Initial Report on the Hydrology of the Burnette Foods Wastewater Application Fields

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Contents

1 Introduction

This report examines the surface and groundwater hydrology of the Burnette Foods wastewater application fields, the application and land management practices evident at the site, the pathways and travel times through which contaminants reach the wetlands, and the concentrations of contaminants in soils and groundwater. The report is organized into four sections: 1) Hydrology of the Burnette Foods Wastewater Disposal Region, 2) Wastewater Surface Applications, 3) Surface Runoff and Ponding, and 4) Wastewater Composition and Groundwater Quality.

The report is based on a wide variety of source data and observations, including: materials provided by Burnette to Plaintiffs in discovery, permit and reporting materials available from the State of Michigan, aerial imagery from the USDA, land characteristic data from the USGS and USDA, map datasets from the State of Michigan, hydrology and wetlands data from the State of Michigan and USFWS, report datasets from the USGS, published scientific literature, and other sources. Every effort is made to properly cite the data sources as they are used and referenced.

This report also describes several original analyses, conducted using standard methods. These include: hydraulic conductivity analysis from nearby well data, groundwater flow rate calculation with multiple methods, and surface runoff flowpath calculation.

Burnette Foods is permitted to apply wastewater to six different fields, totalling 48.7 acres. The most recent permit, effective June 1 2017, includes a variety of conditions. These include (summarized from the GW1810211 v2.0 permit document):

- Maximum daily and annual limits on the volume of wastewater that can be applied to the fields.
- Maximum daily and weekly limits on the depth of wastewater that can be discharged to each field
- Concentration limits on a variety Total Inorganic Nitrogen (TIN), Total Phosphorus (TP), Chloride (Cl), and Sodium (Na).
- Downgradient groundwater monitoring well water quality limits to pH, TIN, Nitrite Nitrogen (NO_2-N), TP, and Sulfate (SO_4)
- ”The discharge shall not be, or not be likely to become, injurious to the protected uses of the waters of the state.”
- Runoff is not to be created on site: ”A portion of the flow is expected to percolate to the groundwater while the remainder is utilized by plants or lost through evaporation.”
- A cover crop, here a mixture of perennial vegetations, is to be grown on the fields.
- Applied nutrients should not be in excess of the cover crop’s needs: ”In no case shall nutrients provided by wastewater and supplemental fertilization exceed the nutrient requirements of the crop based on the yield goal for that crop.”
- Sufficient time between applications should be given for the soil conditions to become unsaturated and aerobic.
- Discharge system should be designed such that the discharge volume plus the precipitation from a 10-year, 24-hour storm does not overflow the designed discharge area.
- If modifications are made to the approved Discharge Management Plan (DMP), the permittee must submit a revised DMP to EGLE (then, DEQ) for approval.

Each of the items mentioned above will be discussed in the following sections, with Burnette Foods in substantial violation of each of them. Critically, these violations are likely driving substantial loading of barely altered wastewater into the adjacent wetlands. This wastewater contains loads of biological oxygen demand, nitrogen, phosphorus, and sodium—along with a variety of other contaminants—that are likely to be harmful to the wetland ecosystem.

2 Hydrology of the Burnette Foods Wastewater Disposal Region

Burnette Foods' wastewater application site is located roughly 1 mile south of Elk Rapids, between Elk Lake to the east and Lake Michigan's Grand Traverse Bay to the west. Application fields surround a wetland complex, and a small creek, called here Spencer Creek, emerges within that wetland complex. There is a farm road that bisects the wetland complex, with two sub-grade culverts providing connectivity between the two halves. The National Wetlands Inventory (Figure 2) includes the wetland complex as a mix of forested and emergent wetlands. The State of Michigan, in their Framework Hydrology dataset maps Spencer Creek as beginning at that farm road.

The topography of the region is, for Michigan, highly varied (Figure 3). To the south of the site, hills reach 700 feet above sea level, while the wetlands surrounded by the site are at approximately 600 feet. The dataset mapped in Figure 3 is a 1 meter DEM collected via airborne laser infrared detection and ranging (LIDAR) survey in 2016. The elongated North-South oriented features are glacial in origin.

The region is composed of thick deposits of glacial materials (Figures 4 and 5). The Burnette site is mapped as coarse-textured glacial till. Such sediments can be highly varied, including sands and gravels, as well as lenses or layers of finer-textured materials.

The thickness of these sediments is highly variable, with the thickest deposits in the region being to the south and east of the site, and the thinnest to the southwest. In general, thicknesses of glacial sediments around the site exceed 150 feet. Glacial sediment thickness was computed using a bedrock topography layer extracted from a groundwater model of Lake Michigan created by the USGS (Feinstein et al., 2010). The thickness of the glacial sediments was computed as the difference between the bedrock surface and the ground surface elevation.

Hydraulic conductivity, a measure of how easily water flows through sediments, is also highly variable (Figure 6). Higher values will allow water to flow more easily, and rapidly, than lower values. To compute this, data from Michigan's Wellogic system were used. Many of the Wellogic wells include estimates of hydraulic conductivity based on the types and thicknesses of materials in each well log. Then, the proportion of confining materials (non-aquifer materials) in each well was computed. The effective hydraulic conductivity was computed as the product of aquifer hydraulic conductivity and the proportion of the well that is composed of aquifer materials (1 - confining material proportion). For this graphic, aquifer hydraulic conductivity values at each well were then averaged within polygons of glacial geology units from Fullerton et al. (1984).

2.1 Site Hydrogeology and Groundwater Flow Rates

In 2009, Mackinac Environmental produced a Hydrogeological Evaluation Report for the Burnette Foods site. As part of this work, Mackinac Environmental installed 6 new monitoring wells, and two additional vertical wells within the the wastewater application fields (Figure 7). Mackinac then conducted recharge tests in the wells, which were used to estimate hydraulic conductivity (pp. 5–7 of the report). This test has many assumptions, and brings with it substantial uncertainty. Yet, the results are consistent with well lithology data. In the South field #36, values range from 3.64 - 140.9 ft/day—within a regional estimate of 16.96 ft/day as an average of Wellogic data (Figure 8).

As noted in the report, groundwater flows towards the wetlands. Average monitored water levels from 2002–2024, listed in Burnette Foods documents, are shown in Figure 9. The wetland, situated at approximately 603 ft, lies significantly below water table levels in the monitoring wells. In the South field #36, the hydraulic gradient from MW-11 to the wetland is approximately 2 ft/300 ft. Across more of the South field, the gradient is roughly 6 ft/600 ft. This gradient, between 0.0067–0.01, is substantially higher than the 0.002 gradient estimated by Mackinac Environmental. In Field #37, the gradient of 6 ft/230 ft is 0.02. In Field #38, the gradient is closer to 0.03–0.04.

We compute groundwater flow velocity using the equation $v = K \cdot i/n$, where v is the velocity, K is the hydraulic conductivity, i is the hydraulic gradient, and n is the effective porosity. Mackinac Environmental seleect an effective porosity value of 0.35, taken from literature not from samples analyzed at this site. This value is used in the calculations below. Note that, when discussing values of hydraulic conductivity, the units are feet/day. Though these units are the same as velocity, hydraulic

Figure 1: Location map of the Burnette Foods wastewater application fields. Hydrography lines and polygons are the State of Michigan Framework Hydrology v17a. Other products such as the National Hydrography Dataset have nearly identical features, notably including Spencer Creek up to the farm road.

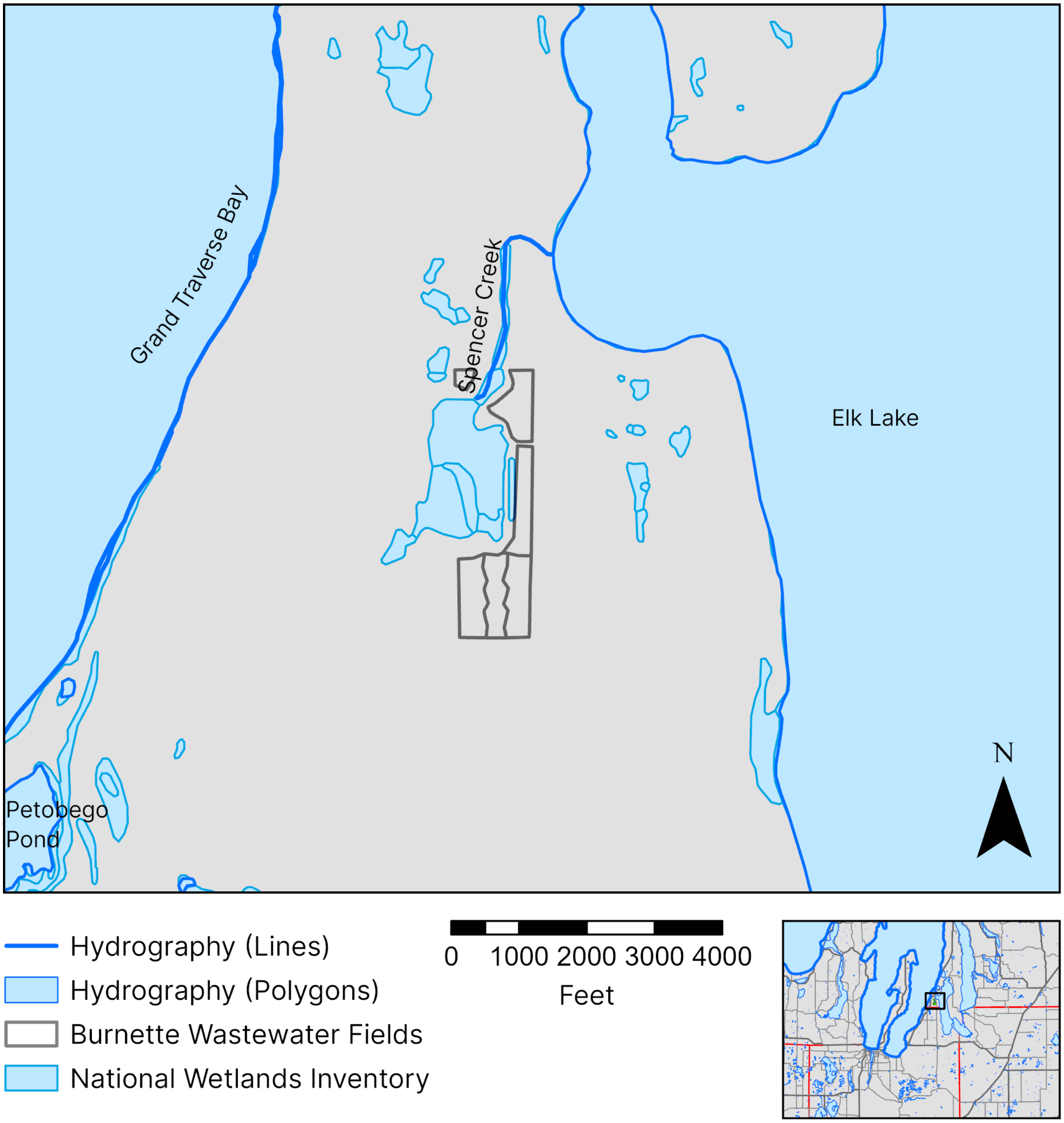


Figure 2: Hydrology of the region overlain with mapped wetlands in the National Wetlands Inventory.

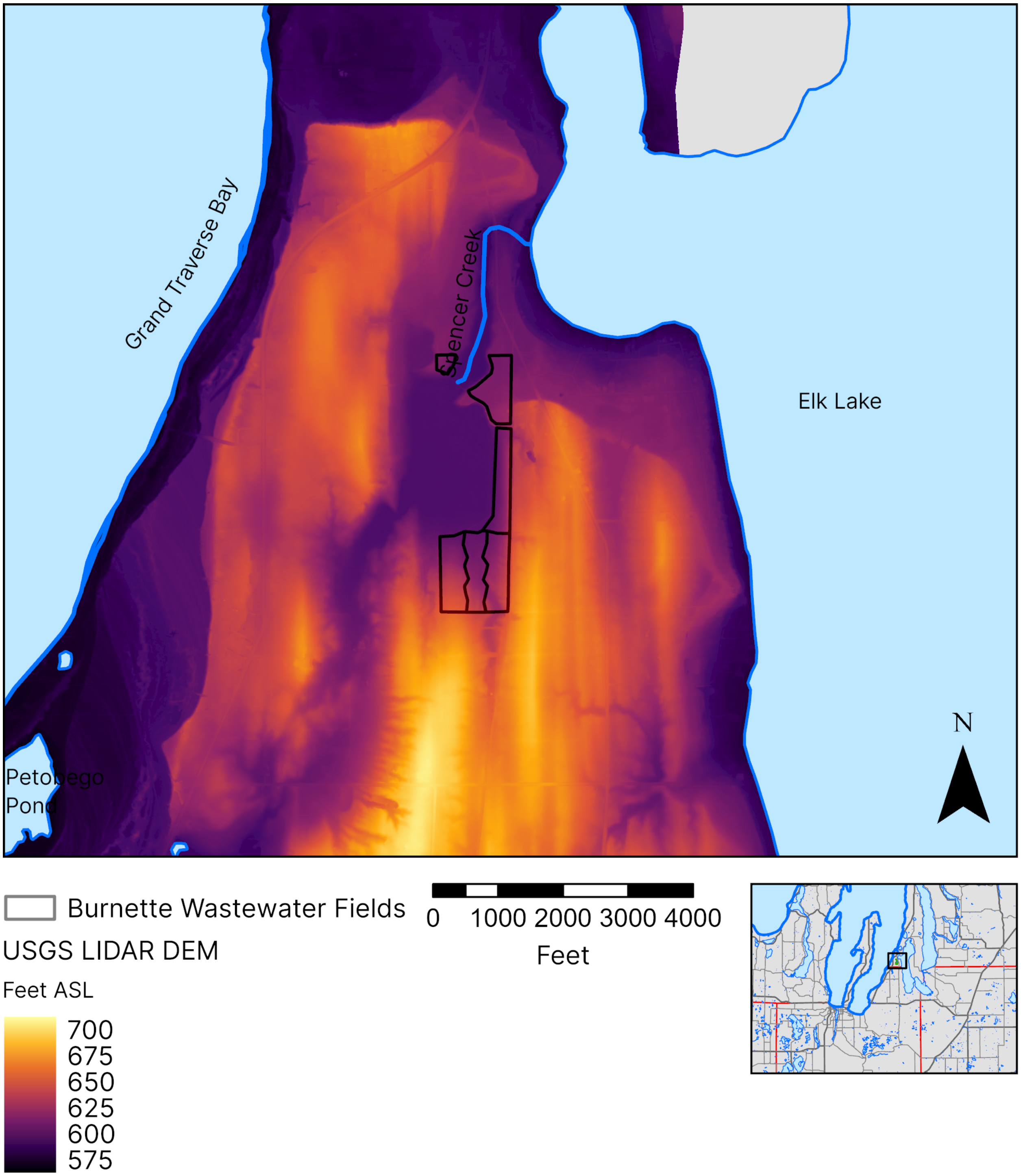


Figure 3: Topography of the region surrounding the Burnette Foods wastewater application fields. Data are from the USGS 1 meter DEM, collected via airborne LIDAR survey in 2016.

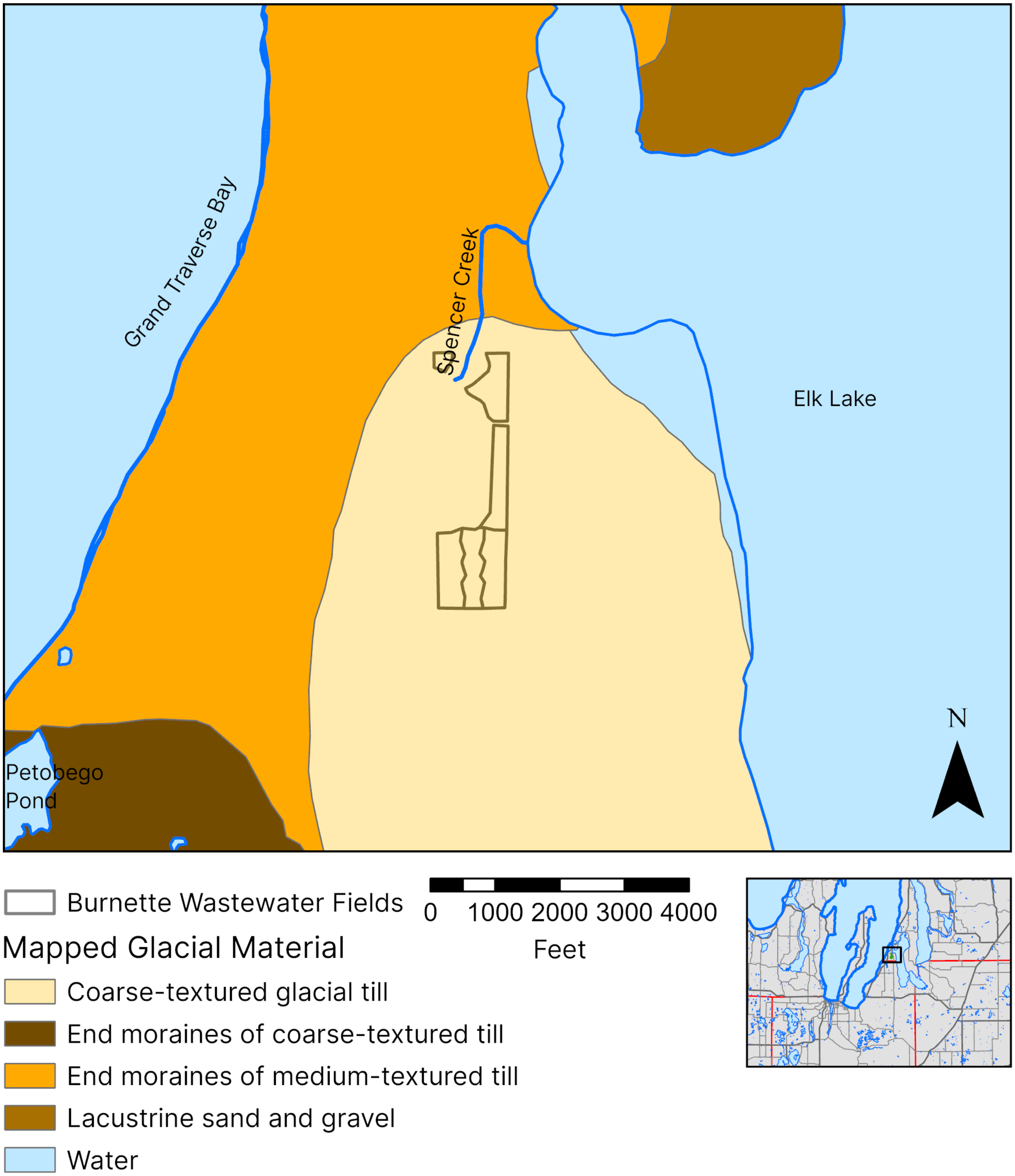


Figure 4: Glacial geology, from the map of the Quaternary Geology of Michigan by Farrand and Bell, 1982. Note, there the relatively coarse-scale geologic map has a different boundary for Elk Lake than that of the more accurate Framework Hydrology product.

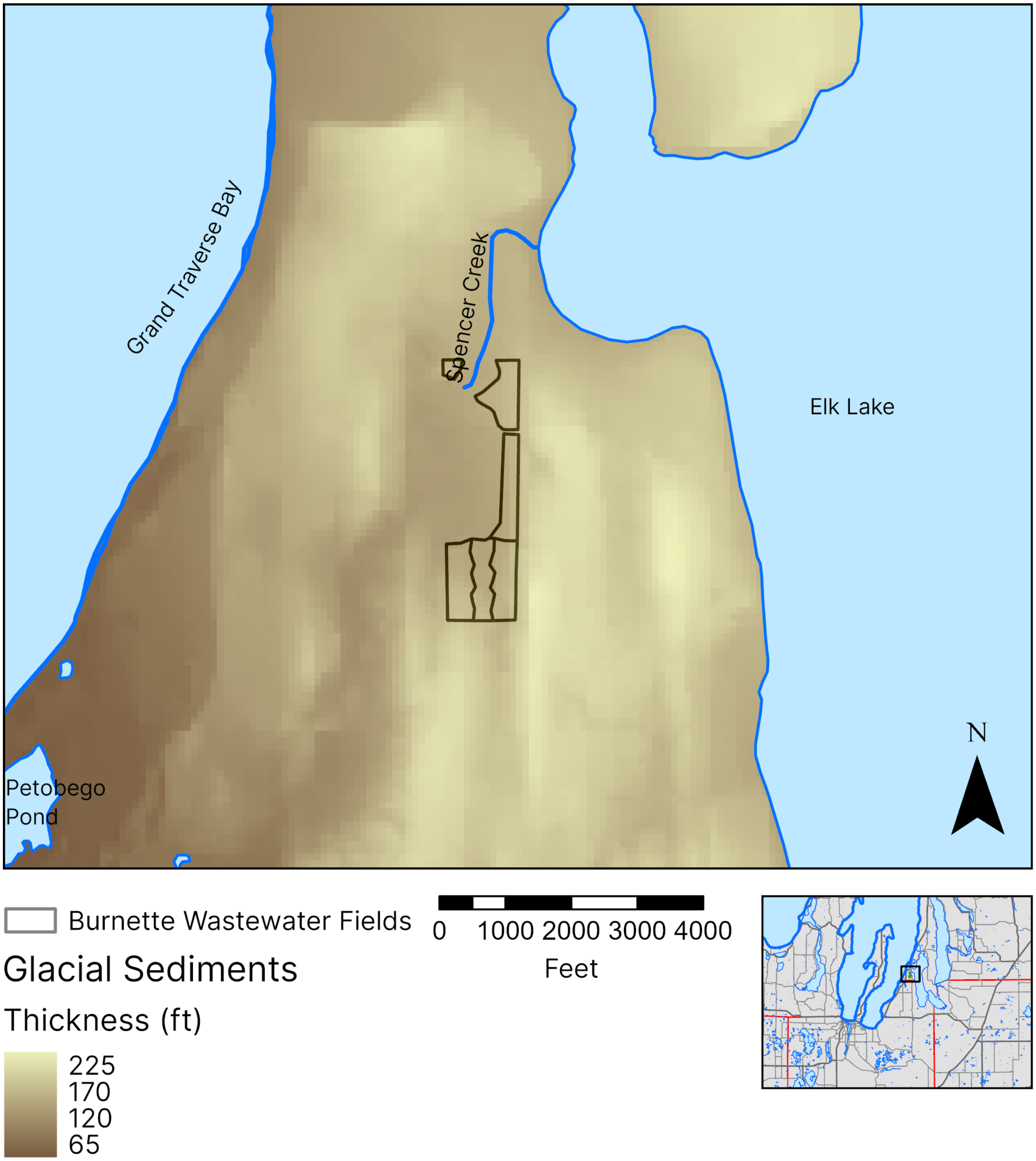


Figure 5: Thickness of glacial sediments, from Feinstein et al. (2010).

