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HYDROLOGIC INVESTIGATION OF THE CHIWAUKEE PRAIRIE (WISCONSIN) RESTORATION

By

Nicholas A. Potter

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Geology

MICHIGAN TECHNOLOGICAL UNIVERSITY

2021

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This report has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Geology.

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Author Contribution Statement

The purpose of this report is to provide a concise baseline framework for the hydrologic research conducted at Chiwaukee Prairie and The Nature Conservancy's restoration site during the beginning of restoration work to return the hydrology and vegetation to more natural conditions. This research provides insights into the shallow groundwater system and an example of monitoring practices to serve as a foundation from which to continue to monitor the site restoration effects. I hope this document will aid in decision making for the area. It is also meant to show the accumulated work that has been done at Chiwaukee.

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This Master's was a mountain to climb. My supporters and colleagues have been my climbing partners, the past research of countless scientists, my fixed ropes, and my advisors are my Sherpa who have climbed the mountain countless times. I am just one student trying to summit, thinking and only focusing on one step at a time. I will one day look back at this day and see that it was merely the training I needed to climb to peaks of wonder far greater than this degree. Before I present my research, I would like to thank and give acknowledgement to some of the key people and organizations that have helped me accomplish summiting one of my mountains. I would like to thank my friends and family for their support, especially my parents who always provided advice when asked, and my professors who taught me the skills and core knowledge I needed.

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Special thanks to Steph Judge at The Nature Conservancy, the reason the project was a reality.

Definitions

Flashy, rapidness of change in change in water level
Logger, pressure transducers

List of Abbreviations

ILGS - Illinois Geological Survey
TNC - The Nature Conservancy
CP - Chiwaukee, Chiwaukee Prairie, Chiwaukee Prairie State Natural Area
USGS - United States Geological Survey
DNR - WDNR, Wisconsin Department of Natural Resources
CPF - Chiwaukee Preservation Fund
SEWRPC - Southeastern Wisconsin Regional Planning Commission
WISCORS - Wisconsin Continuously Operating Reference Station
MTU - Michigan Technological University
UWP - University of Wisconsin-Parkside
USDA - United States Department of Agriculture
NWI - National Wetland inventory
RN - Restoration Site North
RS - Restoration Site South
CN - Chiwaukee North
CS - Chiwaukee South
MRC – Master Recessions Curve

Abstract

Wetlands are a vital component of the landscape, a keystone ecosystem, that are prone to degradation and destruction with urbanization. As a result, significant efforts from communities, scientists, sportsmen and government agencies have been made to protect and restore wetlands. In 2019, The Nature Conservancy began re-wetting, contouring, and seeding a 55-ha parcel of farmland in Pleasant Prairie, Wisconsin, restoring the site in an attempt to resemble pre-settlement conditions. The Nature Conservancy Restoration site is part of the groundwater recharge zone of Chiwaukee Prairie and its restoration aimed to increase the available groundwater for adjacent Chiwaukee Prairie State Natural Area wetlands. This research examines the pre-restoration hydrology of the study area using water table levels, water temperature, and meteorological data. Electric sounding tape and pressure transducers were utilized to collect water table measurements from May to November 2019 and June to November 2020. Meteorological data were acquired from the Wisconsin Department of Natural Resources air quality station located within Chiwaukee Prairie. This data allows for a comparison between the restoration site and Chiwaukee Prairie and is assisting The Nature Conservancy's restoration efforts by providing valuable feedback while providing a better understanding of the shallow groundwater systems within the Chiwaukee Illinois Beach Lake Plain.

1 Introduction

In 2019 a wetlands restoration project was undertaken by The Nature Conservancy on an area adjacent to Chiwaukee Prairie, near Pleasant Prairie in Kenosha County, Wisconsin. Their project was to restore a 150 acre parcel of adjacent abandoned farmland to wetland and prairie (The Nature Conservancy, 2019) Personal. Wetlands have many different names and nomenclature of historical terms. that are used U.S. legal definitions. Wetlands have an expansive geological history (in the Quaternary) and are coupled to human history in terms of settlement and development, not to mention changes in wildlife abundance, ecosystem function, and hydrology. Wetlands also play such a large part of cultural roles that RAMSAR has created a guidance document for culture and wetlands (Gland, 2008). Wetlands contribute to our environmental health and people all over the world have identified these very real benefits and take part in remediation and restoration using a variety of means (Gosselink, 2015) The restoration site and the adjacent Chiwaukee Prairie itself have their own history that makes it a unique site. This research is one small part to enhance our understanding of how restoration plays a role in this interconnected world.

1.1 Wetlands

1.1.1 Definitions

Wetlands are integral components of ecosystems and are where the hydrosphere, biosphere, and geosphere converge. Wetlands represent the transition zones of land and water, a place that is not always wet and not always dry (Gosselink, 2015). A wetland is an area that represents a triple point where water, living organisms (flora and fauna), and earth (soils and rock) meet. It is an area where water is close to the surface and allows the development of hydric soils, hydrophytes and other water adapted plants (U.S. Army Corps of Engineers, 2010). These areas commonly provide unique habitats and several ecological services (Edward; & Acreman, 2011; Gosselink, 2015). They have three key components: hydrophytes, hydric soils, and wetland hydrology (Gosselink, 2015; U.S. Army Corps of Engineers, 2010). They are known by many names and represent a wide variety of environments. Wetlands have many different definitions and their own nomenclature depending on the applicable language, cultural background, scientific discipline, or historical period (Gosselink, 2015). Wetlands are known by the names of fen, bog, marsh, swamp, vernal pool, prairie pothole, wet meadow, playa lake, and pocosin (Gosselink, 2015).

1.1.2 Regulatory History of Wetlands in the U.S.

Wetlands have historically been looked upon negatively by humans wanting to develop lands. They were difficult to cross and build on/cultivate, breeding places for mosquitoes and disease (Thomas E. Dahl & Allord, 1996; Joosten, 2019). In the past, wetlands were commonly drained or filled and developed, or converted to agricultural lands (like The Nature Conservancy restoration site) (Thomas E. Dahl & Allord, 1996). The United States government originally had laws like the Swamp Land Act of 1850 that allowed states to “reclaim” wetlands for human usage. These encouraged draining wetlands for more practical uses like agriculture. Overhunting and decades of drought led to increased awareness of wetlands as habitat for migratory birds. The Dust Bowl era altered agricultural practices to conserve soil. We learned over the years the true value of wetlands and now understand their many benefits. Today, several laws (including the 1972 Clean Water Act) have been enacted that are directly or indirectly protecting or

encouraging the restoration and creation of wetlands. This includes: Rivers and Harbors Act of 1899, Rivers and Harbors Act of 1938, 1972 Coastal Zone Management Act, the 1982 Coastal Barriers Resources Act, the 1985 Farm Bill (a.k.a. "Swampbuster"), and the most well known, the 1972 Clean Water Act (CWA) (Nagle, 2008). At this time, there is no specific federal wetland protection law and the current standard for wetland protection comes from state agencies and Section 404 of the Clean Water Act. Section 404 of the CWA requires permits for dredging or filling activities in wetlands. The Environmental Protection Agency and the Army Corps of Engineers co-manage the Section 404 permitting process, with assistance from the United States Fish and Wildlife Service.

1.1.3 Importance of Wetlands

Wetlands provide habitat for animals, water management, and a myriad of other ecological services. They provide essential habitat for endangered species and migratory birds. They are the home for over 35% of the world's endangered species (Ramsar, 2018). They provide breeding and nesting grounds. They act as green corridors for animals to move though in the ever-urbanizing landscape.

Wetlands provide water management for watersheds. They are directly connected to groundwater systems. They are areas that recharge aquifers and act as flood control. Wetlands act as sponges during flood events to soak up flood water and release it slowly instead of in a large pulse. Wetlands also improve the water quality in the area by acting as chemical and sediment filters and by absorbing nutrients. They are commonly used in wastewater and runoff projects. One of their nicknames is "the kidneys of the land."

Wetlands support humans directly in many ways. They hold valuable diversity where we can find plants that can act as a natural medicine cabinet. They produce food like rice and cranberries. They also provide areas of recreational activities, including hunting, fishing, boating, and birding. In addition, they provide an area for scientific research (like this project). Wetlands also provide a carbon sink and store huge amounts of carbon as peat. Their preservation can keep this sequestered for thousands of years (Edward; & Acreman, 2011). They are also rallying points for our communities. We use wetlands as a gathering space, for service, for classrooms, and they plan a large role in humanity's culture and history (Gland, 2008).

1.1.4 Why Restore Wetlands

Wetlands are a vital component of the ecosystem and are considered a keystone habitat that are true workhorses of the environment. Despite their benefits, humanity has destroyed or degraded a large portion of our wetlands. Over half of the lower 48 states have lost over 53% of their pre-1800 wetland area and some states have lost over 70% of their pre-1800 wetlands (T. E. Dahl, 2011). Most of this destruction comes from urban development and agricultural activity (T. E. Dahl, 2011). This loss is based on area and does not fully represent the functionality of the remaining wetlands. Our true impact on wetlands can only be estimated. Flooding, habitat loss, excessive sedimentation or erosion, and chemical imbalances arise when our wetland environments are damaged. Section 404 governs the law regarding mitigation and requires large restoration and creation of wetlands. Wetland restoration has become a common practice for developers as they are required to mitigate wetlands for any wetlands damaged during a project. Wetland Credits are now traded on a market and wetland banks have come into existence, allowing the creation of restored wetlands credits and their sale and transfer to developers.

1.1.5 Different Types of Restoration

Restoration of wetlands takes many forms and can have a variety of outcomes depending on your definition of restoration and the goals of the project. These goals can be aimed at a specific outcome, as in creating waterfowl habitat, reducing sediment loading, or to improve the overall habitat and wetland function. Restoration can take two main forms, physical or biological. Physical methods using hydrology can include managing water withdrawal (pumping), removing or blocking drain tile, removing roads, filling ditches, creating dams, recontouring with bulldozers, or making small changes to the microtopography (Bork et al., 2013; Chimner et al., 2019). Methods of biological restoration can include adding plants like phreatophytes, mosses (peat), mangroves or removing invasive plants like reed canary grass, giant knotweed, or buckthorn. Biologic restoration also includes the addition or removal of animals like the reintroduction of wolves in Yellowstone that help restore the river corridors.

1.2 Objectives

The role of this research was to examine the hydrology component of the restoration work in the Chiwaukee Prairie complex. This research focused on the hydrology of the shallow groundwater system and vadose zone, where the environment is not always wet, and soil moisture plays a large role. This research installed additional piezometers and expanded the coverage of the preexisting network used in prior research. The research included recording the water levels and interpreting the water table data responses over the courses of two growing season
This research set out to address 3 overarching questions:

1. How did the water levels change seasonally?

2. What factors affected the shallow groundwater system in the Prairie?

3. Does the hydrological response of the restoration area differ from the natural Chiwaukee Prairie system?

2 Setting and Background

2.1 Geographic Location and Scope

The study area is located in the Great Lakes region of the United States of America (Figure 2.1). It sits on the western shore of Lake Michigan in Pleasant Prairie, Wisconsin. The study area is on the border of Illinois, located approximately 42.5032 latitude, -87.8124 longitude. The study area consists of The Nature Conservancy restoration site and a portion of Chiwaukee Prairie. The study area is approximately 1.6 km N-S, 1.1 km E-W, and is 180 total ha. The Nature Conservancy's restoration site is a 55-ha parcel of farmland. For this research, the study area was divided into two sites, Chiwaukee Prairie and The Nature Conservancy Restoration site, and four subsites (dividing each site into two, a north and south) to form four quadrants (Figure 3.3). These quadrants are divided north and south by 122 street and east and west by a rail line. The study area's elevation is between 192 m and 174 m above mean sea level.

Figure 2.1 Map of the Great Lakes Region with the study site highlighted in red (Made using Esri ArcGIS Pro).

2.2 TNC Restoration Site

The Nature Conservancy restoration site is approximately 55 ha (150 acres) of farmland. The overall geology is very similar to Chiwaukee Prairie (CP) according to the available data from the well cores, remediations of the neighboring gas station restoration project, and previous research within the study area; the major difference between the sites being in the vadose zone and vegetation coverage. The site sits at a slightly higher elevation just west of Chiwaukee Prairie and is bordered by Highway 32 to the west, 116 St. to the north, and residents within the Illinois border. It shares its east border with CP, and a rail line acts as a buffer between the properties. A report produced by the U.S. Geological Survey (USGS) states that the area where the restoration site sits is a groundwater recharge zone for CP. The restoration site (Figures 2.3 - 2.4) originally had a drainage network that included ditches and drain tile. The previous vegetation of the site were very mixed and included forested areas, open farm fields, and a remnant wetland located in the southwest of the northern half of the restoration site. The remnant wetland has maintained soil, plants and a hydroperiod similar to CP and relatively undeveloped compared to the rest of the restoration site.

2.3 Chiwaukee Prairie

Chiwaukee Prairie is a ridge-and-swale wetland complex, creating a variety of wetland microhabitats such as wet prairies, marshes, and fens. Its key feature is its ridge and swale topography (Wisconsin Department of Natural Resources, August 31, 2021). This is one of Wisconsin's largest prairie complexes, its only lake plain prairie complex, and its best example of a coastal wetland in southeastern Wisconsin (Wisconsin Wetlands Association). Chiwaukee has earned several acknowledgements and recognitions because of its special features and functions. The Wisconsin Wetlands Association has named it one of Wisconsin's Wetland Gems, the Convention on Wetlands of International Importance have named it a RAMSAR site. It is a Wisconsin State Natural Area, a Wisconsin Land Legacy Place, Coastal Wetland Inventory Primary Site, and Wildlife Action Plan Reference Site. The Nature Conservancy lists it as a Priority Conservation Area. The State of Illinois has it as a Chicago Wilderness Biodiversity Recovery Plan Site. Chiwaukee is part of a much larger wetland complex known by many names but here we will refer to the area as the Chiwaukee-Illinois Beach Lake Plain or Lake Plain for short. Its true range is from Kenosha county's dunes in Wisconsin to Waukegan, Illinois. The Lake Plain area holds several nature areas that include Kenosha Sand Dunes, Chiwaukee Prairie State Natural Area, and Illinois Beach State Park (Figure 2.2). It represents a large portion of the unmodified coastline of Southwest Lake Michigan.

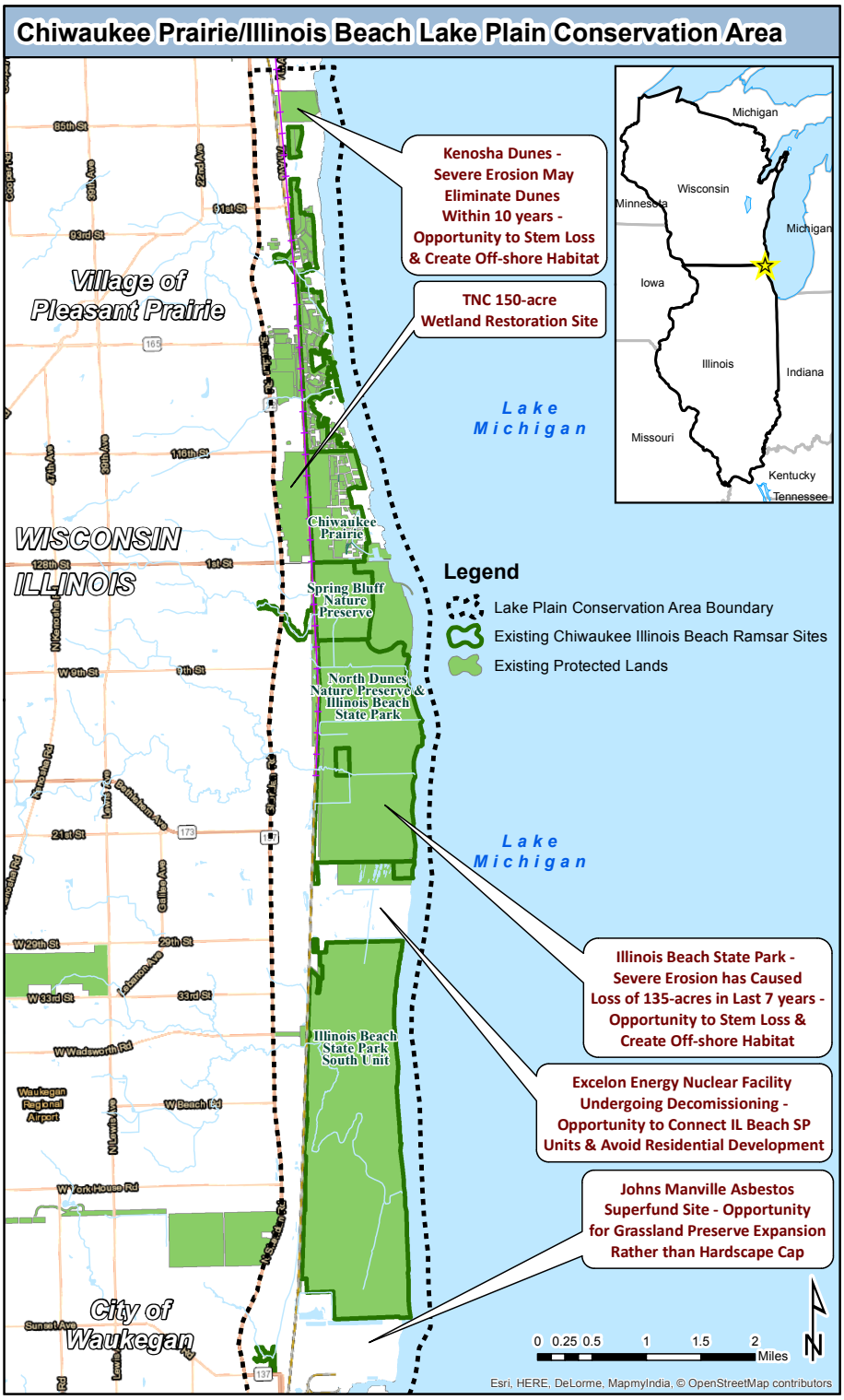


Figure 2.2 Map From The Nature Conservancy Highlighting the Chiwaukee Prairie/Illinois Beach Lake Plain (TNC).

2.4 Geology

The study area sits on the stable interior of the North American Plate. It sits on the slope of the Wisconsin syncline. It has seen great evolution in landscapes over the eons. Like most of the Midwest of the United States, it has seen several episodes of transgressions and reassertion when the area was covered by vast inland seas and, much later, by the great influence of the glaciers during their advances and retreats. Most recently, soil layers are associated with the last glaciation and the related fluctuations of Lake Michigan and its previous forms (Chrzastowski, 2001). The top layers of soils and surface material vary depending on the microtopography of the area. The top layers that were encountered in the auguring in this work (see Sections 3 and 4 below) varied between peat, clay, sand, and loam. The entire area lies within the high-water mark of prehistoric Lake Chicago. The current landscape is dominated by ridge and swale topography (Chrzastowski, 2001).

2.4.1.1 Stratigraphy

The very base of the geologic column is Precambrian igneous and metamorphic bedrock (Feinstein, Eaton, Hart, Krohelski, & Bradbury, 2004). This bedrock is overlain by layers of several successions of sandstones, siltstones and carbonates (Figure 2.3) (Feinstein et al., 2004). This is all topped by Silurian dolomite. At the study site the top of this dolomite is found 70 to 150 feet below the ground surface according to the more than 200 well logs within and surrounding the study area (Wisconsin Department of Natural Resources). Above this bedrock there are layers of quaternary gravels, sands, clays, and of course glacial till also known as “hardpan”. The following is an example from one of the drill logs: sand, gravel, stony clay, gray clay, hard pan, gray clay, gravel, limestone. While interesting, deeper layers beyond the first few layers are beyond the scope of this research.

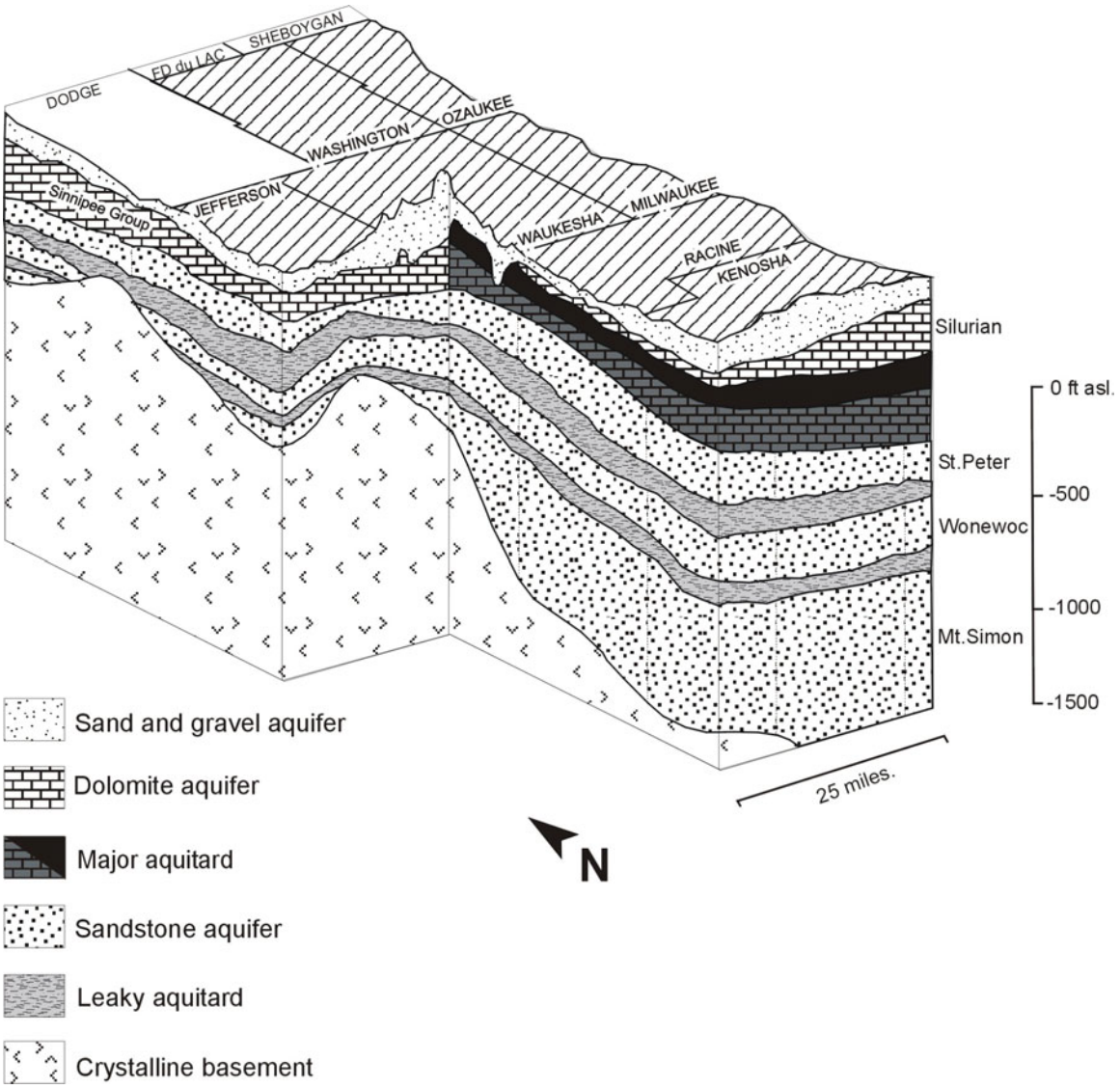


Figure 2.3 The major stratigraphy of the southeastern from Wisconsin from Feinstein (2004).

2.4.1.2 Glacial Influence and Ridge & Swale Topography

Glacial activity has played a large role in shaping the surface and near surface environment of the study area. Glacial advances and retreats caused the rise and fall of lake levels. The study area lies within the area of Proglacial Lake Chicago. The Lake Chicago ridges roughly corresponds with State Highway 32 just West of the study site (Chrzastowski, 2001).

Ridge and swale topography are formed from the fluctuations of a large body of water combined with dune making processes (Otvos, 1999). These structures are not generally associated with lakes, but bodies of water as large as the Great Lakes combined with the glacial fluctuation allowed for this type of formation to be made in this non-marine environment. The ridges in the ridge-and-swale topography represent the shoreline ridges or high-water mark.

The case of Chiwaukee Prairie the sediment supply was from the Root River which outflows Racine WI, 26 km north of the study area (Chrzastowski, 2001). The ridge and swales have an

NNE-SSW trend which can be observed from aerial photographs. The swales are the low areas between the ridges. At Chiwaukee Prairie these areas have developed several feet of peat. The ridge and swale topography has Chiwaukee Prairie's a sandy to clayey unconfined aquifer. This unconfined aquifer helps supply the groundwater fed wetlands in Chiwaukee.

2.4.1.3 Soils

The soils of the area are as one would expect in an environment that has both beach and glacial influence. The United States Department of Agriculture Soil Survey Geographic Database shows that the study site is a mixture of sandy soils (primarily in Chiwaukee) and loamy soils (mixed through the TNC restoration site). The soils in the study site are show in Figure 2.4 and the breakdown of the data is outlined in Table 2.1. Observation from digging the piezometers confirm this. The soils are generally sand, sandy loam, and silty sand with some areas having high amounts of clay. The swales and wetland areas hold much more organic material and can be found several feet above the sandy layers (Skalbeck, Reed, Hunt, & Lambert, 2008). There are some areas where clay lenses or beach cobbles are present. The surface layers are not homogenous and can change with the microtopography. The National Resources Conservation Service (NRCS) states the area is covered in Granby fine sandy loams and the Boyer loamy sands. Other research has stated the soils are more than 90% sand (Wolf, Baker, & Reed, 2012a).

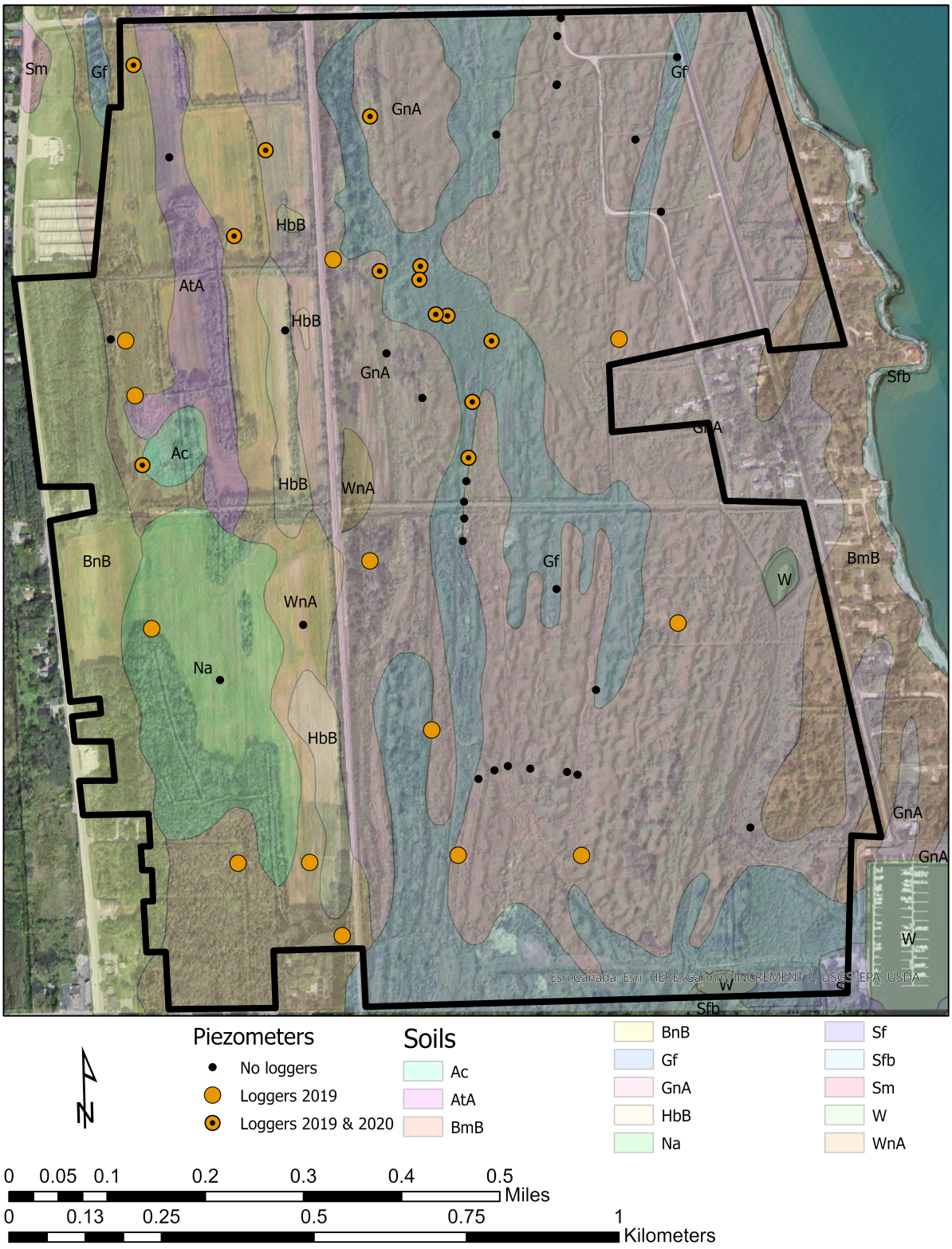


Figure 2.4 Map of the study site showing the piezometer locations and the soils according to the United States Department of Agriculture Soil Survey Geographic Database

Table 2.1 Table showing the soils in the study site and there area and percent area. This table can be used as a key for figure 2.4

Map Unit Symbol	Map Unit Name	Acres in Study Area	Percent of Study Area
Ac	Adrian muck, 0 to 2 percent slopes	2.5	0.50%
AtA	Ashkum silty clay loam, 0 to 2 percent slopes	15.7	3.40%
BmB	Boyer loamy sand, 1 to 6 percent slopes	12.4	2.70%
BnB	Boyer sandy loam, 2 to 6 percent slopes	26.1	5.60%
Gf	Granby fine sandy loam	83.1	17.90%
GnA	Granby fine sandy loam, brown subsoil variant, 0 to 3 percent slopes	220.7	47.60%
HbB	Hebron sandy loam, 2 to 6 percent slopes	10.8	2.30%
Na	Navan silt loam	30	6.50%
Sf	Sandy and gravelly land	0.8	0.20%
Sfb	Sandy lake beaches	0.1	0.00%
W	Water	1.7	0.40%
WnA	Wasepi sandy loam, clayey substratum, 1 to 3 percent slopes	59.3	12.80%
	Total	463.1	100%

2.5 Hydrology

The study area sits in the Lake Michigan watershed. The study area encompasses multiple shallow and deeper aquifers. The focus of this research is the wetlands and shallow groundwater. The shallow groundwater is resupplied by infiltration and the unconfined aquifer that is from the sands and clays deposited from the glacier period. The recharge zone of the wetlands of Chiwaukee includes The Nature Conservancy restoration site (United States Geological Survey, 2014). The deeper aquifer is Silurian-age dolomite. According to the NRCS Climate data, the precipitation in Kenosha County averages 110 cm annually (Natural Resources Conservation Service, 2021). The study area has no streams or rivers and it drains directly into Lake Michigan. Lake Michigan plays a role in all aspects of its hydrology. It is the local base level, affects the precipitation and temperature, and is connected to the shallow and deep groundwater systems. The elevation increases to the west and decreases towards Lake Michigan to the east. The study area has a southeast dip (causing the area to the SE to be generally wetter). The study area lies between 30 m to 1.8 km upslope from Lake Michigan. Surface water follows the swales north to south and ditches that have been cut through the landscape. On the south side of the restoration site, a creek has cut though the surface bluff. There are several areas where water can collect, including swales, ditches and the artificial pond found in the northeastern corner of the south Chiwaukee subsite. The ditches play a role in concentrating and channelizing flow (Kay, Miner, Maurer, & Knight, 2010). The different soils in the study area cause different amounts of infiltration from precipitation. The TNC restoration site has higher percentages of clay in its stratigraphy and will have slower infiltration rates than the sandier areas of Chiwaukee Prairie.

2.6 Vegetation

The vegetation of the study area varies between the four different subsites. The study area hosts a multitude of plant communities, including dryer communities like beach dune or sandy ridge, oak savanna, dry prairie, sedge meadow and small stands of lowland hardwoods. Chiwaukee also supports wetter communities like shallow marsh, calcareous and prairie fens, and shrub carr (Kay et al., 2010; Wisconsin Wetlands Association; Wolf, Baker, & Reed, 2012b). It hosts over 400 species of vascular plants and 26 rare plant species of which ten are endangered or threatened (Kay et al., 2010; Wisconsin Wetlands Association; Wolf et al., 2012b).
In the restoration site, the vegetation pre-restoration consisted of a mixture of upland trees, farm crops, and some native wetland plants and can easily be seen from historic arial photography. For the restoration, the majority of the vegetation was cleared. During the restoration, the vegetation was modified through the removal of trees and upland vegetation and the planting of more wetland vegetation. The Southeastern Wisconsin Regional Planning Commission (SEWRPC) provides local wetland maps and can provide some idea of what is at the site. The SEWRPC data shows that almost all of Chiwaukee North and South are scrub shrub wetlands with some emergent wetlands (Figure 2.5). The TNC restoration site has pockets of forested wetlands (where vegetation was cleared see 2.7.4) and a pocket of emergent wetland. While walking the site is this was fairly accurate. At the beginning of the research the restoration site was fairly barren, after the vegetation removal, but slowly saw a return in vegetarian by the end of the research. The emergent wetland where RN4 is located was the completely different to the rest of the restoration site and showed wetland communities seen nowhere else in their restoration site. The site holds a variety of wetlands. Chiwaukee prairie has seen little change in plant cover. There has been removal of invasive species like buckthorn during this research. The plant communities change with the microtopography and will have completely different communities whether you are on a ridge or a swale. These communities include oaks, forbs, grasses on the ridges and sedges, rushes, and mosses in the swales. Two areas that are also different are by CN4 and CS3. These Piezometers are both at the outflow of culverts coming from the TNC restoration site and large amounts of cattails present. The cattails in Chiwaukee North extend from CN4 to ILP4 The swales are dominated by sedges and rushes are present in the deeper swales (most abundant in Chiwaukee South).

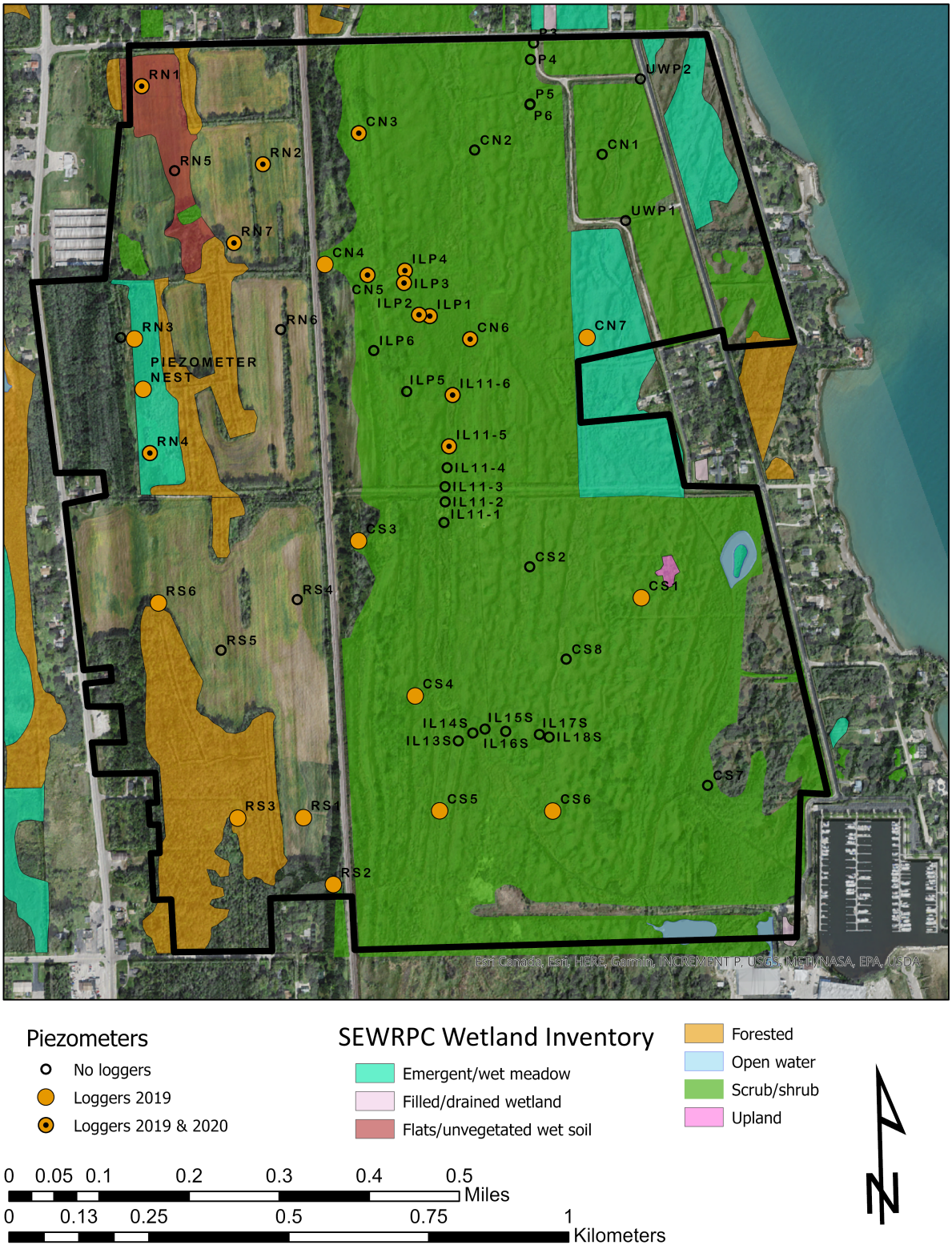


Figure 2.5 Map of the study site showing the piezometer locations and the wetlands types according to the South Eastern Wisconsin Regional Planning Commission (SEWRPC).

2.7 Human Development

2.7.1 Land Use

During this research, few records were found of pre-settlement use of the prairie when the Potawatomi and other Tribes where living in the area (Digital, 2021; Flores, 2018).
The study site has experienced several different uses, among them a failed luxury housing development and golf course. Old developments are shown in aerial photographs and from walking the study area. A succinct history was given by Jennifer May, a local Carthage College Undergraduate in her 2015 thesis on the early history of Chiwaukee:

> *When development and settlers came to Wisconsin, a woman named Edith Rockefeller McCormick bought all of the land on the lakeshore. She was planning on building on it and making it a golf course, hotel, and a harbor. The area was to be called "Chiwaukee on the Lake." The golf course was built but then was later abandoned because of the wet soils being difficult to build on or golf on. Since it is hard to build homes on, homes were only built on the sand dunes. The waves eventually got to those houses and destroyed them, but many of the homes that were saved from the waves were moved instead of waiting for them to be taken by the waves. Protective barriers made from large stones and concrete were put along the lakeshore to protect the million dollar homes that were put there later on. The plans for the beach hotel never came to fruition due to the stock market crash in 1929. The lots eventually went up for sale and were bought and sold a few times. In 1937, some of the land was used for anti-aircraft training for World War II, making this a memorable and historic area in more than a few ways. In 1947, the land was sold again to developers and a portion was newly named "Carol Beach", after the developer's daughter. Seven plots had homes built on them for various types of families (May, 2015).*

The impacts of the development of Chiwaukee prairie are shown easily using LiDAR or aerial photography (Figure 2.6). Old roads, ditches, and a small artificial pond appear in high-resolution imagery. These features continue to be reclaimed by the natural vegetation but still have a lasting impact, especially the ditches that allow easy conduits for surface water.

Figure 2.6 Map of the study site with MDOW hillside and aerial photography to highlight land features.

The Wisconsin Department of Natural Resources and the Chiwaukee Preservation Fund are both actively restoring Chiwaukee Prairie through projects like invasive species removal, which has caused a visual difference in the last few years.

