in the prairie have over two times more organic carbon, seen as the dark brownish black horizon in the far-right photo of Figure 9. On the agricultural side of the watershed, soils are Contrary silt loam (Fine-silty, mixed, superactive, mesic Dystric Eutrudepts) while prairie soils are Monona silt loam (Fine-silty, mixed, superactive, mesic Typic Hapludolls). Another notable difference between agricultural and restored prairie soils is the presence of deep and abundant roots in the restored prairie, which has helped create soil structure and connected pores through which water and gases can move. Earthworms are present in both agriculture and restored prairie soils, but their traces are especially visible in the agricultural soil (middle photo of Figure 9) due to minimal mixing and horizonation. For comparison, the left photo of Figure 9 is an example of a native prairie soil in Eastern Iowa showing thick accumulation of organic matter that elsewhere has been significantly lost due to agricultural activities.

Figure 9: Images of soil pit profiles from unfarmed prairie soil in Eastern Iowa (left), the agricultural soil at Glacier Creek (middle) and the restored prairie at Glacier Creek (right). All three soils are developed in loess with broadly similar climatic conditions, although the Iowa soil receives higher rainfall (89 cm mean annual precipitation versus 78 cm mean annual precipitation in eastern Nebraska). The humus content is one obvious difference, and what is of interest is the significant humus accumulation after only ~50 years of being restored as a prairie. Image courtesy Dr. Ashlee Dere.

The change in soil structure due to land management may influence water infiltration and water flow paths to the stream. A cross section of electrical resistivity measurements from ridgetop to ridgetop suggests higher resistivity in surface prairie soils (warmer colors), indicative of drying/drainage of the soil, whereas increased conductivity in surface agriculture soils (cooler colors) suggests the water is staying shallower (Figure 10). The green to light blue color change with depth in Figure 10 appears consistent with the loess/till boundary observed in well cores. In addition, this data suggests that the terracing, done for soil erosion purposes when the entire site was actively farmed, strongly influences the shallow electrical resistivity, and indicates shallow water "pooling" behind the terraces, altering hillslope drainage (Figure 11). Moisture tends to concentrate upslope of and under the terrace berm. This has implications for other prairie restoration projects, and for soil development. Substantial hydrogeologic and geochemical differences are apparent between the farmed and restored prairie soils due to the different hydrology induced by land management. Agricultural soils may retain water that interacts with shallow minerals before flowing to the stream whereas restored prairie soils allow rapid water infiltration that dissolves deeper minerals before reaching the stream (Dere et al. 2019a).

Future work will focus on characterizing how biotic and abiotic factors influence nutrient and carbon flux and storage under different land management. One tool for understanding soil biology is through measurement of CO_2 and O_2, both of which are important indicators of microbial respiration as well as weathering reactions. Preliminary data from the restored prairie at Glacier Creek show a rapid increase of CO_2 and concurrent drop in O_2 as soil microbial respiration increases in spring (Figure 12). Notably over the winter months, when cold soil temperatures and dormant vegetation inhibit microbial activity, steadily high CO_2

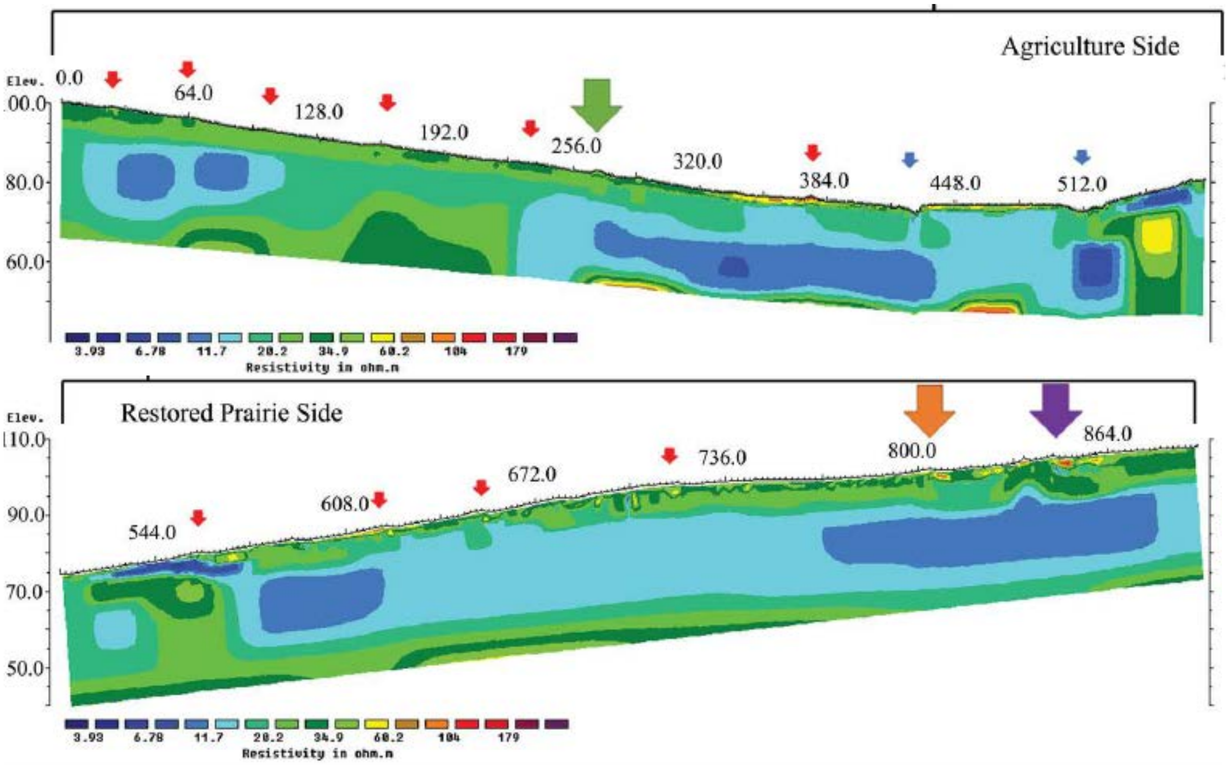


Figure 10: Electrical resistivity tomography data for agricultural (top) and restored prairie (bottom) hillslopes at Glacier Creek Preserve. Green to light blue is interpreted as the loess/till boundary. Higher resistivity (warmer colors) near the surface in prairie soils suggests drier/more well-drained soils while higher conductivity (cooler colors) in surface soils on the agricultural side suggests water remains in these shallow soils. Colored arrows correspond to detailed terrace measurements shown in Figure 11. Figure from Mount et al. (2019)

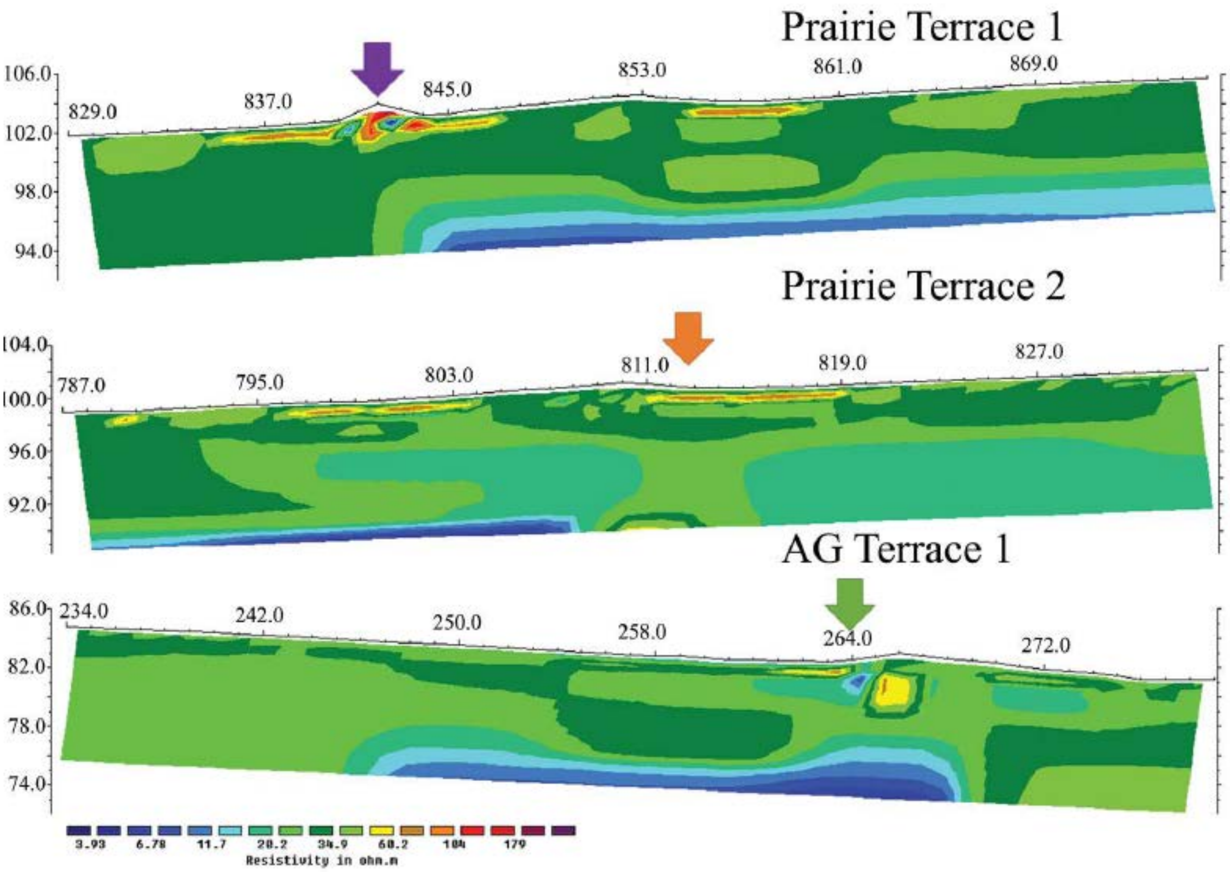


Figure 11: Electrical resistivity tomography data for select constructed terraces at Glacier Creek Preserve suggest the terraces alter surface soil hydrology by retaining moisture behind the terrace berms, regardless of surface management. Figure from Mount et al. (2019).

