2024 SPUR LAKE MANAGEMENT PLAN

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Introduction and Background

Spur Lake is a 113-acre, undeveloped, muck-bottomed shallow headwater drainage lake located in Oneida County that is owned by Wisconsin Department of Natural Resources (WDNR) and was designated as a State Natural Area in 2007. The lake supports dense beds of emergent, submergent, and floating-leaved aquatic plants. Wild rice (manoomin; *Zizania palustris*) was once a dominant emergent species, but the lake has been experiencing declines in rice production since the late-1990s, and today, few plants are present. High and static water levels and an increase in native perennial vegetation that competes with rice are thought to be the driving factors contributing to decline.

Spur Lake's surrounding shoreline is composed of wetlands including open bog, alder thicket, and black spruce-tamarack-white cedar swamp. Along the northeast corner of the lake is a small stand of old-growth hemlock hardwoods and a floating bog mat. The surrounding landscape is comprised of forest, wetlands, scattered lakes, commercial forestry, and small amounts of agriculture. Development is concentrated around the surrounding lakes and is characterized by cottages, second homes, and a few primary residences. The outlet stream, Twin Lakes Creek, is a shallow, muck-bottomed creek flowing through a large wetland comprised of sedges and willows. It flows southward, joining the North Branch Pelican River, which in turn flows into the Wisconsin River. Twin Lakes Creek Watershed is in the top 13% highest quality HUC 12 watersheds in the state (Marti et al 2022). The lake and surrounding wetlands provide habitat for a variety of migratory waterfowl, including several Species of Greatest Conservation Need. Spur Lake is culturally significant for local tribes who have historically used this waterbody as an important wild rice resource.

In 2019, a Climate Adaptation Workshop was hosted by the Northern Institute of Applied Climate Science (NIACS) and attended by the WDNR and interested partners to discuss climate adaptation and management options to restore wild rice on Spur Lake. The Spur Lake Working Group was formed from this workshop and includes the following partners: WDNR Bureau of Natural Heritage Conservation, WDNR Lakes Program, WDNR Wildlife Management, Lac du Flambeau Band of Lake Superior Chippewa Indians, Lac Vieux Desert Band of Lake Superior Chippewa Indians, Sokaogon Chippewa Community – Mole Lake Band of Lake Superior Chippewa (SCC), Great Lakes Indian Fish and Wildlife Commission (GLIFWC), Northland College, and the Stella Lake Association.

The goal of the Spur Lake management plan is to maintain the lake as an important shallow, muck-bottomed lake for wildlife (game and non-game) resources. This is not a management plan for the Spur Lake State Natural Area's entire property; management actions described here are specifically focusing on the lake. The Spur Lake Working Group has a goal of restoring the hydrology of Spur Lake and promoting the re-establishment of wild rice on the lake, if possible. The intention of this plan is to aid in the facilitation of various management objectives and recommendations that will promote this goal.

Relevant Data

Various monitoring has taken place over the years to establish baseline data to inform management actions and document changes in Spur Lake over time. This monitoring has included annual aquatic plant surveys, documenting water levels and quality, wild rice flights, a pilot seed bank study, and a hydraulic study. Listed below is relevant data:

- Aquatic Plant Surveys (See Appendix A: Spur Lake Aquatic Plant Maps)
    - Surveys have been conducted in 2010 and on an annual basis since 2020 (Tables 1 and 2). Dominant aquatic species observed presently are watershield (*Brasenia schreberi*), white waterlily (*Nymphaea odorata*), coontail (*Ceratophyllum demersum*), stonewort (*Nitella* spp.), spatterdock (*Nuphar variegata*), and common bladderwort (*Utricularia vulgaris*).
    - In 2010, wild rice was found at 69% of survey points (within 6 feet). The amount of wild rice found in surveys in 2020 and 2021 was significantly less. Although the amount of wild rice noted at (within six feet of) survey points increased from 5% in 2020 to 17% in 2021, it is still sparse and only found as scattered individual plants within the lake.
    - While the overall aquatic plant coverage was not different between 2010 and the recent surveys, the amount of submersed and floating leaf aquatic plants increased significantly from 2010 to 2020/2021. This is likely due to the rise in water levels from 2010 to 2020. The only emergent species that increased was Creeping spikerush (*Eleocharis palustris*).
        - The increase in floating leaf plants was due to a large increase in watershield, while white water lily and spatterdock remained largely the same.
        - Chara macroalgae species and floating leaf pondweed were much lower than in the 2010 survey while many of other submersed vascular plants were more abundant in recent surveys.
    - The number of species found in recent surveys was higher than in 2010. Species found in Spur Lake in 2020 or 2021, but not in 2010 include *Carex species*, *Dulichium arundinaceum*, *Eleocharis acicularis*, *Heteranthera dubia*, *Myriophyllum verticillatum*, *Najas gracillima*, *Najas guadalupensis*, *Nitella flexilis*, *Potamogeton epihydrus*, *Potamogeton nodosus*, *Potamogeton obtusifolius*, *Schoenoplectus subterminalis*, and *Utricularia minor*. *Lemna minor* and *Vallisneria americana* were found in the 2010 survey but not in the more recent surveys.

Table 1. Comparison of number of survey points documenting plant species in Spur Lake in 2010 and 2021. Data provided for species found at >5% of survey points in at least one of the two surveys.

* Indicates a statistically significant difference in number of survey points at which the species was detected between years.

	2010	2021
Submersed Species		
Ceratophyllum demersum* , Coontail	18	116
Chara spp.* , Muskgrasses	67	5
Elodea canadensis* , Common waterweed	1	34
***Myriophyllum sibiricum* , Northern watermilfoil**	22	15
Najas flexilis* , Slender naiad	4	66
Nitella spp.* , Stonewort	0	13
Potamogeton natans* , Floating leaf pondweed	44	16
***Potamogeton zosteriformis* , Flatstem pondweed**	44	16
thin-leaf pondweeds (*Potamogeton foliosus* and *Potamogeton pusillius), Leafy and Small pondweed**	6	43
Utricularia gibba* , Creeping bladderwort	17	60
Utricularia minor* , Small bladderwort	0	30
***Utricularia vulgaris* , Common bladderwort**	38	45
Floating Species		
Brasenia schreberi* , Watershield	32	116
***Nuphar variegata* , Spatterdock**	26	23
***Nymphaea odorata* , White water lily**	132	106
Emergent Species		
Eleocharis palustris* , Creeping spikerush (includes visuals)	3	31
***Pontedaria cordata* , Pickerelweed (includes visuals)**	10	18
Zizania palustris* , Wild rice (includes visuals)	155	36

Table 2. Comparison of plant community metrics in Spur Lake in 3 years.

	2010	2020	2021
Percent of littoral sites with plants	98	91	94
Number of species (including visuals)	19 (23)	25 (40)	26 (31)
Average conservatism of species	6.1	6.6	6.8

- Water Levels and Quality
    - Since 2018, the University of Minnesota's Manoomin/Psiŋ Collaboration (UMN) has deployed both a surface water gauge and groundwater well (started in 2019) to record water levels (See Appendix B: Spur Lake Report: 2018-2022). Additionally, in 2019 and 2021, surface water samples were analyzed for geochemistry to determine if wild rice disappearance might be attributed to hydrology alone. In 2021, physical sediment data was collected to determine if Spur Lake's sediment is too loose for wild rice to grow.
        - Preliminary results of this study have revealed water levels briefly dropping after various management actions (artificial riffle removal, beaver dam removal, and

vegetation removal), but rising again after precipitation events and then remaining static (Spur Lake Report Team 2022).