The area known as Chiwaukee Prairie has complicated ownership. Four entities own different parts of the prairie, these include The Wisconsin Department of Natural Resources (the primary land manager), The Nature Conservancy (TNC), the University of Wisconsin-Parkside, the Chiwaukee Preservation Fund, and the Village of Pleasant Prairie. The area is actively being used for hunting, hiking, birding, several research projects, and a classroom for university classes.

The Nature Conservancy restoration site was used as farmland from the 1800s until recently, when it was purchased by TNC. This property was drastically modified for agriculture. Ditches and drain tile lay in multiple fields and plowing have flattened any of the ridges that might have been present. It is visually starkly different then the adjacent Chiwaukee Prairie.

2.7.2 Investigations in the Chiwaukee Area

There have been multiple studies conducted within the study area. In 2001, the Illinois Department of Natural Resources, Illinois State Geological Survey, and the Society for Sedimentary Geology produced a field trip book outlining the evolution of the lake plain and area. There have also been multiple hydraulic investigations. Skalbeck et al. (2008) looked at the seasonal changes in the water table and the diurnal change plants have on the water table. In 2004, the United States Geological Survey Water Resources Discipline conducted research and examined where the water recharge zone is for the Chiwaukee wetlands. The Illinois Geological Survey (ILGS) conducted hydrologic monitoring in 2013. This study looked to establish baseline geochemical and hydrologic conditions. The USGS conducted research in 2007-2008 to study the hydrology, water quality, and vegetation. Soils study from Carthage College in Kenosha. There was also a remediation project conducted in 2004 by K. SINGH & ASSOCIATES, INC. on a gas station that sits adjacent to the TNC property. The reporting for that project holds a wealth of data. There has also been biologic research in the area, for example, Wolf (2012) describes vegetation coverage. The Wisconsin Department of Natural Resources (WDNR) has also been monitoring the air quality of the site since the year 2000.

2.7.3 The Nature Conservancy Restoration

In 2019, The Nature Conservancy began wetland restoration on a property adjacent to Chiwaukee Prairie Natural Area in the southeastern corner of Wisconsin. With support from Michigan Technological University and The Nature Conservancy, research was conducted to examine the pre and post-restoration hydrology of Chiwaukee Prairie and The Nature Conservancy Restoration site. Their primary goal was to keep the area from being developed. Once attained, they found they had acquired a sizable property and the decision was made to restore it by re-wetting, contouring, and seeding to bring it closer to pre-settlement conditions. The restoration site is also part of the groundwater recharge zone for the adjacent wetlands in Chiwaukee Prairie State Natural Area and will increase the available groundwater to its wetlands. The Nature Conservancy restoration is meant to aid this shallow water system that directly influences the health of the wetland.

2.7.4 Restoration Timeline

Starting in 2019, the Nature Conservancy took several steps toward the restoration of the site. The aim was to return the environment to oak savanna with ridge and swale wetlands. First, in

January 2019, most of the vegetation was removed from the restoration site but oaks were left standing. In October 2019, they recontoured the landscape, filling the ditches, to better match the original dune-and-swale topography (Figure2.7-8) (Unlimited, 2019). Valves were added to the drain tile to prevent dewatering while still giving the ability to drain the water in case flooding occurs (2020). Native prairie grasses, wildflowers, sedges and shrubs were replanted or reseeded (2021).

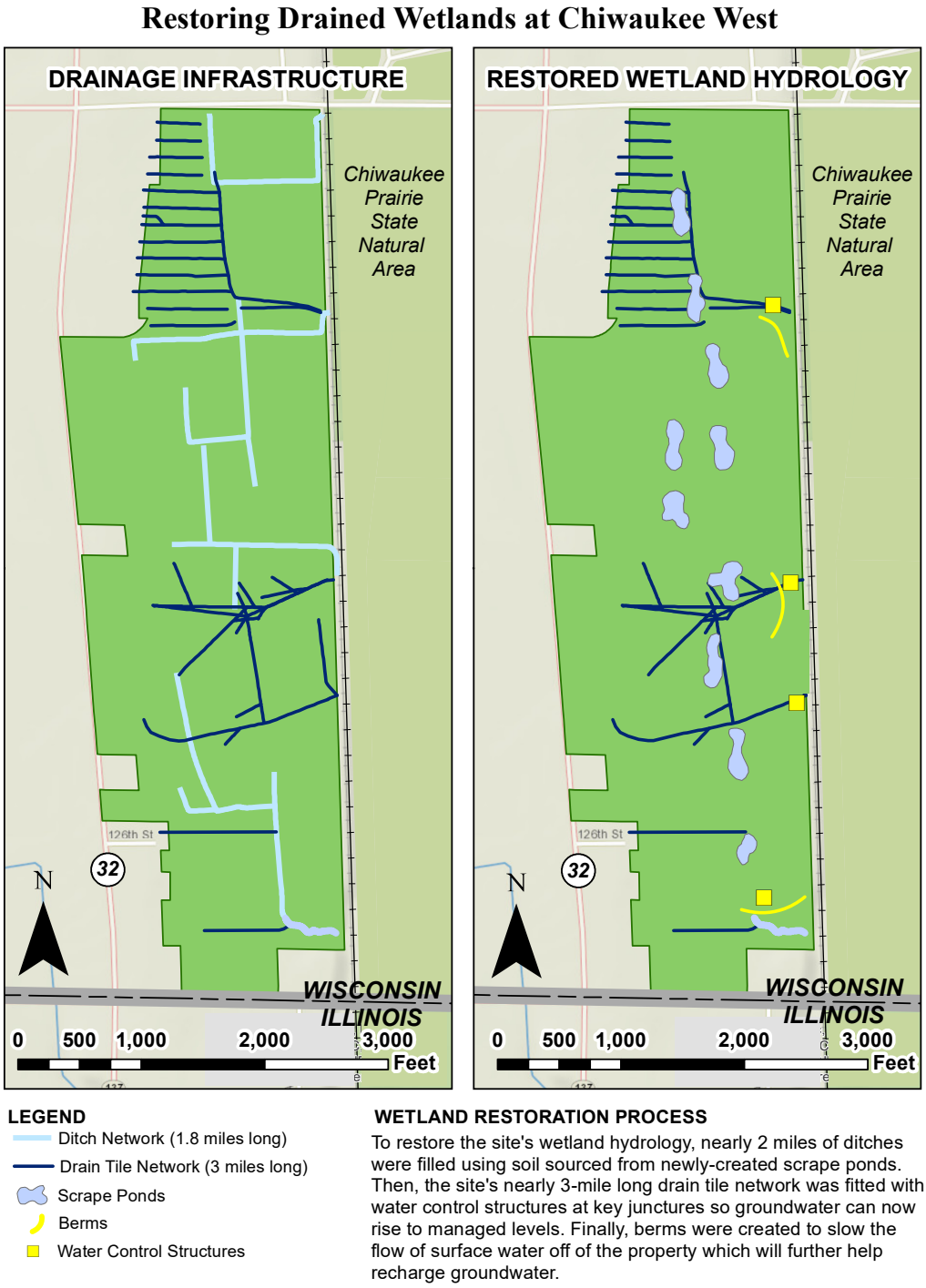


Figure 2.7 Map of the TNC on the left showing location of pre-restoration ditches and drain tile and the right post-restoration plans.

Before/After Photo Points

Figure 2.8 Map from The Nature Conservancy showing the acquisition times for different portions of the restoration site and images before and after recontouring and the addition of water control structures of the restoration site.

3 Methods

Data was collected by the author in the field and retrieved from government sources. data collection took place in two separate field seasons, 2019 and 2020. The restoration occurred in two separate episodes (Section 2) and the field seasons were designed to capture the differences. The 2019 season lasted from May 20 to November 29. The 2020 season lasted from June 13 to October 18. The field data collection between 2019 and 2020 seasons differed slightly in methodology due to equipment availability.

3.1 Piezometers Construction and Installation

This research took the existing piezometer network and expanded it. This expansion required new piezometers to be designed, installed, and surveyed. Chiwaukee Prairie had a total of 24 piezometers before this research began. Prior to this research the Illinois Geological Survey installed 18 piezometers and the University of Wisconsin-Parkside had installed 6 (not used in this research). This research project installed 28 piezometers between the restoration site and Chiwaukee Prairie. This brings the total piezometer in the study area to 51 with 45 of which used for this research.

3.1.1 Construction

Piezometers were built from standard 5.08-cm (2 inch), schedule-40 sch PVC pipe in 3.05-m (10-ft) lengths, which were cut in half to provide 1.524-m (5 ft) piezometers. Slits were then cut into the pipe at a 45˚ angle using a hacksaw (Figure 3.1). These cuts run from the bottom to the top of the piezometer spaced in a way to provide full coverage. The lower 4-ft was then wrapped in weed-barrier cloth to help keep fine material from filling the pipe. These simple yet effective designs worked well for this study and offered effective and economical tools for large scale operations.

Figure 3.1 Construction of piezometers.

3.1.2 Installation

The 28 MTU piezometers were installed between May 19 and June 2, 2019. Figure 3.3 shows the location of all the piezometers in the study site including the 28 installed by MTU. The general locations were chosen using ArcGIS and then were scouted on foot before installation. Each location was chosen based on multiple factors, including its ability of filling holes in coverage, and the likelihood of catching the response to restoration. Holes were dug using a soil auger (Figure 3.2). The holes were all approximately 120-cm deep. Then the piezometer was placed in the hole and the material was backfilled into the hole. In some locations the 120-cm mark was not possible to reach due to the presence of beach cobble at depth (RS5) or collapsing sands (CS1). In these locations, the holes were dug to the deepest point possible.

Figure 3.2 Author using a soil auger to dig a hole for piezometer RN1.

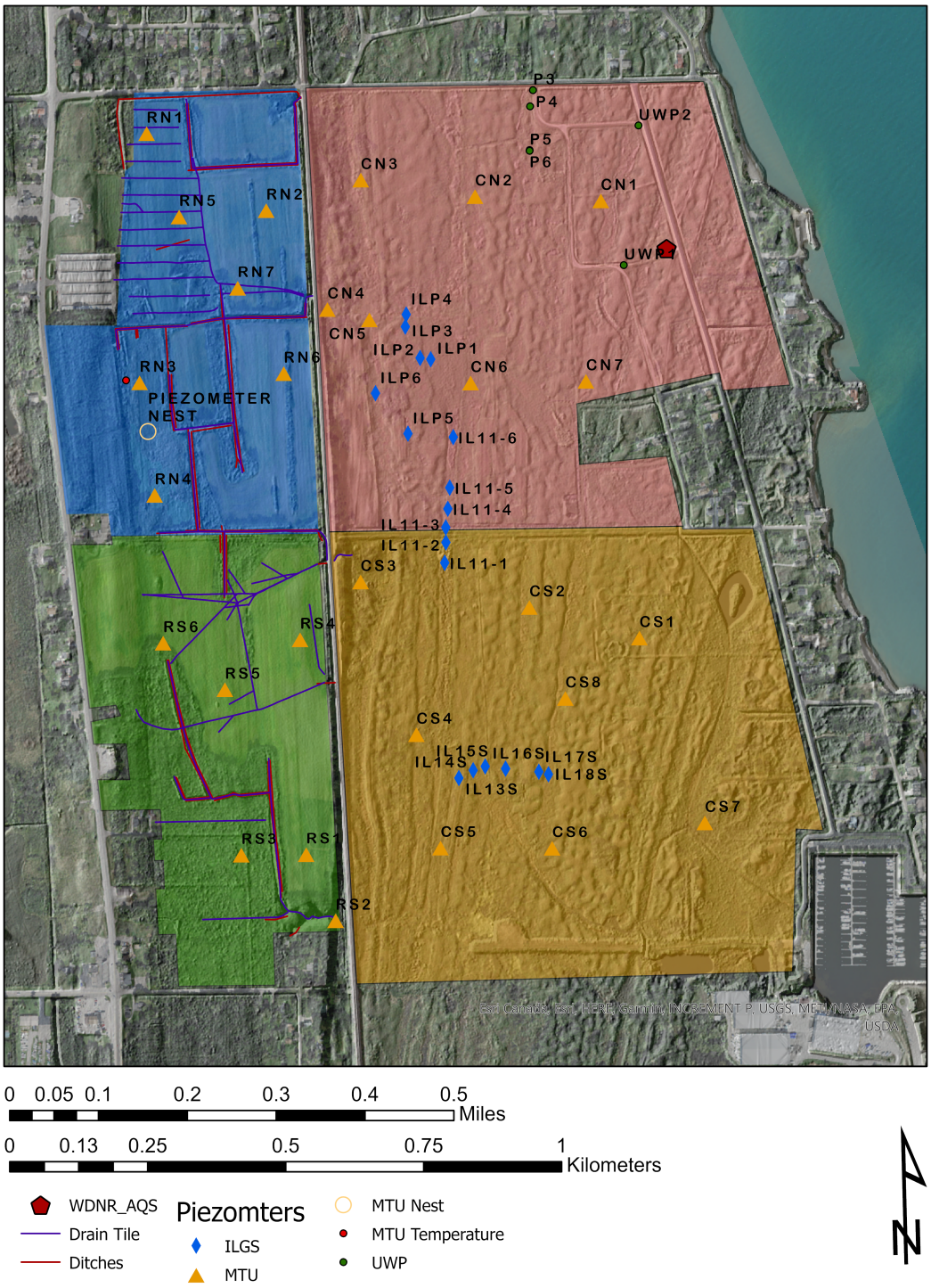


Figure 3.3 Map of the Chiwaukee Prairie showing all piezometers and their installers.

The geographic distribution of the piezometers and other measuring devices are shown as yellow triangles representing the piezometers installed by Michigan Technological University (MTU). Blue diamonds represent the piezometers installed by the Illinois Geological Survey. Green circles represent the piezometers installed by the University of Wisconsin-Parkside. The red,

filled circle represents where MTU installed a temperature sensor. The red, filled pentagon represents the Wisconsin Department of Natural Resources' air quality monitoring station. Red lines represent where ditches were before the restoration. Blue lines represent where drain tile is located.

3.2 Surveying

Spatial data were obtained from a variety of sources. The wetland maps came from the Southeastern Wisconsin Regional Planning Commission (SERWRPC) wetland map and the USDA NWI map. The SERWRPC wetland can be seen in Figure 2.5 .The 2-ft DEM came from Wisconsin View (WisconsinView, 2004). Piezometer position and elevation was determined using a Trimble r10 with and a Trimble TSC7 connected to the Wisconsin Department of Transportation's WISCORS (Wisconsin Continuously Operating Reference Station) (Figure3.5) (Transportation).This is a continuously operating reference station maintained by the state of Wisconsin. Site calibration was done using the local U.S. Public Land Survey System (USPLSS) as control points (Figure 3.4). This research used the National Geodetic Vertical Datum of 1929. The site calibration is reported in Appendix.

Figure 3.4 U.S. Public Land Survey System survey marker used in research.

Figure 3.5 Author GPS survey of RN6 location using Trimble TSC7 RTK GPS.

3.3 Water Chemistry

Water Chemistry was collected to provide baseline chemistry of the Chiwaukee Prairie and at runoff from The Nature Conservancy restoration site as well as to compare against previous

research.
Water chemistry was Collected during the 2019 field season. The chemistry was collected two ways, using a YSI 63 during each of the first seasons sampling trips and by grab samples collected in October 2019.

3.3.1 Hand Measurements

Hand measurements used a YSI 63 during each of the first seasons sampling trips. Conductivity, temperature, and pH were measured over the 10 sampling trips of the first season using a YSI 63. This was done to expand the chemistry data for Chiwaukee Prairie and provide baseline data for The Nature Conservancy restoration site. This data also provides information to be against previous research. The YSI was calibrated before every trip to ensure accuracy. water chemistry data was collected during the first season. The water chemistry was collected alongside the water levels measurements at each piezometer. These where collected whenever water levels by hand.

3.3.2 Grab Samples

Grab samples were collected on October 14 of 2019 during the first season to acquire pre-restoration chemical data and to compare against past research. 5 samples were taken from locations around the study area. Two samples were taken at the surface water outflows, one from the northern and one from the southern section of the restoration site, one sample from the remnant wetland in the northern section of the restoration site, and one from swales in north and south Chiwaukee. Samples were put on ice and taken directly to the Wisconsin State Lab of Hygiene in Madison for Analysis. The lab analyzed the water for conductivity and pH were measured and total nitrate and phosphorous was calculated.

3.4 Water Level Measurements

Water levels were measured in two ways, from pressure transducers (also referred to as loggers) placed in the piezometers and by hand using a water level measuring tape, both of which are described below in detail.

Figure 3.6 Author holding HOBO Logger tied with monofilament line.

3.4.1 Loggers (Pressure Transducers)

Pressure transducers were used to collect water-level measurements over fixed time intervals (60 minutes). The 2019 Season utilized 18, and the 2020 season used 7 loggers. A combination of transducer models was used for this research. The modes were as follows: Onset HOBO U20-002-02 and U20L-(01,02,04) water level loggers (Onset Computer Corporation, Bourne, Massachusetts) (Figure 3.6), Solinst LT F6/M2 Leveloggers, (Solinst Canada Ltd., Georgetown, Ontario) and In-Situ Inc. Level TROLL 500 (provided by the ILGS). The Michigan Technological University loggers collected measurements at a 1-hour or finer interval and the ILGS logger collected once every four hours. The Illinois loggers have been deployed since March 2011 and have been kept in the Prairie for long-term monitoring. The ILSG loggers are located in Piezometers P1, P2, P3, P4, 11-4, 11-5, 11-6 (Figure 3.3). These piezometers are in one of the larger swales of CN.

Figure 3.7 Typical sampling trip equipment. From left to right are sounding tape, computer with HOBO adaptor, notebook, piezometer, multimeter, HOBO logger.

3.4.1.1 2019 Season

Pressure transducers were deployed between May 18 and June 2. Pressure transducers were placed inside 18 of the piezometers: RN1, RN2, RN3, RN4, RN7, RS1, RS2, RS3, RS6, CN3, CN4, CN5, CN6, CN7, CS1, CS3, CS4, and CS5. Two transducers were placed in the RN P3 to measure barometric pressure. The first season the pressure transducers were hung using 50-lb strength monofilament. Each length was measured to at least one hundredth of a foot or to the nearest 0.5 centimeter. The piezometers were chosen based on expected reaction to the restoration. The greatest anticipated reactions were expected in the fields of the restoration site and in piezometers on the west side of Chiwaukee Prairie. Transducers were deployed on May 20 (R) and June 2 (CP) and removed on Dec 2, 2019.

3.4.1.2 2020 Season

In the second season, braided metal cable was used instead of monofilament, which tended to stretch over time. Fewer transducers were deployed in the second season due to battery failure during winter storage. This caused a significant reduction in coverage. Only piezometers RN1, RN2, RN4, RN7, CN3, CN5, and CN6 could be monitored. Loggers were deployed June 2, 2020. The loggers would have been deployed earlier but were delayed due to the COVID-19 pandemic and the restrictions put in place during that time. Loggers were removed October 17-18, 2020.

3.4.2 Hand Measurements of Water Levels

Sampling with an electric sounding tape (Model 101 Water Level Meter, Solinst Canada Ltd., Georgetown, Ontario) (Figure 3.8), referred to as hand measurements, was conducted approximately every two weeks. A total of 45 piezometers were used in this study. Ten sampling trips were conducted during the 2019 season and 3 trips during the 2020 season. Each of these sampling trips provides a snapshot of the conditions. Figure 4.7 shows the equipment used for a typical trip. Piezometers near the restoration site were prioritized when time was limited. Water-level hand measurements were collected by using the water level meter. Measurements were measured from the north side of the piezometer. Each measurement was repeated a minimum of three times to obtain consistent measurements. The distance between the top of the pipe and the ground (stick-up) was measured and the water depth from the top of the casing to the depth below ground surface.

Figure 3.8 Solinst water-level meter next to piezometer RN1.

3.4.3 Recession Curve Analysis

Recession curve analysis is the examination of how the water table drops in a hydrograph. The falling curves or recessions of the hydrographs tell us about characteristics of an aquifer or stream in question.

Recession curve analysis is a quantitative method of analyzing hydrographs of streams and piezometers that has been used for decades (Delin, Healy, Lorenz, & Nimmo, 2007; Posavec, Giacopetti, Materazzi, & Birk, 2017). There are several different methods of recession curve analysis. This research used an automated matching strip method to create what is known as a master recession curve (MRC). The only input needed is the water table data collected by the pressure transducers. This research used a published and publicly available Visual Basic program in an Excel spreadsheet to create and produce the MRCs for all of the piezometers used both years. A description of the tool is outlined in (Posavec, Bacani, & Nakic, 2006). This method

analyzes the recession portions of the hydrograph. An MRC is created by taking multiple recession curves and aligning them by the initial head before they begin dropping. The y-axis is head and the x-axis is converted to relative time in days. MRC trends provide the average characterization of the hydrograph (Posavec et al., 2006). The idea behind the use of this research is that the characteristics between the two years are not as affected by precipitation and temperature and that the aquifer parameters would remain the same. Then, a comparison between the same piezometers comparing the separate years was performed.

4 Results and Discussion

4.1 Precipitation

Precipitation and evapotranspiration are key processes governing soil moisture in the near surface (root zone). As such, the piezometer hydrographs are strongly influenced by these processes as witnessed in this and previous research (Higley, 2013; Kay et al., 2010; Skalbeck et al., 2008; Southeastern Wisconsin Regional Planning Commission, 2004). The water tables rapidly increase with each rain event. This is clearly seen in the hydrographs of this and previous research (Higley, 2013; Kay et al., 2010; Skalbeck et al., 2008; Southeastern Wisconsin Regional Planning Commission, 2004).

Meteorologic data was obtained from a Wisconsin Department of Natural Resources air quality monitoring station (AQS) and the Kenosha Wastewater Treatment Plant (WWTP) through the Natural Resource Conservation Service's Agricultural Applied Climate Information System. Both AQS and WWTP data were downloaded as a comma-separated value (.csv) (Natural Resources Conservation Service National Water and Climate Center, 2020; Wisconsin Department of Natural Resources, 2021). The Chiwaukee Prairie AQS (AQS ID - 55 059 0019) is located in the northeast portion of the study area, with Lat: 42.504690° and Lon: -87.809257°. Parameters taken from the station were air temperature and precipitation, which were recorded hourly. The AQS data does not span the entirety of the year but are only complete for June – October of the study period and does not include snowfall. It provides on-site records from the WDNR going back to 2015. The data was processed as a times series in an Excel spreadsheet to compare with the piezometer data and is displayed with the hydrographs. The AQS data works when displaying and comparing the precipitation in 2019 and 2020. To understand how these values relate to long-term averages, the data from the WWTP (6.25-km north of the study site) were used. The WWTP has records at a daily frequency, but the data extends back to 1951. A 20-year ("long term") average and upper 75 and lower 25 percentiles were calculated from WWTP data. It shows that average precipitation in the last 20 years was 42 cm, the upper 75% was 127 cm and the lower 25% was 91 cm. Figure 4.1 shows the annual precipitation for 2015 through 2020. The blue and orange bars represent AQS and the WWTP data. The upper 75 and lower 25 percentiles are shown as black dashed lines and the red line represents the long-term average (20 years). The WWTP-measured precipitation was higher than the AQS observations, and show that there was a 16-cm difference between 2019 and 2020.

The monthly rainfall summations for 2019 and 2020 are shown in Figures 4.2 and 4.3. Precipitation differed annually in both quantity and distribution. In 2019 it rained 101 days during the ~6-month field season in 2019 and only it rained only 79 days during the same period in 2020. The precipitation in 2019 is above the 75th percentile. The precipitation in 2020 is above the 25th percentile. The records show the AQS and WWTP results are all within 5 cm of each other. The data shows low amounts of rain in the beginning of the year. Monthly totals for the study years show a very similar distribution until September. The precipitation amounts for 2020 are lower than 2019 and show the opposite trend for 2019 where precipitation is higher in the spring and decreases into the summer and fall.

The 2019 season had a higher annual total than an average year of precipitation compared to the 20-year average. The 2019 total is close to the upper 75th percentile while 2020 is just below the

mean in the last 20 years. The much higher than average precipitation in the fall of 2019 contributed to this difference. The 2020 year shows values just below average of the 20-year mean. Month to month 2020 is very similar to 2019, having higher levels in April and May and much lower levels in September and October. The 2020 season shows a higher water level and precipitation for the first part of the year. Considering that precipitation plays a large role in water levels, 2020 would provide a much closer to an average year.
It was observed that the two stations show the same trends but the AQS shows lower precipitation. When comparing the monthly summations we can see that the WWTP almost alyays has higher values (Figure 4.2). This may be due to different methods of collection, errors in calibration or collection, or the fact that it consistently rains less at the AQS compared to the WWTP. When comparing 2019 and 2020, average water levels in 2020 are lower. The precipitation record by the AQS shows lower results compared to the WWTP. This can be partly because the AQS excludes snow and does not operate all year, but when comparing the annual data month to month, they are much closer. The AQS results are lower but follow the same trend as the WWTP data.

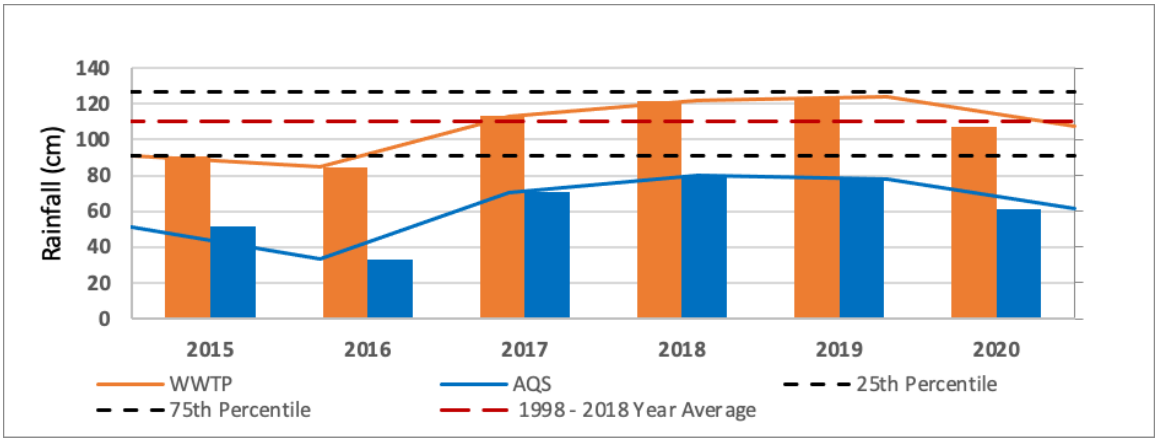


Figure 4.1 Bar graph showing the the annual sumations presipitaion of the Wiscinsin Departmnt of natiral resources air quality monitoirtin sataion (AQS) and the Kenosha waste water traement plant (WWTP).

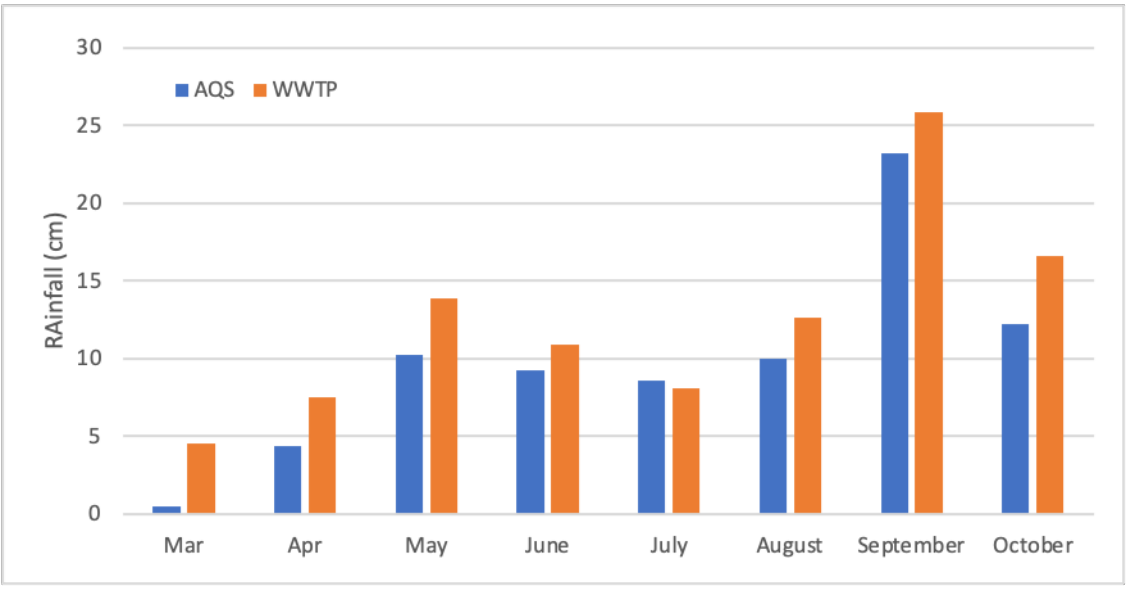


Figure 4.2 Monthly precipitation for 2019. The blue represents the WDNR AQS data, and the orange represents WWTP data.

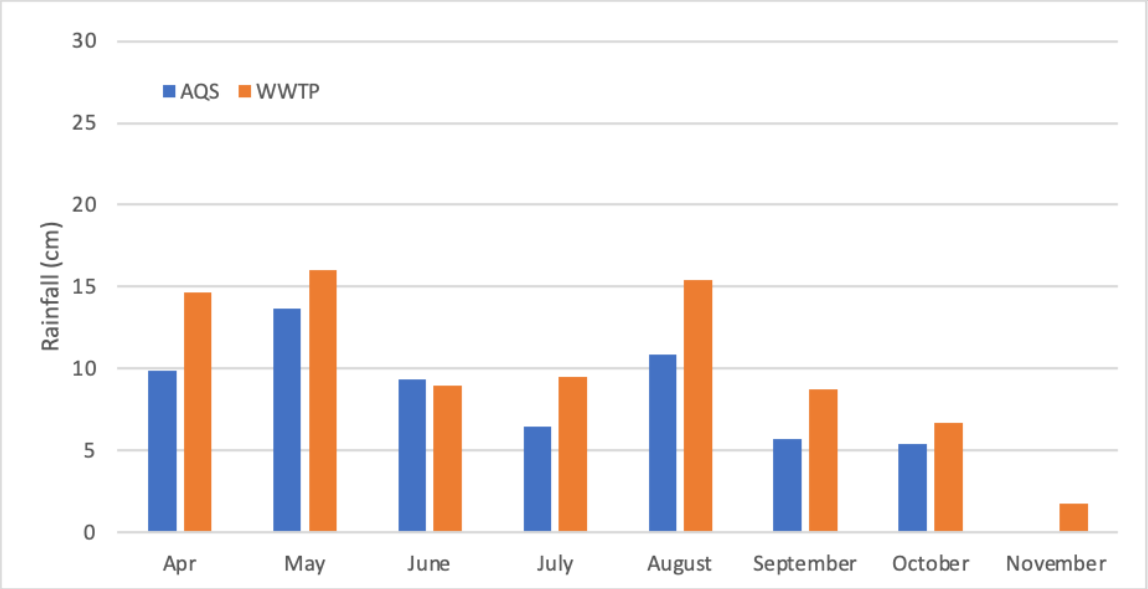


Figure 4.3 The monthly precipitation for 2020. The blue represents the WDNR AQS data, and the orange represents WWTP data.

4.2 Thornthwaite-Type Monthly Water Budget

Thornthwaite-type monthly water budget analyses were performed using precipitation and temperature from the WETS/WWTP in three scenarios using the 2019, 2020, and long-term monthly averages (see Dingman (2015)). The precipitation and temperature data were downloaded from the NRCS database and collected at the Kenosha wastewater treatment plant (approximately 6.25-km north of the study area). The results are depicted in Figures 4.4 – 4.6 below. Green lines represent the estimated combination of runoff and recharge, essentially the excess of precipitation less evapotranspiration (The black line with black triangles represents the estimated snowpack as depth of liquid-water equivalent (snowfall and depth are measured in

liquid-water equivalent), based on observed precipitation and adjusted for monthly average temperature. The yellow line with diamonds is precipitation (snowfall is represented as precipitation in liquid-water depth equivalent). Blue lines with triangles represent snowmelt. Magenta lines with squares represent soil moisture as depth-equivalent liquid water (Note: "depth equivalent" is a representation of the amount of water present in an equal depth as liquid rather than distributed as moisture throughout the soil profile to facilitate water-balance calculations using all depth equivalents as liquid water.). The x-axis represents time in months and the y-axis represents water volume in mm equivalent. Snowpack was higher in 2019 than 2020, which experienced the lowest snowpack and earliest melt compared to the 2019 and long-term results.

The calculated evapotranspiration (Dingman, 2015) was slightly higher in 2020 because of the higher monthly temperatures. The 2019 season saw very high rainfall in the fall. The 2020 season was still above average rainfall. The 2019 season likely experienced a higher runoff and recharge according to these monthly water budget analyses.

The results from the Thornthwaite-type monthly water balance showed trends that agree with the water table trends. The data shows the runoff/recharge was higher in 2019 when compared against the 2020 and long-term average. The snowpack and precipitation were higher in 2019 (especially in the fall), while evapotranspiration for the three years was very similar. The 2019 season had a larger amount of available water. With less water available in 2020, it would be expected that water levels in 2019 would be higher. There are several factors (like a through studied of evapotranspiration and snow depth) that have not been thoroughly studied and therefore, making conclusions with this method on its own would not be prudent.

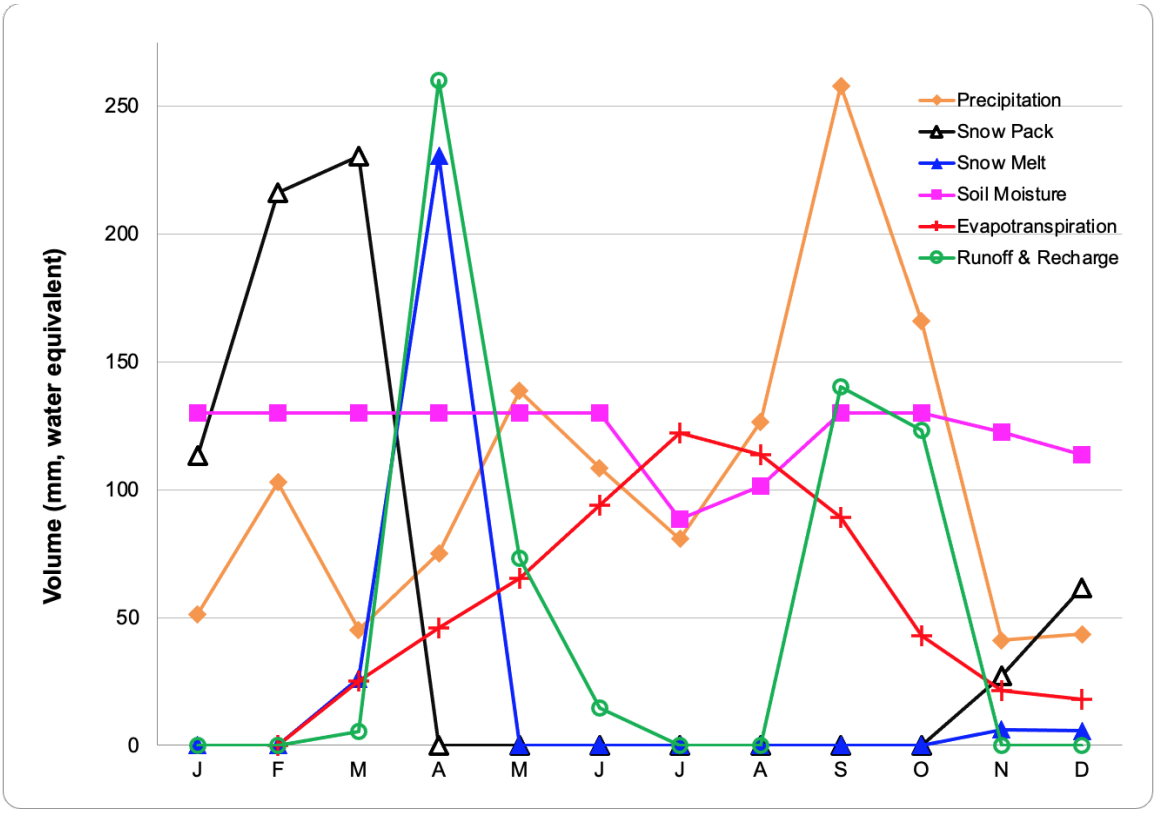


Figure 4.4 Results of the Thornthwaite-type monthly water budget using 2019 monthly averages (runoff and recharge could not be separated, so they were left as a combined variable, which is primarily recharge because of the low topographic relief).

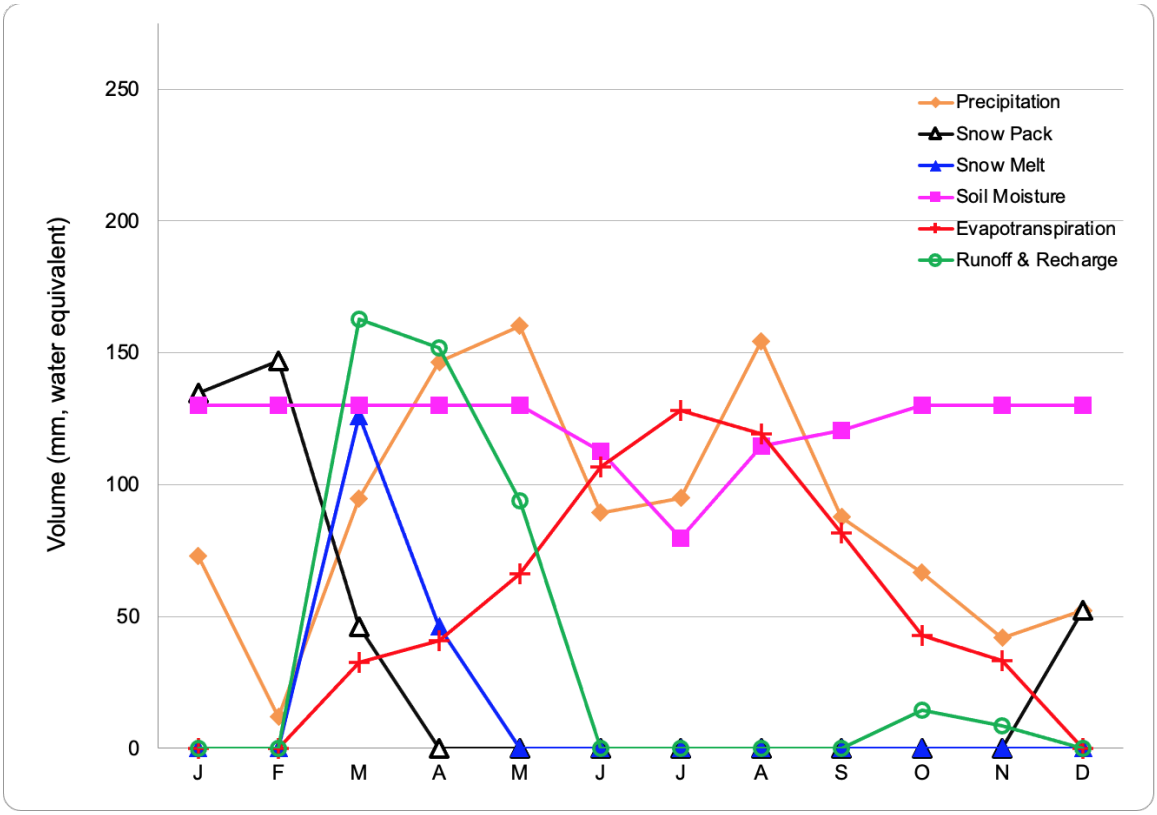


Figure 4.5 Results of the Thornthwaite-type monthly water budget using 2020 monthly averages (runoff and recharge could not be separated, so they were left as a combined variable, which is primarily recharge because of the low topographic relief).