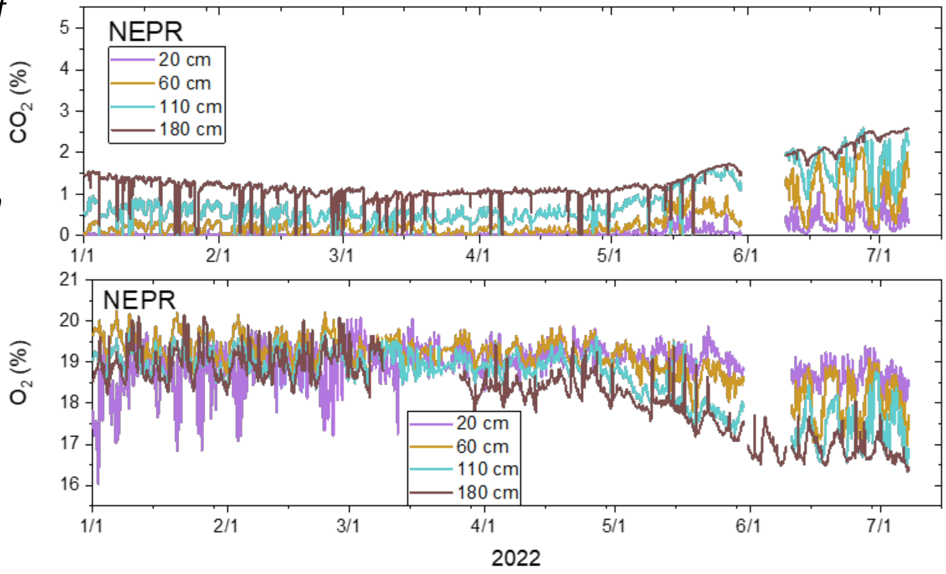


Figure 12: An example of the fine resolution soil gas data collected at the restored prairie site at Glacier Creek Preserve. The increase in CO_2 and concurrent decrease in O_2 in the spring months reflects increased plant and microbial activity. Sudden periodic CO_2 drops over the winter months are the result of sensor malfunction, an unfortunate reality with many high-resolution automated sensors. From Dere et al. (2022).

concentrations are still observed at deeper soil depths. One challenge will be to untangle the biotic CO_2 contributions from abiotic weathering of carbonate that also releases CO_2, a question we hope to tackle with isotopic gas data manually collected from the soil gas samplers.

Undergraduate research at the preserve has also looked at aeolian dust input into the system, the geoarchaeology of a site on the preserve, mineralogical and hydraulic conductivity changes in burned or mowed prairie grasses, microbial activity through decomposition experiments, and soil DNA extraction and sequencing. Service-learning projects with K-12 students have also looked at critical zone science at the preserve (Dere et al 2019b). The preserve provides an invaluable learning environment.

Notes

Heflinger Park: an old landfill that has gone to the dogs

Location: The park is SW of N 108th Str. and W Maple Road with an approximate latitude & longitude of 41.2873°, -96.0882°.

Parking: There is a public parking lot for the dog park.

Background information: This was a county landfill from 1967-1973 and is about 67 acres in size. The Douglas County landfill was then moved to State Street where it operated from 1973 to 1989. Subsequently the Heflinger site was given to the city and turned into a public park space (Figure 13 & 14). With urban growth both landfills became embedded in the city and are now surrounded by dwellings and businesses. The topography at Heflinger is that of a gentle slope down towards the Big Papillion Creek to the west. Ostensibly, shallow ground water flow is in that down slope direction, although a creek is entrenched on its N side and there may be a local component of flow in that direction. Sandstones of the Dakota Formation outcrop on the east side of the Big Papillion creek several hundred meters to the south, suggesting substantial paleo-relief on the base of the Quaternary in the area, and the presence of an underlying aquifer for the landfill.

Figure 13: USGS air photo image (≈2001) of Heflinger Park back when it was used as public softball fields and after the development to the south had been built. North is to the top. The southeast corner of Heron Haven can be seen north of the double lane West Maple road in the upper left corner of the image. The wooded Papillion creek riparian corridor runs north to south to the left.

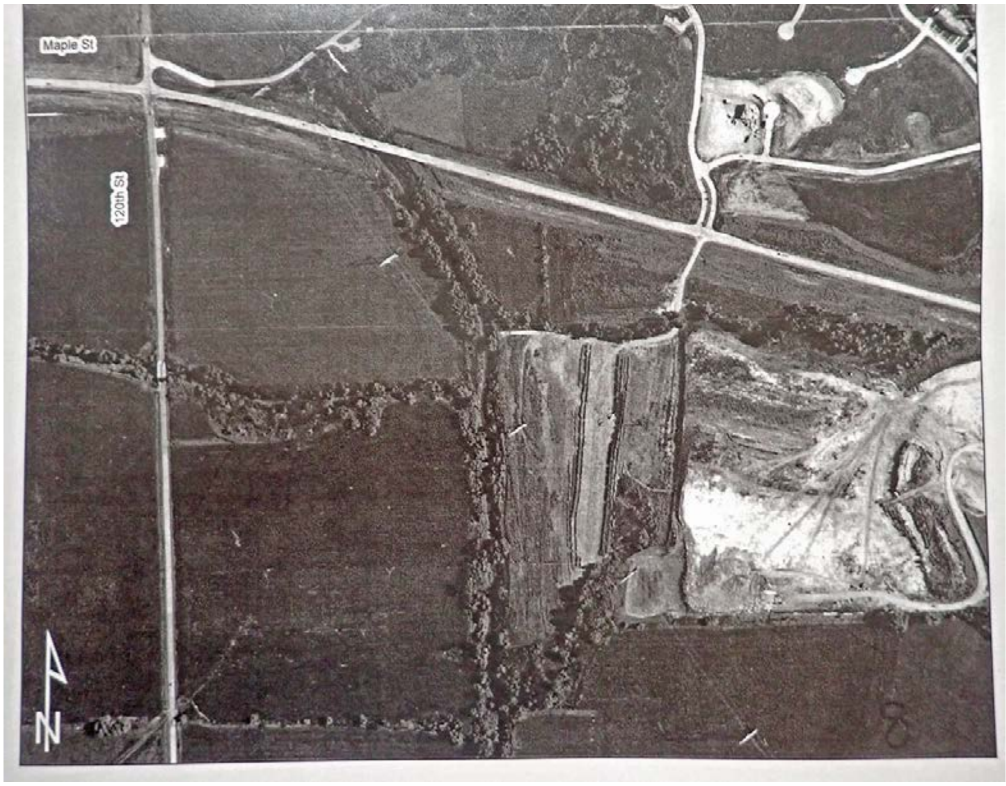


Figure 14: 1971 air photo of Heflinger Park area with evidence of ongoing land fill activity. This was toward the end of the landfill's lifespan. This photo is courtesy of the Friends of Heron Haven. The Haven can be seen in the upper middle portion of the image prior to damming for wetland construction purposes.

Subsidence trenches are quite visible to the south of the park road as linear surface depressions several feet deep and that run roughly north-south (Figure 15). In addition to trenches cut into the existing landscape, waste and cover material were likely mounded above the previous land surface. In other areas trenches run more northwest-southeast, and in other areas the subsidence depressions are more irregular. Some depressions have reedy vegetation at times and may serve as ephemeral wetlands (Figure 16). They may also serve as groundwater recharge points into the fill. Through the years the subsidence has caused significant damage to the road, requiring regrading and repaving. The cumulative influence of differential compaction of the trench can be better seen in the parking lot, which has not been regraded and repaved for a much longer period than the road.

Five methane venting pipes are surrounded by fences to S of the road with the neighborhood development just further south. Some of the surface venting pipes are tilted significantly due to differential settling, and may not be operating as initially engineered (Figure 17). It is unclear how much methane is still being produced. Some of the wastes were from South Omaha packing houses, paunch manure, promoting both methane production and significant differential settling through biodegradation. Drainage to capture runoff/leakage exists along the S border. In places on the steeper southern slope there are minor patches of shallow erosion. In these, garbage fill (rusty tin cans, bones, plastic, one tire) has either worked its way to the surface or has been exposed. Close mowing may have helped sheet wash to remove cover material. Rip-rap was placed along the steep-walled and entrenched small creek that flows along the northern border. In its lower section sheet piling and sediment dams were installed. One has to work through the brush and small trees to find these structures. Garbage fill may be exposed here in a few places (figure 18). Monitoring wells used to exist toward the south, but could not be found on the well registry or on site.

Figure 15: View of road in Heflinger Park looking southwest of where it crosses two of the trenches with waste fill that underwent significant compaction during biodegradation. The road has since been regraded and repaved, but additional subsidence continues.

Figure 16: View looking westward from the top of the landfill site down slope towards the Big Papillion Creek. An enclosed depression with dried out reedy plants is evident in the foreground. A second one is just evident to left and down the slope. Image taken in August 2022.

Figure 17: View looking east at uppermost methane venting site. A sign on the gate says “no smoking”. In the upper right image section a small drainage ditch, along with a house belonging to the development to the south, also is evident. Image taken in August 2022.

Figure 18: View from south slope of landfill showing garbage exposed that was and likely part of the fill. Sheet wash may have removed overlying soil, or the garbage has worked its way up to the surface. Illegal dumping after the land fill was closed can not be ruled out.

The facility has become a well utilized dog park. Earlier on it was a softball park that had to be abandoned because of the deterioration of the playing surface related to subsidence. Douglas County Environmental Services retains the responsibility of monitoring the landfill (http://www.dceservices.org/landfills/environmental-compliance) along with the State Street Landfill at 126th and State Street (which also has a methane collection system). Heflinger Park is a good example of an urban legacy environmental site, the general type that motivates Phase 1 studies for commercial real estate transactions. With present day criteria for land fill siting this site would likely not be chosen as a landfill because of its proximity to the Big Papillion Creek and associated groundwater table and to residential development. The site is also a good example of how environmentally challenged sites often become much needed and utilized public green spaces.

Notes

Heron Haven

Location: Just north of Maple Road and a bit east of 120th street. 41.2925° -96.0973°.

Parking: A small parking lot dedicated to the Haven exists just off of Old Maple Road (Figure 20). The Haven is open to the public during daylight hours.

Background information: Wetlands provide crucial environmental services. These include: a) habitat and a biodiversity reservoir, b) storm water storage, and c) improvement of surface and ground water quality (Anon, EPA Fact Sheet). Added to this could be carbon sequestration, and if public access is provided (usually involving walkways for wetlands) the opportunity to connect with a bit of nature within the city, aiding mental health.

Figure 19: Boardwalk at Heron Haven. The high biologic productivity of the wetlands is clear. Stirring the bottom sediment with a stick typically releases bubbles of methane from anaerobic decay, which can remind one of the carbon sequestration associated with wetlands. Fish, frogs and turtles in the water attest to the water quality above the sediment bottom.