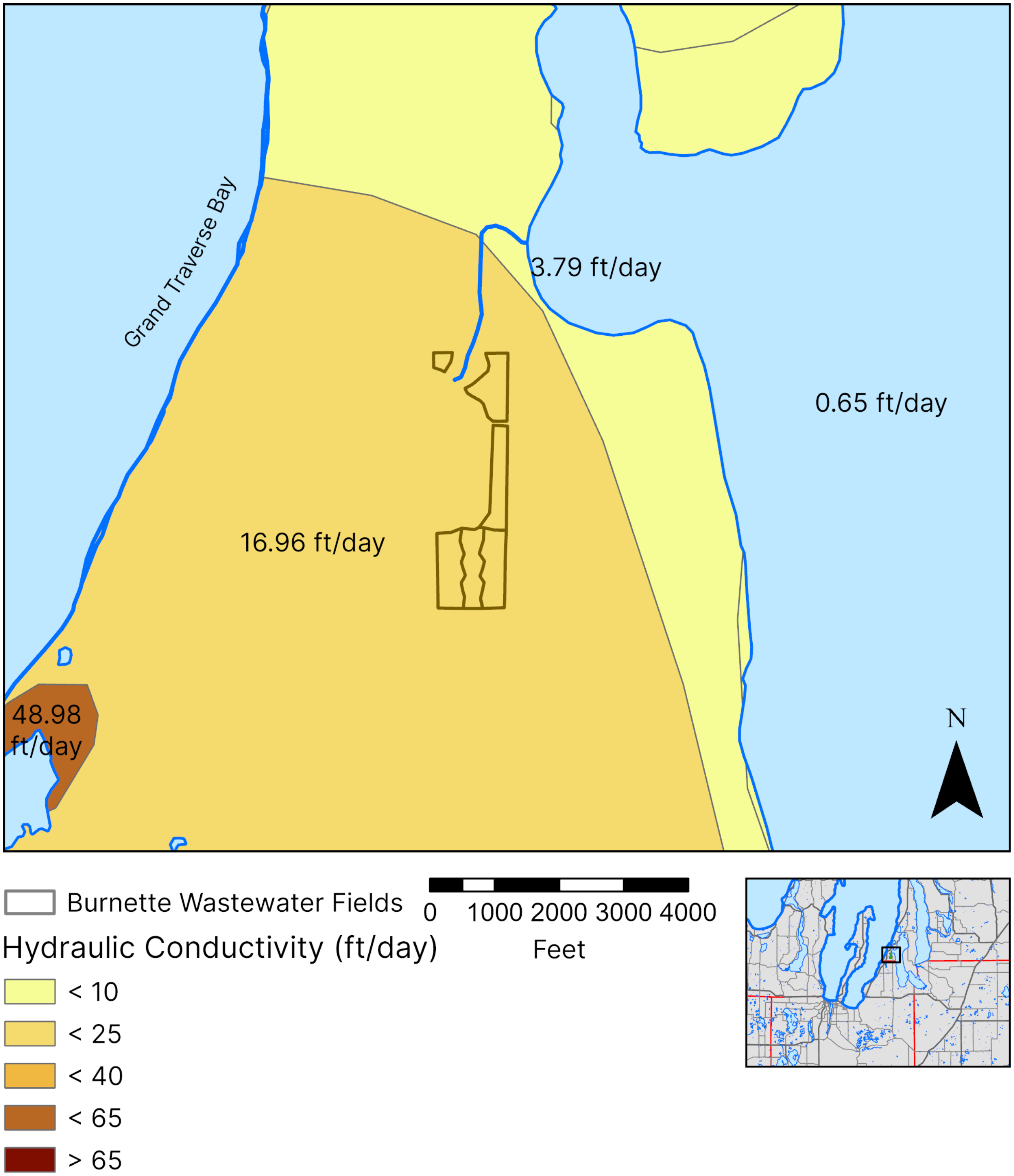


Figure 6: Hydraulic conductivity of the glacial sediments, estimated from Wellogic lithology data, overlain on the map from Fullerton et al. (1984).

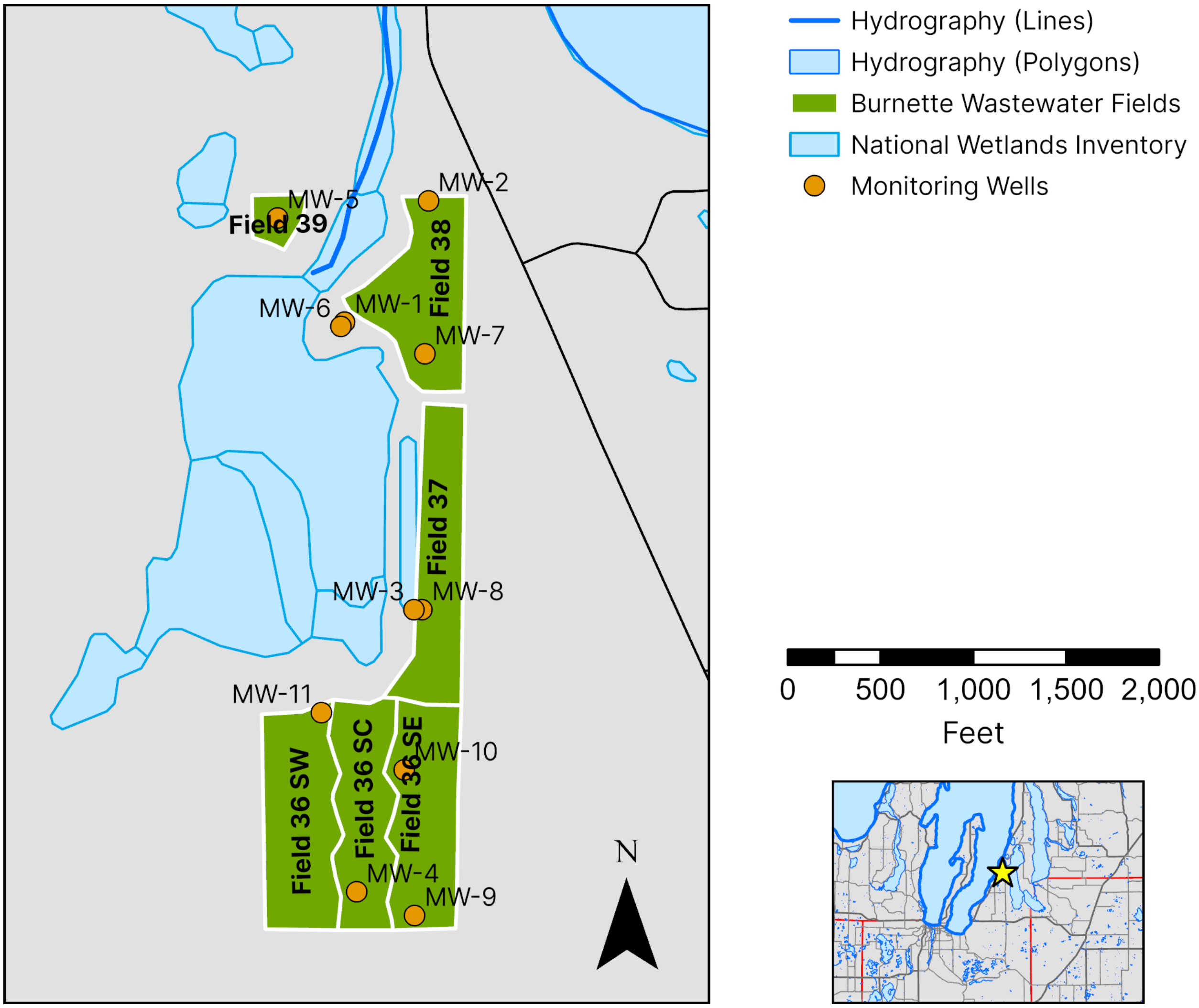


Figure 7: Monitoring wells 1–11 installed in the Burnette Foods site.

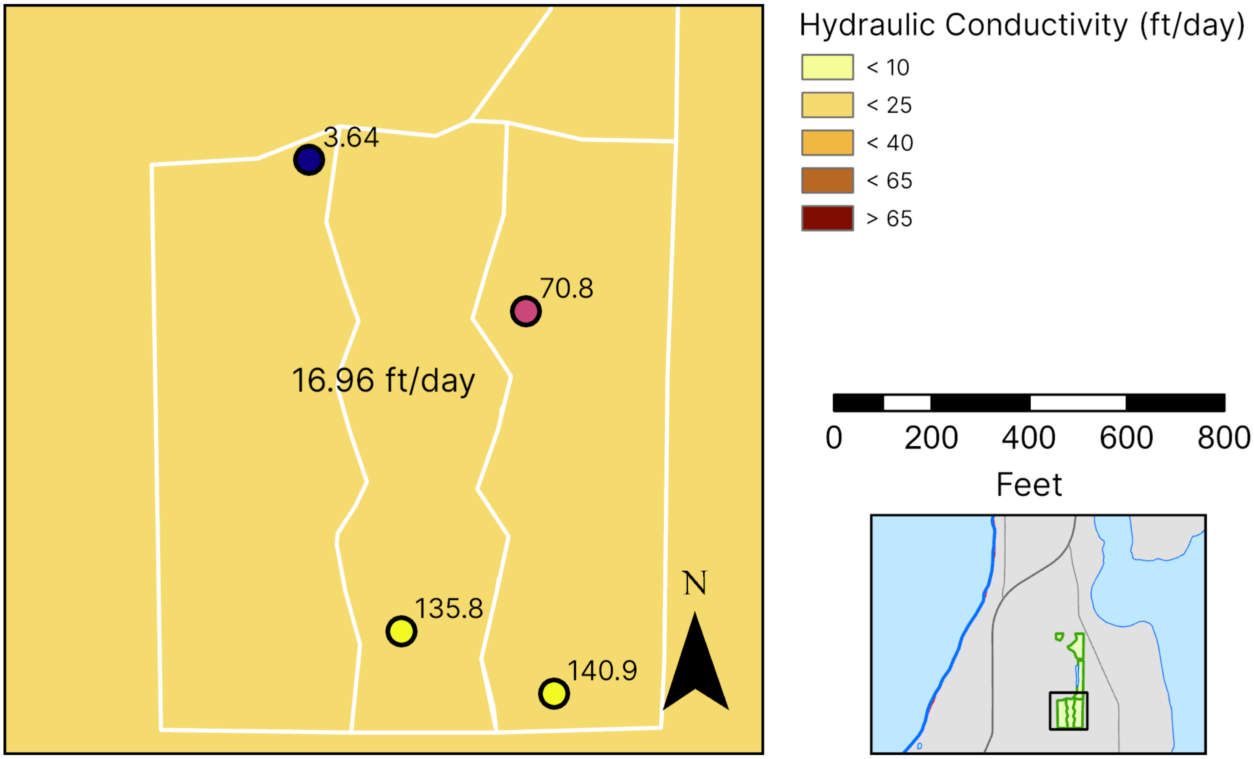


Figure 8: Hydraulic conductivity estimates from the Mackinac Environmental 2009 Hydrogeological Evaluation.

conductivity is not directly a velocity, but is directly related to it via this equation.

As Mackinac Environmental's recharge tests (also referred to as ”slug tests” in hydrogeology) show, hydraulic conductivity values can vary by factors of 100 or more within the same site. If the sediments have a higher hydraulic conductivity, then water will flow more quickly than in sediments with lower conductivity. Values of conductivity taken via the recharge method are influenced primarily by the materials around the well screen (in this case, just a 5' interval), while flow through the aquifer is controlled by connections of higher conductivity materials across the entire site. Woessner et al. (2024), and other introductory hydraulic testing textbooks, emphasize that the ”slug tests” performed by Mackinac Environmental are useful, but are not representative of site-scale flow conditions. This is particularly true when the well screen is as short as it is on these monitoring wells (5 feet).

In South field #36, hydraulic conductivity value estimates range from 3.64–140.9 ft/day, with a central estimate of 17 ft/day. Hydraulic gradient values range from 0.0067–0.01, and an effective porosity of 0.35 (as reported by Mackinac Environmental). The range of velocities is 0.07–4.0 ft/day, with a central estimate of 0.49 ft/day. The distance from the northern edge of the field to the nearby, downgradient wetland, is just 70 feet. From this point, the travel time through groundwater likely ranges from 17.5–1000 days, with a central estimate of 143 days. Further away, travel times from the center of the field to the wetland are likely closer to 1000 days. There exists a lot of uncertainty in these estimates due to the variability of subsurface materials. A more detailed hydrogeologic investigation, including additional samples and groundwater modeling, would be required to further refine this estimate.

In field #37, hydraulic conductivity estimates are even more uncertain, given that both samples are in the same location. With our central estimate of 17 ft/day, and a gradient of 0.02, the velocity is roughly 0.97 ft/day. Travel times from the base of Field #37 to the wetland, roughly 125 feet away, are approximately 128 days.

In field #38, conductivity values may be higher, though the data are thin. Using the same 17ft/day estimate, velocities are likely 1.5–2.0 ft/day. At distances of 70-150 feet to the wetland, dependent on field position, travel times are likely 28–100 days. Note, however, that surface runoff is likely less com-

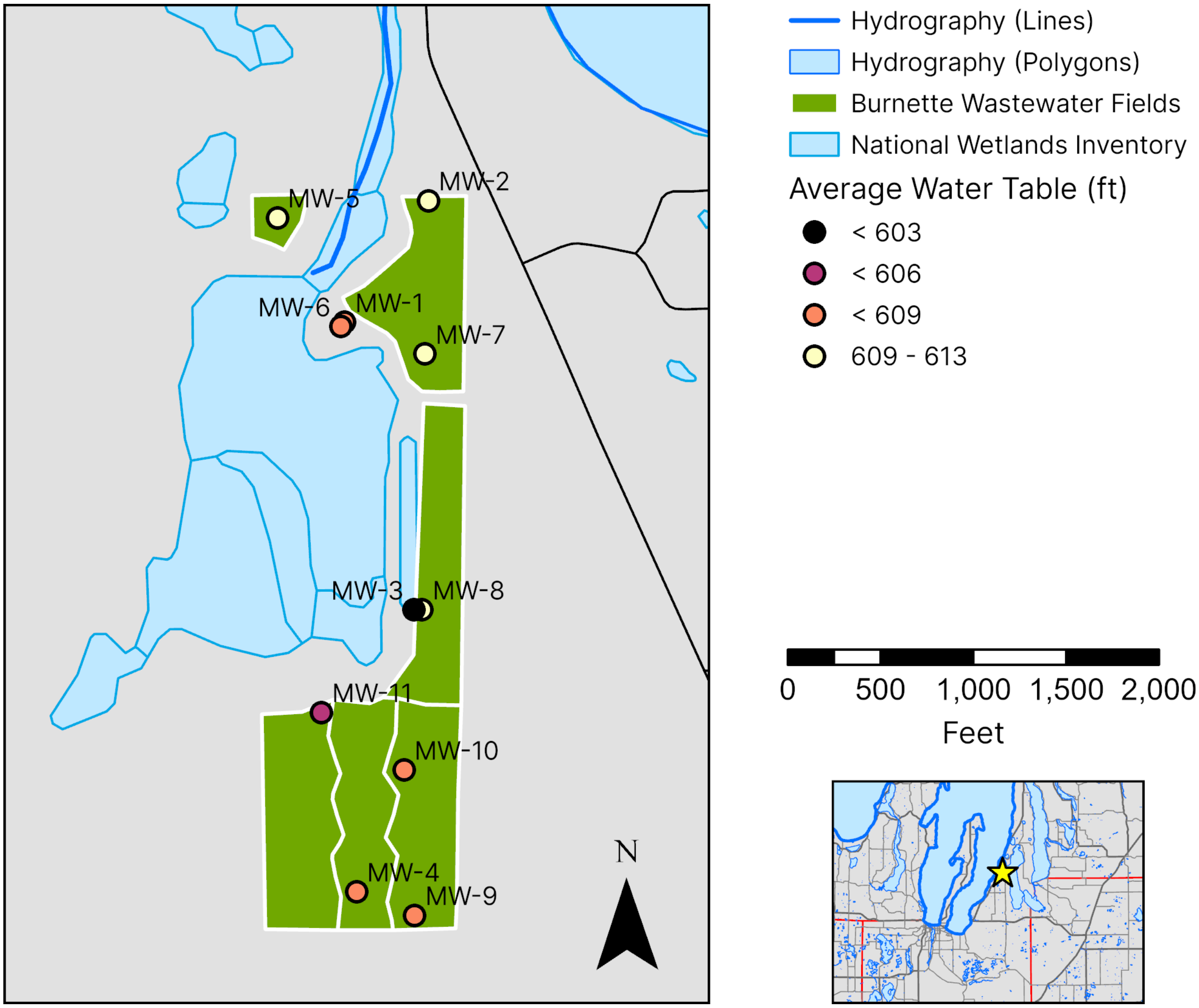


Figure 9: Average water table elevation from 2002 - 2024, from monitoring data.

mon in Field #38 because of its higher infiltration capacity. Thus, a more representative travel time would be that from a point 1̃/2 the radius of the irrigation polygons about 300 feet from the wetland. Travel times, then, likely range from 150–200 days. These calculations are summarized in Table 1.

Table 1: Summary of estimated hydraulic gradients, velocities, and groundwater travel times. These estimates generally assume a 17 ft/day hydraulic conductivity value, and 0.35 effective porosity. Travel times are based on distances of 75 feet (Field #36), 125 feet (Field #37) and 300 feet (Field #38). Note, hydraulic conductivity values are highly uncertain. Hydraulic gradients are based on observations from Burnette, collected in documents BFI #00018741-00018746.

Field	Gradient(ft/ft)	Velocity(ft/day)	Travel Time Estimate(days)
36	0.0067–0.01	0.33–.49	142–212
37	0.02	0.97	128
38	0.03–0.04	1.5–2.0	150–200

Groundwater travel times this short mean that the wastewater applied to the fields is likely to reach the wetland in a matter of months. This is particularly true in the South field #36, where the travel time from the runoff retention basin is likely less than 6 months, and for Field #38 where travel times are demonstrably even shorter (see the subsection below on Excessive Sodium Concentrations). This is a substantial concern, given the high BOD, nutrient, and salt loads in the wastewater, and the potential for these contaminants to reach the wetland. To reiterate, these estimates of travel time are highly uncertain, and a more detailed hydrogeologic investigation would be required to refine them. Nevertheless, if the application system is not functioning as designed at the surface, it is likely that the wastewater is reaching the wetland in a matter of months.

3 Wastewater Surface Applications

The section below will show that Burnette Foods has a long history, going back to within days of reissuance of its latest permit in June 1, 2017, of violating the volume and depth conditions of its permit. These violations are not occasional, rather, they are operational. The volume of wastewater applied to the fields has exceeded the permitted annual limit in 4 out of 6 years, with the most significant violation occurring in 2020. The daily volume limit was violated twice, in 2019 and 2021. The daily depth limits are violated on average 20% of the time, with 185 violations of daily permitted maximum depths occurring. Weekly depth limits are violated 52% of weeks, peaking at over 80% of weeks during July, with a total of 348 violations of weekly maximum depths. The fewest depth violations occurred in 2023, with 37, while the most occurred in 2019, with 104.

3.1 Volume of Wastewater

Table 2 summarizes the permit land application rate limits, daily and weekly, for each field. The table also includes the volume equivalents that correspond to the permitted daily and weekly application depth limits. Note, these volumes assume wastewater is applied evenly to the total area of each field. These daily and weekly by-field volumes are not specific permit conditions. However, the permit limits the total volume of wastewater applied to all fields at 425,000 gallons per day, and 15,000,000 gallons per year.

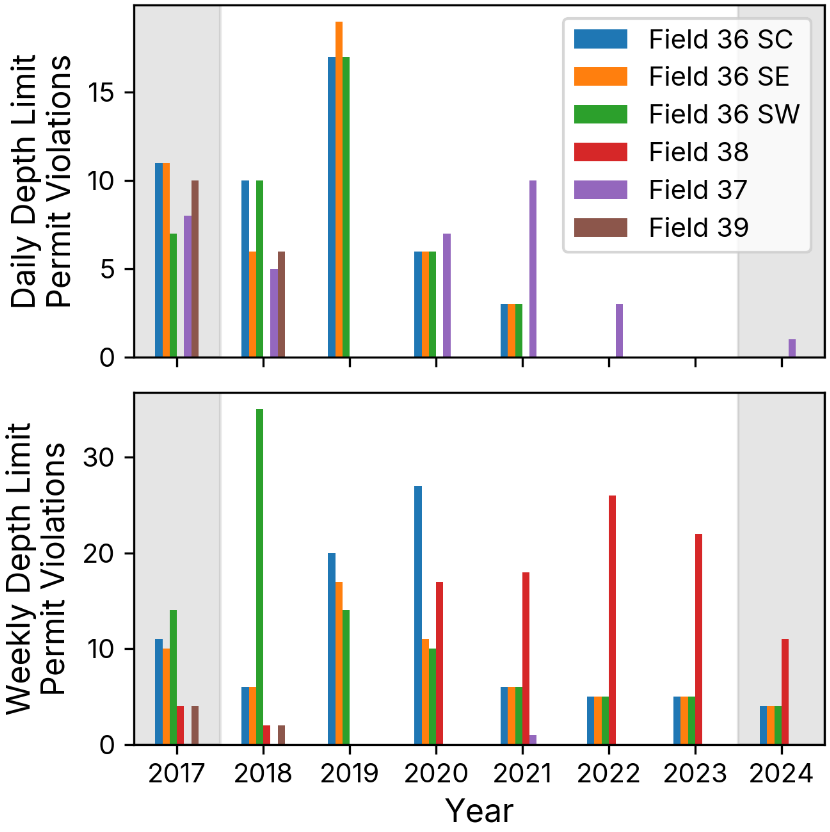
To analyze compliance with these permit conditions, monthly and annual Discharge Monitoring Reports (DMRs) were analyzed from June 2017 to September 2024. The DMRs were downloaded as PDF files from the MiEnviro Portal, searching for the GW1810211 permit number. A Python script was then used to extract the data from the PDFs. The accuracy of this extraction was validated by comparison to application and sampling data provided by Burnette Foods as part of the discovery process in this case.

Figure 10 shows violations of daily and weekly application depth limits for each field, along with tables that summarize those violations. With the exception of 2023, violations in daily depth limits occurred each year from 2017–2024, with a notable decline since 2022. From 2017–2019, weekly and

Table 2: Summary of permit land application rate limits, daily and weekly. Rates and areas taken from the approved Discharge Monitoring Pla, 2019 revision C (DMP) and the permit document for Permit GW1810211 v2.0. Italicized values are calculated from the permitted values and field sizes data. Additionally, total discharge volumes are to be limited to 425,000 gallons per day, and 15,000,000 gallons per year.