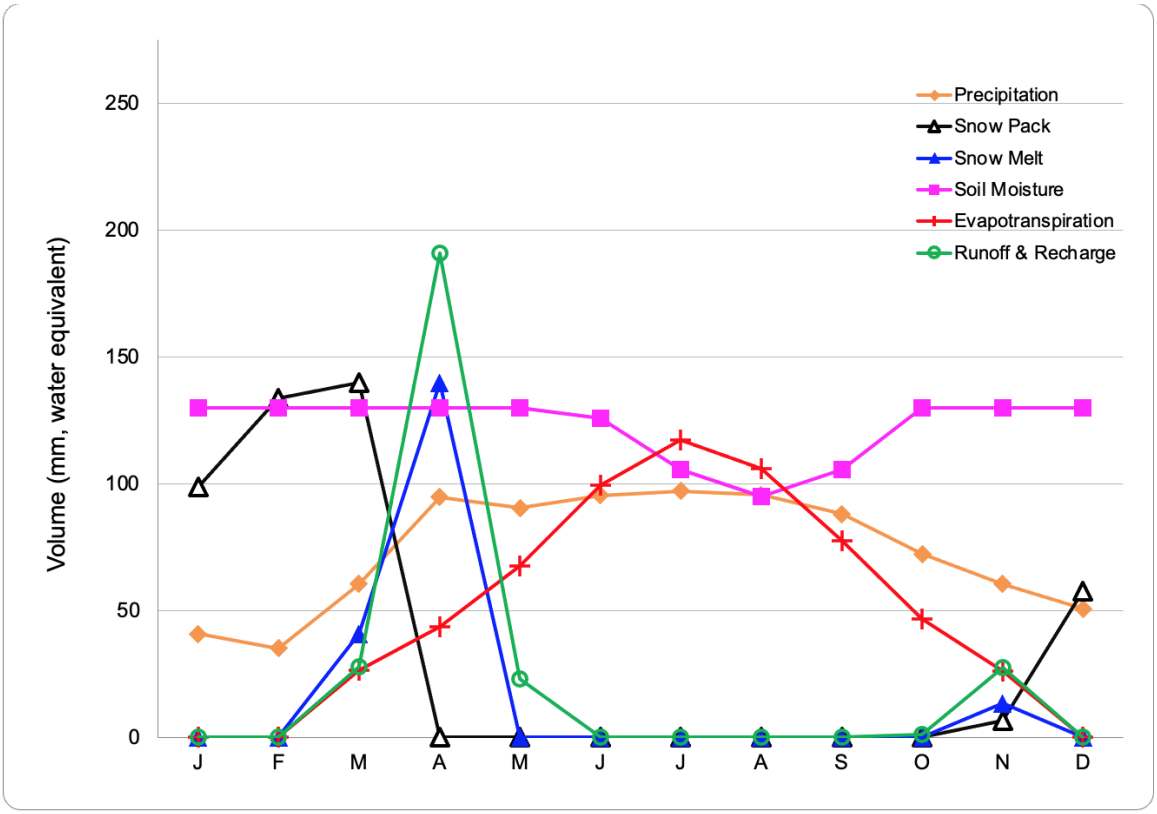


Figure 4.6 Results of the Thornthwaite-type monthly water budget using long-term monthly averages (runoff and recharge could not be separated, so they were left as a combined variable, which is primarily recharge because of the low topographic relief).

4.3 Water Chemistry

Hand measurements were collected in the 2019 field. Measurements were collected during each of the 2019 season sampling trips. This was done to expand the chemistry data for Chiwaukee Prairie and provide baseline data for The Nature Conservancy restoration site. Time was not an ally of the water chemistry data and when time was limited, water chemistry was not taken. In 2020, after a cursory look at the 2019 data, it was decided to focus time and energy into the water level data. This data is not the focus of this research.
It is displayed here only for the sake of prosperity and to give the reader a more complete picture of the site conditions, but will not be elaborated on.

4.3.1 Conductivity

Conductivity measured in microsiemens (µS). The mean was 661 µS and varied between .06 µS and 1801 µS with outliers at 3084, 4083, 4538, and 6771 µS. The distribution without the outliers can be seen in Figure 4 .The average value for each piezometer is shown in Figure 4.7. The individual piezometers did not see the same frequency of measurements. This means that not all the averages have the same number of measurements.

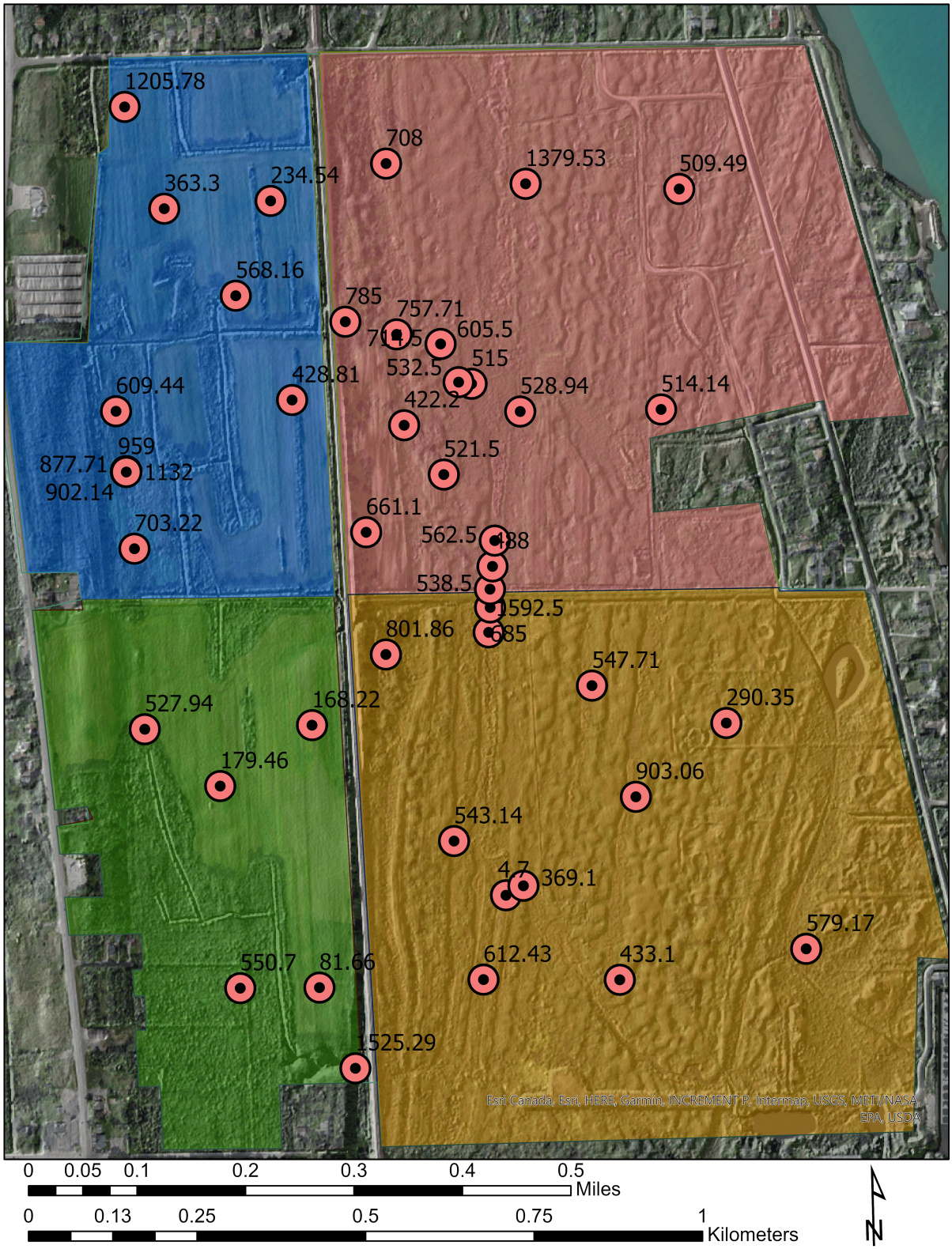


Figure 4.7 Map showing the average conductivity for each piezometer in microsiemens for the 2019 field season.

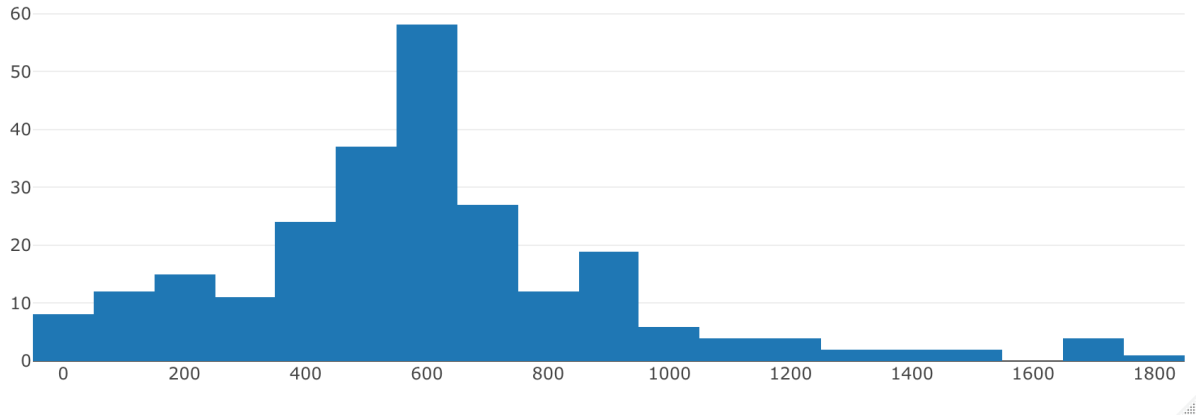


Figure 4.8 Histogram of recorded conductivity measurements in microsiemens during the 2019 field season.

4.3.2 pH

Overall, the pH was fairly consistent in the study site. The data shows that the site was slightly acidic with an overall average of 6.80. The pH varied between 5.2 and 7.88 with two outliers at 1.18 and 9.09. These outliers could be a malfunction or a problem with the device not properly calibrating. The distribution with the outliers removed can be seen in Figure 4.9. Seasonal averages for each piezometer can be seen in Figure 4.10. Like conductivity, the individual piezometers did not see the same frequency of measurements. This means that not all the averages have the same number of measurements.

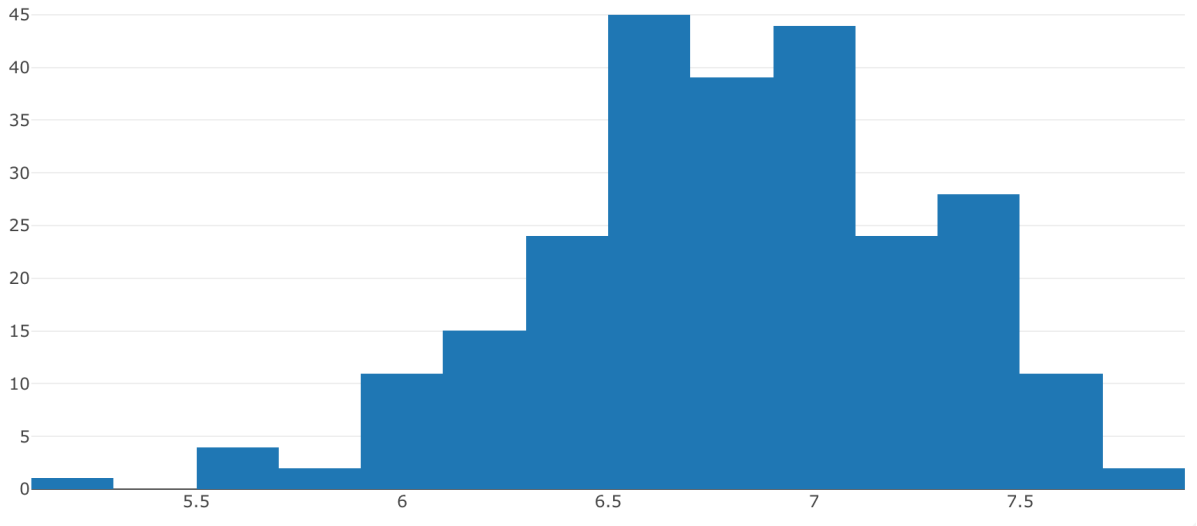


Figure 4.9 Histogram of recorded pH measurements during the 2019 field season.

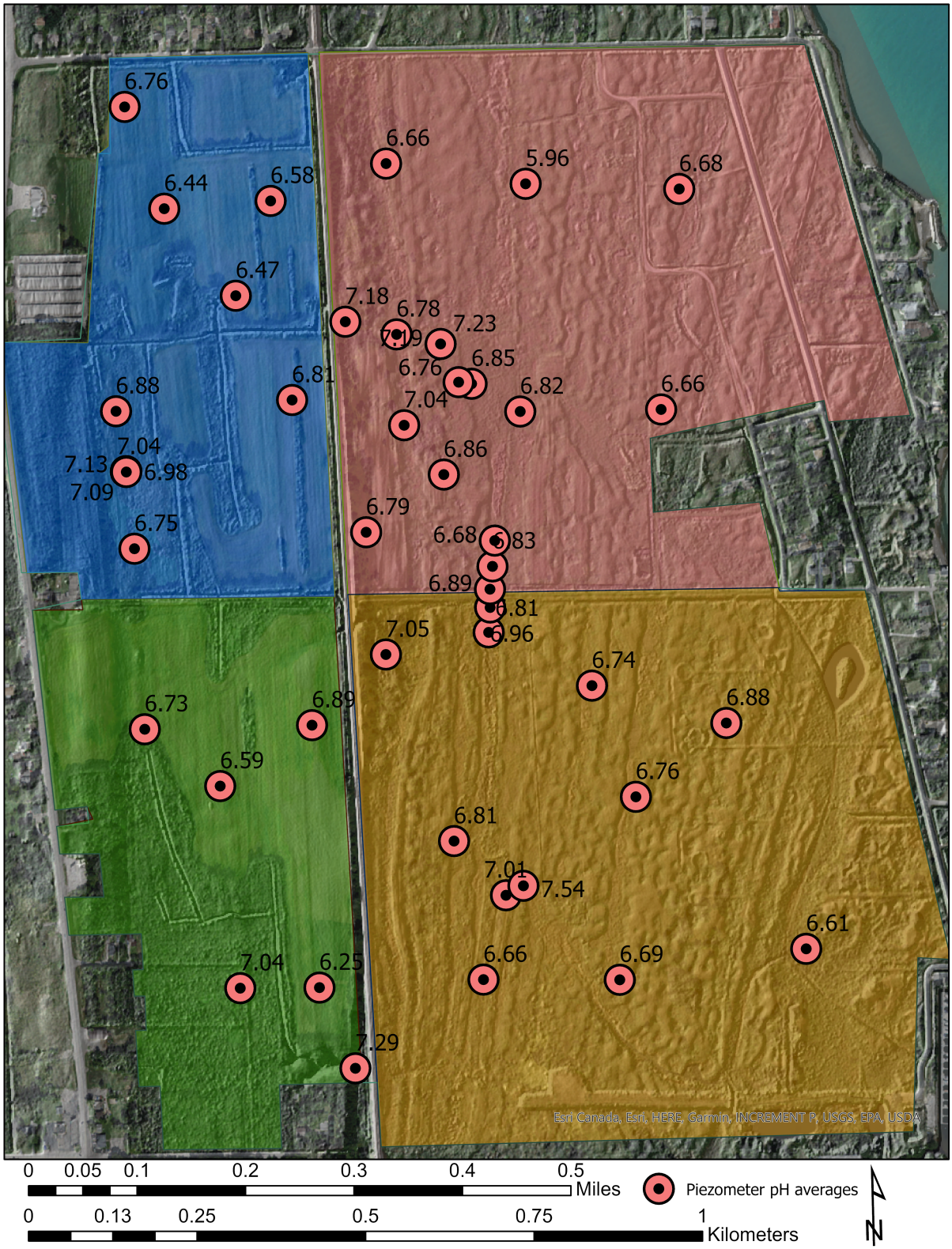


Figure 4.10 Map showing the average conductivity for each piezometer for the 2019 field season.

4.4 Water Levels

Water levels were collected in two ways: by hand using an electronic sounding tape, and by pressure transducers deployed in piezometers and recording pressures at 60-minute intervals. The 2019 season acquired water-table depth measurements from all four subsites (RN, RS, CN, and CS), but the 2020 season only has data from RN and CN. This reduction was necessitated by a decrease in the number of available pressure transducers for 2020. Because the 2020 season presented a much smaller number of transducers to work with, the decision was made to monitor the northern portion of the prairie and the restoration site. Figure 4.11 is a map that shows piezometer locations and the distribution of the transducers for the two seasons. The empty circles represent piezometer locations where no loggers were used. When sampling in the field, hand measurements were always taken at all MTU piezometers; When time allow, hand measurements were taken at ILGS; and the UWP piezometers were not used for this research (Figure 3.3). In Figure 4.11 Yellow circles are locations where loggers were used in the 2019 season. Yellow circles with black centers are locations where loggers were used in both the 2019 and 2020 seasons.

The results of this research show that the water levels in the restoration site has increased but the nuances of the restoration is not clear. The increase of the water table makes sense based on the Thornthwaite type monthly water budget results in section 4.2. differences in precipitation from year to year make it difficult to tell if there was an impact of the restoration to the natural Chiwaukee Prairie. The slope of the recession curve analysis increased in magnitude in all but one of the Chiwaukee piezometers (CN3) and decreased in all but one in the restoration site (the control piezometer RN4). This could be interpreted many ways, but the author interprets this as the amount of surface water feeding the wetlands decreasing the water available for the wetlands in Chiwaukee. The water level results are expected but do not give conclusive evidence to support the statement that the restoration has caused an increase in groundwater flow to the Chiwaukee wetlands. While there is obvious change in the water levels, it is not clear what factors played the largest role. For example, there may not be a strong enough hydrologic connection to the shallow aquifer to see results in this research study period.

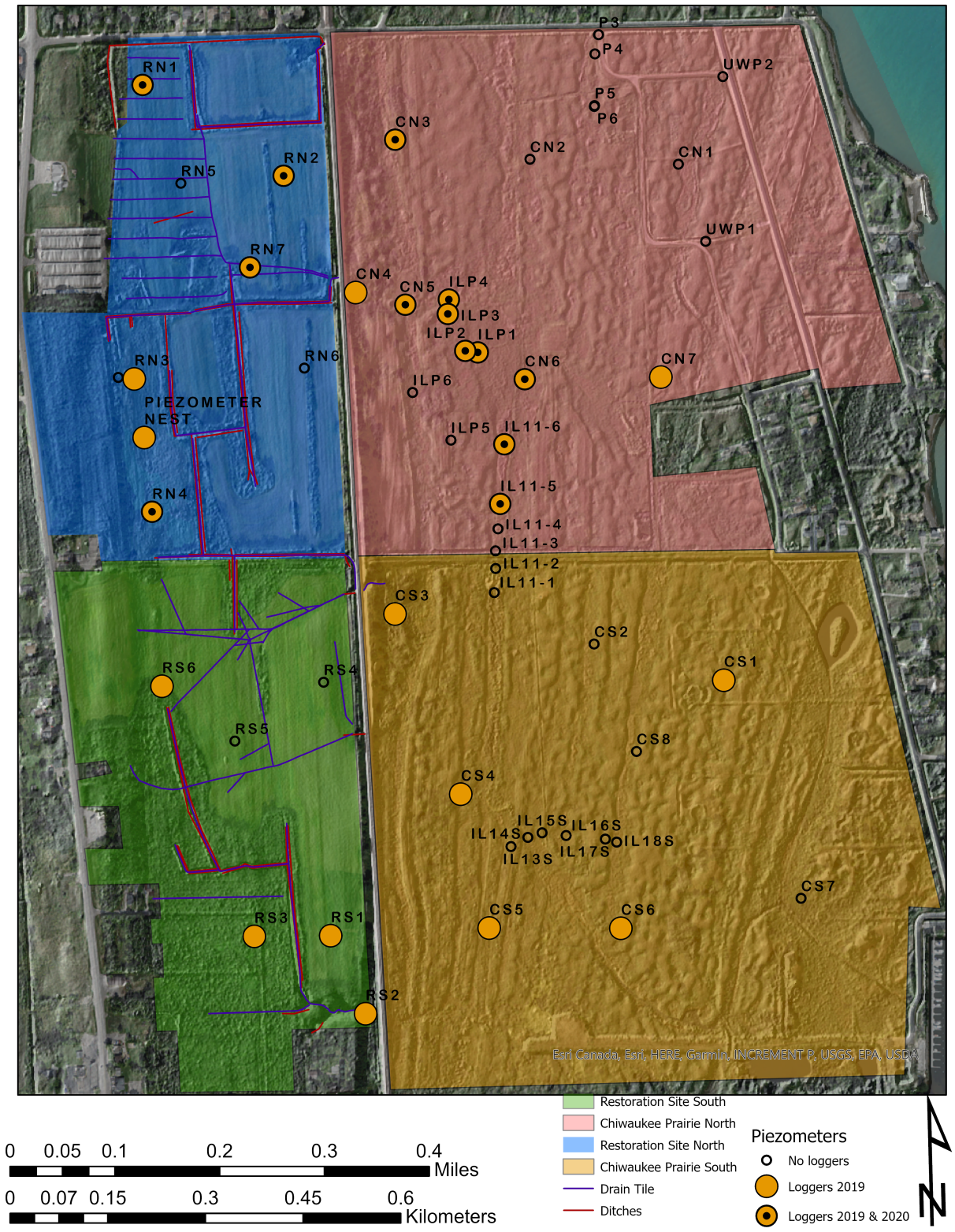


Figure 4.11 A map of the study site showing the piezometer and pressure-transducer locations for 2019 and 2020.

4.4.1 Hand Measurements

Hand measurements were used to ascertain the confidence in the pressure sensor (a.k.a. the logger) data. The loggers measure water height and atmospheric pressure (as water-height equivalent) above the pressure transducers inside the logger probes. To process the logger data into water depths, the logger readings needed to be adjusted for the corresponding atmospheric pressures from the AQS data and depth below ground surface the logger was suspended in the piezometer. The manual (hand) measurements were a direct reading of the water level. The loggers collected data more frequently and unattended, compared to the manual measurements, which were collected over time to check the logger data.

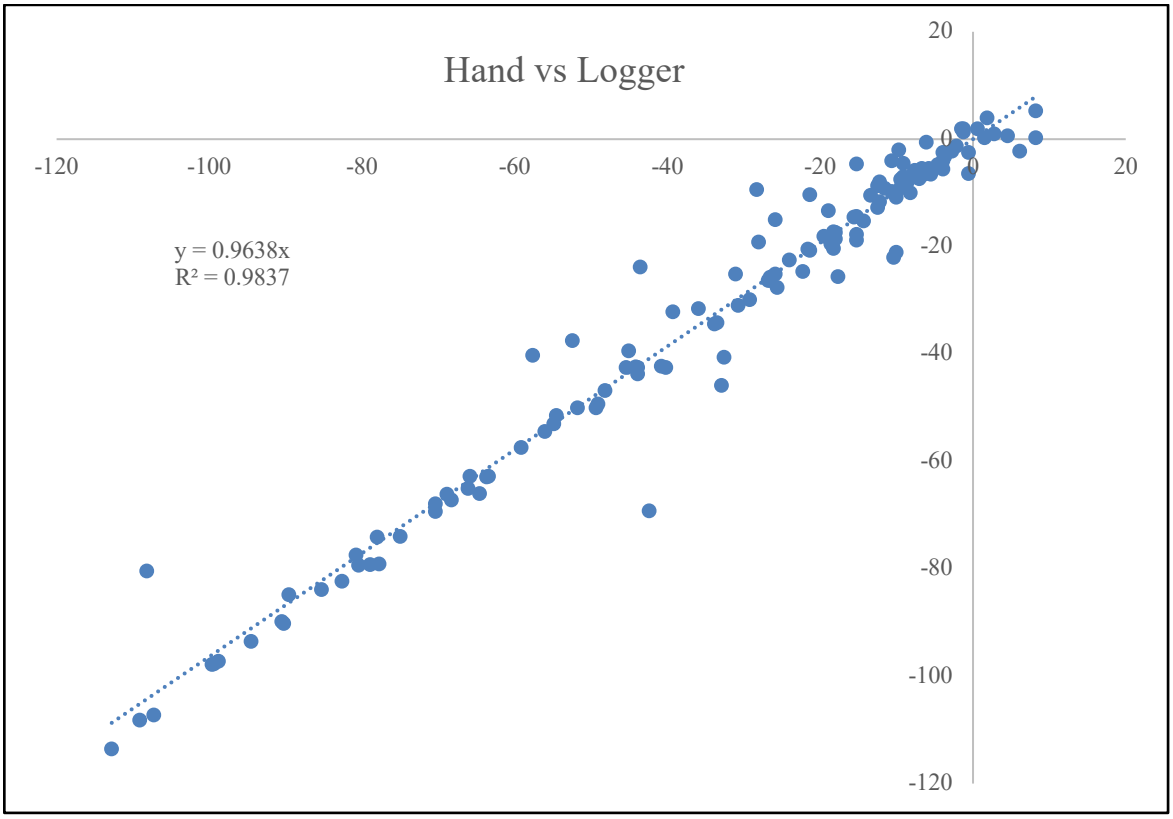


Figure 4.12 Comparison of calculated distance from ground surface (cm) hand measurements to logger results.

Examples of these are given in Figure 4.13 which shows three maps of mid-June, mid-August, and mid-October sampling trips. When comparing hand measurements against the pressure transducer measurements (seen in Figure 4.12), the results show good correlation. The results have a correlation coefficient (R2) of 0.97 to the 1:1 corresponding line. Viewing the individual hydrographs with the hand measurements in the appendix shows they are very close with only a few outliers.

The sounder and logger measurements show there is a good correlation between the two in the RN CN subsites. The data from CN3 and CN6 from 2020 and the Illinois Geologic Survey piezometers showed more error between the hand measurements and the logger data. The loggers

in CN3 and CN6 where the Solinst LT F6/M2 Leveloggers, (Solinst Canada Ltd., Georgetown, Ontario) and the loggers in the ILGS piezometers were In-Situ Inc. Level TROLL 500. A possible reason for the greater error is these units did have a reference logger, or barro logger, to measure the atmospheric pressure. The hand measurements still show that even if individual loggers are not precise, they still provide valuable trends. The hand measurements flushed out the areas in question, but they only provide snapshots of time. They still capture the general trends of the areas outside of logger coverage. Three-dimensional plotting of the hand measurements was used for understanding the data and can be seen in the appendix. Interpolated water table elevation maps were also made and are shown in Figures 4.14-18. These maps were produced using the ArcGIS Pro Inverse Distance Weighted (IDW) tool with the hand measurements as the input. This tool uses the IDW technique to interpolate values and has some shortcomings because of the sparse spatial distribution of data, resulting in some "bullseye" contours, but gives a general representation of how the water table slopes approximately with the topography from west to east, towards Lake Michigan. Another note that these measurements were not taken simultaneously. Some of the sampling trips took two days to collect. While the measurements of the water table are precise, the later levels are constantly changing and between measurements there may be a few centimeters of drop or increase from changing conditions.

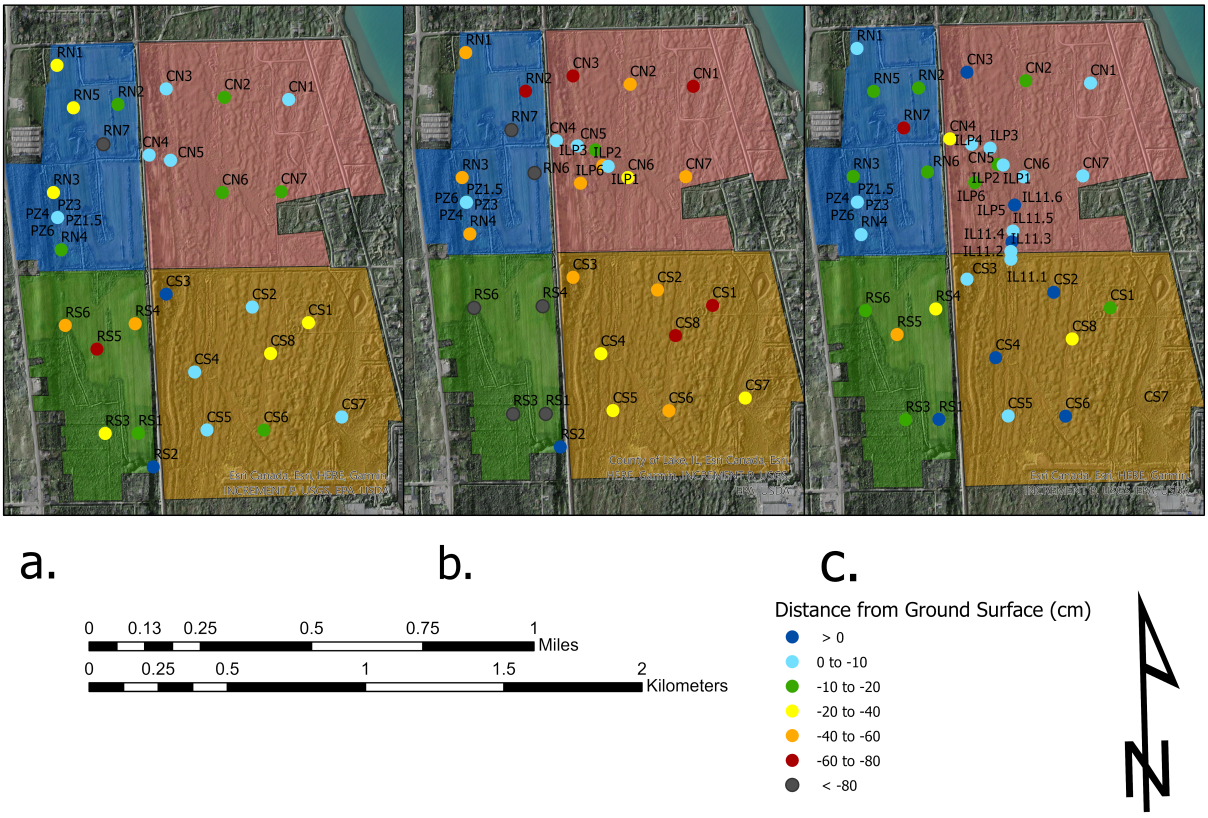


Figure 4.13 Maps showing the results of hand measurements throughout the year. a. Shows measurements from June; b. Shows measurements from August; and c. Shows measurements from October.

Figure 4.14 Water table elevation map showing the interpolated water table for 06/02/19 sampling trip. orange filled circles represent the points at where the water table was measured for interpolation. Dark blue lines represent 2-ft contours interpolated water table.

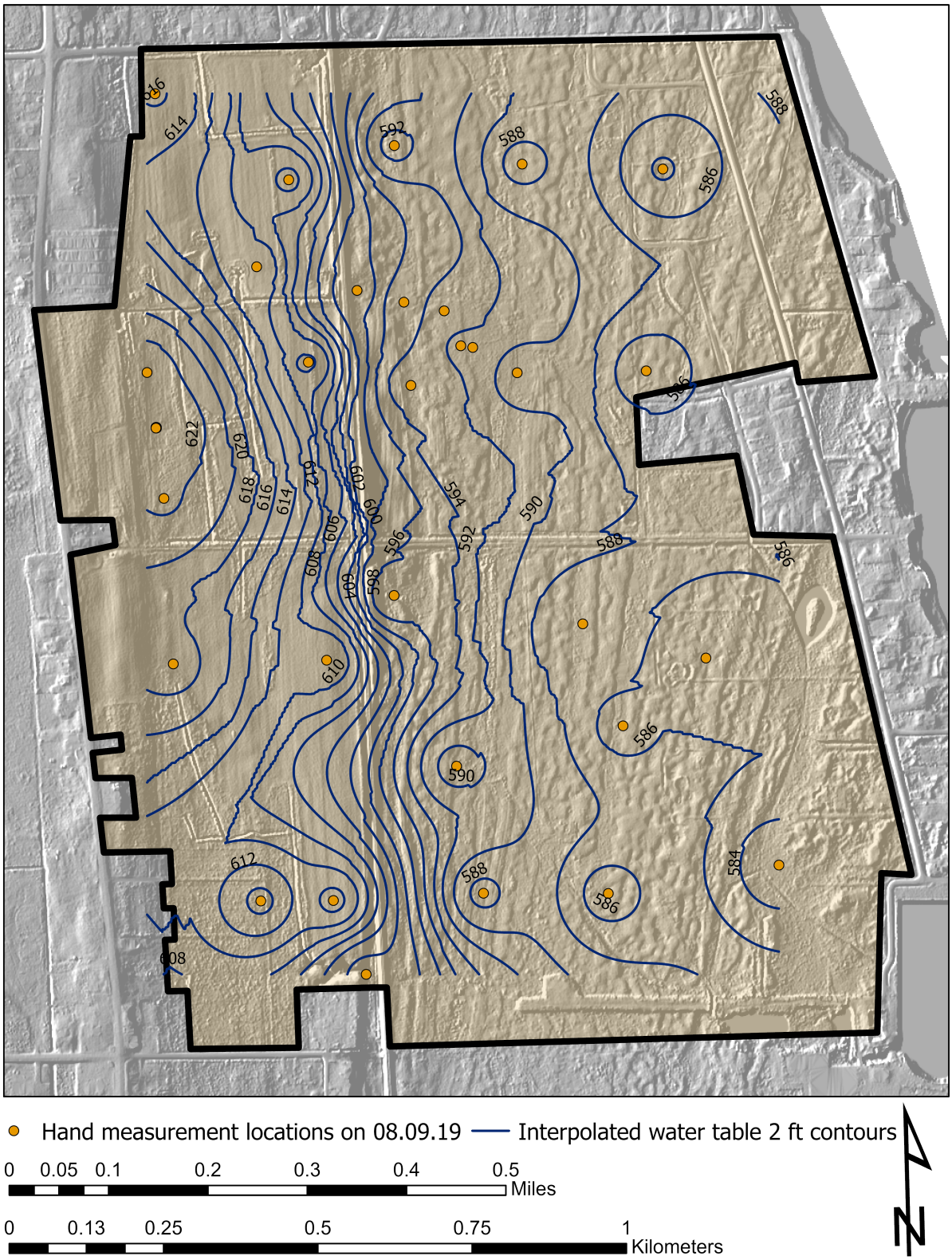


Figure 4.15 Water table elevation map showing the interpolated water table for 08/09/19 sampling trip. orange filled circles represent the points at where the water table was measured for interpolation. Dark blue lines represent 2-ft contours interpolated water table.

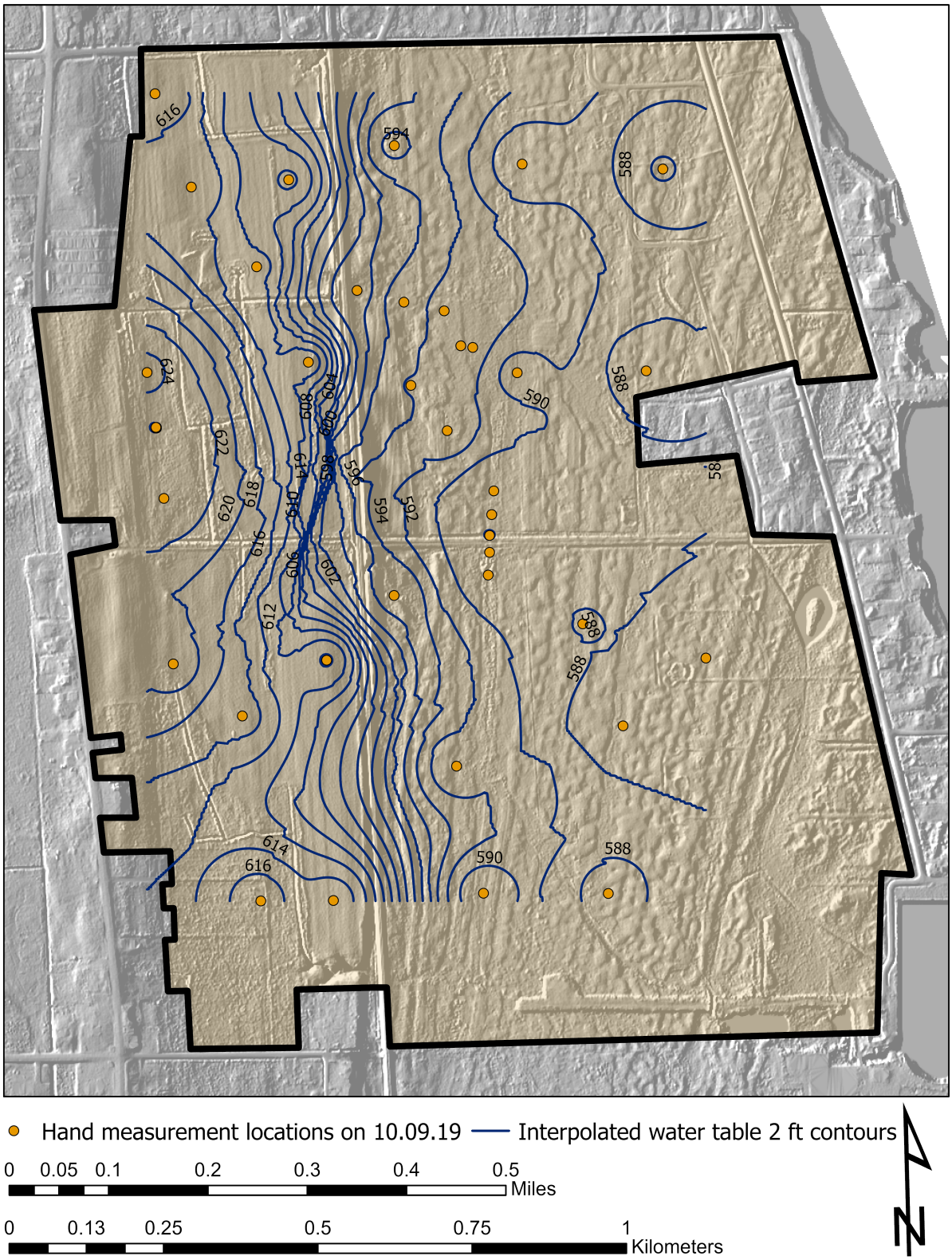


Figure 4.16Water table elevation map showing the interpolated water table for 10/09/19 sampling trip. orange filled circles represent the points at where the water table was measured for interpolation. Dark blue lines represent 2ft contours interpolated water table.