Heron Haven is a restored and expanded wetland about 25 acres in size in total (Figure 19 and 20). One sinuous water body present (Figure 20) is a relict 'oxbow', lake. Instead of being formed naturally by a channel cutoff during a flood, in this particular case the channel was abandoned and left elevated on the flood plain when the Big Papillion Creek was straightened and entrenched sometime before 1941 (Figure 21). Large cottonwoods along the oxbow's margin likely predate that engineering. A supply of water from vigorous springs upstream (Figure 22) keeps the water table fairly high. In addition, the city storm sewer system is connected to the small pond in the southeast corner contributing water and sediment. The entrenched natural valley upstream (north) of the haven and main suite of wetlands has a distinctive linear geomorphology with the springs near its upper reaches and a relative lack of any significant drainage branching along its length. Sapping and groundwater-fed flow may have influenced the valley's development.

A low earthen dam with a simple control structure creates and controls the small and shallow pond. Siltation does occur (Figure 23) and in order to restore open water habitat the wetland was drained and dredged in 2012, 2013 (Sam Bennett, pers. comm.). A careful look on some of the trails in the northern portion brings to light cement and bricks poking through the leaf litter, and the site was used to dump construction waste material in the past.

Figure 20: Modified image of Heron Haven from Douglas County GIS web site. 1 – Entrenched Big Papillion Creek. 2 – Small spring fed creek that feds into the wetland. The springs can be found on either side of the upper third of the creek. 3) More northern portion of the ox bow channel on the Big Papillion Creek floodplain that become a 'perched' pond when the Big Papillion creek was entrenched. 4 – Small artificial "Dragonfly Pond" that reflects the shallow groundwater table in the area. 5 – Parking lot and educational building. 6 (dashed line) – Small earthen dam structure that creates the main water and wetland body (7).

Springs are not uncommon in the Omaha area and are stratigraphically associated with glacial till and outwash. In this particular case the till may be overlying and confining the outwash gravels. Based on larger till-outwash outcrops seen along the Elkhorn and Platte rivers outwash gravels can also be deformed as pockets within the till. A suite of springs and seeps can also be found in a similar stratigraphic position along the creek in Elmwood Park just southeast of the UNO campus. Glacial till deposits vary significantly in thickness in the Omaha area, generally thinning to the south. The long term vigor of the Heron Haven springs suggests a connection with the underlying Dakota aquifer may exist.

In 1991 the area was slated to be turned into an apartment complex, when Ione Werthmen, an Audubon Society member, rallied support and donations along with funding from the Nebraska Environmental Trust to turn the wetlands into a preserve. The site had been used as an illegal dumping site, and house hold appliances and other debris had to be cleared out (Bruce Warr, pers. comm., 2022). The Audubon Society managed the site until 2004 when it was turned over to the non-profit, Friends of Heron Haven, who have an agreement with the

Papio-Missouri River NRD to oversee the site. A bar, named at various times Gillies Bar and the City Edge, was purchased and became an on-site education and administrative facility.

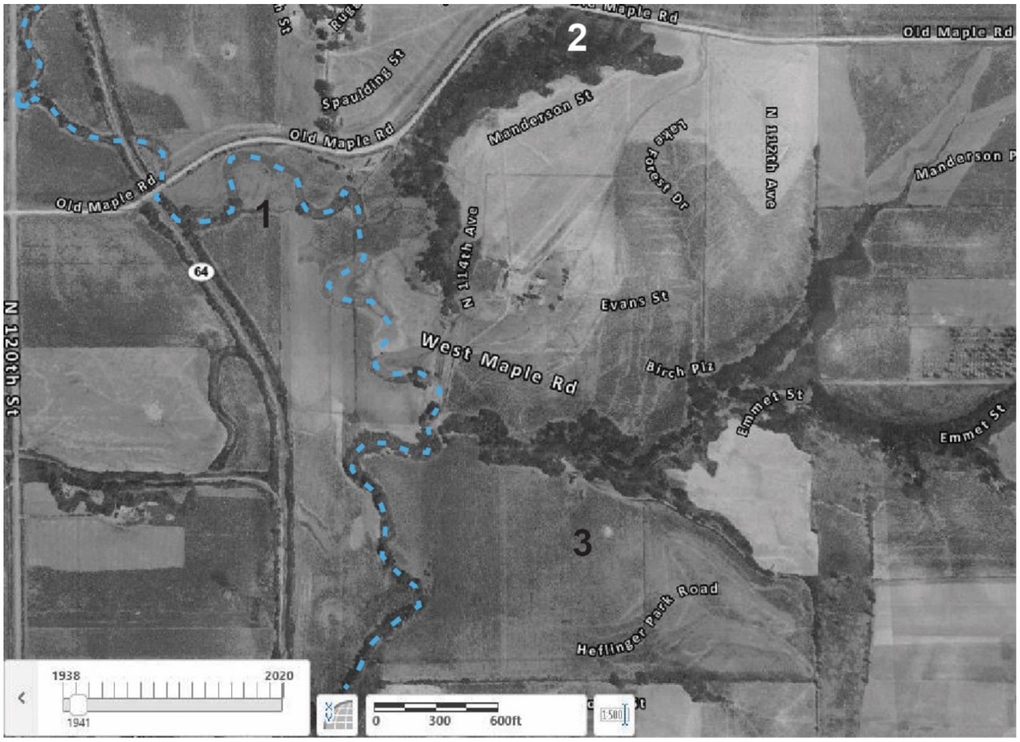


Figure 21: Airphoto image of Heron Haven and Heflinger Park area from 1941, obtained from the Douglas County GIS web site, with top to the north. The blue dashed line represents the meandering trace of Big Papillion Creek which had already been straightened out and incised into the channel to the west. Only traces of the meanders remain to this day within the haven. 1 – approximate position of Heron Haven. 2 – steep ravine (hence unfarmed) with springs at is source. 3 – approximate position of future Heflinger landfill and the dog park. In 1941 the area is clearly rural farmland, yet to be engulfed by a growing Omaha.

Figure 22: Spring source upstream from Heron Haven. Note the clay rich material above the spring, and the gravel clasts in the outflow. The pink clasts are Sioux quartzite and the light-colored clasts are Paleozoic limestones. Some of the dark clasts are Precambrian metavolcanics. These are a clear indication that glacial till and/or outwash is involved. A visual estimate is that the

discharge for this particular spring was several gallons per minute. At least 4 similar separate springs were observed and more likely exist. The white covering is frost.

Figure 23: Oblique air photo view of Heron Haven before dredging showing the amount of siltation that had occurred. Photograph courtesy of Friends of Heron Haven.

That Heron Haven is a human enhanced wetland introduces the question about habitat restoration versus creation. Emma Marris wrote a book, A Rambunctious Garden (2013), that explores this issue. She argues that restoration and preservation is often a misguided goal because of the difficulty of deciding what time and state in the past serves as the restoration goal for a particular project. In addition, changing conditions can make maintenance of the 'restoration' expensive and/or non-sustainable. She argues that instead we need to manage for and create rambunctious sustainable gardens that support high biodiversity. In Heron Haven's case, the habitat and natural beauty, are highly influenced by human efforts, and specifically the dam is crucial to the preserve. This site is particularly well chosen as the natural springs help make the wetlands sustainable as a 'rambunctious garden'. It is not uncommon that wetlands are constructed for offset purposes, counterbalancing the destruction of wetlands in one place with their recreation in another place. The question then becomes – what makes an effective and sustainable wetland that can be a valuable part of a healthy landscape and ecosystem? An abundance of literature exists on constructed wetlands (one starting place is at the EPA website, https://www.epa.gov/wetlands/constructed-wetlands) much of it focused on those developed for the purpose of wastewater treatment. Such an endeavor requires a system science approach and must consider the hydrogeology, the water and soil geochemistry, meteorology, the biota (especially the microbial), siltation, and more. Geoscience input into their design is thus crucial.

Carter Lake and Eppley Airfield

Location: Levi-Carter Park, 809 Carter Lake Shore Drive, Omaha, NE 68110 41° 18' 8.3124" N, 95° 55' 35.3532" W Access to the lake is available at several other sites.

Parking: Available at several lots along the lake shore.

Background: How Carter Lake came to be is fairly well known. In 1877 a flood resulted in a meander cutoff produced the original oxbow, now Carter Lake. The previous river position was the state boundary, and a small bit of Iowa now resides on the W side of the present Missouri River path. Perhaps less appreciated is how highly managed this urban lake presently is, how the lake sediments can provide a record of environmental change in the area, or how close Omaha came to losing the airport during the 2011 flood.

While Carter Lake was a naturally formed oxbow, the lake is also now highly modified and managed. Due to a high nutrient loads, particularly phosphorous, Carter Lake was hypereutrophic, and attendant toxic algal blooms closed the lake to use for 24 weeks in the summer of 2004 alone (Holz et al. 2015). Yet, it was also estimated to have a $13 million or greater annual economic value at that time. The response was the formation of a recovery and management plan through a collaboration between a private-citizen group (Carter Lake Environment Assessment and Rehabilitation Water Council), and state, city and federal government (CLEAR 2008). The following description of the management strategies and results are largely taken from the management plan and from Holz et al. (2015). Four lake management goals were: maintenance of water levels, improvement of water clarity, reduction of nutrient load (especially phosphorous), and establishment of a game fish population. Regarding lake levels the already existing North Flood Control Lift Structure could pump out 9000 gpm and empty the lake in 10 days or thereabout, allowing response to flooding associated with intense rains. For times of drought, the plan pursued developing groundwater wells near the Missouri River to augment lake levels when needed. Pumping water from the Missouri River directly would supply undesired sediment and nutrients, and hence the well option was selected.

To promote water clarity and address shoreline erosion and sediment and nutrient introduction, limestone rip-rap has been placed along the shore in a variety of places. Offshore breakwaters of rip rap serve to protect wetland shorelines behind them from wave action. Waves are generated both by winds and boating. These fringes of wetlands also act as filters, promoting uptake of nutrients and biodegradation of contaminants that would be introduced from surface runoff . The Carter Lake Preserve at lake's north end (https://swmlc.org/project/carter-lake-preserve/) represents an extensive suite of marginal wetlands. The preserve is held by the Southwest Michigan Land Conservancy and is not open to the public. Interestingly, increasing the clarity of water led to substantial increased growth of aquatic plants. As a result, 'weed' harvesters are presently used to keep portions free for boating purposes. Dredging to reestablish water depths was conducted in 2012, and more is planned and will be needed. One consideration during dredging is not to change the shallow hydrogeology significantly when removing or disturbing bottom sediments (e.g. perforating a fine-grained sediment seal).