Field	**Area (acres)**	**Depth (inches)**	**Volume (gallons)**	**Period**
July 1 - August 15				
North Site (IRR-38)	8	0.68	144,000	daily
		4.0	*847,059*	weekly
South-East Site (IRR-36 SE)	10	0.34	*92,333*	daily
		2.04	*553998*	weekly
South-Center Site (IRR-36 SC)	10	0.34	*92,333*	daily
		2.04	*553998*	weekly
South-West Site (IRR-36 SW)	10	0.34	*92,333*	daily
		2.04	*553,998*	weekly
Field 37 (IRR-37)	6.7	0.34	62,000	daily
		2.04	*372,000*	weekly
Field 39 (IRR-39)	4	0.1	11,000	daily
		0.7	*77,000*	weekly
August 16 - June 30				
North Site (IRR-38)	8	1.96	426,000	daily
		4.0	*869,388*	weekly
South-East Site (IRR-36 SE)	10	0.34	*92,333*	daily
		0.34	*92,333*	weekly
South-Center Site (IRR-36 SC)	10	0.34	*92,333*	daily
		0.34	*92,333*	weekly
South-West Site (IRR-36 SW)	10	0.34	*92,333*	daily
		0.34	*92,333*	weekly

daily violations occurred at roughly the same rates. But, since 2020, weekly violations have continued to occur at similar frequency, while daily violations have tapered significantly. In total, 185 violations of daily permitted maximum depths occurred, and 348 violations of weekly maximum depths. The fewest violations occurred in 2023, with 37, while the most occurred in 2019, with 104.



Year	Total
2017	47
2018	37
2019	53
2020	25
2021	19
2022	3
2023	0
2024	1

Year	Total
2017	43
2018	51
2019	51
2020	65
2021	37
2022	41
2023	37
2024	23

Figure 10: Violations of the daily and weekly application depth limits for each field from June 2017 to September 2024. Refer to Table 2 for the permit limits. Note, 2017 and 2024 have incomplete data, indicated by shaded backgrounds on the plots. The most recent permit was issued as of June 1, 2017, which marks the beginning of DMR data. Data were only available through September, 2024. The tables to the right of each plot sum violations across fields for each year.

Those violations were far more common in July and August than other months (see Figure 12). This is particularly true for daily application depth violations that almost all occurred during those two months. Weekly violations were more evenly distributed throughout the year, occurring in all months. The most violations occurred in July, with 108 each for weekly and daily depth limits. August, the second most likely month for permit violations to occur, saw 70 daily and 61 weekly violations.

While there were not as many violations from September–June, the percent of weeks during which at least one weekly depth limit violation occurred was more uniform throughout the year (Figure 12). July saw weekly violations occurring on at least one field 88% of the time, while 74% of the weeks in May had violations, and 62% of the weeks in August did. Even the lowest month, December, had more than a 25% chance of a weekly depth limit violation occurring. Daily depth limit violations occurred less frequently, with only July and August have significant proportion of days with violations, at 27% and 17% of days, respectively.

In addition to daily and weekly application depth limits per field, the permit specifies daily and annual maximum volume limits, at 425,000 and 15,000,000 gallons, respectively. Figure 12 shows

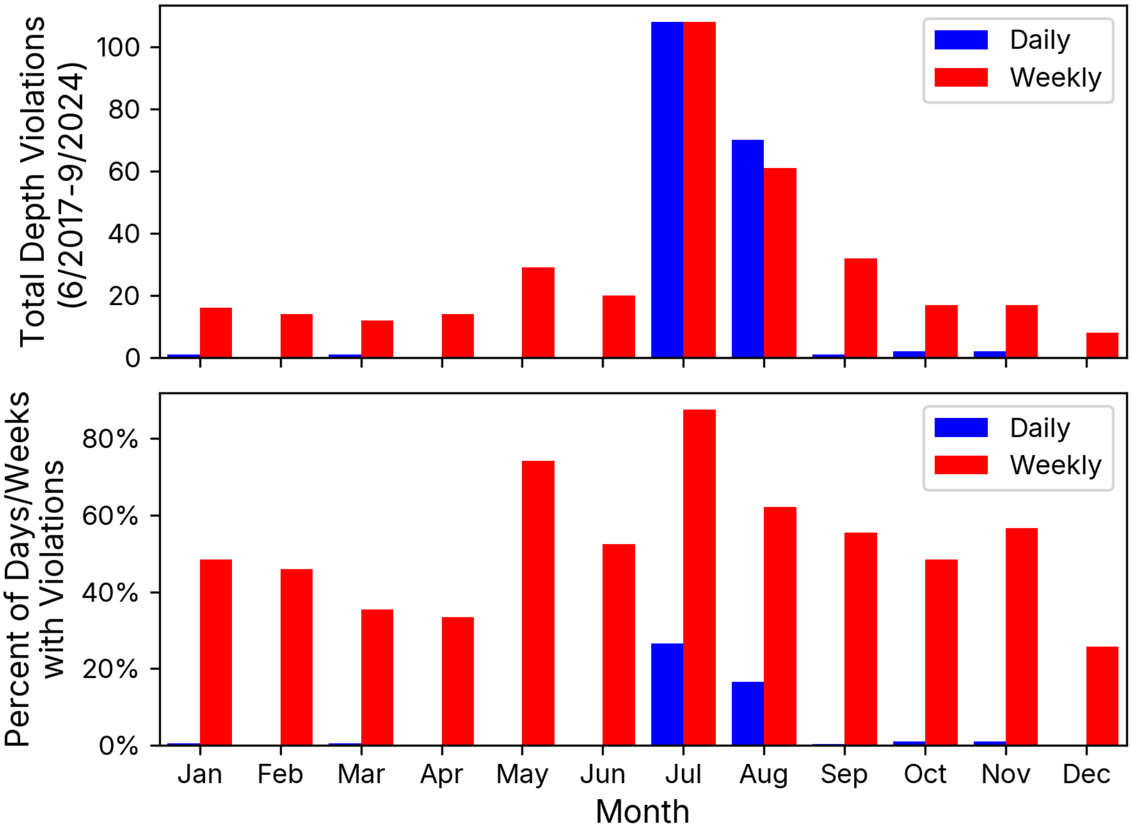


Figure 11: Total violations of the daily and weekly application depth limits each month(top) for all fields from June 2017 to September 2024. On bottom, the percent of days or weeks in each month with violations occurring. Refer to Table 2 for the permit limits.

the cumulative volume of wastewater applied to all fields, as well as the daily application volumes. The daily application volumes are calculated as the sum of the daily application depths for all fields, multiplied by the area of each field. The cumulative volume of wastewater applied to all fields is the sum of the daily application volumes within a year. The dashed red lines in each plot indicate the permitted maximum daily and annual volumes. 2017 and 2024 were omitted from this figure as they had incomplete data available. During most years (4 out of 6), Burnette violated the maximum wastewater application amounts, by nearly 33% (approximately 5,000,000 gallons) in 2020. Daily total volume violations were reported only twice, once in 2019 and again in 2021.

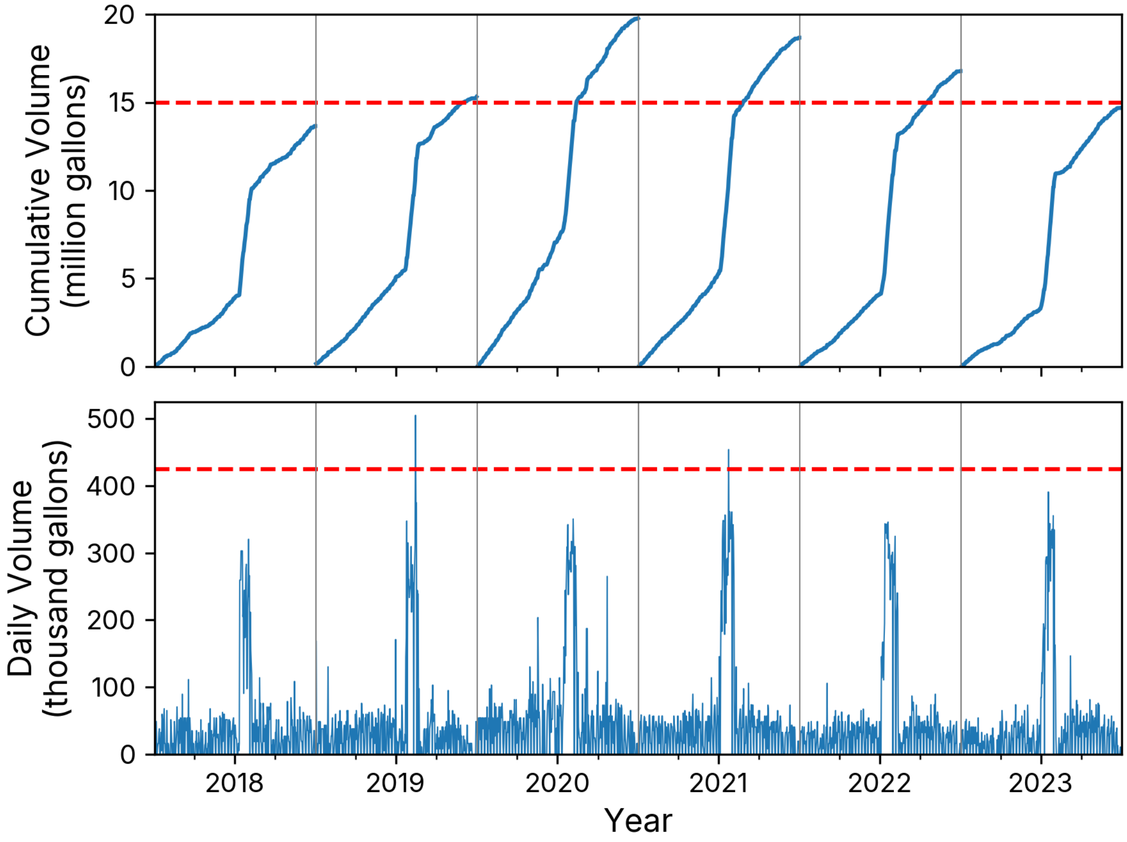


Figure 12: Cumulative volumes of applied wastewater to all fields (top) and daily applications (bottom), from 2018–2023. Note that 2017 and 2024 were excluded as these years had incomplete recorders available. For each plot, a dashed red line indicates the permitted maximum 425,000 gallons per day, and 15,000,00 gallons per year.

Taken together, these data suggest that violating the depth and volume conditions specified in their permit is regular operating procedure. Weekly application depth limits are violated on at least one field, on average 52% of the time. Daily application limits occur roughly 20% of days during peak season (July and August). In total, 533 depth limit violations occurred from June 1, 2017–September 30, 2024. The volume of wastewater applied to all fields exceeded the permitted annual limit in 4 out of 6 years, with the most significant violation occurring in 2020. The daily volume limit was violated twice, in 2019 and 2021.

4 Surface Runoff and Ponding

Burnette Foods is applying wastewater in sufficient volumes and in such a way as to generate surface runoff on a regular basis. As the four subsections below will demonstrate: 1) surface runoff occurs regularly, 2) is exacerbated by an irrigation system that utilizes only part of the permitted area while still using the full permitted application volumes, 3) over decades of use has likely reduced the infiltration capacity of the fields, and 4) collects water either along a constructed berm, or in a triangular-shaped pond with raised sides (hereafter ”retention basin”). The combined effects of the management choices and site conditions through decades of use renders the system less effective at treating wastewater.

This retention basin was presumably constructed at some point during the site’s current use, at the northern edge of the South Field that is nearly always at least partially wet. This retention basin is located at the lowest spot on the landscape, where multiple overland flow paths converge. It would not have been built were regular runoff not occurring, as it is not part of the wastewater treatment infrastructure. Its nature was immediately obvious upon visiting the site. The basin is not part of the treatment area, and is inside the berm. Its regular geometry and raised sides indicate it was constructed, rather than occurring naturally.

While likely much of the wastewater is still percolating into the ground, a substantial portion of untreated wastewater currently, and for at least 16 years, flows overland and collects at the base of the South Field, and potentially others as well (particularly Field #37). This overland flow has a very short travel time with minimal biogeochemical alteration of the wastewater. There, it has the chance to infiltrate within just 75 feet of the edge of the wetland adjacent to the fields. Depending on the condition of the artificial berm built around the edge of the field, sufficient water may collect in the retention basin to flow directly into the wetland. Even a repaired berm, as reported by the client, can likely be overtopped one or more times a year, given the low observed infiltration rate on Field #36.

4.1 Observations of Surface Runoff

According to a letter from EGLE to Burnette, Dated November 15, 2021 (Document #BFI 00000101), during an inspection on July 27, 2021, runoff from field 36 was observed ponding along the northern edge of the field, leading into the wetlands north of the field. This is not the only time that such runoff was observed. In two site photos, dated 8/25/2008, retrieved from the MiEnviro Portal, show ponded water in one of the spray fields. A letter dated August 3, 2007, also retrieved from the MiEnviro Portal, describes a similar situation, with ponded water observed in the North field.

Burnette Foods built a berm surrounding the entire perimeter of their field sometime before 2016 (when high-resolution digital terrain maps were constructed). In the letter dated August 3, 2007 retrieved from the MiEnviro Portal, the berm was mentioned as being in place. Concern was noted, saying ”The application rate should be checked for this sloping site.”

Another source of observations include aerial imagery, collected at regular 2–3 year intervals through the National Aerial Imagery Program (NAIP). These data, taken at quite high resolution, show both irrigation occurring as well as runoff ponded in the triangular drainage retention area at the bottom of the slope, along the north edge of the south field #36. The series of Figures below, (Figures 13 to Figures 19), show observable ponded water in a triangular-shaped retention basin at the north end of the field in 6 out of 7 images, collected in July, August, and September of 2009, 2012, 2014, 2016, 2018, 2020, and 2022. These images thus show ponded water 85% of the time.

Additionally, on a July 31, 2024 site visit, saturated soils were observed along the center column of irrigation sprinklers. At this time, the retention pond at the north end of Field #36 was empty, following a relatively light week of irrigation applications. Yet, the soils were saturated. The visit lasted a bit over 1.5 hours, during which no irrigation on Field #36 was observed, yet saturated soils remained.

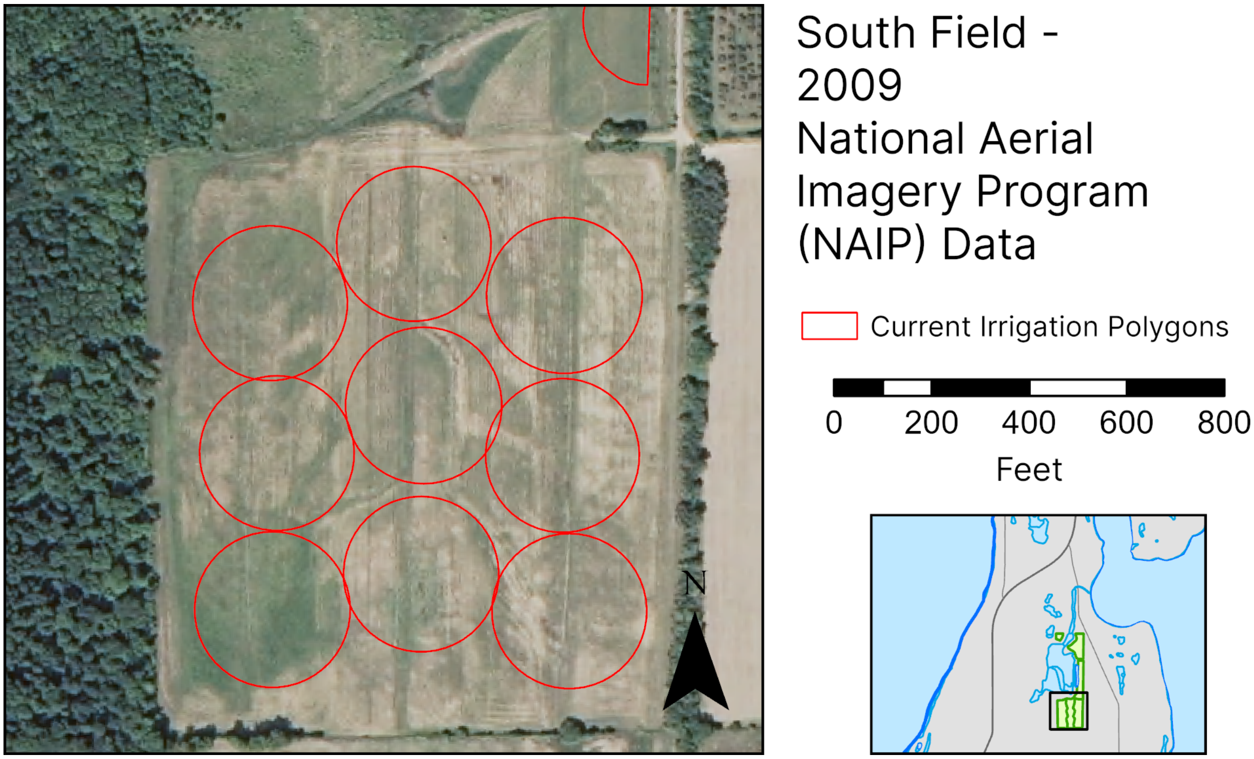


Figure 13: 2009 NAIP image, collected on 7/12/2009. Note the flooding indicated by the dark color in the triangular retention pond at the north end of this photo.

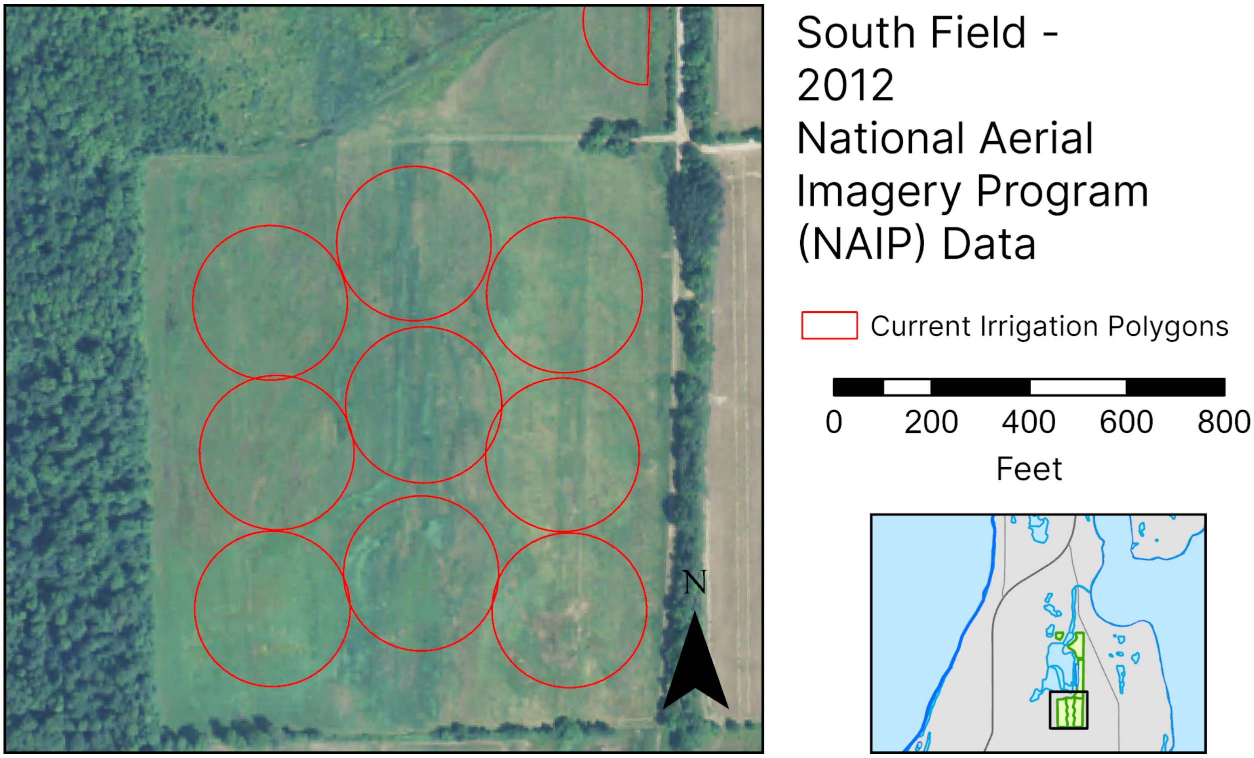


Figure 14: 2012 NAIP image, collected on 7/4/2012.

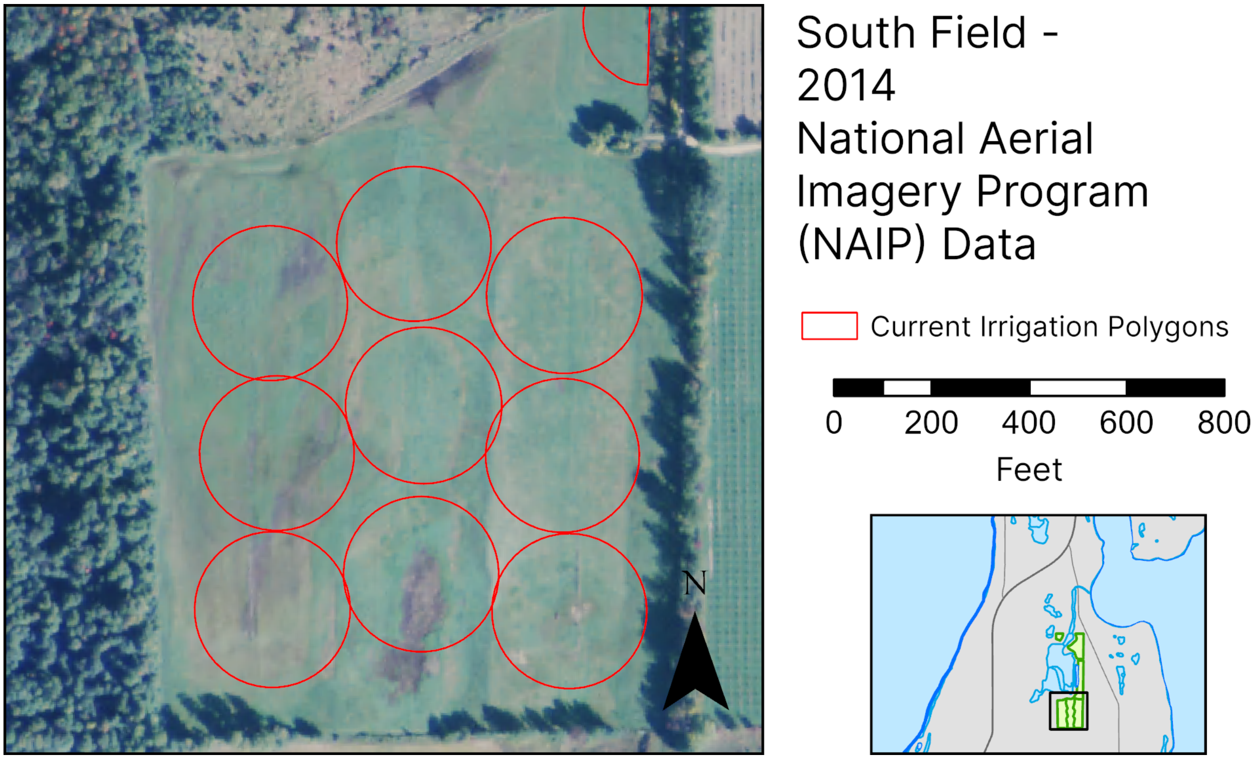


Figure 15: 2014 NAIP image, collected on 9/26/2014. Again, flooding is observed in the retention basin. Also, note the large brown patches of soil where the perennial crops required by the DMP are not established.