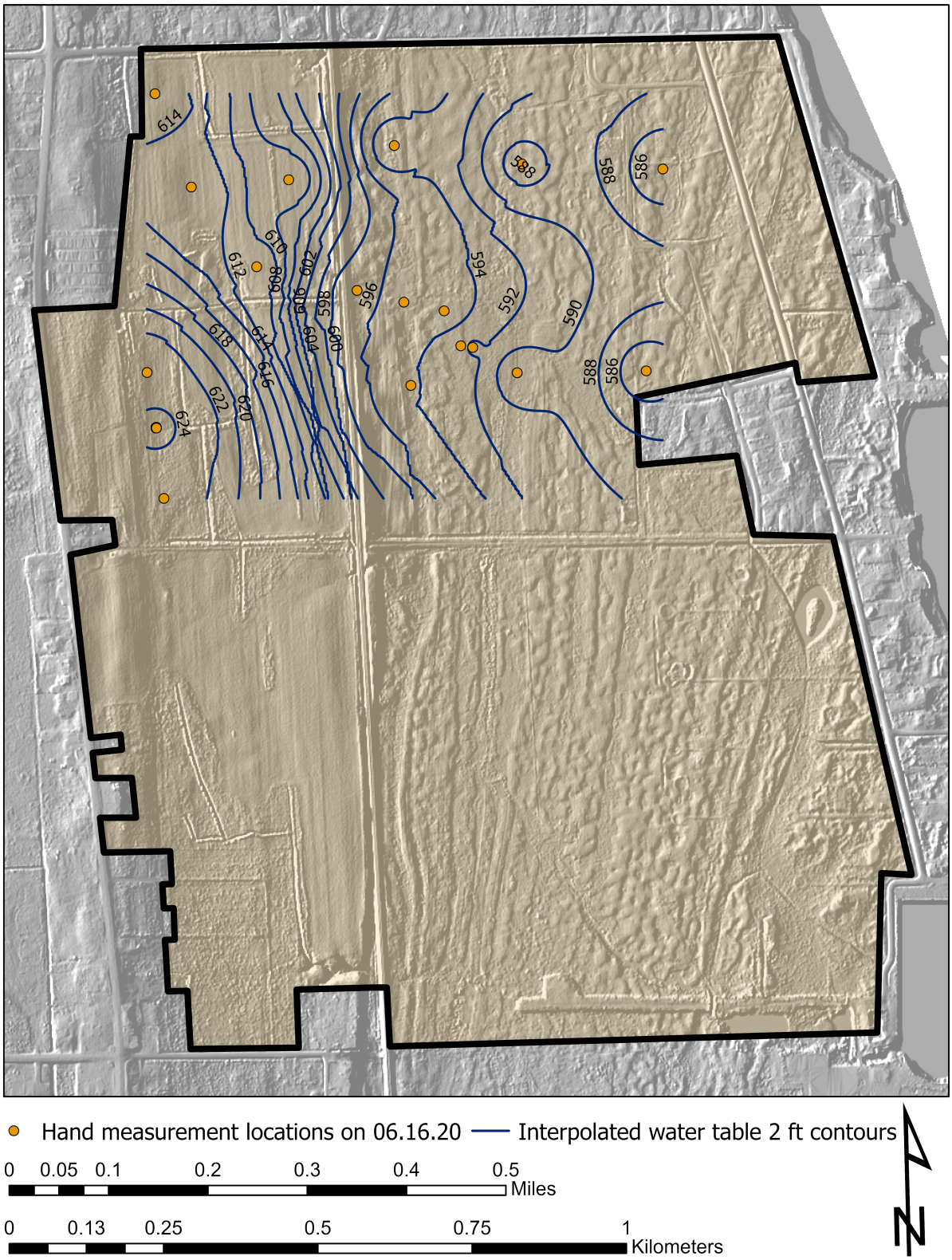


Figure 4.17 Water table elevation map showing the interpolated water table for 06/16/20 sampling trip. orange filled circles represent the points at where the water table was measured for interpolation. Dark blue lines represent 2-ft contours interpolated water table.

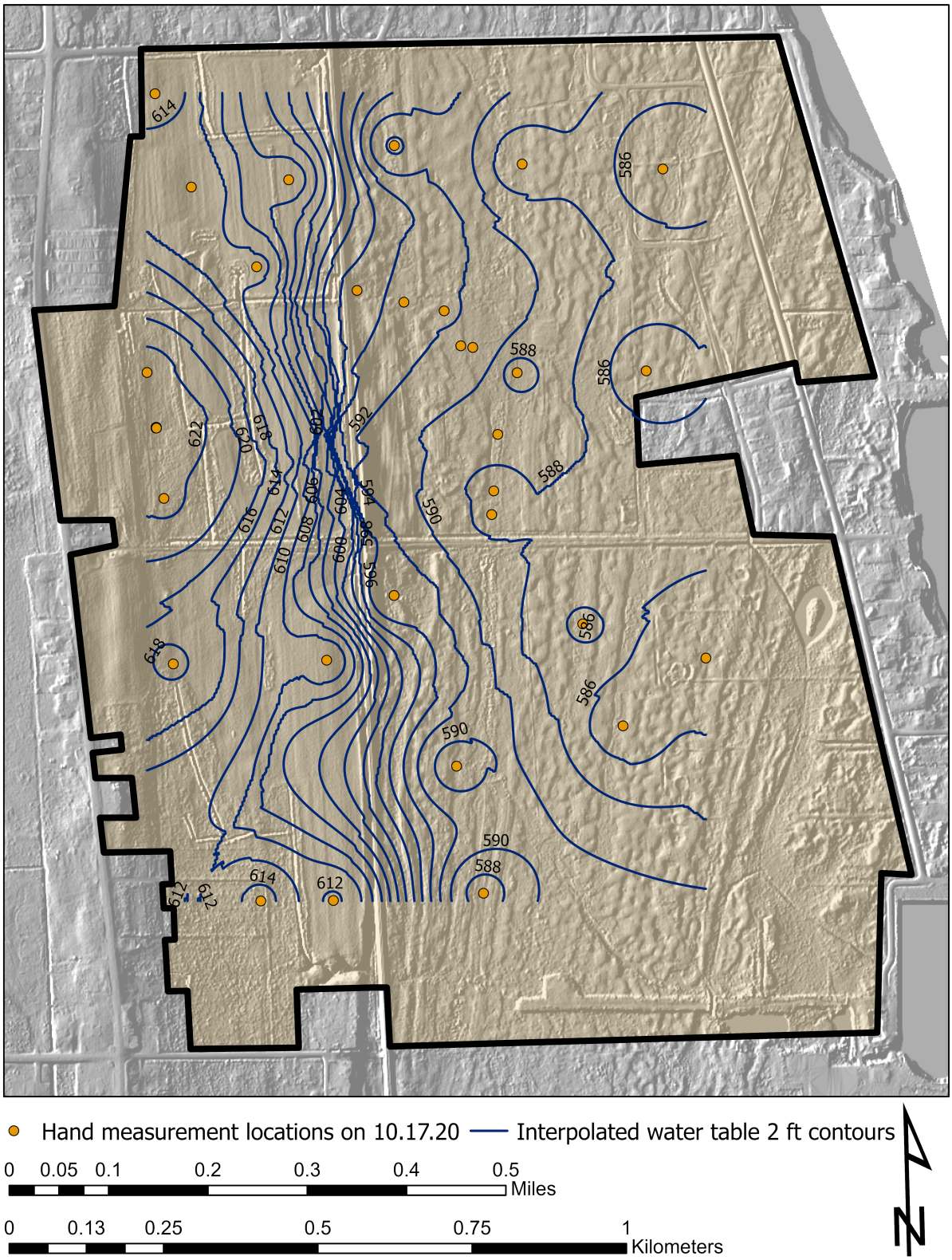


Figure 4.18 Water table elevation map showing the interpolated water table for 10/17/20 sampling trip. orange filled circles represent the points at where the water table was measured for interpolation. Dark blue lines represent 2-ft contours interpolated water table elevation.

4.4.2 Complete-Season Water Levels Observed in Piezometers

The water table elevations were observed in several piezometers over the two seasons (figures 4.19-20). Both 2019 and 2020 showed wetter springs that dried during the summer and then experienced a wetter fall season, which is typical in the Great Lakes region. The hydrographs are shown herein as depth to the water table from ground surface. Water table trends can be looked at in many ways and this report presents the date both in water table elevation (Figures 4.21-24) and relative to ground surface (Figures 4.25-28). when looking at water table elevation across all the sites in figure 4.18-19 we can see that that the water table elevation drops from the restoration site to Chiwaukee Prairie. The interpolated potentiometric maps have also been made and are represented in Figures 4.13-17. Time-series plots of water table depths (Figures 10.17-10.25) show how different the shallow groundwater system responds in periods between rain events and at the start of the snow melt. The hydrographs are organized by subsite, which roughly corresponds with water table level and ground surface elevation, the northwest (RN) being the highest in elevation and the southeast (CS) being the lowest in elevation. A control piezometer, RN4, was installed in the small undeveloped area within the restoration site. This area is a remnant of the original wetland landscape and shows similar hydrographs to those in the northwest Chiwaukee Prairie subsite, CN. Because of the shallow depths to the water table, all the piezometers showed flashy responses to precipitation events; piezometers in the restoration site were flashier than those in the Chiwaukee Prairie.

The results from this research follow the same general trends from previous research in the study area (Higley, 2013; Kay et al., 2010; Skalbeck et al., 2008; Southeastern Wisconsin Regional Planning Commission, 2004). Each subsite's piezometers have their own characteristic behaviors. The water table in Chiwaukee Prairie is higher than the water table in the restoration site. The subsites wettest to driest are CS>CN>RN>RS, 2020 CN>RN. The piezometers in the restoration site have larger fluctuations Figures 25-28.

The subsites water levels wettest to driest were as follows CS>CN>RN>RS (2019), CN>RN (2020). The logger results for 2019 are shown in Figures 4.25-28, where each color represents a different piezometer. The black line represents precipitation in cm. The x-axis is time, while the y-axis is the distance to water table in the piezometer from the ground surface.
The relative positions of each piezometer were almost identical to the previous year. RN7 was wetter in 2020 relative to the other piezometers (Figure 4.10). In Figures 4.25a and 4.27, RN7 and CS1 respectably, have sections that are straight lines. These straight lines represent times when the loggers were turned off and no measurements were being taken. The subsites wettest to driest were as follows.

- In 2019 the RN piezometers wettest to driest were RN4, RN1, RN3, RN2 and then RN7.

- In 2020 the piezometers wettest to driest were RN4, RN7, RN1, and RN7. On a note, RN7 had a drain leaking for part of the year between July 1 and August 9.

- In 2019 the piezometers wettest to driest were CN5, CN4, CN6, CN3, and CN7. In 2020 the piezometers wettest to driest were CN5, CN6, and CN3.

- In 2019 the piezometers wettest to driest were CS4, CS5, CS3, CS1.
- In 2019 the piezometers wettest to driest were RS1, RS3 then RS6.

The piezometers in the restoration site were flashier than the ones in the prairie. The flashier piezometers tended to have faster water table drops and were generally dryer. These tended to be in the farm fields of the restoration site. Overall, the water levels in 2020 were lower than water levels in 2019. The water table acts as one would expect in a wet prairie and shows the same pattern as previous research. The water table was close to the surface early in the year, until around June, and then goes through episodes of drying which are punctuated by precipitation events. During these precipitation events, the water table quickly rises as the ground becomes saturated—then starts dropping quickly. This flashy response can be attributed to the high amounts of sandy loam at the surface of the restoration site and the sand at Chiwaukee Prairie. The results show that 2020 had lower water table levels everywhere except RN7. It expected that water level would be lower in 2020 as it saw higher temperatures and lower precipitation. These two stresses have great influence on water table levels and the vadose zone. Piezometer RN7 showing an increase in water table can be attributed to TNC restoration efforts. It makes sense that RN7 would have a large increase in water considering its position relative to the blocked drain tile and filled ditches.

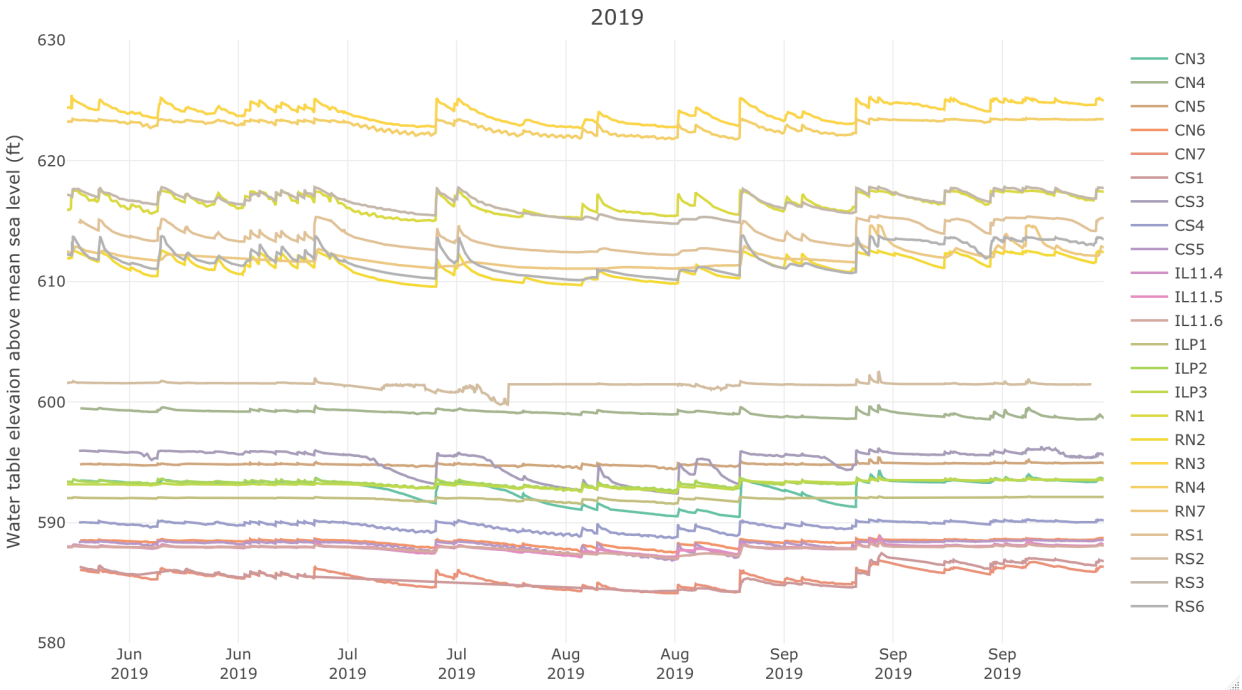


Figure 4.19 Graph showing water table elevation of piezometers in 2020.

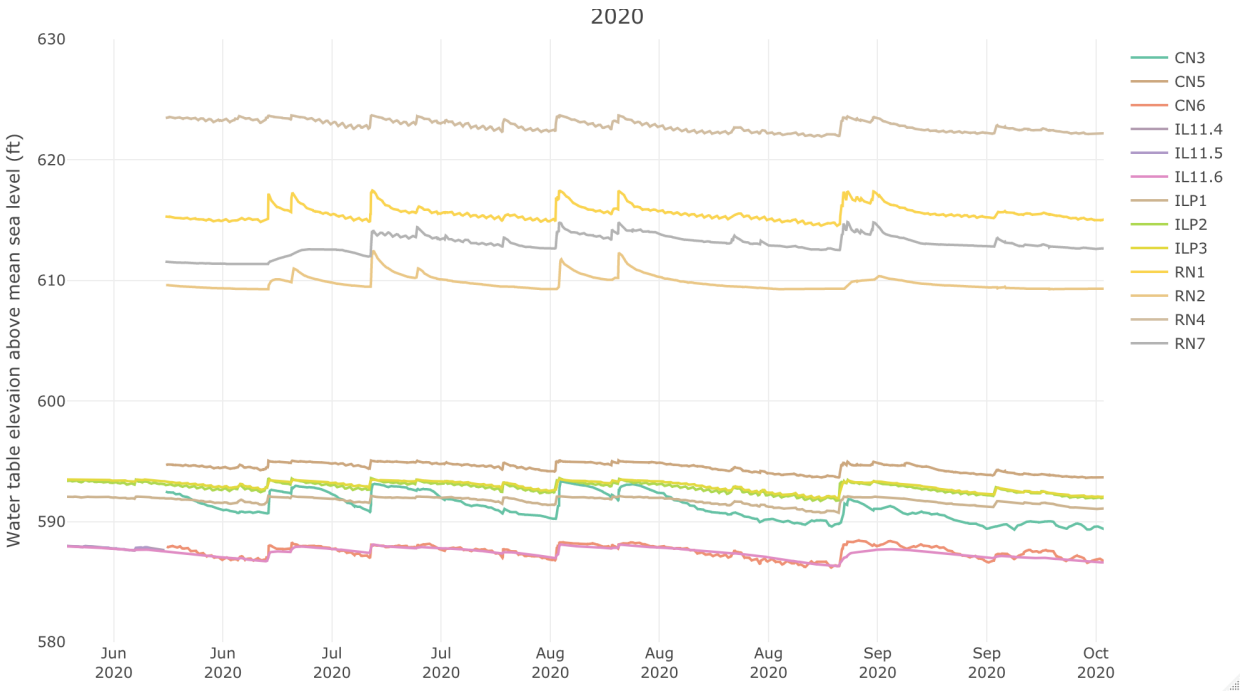
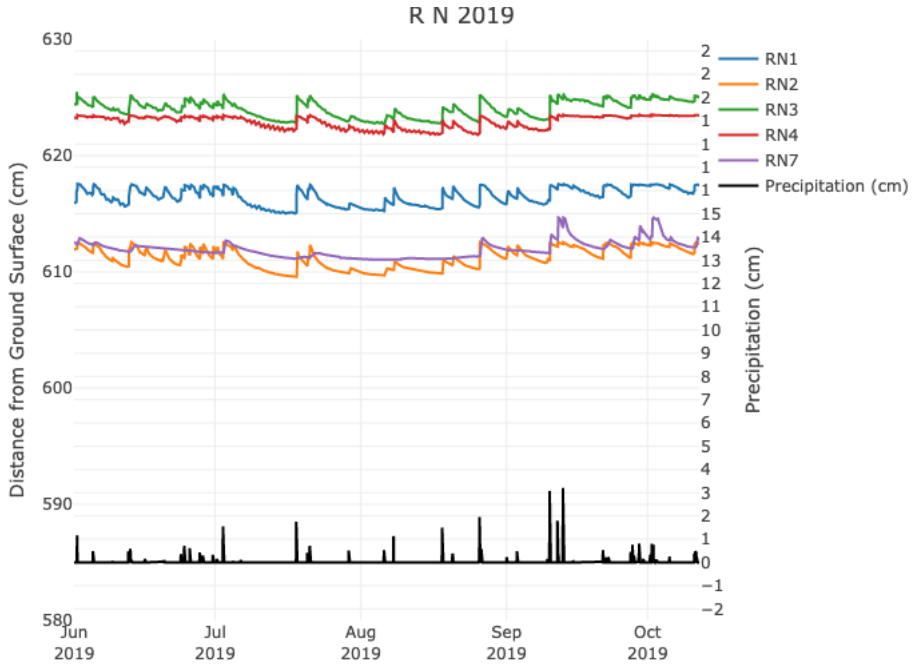


Figure 4.20 Graph showing water table elevation of piezometers in 2019.

A.



B.

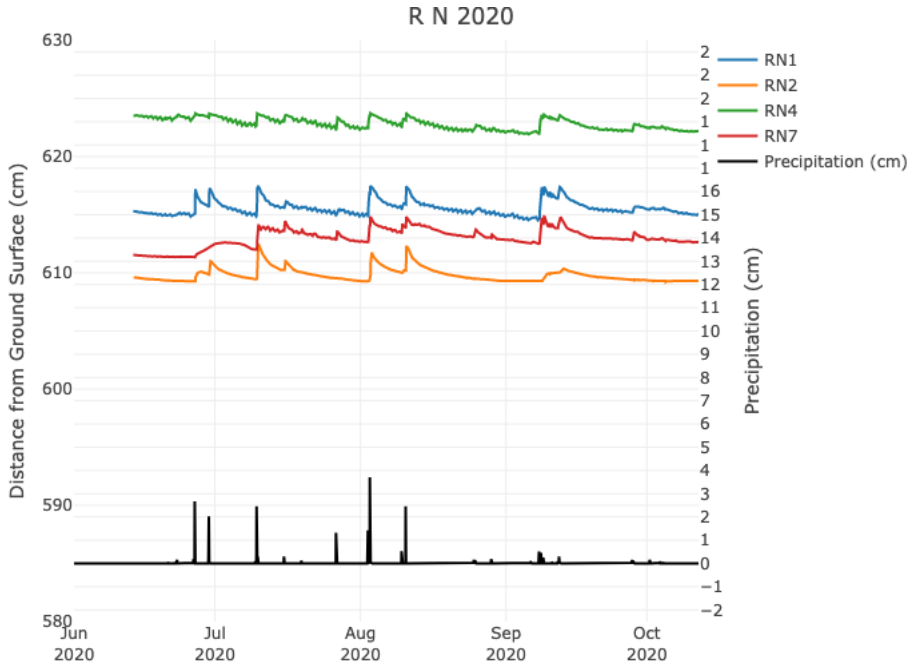
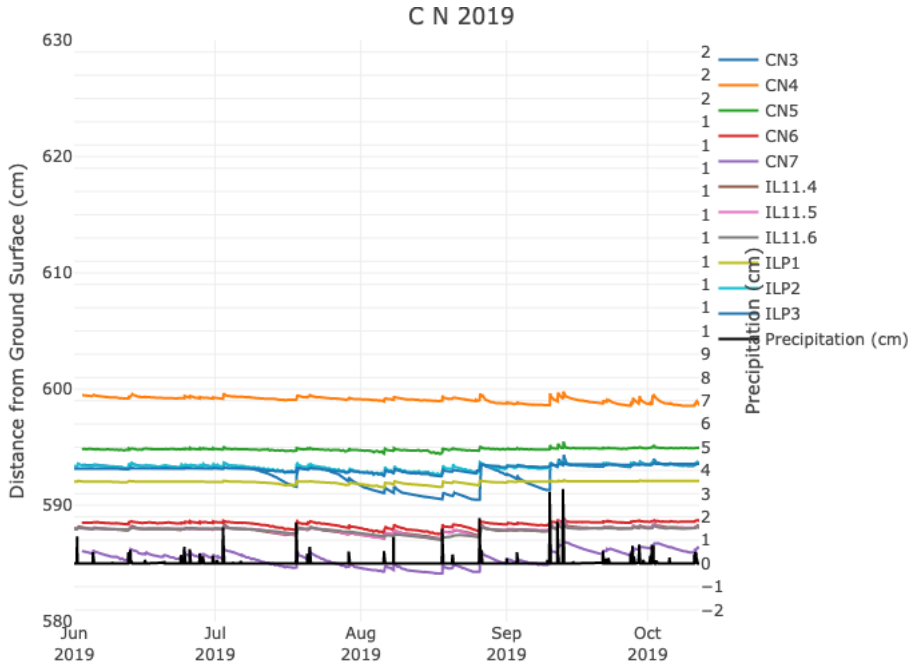


Figure 4.21 Water table elevation in piezometers in the northern section of the restoration site. a. 2019 field season RN1, RN2, RN3, RN4, and RN7. b. 2020 field season RN1, RN2, RN4, and RN7.

A.



B.

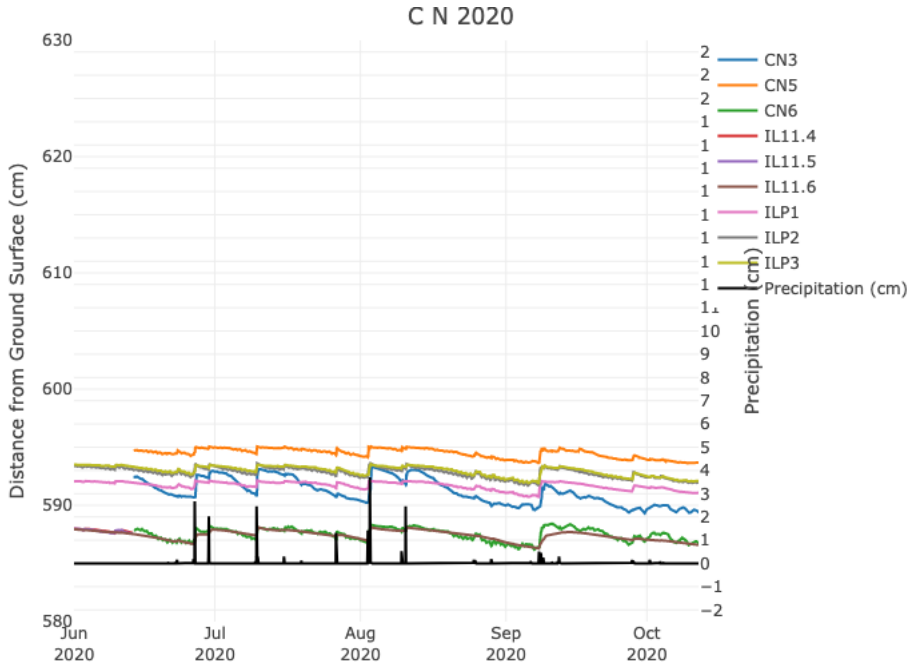


Figure 4.22 Water table elevation for the northern section of Chiwaukee Prairie: a. 2019 field season water depths in piezometers CN3, CN4, CN5, CN6, CN7, ILGS11.4, ILGS11.5 ILGS11.6 ILP1, ILP2, and ILP3; and b. 2020 field season water depths in piezometers CN3, CN5, CN6, ILGS11.4, ILGS11.5 ILGS11.6 ILP1, ILP2, and ILP3.

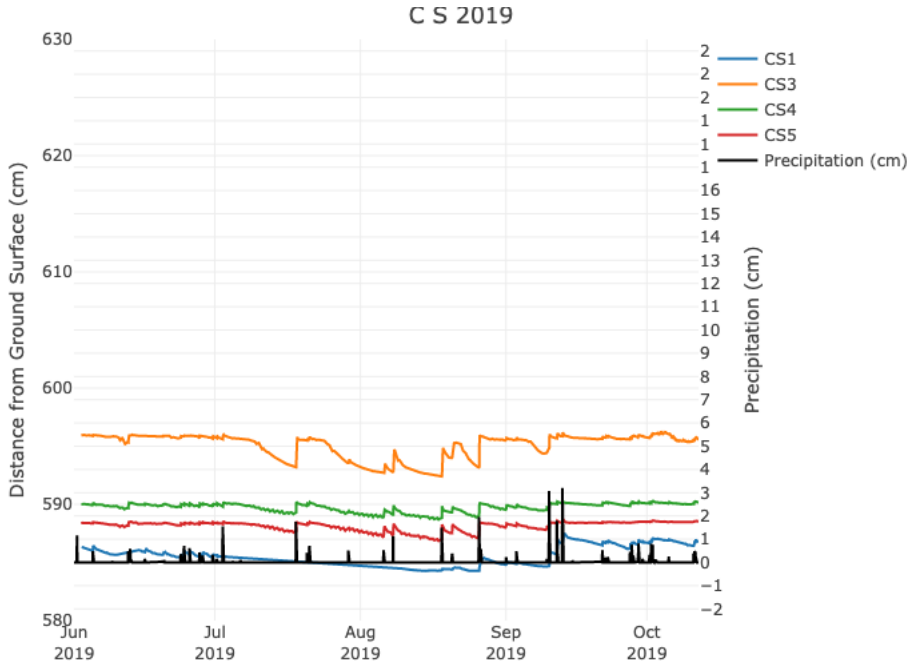


Figure 4.23 Water table elevation in piezometers CS3, CS4, and CS5 in the 2019 field season. CS1 experienced a 6-week span of no data between the July 1 and August 9.

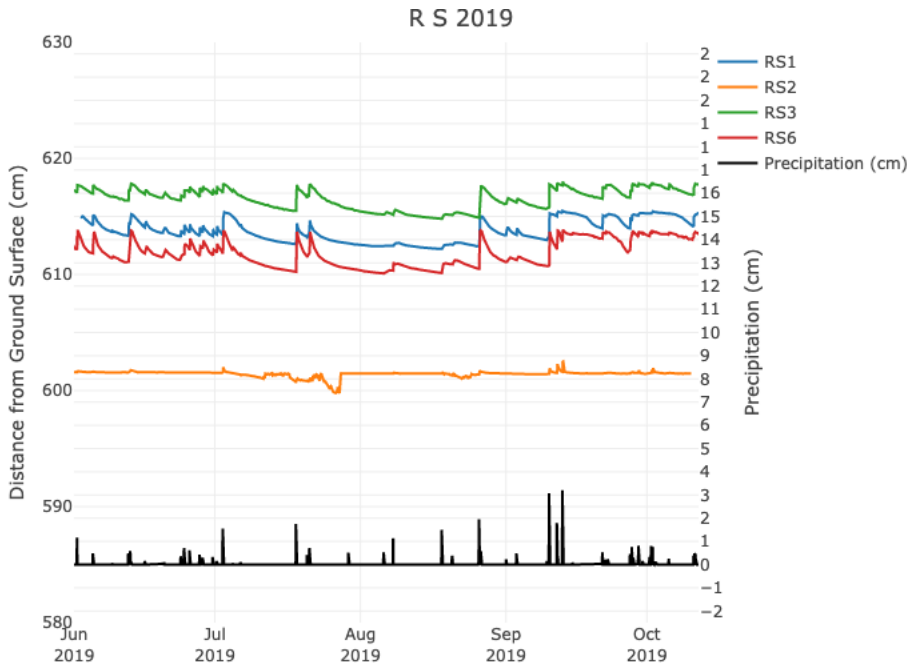
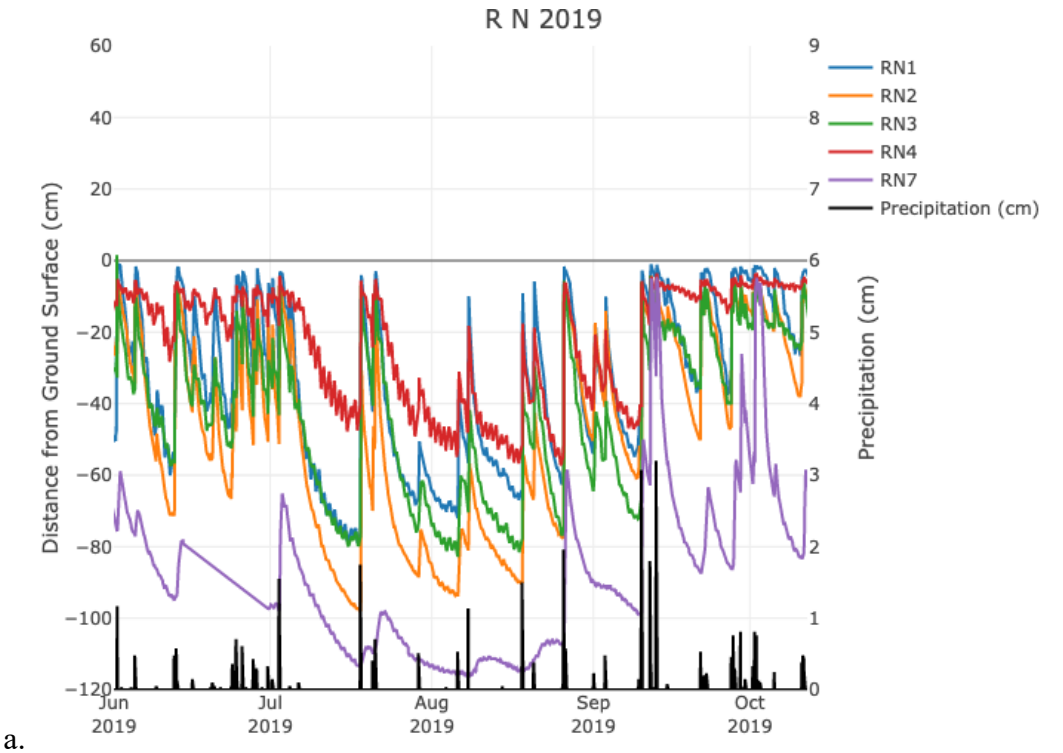
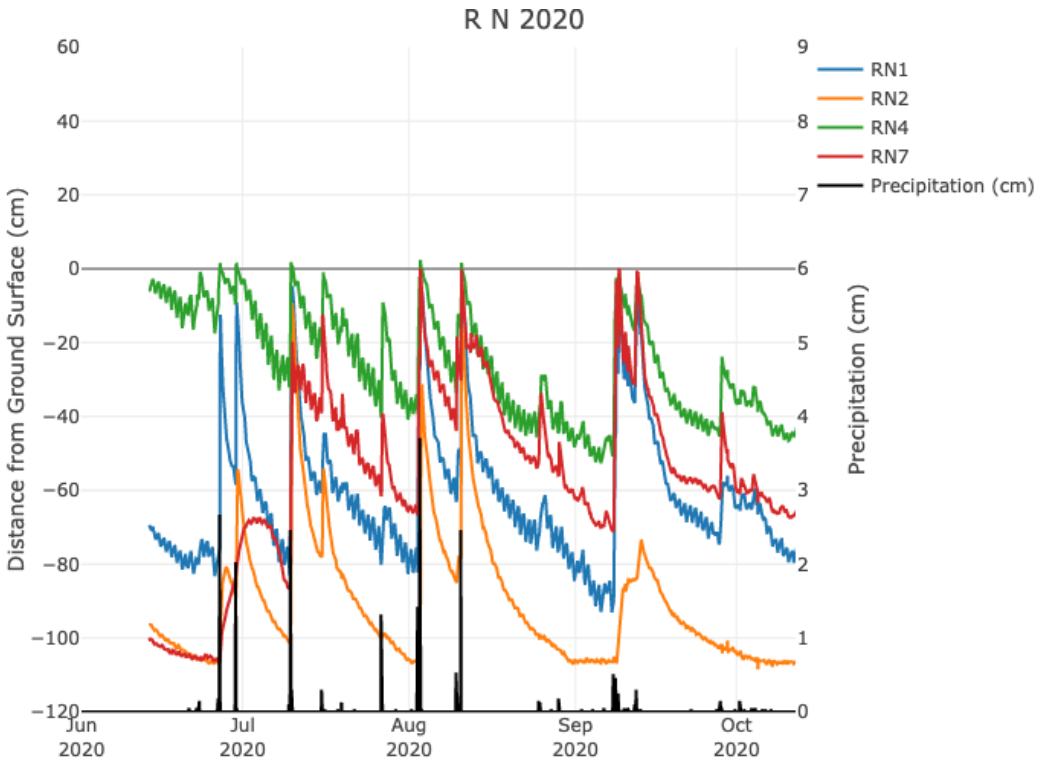


Figure 4.24 Water table elevation in piezometers RS1, RS3, and RS6 in the 2019 field season.



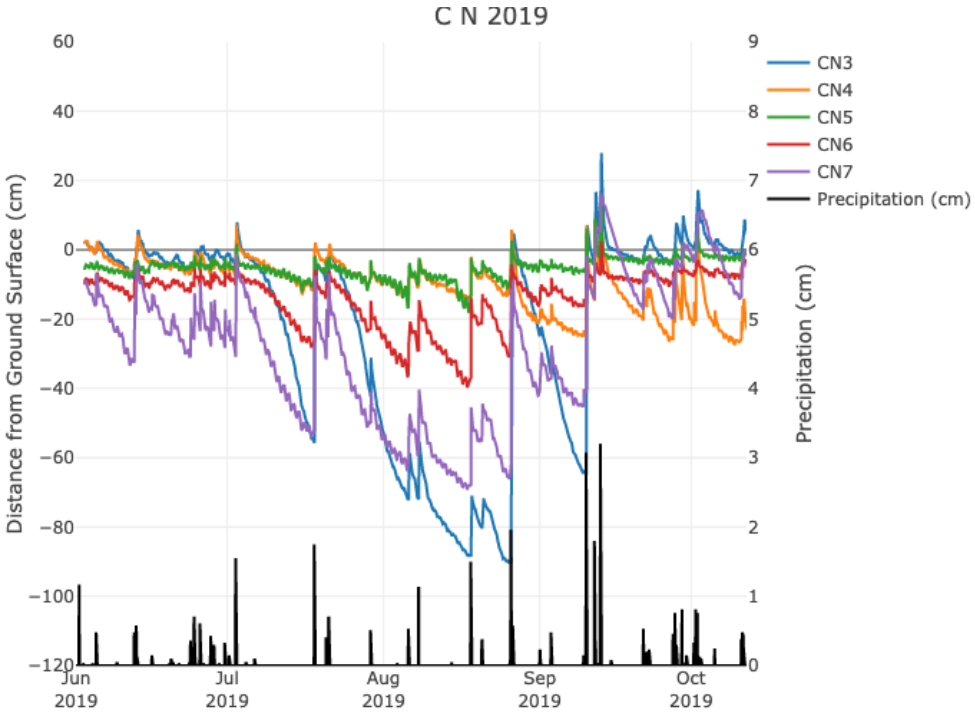
a.



b.

Figure 4.25 Water depths in piezometers in the northern section of the restoration site.
a. 2019 field season RN1, RN2, RN3, RN4, and RN7. b. 2020 field season RN1, RN2, RN4, and RN7.

a.



b.

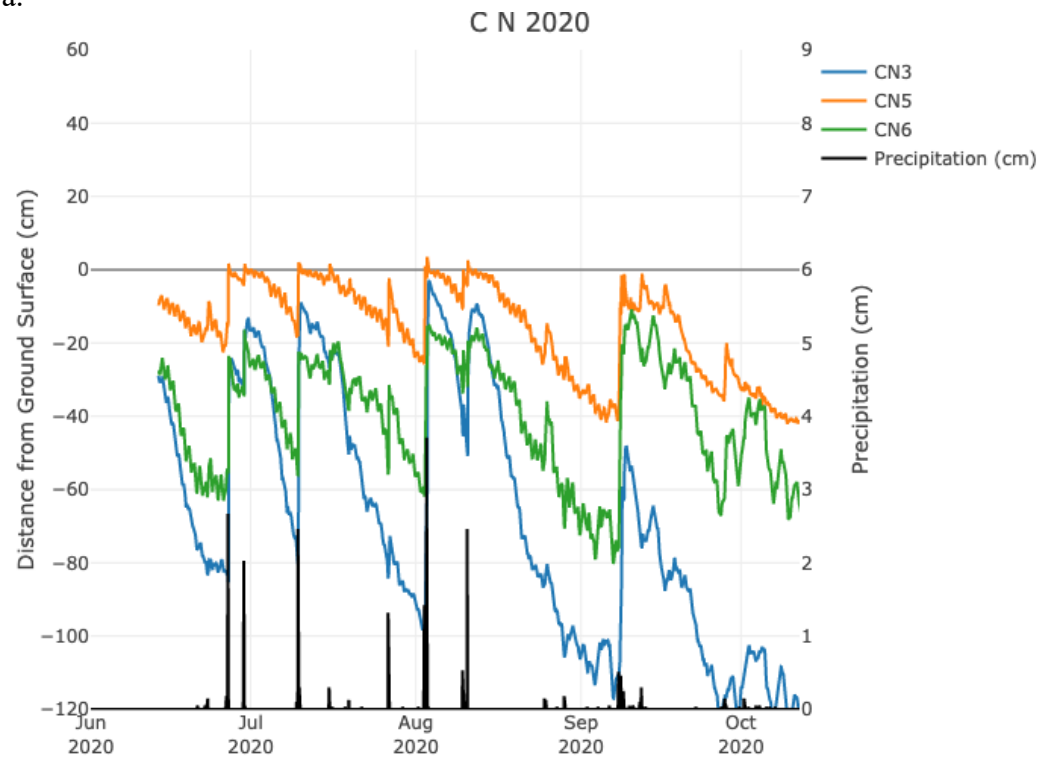


Figure 4.26 Water depths for the northern section of Chiwaukee Prairie: a. 2019 field season water depths in piezometers CN3, CN4, CN5, CN6, and CN7; and b. 2020 field season water depths in piezometers CN3, CN5, and CN6.