To reduce phosphorous levels an alum application of 156,640 gallons of aluminum sulfate and 78,320 gallons of sodium aluminate was added to the lake in May of 2010. The phosphorous chemically combines with the alumina sulfate to form a water insoluble aluminum phosphate compound which settles to the sediment bottom due to flocculation (Wisconsin Department of Natural Resources, 2003), effectively removing dissolved phosphorous from the water column. In addition, the alum compounds that have settled to the sediment bottom act as an uptake barrier, preventing phosphorous in the lake sediments from entering the water. Phosphorous in the lake sediment accounts for over 50% of the nutrient load, and wave action can resuspend sediment and reintroduce it. A secondary precaution against resuspension involved the introduction of no-wake zones. In addition, in Sept. 2010, 2,520 lbs of rotenone was applied to kill off the existing fish population. An estimated 176,000 lbs of fish, with 4,013 lbs of phosphorous and 18,480 lbs of nitrogen were removed and taken to the land fill. The lake was then restocked with large-mouth bass, crappie, bluegill and channel catfish. The amount of phosphorous and nitrogen removed by 'weed' harvesting is not estimated, but should also represent a reduction of internal lake nutrient load. These nutrient mitigation strategies were deemed successful by reducing the presence, time, and duration of harmful toxic algal blooms in the lake (EPA, 2011, accessed 8/8/2022).

Oxbow lakes have variable, but naturally limited lifetimes, geologically quickly filling in with sediment, and evolving into wetlands, and then into land. The fact that abundant scars of past meanders on the Missouri River flood plain can be seen, but oxbow lakes are relatively rare, suggests their lifetimes are variable (in the range of 100s to 1000s of years), but relatively short. Most have filled in since Missouri River stabilization, although the role of farming in this history is unclear and may be substantial. This suggests that management efforts to sustain the Carter Lake's area, water depth, water clarity, and ecosystem are in opposition to the natural evolution of oxbows and will require persistent dredging, water treatments, and biota management for as long as status quo maintenance is required. The estimated costs for the projects described above is close to $6 million.

The study of lakes, limnology, has blossomed with the need to understand local environmental and climatic change better. A subset of this field, paleolimnology (the study of past lakes) expanded with the realization that lake sediments could carry detailed and diverse records of that change in their sediments. Relatively little work is typically done on urban lakes because of their short lifespans and often disturbed stratigraphy, but Carter Lake has been the focus of a pilot study conducted by Sarah Nelson Wiese (UNO geology undergrad student) and Dr. Melina Luethje that specifically focuses on diatoms. The work was funded by a grant from the Sherwood Foundation (ID #5444). Diatoms are a diverse and widespread golden brown algae that create striking and very species-specific siliceous skeletal elements that preserve well. One visible manifestation of diatoms is as a brown-green fuzz that cover the sediment bottom in shallow waters, and which can have small gas bubbles trapped (O_2 from photosynthesis). The various species are good paleoenvironment indicators (Douglas & Smol, 2010). As an example, diatoms have been effectively used to reconstruct salinity changes in the Nebraska Sandhills over thousands of years in an effort to understand Holocene paleoclimate (Fritz, 1991).

One research question implementing paleolimnological practices was as to whether the water quality treatments described above also changed the diatom assemblage, and if so how?

A shallow 21 cm long core was taken from the lake (Figure 24) at a water depth of 7.6' and analyzed for diatom species and concentrations. Six species found in the greatest abundance are depicted in Figure 25. Diatoms associated with nutrient rich, turbid waters show a sharp decrease and then begin to increase again stratigraphically upwards, consistent with a treatment response, but one whose effects are beginning to diminish (Figure 26). The lake is typically alkaline (pH >8) which promotes silica dissolution, and this may have also influenced results for some of the diatoms, which were absent from ~10 cm of the core. In summary, the pilot study suggests that diatoms in urban lakes may give insight into urban lake water treatment efficacy and longevity, and insight into other events. This work is a reminder of the rise of the discipline of biogeology, looking at the interplay of biologic and geologic processes, often with a focus on microbes. The use of microbes for bioremediation processes in soil and groundwater clean-up is a reminder of the benefits of crossing disciplinary boundaries.

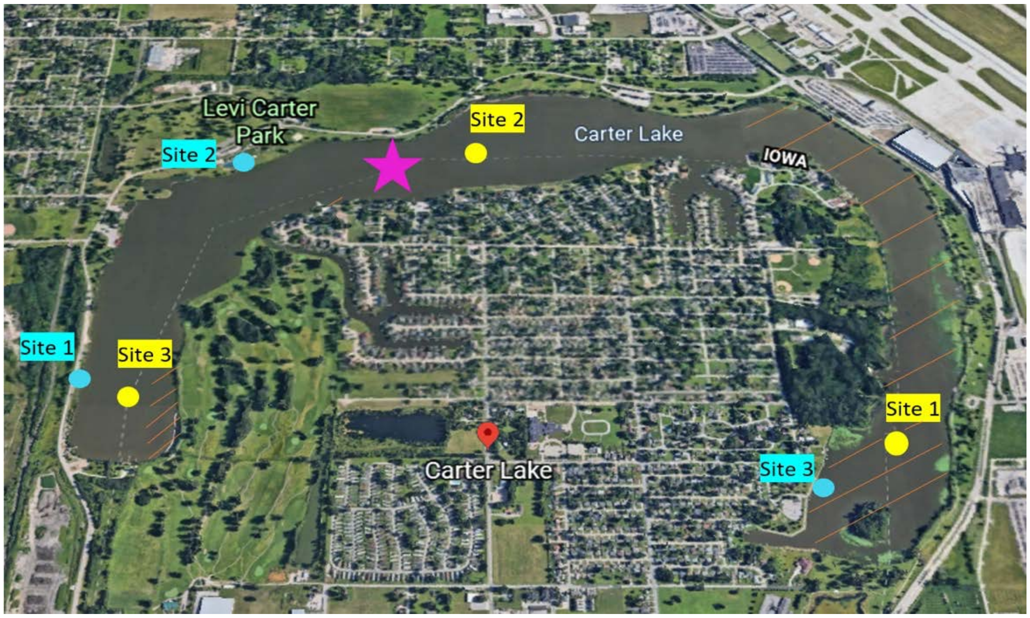
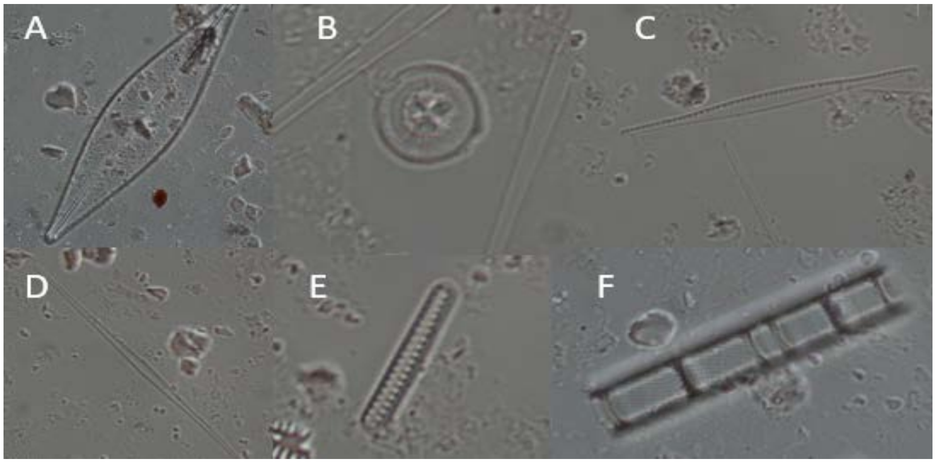


*Figure 24**:** Map of Carter Lake modified from Google Earth showing where samples and measurements were collected. Blue - samples were collected at the surface. Yellow - where pH, temperature, conductivity, and clarity data was collected on the boat. Star indicates the spot where the core was obtained. Orange indicates areas of the lake with no-wake zones.*

Figure 25: Species of diatoms found include Craticula sps. (A) , Lindavia ocellata (B), Nitzschia sps. (C), Fragilaria tenera (D), Staurosirella sps. (E), and Aulacoseira sps.(F). Images taken at 1000X.



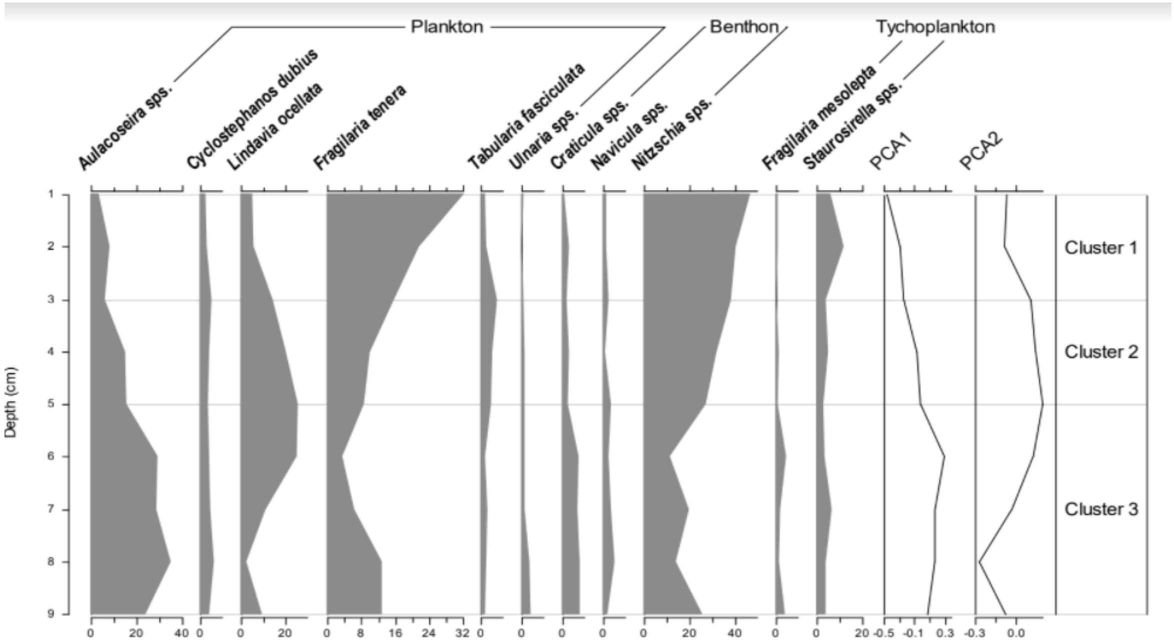


Figure 26: Carter Lake diatom relative abundances calculated and plotted stratigraphically against depth. The change at about 6 cm depth may correspond to the 2010 treatment of Carter Lake. This would suggest a recent sedimentation rate of .6 cm per year for this part of the lake. Given it is from the deeper middle part of the lake (Figure 24), sedimentation rates may be greater elsewhere.