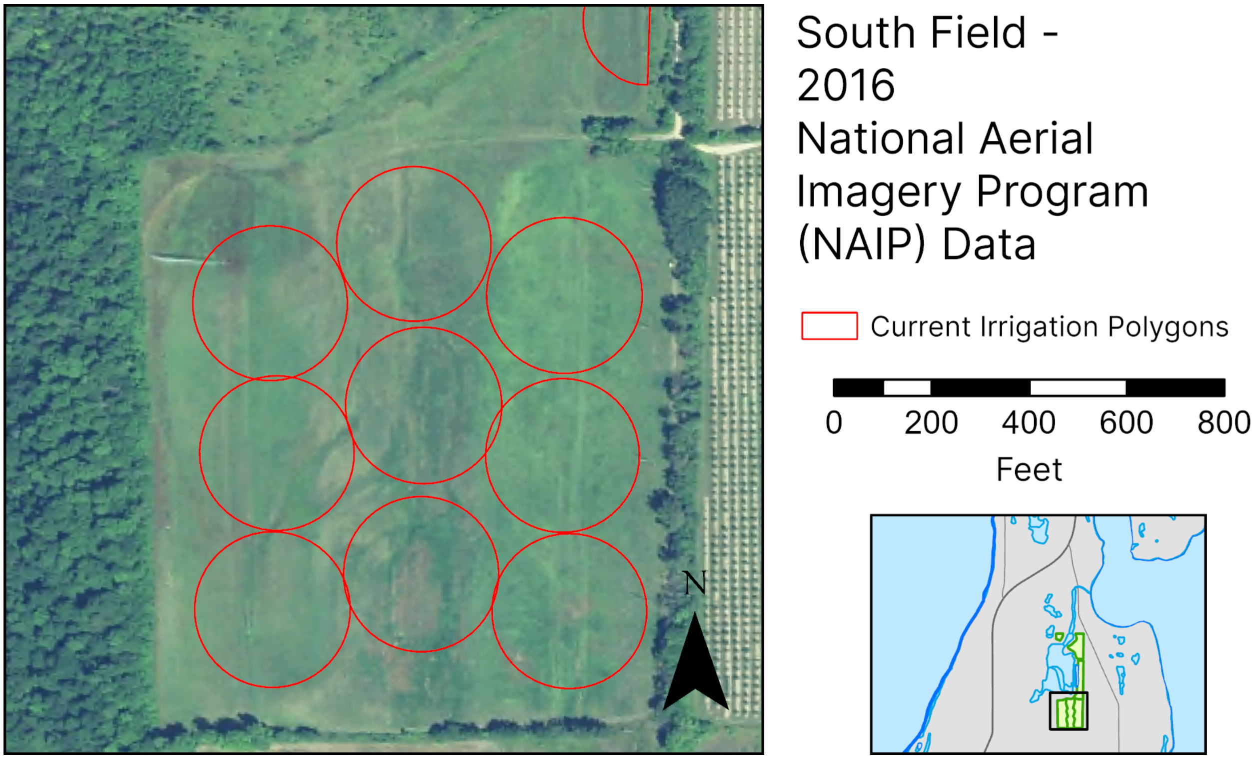


Figure 16: 2016 NAIP image, collected on 7/25/2016. Here, active irrigation is observed in the northwest corner of the field. Dark accumulations of runoff can be seen along the berm, just west of the retention basin.

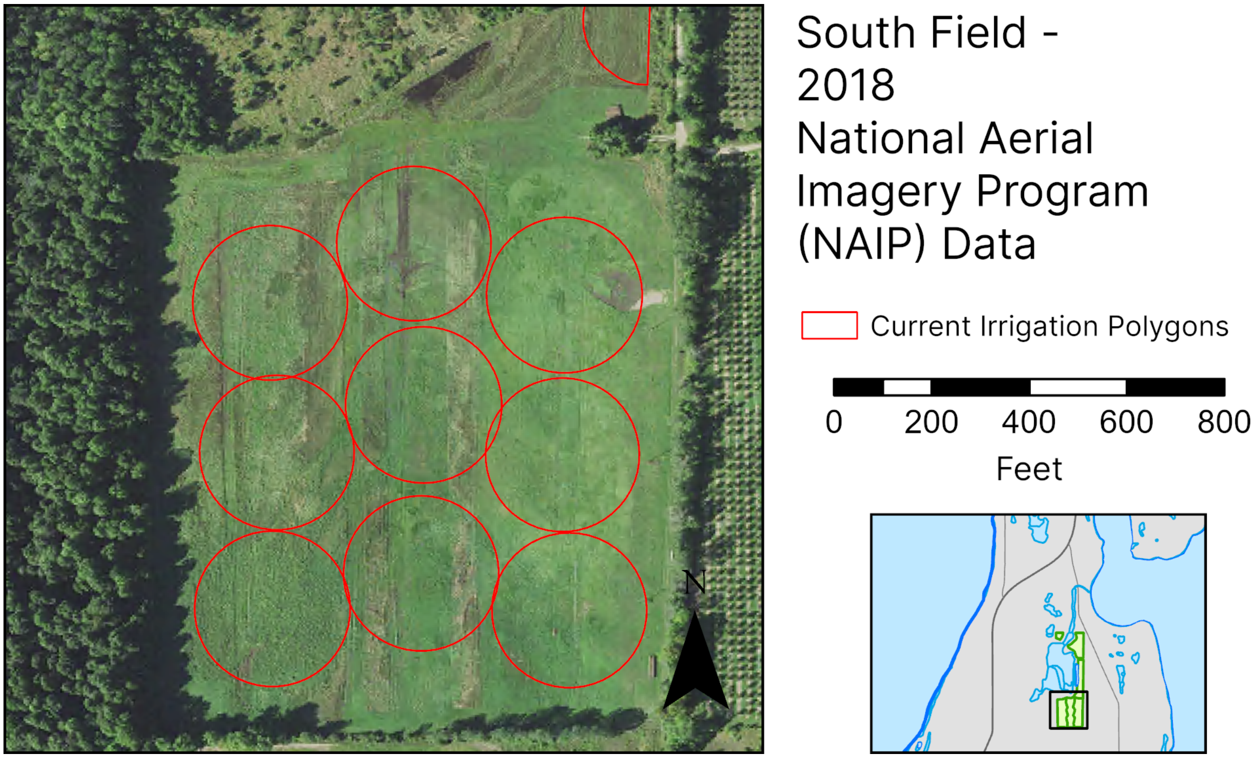


Figure 17: 2018 NAIP image, collected on 9/26/2018. Again, flooding is observed in the retention basin.

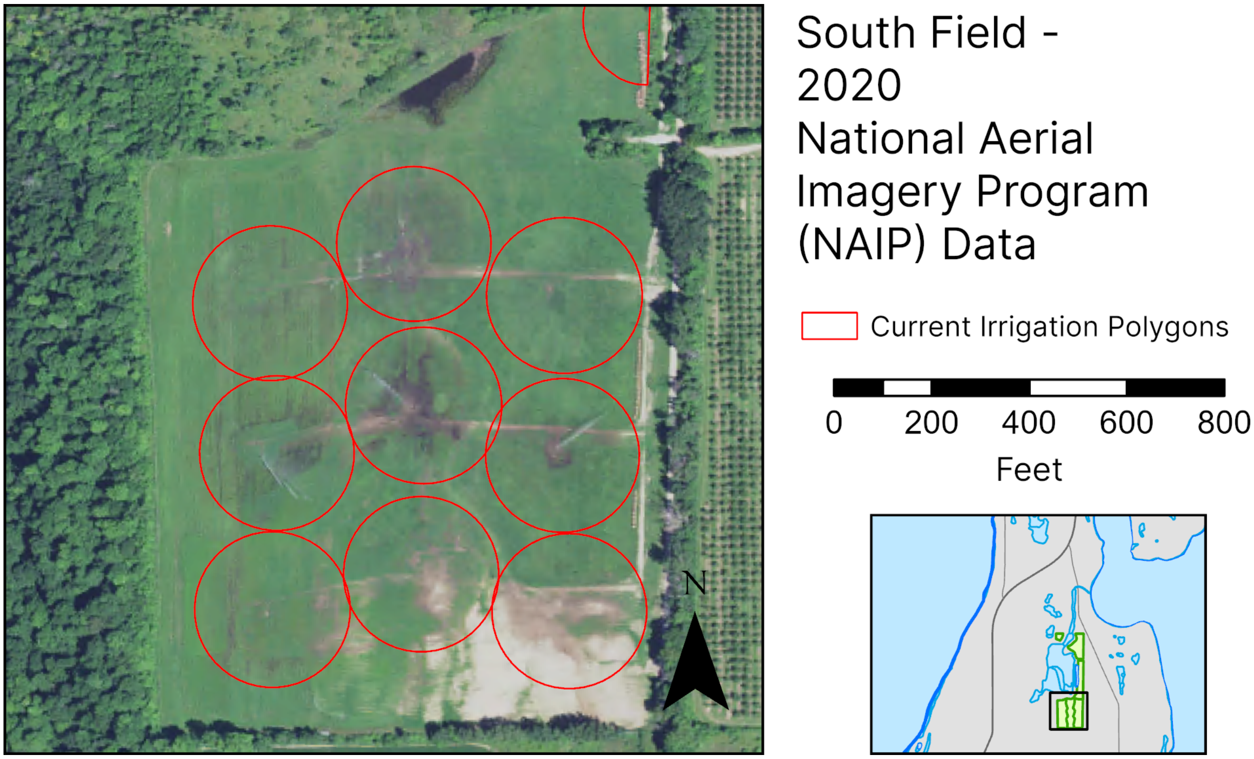


Figure 18: 2020 NAIP image, collected on 7/28/2020. This image, taken shortly after installation of a new fixed sprinkler system (see the lines marking buried piping), shows active irrigation, flooding, and large patches of unvegetated field.

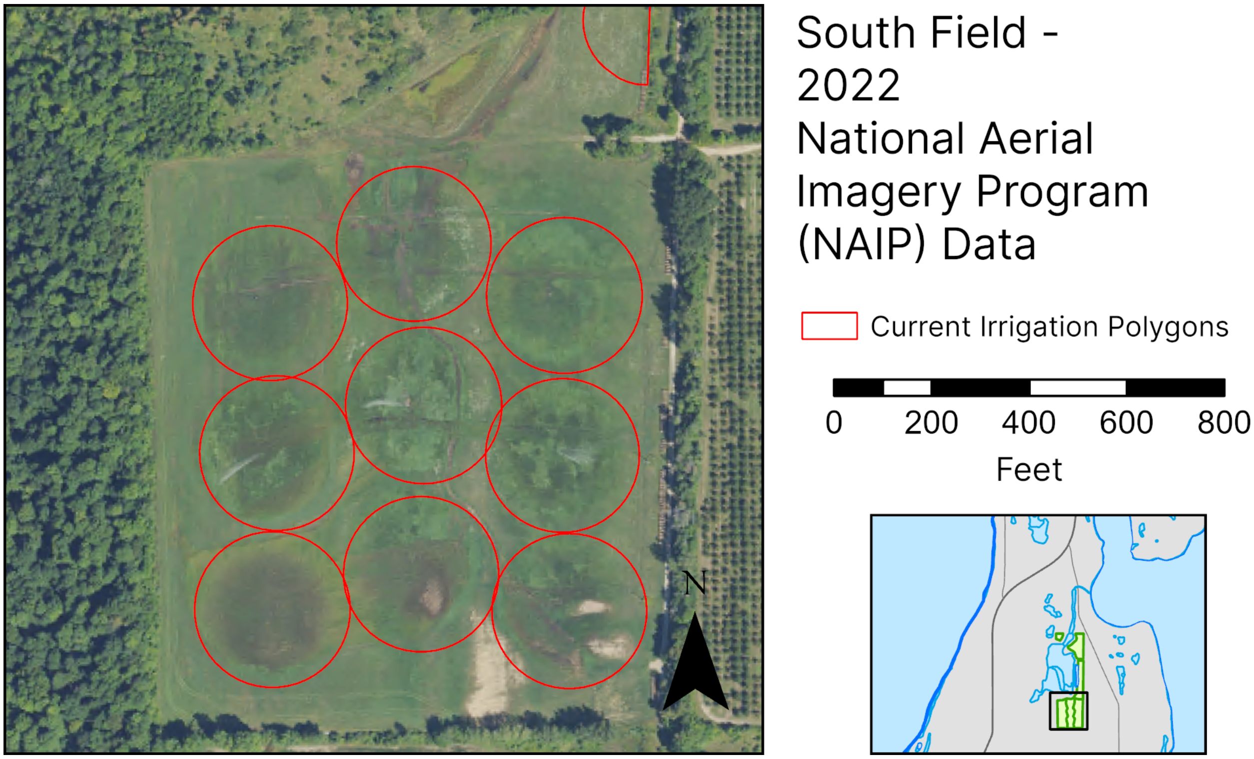


Figure 19: 2022 NAIP image, collected on 8/10/2022. Active irrigation is occurring in the center row of sprinklers. The retention basin has standing water, and large patches of field do not have vegetation.

4.2 Reduced Effective Application Area

In the summer 2020, Burnette installed a new fixed irrigation system across Fields #36, #37, and #38. The soil disturbance left by burying pipe can be seen in Figure 20. This system replaced the previous system, which included a variety of sprinklers, including: small distributed solid set sprinklers in #38; two types of traveling sprinklers for all fields, one large 425 GPM sprinkler, and another 150 GPM; and finally, there was a large solid set sprinkler head in Fields #36 and #38. Documents provided by Burnette (e.g. BFI #00000020, dated April 2020), show a design with planned sprinkler circles and semi-circles across the three fields. This image was overlain on the site map, and the circles digitized. These are displayed in Figure 20.

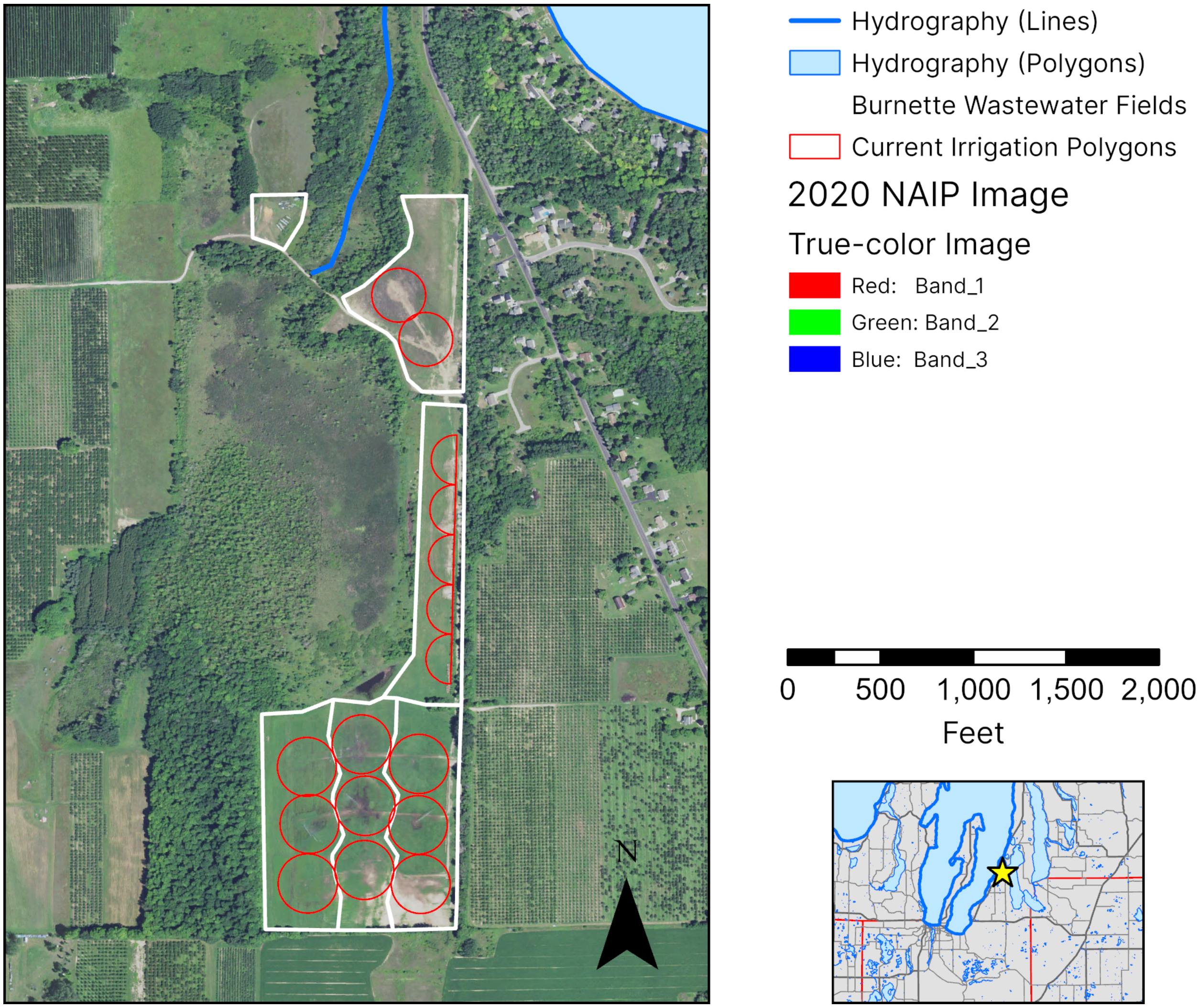


Figure 20: 2020 NAIP image of the entire Burnette Foods site showing disturbance from buried pipe in Fields #36, #37, and #38.

Additionally, the field polygon boundaries were digitized. First, the drawing by K. Kalchik (BFI #00000020) included green-shaded areas presumed to be the field boundaries. Sub-field boundaries for field #36 were identified first using the map in (BFI #00000025). Then the irrigation circles (”polygons” in mapping parlance) were used to better define sub-field boundaries in the south field #36. This allowed for a set of three irrigation polygons to fit within each sub-field boundary. A map of the site, with field boundaries and digitized irrigation circles, is shown in Figure 20.

Next, the areas of all polygons were calculated, shown in Table 3. The area of the irrigated polygons are substantially smaller than either the permitted field application area (for which irrigation application volumes and depths are permitted) or the digitized area.

The planned irrigation system improvement in 2020 included drawings for a distribution system for drip irrigation for Fields #37 and #38 (BFI #00000011). It is not clear if this system was installed, or in use, by 2022. No disturbance was noted in Figure 20 for the installation of this system in 2020, and green areas corresponding to this drip system are not evident in Figure 21.

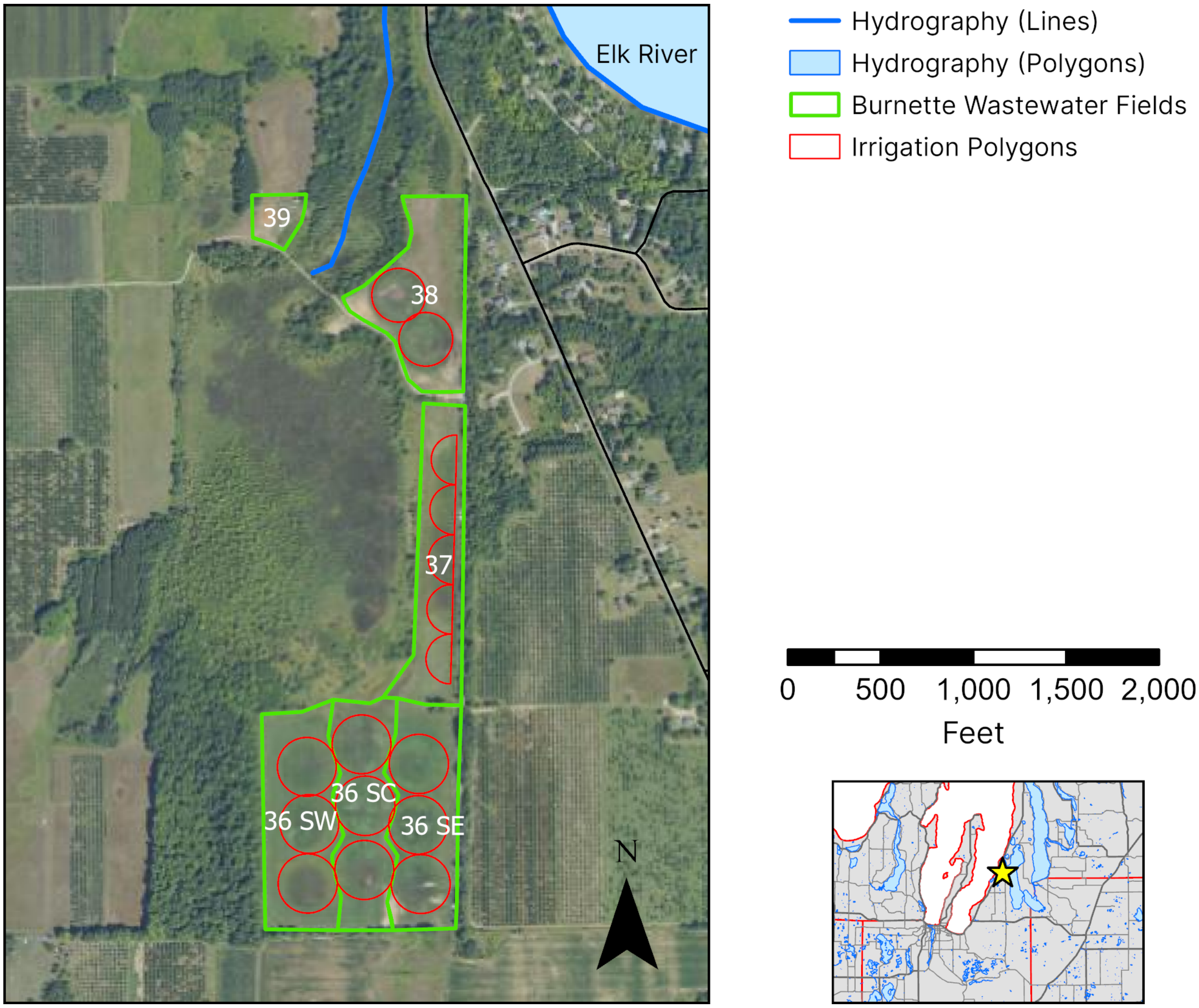


Figure 21: Map of the Burnette Foods site including field boundaries and digitized irrigation circles. These are overlain on the 2022 National Aerial Imagery Program (NAIP) aerial photo of the site. Note the green circles that follow the boundary of the digitized irrigation polygons.

The approved 2017 DMP as modified by Revision C in March of 2019 does not include the new irrigation system. While there may be an updated DMP, the MiEnviro Portal did not seem to include it. If there is not an updated DMP, then the new irrigation system is out of compliance with the approved DMP. This approved DMP describes a variety of sprinklers in use for Field #36, including traveling sprinklers. Similarly, it describes a drip system in the North Field #38. While these systems might exist, visual evidence from 2020 (Figure 20) and (Figure 21) show green areas corresponding only to the solid set sprinklers installed that year.

Secondarily, the DMP lists a 30 acre irrigated area for Field #36, which is, as discussed above not what is apparently in use either via aerial imagery or direct observation. Thus, the effective irrigated area is substantially smaller than the permitted area. The area irrigated in the South field #36 is

Table 3: Effective application areas for each field, based on the digitized irrigation circles.