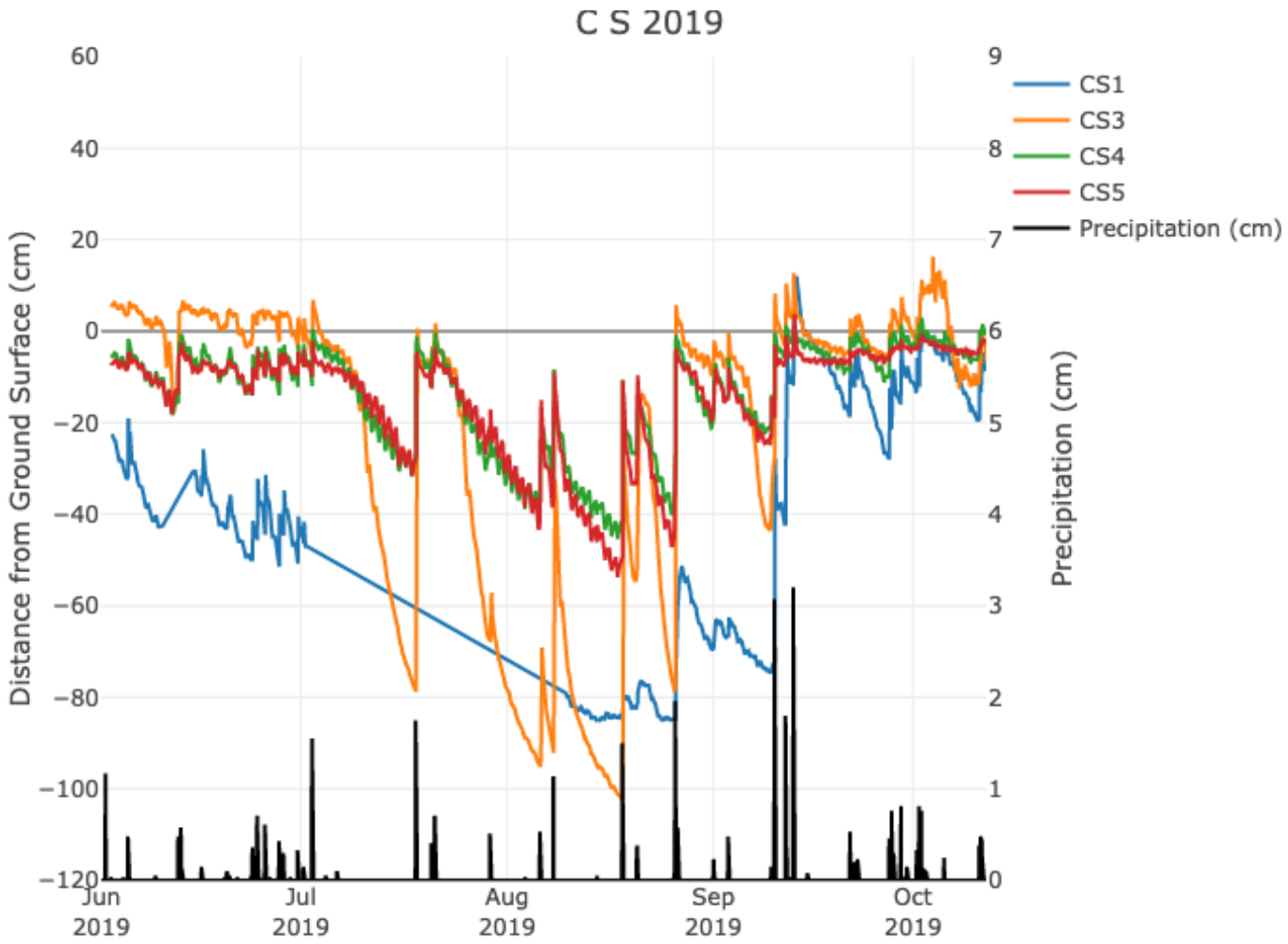


Figure 4.27 Water depths in piezometers CS3, CS4, and CS5 in the 2019 field season. CS1 experienced a 6-week span of no data between the July 1 and August 9.

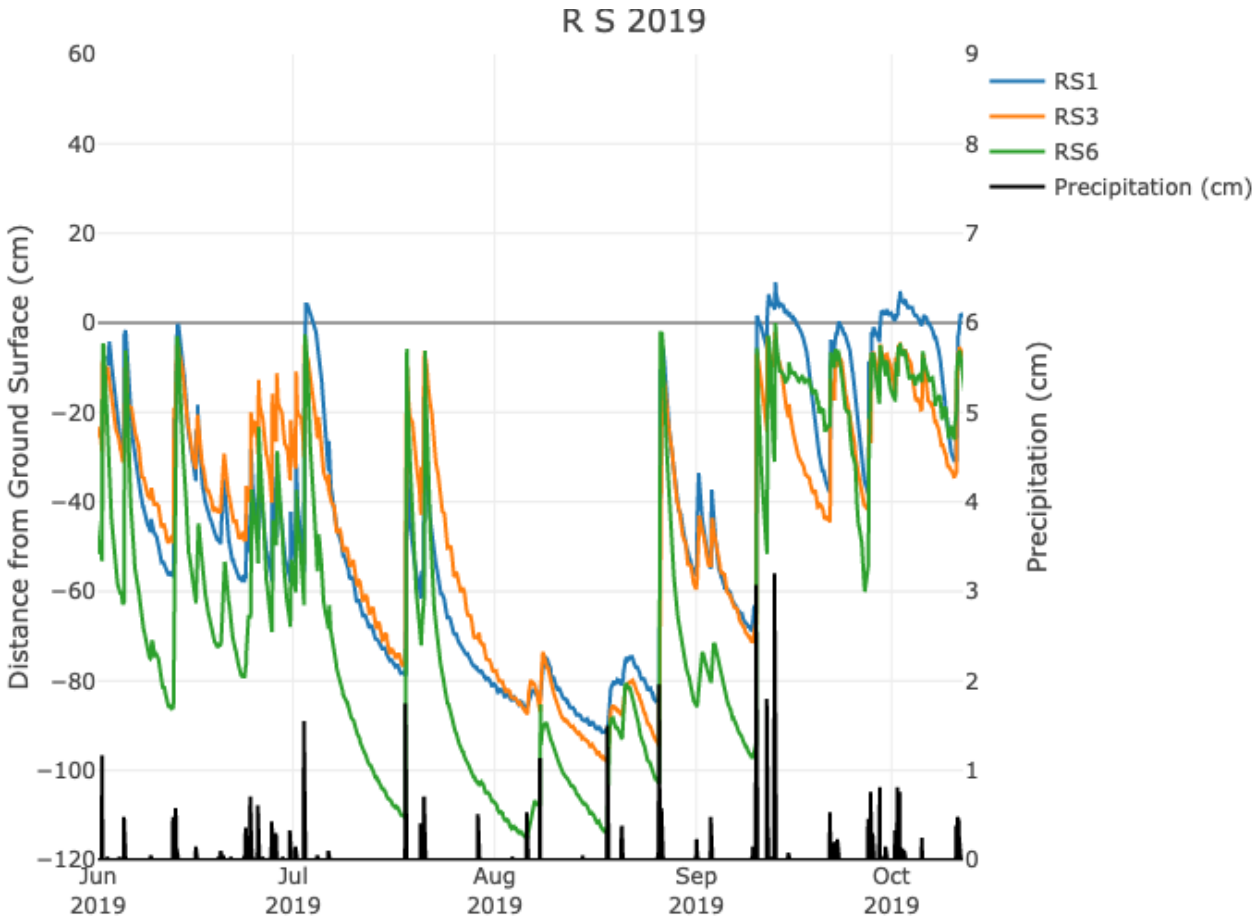
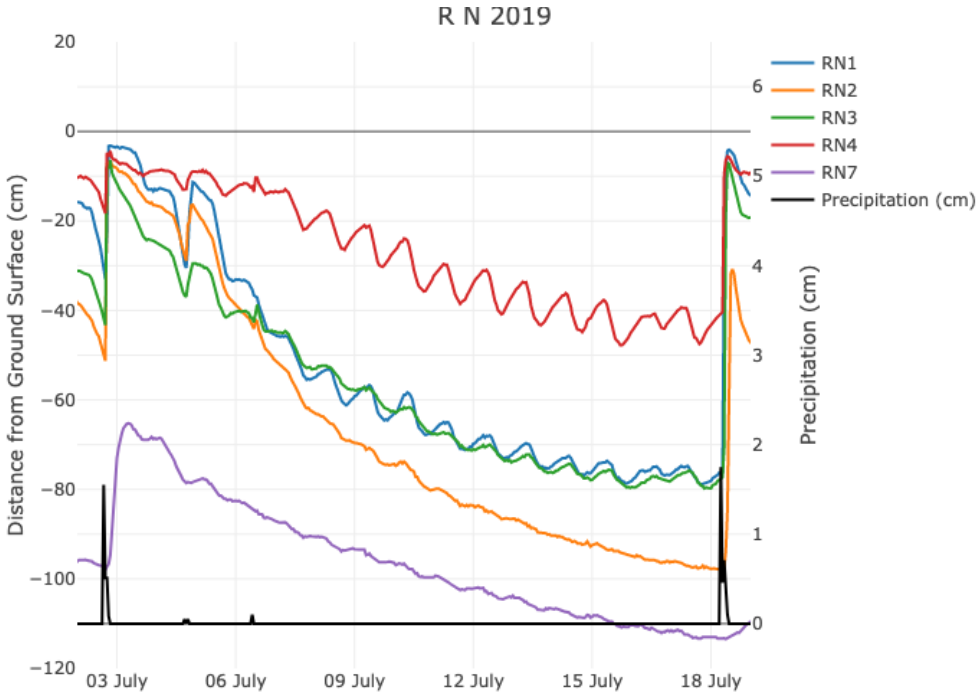


Figure 4.28 Water depths in piezometers RS1, RS3, and RS6 in the 2019 field season.

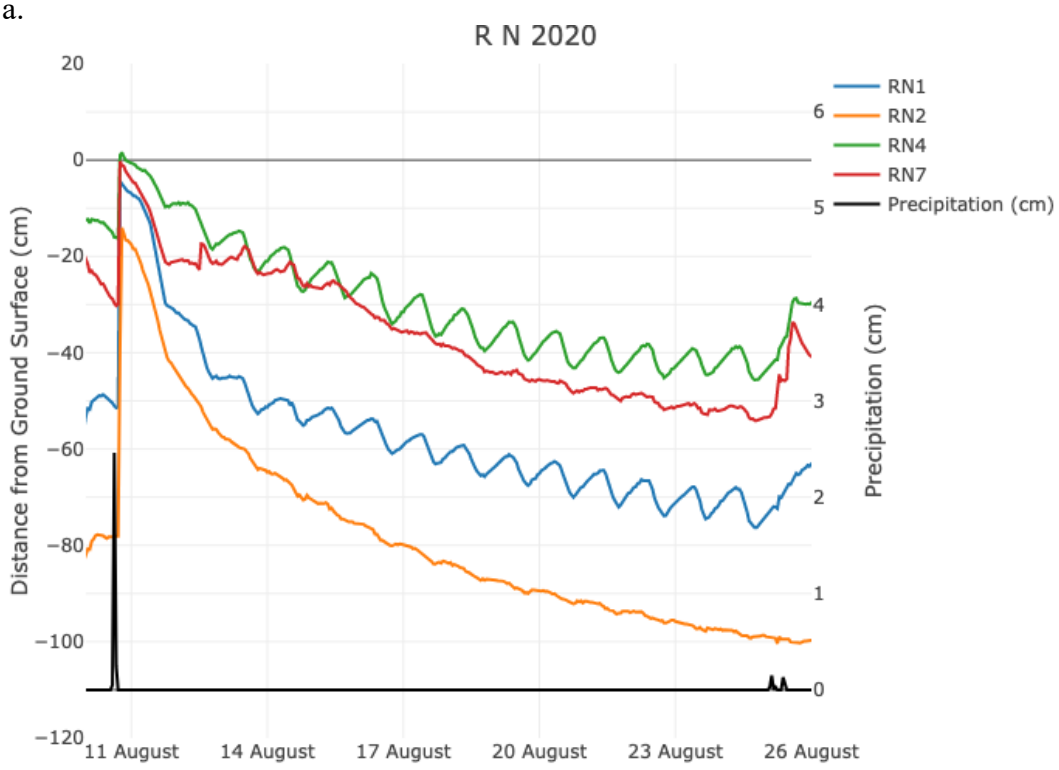
4.4.3 Example Water Levels for 2-Week Recession Periods

The water-level data for 2-week recession periods in 2019 and 2020 are displayed below. These periods are different calendar days but span the same duration between significant rainfall in each year. The 2019 season was rainier than 2020. One of the phenomena that was captured in these recession curves was diurnal variations. These variation are represent the diurnal activity of plant and in previous research (Skalbeck et al., 2008). Almost all of the piezometers showed diurnal changes to varying degrees. The diurnal variations were unique for each piezometer and each year. Piezometers in areas with stripped vegetation (from the restoration site) showed muted variation compared to those with more vegetation coverage (Figure 4.29 – 32) The daily variations demonstrate the effect of evapotranspiration by plants during the daytime and are more pronounced when the water table is nearest the surface. Each color represents a different piezometer color; the black line represents precipitation in cm.

When examining the hydrograph each displays a unique drying curve for each piezometer and for each year. The results show similarities between subsites. Chiwaukee piezometers are wetter and dry slower. The areas with more vegetation show greater diurnal variation. Piezometers in the less vegetated restoration site show faster and more linear drops.

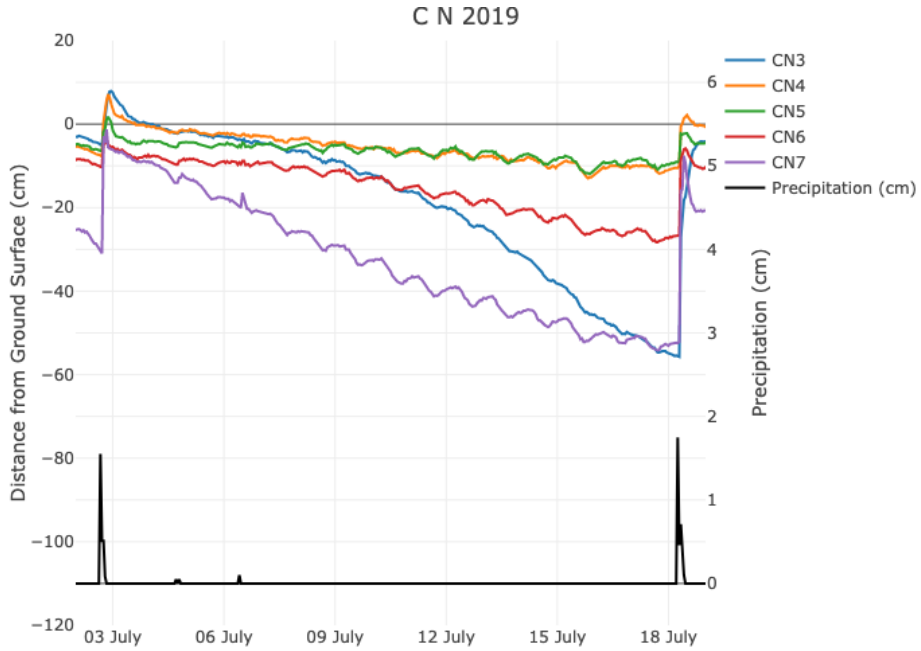


a.

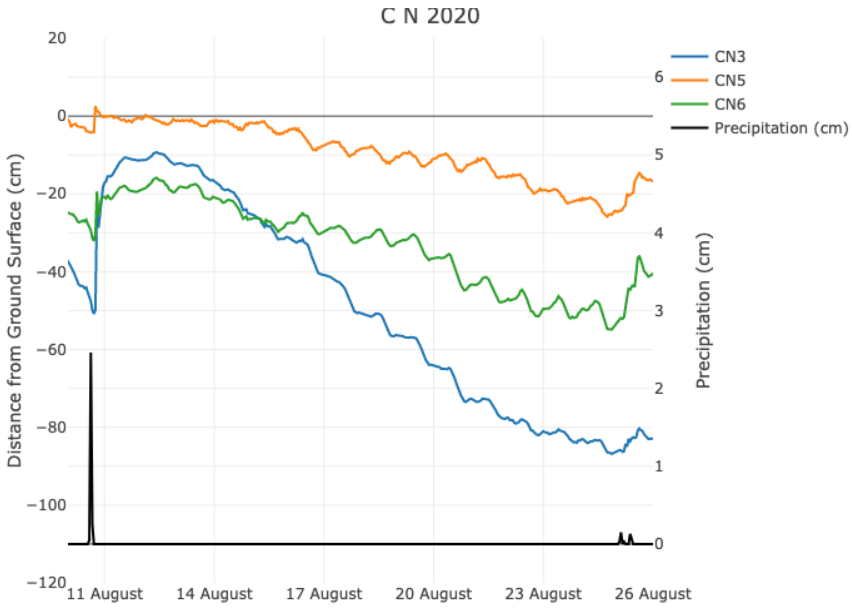


b.

Figure 4.29 Dry-period recession curves from the northern section of the restoration site from 2019 and 2020. a. Water depths in piezometers RN1, RN2, RN3, RN4, and RN7 in the 2019 field season during one 2-week recession period between rain on 3 July 2019 and then on 18 July. b. Water depths in piezometers RN1, RN2, RN4, and RN7 in the 2020 field season during one 2-week recession period between rain on 11 August 2019 and then on 26 August.



a.



b.

Figure 4.30 Dry-period recession curves from the northern section of Chiwaukee Prairie from 2019 and 2020. a. Water depths in piezometers CN3, CN4, CN5, CN6, and CN7 in the 2019 field season during one 2-week recession period between rain on 3 July 2019 and then on 18 July. b. Water depths in piezometers CN3, CN5, and CN6 in the 2020 field season during one 2-week recession period between rain on 11 August 20 19 and then on 26 August.

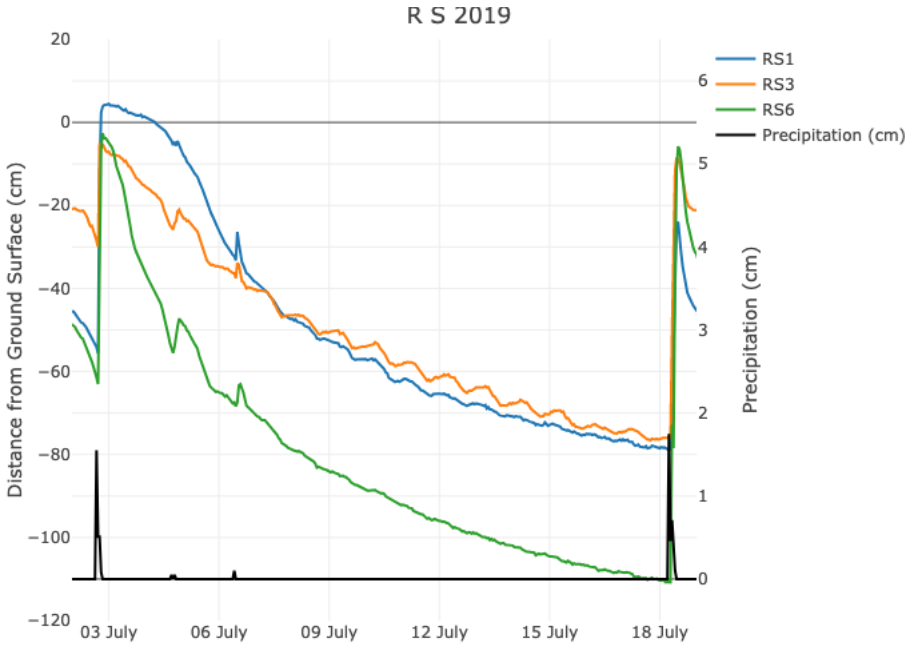


Figure 4.31 Water depths in piezometers RS1, RS3, and RS6 in the 2019 field season during one 2-week recession period between rain on 3 July 2019 and then on 18 July.

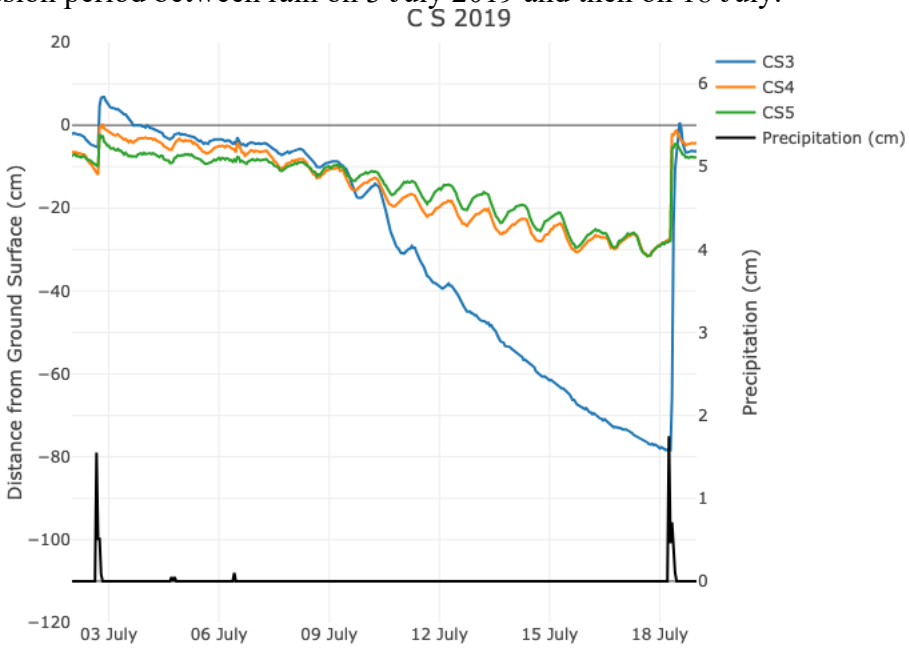


Figure 4.32 Water depths in piezometers CS3, CS4, and CS5 in the 2019 field season during one 2-week recession period between rain on 3 July 2019 and then on 18 July.

4.4.4 Regression Curve Analysis Results

The regression curve analysis allows for another method of comparison between the two years of data. A Master Recession Curve analysis method was used in this work to computationally orient all the recession curves to have a common starting point (peak water level) at the end of a rain event to evaluate the recession behavior using a common model. The regression curve analysis

has five outputs: maximum, minimum, mean, y-intercept, and slope. The maximum, minimum and mean represent the collective water table height at the beginning of each recession period. The y-intercept is the average starting height for the recession periods and the slopes represent the rate of drop in the water table. For this work, a linear recession model was fit to the hydrographs.

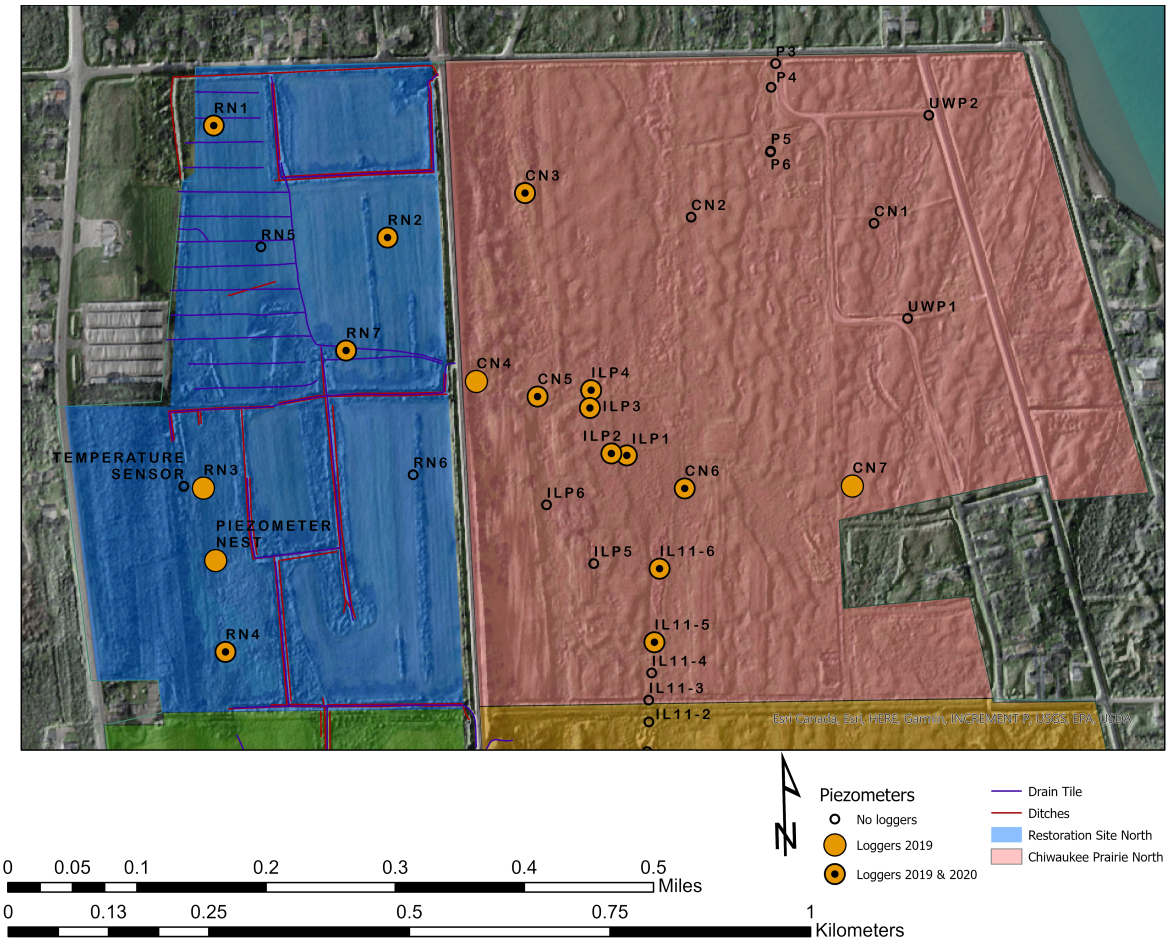
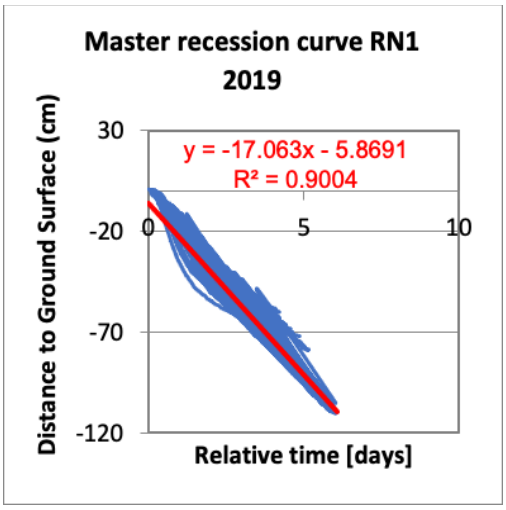


Figure 4.33 Map of the northern sections of the restoration site and Chiwaukee Prairie and the piezometer and pressure-transducer locations for 2019 and 2020.

a. 

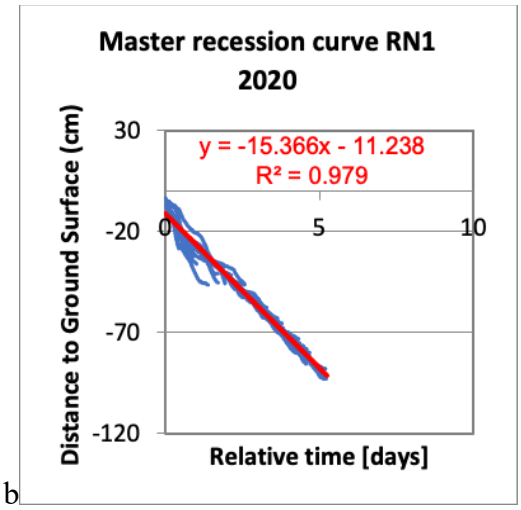
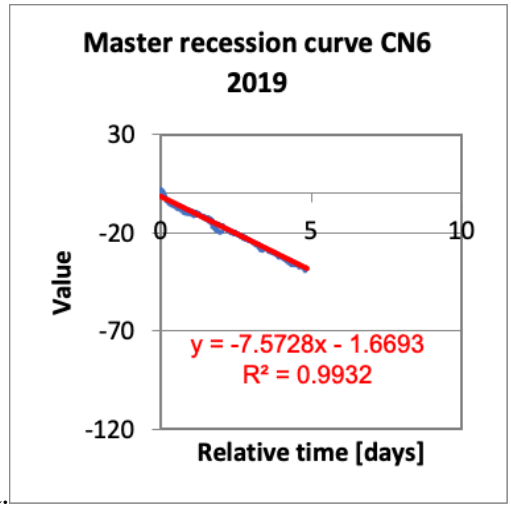
b 

Figure 4.34 Master recession curves for RN1 for 2019 (a) and 2020 (b).

a. 

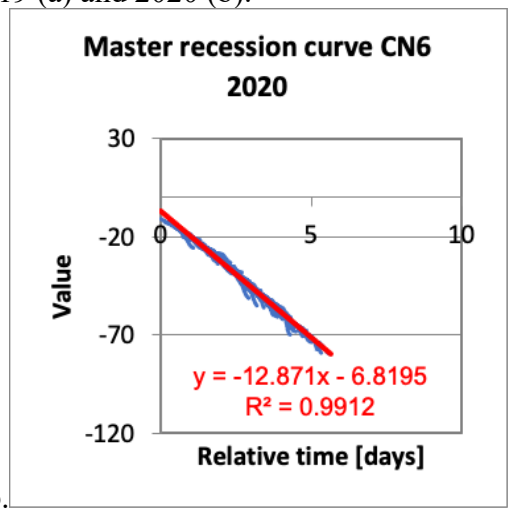
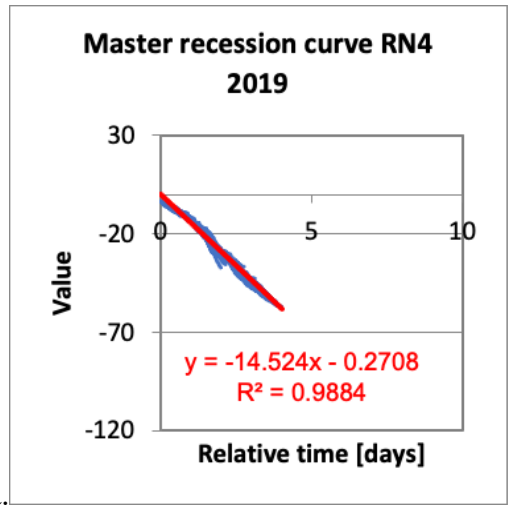
b. 

Figure 4.35 Master recession curves for CN6 for 2019 (a) and 2020 (b).

a. 

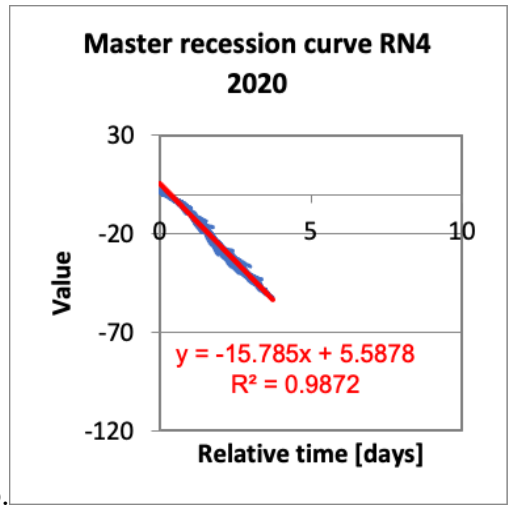
b. 

Figure 4.36 Master recession curves for RN4 for 2019 (a) and 2020 (b).

The maximum, minimum, and mean of each of the piezometers for the two years are shown in Table 4.2. The slopes and y-intercepts are summarized in Table 4.1 and the difference between the two years and shown in Table 4.3. Table 4.1 shows the minimum, maximum, and average values MRC analysis. Green denotes an increase in the fitted values between 2019 and 2020 data and red denotes a decrease. All restoration site piezometers, except RN4, showed a decrease in slope magnitude (because the slope reflects the rate of water level decline, all slopes are negative). Only CN3 did not experience a slope change between the seasons. The following piezometers showed an increase in slope magnitude and are ordered in most-to-least change in slope: CN6, P2, CN5, P1, P3, RN4. The other piezometers, CN3, RN2, RN1, RN7, experienced none or lesser changes in slope magnitude (a slower water table recession). The individual recession curves are compiled in the appendix.

Results from the MRC analysis could support the idea that the restoration increased the groundwater availability for Chiwaukee Prairie. When observing the difference in the 2019 and 2020 MRCs (Table 4.3) piezometer RN4 shows the same trend as the majority of Chiwaukee piezometers showing a faster drying speed (increase slope magnitude). RN4 is located within a emergent wetland hydrologically above the restoration and acts as the reference of what the natural restoration looks like. Piezometer CN3 showed the opposite reaction to all other Chiwaukee piezometers showing a decrease in drying speed (slope magnitude). Piezometer CN3's slope followed the trend of the restored restoration site piezometers (Table 4.3). This correlation of CN3 and the restoration site piezometers and RN4 and the Chiwaukee piezometers may show that the restoration is increasing the groundwater availability for Chiwaukee. There has been a greater effect from the restoration, but results are not conclusive because it would be basing the conclusion on only one piezometer. The MRC data shows changes in the restoration site piezometers along with CN3. This result suggests that CN3 has seen a slower drop in groundwater. CN3 is the piezometer closest to the restoration site and sits directly in the presumed groundwater flow path. RN4 is the control piezometer and sits hydrologically above the restoration. CN3 followed RN1,2,7 in showing a decrease in slope magnitude where the rest of the piezometers showed an increase in slope magnitude. This suggests that CN3 showed slower drying than the previous year. The increase in the slope may also be from the lack of input combined with similar temperature.

Table 4.1 shows the master recession curve y-intercepts and slopes for the piezometers used in both 2019 and 2019. y-intercepts relate to the maximum water level relative to ground surface while the slopes represent the speed of drying.

ID	Y-intercept		Slope	
	2019	2020	2019	2020
CN3	17.75	3.63	-8.93044	-8.52987
CN5	2.90	3.10	-8.02312	-10.07715
CN6	-1.67	-6.82	-7.57275	-12.87118
P1	3.06	3.37	-2.47226	-4.04140
P2	6.95	4.76	-5.65966	-7.99486
P3	2.50	0.19	-2.25932	-3.78397
RN1	-11.64	-11.24	-16.69716	-15.36560
RN2	-3.43	-25.17	-15.58385	-14.27566
RN4	-0.27	5.59	-14.52447	-15.78471
RN7	-11.64	7.81	-16.69716	-14.16968

Table 4.2 Results from the master recession curve analysis displaying minimum, maximum, and average values in cm relative to ground surfaces.

	Min. value		Max. value		Average value	
ID	2019	2020	2019	2020	2019	2020
CN3	-85.82	-130.99	32.27	-3.11	-19.84	-68.76
CN5	-17.90	-42.07	13.51	3.51	-5.33	-16.12
CN6	-39.69	-80.24	2.33	-10.85	-14.50	-40.41
P1	-15.70	-40.40	3.50	2.70	-2.14	-11.56
P2	-25.60	-52.30	10.80	5.80	-4.44	-20.14
P3	-32.50	-49.00	6.50	0.60	-10.34	-18.89
RN1	-110.54	-93.06	0.91	-3.43	-83.11	-61.77
RN2	-94.43	-108.46	-2.86	-9.24	-45.13	-90.90
RN4	-57.16	-52.68	-3.43	2.39	-24.09	-25.61
RN7	-110.54	-97.55	0.91	15.95	-83.11	-41.21

Table 4.3 Comparing the change in master recession curves between 2019 and 2020 seasons.

ID	Y-intercept	Slope	Min. value	Max. value	Average value
CN6	-5.15	-5.30	-40.55	-13.18	-25.91
P2	-2.18	-2.34	-26.70	-5.00	-15.70
CN5	0.20	-2.05	-24.17	-10.00	-10.79
P1	0.31	-1.57	-24.70	-0.80	-9.42
P3	-2.31	-1.52	-16.50	-5.90	-8.56
RN4	5.86	-1.26	4.49	5.81	-1.52
CN3	-14.12	0.40	-45.17	-35.38	-48.92
RN2	-21.74	1.31	-14.02	-6.37	-45.77
RN1	0.40	1.33	17.49	-4.34	21.34
RN7	19.45	2.53	13.00	15.04	41.90

4.5 Challenges

Many problems were overcome during this project. It took place during the COVID-19 pandemic when there were several restrictions in travel, sampling, and use of facilities during the second field season. Piezometer RS2, in the southeast corner of the restoration site, was vandalized and a broken transducer and data was received. It was found to be inaccurate, and the dataset was removed from analysis. There were two incidents of transducers being mis-programmed during routine collection. These incidents caused gaps in data from RN7 and CS1. Another instance of equipment trouble was one of the two pH meters used malfunctioned and the results from that day are skewed. In the second field season a lawnmower destroyed RN7.

5 Conclusions

This research provides a better understanding of how the shallow aquifers respond seasonally in the Chiwaukee Prairie wetland complex. It shows the different results that can occur year to year with changing conditions. It shows the difference that restoration can have on individual wells. The study area is an evolving wetland, and its managers modify the environment to change it to their vision of what the landscape should be. The 2019 and 2020 water level results of the northern subsites show that the attempts of The Nature Conservancy to modify the environment have been successful so far.

Returning to the research questions:

- How did the water levels change during the study?
    - The water levels decreased overall from 2019 to 2020. Both years showed high water levels in spring, then a drop in the summer, and then rose again in the fall.

- What affected the prairie's groundwater?
    - Precipitation played a large role in the water level of the wells.
    - The restoration had direct effect on the water table of the restoration site.

- Can you see a direct correlation between the restoration and the water levels?
    - The restoration has shown an increase in the water availability. This was seen through the change in master recession curves slope magnitudes (or slower drying rates) in the majority of the restoration site piezometers. This is seen in Table 4.3 and shown in Figure 5.1. This decrease in drying rate was not uniform though. All the Chiwaukee piezometers (excluding CN3) and RN4 showed the opposite result and had faster drying rates. Of the Chiwaukee piezometers, only CN3 saw a decrease in drying speed despite matching the other trends of the Chiwaukee piezometers. The evidence that supports these ideas is linked to the control piezometer RN4 and CN3 behavior. While this might hint at interactions, the limited data is not conclusive

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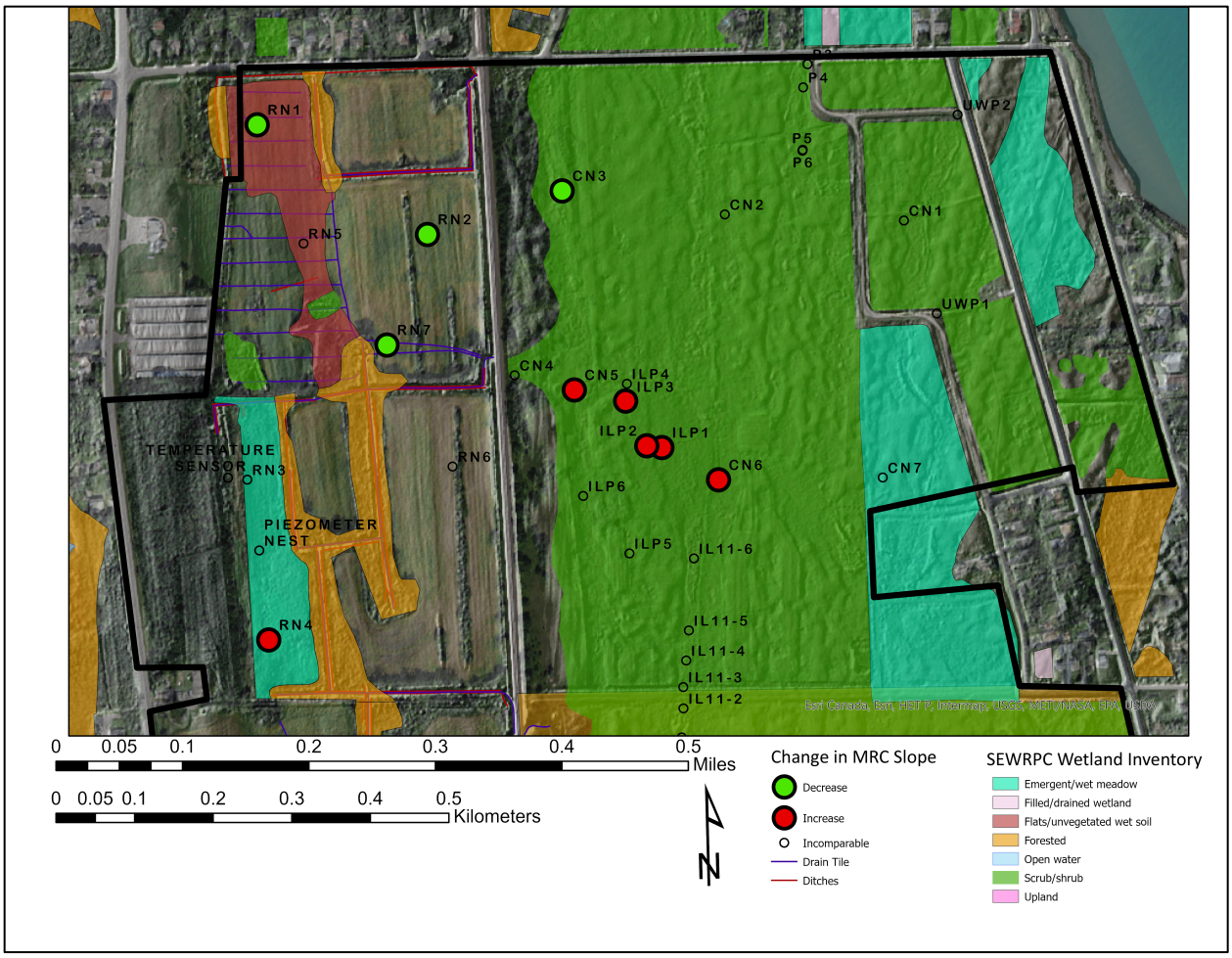

Figure 5.1 Map of the study area showing the piezometers that showed a decrease in master recession curve (MRC) slope in green (slower drying rate), an increase in red, and empty circles where piezometers that were not comparable because the piezometers did not have loggers both years.