Many people living in the Omaha area have likely seen Carter Lake on the way to the Eppley airport, or perhaps from the jet window. The airport is protected from Missouri River flooding by a substantial levee (Figure 27), and we can use this opportunity to review the efforts required to save the airport during the **historic 2011 flood**. A key aspect of that flood was its duration. In the Omaha area the river was in flood stage for some 3 months (Figure 28). This was sufficient time for the substantial head provided by the water behind the levee to drive groundwater flow under the levee, and raise the already shallow groundwater table under the airport area, forming sand boils and standing water in areas (Figure 29). The river was ≈20 feet above the level of the airport runways. As sand boils formed they were covered with gravel pads to stabilize the sediment in that area, but clearly much more had to be done given that water table could be expected to continue to rise. Basically, the airport was in danger of flooding from underneath, and the sand boils and associated sediment mobilization could threaten the stability of the levees leading to a more catastrophic event. The economic worth of the airport was estimated at $745 million a year, and so a major, multi-party response costing about $24 million was launched (Hendee 2011).

A major component of the response was the immediate installation of 70 dewatering wells (Figures 29 and 30) drilled to a 95' depth (Griffin, accessed 7/2022, and interview on 7/25/2022). The straightforward objective was to lower the groundwater table through pumping as quickly as possible. Griffin Dewatering is thanked and acknowledged for many of the following details. The wells had to be installed from on top of elevated gravel pads (Figure 29) in order to counter the head the river was providing, with ≈1 foot of elevation for each 10 feet of well depth. Above 10-15’ depth the wells were cased and below they were screened to the bottom with a borehole diameter of 42 inches. Each well was capable of pumping 1,400 gpm. The water was pumped to existing pump stations that then pumped it back into the river. Surface casings were used for the section where the gravel pad met the underlying alluvium. The groundwater table under the airport naturally fluctuates between 968’ and 974’ as the level of the river changes. Only three pumping wells existed prior to the flooding. Seepage berms on the airport side were also installed to allow for stable seepage and prevent levee liquefaction. Crucial infrastructure was sandbagged.

Figure 27: View of Eppley airport looking northwest during the June 16th 2011 flood. Carter Lake can be also be seen on the far side of the airport. Image from Army Corp of Engineers, retrieved from https://en.wikipedia.org/wiki/Eppley_Airfield#Accidents_and_incidents *7/14/2022.*

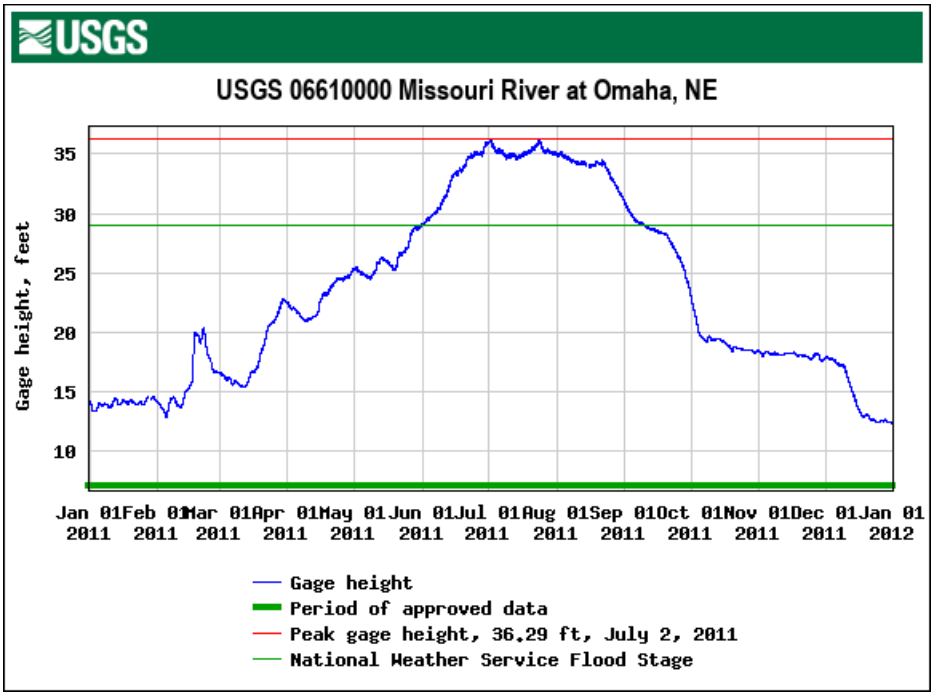


Figure 28: Missouri River Gage height for 2011 from USGS website. Note how the river was above flood stage (thin green line) for 3 months.

Figure 31 shows 10 sediment logs from the Nebraska Registered Wells Inventory in a west to east sequence from the northern portion of the arcuate array of wells, providing some insight into the Missouri River floodplain alluvial sediments. Data intervals suggests that sediment type was logged at 5’ intervals. Sand with silt and clay is the dominant lithology logged, and is interpreted to mostly represent flood plain facies. Clay may reflect abandoned or side channel fill. Historic imagery and accounts indicate the Missouri River in this area was a wider, multi-channel system with abundant sand bars, substantially different from the present (Figures 31 and 32). Coarser facies tend to be found in the bottom quarter of the drill holes. It is interesting to note that at about 60’ depth 7 of the 10 logs show a significant change, and in 6 out of those 7 the change involves an increase in overall grain size from sand with clay/silt to sand and/or gravel. One can speculate that this level represents a significant stratigraphic boundary, perhaps between the Pleistocene and Holocene. The reader is invited to correlate units from column to column, but fairly quick changes must occur from well to well, as would be expected from alluvial sediments. Anderson (2015) shows cross-section for a ≈30 m thick Missouri River alluvium at Herman, Nebraska, downstream that includes >5 cut and fill cycles and two major erosional surfaces. This includes the Carrolton surface and aggradational cycle, with optical ages of ≈14,000-16,000 years, and with underlying gravels and sands. Again, on a speculative note, the change seen in the well logs underneath Eppley may reflect the Carrolton Alloformation.

Figure 29: One of the drilling sites during the 2011 flood Eppley airfield dewatering response. The levee and river are to the viewer’s back. Note how the drill rig had to be on an elevated pad. To the left of the drill pad is one of the seep sites with a gravel pad installed on top to stabilize the sediment and prevent liquefaction and attendant loss of strength. Photograph courtesy of Griffin Dewatering.

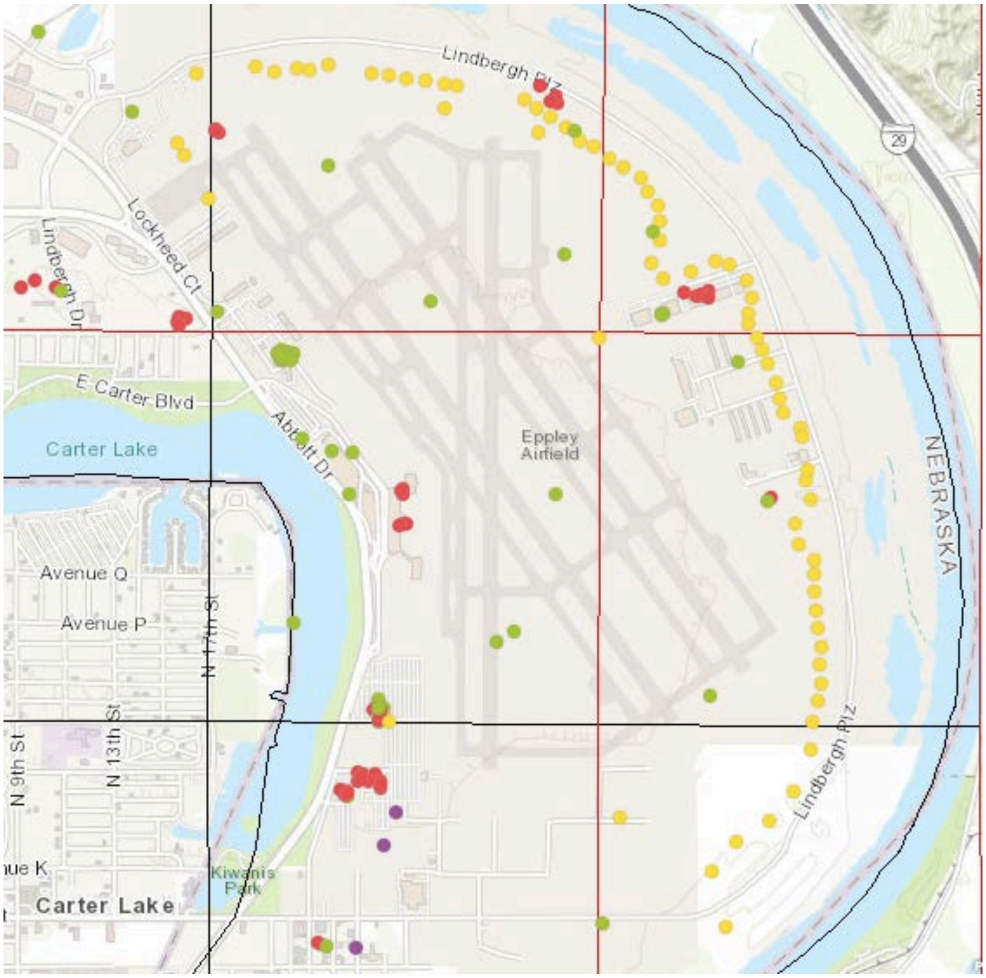


Figure 30: Map showing wells in the Eppley airport area obtained from the CSD Geology and Groundwater Data Portal. The irregularly arcuate suite of yellow dots on the inside of Lindbergh Plz on top of the levee are those used during the 2011 dewatering operation. Green wells are observation wells. Image obtained from web site (https://universityofne.maps.arcgis.com/apps/webappviewer/index.html)

The response to the 2011 flood is also a demonstration of how when the need is agreed upon, things can get done. The 2011 response involved the coordination of effort by a great variety of governmental and private organizations within a time frame of weeks. How this was accomplished is beyond the scope of this document, but is a crucial element in the arena of environmental and urban geology and engineering. Perhaps the greater challenge is to get agreement on what should be done, which was fortunately clear in this case. As more sophisticated environmental management is required by a growing population, management of limited resources such as ground water, and continued event risks such as floods, the need for coordination will only increase. Having the urban geology well documented ahead of time will facilitate such efforts.

Figure 31: West to east diagram of drill logs of Missouri River alluvium from the northern portion of Eppley airport dewatering well field. The curved feature at the top is the levee, North is to the top, and the scale bar in lower left is 300'.

Top: Portion of well registry website map showing the position of the well logs depicted below.

Bottom: Columns of the sediment types logged in these nine holes. Data is from the Nebraska Registered Wells Inventory database, Dept. of Natural Resources. The last 3 digits of the registered well number is at the column top (e.g. 811 is well 60811). The total logged well depth is at the bottom of each column. The wells are spaced a bit unevenly, but in the range of several hundred feet apart.