Field	Permitted Area(acres)	Digitized Area(acres)	Solid-Set Area(acres)
36 SW	10	10.6	5.4
36 SE	10	10.0	5.4
36 SC	10	8.6	5.4
37	6.7	9.5	3.3
38	8	9.7	3
39	4	1.6	n/a

about 55% of the permitted area. The irrigated area in Field #37 under 50% of that permitted, while in Field #38, the two solid-set sprinklers irrigate just 38% of the permitted area. Field #39 does not have a solid-set installation, apparently, however the area demarcated in drawings is only 40% of the permitted area.

Permitted application depths, and thus volumes, are calculated based on what the soils can handle over a specified area. If just half of the area is specified, then only half of the permitted volume should be applied. Prior to 2020, it appears that use of traveling sprinklers allowed for more of the South field to be utilized. For instance, in 2016, Figure 16 a sprinkler can be seen spraying well outside the northwest present-day sprinkler polygon. This suggests that the effective application area was larger in 2016 than now after 2020 (Figure 18).

Burnette Foods simply does not appear to be using acreage anywhere near that used to design and approve their wastewater treatment system. Applying the same amount of water over half the specified area will likely produce more runoff and make growing vegetation on the field more difficult. The vegetation plays a critical role: 1) aiding evapotranspiration of applied wastewater, 2) helping keep soil permeability via roots, 3) helping reduce erosion and slow runoff to allow infiltration, and 4) removing nitrogen and phosphorus when the crops are harvested twice each year. Indeed, the observed un- and under-vegetated areas will result in lower yields, and thus reduce the ability of the system to absorb nutrients.

4.3 Reduced Infiltration Capacity

Given observations of surface runoff occurring, with relative frequency, it is likely that the infiltration capacity of the fields is reduced. Two mechanisms generate surface runoff: 1) the soil is saturated, down to some confining layer or water table, and 2) the infiltration capacity of the soil is exceeded by the precipitation or wastewater irrigation rate. Data from monitoring wells show water table depths consistently exceeding 3 feet in the wells nearest the wetlands (MW-11, MW-3, and MW-8, noted in the Mackinac Environmental report, and demonstrated directly via observation data from Great Lakes Environmental and Burnette Foods provided in BFI #00003295, 7739, and #00018741–18746), suggesting that the water table is not the primary mechanism generating surface runoff. Instead, the infiltration capacity of the soil is likely the primary mechanism generating surface runoff.

This could be due to a variety of factors, including:

- Clogging of soil pores due to redistribution of fine soil particles during erosive events.
- Clogging of the soil pores from organic matter or wastewater solids.
- Relatively steep slopes on the fields, which reduces infiltration capacity relative to a flat surface.
- Reduced effective application area (see above) that increases application intensity.

Soil infiltration capacity is a function of soil texture, organic matter content, and soil structure. The GSSURGO database provides proportions of sand, silt, clay, and organic matter content. The ROSETTA v3 algorithm was used to map soil textures to infiltration capacity values (Zhang and Schaap, 2017).

Figure 22 shows the infiltration capacity values for the fields surrounding the Burnette Foods wastewater application site. The fields are primarily composed of soils with low to moderate infiltration capacities (1.75–2.5 in/hr), with the exception of the North field, which has a higher infiltration capacity (more than 7.5 in/hr).

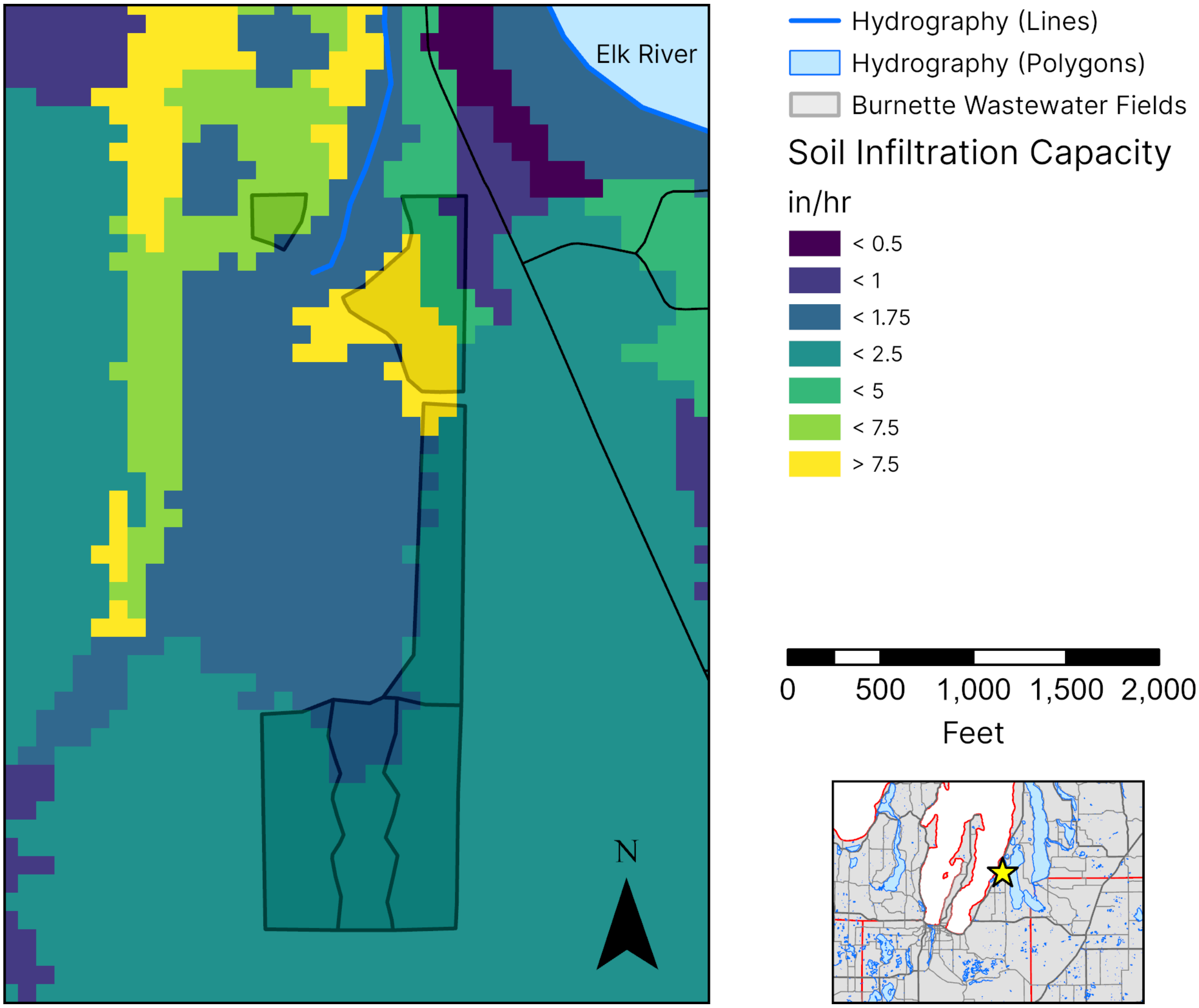


Figure 22: Map of infiltration capacity values from the GSSURGO database, mapped to soil textures using the ROSETTA v3 algorithm.

Nevertheless, these infiltration capacities substantially exceed maximum allowable (and reported) application rates—which, even when in violation, are no greater than 1.75 in/day, and more often approximately 0.75 in/day (see Figure 23). According to the approved 2017 Discharge Management Plan (DMP), applications take at least 3.6 hours in Fields 36 and 38. Thus, a realistic maximum application rate equals 0.75/3.6 = 0.21 in/hr. This is roughly an order of magnitude below the mapped infiltration capacity values.

We can refine this estimate a bit by selecting days during which runoff was observed on the South fields (#36), as discussed above. These include: August 10, 2022 (NAIP image), July 27, 2021 (EGLE visit), and July 28, 2020 (NAIP data). Application rates on these days were: 0.17, 0.21, and 0.34 inches, respectively. Each of the three south fields had identical applications, which is true of all south field applications after mid-2020 (see above). Total volumes applied to the fields (at a nominal 10 acres), were then 46,200, 57,000, and 92,300 gallons. If we assume that the spray guns apply to 5.4 acres, at roughly 400 gallons/minute (a reasonable estimate, given the type and radius of gun), then the applications took 116, 143, and 231 minutes, respectively. Effective, application rates were then 0.32 inches/hr. Given that runoff is reliably observed at such rates, the effective infiltration capacity must be less than 0.32 inches/hr over at least part of Field #36.

Observed runoff at 0.21–0.32 in/hr, roughly 1/10 to 1/8 of the expected saturated infiltration capacity, requires explanation. Slopes reduce the effective infiltration rate, according to $I_{eff} = cos(slope) \times I$. Typical slopes at the site can reach 12% (Figure 24), which reduces the expected infiltration rate to 1.47–2.1 in/hr. This is still almost 7 times the observed rate.

The remaining explanation is that infiltration capacities have been reduced by wastewater treatment. This phenomenon has been observed (Gharaibeh et al., 2016) and simulated (Albalasmeh et al., 2020). Explanations for this include: 1) clogging of soil pores by fine particles, 2) clogging of soil pores by organic matter, 3) increased water repellency due to organic matter buildup, and 4) changes in soil structure. Without a detailed site-specific study, the exact mechanism is unknown, but we know that one or more of these phenomenon are occurring.

It is important to note that infiltration capacities in the south field has been reduced to *at least* 0.21-0.32 in/hr, but might be substantially lower. While on a site visit, on July 31, 2024, saturated conditions were observed at the surface. These occurred at least an hour after the irrigation of Field #36 had ceased—as this field was not irrigated during our visit. Records for that day indicate 0.07 in was applied to that field. Given that the 0.07 in was applied to just over half of the field, the applied amount within the irrigation radius was 0.13 in. Assuming that application was just before our visit (unlikely, given the visit was at 10 AM in the morning), maintaining these saturated conditions well after sprinkling stopped suggests that the true infiltration capacity may be well under 0.10 in/hr.

An infiltration rate this low suggests that the fields would not only generate runoff during irrigation events, but during many rain events as well. This may have necessitated the creation of a retention basin at the north end of the South field, and help explain the frequent observed ponding. While no documents available detailed the design and construction of the retention basin, its location at the lowest point in the field, its triangular shape, lowered bottom, and raised sides all point to its construction for the purpose of rainfall runoff retention.

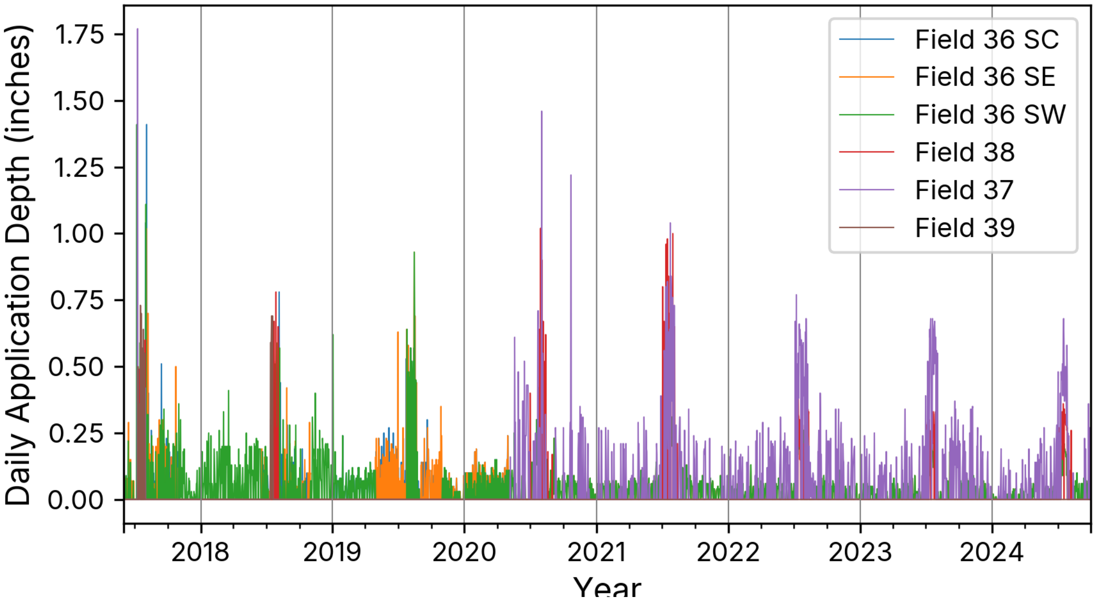


Figure 23: Plot of reported daily application depths for all application fields, using the permitted application areas.

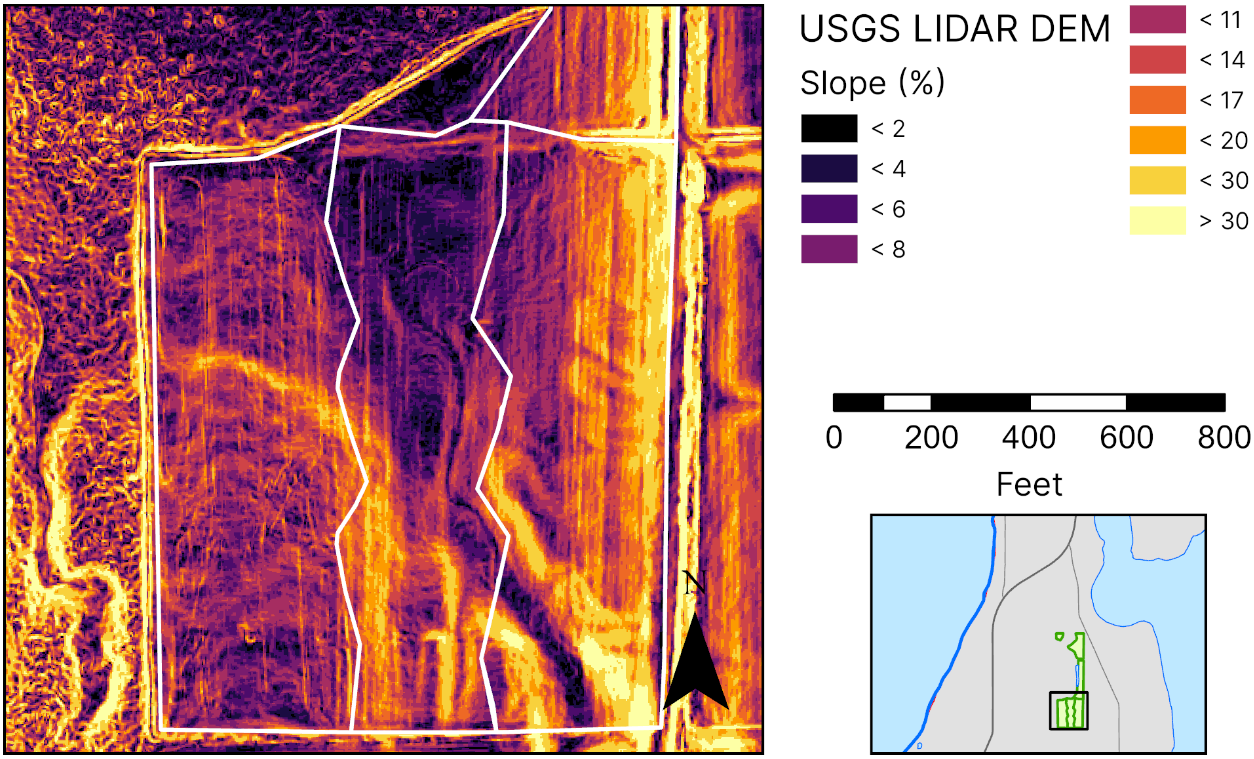


Figure 24: Slope of the land surface, calculated from the 1 meter resolution LIDAR DEM.

4.4 Surface Drainage and Retention Basin

The volume of the retention basin on the north end of the South field #36 depends on the height of the berm surrounding the field. The lowest point in that berm defines the volume. In 2016, that elevation (607.7 feet, measured directly from the LIDAR DEM) was just 0.4 feet above the bottom of that retention basin. The dimensions of this retention basin can be clearly seen in Figure 24, as a roughly triangular basin immediately north of Field #36-South Central, bounded by Field #37, and the berm itself. This area is roughly 0.6 acres. The volume of water needed to fill this basin to the 2016 low point in the berm is 63,500 gallons. In Figure 25, daily applications to Field #36 are shown in gallons, with this threshold marked. This provides a reference for the capacity of this retention basin, relative to daily applied volumes.

The retention basin is strategically located at the drainage point for all of Field #36 and a portion of #37. To determine drainage directions, the tool TopoToolbox was used to calculate the flow direction from a 1 meter resolution LIDAR DEM (Schwanghart and Scherler, 2014). The resulting flow direction map is shown in Figure 26. This tool is capable of generating robust flow networks despite obstructions, such as the berm. The point at which the flow network crosses the berm is the lowest elevation point of that berm, identified in the previous paragraph. The drainage network collects in the center of Field #36, passing near the centers of the two lower elevation solid-set sprinklers in the central sub-field. The ground at each of these sprinklers was observed to be very wet—unwalkably so—during the July 31, 2024 site visit.

If the low spot in the berm were raised to a more typical prominence of the rest of the berm 0.6 meters (2 feet), this storage capacity would increase to 381,000 gallons. While this sounds like a substantial amount of water, it is just 0.47 inches over the 30 acre field that drains to that point (not including an additional 5̃ acres from Field #37). Rainfall events of this magnitude are not uncommon, occurring multiple times each year. Indeed, a 0.91 in/hr rain event is expected to occur each year, according to data from the nearby Bellaire weather station (NOAA PFDS, 2024). With an infiltration capacity of just 0.1 in/hr, the annually-occurring, 0.91 in/hr rain event would generate 0.81 inches of runoff. This is

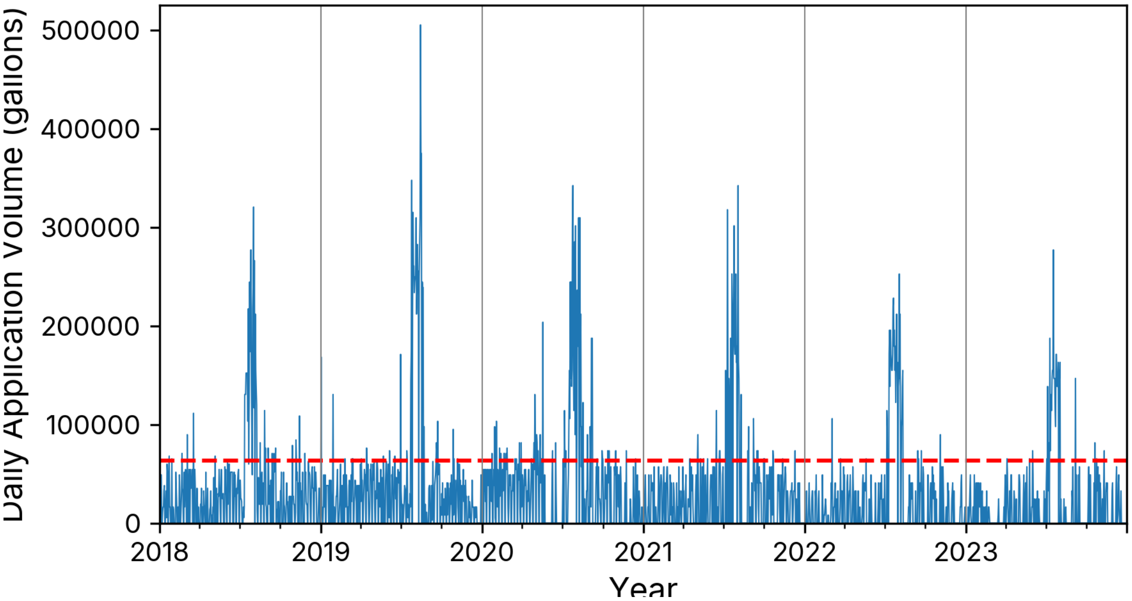


Figure 25: Total daily volume of applications to Field #36, with a dashed red line at 63,500 acres, the volume of the retention basin before overflow at the north end of the field in 2016.

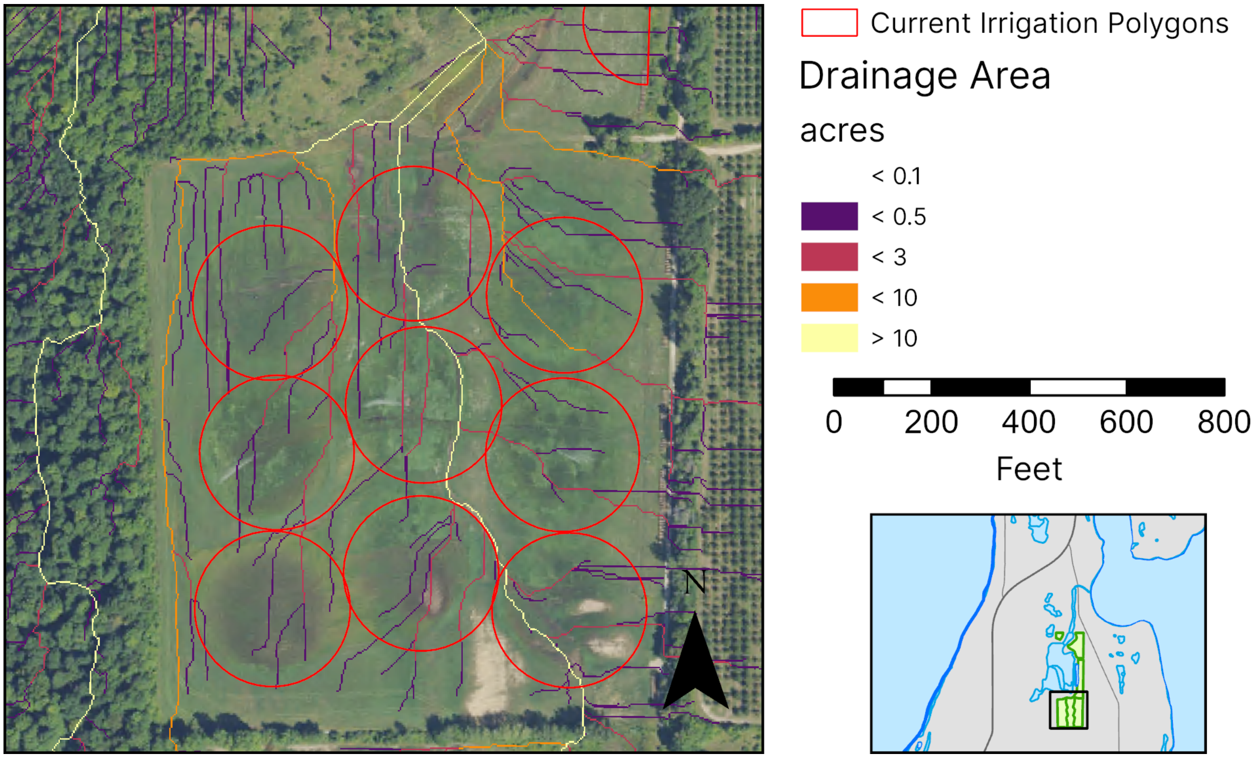


Figure 26: NAIP 2022 image of South field #36, overlain with a drainage network computed from the LIDAR DEM.

Table 4: Summary of wastewater composition data from the 2017-2024 Discharge Monitoring Reports (DMRs).