This research has added a great deal of value to the Chiwaukee Prairie study area. It vastly increases the hydrologic data available to land managers and researchers. It expanded the hydrologic monitoring capacity of the study area, more than doubling the number of piezometers available. The data and new piezometers can be used for many additional studies in the prairie. In addition, this characterization of the water tables has never been looked at in such a large scope and in so much detail. While this report does not equivocally show that The Nature Conservancy's restoration increased the groundwater to Chiwaukee Prairie, it does provide a plethora of data that have not been seen from Chiwaukee in a decade. More work needs to be done to understand the hydrologic connection between the restoration site and Chiwaukee Prairie. However, this report acts as the most recent reference for land management and new research.

6 Reference List

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A Additional Information

A.1 Accuracy of Units

This is an acknowledgement of the accuracy of each device used in this research.
Pressure transducers
Typical error: ±0.05% FS, 0.5 cm (0.015 ft) water
Maximum error: ±0.1% FS, 1.0 cm (0.03 ft) water
YSI 63
pH
± 0.1 pH unit Conductivity
Temperature
± 0.1°C
Conductivity
± 0.5% FS
The Solinstwater level meter was read to 0.01 ft. The pressure transducers are accurate to ±0.05% full scale (FS), 0.5 cm (0.015 ft) water and a maximum error: ±0.1% FS, 1.0 cm (0.03 ft) water.
The YSI 63 pH ± 0.1 pH, Temperature ± 0.1°C, Conductivity ± 0.5% FS.

A.2 Reports

A.2.1 GPS Calibration Report

GPS Calibration Report

Job name:	CP Wells	**Trimble General Survey version:**	19.10
Creation date:	2019-10-09	**Distance/Coord units:**	US survey feet
Geoid model:			

Horizontal Adjustment Parameters

Northing coordinate of rotation center	191241.780sft
Easting coordinate of rotation center	2589479.611sft
Rotation about the center point	-1°29'48"
Translation north	69.747sft
Translation east	35.064sft
Scale factor	1.00002117

Vertical Adjustment Parameters

Northing coordinate of origin point	192610.928sft
Easting coordinate of origin point	2586837.636sft
Vertical separation at origin	113.741sft
Slope north	5.385ppm
Slope east	9.663ppm

Residual Differences Between GPS And Known Coordinates

Summary

	Maximum error	Root Mean Square error	Point
Horizontal	0.336sft	0.069	Ct3
Vertical	0.005sft	0.001	ct5
Three-dimensional	0.336sft	0.069	Ct3

Point Residuals

GPS point		Calculated point		Control point	
Point	Ct3	**Northing**	192610.928sft	**Point**	cs3
Latitude	42°30'26.91641"N	**Easting**	2586837.636sft	**Northing**	192610.630sft

Figure Calibration report from surveying all the piezometers

A.2.2 Wisconsin State Laboratory of Hygiene Chemistry Report

Wisconsin State Laboratory of Hygiene
2601 Agriculture Drive, PO Box 7996
Madison, WI 53707-7996
(800)442-4618 - FAX (608)224-6213
http://www.slh.wisc.edu

Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046001

Report To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405

Invoice To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405
Customer ID: 354700

Field #: RSN
Project No:
Collection End: 10/14/2019 10:56:00 AM
Collection Start:
Collected By: NICHOLAS POTTER
Date Received: 10/14/2019
Date Reported: 11/11/2019
Sample Reason:

ID#: NA
Sample Location: AL KAMPERT TRAIL, PLEASANT PRAIRIE, WI 53158
Sample Description:
Sample Type: SU-SURFACE WATER
Waterbody:
Point or Outfall:
Sample Depth:
Program Code:
Region Code:
County: 30

Sample Comments

ACID TRACEABILITY INFORMATION NOT SUBMITTED WITH TEST REQUEST FORM

Analyzed past the 15 minutes holding time: Method SM4500-H+B analyzed on 10/16/19 1350

Inorganic Chemistry

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/30/19 15:51	Analysis Date: 10/30/19 15:51				
Chloride	SM4500-CL-E	48.5	mg/L	1.00	3.20
Prep Date: 10/16/19 13:50	Analysis Date: 10/16/19 13:50				
Comments: Analyzed past the 15 minutes holding time.					
pH	SM4500-H+B	7.86	SU	1.00	1.00
Prep Date: 10/24/19 12:00	Analysis Date: 10/30/19 11:05				
Phosphorus	EPA 365.1	0.0412	mg/L	0.00800	0.0270

Inorganic Chemistry, Dissolved

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/15/19 15:00	Analysis Date: 11/01/19 11:42				
Nitrate + Nitrite (as N)	EPA 353.2	1.66	mg/L	0.0360	0.120

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Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046001

Field Data

Analyte	Analysis Method	Result	Units
Sample Temp-field (C)	Field Data	10.4	Centigrade
pH (SU) field	Field Data	6.39	SU

List of Abbreviations:

LOD = Level of detection
LOQ = Level of quantification
ND = None detected. Results are less than the LOD
F next to result = Result is between LOD and LOQ
Z next to result = Result is between 0 (zero) and LOD
if LOD=LOQ, Limits were not statistically derived

Test results for NELAP accredited tests are certified to meet the requirements of the NELAC standards. For a list of accredited analytes see http://www.slh.wisc.edu/about/compliance/nelac-laboratory-accreditation
Results, LOD and LOQ values have been adjusted for analytical dilutions and percent moisture where applicable.
Results relate only to the items tested.
This Laboratory Report shall not be reproduced except in full, without written approval of the laboratory.
The water microbiology unit analyzes samples as received and not all samples are tested for preservation before analysis is performed.

Responsible Party

Inorganic Chemistry: Graham Anderson, Supervisor 608-224-6281
Metals: Graham Anderson, Supervisor 608-224-6281
Organics: Erin Mani, Supervisor 608-224-6269
Environmental Toxicology: Dawn Perkins, Supervisor 608-224-6230
Water Microbiology: Martin Collins, Supervisor 608-224-6239
Radiochemistry: David Webb, Division Director 608-224-6227

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Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046002

Report To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405

Invoice To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405
Customer ID: 354700

Field #: RSC
Project No:
Collection End: 10/14/2019 12:08:00 PM
Collection Start:
Collected By: NICHOLAS POTTER
Date Received: 10/14/2019
Date Reported: 11/11/2019
Sample Reason:

ID#: NA
Sample Location: AL KAMPERT TRAIL, PLEASANT PRAIRIE, WI 53158
Sample Description:
Sample Type: SU-SURFACE WATER
Waterbody:
Point or Outfall:
Sample Depth:
Program Code:
Region Code:
County: 30

Sample Comments

ACID TRACEABILITY INFORMATION NOT SUBMITTED WITH TEST REQUEST FORM

Analyzed past the 15 minutes holding time: Method SM4500-H+B analyzed on 10/16/19 1350

Inorganic Chemistry

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/30/19 15:55	Analysis Date: 10/30/19 15:55				
Chloride	SM4500-CL-E	12.2	mg/L	1.00	3.20
Prep Date: 10/16/19 13:50	Analysis Date: 10/16/19 13:50				
Comments: Analyzed past the 15 minutes holding time.					
pH	SM4500-H+B	8.05	SU	1.00	1.00
Prep Date: 10/24/19 12:00	Analysis Date: 10/30/19 11:06				
Phosphorus	EPA 365.1	0.222	mg/L	0.00800	0.0270

Inorganic Chemistry, Dissolved

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/15/19 15:00	Analysis Date: 11/01/19 11:44				
Nitrate + Nitrite (as N)	EPA 353.2	ND	mg/L	0.0360	0.120

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http://www.slh.wisc.edu

Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046002

Field Data

Analyte	Analysis Method	Result	Units
Sample Temp-field (C)	Field Data	11.5	Centigrade
pH (SU) field	Field Data	6.5	SU

List of Abbreviations:

LOD = Level of detection
LOQ = Level of quantification
ND = None detected. Results are less than the LOD
F next to result = Result is between LOD and LOQ
Z next to result = Result is between 0 (zero) and LOD
if LOD=LOQ, Limits were not statistically derived

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Metals: Graham Anderson, Supervisor 608-224-6281
Organics: Erin Mani, Supervisor 608-224-6269
Environmental Toxicology: Dawn Perkins, Supervisor 608-224-6230
Water Microbiology: Martin Collins, Supervisor 608-224-6239
Radiochemistry: David Webb, Division Director 608-224-6227

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Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046003

Report To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405

Invoice To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405
Customer ID: 354700

Field #: RSS
Project No:
Collection End: 10/14/2019 12:30:00 PM
Collection Start:
Collected By: NICHOLAS POTTER
Date Received: 10/14/2019
Date Reported: 11/11/2019
Sample Reason:

ID#: NA
Sample Location: AL KAMPERT TRAIL, PLEASANT PRAIRIE, WI 53158
Sample Description:
Sample Type: SU-SURFACE WATER
Waterbody:
Point or Outfall:
Sample Depth:
Program Code:
Region Code:
County: 30

Sample Comments

ACID TRACEABILITY INFORMATION NOT SUBMITTED WITH TEST REQUEST FORM

Analyzed past the 15 minutes holding time: Method SM4500-H+B analyzed on 10/16/19 1350

Inorganic Chemistry

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/30/19 15:55	Analysis Date: 10/30/19 15:55				
Chloride	SM4500-CL-E	43.9	mg/L	1.00	3.20
Prep Date: 10/16/19 13:50	Analysis Date: 10/16/19 13:50				
Comments: Analyzed past the 15 minutes holding time.					
pH	SM4500-H+B	7.50	SU	1.00	1.00
Prep Date: 10/24/19 12:00	Analysis Date: 10/30/19 11:07				
Phosphorus	EPA 365.1	0.00898F	mg/L	0.00800	0.0270

Inorganic Chemistry, Dissolved

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/15/19 15:00	Analysis Date: 11/01/19 12:11				
Nitrate + Nitrite (as N)	EPA 353.2	3.64	mg/L	0.0720	0.240

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Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046003

Field Data

Analyte	Analysis Method	Result	Units
Sample Temp-field (C)	Field Data	14.9	Centigrade
pH (SU) field	Field Data	6.4	SU

List of Abbreviations:

LOD = Level of detection
LOQ = Level of quantification
ND = None detected. Results are less than the LOD
F next to result = Result is between LOD and LOQ
Z next to result = Result is between 0 (zero) and LOD
if LOD=LOQ, Limits were not statistically derived

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Inorganic Chemistry: Graham Anderson, Supervisor 608-224-6281
Metals: Graham Anderson, Supervisor 608-224-6281
Organics: Erin Mani, Supervisor 608-224-6269
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Water Microbiology: Martin Collins, Supervisor 608-224-6239
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Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046004

Report To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405

Invoice To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405
Customer ID: 354700

Field #: CPS
Project No:
Collection End: 10/14/2019 9:42:00 AM
Collection Start:
Collected By: NICHOLAS POTTER
Date Received: 10/14/2019
Date Reported: 11/11/2019
Sample Reason:

ID#: NA
Sample Location: AL KAMPERT TRAIL, PLEASANT PRAIRIE, WI 53158
Sample Description:
Sample Type: SU-SURFACE WATER
Waterbody:
Point or Outfall:
Sample Depth:
Program Code:
Region Code:
County: 30

Sample Comments

ACID TRACEABILITY INFORMATION NOT SUBMITTED WITH TEST REQUEST FORM

Analyzed past the 15 minutes holding time: Method SM4500-H+B analyzed on 10/16/19 1350

Inorganic Chemistry

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/30/19 15:56	Analysis Date: 10/30/19 15:56				
Chloride	SM4500-CL-E	23.9	mg/L	1.00	3.20
Prep Date: 10/16/19 13:50	Analysis Date: 10/16/19 13:50				
Comments: Analyzed past the 15 minutes holding time.					
pH	SM4500-H+B	7.74	SU	1.00	1.00
Prep Date: 10/24/19 12:00	Analysis Date: 10/30/19 11:08				
Phosphorus	EPA 365.1	0.0104F	mg/L	0.00800	0.0270

Inorganic Chemistry, Dissolved

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/15/19 15:00	Analysis Date: 11/01/19 11:49				
Nitrate + Nitrite (as N)	EPA 353.2	ND	mg/L	0.0360	0.120

Wisconsin State Laboratory of Hygiene
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Wisconsin State Laboratory of Hygiene
2601 Agriculture Drive, PO Box 7996
Madison, WI 53707-7996
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http://www.slh.wisc.edu

Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046004

Field Data

Analyte	Analysis Method	Result	Units
Sample Temp-field (C)	Field Data	7.1	Centigrade
pH (SU) field	Field Data	5.1	SU

List of Abbreviations:

LOD = Level of detection
LOQ = Level of quantification
ND = None detected. Results are less than the LOD
F next to result = Result is between LOD and LOQ
Z next to result = Result is between 0 (zero) and LOD
if LOD=LOQ, Limits were not statistically derived

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Metals: Graham Anderson, Supervisor 608-224-6281
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Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046005

Report To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405

Invoice To:
NICK POTTER
3627 STANDISH LN
MOUNT PLEASANT, WI 53405
Customer ID: 354700

Field #: CPN
Project No:
Collection End: 10/14/2019 10:56:00 AM
Collection Start:
Collected By: NICHOLAS POTTER
Date Received: 10/14/2019
Date Reported: 11/11/2019
Sample Reason:

ID#: NA
Sample Location: AL KAMPERT TRAIL, PLEASANT PRAIRIE, WI 53158
Sample Description:
Sample Type: SU-SURFACE WATER
Waterbody:
Point or Outfall:
Sample Depth:
Program Code:
Region Code:
County: 30

Sample Comments

ACID TRACEABILITY INFORMATION NOT SUBMITTED WITH TEST REQUEST FORM

Analyzed past the 15 minutes holding time: Method SM4500-H+B analyzed on 10/16/19 1350

Inorganic Chemistry

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/30/19 15:57	Analysis Date: 10/30/19 15:57				
Chloride	SM4500-CL-E	13.6	mg/L	1.00	3.20
Prep Date: 10/16/19 13:50	Analysis Date: 10/16/19 13:50				
Comments: Analyzed past the 15 minutes holding time.					
pH	SM4500-H+B	7.69	SU	1.00	1.00
Prep Date: 10/24/19 12:00	Analysis Date: 10/30/19 11:14				
Phosphorus	EPA 365.1	0.0161F	mg/L	0.00800	0.0270

Inorganic Chemistry, Dissolved

Analyte	Analysis Method	Result	Units	LOD	LOQ
Prep Date: 10/15/19 15:00	Analysis Date: 11/01/19 11:51				
Nitrate + Nitrite (as N)	EPA 353.2	ND	mg/L	0.0360	0.120

Wisconsin State Laboratory of Hygiene
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Laboratory Report

D.F. Kurtycz, M.D., Medical Director - Prof. James J. Schauer, Ph.D., Director

Environmental Health Division

WDNR LAB ID: 113133790 NELAP LAB ID: 2091 EPA LAB ID: WI00007, WI00008 WI DATCP ID: 105-415

WSLH Sample: 476046005

Field Data

Analyte	Analysis Method	Result	Units
Sample Temp-field (C)	Field Data	7.5	Centigrade
pH (SU) field	Field Data	5.6	SU

List of Abbreviations:

LOD = Level of detection
LOQ = Level of quantification
ND = None detected. Results are less than the LOD
F next to result = Result is between LOD and LOQ
Z next to result = Result is between 0 (zero) and LOD
if LOD=LOQ, Limits were not statistically derived

Test results for NELAP accredited tests are certified to meet the requirements of the NELAC standards. For a list of accredited analytes see http://www.slh.wisc.edu/about/compliance/nelac-laboratory-accreditation
Results, LOD and LOQ values have been adjusted for analytical dilutions and percent moisture where applicable.
Results relate only to the items tested.
This Laboratory Report shall not be reproduced except in full, without written approval of the laboratory.
The water microbiology unit analyzes samples as received and not all samples are tested for preservation before analysis is performed.

Responsible Party

Inorganic Chemistry: Graham Anderson, Supervisor 608-224-6281
Metals: Graham Anderson, Supervisor 608-224-6281
Organics: Erin Mani, Supervisor 608-224-6269
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Water Microbiology: Martin Collins, Supervisor 608-224-6239
Radiochemistry: David Webb, Division Director 608-224-6227

A.3 Low Battery Notifications

Loggers
Low battery readings on loggers in
6/14/19 RS3, CS4, CS3
6/15/19 CN5 CN6
7/1/19 RS3
10/12/19 RN2, CS5, RN4, RS3, CN5, CN6

A.4 General Piezometer Locations Description

When referring to the Northern section or Southern section it refers to North or South relative to 122nd Street.

Ridge
Slightly higher in elevation. Sandy areas that promote more forbs, gasses, and shrubs.
CN2
P2
CS1
CS8

Swale
Lower in elevation. Varies in wetness. Sedges, rushes and tussock grass found in this area.
CN3
CN5
CN6
P1
P3
P4
IL11.3
IL11.4
IL11.5
IL11.6
CS4
CS5

Remnant wetland
The remnant wetland is an area (hydrologically) above the restoration work the Piezometers here where at least 30+ m from any dich

RN4 (wettest location in the restoration site)
RN3 (dryer then RN4 vegetation showed this as well)

Depressed area
These piezometers were in depressional areas that were not quite as wet as the swales but not as dry as the ridges. Areas that would fill during rain events.
CN1
CN7
P5
CS6

Culvert outflows

TNC site had multiple outflow culverts. These piezometers were placed near the outflow water from those culverts
CN4
CS3

Farm fields
In the farm fields of the TNC site
RN1
RN2
RN5
RN6
RN7

RS1
RS4
RS5
RS6

Forested wetland
Forested area that has not been cleared yet in the southwest portion of the TNC site
RS3

Outflow Creek
Outflow creek at the south edge of TNC site
RS2

A.5 Piezometer Location Description

A.5.1 Chiwaukee Prairie North

CN1 Well in a depressional area in the NE of CN.

CN2 sandy ridge between swales in the north central part of CN

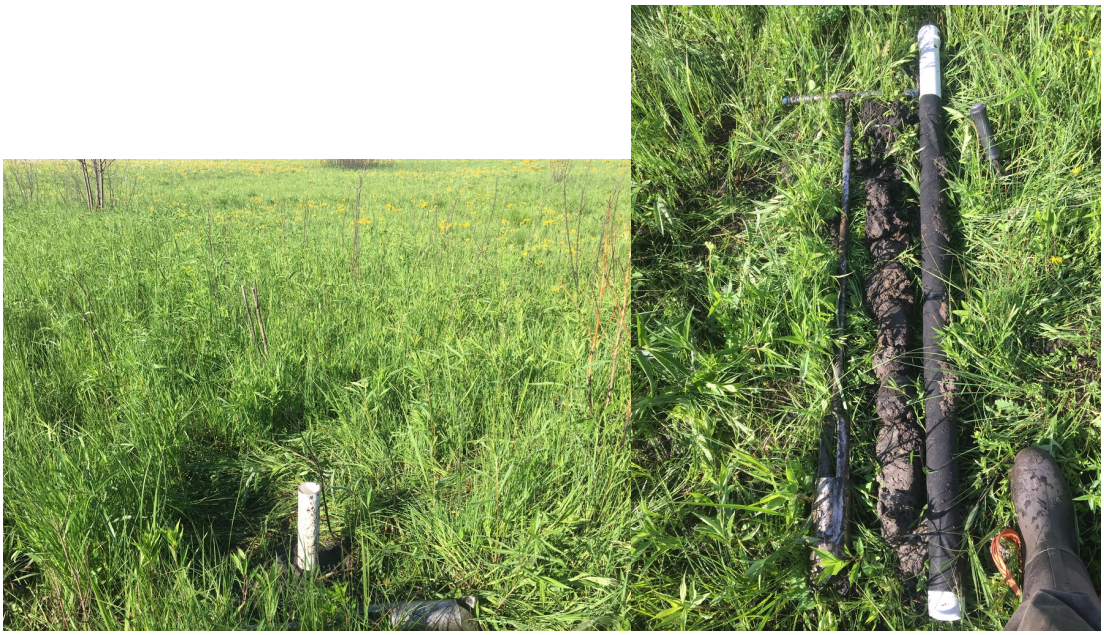
CN3 Far north end of the primary swale in the north western corner of CN

CN4 in the outflow area for restoration site culvert

CN5 in primary swale near culvert outflow

CN6 In primary swale, shrubby and filled with sedges

CN7 depressional area



P1 In primary swale. This is in a dryer area of the primary swale.

P2 On the wester ridge of the primary swale

P3

P4 In cattails wet area

P5 in small depression just southeast of wooded area similar to p1 in vegetation

P6 in swale not as wet as other swales

IL 11.3 –11.4 in the “primary swale the ground was almost always saturated

IL 11.5 –11.6 in the “primary swale very wet 6 was at a depth were I almost always overtopped my boots 4 was usual

A.5.2 Chiwaukee Prairie South

CS1 Sand ridge or upland area. Very sandy with more shrubs and grasses

CS2 On the edge of a edge of a ridge in the center of CS

CS3 In the outwash plane of a culvert coming from RS

CS4

CS5

CS6

CS7

CS8

A.5.3 TNC Restoration Site North

RN1 In field in the most northwest portion of the restoration site

RN2 In field in the northeast portion of the north section of the restoration site

RN3 In the northern portion in the remnant wetland

RN4 In the southern portion remnant wetland

RN5 in the field in the north portion of the northern section of restoration site south of RN1

RN6 In the In the southwest portion of the northern section of the restoration site closest to 122nd Street

RN7 In the middle portion of the northern section of restoration site near the most northern E-W ditch

A.5.4 TNC Restoration Site South

RS1 Well in the most southeast portion of field of the southern section

RS2 In the wooded creek on southern border of TNC property and is considered to be surface water

RS3 In the forested area just past the cleared trees in southwest portion of the southern section TNC restoration site.

RS4 In the farm field in the northeast portion of the southern section

RS5 In the farm field in the center of the southern section of the restoration site

RS6 In the northwest farm field in the southern section of the restoration site just north of the wooded area

B Extra Figures & Tables

B.1 Water Level Table

Additional Table B.1 The monthly average for 2019 and 2020 and a comparison between the two years. It lists each piezometer that was used for both 2019 and 2020. The tables list the average water levels for each month between June and October (when the loggers were deployed). The colors correspond with the water level. Dark blue above ground surface, light blue within 10 cm below the ground surface, green between -10 and -20 cm, yellow between -20 and -40 cm, orange between -40 and -60, red between -60 and -80, and grey more than 80 cm below ground surface. The third column represents the difference between 2019 and 2020. Red represents the water levels in 2020 where lower blue represents higher water levels in 2020. The annual averages and differences are shown in the lower right side of the Table B.1-1

	CN3		
	2019	2020	Difference
Average	**-19.3**	**-70.1**	-50.9
Jun	-2.0	-54.6	-52.6
Jul	-18.7	-47.6	-28.9
Aug	-63.3	-54.4	8.9
Sep	-13.4	-93.5	-80.1
Oct	1.2	-115.3	-116.5

	CN5		
	2019	2020	Difference
	-5.0	**-16.8**	-11.9
	-5.1	-11.0	-5.9
	-6.5	-7.5	-1.0
	-8.0	-12.2	-4.1
	-3.2	-22.9	-19.7
	-1.7	-38.1	-36.5

	CN6		
	2019	2020	Difference
	-12.8	**-41.0**	-28.2
	-9.7	-43.6	-33.9
	-15.1	-34.7	-19.5
	-24.0	-37.0	-13.0
	-9.3	-43.0	-33.7
	-5.9	-54.0	-48.0

	RN1		
	2019	2020	Difference
Average	**-31.4**	**-62.4**	-31.0
Jun	-25.1	-67.4	-42.2
Jul	-48.4	-61.3	-13.0
Aug	-47.6	-57.6	-10.0
Sep	-22.2	-59.8	-37.6
Oct	-12.5	-71.9	-59.4

	RN2		
	2019	2020	Difference
	-44.2	**-91.5**	-47.2
	-37.8	-97.1	-59.4
	-66.0	-84.0	-18.0
	-68.5	-82.7	-14.2
	-28.6	-96.4	-67.8
	-27.7	-106.2	-78.4

	RN4		
	2019	2020	Difference
	-19.6	**-26.2**	-6.6
	-12.4	-7.1	5.3
	-27.0	-19.6	7.4
	-41.5	-28.6	12.9
	-17.4	-33.0	-15.6
	-6.6	-40.9	-34.3

	RN7		
	2019	2020	Difference
Average	**-84.9**	**-41.8**	43.1
Jun	-80.5	-90.5	-10.0
Jul	-100.9	-37.0	63.8
Aug	-106.2	-23.5	82.7
Sep	-73.0	-33.4	39.6
Oct	-70.1	-48.5	21.6

	ILP1		
	2019	2020	Difference
	2.1	**-3.9**	-6.1
	-0.1	-5.5	-5.4
	-3.0	-5.5	-2.5
	-6.4	-9.6	-3.2
	0.3	-16.3	-16.6
	1.9	-24.3	-26.2

	ILP2		
	2019	2020	Difference
	-0.6	**-8.2**	-7.6
	-1.0	-11.0	-9.9
	-6.8	-12.4	-5.6
	-12.4	-17.2	-4.8
	0.7	-26.3	-27.0
	2.9	-38.5	-41.4

	ILP3		
	2019	2020	Difference
Average	**-8.3**	**-8.5**	-0.3
Jun	-10.9	-9.1	1.8
Jul	-14.6	-10.4	4.2
Aug	-18.5	-15.3	3.2
Sep	-1.8	-25.8	-24.0
Oct	-0.1	-39.9	-39.7

Value cm compare to ground surface
<=80
-60 to -80
-40 to -60

Annual Average cm

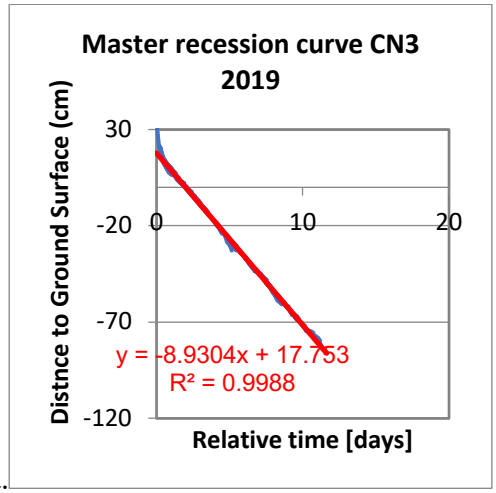
ID	2019	2020	Difference
CN3	**-16.3**	**-70.1**	-53.8
CN5	**-5.0**	**-16.8**	-11.9
CN6	**-12.8**	**-41.0**	-28.2
IL11.4	**-7.5**	**-5.3**	2.2
IL11.5	**-8.6**	**-7.3**	1.3
IL11.6	**-1.2**	**-8.5**	-7.3
ILP1	**2.1**	**-3.9**	-6.1

	IL11.6		
	2019	2020	Difference
Average	-1.2	-8.5	-7.3
Jun	-0.8	-17.1	-16.2
Jul	-4.3	-10.3	-6.0
Aug	-16.8	-12.3	4.5
Sep	-0.8	-25.6	-24.8
Oct	1.0	-38.6	-39.6

-20 to -40
-10 to -20
0 to -10
>0

ILP2	-0.6	-8.2	-7.6
ILP3	-8.3	-8.5	-0.3
RN1	-31.4	-62.4	-31.0
RN2	-44.2	-91.5	-47.2
RN4	-19.6	-26.2	-6.6
RN7	-84.9	-41.8	43.1

B.2 Master Recession Curves



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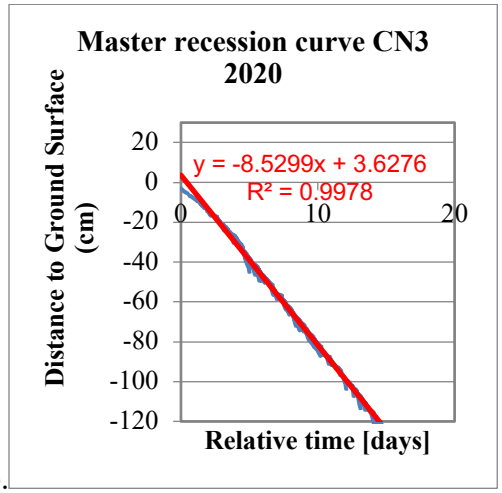
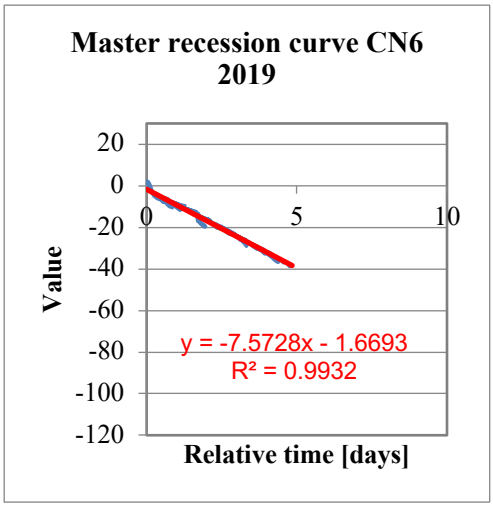


b.

Additional Figure B.1 Master recession curves for RN1 for 2019 (a) and 2020 (b).



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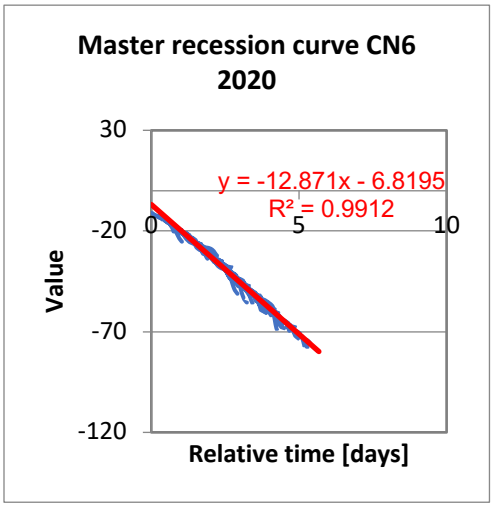
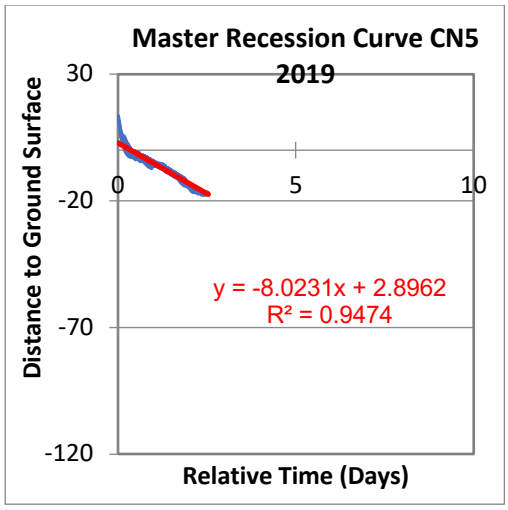
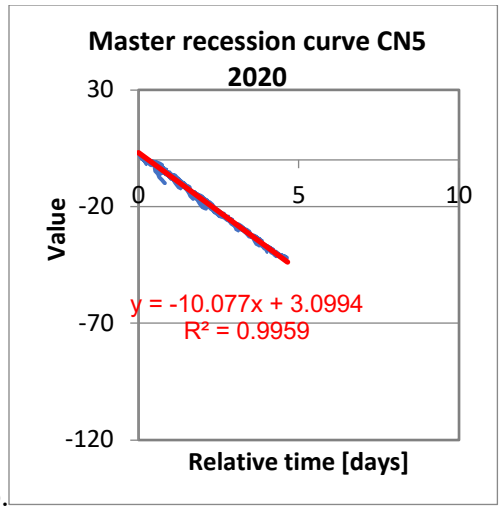


b.

Additional Figure B.2 Master recession curves for CN6 for 2019 (a) and 2020 (b).

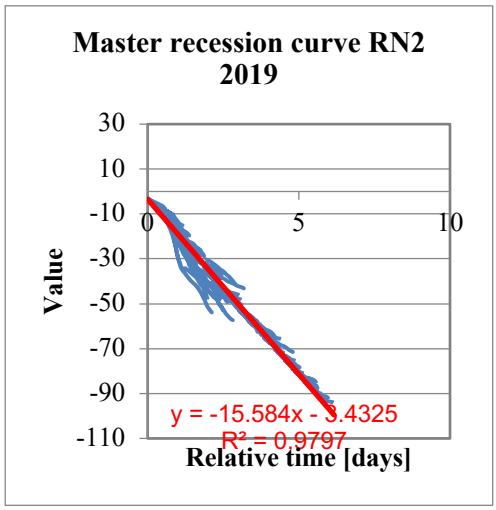


a.



b.

Additional Figure B.3 Master recession curves for CN6 for 2019 (a) and 2020 (b).



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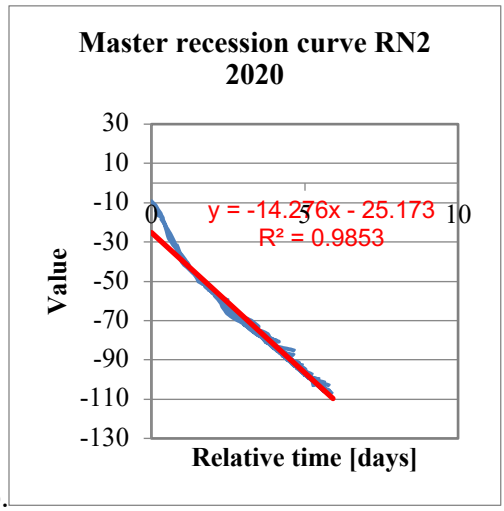
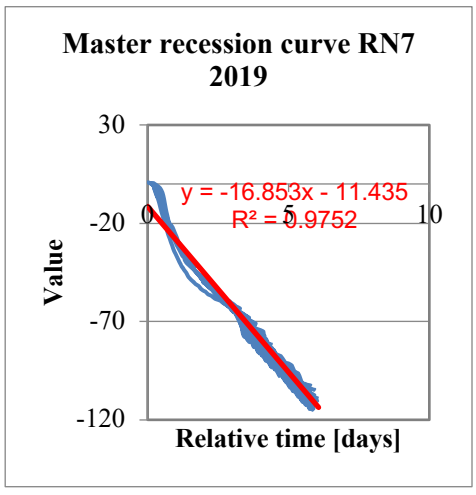
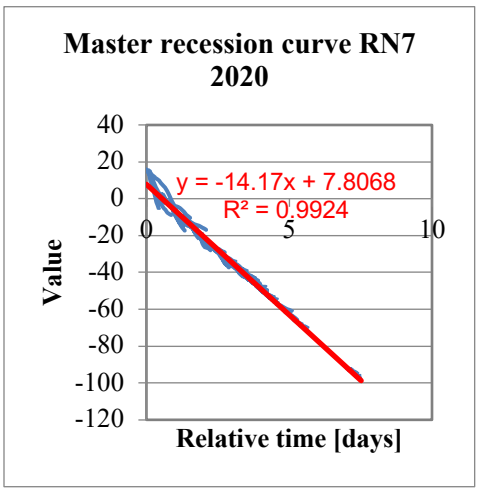


b.

Additional Figure B.4 Master recession curves for CN6 for 2019 (a) and 2020 (b).

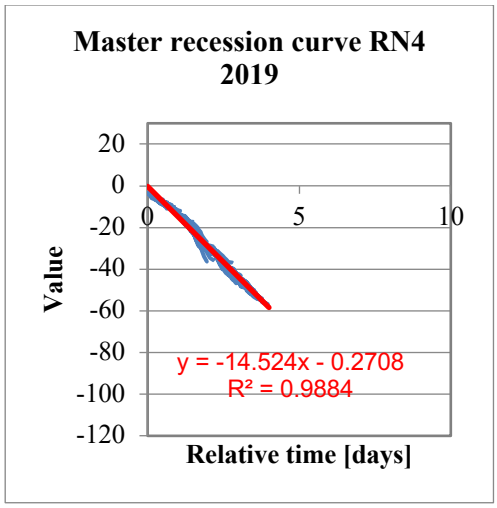


a.



b.

Additional Figure B.5 Master recession curves for CN6 for 2019 (a) and 2020 (b).



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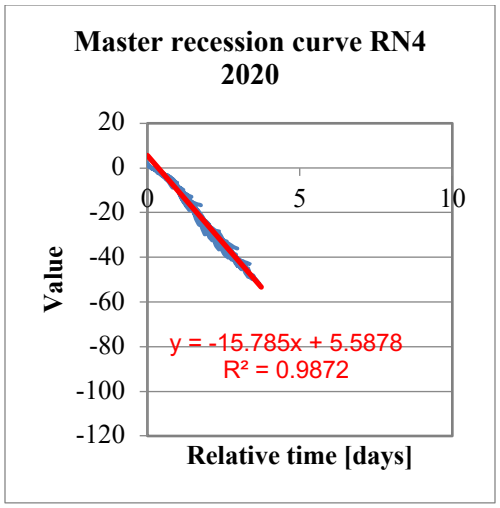
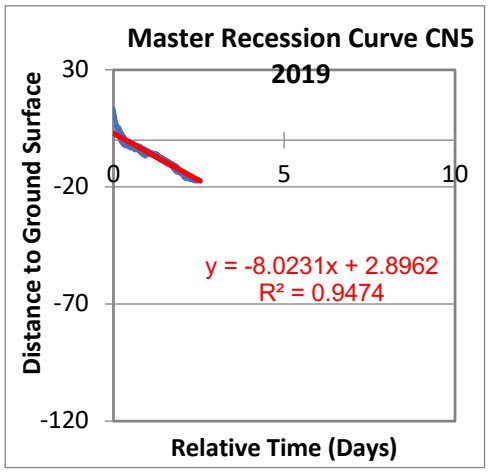
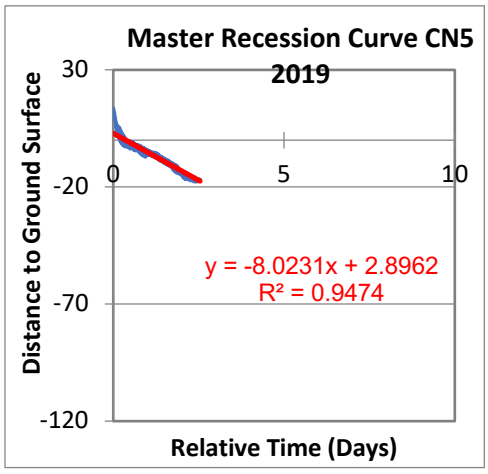


b.

Additional Figure B.6 Master recession curves for CN6 for 2019 (a) and 2020 (b).