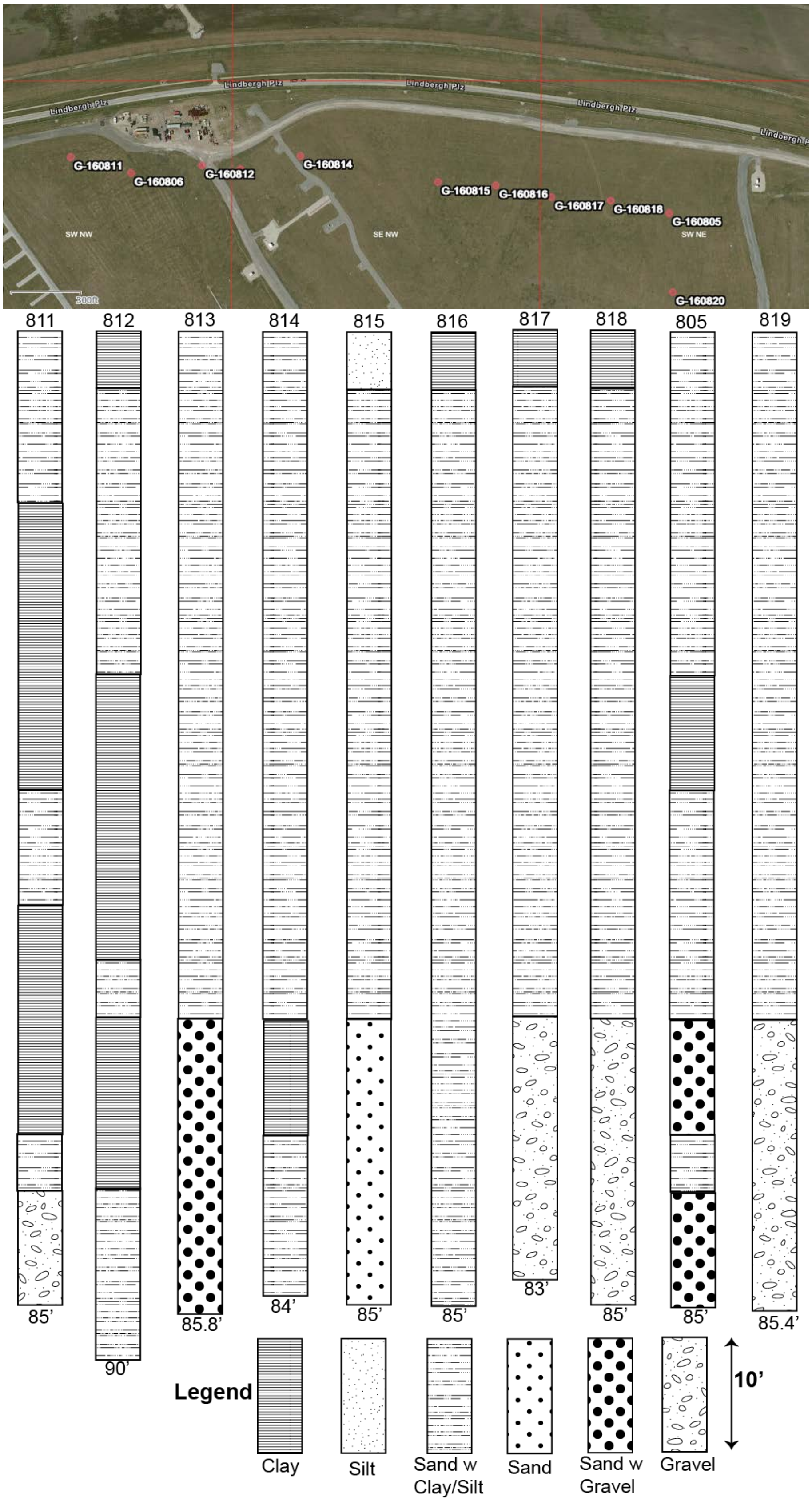


Figure 32: 1938 air photo image of portion of Carter Lake and the Missouri River taken from the Douglas County GIS website. The image was enhanced (contrast increased) to make features more evident. 1 – top of Carter Lake. 2 – early version of the airport. 3 – flood plain of the Missouri River prior to more extensive Army Corp engineering, with a broad suite of exposed sandbars in a point bar position. This type of geomorphology, with side chutes and more extensive sandbars, and a much more mobile main channel was typical of the Missouri River at this time. 4 – a linear feature interpreted to be a levee, separating agricultural fields to the south from the sand bars.

Figure 33: Roughly the same area as above, but in 1991. The airport has expanded significantly behind a new levee (marked with 1s). The river has been constrained to a ≈constant width channel by Army Corp structures. A close look shows small indentations that likely represent small scour pits down-flow of the wing dikes. Much of the point bar area of exposed sand bars is now on the protected side of the levee, but remnants are evident in the air photo. These sand bars would influence the shallow groundwater flow under the airport. Note the residential development in the area.

Bob Kerry Bridge and the ASARCO site

Location: Downtown Omaha along the Missouri River, near the National Park Service building, 41.2656° -95.9222°

Parking: A number of public parking lots are within easy walking distance of the bridge, including a small lot at the bridge end. At times usage is high and parking can be hard to find.

Background: Two themes associated with this particular stop are: a) Missouri River flooding (Figure 34) and related control structures and engineering, and b) the environmental legacy of earlier industrialization. The bridge provides a good perspective to see many of the types of structures involved in flood control.

Figure 34: July 4th 2018 images of Heartland Park from the Bob Kerry bridge (above) and minor flooding and siltation on the Council Bluff side (below) in Tom Hanafan's River's Edge Park. Note the marina just upstream from the metal sculpture that is part of the Heartland Park.

Visible from the bridge and spaced approximately every 1500’ along the Iowa banks are protruding collections of quarried rocks known as **wing dikes** (Figure 35). On the outer bend banks are fortified with rip-rap and flood walls. Together the dikes and bank armoring keep the swift water in the present channel pinning the river in place and deepening the channel for navigation purposes. A prime Army Corp’s directive is to maintain a navigable channel for barge traffic. The lack of channel migration in the past 50 years or so speaks to the effectiveness of wing dikes.

At lower water levels the influence of the wing dikes on sediment dynamics is better exposed. Upstream sediment bars form banked against the dikes, and in the summer these are used as common pullouts for partying boaters. Downstream an eddy and scour pool typically forms and some consider these to be good fishing holes. Further downstream is another sand bar, which changes substantially with flow regime. At a larger scale Heine and Lant (2009) argue that the channel deepening associated with the wing dikes essentially lowered the regional base level and has produced drainage incision in the easily eroded loess. In this case the footprint of Missouri River wing dikes is substantially larger than the main channel.

Figure 35: View looking upstream at Iowa side of the river showing the prominent wing dikes with eddy scour pools immediately downstream and sand bars further downstream. This image was taken during August of 2022 when flows were relatively low and the wing dikes and associated features well exposed.

Levees on the Omaha side of the river extend for 13.26 miles, have an average height of 14’ and were constructed in 1950. This includes those that protect the airport. They are of variable design from earthen to reinforced concrete cantilevered walls and steel sheet pile. More details can be found at the USACE levee database (https://levees.sec.usace.army.mil/#/levees/system/4705000082/summary). Levees on the Council Bluffs side of the bridge (the inner bend of the river), are set back from the normal channel margin some 300 m. In the intervening area are wetlands and wooded areas providing some riparian habitat. In addition, the levee setback provides some storage room during flooding. Levee setbacks, although advantageous for flood control, were likely more challenging to include because of pre-existing urban construction and the high value of urban property. The levees and set-back areas are also used as part of a fairly extensive bike trail system and for Tom Hanafan's River's Edge Park. A large Harrah's casino parking lot can be found in the setback area further downstream. Such practices fit a theme of multi-use of areas set aside for flood control or for environmental purposes. The infrastructure in such areas can be restored to use after a flood event with relatively minimal costs.

Much thought involving Missouri river management and engineering is related to sediment. Not surprisingly, the river has always been particularly sediment rich, and the section that flows by Omaha these days is still quite 'muddy', sediment rich, despite the main stem dams upstream. The >150 mile long stretch upstream to Gavins Point Dam and the Lewis and Clark Reservoir crosses loess and till rich stretches, and has substantial drainage coming in (e.g. the Big Sioux River at Sioux City), so that the sediment resupply is significant. Heiman (2016) estimates the annual average sediment load at Omaha at 6.61 million tons per year and details how much the various tributaries contribute. The marina at the riverfront is an excellent example of the significance of this sediment load. In August of 2022 the maraine was being dredged (Figure 35) by a company based in in Kansas City (Dredge America) at a reported cost of $447,375 (Crisler, D. 2022). FEMA will cover 95% of the costs. Most of the infilling was during the 2019 floods. The dredged sediment was reintroduced into the river. This marina, with room for perhaps 30 boats, is an example of the long term maintenance costs associated with engineered river structures. The basin is basically a backwater body where the sediment laden current slows down, and some of the sediment load is deposited. The tension is between having 'quiet' waters, good for mooring boats, and waters swift enough to prevent sediment from accumulating. Like oxbow lakes, marinas or ephemeral basins, and must be maintained.

Figure 35: Image of the marina being dredged in August 2022. Sediment is still visibly exposed under the docks on the right side. Part of the Bob Kerry Bridge is visible in upper right corner.

Underneath the area on the Omaha side is a cap hopefully isolating contaminated soil and ground water from the 125 year legacy of smelting operations at the **American Smelting**

and Refining Company, Inc., (ASARCO) and other industrial operations (Figure 36). Because of available water for cooling and processing, and river transportation, rivers passing through urban centers were or are often sites of industrialization. As in Omaha's case, many cities are reclaiming such once industrialized areas for public use.

Chapman et al. (2001) sampled and analyzed ground and surface water (a surface drain and the Missouri River) to evaluate the hydrologic biotoxicity of the ASARCO site, with a focus on arsenic, cadmium, lead and zinc. Relatively low values in the river water were attributed to dilution due to more precipitation and a higher discharge. Low values in the one well sampled were either because of a lack of contaminant mobilization, or because the well was dominated by river water at the time sampled (at other times the same well tested ≈2.5 times higher). The site of the monitoring well was near the river, but otherwise unspecified.