Name	Maximum	Units	Mean	Median	Violations
Biochemical Oxygen Demand (BOD5)	(report)	mg/L	4,698	3,950	—
Nitrate Nitrogen	(report)	mg/L	0.20	0.15	—
pH minimum	(report)		7.29	7.12	—
pH maximum	(report)		7.16	7.06	—
Dissolved Oxygen (TIN)	(report)	mg/L	3.07	0.67	—
Ammonia Nitrogen	(report)		0.60	0.10	—
Total Inorganic Nitrogen (TIN)	50	mg/L	0.79	0.40	0
Sodium	400	mg/L	396	309	61
Chloride	500	mg/L	236	198	13
Total Phosphorus	10	mg/L	2.09	1.74	2

more than enough to fill the retention basin to the berm, and generate runoff into the wetland. Applying wastewater on this already rain-soaked field will then generate substantial amounts of runoff, with a direct route of surface water flow into the wetlands. This is similar to the conditions that currently exist, as Burnette has indicated that the berm was repaired in 2021. With substantial rain events, runoff sufficient to overtop the berm likely still occurs during periods of wastewater applications on Field #36.

Water that does not runoff directly into the wetland over the surface from the retention basin or along the berm edge will then infiltrate into the ground over a period of hours to days. This then meets the water table just a few feet below (see Figure 9 for elevations, depths are roughly 3–5 feet). From there, groundwater travels through a very shallow pathway directly into the edge of the wetland nearby. Water recharged further up into the fields follows somewhat deeper flowpaths, discharging further into the wetland. Areas of the field furthest away, and areas outside of the Burnette property, discharge closer to the wetland center. Because of the concentration effect induced by frequent runoff accumulating near the berm—even without direct surface runoff—wastewater is reaching the wetlands along the periphery, creating the conditions for stronger localized effects.

5 Wastewater Composition and Groundwater Quality

Burnette Food's wastewater effluent has exceeded concentrations of three out of four constituents with permitted maximums, between 2017 and 2024. Total phosphorus (TP) exceeded maximum concentrations twice, Chloride 13 times, and Sodium 61 times. During that period, there were 197 weekly DMR reporting intervals, thus sodium exceeds the maximum concentration 31% of the time, and chloride 7% of the time. These values, along with the permitted maximums, are listed in Table 4.

These excessive applications, combined with decreased field acreage utilization brought about by the switch to solid-set sprinklers in 2020, has decreased soil and groundwater quality, and increased the load of contaminants into the wetlands. Sodium concentrations have increased substantially; other constituents may have increased as well, however this analysis focuses on sodium, as it has active negative effects in both soil infiltration capacity (where sodium can degrade soil structure and lead to sodicity—where sodium becomes the dominant ion in soils, and reducing permeability), as well as wetland ecosystem health. The concentrations observed here, well above 230 mg/L, are of direct concern for ecosystem health, as well as for the groundwater and surface water quality for other water users and uses.

The management of Field #36 also creates concern that nitrogen and phosphorus would not adequately be removed if Burnette operates at permitted concentrations. Failure to maintain cover crops, linked to excessive waterlogging of soils, and potentially buildup of sodium, reduces the effectiveness of the treatment system, allowing nutrients to travel from the site into the adjacent, downgradient wetlands.

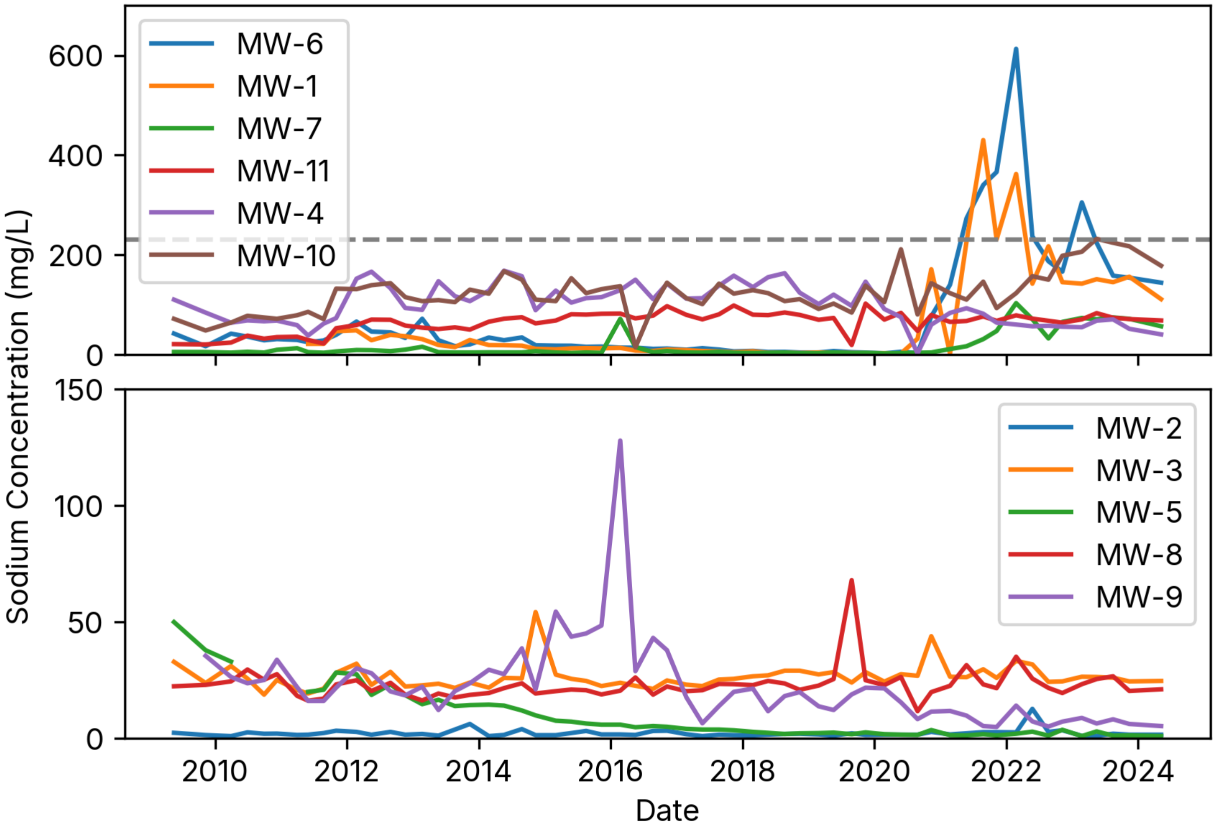


Figure 27: Sodium concentrations in monitoring wells near the Burnette Foods wastewater application site. Top panel are higher concentration wells in Field #38 (MW-1, -6, -7), and Field #36 (MW-11, -10, and -4). Bottom panel are the upgradient well MW-2, and Field #39 well MW-5, the two Field #37 wells MW-3 and -8, and the southeastern-most well on Field #36, MW-9. A dashed horizontal line indicates the 230 mg/L action level for sodium specified in the NREPA.

5.1 Excessive Sodium Concentrations

As a result of this excessive application of sodium, concentrations in downgradient wells are exceeding the 230 mg/L action limit specified in the Permit under Part 11, ”Compliance Requirements” (Figure 27). Given these excessive concentrations, occurring since 2020—when the new solid-set sprinkler system was installed, and when Field #38 started seeing intensive use (see Figure 23)—concentrations in Field #38 have spiked well above 230 mg/L in two wells (MW-1 and -6), and also in MW-10 within Field #36. The new sprinkler system, and the intensive use of Field #38, are clearly negatively impacting groundwater chemistry.

Concentrations spike in the two Field #38 wells within months of that field beginning to be used intensively again. Specifically, starting about mid-May, 2020, Field #38 began to be pumped after having been used very little in the previous years (Figure 28). At the August 26, 2021, sampling about 3 months later, the concentrations in MW-1 had spiked from 2 to 31.6 mg/L. MW-1 is roughly 230 feet from the half-radius of the closest irrigation polygon in Field #38. This means that the groundwater travel speed was at least 230 feet/90 days = 2.6 feet/day. Importantly, the concentration in MW-6, just 30 feet further from the irrigation polygon, had yet to rise. But, by the next sampling event, November 11, 2020, concentrations in MW-6 had spiked from 3 mg/L to 76.5, while MW-6 increased from 31.6 mg/L in August to 171 mg/L in November. In the Site Hydrogeology section above, groundwater flow rates in Field #38 were estimated to be 1.5–2.0 ft/day (Table 1). Thus the rate of 2.6 feet/day calculated here empirically indicates the prior estimates were slightly conservative. Given this, travel time of groundwater from spray fields to the wetland at Field #38 is likely to be about 120 days.

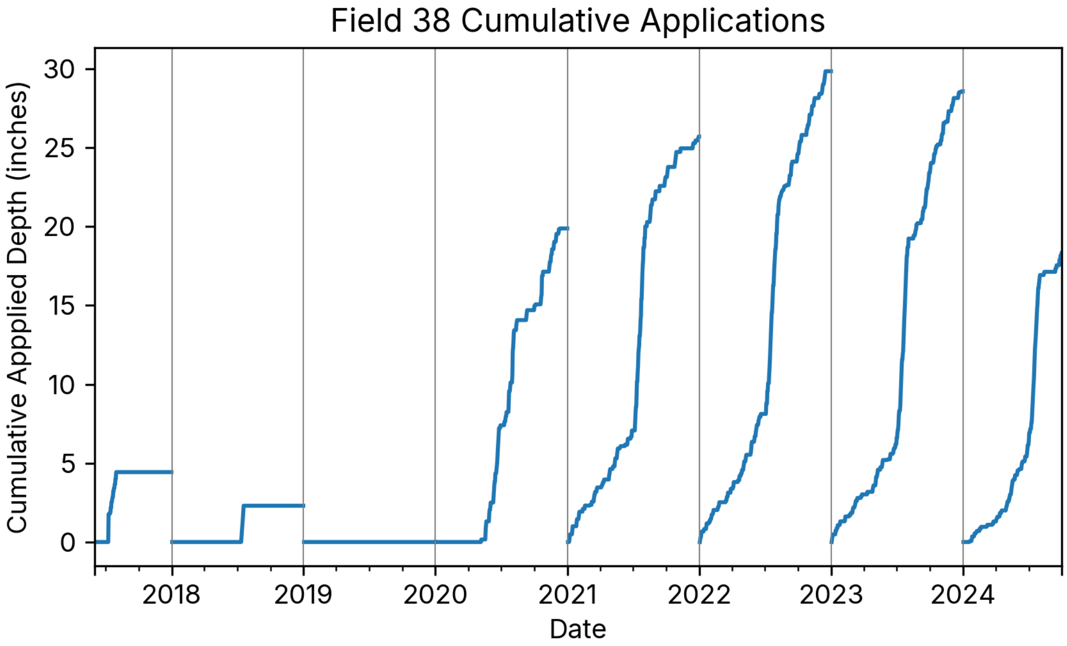


Figure 28: Cumulative application depths within each year on Field #38 from the DMR data.

Along with well concentrations, sodium levels have spiked in the soils in Fields #38 and #36 since 2020 (Figure 29). This spike corresponds with the newly-installed sprinkler system in 2020, highlighting the degree to which the intensity of wastewater irrigation increased dramatically. Unlike Field #38, which was lightly used in prior years, Field #36 saw intensive use throughout the 2017-2024 period—manifesting in higher soil sodium concentrations. Nevertheless, the switch from the use of a variety of different sprinklers, both traveling and solid-set, meant that both soil and well concentrations of sodium increased dramatically.

5.2 Reduced Nutrient Uptake

Two factors combine to substantially reduce the effectiveness of Burnette Food's wastewater treatment system: 1) the reduced effective application area, and 2) the apparent inability to maintain sufficient cover crops at the site, resulting in large areas of bare soil. According to the DMP, the total allowed nutrient load for the site is 12.8 lb Total Inorganic Nitrogen (TIN)/acre/yr, and 25.7 lb Total Phosphorus (TP)/acre/yr. Thus, in Field #36, the total nutrient load, assuming a 30 acre field, is 384 lb TIN/yr, and 771 lb TP/yr. However, as detailed above, only 16.2 acres of Field #36 is irrigated. Therefore, the resultant per-acre permitted nutrient input is now a factor of 1.85 (30 acres/16.2 acres) higher, giving an effective nutrient input of 23.7 lb TIN/acre/yr, and 47.6 lb TP/acre/yr—assuming applications at the permitted maximum.

Burnette is not meeting their intended cover crop production requirements, meaning that far less N and P is being removed from the fields than intended in their DMP. According to the DMP, in areas where cover crops are sufficiently healthy, most or all of the TIN should be taken up by crops and removed from the site, while only roughly half of TP would be. From the DMP Appendix 6, uptake by crops (mix of Alfalfa, Bromegrass, Timothy, and Orchardgrass) should be 171.6 lb/acre for N, and 26.2 lb/acre for P. However, Burnette Foods is not meeting their intended production targets specified by the DMP, producing just 37–45% of the intended 4 tons/acre (Table 5). Thus, actual average N and P removal is 64.0–76.8 lb/acre and 9.8–11.7 lb/acre, respectively.

However, because of the poor soil and water conditions in the irrigation areas, the actual number is much lower than even this. Aerial imagery and visual observations from the site visit support that

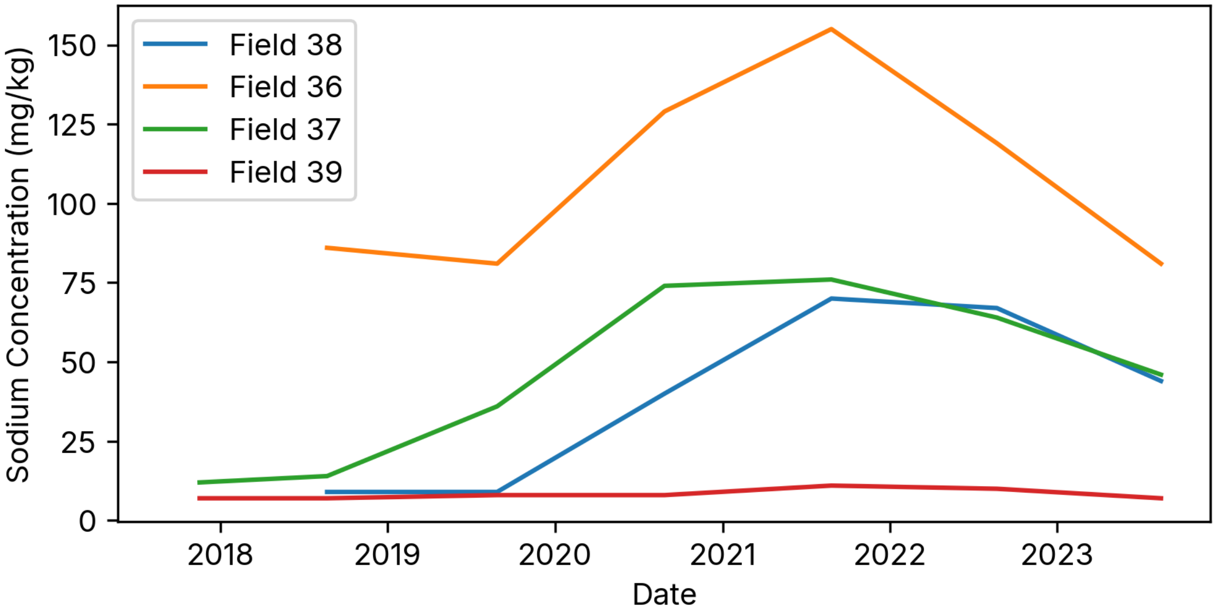


Figure 29: Sodium concentrations in soils at each field.

crop yields in the irrigated areas of Field #36 are lower than the surrounding area. Observed bare soil areas make up a substantial portion of the irrigated area, and crop greenness is lower in many of the irrigated polygons. Though the aerial imagery data are limited (only 2020 and 2022 following the installation of the new irrigation system), the 2022 data show substantial bare ground areas within the irrigated fields. Roughly, perhaps 20% of the irrigated area is bare soil. If we assume, then, that the yield in the irrigated portions are only 80% of those everywhere else, then the bare-ground reduced N and P removal are 51.2–61.4 lb/acre and 7.8–9.4 lb/acre, respectively.

Note that also, in bare soil areas, very little N is removed, instead it travels readily into groundwater. TP is still retained by soil to a substantial degree. Thus, failure to maintain a cover crop in consistently wet areas (as is observed in the NAIP imagery, Figures 13–19) creates a pathway for N and P to circumvent treatment in the shallow subsurface. Thus, if the bare soil fraction were 20%, then something close to 20% of applied N would travel directly to groundwater, while that 20% of applied P would place an additional burden on soil adsorption.

The combination of reduced application area and an underperforming cover crop system means that, for Field #36 at the very least, the fields are removing just a fraction of the N and P intended in the treatment system design. Including all factors for Field #36, the cover crop is capable of removing just 30–36% of the designed N and P removal. The story for other fields is similar, but depends substantially on whether the purported drip irrigation systems are installed and in-use. If Burnette Foods were to apply N and P at the permitted rates on Field #36 (23.7 lb/acre and 47.6 lb/acre) then approximately 38–40 lb/acre excess phosphorus due to reduced irrigation area will create additional burdens on soil adsorption, substantially shortening the useful life of the field.

Despite the calculations above, for the water that infiltrates into the soil within the irrigated areas, Burnette is applying at rates significantly below their permitted maximums. Based on the reported values in the 2017-2024 DMRs, the median maximum weekly concentrations are 0.4 mg/L for TIN, and 1.81 mg/L TP. This indicates that Burnette Foods is averaging concentrations roughly 1% of maximum for TIN, and 18% of maximum for TP. Therefore, application rates are within the irrigated polygons in Field #36 are 0.24 lb TIN/acre and 8.7 lb TP/acre. For N, this is well within the capacity of the crop to remove (though some TIN does inevitably leak in bare soil areas). For P, the crop is likely removing approximately this much P, while soil adsorption can probably handle most of the remainder.

Nevertheless, there are phosphorus contamination concerns for the wetlands because of the sur-

Table 5: Hay production and nutrient removal from the fields, calculated from Burnette Foods data (BFI #00018740–00018745). Note, 2024 production data were incomplete, thus they were not included in the averages, which would have potentially skewed them lower if another hay cutting occurred later in the 2024 season. For the calculation of N and P removal, the same distribution of cover crop types and uptake rates were assumed as those reported in Appendix D of the DMP.

Year	Hay Harvested	Tons/Acre	N removed (lb/acre)	P removed (lb/acre)
2018	200,000	2.1	88.1	13.4
2019	160,000	1.6	70.5	10.8
2020	0	0.0	0.0	0.0
2021	154,000	1.6	67.8	10.3
2022	144,800	1.5	63.8	9.7
2023	212,800	2.2	93.7	14.3
2024	*116,800*	*1.2*	*51.4*	*7.8*
Average	145,267	1.5	64.0	9.8
Average (w/o 2020)	174,320	1.8	76.8	11.7

face runoff to the bottom of the fields resulting from reduced infiltration capacity. The N and P carried by this runoff will then pond in the retention basin and along berm edges, where essentially none of it will be removed by harvest. While some P will still be removed by soil adsorption, concentrated infiltration over a sustained period of time likely means that little or no P adsorption capacity remains in those soils. It is not possible to accurately estimate the total N and P load carried to the base of the slope via surface runoff, but perhaps 1-10% of the applied water will become runoff (the number could be higher, but not likely lower). Given Burnette's reported applications, this means that for Field #36, 0.04–0.4 lb of TIN and 1.4–13.9 lb of P reach the retention basin and berm edges each year. Most of this P will then percolate down to the water table and be carried to the wetland over several months (or much more quickly if surface runoff overtops the repaired berm). This is a substantial amount of nutrient load, and likely increases eutrophication in the wetlands and downstream Spencer Creek and Elk Lake.

5.3 Limited Biogeochemical Processing and Metals Mobilization

Because of the intensive water loading, lack of maintenance of aerated soil conditions, and very high BOD loads into the subsurface at this site, dissolved oxygen levels in the groundwater are very low, indicating anoxic conditions. Without oxygen, microbes cannot consume excess organic carbon and nutrients as quickly. Thus, as the oxygen-depleted water flows through the groundwater it undergoes little alteration.

From Burnette's monitoring data, e.g. BFI #00018745, dissolved oxygen (DO) levels in MW-11 in Field #36 nerest the wetland are typically well below 0.5 mg/L, the threshold where microbes can no longer use oxygen effectively, or even below detection threshold. This occurs also in MW-1, and MW-6, both between the wetland than the Field #38 irrigation polygons. Even wells further out, MW-4, and MW-10 in Field #36 experience these low levels most of the time. In contrast, MW-2, the upgradient well representative of background conditions, has DO levels consistently above 3, often reaching saturation conditions at or above 10 mg/L. MW-3 and MW-8, both in Field #37 are variably impacted, sometimes showing very low DO values, others showing values up near 2 or 3 mg/L. Significantly, MW-5, in Field #39 which is rarely used, shows very low DO values much of the year, indicating a long legacy of groundwater contamination due to the decades of applying far too much BOD in this underdesigned system.

Without oxygen, not only can microbes less effectively remove nutrients, but metals that would otherwise be immobilized can start to move. These metals, either present in the sediments natively, or sprayed on the surface by Burnette, can then move into the wetlands. There, they can reduce water quality and harm ecosystems. Background levels of Iron and Manganese in MW-2 are mostly below detection thresholds of 100 and 50 μg/L, respectively. In contrast, highly impacted wells like MW-4 show concentrations of 20,000–100,000 μg/L (iron) and 700–2500 μg/L (manganese). Similarly high concentrations occur in MW-1, -6, -7, -10, and -11. While the data are sparse for Arsenic, impacted fields like MW-4 show detectable and elevated levels in the range of 5-20 μg/L, against a background of 2 μg/L or less. Burnette's activities are clearly mobilizing these metals, some acutely toxic, from which they move freely into the wetlands.

6 Conclusion

Burnette Foods is applying more water at lower quality than permitted on an ongoing, operational basis, accruing hundreds of violations over a seven year period. They are operating outside of their Discharge Management Plan (DMP), with a modified irrigation system. This system no longer utilizes half or more of the permitted area—thus effectively doubling per-acre application rates. In some years, Burnette has applied more than 5,000,000 gallons of excess wastewater, an amount that would overwhelm even a properly-managed system. Clear degradation in groundwater quality followed an irrigation system redesign in 2020 that violates both permit and DMP conditions.

Through decades of wastewater application and inadequate management, the infiltration capacity of the fields has been reduced. This has resulted in regular surface runoff, which is collected in a constructed retention basin at the north end of the South field. This retention basin is nearly always at least partially full, and is located just 70 feet from nearby wetlands. Water that is collected in this retention basin will ultimately percolate over a period of hours or days into the ground, reaching the shallow water table in a matter of days, and then traveling laterally to be discharged in the nearest edge of the wetland within a few months. Even moderate rainfall likely lead to retention basin overflow until recent repairs, flushing wastewater into the nearby wetland. Even after those repairs, overflow events are still expected.