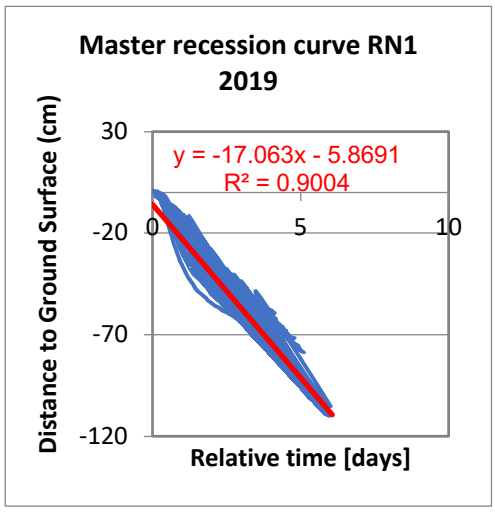


a.

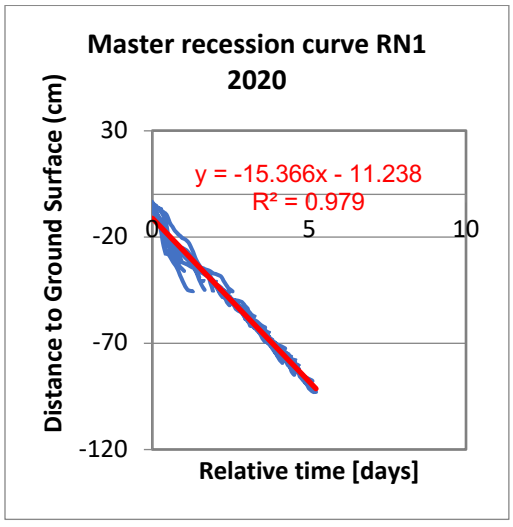


b.

Additional Figure B.7 Master recession curves for CN6 for 2019 (a) and 2020 (b).

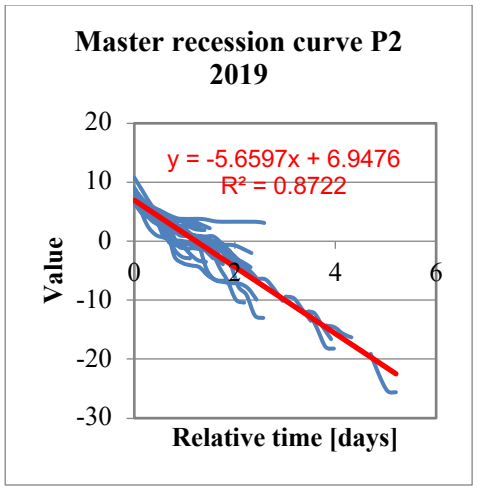


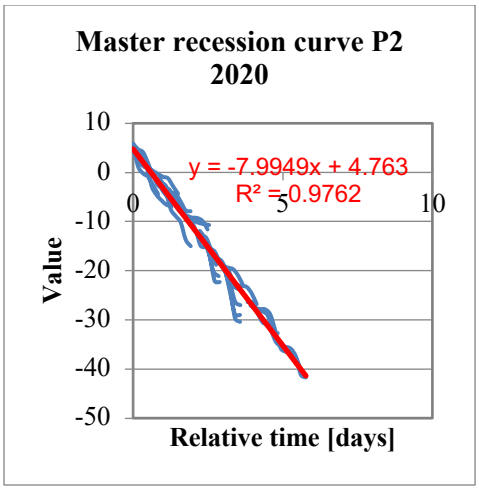
a.



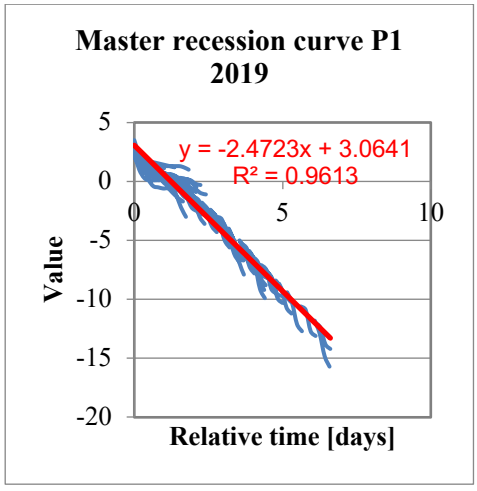
b.

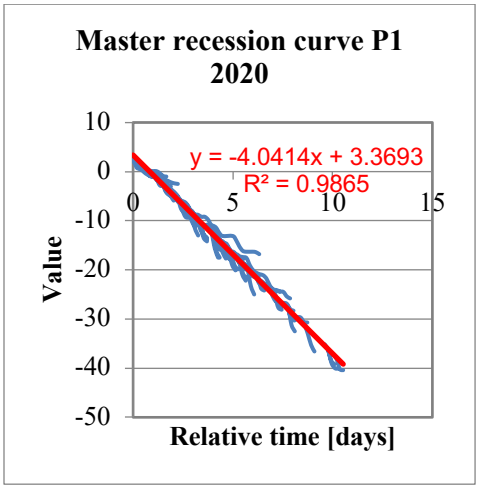
Additional Figure B.8 Master recession curves for CN6 for 2019 (a) and 2020 (b).

a. 

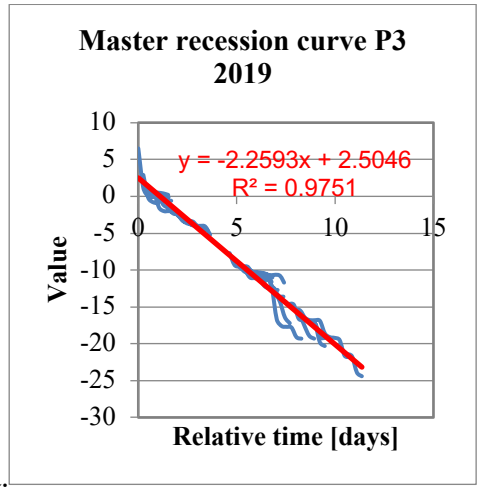
b. 

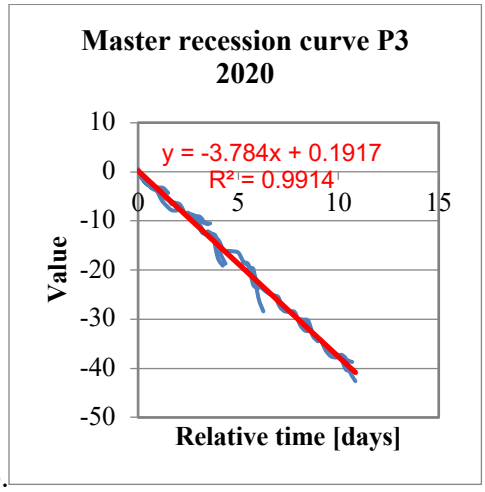
Additional Figure B.9 Master recession curves for CN6 for 2019 (a) and 2020 (b).

a. 

b. 

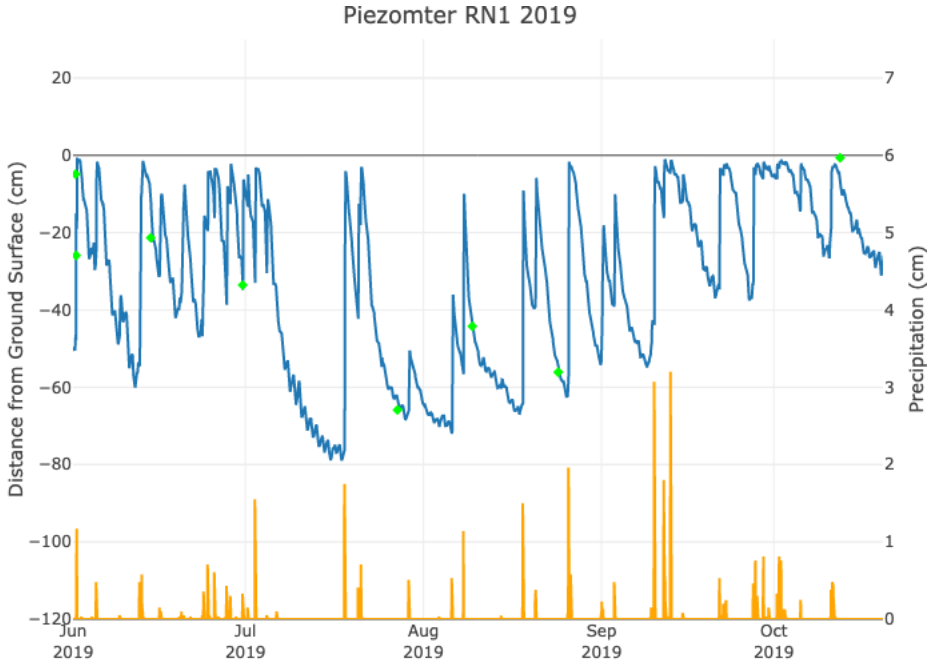
Additional Figure B.10 Master recession curves for CN6 for 2019 (a) and 2020 (b).

a. 

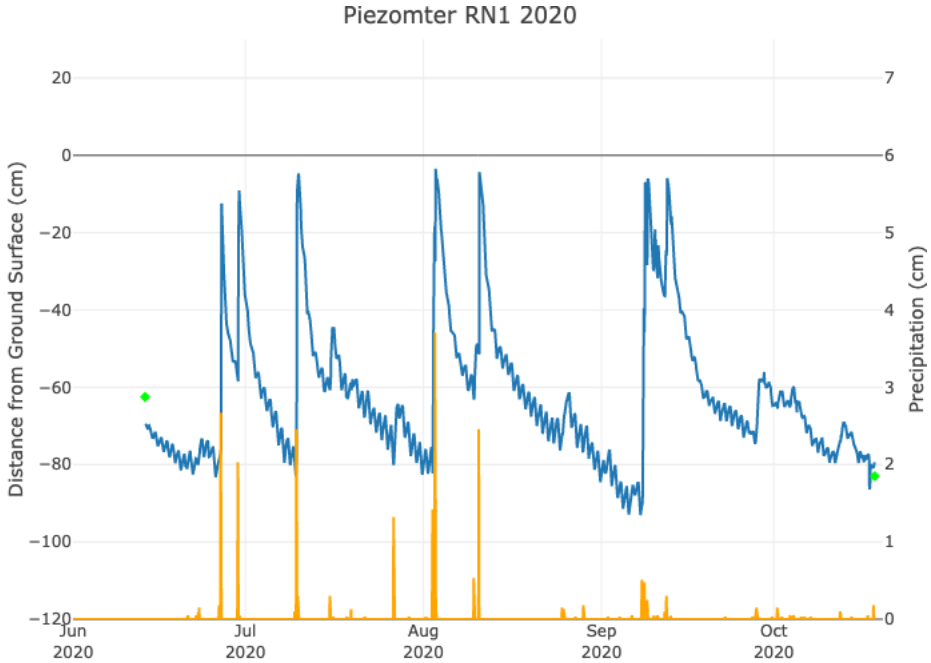
b. 

Additional Figure B.11 Master recession curves for CN6 for 2019 (a) and 2020 (b).

B.3 Individual Hydrographs with Hand Measurements



Additional Figure B.12 Water depth in piezometer RN1 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



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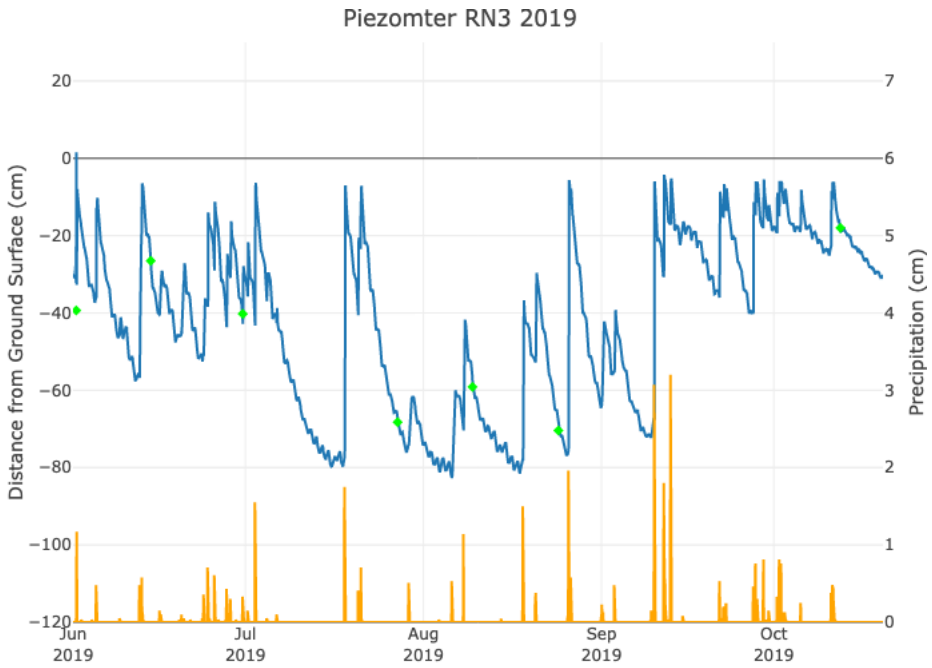
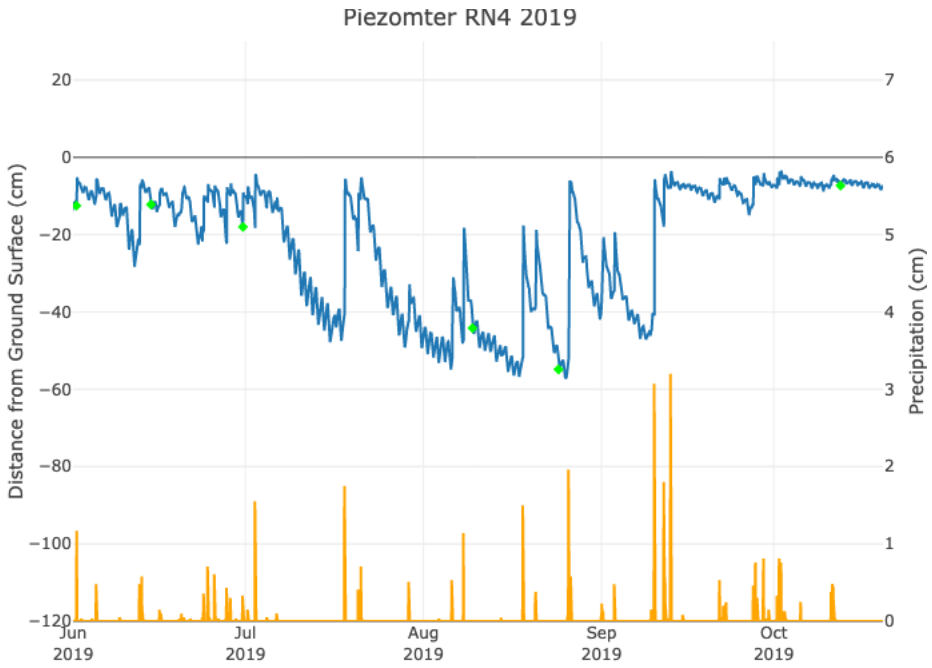
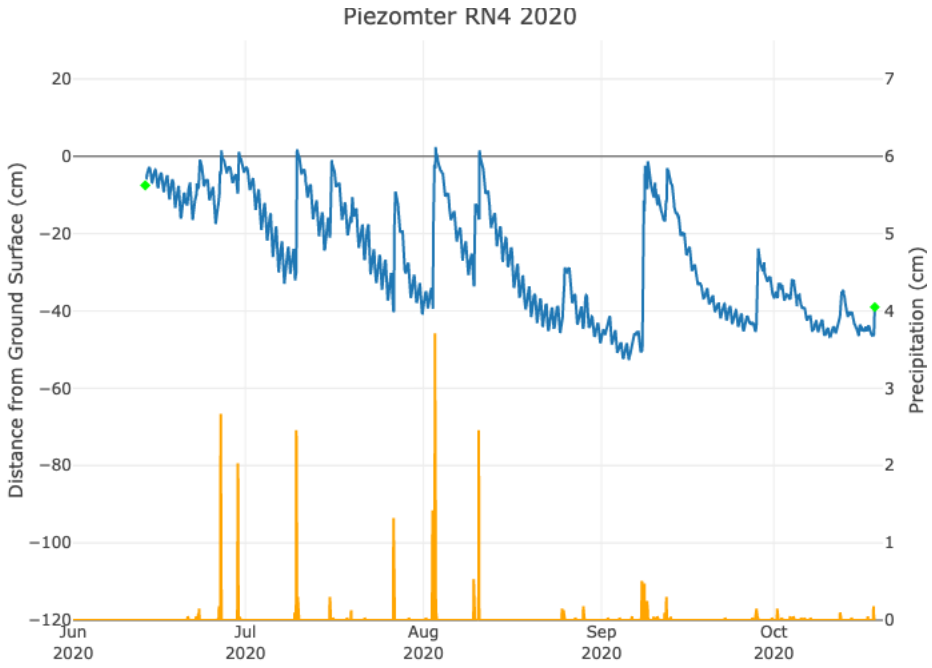
Additional Figure B.13 Water depth in piezometer RN1 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



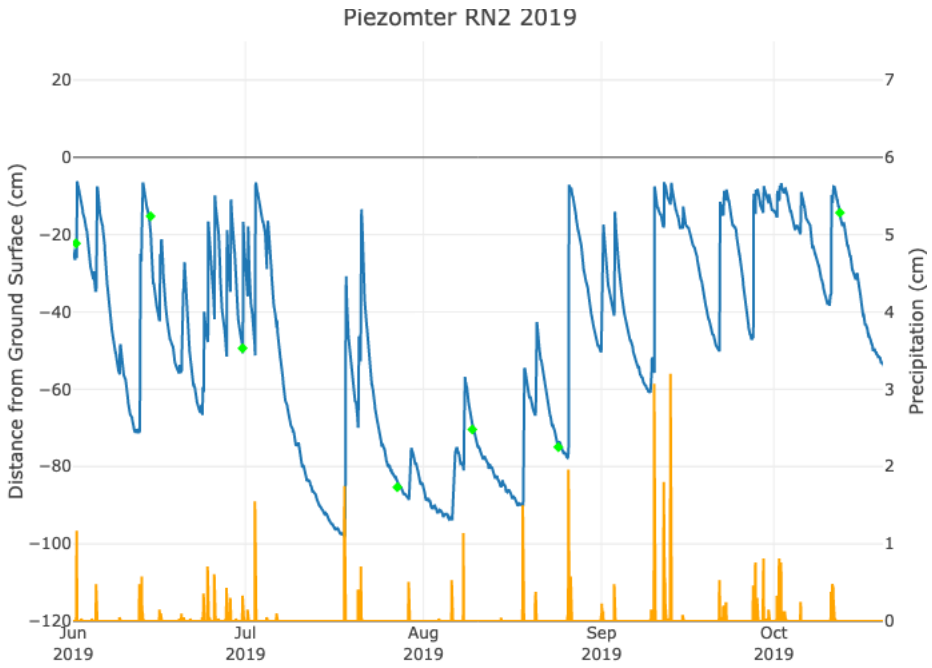
Additional Figure B.14 Water depth in piezometer RN3 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



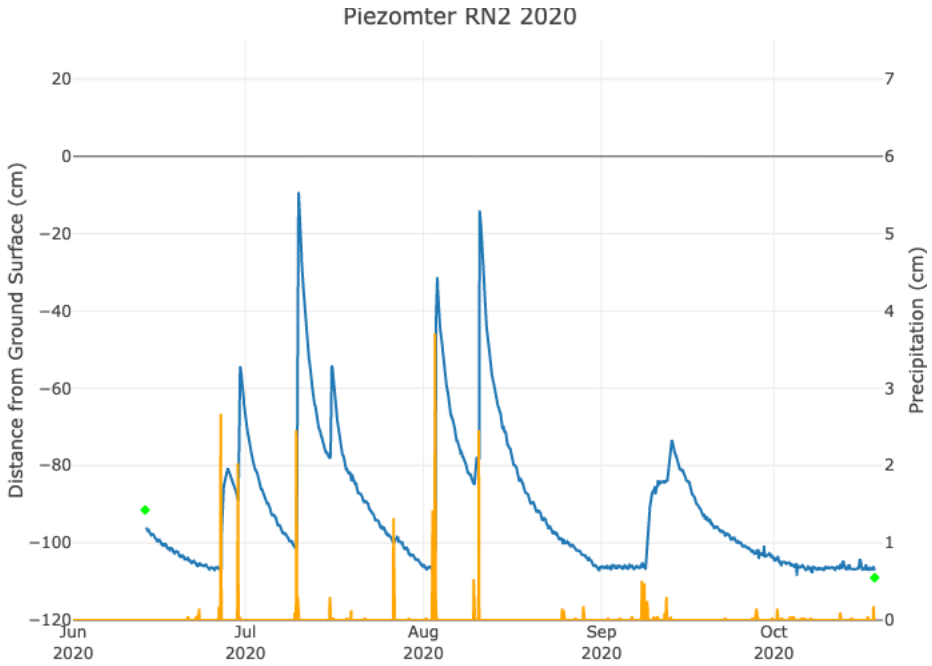
Additional Figure B.15 Water depth in piezometer RN4 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



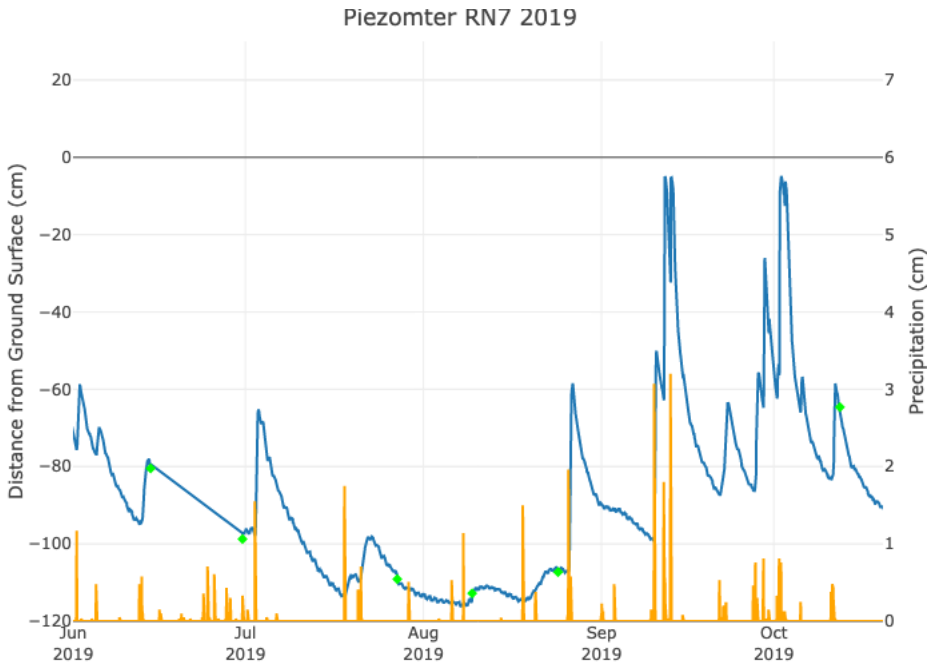
Additional Figure B.16 Water depth in piezometer RN4 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



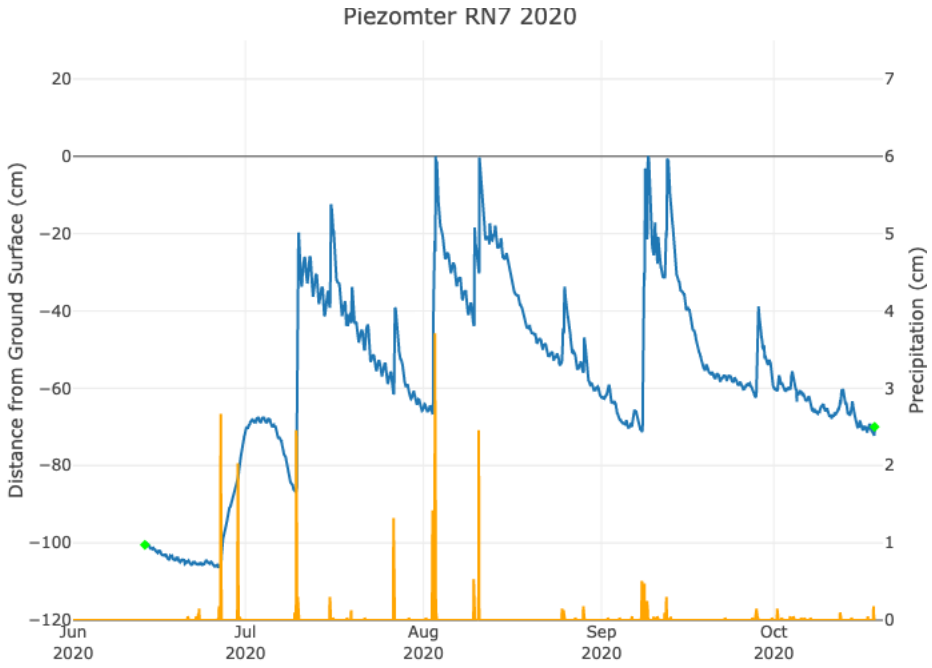
Additional Figure B.17 Water depth in piezometer RN2 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



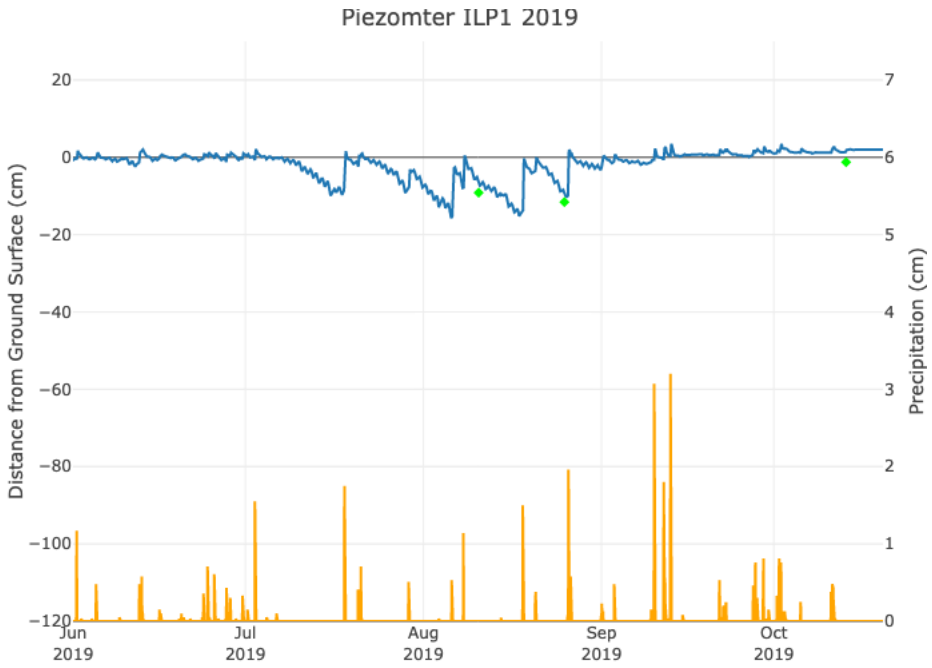
Additional Figure B.18 Water depth in piezometer RN2 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



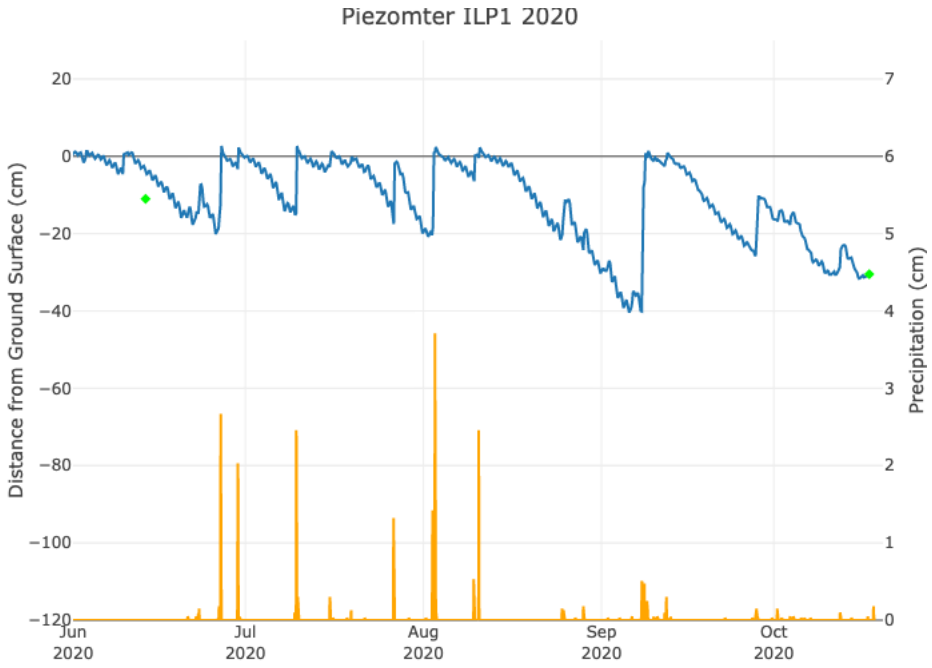
Additional Figure B.19 Water depth in piezometer RN7 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



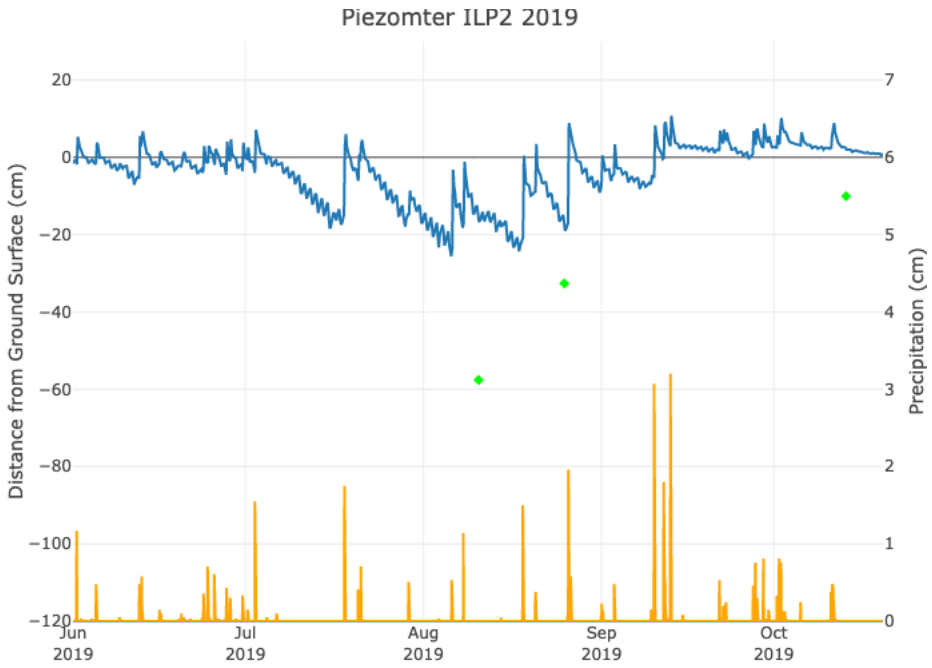
Additional Figure B.20 Water depth in piezometer RN7 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



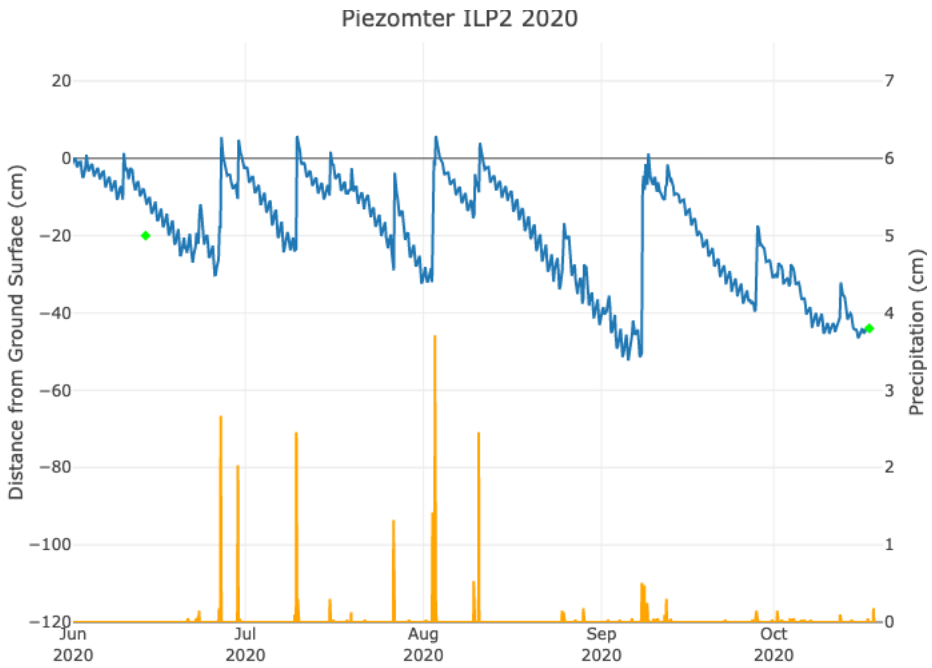
Additional Figure B.21 Water depth in piezometer ILP1 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



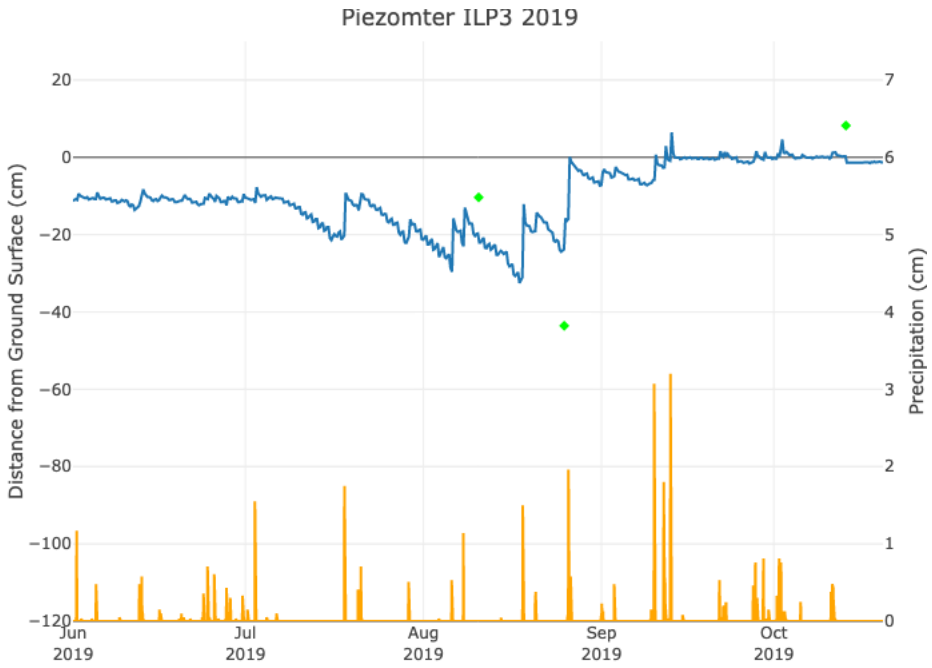
Additional Figure B.22 Water depth in piezometer ILP1 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



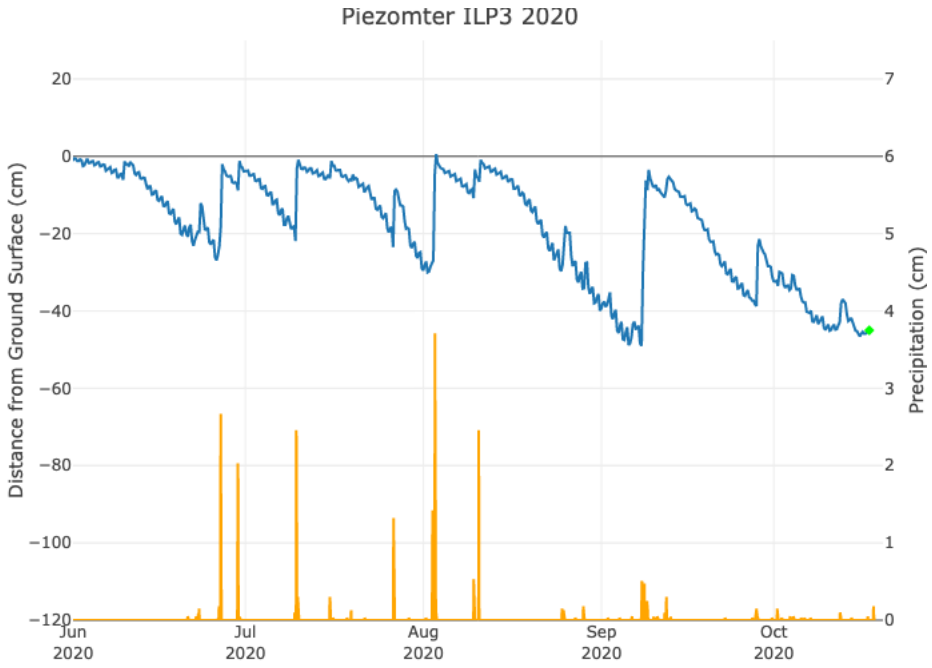
Additional Figure B. Water depth in piezometer ILP2 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



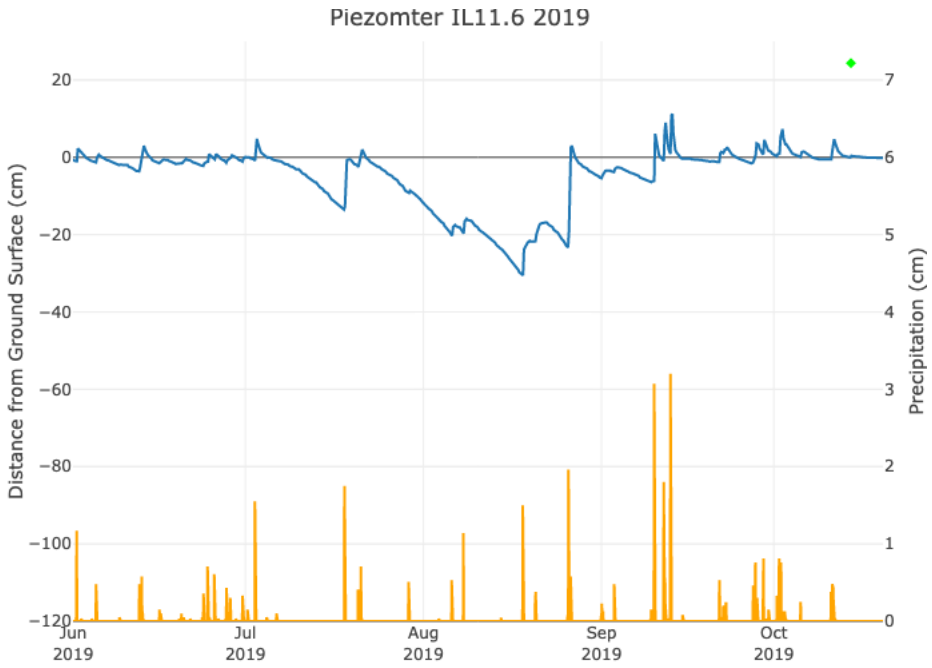
Additional Figure B.23 Water depth in piezometer ILP2 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



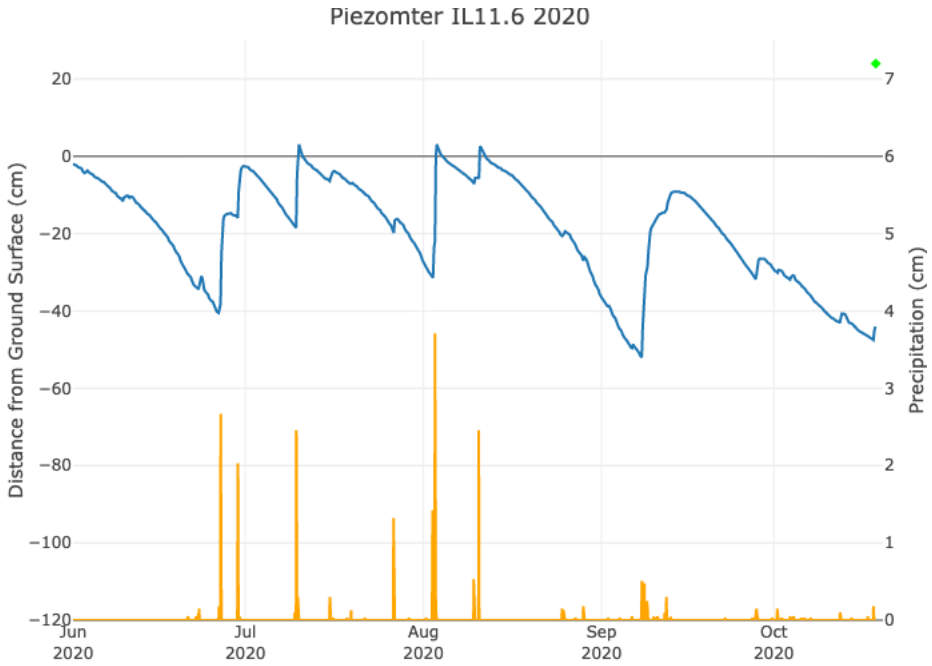
Additional Figure B.24 Water depth in piezometer ILP3 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



Additional Figure B.25 Water depth in piezometer ILP3 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.