The following description of the geology and remediation efforts for the river front area have been summarized from the 2019 environmental assessment of riverfront development conducted by the USACE for the city of Omaha (USACE 2019). Groundwater varies from 8 to 23.5 feet bgs and likely "flows in an easterly/southeasterly direction". The Heartland of America Park was the former Aaron Ferer/Gould battery recycling plant, where some 48,000 cubic yards of contaminated soil were stabilized on site and some 15,200 cubic yards were sent to a smelter to recover lead prior to 1991. Lewis and Clark Landing, which was formerly owned by ASARCO, was remediated starting in 1996 as part of an agreement between Nebraska's Department of Energy and Environment (then DEQ). Brick, concrete and soil were placed in a lined fill area on site, clean soil placed on top, with a multi-layered capping system installed that included a geosynthetic clay liner (GCL) at a depth of about 6 feet. Environmental covenants restrict use and require NDEE approval for development. At issue in present plans for development are strictures against planting trees. Because it was a voluntary clean-up less publicly available information exists.

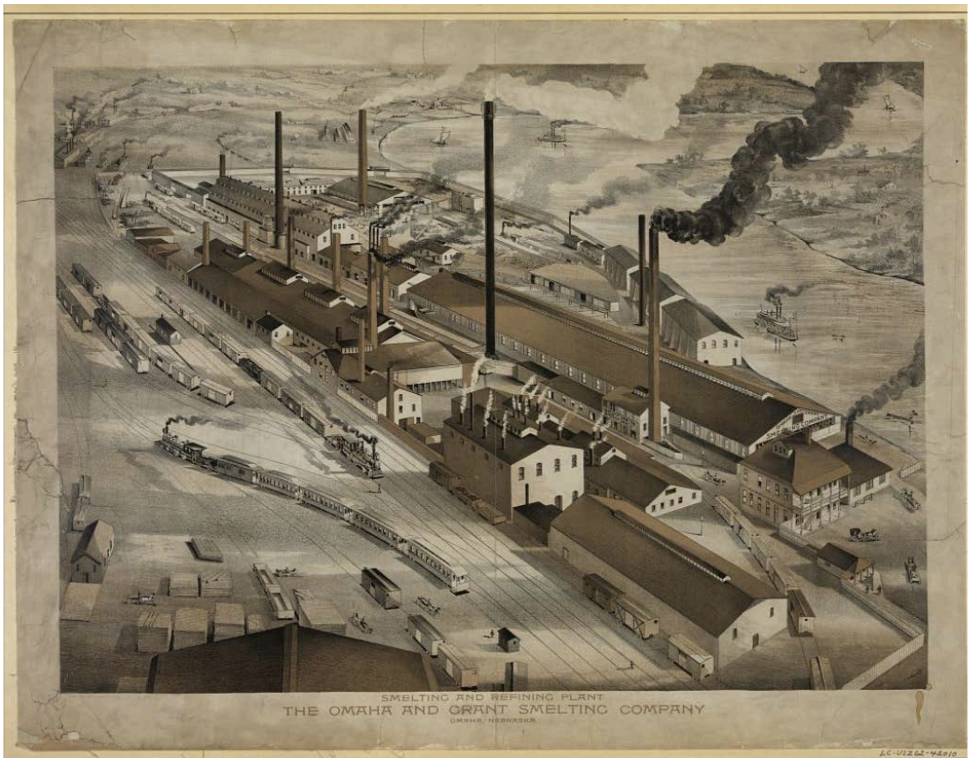


Figure 36: Image from Library of Congress, likely prior to 1899 when this site became part of the newly formed ASARCO. The dark plume of smoke is notable, although the wind direction here is depicted as towards Council Bluffs.

The smelting and recycling operations along the river led to significant soil contamination over a much wider area, and to a 27 square mile area Omaha being designated a Super Fund site (Figure 37). By definition the site includes residential, child care and residential- type properties which meet the criteria of over 400 ppm of Pb in the soil. In between 1999 and 2015 some 13,000 residential sites met this criteria and were remediated (Anon., EPA), typically by removal and replacement of the contaminated soil. A primary source of the contamination was smokestacks associated with the American Smelting and Refining Company, Inc., (ASARCO) and with a lead battery recycling plant. Lead based paints in older houses is another source of soil lead contamination.

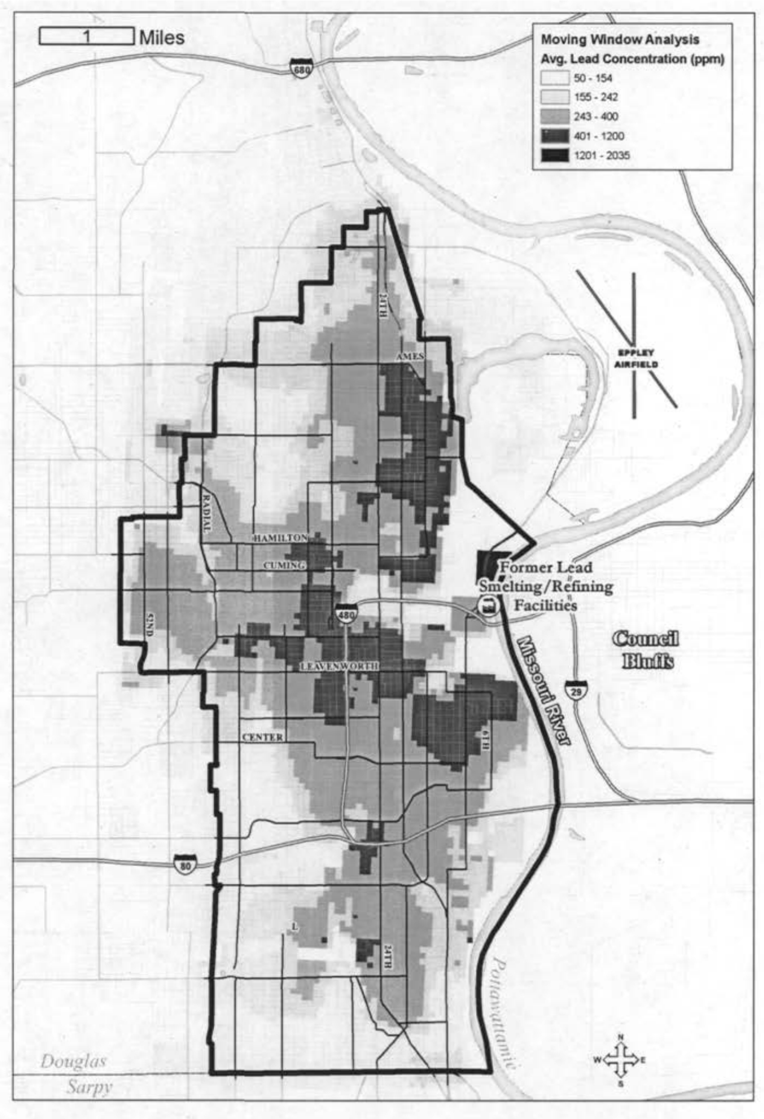


Figure 37: 2009 map showing EPA map of average lead concentrations in Omaha area. From EPA Final Decision (2009).

Notes

Alternate Field trip stops

One may be forgiven for thinking that the urban geology of Omaha is a rather limited topic, especially compared to a place such as San Francisco with its notable earthquakes and landslides. However, through the decades, as we have put together resources for short field trips associated with our environmental geology courses it has become apparent that the urban geology of Omaha is fairly rich, and is likely to be so for most any city, due to the significant interaction between whatever geology exists and intense human activity. Our intent is that this field trip guidebook will evolve into a more comprehensive description of the topic. With this in mind and for those interested, we are including two additional sites that can be visited. The associated descriptions will be briefer.

Optional stop 1 - Thompson Creek

Location: 72nd St. to 84th St. La Vista

Parking: There is parking access along the restored portion of the creek along Park View Road.

Background: This small urban drainage had a history of repeated flooding and in 2009 the city of La Vista decided to acquire and demolish 24 homes along the creek's north side and turn it into a green space. The site has since developed into a 1,250 acre watershed restoration project (Figures 38 and 39), with improved water quality and riparian habitat, and reduced flooding as primary goals (La Vista City Government, retrieved 8/2/2022). Funding came from a combination of the Nebraska's Environmental Trust Fund, the City of La Vista and EPA. The improved habitat includes channel meandering. and channel pools and riffles, and bioretention basins on a flood plain bench upstream of 72nd street, all open to the public. Native and diverse vegetation was planted for stabilization purposes. The history of houses being removed, and the changes made along the creek can be seen in the historical imagery available on Google Earth. While called a restoration project, the stream is not being restored to a previous condition. Instead the environmental services it provided are being restored.

Figure 38: Image taken during construction associated with the restoration project (Oct. 2015). The intentional channel meanders are evident. Some of the bank material was clay and organic

rich, contributing to a small scale slump (right side, lower channel reach here) also associated with an orange colored seep. The particularly organic rich and fine sediment suggests a previous history as a wetland.

Figure 39: Excavation face from Oct. 2015 showing Anthropocene related deposition (4-5 cycles of different fill types), with the soft-sediment deformation in the upper darker layer likely related to construction machinery moving over wet soil. Exotic clasts in the fill indicate human emplacement.

Downstream of the 72nd street bridge substantial erosion and incision has occurred, locally 7-15 feet (La Vista City Government, retrieved 8/2/2022), locally exposing the loess. Exposed tree roots and drainage pipe indicates the relative recency of the erosion, and control structures including sheet pilings and large rip-rap have been emplaced (Figures 40 through 42). That the stream morphology is so different above and below 72nd street (even before the watershed restoration) suggests that the street has significantly modified the fluvial processes,

Figure 40: Image taken Oct. 2015 of erosion control structures along Thompson Creek south of 72nd street. Brown losess silts are exposed in the steep bank behind the vegetation. Note the house on the cliff top.

The geomorphology, of the Thompson Creek upstream of 72nd street was recnstructed to mimic a natural system in part (e.g. the channel meanders), but is clearly designed and constructed by humans. In an urban environment, substantial portions of the landscape have been purposefully reshaped, and a framework for working with such anthropogenic geomorphology is explored by Brown et. al. (2017). Levees, retention basins, straightened channels, and retaining walls all become distinct geomorphic elements, ones that influence geologic processes such as sedimentation and erosion (Figure 43). The section downstream of 72nd here, has also been influenced by human action, but the incision is also a natural process, and but one anthropogenically modified. Deltas at the input end of reservoirs would be another good example of a feature included in existing geomorphologic classifications and frameworks, but modified by human activity. The geomorphology of much of the present Missouri River could be recast in terms of anthropogenic related geomorphology. Some of the flood plain protected by levees no longer floods. Some side channels, such as Boyer Chute north of Omaha were purposefully reconstructed for habitat purposes and are engineered so that they do not migrate. De Soto Bend north of Omaha is not a natural oxbow, but a human created oxbow. Classifications and frameworks for documenting urban geomorphic features and process will need revision and expansion.