Through failing to maintain adequate vegetation, underdesigning irrigation systems, and overapplication of wastewater, Burnette has reduced the effectiveness of its treatment system, contaminated the aquifer beneath the field, and sent large quantities of barely-treated water on short paths to the wetlands nearby. In part because of often saturated soil conditions, and rising soil sodium levels, Burnette has been unable to grow thriving cover crops, resulting in insufficient uptake of N and P. Water that accumulates at the base of each field following frequent runoff events, or infiltrates into the ground elsewhere, reaches the wetland in a matter of months—limiting time for biogeochemical processing. This is especially true given the very low dissolved oxygen beneath these fields which limits microbial uptake and mobilizes metals that would otherwise attach to the sediments of the groundwater aquifer. This low DO is a direct result of excessive BOD applications to the surface, and inadequate vegetative and soil treatment.

What emerges from either groundwater or surface pathways along the wetland edge is a potent combination of high sodium, high metals, high phosphorus, low DO water that likely impairs the wetland ecosystem health. Ultimately, these contaminants travel through the wetland down to Spencer Creek and discharge into Elk Lake beyond. This process is intermittent, as the wetland is relatively dry during the summer. Yet Burnette's fields all the while load additional contaminants into the wetland waters. When the summer and early fall rains come, these then flush out of the system rapidly, create acute water quality impacts downstream. Wet summers create particular problems as well for Field #36 that is often waterlogged, and has a very low infiltration capacity, and can experience overtopping of its berms.

These ongoing violations and mismanagement are flushing wastewater into the wetlands through both surface and groundwater pathways. Travel times along those pathways range from hours to days (surface water) to at most several months (groundwater). This is not a necessary outcome of wastewater application, but rather a result of Burnette's deliberate choices and mismanagement of the site. The data clearly demonstrate these impacts, and the need for immediate action to prevent further degradation of the wetlands and downstream waters.

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Appendix 1

Kendall Qualifications

Please see CV, included as Appendix 2.

Kendall Recent Publications

All publications, listed in reverse chronological order, are included in the attached CV, included as Appendix 2.

Kendall Compensation

Hourly fee for document review, analysis, in-person field work, meetings, and report writing: $150

Hourly fee for driving > 1 hour: $75 + reimbursed mileage

Hourly fee for written sworn testimony: $200

Hourly fee for sworn deposition and testimony with live cross-examination: $250

Kendall Recent Testimony

In the past four years, Dr. Kendall has provided written reports and opinions in a variety of cases related to local, state, and federal permitting and conducted one sworn deposition. The deposition was for Realo Estato, LLC v. Lakemore Landings, LLC, case #23-36574-CH in State of Michigan Circuit Court for the County of Grand Traverse. Kendall gave deposition on behalf of the Plaintiff. This deposition was not ultimately submitted as evidence in the case, which is ongoing.

Appendix 2 - CV

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CURRICULUM VITAE

Anthony D. Kendall

Michigan State University

EDUCATION

2004 - 2009	Ph.D. Environmental Geosciences Thesis: *Predicting the Impacts of Land Use and Climate Change on Regional-Scale Hydrologic Fluxes* Advisor: Dr. David W. Hyndman	Michigan State University
1999 - 2004	B.S. Mechanical Engineering	Michigan State University
	B.S. Astronomy and Astrophysics	Michigan State University

PROFESSIONAL APPOINTMENTS

2024 -	Assistant Professor (Tenure Track), Earth and Environmental Sciences, AgBioResearch (joint), MSU
2022 -	Assistant Professor (Tenure Track), Earth and Environmental Sciences, MSU
2017 - 2022	Research Assistant Professor, Earth and Environmental Sciences, MSU
2015 - 2017	Senior Research Associate, Hydrogeology, Earth and Environmental Sciences (formerly Geological Sciences), MSU
2009 - 2015	Research Associate, Hydrogeology, Geological Sciences, MSU
2005 - 2006	Graduate Teaching Assistant, Integrative Sciences Lab Course, MSU
2004 - 2009	Graduate Research Assistant, Hydrogeology, Geological Sciences, MSU
2003 - 2004	Undergraduate Researcher, Dr. Eugene Capriotti, Astronomy and Astrophysics, MSU
2002 - 2004	Undergraduate Researcher, Dr. Manooch Koochesfahani, Mechanical Engineering, MSU
2001 - 2004	Undergraduate Researcher, Dr. David W. Hyndman, Geological Sciences, MSU
1999 - 2001	Professorial Assistant, Dr. David W. Hyndman, MSU

PEER-REVIEWED PUBLICATIONS

2024

60. Zipper, S. Brookfield, A., … **Kendall, A.D.**, et al., Streamflow depletion caused by groundwater pumping: Fundamental research priorities for management-relevant science, *Water Resources Research*: *accepted*

2023

59. Smidt, S., Haacker, E., … **Kendall A.D.**, et. al. Forming the Future of Agrohydrology, *Earth's Future: accepted*

58. Axelrod, M., He, L., Kreske, E., Nawyn, S., Pearson, A., Axelrod, Mark; Pokhrel, Y., Gasteyer, S., Lawrie, S., **Kendall, A.D.**, Interventions Addressing Conflict in Communities Hosting Climate-Driven Migrants: Literature Review, *Environment and Security*: *accepted*

57. Wan, L., **Kendall, A. D.**, Martin, S. L., Hamlin, Q. F., and D.W. Hyndman. Important Role of Overland Flows and Tile Field Pathways in Nutrient Transport. *Environmental Science & Technology*: 10.1021/acs.est.3c03741

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55. Partridge, T., Winter, J., **Kendall, A.D.**, Basso, B., Pei, L., and D.W. Hyndman. Irrigation benefits outweigh costs in more US croplands by mid-century. *Communications Earth & Environment*: 10.1038/s43247-023-00889-0

2022 54. Glose, T.J., Zipper, S.C., Hyndman, D.W, **Kendall, A.D.**, Deines, J.M., and J.J. Butler Jr., Quantifying the impact of lagged hydrological responses on the effectiveness of groundwater conservation, *Water Resources Research:* 10.1029/2022wr032295

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51. Hamlin, Q.F., Martin, S.L, **Kendall, A.D.**, and D. W. Hyndman, Examining Relationships Between Groundwater Nitrate Concentrations in Drinking Water and Landscape Characteristics to Understand Health Risks, *Geohealth*: 10.1029/2021gh000524

2021 50. Dugan, H., Linnea, R., **Kendall, A.D.**, and R. Mooney, Tributary Chloride Loading into Lake Michigan: *Limnology and Oceanography Letters*: 10.1002/lol2.10228

49. Zwickle, A., Feltman, B., Brady, A., **Kendall, A.D.**, and D.W. Hyndman, Sustainable Irrigation Through Local Collaborative Governance: Evidence for a structural fix in Kansas, *Environmental Science and Policy*: 10.1016/j.envsci.2021.07.021

48. Ford, C.M., **Kendall, A.D.**, and D.W. Hyndman, Changes in Snowmelt Hydrology across the Eastern US as Winters Warm, *Science of the Total Environment*: 10.1016/j.scitotenv.2021.148483

47. Kuhl, A.S., **Kendall, A.D.**, van Dam, R.L., Hamilton, S.K. and D.W. Hyndman, Root Water Uptake of Biofuel Crops Revealed by Coupled Electrical Resistivity and Soil Water Content Measurements, *Vadose Zone Journal*: 10.1002/vzj2.20124

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41. Ford, C., **Kendall, A.D.**, Hyndman, D.W., Effects of Shifting Snowmelt Regimes on the Hydrology of Non-Alpine Temperate Landscapes, *Journal of Hydrology*: 10.1016/j.jhydrol.2020.125517

40. Heerspink, B., **Kendall, A.D.**, Coe, M., Hyndman D.W., Trends in streamflow, evapotranspiration, and groundwater storage across the Amazon Basin linked to changing precipitation and land cover, *Journal of Hydrology: Regional Studies*: 10.1016/j.ejrh.2020.100755

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38. Hannah, B.A., **Kendall, A.D**., Martin, S.L., and D.W. Hyndman, Quantifying linkages between watershed factors and coastal wetland plant invasion in the US Great Lakes, *Landscape Ecology*: 3. 10.1007/s10980-020-01124-3

37. Hamlin, Q., **Kendall, A.D.,** Martin, S.L., Whitenack, H., Roush, J., Hannah, B., and D.W. Hyndman, Quantifying Landscape Nutrient Inputs with Spatially Explicit Nutrient Source Estimate Maps, *Journal of Geophysical Research: Biogeosciences*: 10.1029/2019JG005134

2019 36. Partridge, T.F., Winter, J.M., Liu, L., **Kendall, A.D.**, Basso, B, and D.W. Hyndman, Mid-20th Century Globally Anomalous Cooling Boosts U.S. Maize Yield, *Environmental Research Letters*: 10.1088/1748-9326/ab422b

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34. Smidt, S.J., **Kendall, A.D.**, and D.W. Hyndman, Increased Dependence on Irrigated Crop Production across the CONUS (1945 – 2015), *Water:* 10.3390/w11071458

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22. Hyndman, D.W., T.Xu, J.M. Deines, G. Cao, R. Nagelkirk, A. Vina, W. McConnell, B. Basso, **A.D. Kendall**, S. Li, L. Luo, F. Lupi, J.A. Winkler, W. Yang, C. Zheng, and J. Liu, Quantifying changes in water use and groundwater availability in a megacity using novel integrated systems modeling, *Geophysical Research Letters*: 44(16), 8359-8368, DOI: 10.1002/2017GL074429

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13. Basso, B., Hyndman, D.W., **Kendall, A.D.**, Robertson, G.P., and R.P. Grace, Can impacts of climate change and agricultural adaptation strategies be accurately quantified if crop models are annually reinitialized?, *PLOS One* 10(6): e0127333, DOI: 10.1371/journal.pone.0127333

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2014 11. Brena, J.A.N.-, **Kendall, A.D.**, and D.W. Hyndman, Accounting for Irrigation in Satellite-based Groundwater Storage Estimates: A Decade of Monitoring the High Plains Aquifer from Space and Ground Observations, *Geophysical Research Letters* 41, DOI:10.1002/2014GL061213

2013 10. Basso, B., **A.D. Kendall**, and D.W. Hyndman, The future of agriculture over the Ogallala Aquifer: Solutions to grow crops more efficiently with limited water, *Earth's Future*, DOI:10.1002/2013EF000107

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2009 7. Lusch, D.P., Stanley, K.E. Schaetzl, R.J, **Kendall, A.D.**, Van Dam, R.L., Nielsen, A., Blumer, B.E., Hobbs, T.C., Archer, J.K., Holmstadt, J.L.F., and C.L. May, Characterization and Mapping of Patterned Ground in the Saginaw Lowlands, Michigan: Possible Evidence for Late-Wisconsin Permafrost, *Annals of the Association of American Geographers* 99(3): 445-466, DOI: 10.1080/00045600902931629

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2007 5. Pijanowski, B., Ray, D.K, **Kendall, A.D.**, Duckles, J.M., and D.W. Hyndman, Using Backcast Land-Use Change and Groundwater Travel-Time Models to Generate Land-Use Legacy Maps for Watershed Management, *Ecology and Society* 12(2): 25 [online] URL: http://www.ecologyandsociety.org/vol12/iss2/art25

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3. Hyndman, D.W., **Kendall, A.D.**, and N.R.H- Welty, Evaluating Temporal and Spatial Variations in Recharge and Streamflow Using the Integrated Landscape Hydrology Model (ILHM)*, Subsurface Hydrology: Data Integration for Properties and Processes*, AGU Geophysical Monograph Series 171: 121-141

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SELECTED MANUSCRIPTS IN REVIEW OR REVISION (DRAFTS AVAILABLE)

Wan, L., Kendall, A.D., Rapp, J., and D.W. Hyndman. Mapping Agricultural Tile Drainage Using Explainable Random Forest Machine Learning and Satellite Imagery in the US Midwest, *Science of the Total Environment: in review*

Stid, J., Shuklas, S., Kendall, A.D., Anctil, A., Hyndman, D.W., Rapp, J., and R. Anex, Enhancing water and economic security in irrigated regions with agrisolar co-location, *Nature Sustainability*: *in review after revision*

Feltman, B., Zwickle, A., Kendall, A.D., Hyndman, D.W., and Butler, James J. Jr.. Mapping Motivations and Measuring Success: Implementing the Institutional Analysis and Development Framework for the Collaborative Governance of Groundwater, *Society & Natural Resources*: *in revision after review*

Salako, J., Basso, B., Kendall, A.D., and Millar, N., Assessing tree root distributions using ground penetrating radar (GPR) and artificial intelligence, *Computers and Electronics in Agriculture: in review*

Czeszynski,V.M., R.J. Mooney, A.D. Kendall, C.E. Dougherty, H.A. Dugan, and E.A. Strauss. Extensive Sampling of Large Lake Tributaries Reveals Extreme Spatial Variability of Dissolved Organic Carbon Concentration and Composition, *in revision after review*

DATA PRODUCTS

2023 Wan, L. SENSEflux-USGLB: Nitrogen and Phosphorus Loads, Sources and Pathways, *HydroShare*, DOI: 10.4211/hs.90058d6565784aad97cdf51262777590

2021 Ford, C., **Kendall, A.D.**, and D.W. Hyndman. Scripts for "Changes in Snowmelt Hydrology across the Eastern US as Winters Warm", *HydroShare*, DOI: 10.4211/hs.7734e04b7c4f40eb96b08c2e8ab124a7

2020 Hamlin, Q.F., **Kendall, A.D.**, Martin, S.L., Whitenack, H., Roush, J., Hannah, B.A., and D.W. Hyndman, SENSEmap-USGLB: Nitrogen and Phosphorus Inputs, *HydroShare*, DOI: 10.4211/hs.1a116e5460e24177999c7bd6f8292421

Ford, C. Scripts for "Effects of Shifting Snowmelt Regimes on the Hydrology of Non-Alpine Temperate Landscapes", HydroShare, DOI: 10.4211/hs.2ab10feef5d74b849563dba6b854dea8

2019 Xu, T., J. M. Deines, **A.D. Kendall**, B. Basso, D. W. Hyndman. Addressing Challenges for Mapping Irrigated Fields in Subhumid Temperate Regions by Integrating Remote Sensing and Hydroclimatic Data, *HydroShare*, DOI: 10.4211/hs.3766845be72d45969fca21530a67bb2d

Deines, J.M., **Kendall, A.D.**, Crowley, M.A., Rapp, J., Cardille, J.A., and D.W. Hyndman, Annual Irrigation Maps - High Plains Aquifer (AIM-HPA, Deines et al. 2019), *HydroShare*, DOI: 10.4211/hs.a371fd69d41b4232806d81e17fe4efcb

2017	Deines, J.M, D.W. Hyndman, **A.D. Kendall**. Annual Irrigation Maps - Republican River Basin (AIM-RRB; Deines et al. 2017), *HydroShare*, DOI: 10.4211/hs.55331a41d5f34c97baf90beb910af070

TEACHING EXPERIENCE

2023 – 2024	Developed and taught a new graduate level water resources and hydrologic modeling course (GLG 893, to become GLG 811)
2023 – 2024	Co-developed a new introductory environmental sciences large-enrollment course (GLG 200)
2022 – 2023	Taught a module, and coordinated across modules, for ESP 801
2022 – 2023	Led a summer 1.5 week field and computational lab hydrology experience for undergraduate students from a Hispanic-serving institution in Texas
2021 – 2023	Contributed annually to a single lecture to a 1-credit graduate-level seminar/cohort-building course
2021	Taught *Hydrogeology* (GLG 411) for upper level undergraduates
2019 – 2022	Supervised 5 separate graduate student data science special problems courses, focused on time series methods, machine learning, and artificial intelligence algorithms
2017 – 2019	Taught a module within a six-institution virtual course run by CUAHSI on Climate Change, Agriculture, and Hydrology
2016 – 2019	Taught a 3-week module on Natural Sciences for Social Science graduate students, ESP 801
2015 – 2022	Advisor for 3 summer research intern students, NSF REU and other similar
2015	Taught a 3-credit special problems course in Soil Physics, 1 student
2014, 2018	Teaching a 2-credit special problems course in Landscape Modeling with LHM (two years)
2013 –2023	Annual guest-lecturer, 3 class sequence, Hydrogeology
2013 – 2019	Instructor for a 1-credit graduate seminar in research methods in the Geosciences (five years)
2013 – 2014	Instructor for a 1-credit graduate seminar in field methods in the Geosciences (two years)
2013 – 2019	Instructor for a 1-credit graduate seminar in Foundations in Data Sciences methods in the Geosciences (three years)
2012	Team-taught *Hydrogeology* (GLG 411) for upper level undergraduates, 9 lectures
2010 – 2023	Advisor, co-advisor, or committee member for M.S. and Ph.D students, 11 current, 23 graduated
2009 –	Advising numerous undergraduate student independent study projects
2005 – 2006	Instructor, *Integrative Sciences Geology Laboratory*, 4 sections
2003 –	Guest lecturer for several introductory, upper-undergraduate, and graduate courses

GRADUATE STUDENTS ADVISED (18 ADVISED/CO-ADVISED)

Current	Samin Albomaali, PhD Student (advisor)
	Jacob Stid, PhD Student (advisor)
	Brent Heerspink, PhD Student (advisor)
	Jeremy Rapp, MS Student (advisor)
	Behjat Mirzhendehdel, PhD Student (advisor)
	Noah Bohl, MS Student (advisor)

Madeline Sigler, MS Student (advisor)

Caroline Weidner, PhD Student (committee member)

Helio Lopes Guerra Neto, PhD Student (committee member)

Prateek Sharma, PhD Student (committee member)

Nudrat Fatima, PhD Student (committee member)

2023

Jon King, MS (committee member)
The Effects of Fall Grazing of Cover Crops on Soil Health Indicators and Subsequent Corn Yield and Quality

18. Luwen Wan, PhD (advisor)
Quantifying Nutrient Transport Pathways Using Spatially Explicit Modeling and Remote Sensing

John Salako, MS (committee member)
Assessing Roots Distribution of Tart Cherry Tree Using Ground Penetrating Radar (GPR) and Artificial Intelligence

2022

Siddarth Shukla, PhD (committee member)
Design, economic, and environmental assessment of renewable energy systems

Yingjjie Li, PhD (committee member)
Tracking Flows Across a Metacoupled Planet for Sustainability

Meg Castro, MS (committee member)
Documenting the geomorphic impacts of high lake level on freshwater coastal wetlands using topobathymetric surveys: A case study from Saginaw Bay in Lake Huron

17. Chanse Ford, PhD (co-advisor)
Snowmelt Hydrologic Changes Due to Warming Winter Temperatures in Michigan and the Eastern United States

16. Alexis Lanier, MS (co-advisor)
Filling in the gaps: Modeling the role of groundwater in Lake Erie's nutrient budget

15. Ben McCarthy, MS (co-advisor)
Energy Trends in Irrigation: a Method for Estimating Local and Large-scale Energy Use in Agriculture

2021

14. Bailey Hannah, MS (co-advisor)
Evaluating Nitrogen and Phosphorus Impacts Within Watersheds of the Great Lakes Basin

13. Jake Stid, MS (co-advisor)
Detection and Assessment of Food, Energy, and Water Impacts of Solar Photovoltaic Co-Location in the California's Central Valley

12. Allyson Brady, MS (co-advisor)
Assessing Irrigation in the High Plains Aquifer Region: Comparing Irrigation Trends and Mapping Efficient Irrigation Use

2020

Joseph Lee-Cullin, PhD (committee member)
From the Land to the Stream-Groundwater Interface: An Assessment of Watershed-Scale Biogeochemical Interactions

11. Brent Heerspink, MS (co-advisor)
Investigating Climate and Land Cover Driven Changes in Ground and Surface Water Resources Across Scales in the Amazon Basin

10. Quercus Hamlin, MS (co-advisor)
Quantifying the "Nutrient Landscape" in the Great Lakes Region: Mapping and Analyzing Nutrient Sources and Groundwater Nitrate

9. Alexandria Kuhl, PhD (committee member)
Development and Application of a Coupled Hydrogeophysical Model for Estimating Soil and Root Properties

2019 8. Travis Dahl, PhD (committee member)
Quantifying Impacts of Global Change on Hydrology and Sediment

2018 7. Jillian Deines, PhD (co-advisor)
Integrating Satellite Observations into Process-Based Models to Inform Agricultural Water Management

6. Autumn Parish, MS (co-advisor)
The Hydrologic Sustainability of Second-Generation Biofuel Cropping Systems

2017 5. Xiao Liu, MS (co-advisor)
Evaluating the Hydrologic Response to Irrigation and Aquifer Storage and Recover in the Republican River Basin

4. Erin Haacker, PhD (co-advisor)
Sustainability of the High Plains Aquifer: From deliberate impacts to unintended consequences

3. Sam Smidt, PhD (co-advisor)
Redefining Water and Land Management Strategies for the Early 21st Century

2016 2. Kayla Cotterman, MS (co-advisor)
Analysis and Adaptation of the Effects of Climate Change and Groundwater Depletion on Crop Production and Water Availability Across the High Plains Aquifer

2013 1. Emily Luscz, MS (co-advisor)
Modeling Nutrient Loading to Watersheds in the Great Lakes Basin: A Detailed Source Model at the Regional Scale

GRANT FUNDING EXPERIENCE (24 FUNDED, 1 PENDING#)

2024 #PI, NSF GCR $3,596,810 ($2,666,558 MSU)
Collaborative Research: GCR: Advancing Sustainable Net-Zero Energy with REstorative Agroenergy Landscape (REAL) Design

2023 #Institutional PI, NASA SWOT $1,140,661 ($197,860 MSU)
Integrating SWOT, SAR, and hydrologic models to quantify high-resolution dynamic terrestrial water storage across regional watersheds

24. Institutional PI, USDA FFAR $881,526 ($186,088 MSU)
Integrating on-farm solar arrays to enhance recharge, produce energy, and diversify farm income

2022 23. Institutional PI, USGS CASC $357,355 ($85,927 MSU)
Shallow Groundwater and Stream Temperature Modeling to Assess the Effect of Warming Temperatures on Coldwater Fish Spawning

22. Institutional PI, USDA DSFAS $644,459 ($178,526 MSU)
Integrating AI applications and big data to evaluate under-utilized irrigated row crop production zones (IrrigAIt)

Institutional PI, NASA IDS $1,640,080 ($210,203 MSU)
Ecosystem Function and Resilience to Changes in Climate, Water Level, Land Use, and Species Invasion Across the Land-Great Lakes Continuum

21\. PI, MSU Climate Change Research Support Center $100,000
Building a Foundation for SCALE (Sustainable Communities, Agriculture, Landscapes, and Energy)

PI, NSF GCR $3.6M ($2,148,954 MSU)
Achieving Net-zero by Prioritizing Community Benefits with Informed Design of Energy Agroecosystem Landscapes (IDEAL)

20\. Co-PI, NSF FRES ~$3M ($957,349 MSU)
Revealing the hidden groundwater storage dynamics of the Great Lakes Basin by synthesizing geodesy, hydrologic modeling, and remote sensing

MSU, Strategic Partnership Grant (SPG) $239,250
Bridging the Gap between Academia and Stakeholders: Facilitating Data Driven Management across the Great Lakes Coastal Communities.