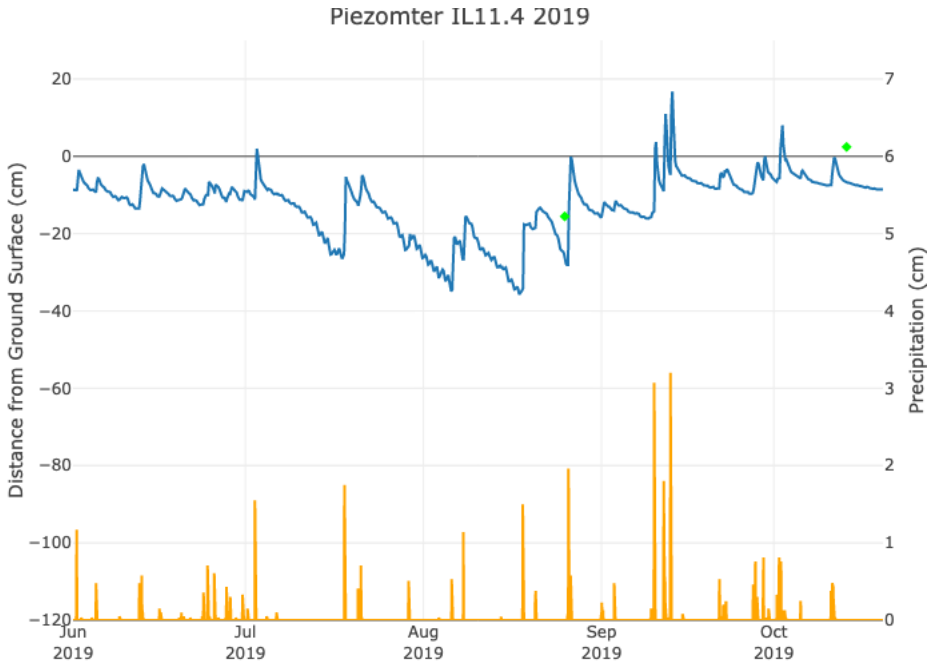


Additional Figure B.26 Water depth in piezometer IL11.6 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.

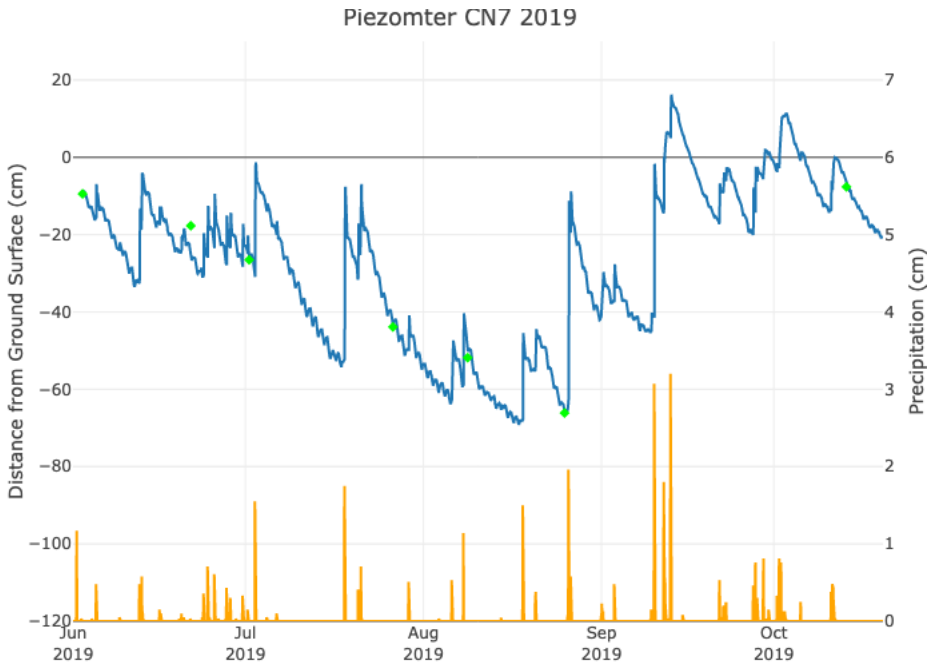


Additional Figure B.27 Water depth in piezometer IL11.6 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.

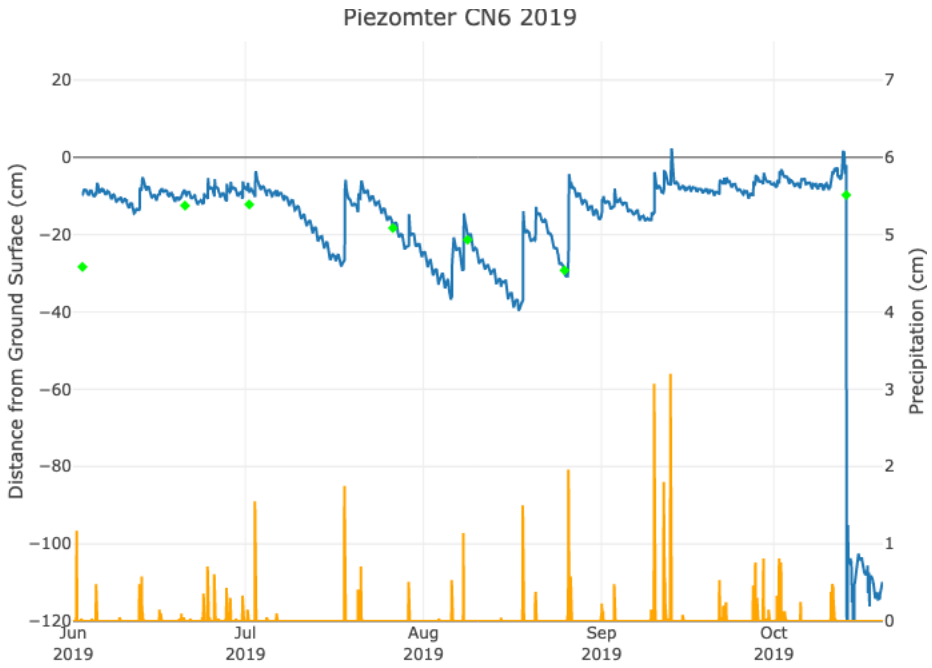
Additional Figure B.28 Water depth in piezometer IL11.5 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



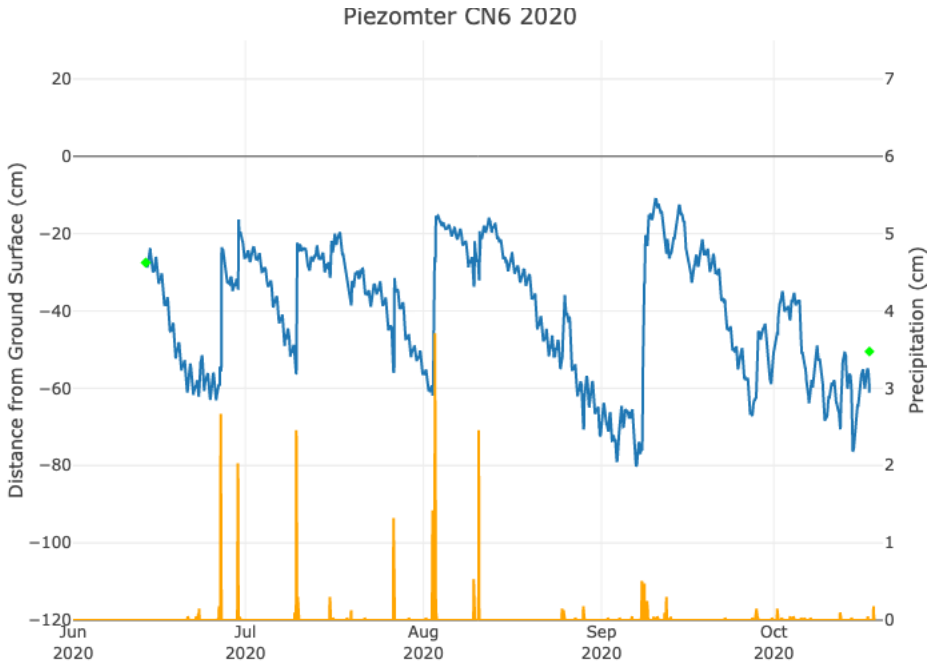
Additional Figure B.29 Water depth in piezometer IL11.4 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



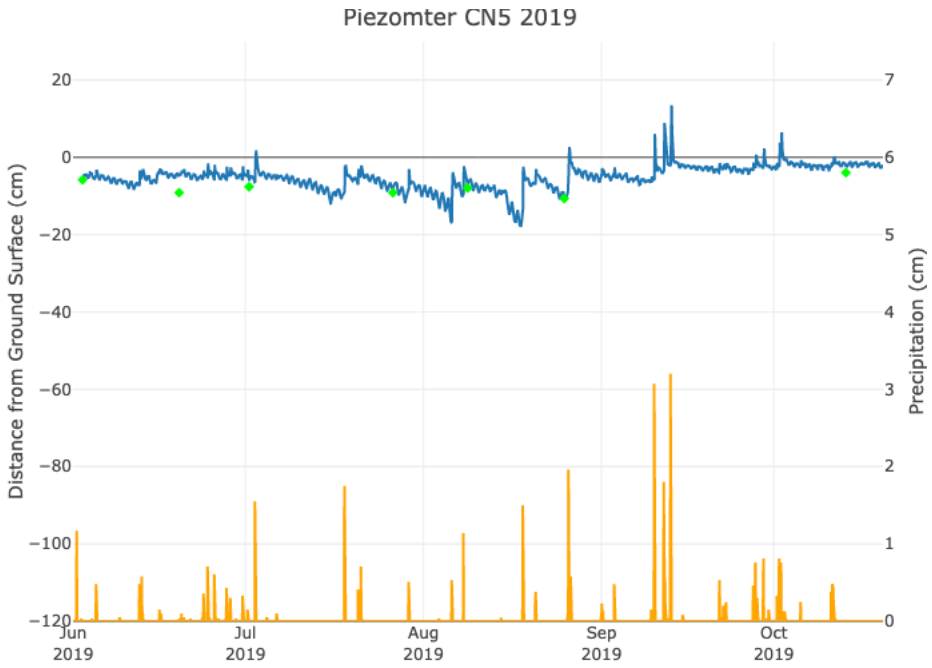
Additional Figure B.30 Water depth in piezometer CN7 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



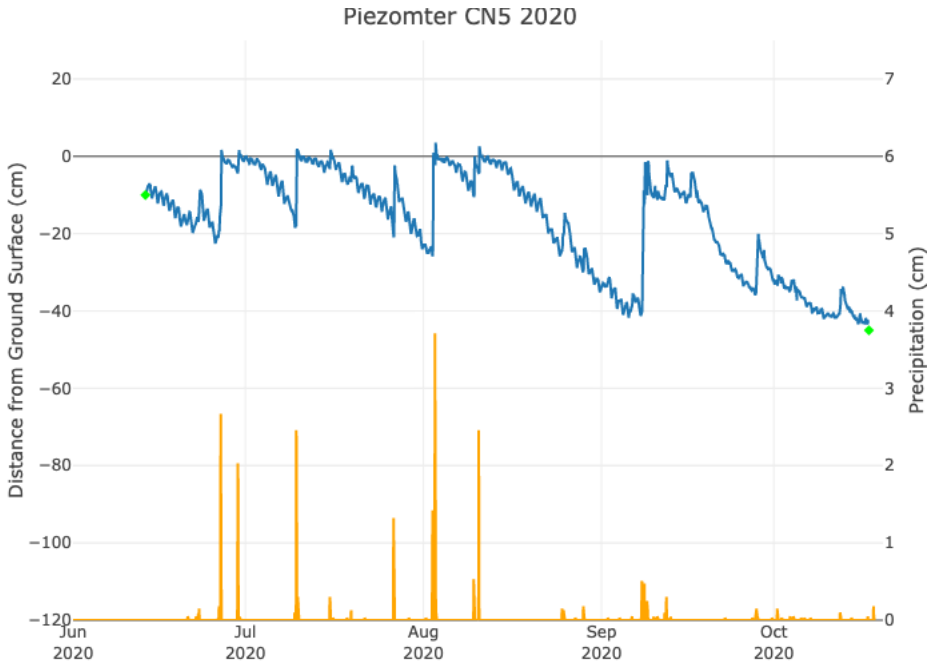
Additional Figure B.31 Water depth in piezometer CN6 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



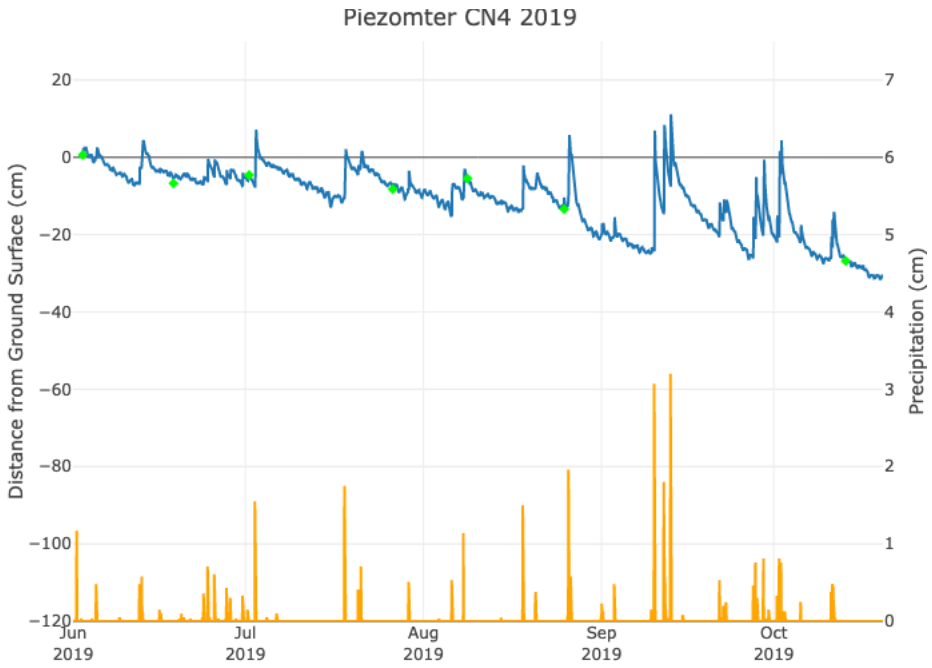
Additional Figure B.32 Water depth in piezometer CN6 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



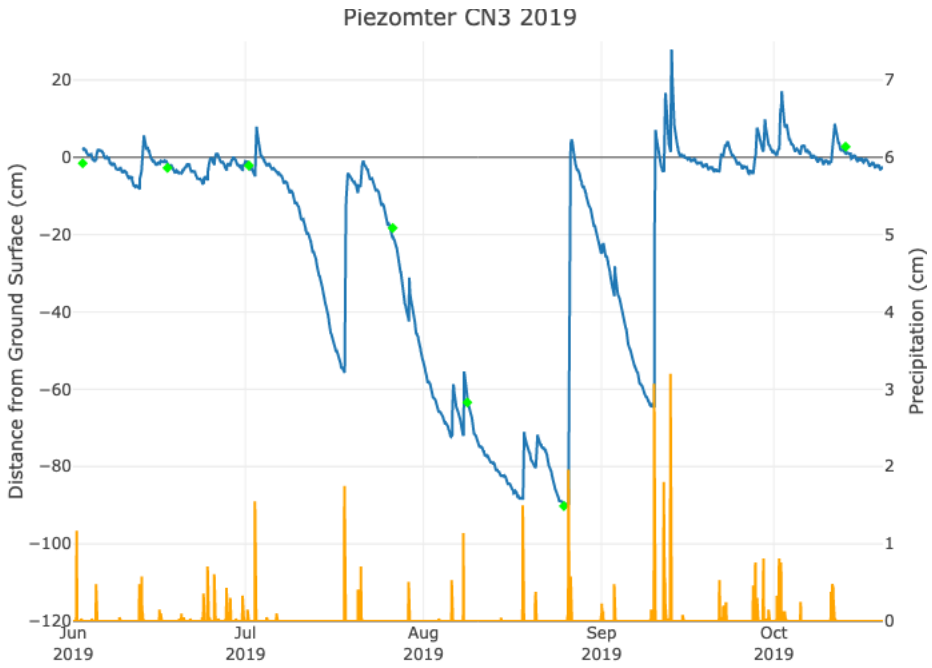
Additional Figure B.33 Water depth in piezometer CN5 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



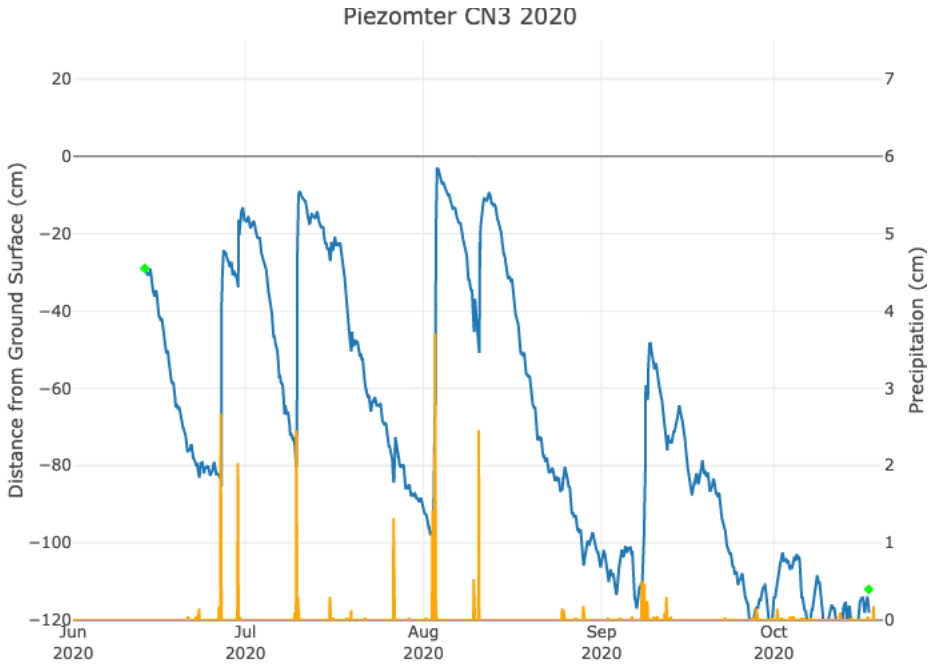
Additional Figure B.34 Water depth in piezometer CN6 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



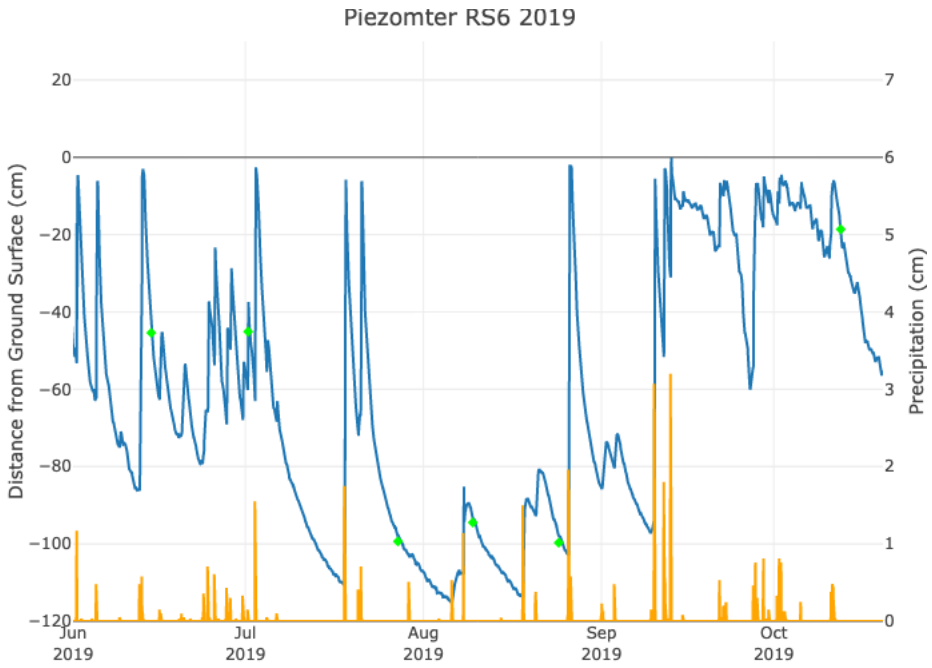
Additional Figure B.35 Water depth in piezometer CN4 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



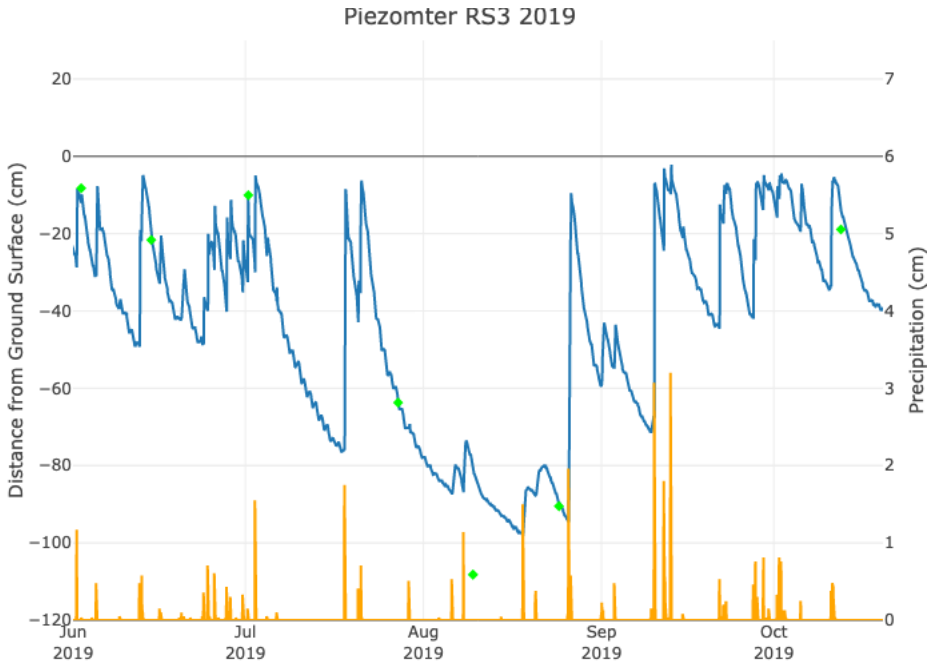
Additional Figure B.36 Water depth in piezometer CN3 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



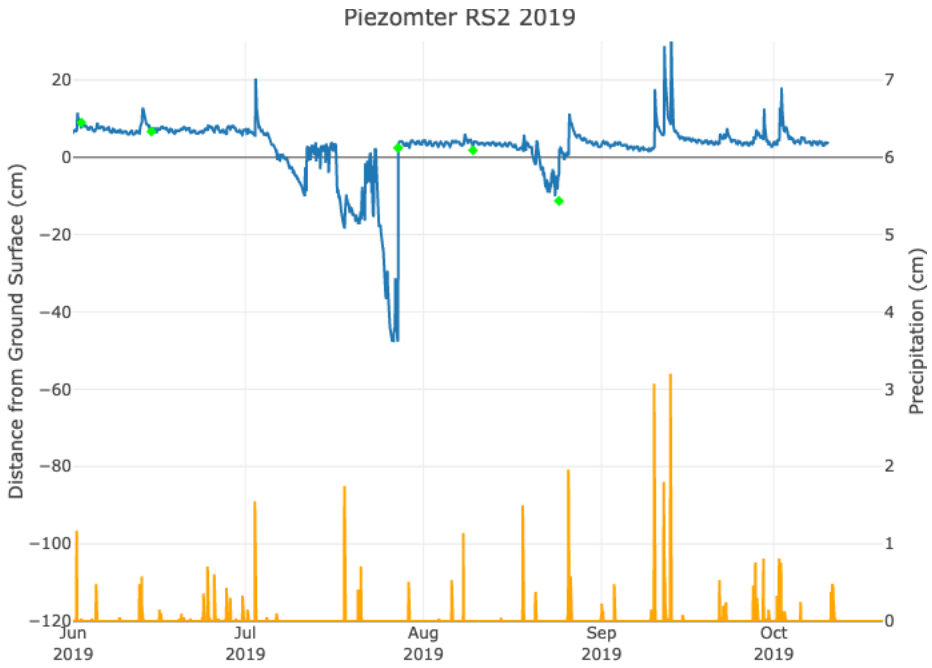
Additional Figure B.37 Water depth in piezometer CN6 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



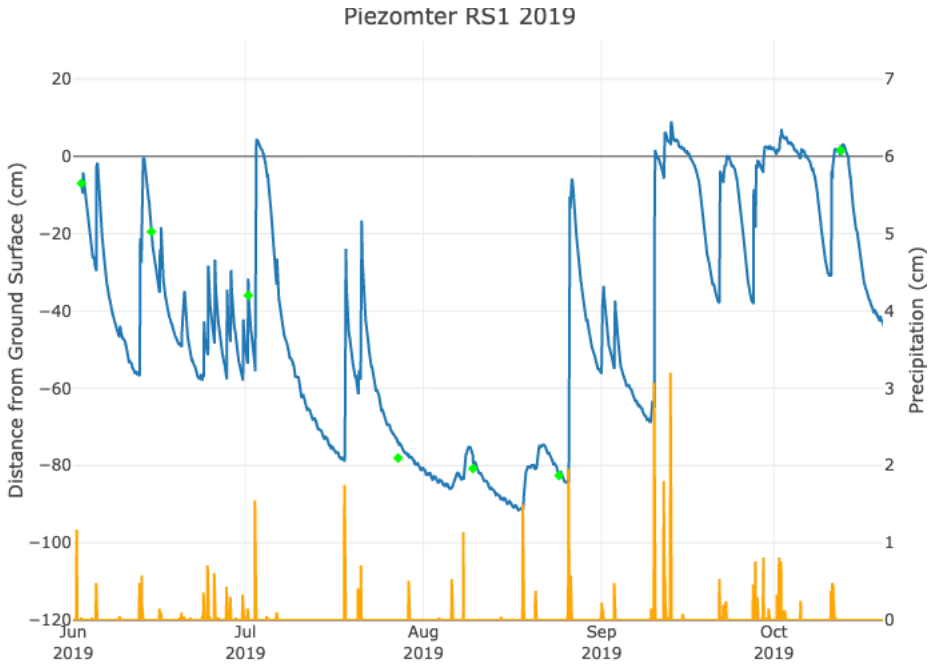
Additional Figure B.38 Water depth in piezometer RS6 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



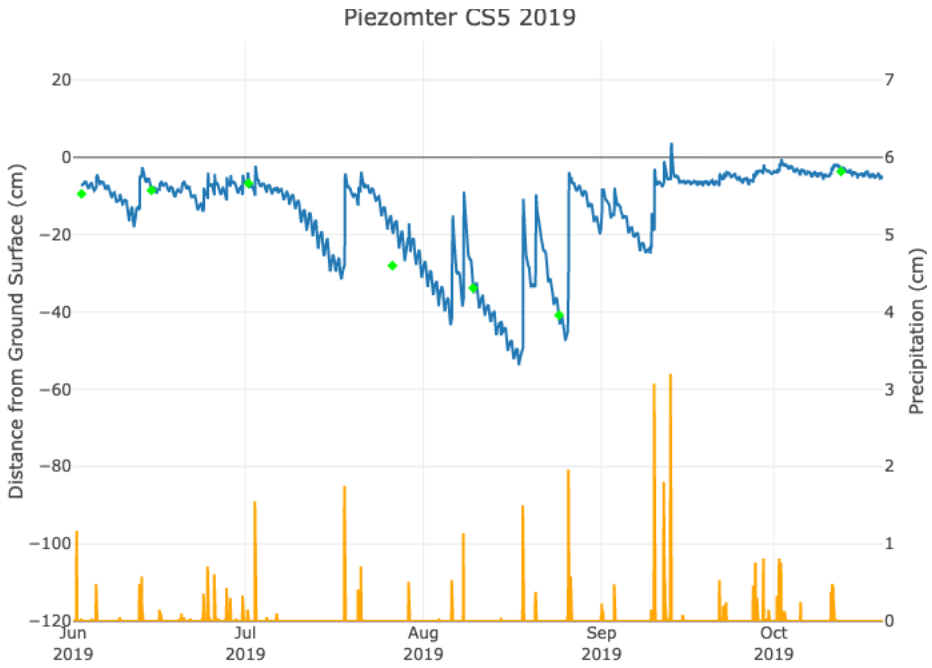
Additional Figure B.39 Water depth in piezometer RS6 during the 2020 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



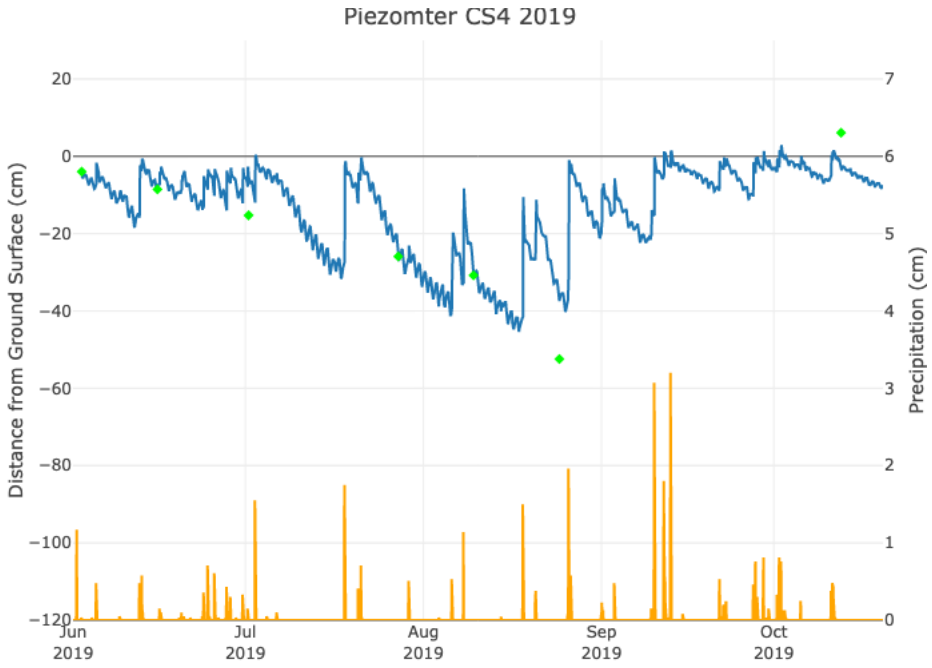
Additional Figure B.40 Water depth in piezometer RS2 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



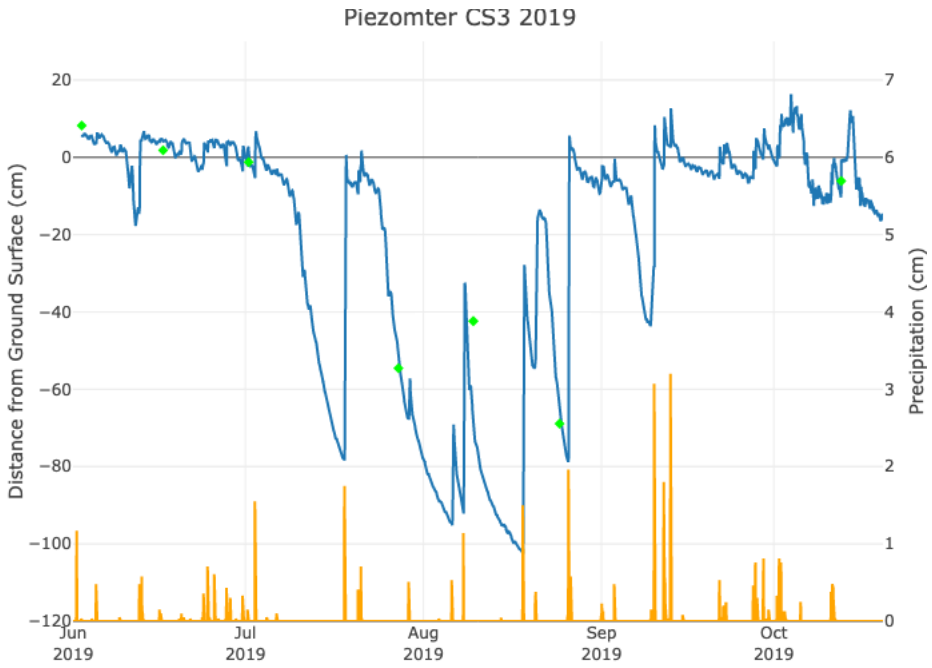
Additional Figure B.41 Water depth in piezometer RS1 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



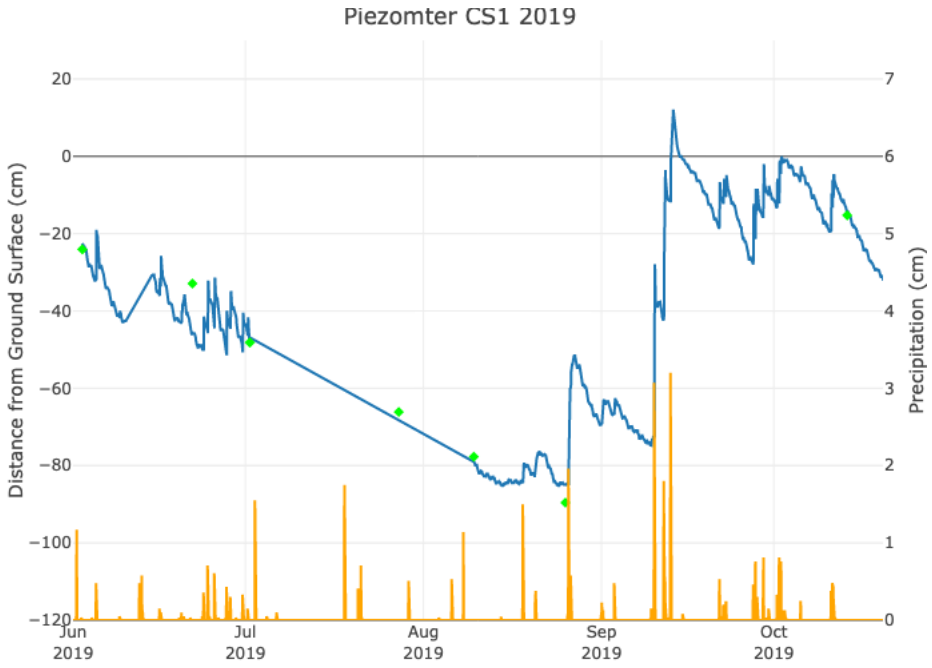
Additional Figure B.42 Water depth in piezometer CS5 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



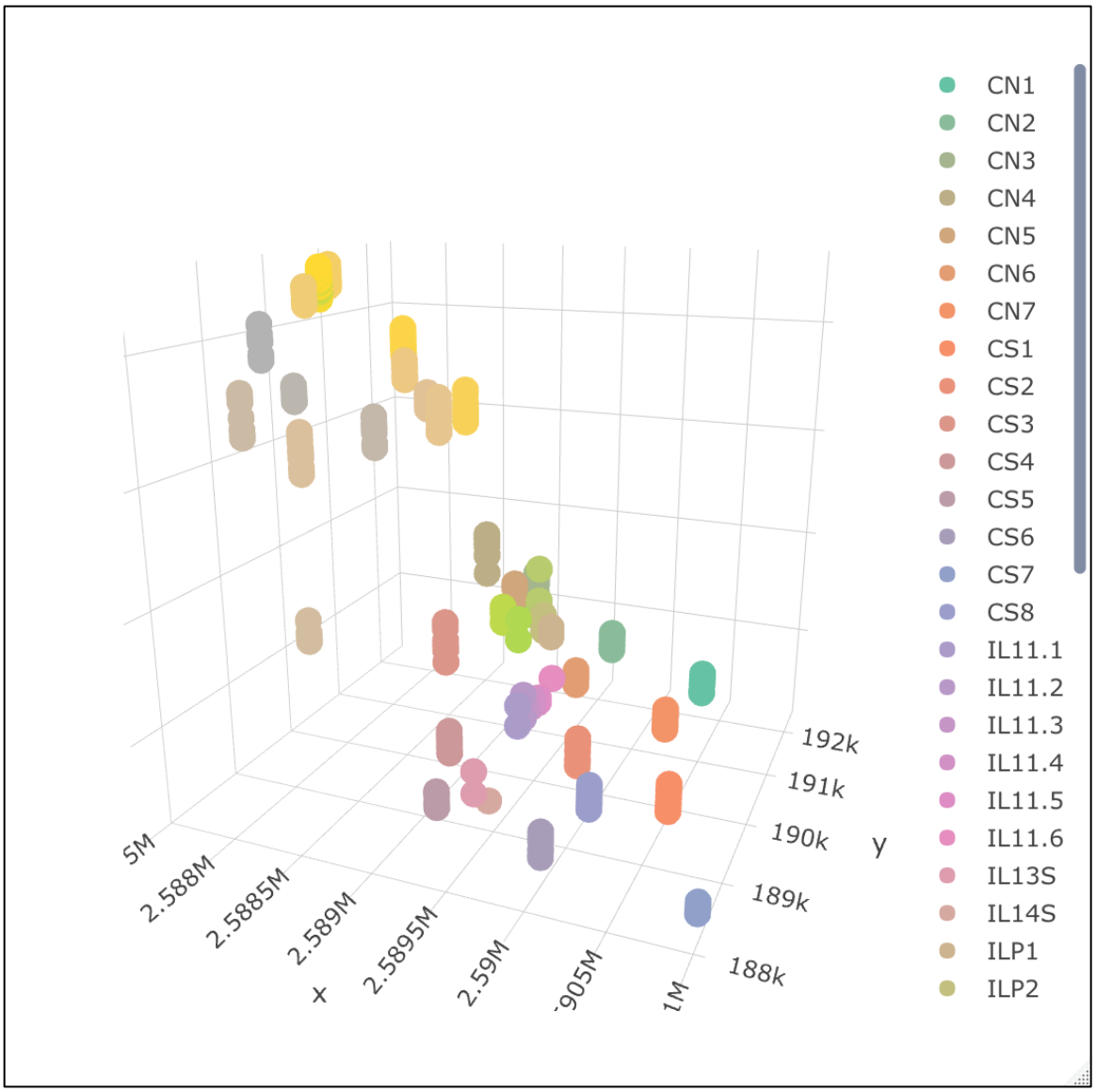
Additional Figure B.43 Water depth in piezometer CS4 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



Additional Figure B.44 Water depth in piezometer CS3 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



Additional Figure B.45 Water depth in piezometer CS1 during the 2019 field season. The blue line represents the pressure transducer measurements, green diamonds are hand orange bars are precipitation.



Additional Figure B.47 Three-dimensional scatter plot of all the recorded water table elevations from the hand measurements.