Mayor's Park on the north side of the creek downstream from 72nd street is distinctly flat (Figure 41). One would be forgiven for assuming it is a natural flood plain surface that the creek has since eroded into. However, along eroded portions along the stream bank construction fill is exposed near the stream level, evident by the limestone and anthropogenic clasts. This flat surface is a constructed human surface that has buried the original topography. Filling along waterways is a relatively common practice that can provide elevation above a given flood level and a more buildable area, but also restrict the channel width, and raise the flood levels.

Figure 41: The flat surface seen here, immediately adjacent to Thompson Creek (immediately behind and below the riparian tree corridor to the right), has the character of an abandoned flood plain, but is actually constructed fill.

Figure 42: Exposure along Thompson Creek downstream of 72nd street, S side taken August 2022. The light tan silt is loess (unknown stratigraphic position). At the bottom a more clay rich, darker and ostensibly clay rich layer can be seen. This could be till or reworked till. Some silt *right above the dark layer appears slightly darker than otherwise because it is moist. This moisture may very well reflect shallow groundwater perched on the dark layer that is seeping. The exposed trees roots demonstrate recent erosion and slope retreat. The dark layer may slow any incision due to its lower erodibility (greater cohesion likely due to the clay content) in comparison to the overlying loess.*

Figure 43: This image, taken August of 2022, shows the upper reaches of the restored area looking upstream. The reeds (cattails) are part of a purposefully constructed wetland engineered for retention purposes. Water is introduced by a drainage pipe (hidden in the vegetation in the corner below the grew house).

Optional stop 2 - Keystone South Omaha Trail Juncture

Location: At the western ends of Buckingham or H street on the east side of the creek. Latitude and longitude: 41.2179° and -96.0126°.

Parking: There is parking both in the school parking lot, and in a small lot associated with the ball fields to the north (W end of Buckingham Street) that will work for buses.

Background: This location along the Little Papillion Creek is a good example of how the drainage in Omaha has been engineered and channelized. A strong rational for doing so was the history of flooding along the drainage. The flood of record here was in 1960 with discharges of > 10,000 cfs (Omaha Planning Department, accessed 8/1/2022). A more devastating flood on the Big Papillion Creek in 1964 with fatalities and significant property damage led to the development of more comprehensive flood control plans by the Army Corp of Engineers in 1967. Implementation and expansion of the engineered flood control system has occurred since then. A contract award of $7.3 million by the USACE in 2022 to repair the Papillion Creek levee system due to damage from the 2019 flooding (USACE, retrieved 8/10/2022) provides some insight into the magnitude of the effort. Figure 44 provides insight into the extent of the associated levees. The Keystone trail, a key recreational source in the Omaha area, was initiated in 1989 and the trail system has expanded significantly since then. The trail crosses the creek here.

A look at historic imagery indicates that significant drainage modification predates the arrival of the expanding city and is associated with agricultural activity (Figure 45), consisting of straightening and deepening the drainage. This can also be seen in the historic imagery from the Heron Haven and Heflinger Park areas. The small stream coming in from the east at this site is an example and is straight in 1938 imagery (the earliest available), separating farm fields on either side.

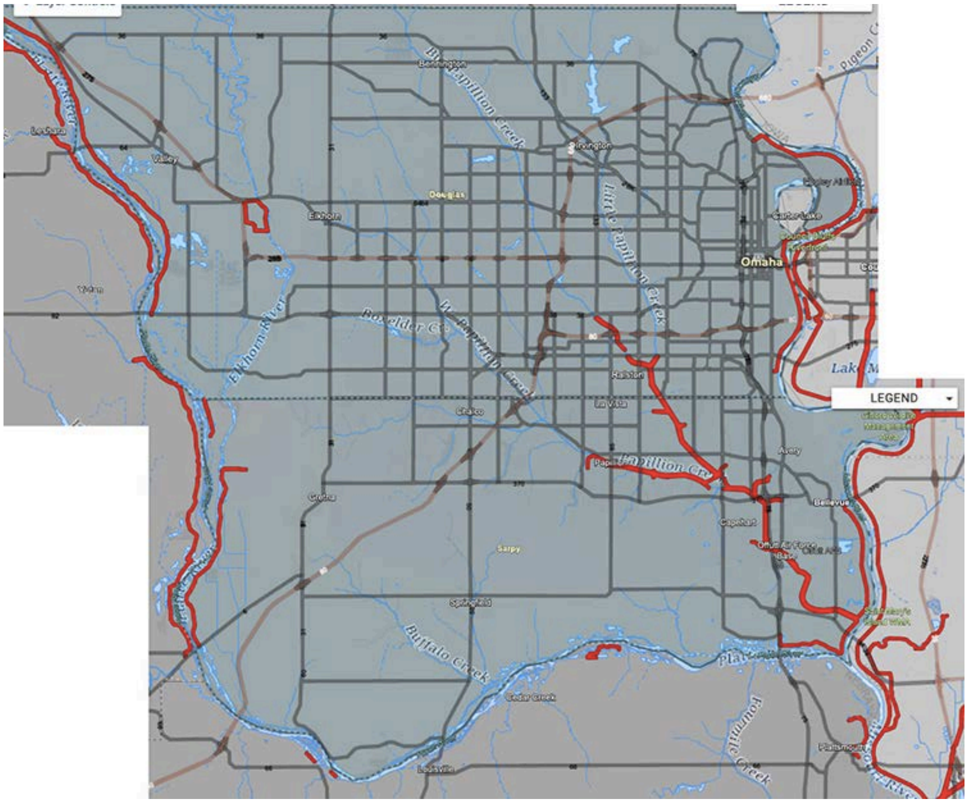


Figure 44: Map from national USACE levee database showing in red the levees for Douglas and Sarpy Counties. Those on the Papillion are mostly on the lower reaches as might be expected.

One of the obvious engineering strategies is the placement of rip-rap to prevent erosion and attendant channel migration. In practice the channel grasses also provide protection from bank erosion, and can be seen flattened and oriented, but intact, after a high discharge event. The rip-rap is comprised of blocks of the light grey local, quarried Paleozoic limestones. Some of the rip-rap has also become entrained in the channel, undoubtedly moved during high-discharge events. This coarser material often collects to form the equivalent of small knickpoints. The influence of the introduced rip-rap on the channel configuration could make an intereesting, small scale research project.

Mass wasting that varies from small slumps to creep of the steeper bank material held together by the vegetation is fairly common. Repairing the Keystone Trail due to this mass wasting occurs on a semi-regular basis. Some slope destabilization may come from local channel incision, which in turn may be related to greater discharges and higher velocities associated with urbanization and the increase in impermeable surfaces. Some of the rip-rap may be introduced into the main channel by mass wasting, instead of entrainment from the banks during flood events. Comparing historic imagery on Google Earth suggests the channel has locally widened 1-2 meters in this area. Such widening may also destabilize the slopes above.

There is a USGS gauging station at Aksarben upstream of this site. Discharge and gauge height (Figure 46) show the very typical pattern expected from an urban stream, where rainfall events (thunderstorms) cause swift increases due to impermeable surfaces that increase runoff and prevent seepage. Note that the one event in Figure 46 produced a 100 fold increase in discharge. There is a suggested base level flow at ≈10 cfs suggesting a component from springs and/or seeps within the drainage.

Figure 45: Top: Air photo image from Douglas County GIS site of area in 1962. The housing development had been recently built, the field to the North was not yet an industrial site, and the Keystone trail had not been constructed. The incoming drainage from the east had already been channelized. Bottom: Image from 2020 of the same area.

Substantial sediment is being moved, and during low flows is resting in a variety of channel positions. A quick look establishes that a substantial quantity of the sediment is of human origin; construction material, pavement, garbage and plastic, with a shopping cart or two sometimes thrown in. This is a clear reminder of the concept of the Anthropocene. From this perspective individual cities can be seen as distinct sediment sources. The chemical and mechanical durability of different types of anthropogenic sediment is yet another potential research project.

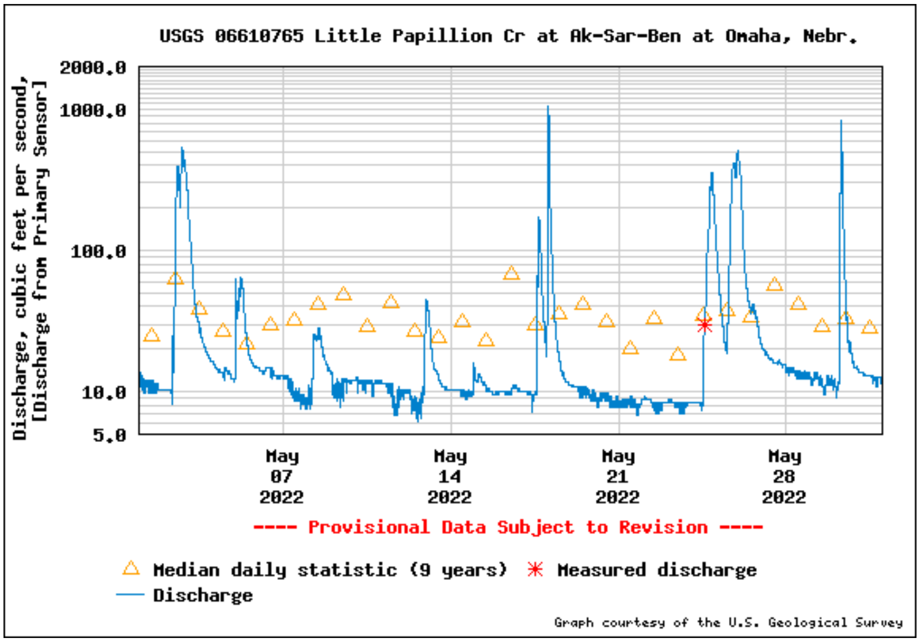


Figure 46: Plot of discharge for the Little Papillion for the month of May, 2022 obtained from the USGS site.

Along some sections the channel bottom erodes into some fine-grained and dark, ostensibly organic-rich alluvial sediment (Figure 48). This suggests that before human related incision of the drainage wetlands may have existed along the drainage. Such fine and organic rich alluvium may locally help destabilize slopes, and may be prone to loading related compaction.

Figure 47: Looking upstream along the small tributary from the east at this site. Through the grass one can see rocks enclosed in wire (gabions) designed to stabilize the creek. In addition two sediment dams can be seen. These are full of sediment and can no longer store sediment. Coarse rip-rap and other debris can be seen in the channel bed.

Figure 48: View of east bank of Little Papillion Creek underneath where the Keystone Trail bridge crosses it. Note the substantial amount of garbage including an old metal drum that is being disinterred. Due to the density of debris, this is interpreted to be an older small-scale dump site. Also note the darker and fine-grained color or the lower alluvium being cut into.

Notes

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