2021 PI, Great Lakes Observing System Mini-Grant $99,733
Mapping and modeling chloride inputs, concentrations, and fluxes from the landscape to Lake Michigan: A first integrative assessment of an emerging environmental threat

Institutional PI, DOE-ESS $999,639 ($144,692 MSU)
Improving Earth System Model Representations of Responses to Fire and Drought in Seasonal and Deep-Rooted Tropical Forests

Institutional PI, Tipping Points $199,463
Evaluating nutrient targets to support Lake Michigan's water quality, food web and fisheries

19\. Institutional PI, NASA OCEAN $142,990 MSU
Integrating Systems Models and Remote Sensing to Explore Aquatic Ecosystem Vulnerability to Global Change in Lake Huron

Co-I, USAID $13,139,860
CAPABLE: Capacity Building for Long-term Climate Adaptation and Enhanced City Resilience in the Philippines

PI, NASA Roses ESA, *Step-1 only*
Nowcasting and seasonal forecasting of groundwater-driven hydrology with satellite data assimilation across a Great Lakes state

Institutional PI, NASA Roses ESA, *Step-1 only*
Strengthening the Tipping Point Planner: Engaging Great Lakes Communities for Climate and Resilience Planning

2020 Co-PI, DOE EERE, *Concept paper only*
Food, energy, and water benefits of co-locating solar and agriculture in marginal and irrigated lands across the US

Co-PI, DOE TES $999,277 ($414,280 MSU)
Improving Earth System Model Representations of Aboveground-Belowground Processes in Drought-Sensitive Tropical Forests on Deep Soils

Co-PI, DOE ESS, *Pre-application only* $999,900 ($390,000 MSU)
Simulating the Dynamic Effects of Perturbations on Ecosystem Function Along the US Great Lakes Terrestrial Aquatic Interface

Co-PI, NASA OBB $287,503 (MSU)
Integrating Models, Remote Sensing and Field Observations to Quantify the Vulnerability of Great Lakes Aquatic Ecosystems to Climate Change

Co-PI, NSF/NSF-C, CBET Environmental Sustainability $499,995 (MSU)
FEW Systems Modeling to Improve a Payment for Ecosystem Services Scheme in a Rapidly Developing Headwater Region of the Yangtze River Delta

Co-PI, NASA Carbon $287,484 (MSU)
Quantifying Effects of Changes in Land Cover Land Use, Climate, and Plant Invasions on Lateral Transport and Deposition of Carbon in Great Lakes Watersheds

Co-PI, NSF CoPE $1,999,984 (MSU)
Large-scale CoPe: Great Lakes Hub (GLHub) for Advancing Ecosystem and Social Sciences

2019 Institutional PI, NASA SWOT $365,982 (MSU)
Integration of SWOT, Radarsat-2, Sentinel-1 and NISAR for Monitoring Great Lakes Coastal Wetlands

Co-PI, NIFA SAS $9,998,939
Pathways to Sustainability through Novel Big-Data Analytics and Participatory Agricultural Systems Science

Co-PI, DOE TES $424,479 (MSU)
Improving Earth System Model Representations of Aboveground-Belowground Processes in Tropical Forests on Deep Soils

PI, Elk River Chain of Lakes Watershed, *Preliminary proposal only* $120,000
Understanding Lake Levels and Assessing Mitigation Scenarios Across the Elk River Chain of Lakes ERCOL) Watershed: Building a Modern Platform for Better Stewardship

Co-PI, NSF FRES $2,146,619 (MSU)
Collaborative Research: Carbon Fluxes Down the Hydrologic Connectivity Cascade: Cross-scale Interactions of Water, Nutrients, and Plants in Freshwater Wetlands

2018 Co-PI, NIFA SAS $9,998,939
Pathways to Sustainability through Novel Big-Data Analytics and Participatory Agricultural Systems Science

18. Co-PI, NOAA GLRI $432,000 ($185,797 MSU)
Using existing data and models deployed through Tipping Points Planner to support LAMP and community planning decisions

2017 17. Co-PI, NSF/NIFA INFEWS $2,473,000
INFEWS/T1: Developing Pathways Toward Sustainable Irrigation across the United States Using Process-based Systems Models (SIRUS)

Co-PI, NSF/NIFA INFEWS $2,499,510
INFEWS/T3: Novel Use of Big-Data to Improve Environmental, Economic and Energetic Efficiency of Fertilizer in Midwest US Agriculture

2016	Co-PI, NSF Macrosystems Biology *Collaborative Research: MSB-FRA: Carbon fluxes down the hydrologic connectivity cascade: Cross-scale interactions of water, nutrients, and plants in freshwater wetlands*	$2,348,693
	16. Co-PI, NASA Interdisciplinary Sciences *Quantifying how Global Change and Land Use Legacies Affect Ecosystem Processes at the Land Water Interface across the Great Lakes Basin*	$1.5 million
	Co-PI, NSF Macrosystems Biology *Collaborative Research: Carbon fluxes down the hydrologic connectivity cascade: Cross-scale interactions connectivity cascade: Cross-scale interactions of water, nutrients, and plants in freshwater wetlands*	$2,335,943
	Co-PI, NSF INFEWS *INFEWS/T1: Developing Pathways Toward Sustainable Irrigation across the Continental US Using Process-based Systems Models (SIRUS)*	$2,999,917
	15. Co-PI, NOAA *Empowering Communities with Online Action Planning Tools: Tipping Points and Indicators for Improving Water Quality Across the Great Lakes*	$407,568
2015	Co-PI, NIFA *Quantifying the Effects of Projected Climate and Associated Shifts of Crop and Animal Systems on Water, Nutrients, and Carbon Across the Upper Midwest*	$449,965
	14. Co-PI, NSF FEW Supplement *Project/Proposal Title: This Proposal: Analyzing Interactions Between Food and Energy Across the High Plains Aquifer Region: Impacts on Water, Food, Economics and Policies*	$143,772
2014	Co-PI, NSF Coastal SEES *Coastal SEES: An ecosystem-human model of climate change impacts on ocean-dependent communities in the developing world: A western Caribbean estuarine system as a prototype testbed*	$1,898,947
	Co-PI, NSF Macrosystems Biology *Collaborative Research: Carbon fluxes down the hydrologic connectivity cascade: Cross-scale interactions of water, nutrients, and plants in freshwater wetlands*	$1,709,258
	Co-PI, NASA *Sustainable Irrigation from Corn to Vineyards: Forecasting Water Use through Remote Sensing and Process-based Modeling*	$1,803,175
	13. Co-PI, USDA NIFA *Developing and promoting water-, nutrient-, and climate-smart technologies to help agricultural systems adapt to climate and societal changes*	$4,994,270
	Co-PI, NSF Coupled Natural Human Systems *CNH-L: Multi-generational Responses of Coastal Socioecological Systems to Global Change: Modeling Dynamic Feedbacks in a Ridge-to-Reef Landscape Microcosm*	$1,799,710
2013	Co-author and senior investigator *Midwest Glacial Landscape CZO*	$4,990,877

	Co-PI, NSF Coastal SEES *Coastal SEES (Track 1): Cross-generational adaptation of a coupled human and mangrove estuary system in the face of progressive global climatic and economic change*	$573,439
2012	13. Co-author and senior investigator, MDNR and Anglers of the Au Sable *Exploring Dynamic Interactions Between Surface Water and Groundwater*	$94,402
	12. Co-PI and institutional lead, USACE *Simulating Sediment Yield Response to Climate Change in Two Large Midwestern Watersheds*	$14,987
	11. PI, Three Lakes and Elk Lake/Skegemog Lake Associations *Understanding the Hydrologic Landscape to Assess Trajectories of Sediment Sources and Stream Condition in the Grass and Rapid River Watersheds*	$12,000
2011	10. Co-author and senior investigator, EPA STAR *Forecasting and Evaluating Vulnerability of Watersheds to Climate Change, Extreme Events, and Algal Blooms*	$749,801
	9. Co-PI, NOAA Michigan Sea Grant *Quantifying the Impacts of Projected Climate Changes on the Grand Traverse Bay Region: An Adaptive Management Framework*	$161,710
	8. Co-PI, MDNR Habitat Improvement Account and Higgins Lake Foundation *Ecohydrologic Evaluation of Removing of the Higgins Lake-Level Control Structure*	$82,885
	7. Co-PI, NOAA Great Lakes Integrative Science and Assessment Center *Predicting the Impacts of Climate Change on Agricultural Yields and Water Resources in the Maumee River Watershed*	$29,938
2010	6. Co-PI, NSF Water Sustainability and Climate proposal *Toward Sustainability of the High Plains Aquifer Region: Coupled Landscape, Atmosphere, and Socioeconomic Systems (CLASS)*	$1,474,356
	5. Co-PI, EPA Great Lakes Restoration Initiative proposal *Nutrient management models to constrain harmful algal blooms*	$499,954
	4. Co-PI, USGS NIWR Water Resources Research proposal *Implications of Climate Change and Biofuel Development for Great Lakes Regional Quality and Quantity*	$247,563
2009	Co-PI, USGS NIWR Water Resources Research proposal *Implications of Converting from Conventional to Biofuel Cropping Systems for Great Lakes Regional Water Resources*	$248,521
2008	3. Co-author, NSF Hydrologic Sciences Proposal, EAR-0911642 *Multi-scale Monitoring and Modeling of Land Use and Climate Change Impacts on the Terrestrial Hydrologic Cycle: Implications for the Great Lakes Basin*	$243,552
2007	2. Co-author, MSU Center for Water Sciences Postdoctoral proposal *The role of climate variations and land transformation on human and ecological health in large watersheds that drain to Lake Michigan*	$116,587

	PI, National Center for Airborne Laser Mapping graduate student data proposal *Improving Regional-Scale Landscape Hydrologic Modeling with High Resolution Topographic Data*	in kind
2002	1. Assisting author, NSF Water Cycle proposal, EAR-02333648 *Quantifying the Impact of Land Use and Climate Change on Groundwater/Surfacewater Interactions in Regional Great Lakes Watersheds*	$490,000

DEPARTMENTAL, COLLEGE, AND UNIVERSITY SERVICE ACTIVITIES

2023 – 2024	Chaired a search committee for two different tenure track positions in EES
2022 –	DEIJ coordinator and liaison, on the College of Natural Sciences DEI Advisory Council
2022 – 2024	Helped lead EES undergraduate curriculum reform, both on an ad-hoc committee and through an additional service appointment
2020 – 2021	Served on the Department of Earth and Environmental Sciences Transition Team

PROFESSIONAL AND OUTREACH ACTIVITIES

2024	Served on an NSF proposal review panel
	Gave interview to *Downtown News* regarding aquifers and groundwater in SE Michigan
2023	Joined MSU's Center for Interdisciplinary Research, Collaboration, and Engagement (CIRCLE) as an affiliate faculty.
	Gave a talk on my hydrogeology research to the Lansing-area tri-counties planning commission to water professionals across the area
	Gave a talk to the Michigan Basin Geological Sciences at their monthly meeting, joint with Dr. Freymueller
	Evaluated student presentations at the World Food Prize Michigan Youth Institute
	Helped present hydrology exhibits at the Marble Elementary Science Night
	Helped present hydrology exhibits at the MSU Science Festival
2022	Joined the Michigan Department of Environment, Great Lakes, and Energy's Water Use Advisory Committee (WUAC) modeling subcommittee, helping to develop specifications for a new State of Michigan water modeling framework tool.
	Co-convener of the session "Forming the Future of Agrohydrology Research" at the AGU/CUAHSI Frontiers in Hydrology Meeting, held in San Juan, Puerto Rico, June 2022
	Radio interview for WKAR 90.5, NPR affiliate at MSU, regarding a new NSF-funded project focused on groundwater levels across the Great Lakes Basin
	Radio interview for WEMU 89.1, NPR affiliate in Ann Arbor, regarding recently-published work on Chloride and Lake Michigan.
	Television interviews for FOX 47 in Lansing, and ABC affiliate WZZM in Grand Rapids. Both regarding recently-published work on Chloride and Lake Michigan.
	Interview for news articles on Chloride in Michigan for Michigan Downtown magazine and the Detroit News.
	Talk for World Water Day on introductory groundwater contamination issues. Organized by the Water Festival in Michigan organizers.
2021	Participant with a scientist and stakeholder group called the Groundwater Table, convened by For the Love of Water, focused on groundwater resource issues in Michigan. Invited to give

a talk, “Modern challenges in groundwater contamination: Policy, science, and practice” on July 7th, in webinar format.

2020 Co-convener of AGU poster session Agrohydrology in a Changing World: From Global Processes to Local Outcomes, AGU Fall Meeting, Virtual, December 7-11

2019 Co-convener of AGU eLightning session Agrohydrology in a Changing World: From Global Processes to Local Outcomes, AGU Fall Meeting San Francisco, December 9-13

Appeared in two podcasts on the show “Science Says” hosted by NBC affiliate WILX and meteorologist Brett Collar. One on the Gulf of Mexico Dead Zone, the other on Great Lakes water levels.

2018 Co-convener of AGU eLightning session Agrohydrology in a Changing World: From Global Processes to Local Outcomes, AGU Fall Meeting Washington D.C. December 10-14

Webinar for the MN/WI/IL/IN Sea Grant National Ocean Service Science Seminar Series on the NOAA Tipping Points Planner

Panelist for an MSU Institute of Public Policy and Social Research forum on Great Lakes Health

Speaker for the Tip of the Mitt Climate Change Summit

2015 Presentation for the MDEQ Webinar Series on Landscape Factors Controlling Stream Pathogen Concentrations

Radio interview for Nebraska Rural Radio about High Plains water modeling work

2011 – 2018 Presentations of project results to audiences including stakeholders and general public, 4 meetings

2010 Webinar for the OSU Sea Grant Climate Change Webinar series on Water Quality in the Great Lakes

2003 – 2018 Stakeholders’ meetings and workshops (15-75 attendees), 9 meetings

ACADEMIC PRESENTATIONS, WORKSHOPS, AND CONFERENCE PAPERS, *INVITED

2023 **Kendall, A.D.** Stid, J.T., Mir Zendeh Del, B., Dahlke, H.E., Hyndman, D.W., and A. Anctil, Exploring the Potential for Managed Aquifer Recharge Within Agricultural Solar Arrays (Solar Ag-MAR) to Enhance Energy and Water Sustainability in California’s Central Valley, AGU Fall Meeting 2024, San Francisco, Dec 11-15

*__Kendall, A.D.__, Understanding Great Lakes Groundwater Dynamics with Hydrologic Models, Geodesy, and Remote Sensing, Seminar of the Geological and Earth Sciences, Western Michigan University, Nov 12

*__Kendall, A.D.,__ Spatial-, Source-, and Pathway-Specific Nutrient Input and Transport Across the US Great Lakes Basin, Workshop of the COMPASS-GLM Project, Ann Arbor, MI, Sep 19-20

*Workshop for the USGS Powell Synthesis Center on Stream Depletion, Ft. Collins, CO, June 12-16

*Workshop for the USGS Powell Synthesis Center on Great Lakes Groundwater, Ft. Collins, CO, May 22-26

2022 **Kendall, A.D.,** Brady, A.J., Deines, J.D., Hyndman, D.W., and J. Butler Jr., Simulating the Hydrologic Effects of Adopting EFFICIENT Irrigation Technologies Across the High Plains Aquifer. Book of Abstracts for Sustain Valencia 2022: Achieving Sustainable Groundwater Management - Promising

Directions and Unresolved Challenges, pp. 67-68, Universitat Politècnica de València, València, Spain, Oct. 8, 2022.

Kendall, A.D., Conservation, Efficiency, and Expansion: New Perspectives on High Plains Irrigation from Remote Sensing and Systems Modeling, University of Nebraska Department of Earth and Atmospheric Sciences Stout Lecture Series, Apr 1

2021 **Kendall, A.D.**, Brady, A.J., Deines, J.M., Glose, T.J., Zipper, S.Z., Liu, X., Butler, J.J.Jr., and D.W. Hyndman, Simulating the Hydrologic Effects of Aquifer-wide Adoption of Efficient Irrigation Technologies, AGU Fall Meeting 2021, New Orleans, Dec 13-17

2020 **Kendall, A.D.,** Battaglia, M., Bourgeau-Chavez, L.L., Currie, W.S., Elgersma, K.J., Goldberg, D.E., Hamlin, Q.F., Hyndman, D.W., Martin, S.L., Martina, J.P., Sharp, S.J., Wan, L., *Connecting Landscape-Applied Nutrients to Widespread Coastal Wetland Invasion Across the Laurentian Great Lakes*, AGU Fall Meeting 2020, Online, Dec 1-17

2017 **Kendall, A.D.**, Deines, J.M., and D.W. Hyndman, Simulating the Effects of Widespread Adoption of Efficient Irrigation Technologies on Irrigation Water Use, AGU Fall Meeting, New Orleans, LA, USA December 11 - 15

2016 **Kendall, A.D.** and D.W. Hyndman, *Quantifying the Impacts of Irrigation Technology Adoption on Water Resources in the High Plains Aquifer, USA*, Toward Sustainable Groundwater in Agriculture, Burlingame CA June 28-30

Kendall, A.D., Cotterman, K., and D.W. Hyndman, *Quantifying the Impacts of Irrigation Technology Adoption on Water Resources in the High Plains Aquifer*, *USA*, EGU Annual Meeting, Vienna, April 18-22

***Kendall, A.D.** and D.W. Hyndman, *Water Sustainability and the Coupled Land Atmosphere and Socioeconomic Systems of the High Plains Aquifer*, University of Arizona Department of Atmospheric and Hydrologic Sciences Seminar, April 6

2015 ***Kendall, A.D.** and D.W. Hyndman, *Simulating the Land Surface Response to Drought and Climate Change Across the High Plains,* Nebraska Water Symposium, Lincoln, NE, USA, March 19

2014 **Kendall, A.D.** and D.W. Hyndman, *Simulating the Land Surface Response to Drought and Climate Change Across the High Plains*, Annual Conference of the Midwest Groundwater Association, Lawrence, KS, USA October 2-3

***Kendall, A.D.,** Martin, S.L., Luscz, E.C., and D.W. Hyndman, *Identifying Stream Nutrient Tipping Points from Spatially Explicit Source Mapping in the US Great Lakes Basin*, Joint Aquatic Sciences Meeting, Portland, OR, USA, May 18-23

2013 **Kendall, A.D.**, Luscz, E.C., Martin, S.L. and D.W Hyndman. *From Landscape Application to the River Mouth: A Fully Explicit Simulation of Nutrient Loads Across Lower Michigan, USA*, 56th Annual Conference on Great Lakes Research, West Lafayette, IN, June 2-6

2012 **Kendall, A.D.** and D.W. Hyndman, *Simulating Regional-Scale Hydrologic Responses to Climate Change Across Michigan, USA,* AGU Fall Meeting, San Francisco, CA, USA, December 3-7

2009 **Kendall, A.D.**, Hyndman, D.W., Pijanowski, B.C., and D. Ray, *Simulating Impacts of Climate and Land Use Change on Regional Hydrology at Fine Resolution with the Integrated Landscape Hydrology Model (ILHM)*, Annual Meeting of the North American Benthological Society (NABS). Grand Rapids, Michigan

Kendall, A.D., Hyndman, D.W., Pijanowski, B.C., and D. Ray, *Simulating Impacts of Climate and Land Use Change on Regional Hydrology at Fine Resolution with the Integrated Landscape Hydrology Model (ILHM)*, Annual Conference of the International Association for Great Lakes Research (IAGLR). Toledo, Ohio

Kendall, A.D., Hyndman, D.W., Pijanowski, B.C., and D. Ray, *Simulating Impacts of Climate and Land Use Change on Regional Hydrology at Fine Resolution with the Integrated Landscape Hydrology Model (ILHM)*, Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. (CUAHSI) Community Hydrologic Modeling Platform (CHyMP) Conference. Memphis, Tennessee.

Kendall, A.D., Hyndman, D.W., Pijanowski, B.C., and D. Ray, *Simulating Impacts of Climate and Land Use Change on Regional Hydrology at Fine Resolution with the Integrated Landscape Hydrology Model (ILHM)*, Annual Meeting of the American Association for the Advancement of Science (AAAS). Chicago, Illinois.

2007 **Kendall, A.D.**, Bernstein, J.A., and D.W. Hyndman, *Improving Regional Groundwater Recharge Models with a Network of High-Resolution Temperature Recording Buttons*, National Meeting of the Geological Society of America, Abstracts with Programs. Denver, Colorado

Kendall, A.D., and D.W. Hyndman, *Simulating Fluxes Through Large Watersheds Using Remotely Sensed and Ground Based Datasets with the Integrated Landscape Hydrology Model (ILHM)*, National Meeting of the Geological Society of America, Programs with Abstracts, Denver, Colorado

Kendall, A.D., Hyndman, D.W., and N.R.H- Welty, *Predicting the Distribution of Groundwater Recharge at Regional Scales with the Integrated Landscape Hydrology Model (ILHM)*, National Meeting of the American Institute of Professional Geologists. Traverse City, Michigan

2006 **Kendall, A.D.**, and D.W. Hyndman, *Predicting Groundwater Recharge, Streamflow, and Watershed Hydrology at the Regional Scale with the Integrated Landscape Hydrology Model (ILHM)*, H31H-06, Eos Trans. AGU. San Francisco, California

2005 **Kendall, A.D.**, and D.W. Hyndman, *Using Dual-Region Calibration To Improve Recharge and Hydraulic Conductivity Estimates for Hydrological Modeling*, H51B-03, Eos Trans. AGU. New Orleans, Louisiana

2004 **Kendall, A.D.**, Hyndman, D.W., Phanikumar, M.S., and B.C. Pijanowski, *Using Spectral Analysis to Relate Climate and Land-Use Changes to Processes Influencing Stream Flow*, H21F-1095, Eos Trans. AGU. San Francisco, California

Kendall, A.D., and M. Koochesfahani, *A New Method for Estimating Wall Shear Stress in Turbulent Boundary Layers*, APS-DFD '04, Abstract KA.004. Seattle, Washington

SELECTED AWARDS AND FELLOWSHIPS

2022	Michigan State University Chapter of the Phi Kappa Phi Honors Society, Excellence Award for Interdisciplinary Studies: *Sustainable Climate, Agriculture, Landscapes, and Energy (SCALE) Team*	$1,000
2020	Purdue Agriculture TEAM Award recognizing interdisciplinary achievements *Tipping Point Planner Team*	
2009	Departmental fellowships (2), Geological Sciences Department, MSU	$2,000
	International Association for Great Lakes Research (IAGLR) Hydrolab Best Presentation Award	$400

2008	Dissertation Completion Fellowship, College of Natural Sciences, MSU	$6,000
	Departmental fellowship, Geological Sciences Department, MSU	$500
2007	Best Graduate Student Poster, American Institute of Professional Geologists	$1,000
	Departmental fellowship, Geological Sciences Department, MSU	$1,500
2006	Doctoral Recruiting Fellowship, College of Natural Sciences, MSU	$23,000
	Rasmussen Fellowship, College of Natural Sciences, MSU	$4,000
2005	Graduate Fellowship, Michigan Space Grant Consortium	$5,000
2004	Outstanding Senior Award, Astronomy and Physics Department, MSU	$300
	Departmental fellowship, Geological Sciences Department, MSU	$1,500