    - Further evidence of groundwater upwelling that may impair wild rice development has been recorded, as illustrated by higher groundwater levels compared to surface water levels throughout the summer of 2021 (Spur Lake Report Team 2022).
    - Physical sediment data taken in 2021 reveals that Spur Lake has plenty of muck that is not too loose for wild rice to thrive (Spur Lake Report Team 2022).
    - Spur Lake had lower concentrations of chloride, sulfate, phosphate, calcium, magnesium, potassium, and sodium, yet higher nitrate and nitrite levels than other lakes UMN sampled (excluding Sand River and Twin Lakes). Since agricultural run-off and wastewater inputs are not present on the lake, it is presumed that high nitrate and nitrite levels can be attributed to internal nutrient cycling from organic matter (Spur Lake Report Team 2022).
  - A volunteer citizen lake monitor has monitored Spur Lake and has taken water quality measurements and recorded water level data (Figure 1) since 2019.
    - Water clarity was measured from 2019-2021 with Secchi disk (Table 3). Water was reported as murky and brown. This information and the high color of the water suggest that Secchi depth is mostly impacted by dissolved organic materials in the water that have leached from the surrounding wetlands.
    - Spur Lake water quality is considered excellent for a shallow headwater drainage lake. Phosphorus, chlorophyll, and aquatic plant data indicate a healthy ecosystem, and it is supporting its designated uses for fish/aquatic life and recreation. Chlorophyll and phosphorus totals have been collected from 2019-2021 (Tables 4 and 5). For context, WDNR's lake quality standards for shallow lakes are 27 ug/L for chlorophyll and 40 ug/L for total phosphorus. Of the 27 (chlorophyll and phosphorus) or 31 (Secchi) shallow headwater lakes that have been monitored in northern Wisconsin over the past ten years (2012-2021) Spur Lake is the 22, 41, and 100 percentiles for chlorophyll, total phosphorus, and Secchi depth, respectively.
    - Spur Lake's Trophic State Index (Figure 2) suggests that it is mesotrophic to eutrophic. Mesotrophic lakes are characterized by moderately clear water but have an increasing chance of low dissolved oxygen in deep water during the summer.
    - Additional water quality parameters collected in 2020 and 2021 help to understand the conditions in Spur Lake (Table 6). In general, the water quality information shows that Spur Lake is a stained, soft water lake with little indication of human impacts on water quality.
      - The pH of Spur Lake shows that the water is slightly acidic, but that it falls within the normal range for Wisconsin lakes.
      - Alkalinity is the ability of bicarbonate and carbonate ions in water to buffer fluctuations in pH that may be caused by acidic rain. 27.5 ppm of alkalinity shows a fairly low buffering capacity.
      - Similar to pH and alkalinity, calcium concentrations illustrate the hardness of the water and largely reflect the geology of a lake's watershed. Calcium and hardness (calcium and magnesium) concentrations are very low in Spur Lake, and it is likely that mussels would not be able to survive here as there isn't enough calcium for them to build shells.

- Chloride levels were also low, indicating that there aren't issues with road salt, fertilizers, or septic systems affecting Spur Lake.
- The water color of Spur Lake water is dark. This is a measure of water clarity once the suspended materials have been filtered out and indicates that Spur Lake water is moderately to highly tea colored. This is likely owing to tannic and humic acids that have leached from the wetlands surrounding the lake. Wetlands make up the majority of the landcover in the Spur Lake watershed.
- Nitrogen and phosphorus data collected in Spur Lake in 2022 indicate that the ratio of nitrogen to phosphorus in the lake was 37:1. N:P ratios greater than 15:1 indicate that phosphorus is the limiting nutrient for algae within a lake. Spur Lake appears to be phosphorus limited.

▪ Temperature profiles (in 1-foot increments) were recorded and show that Spur Lake does not thermally stratify during the summer. The lake is shallow enough that the entire lake remains mixed. July and August water temperatures in 2019 were substantially cooler than in 2020 or 2021. Given that the lake is shallow, and water is stained, it appears that water temperature closely tracks changes in air temperature and can change rapidly within a season. This is very apparent in the variable air and water temperatures in summer of 2021.

▪ Dissolved oxygen profiles were not collected in the lake as part of this project, but this should be considered in future work.

Figure 1. Water level data on Spur Lake from 2021-2022.

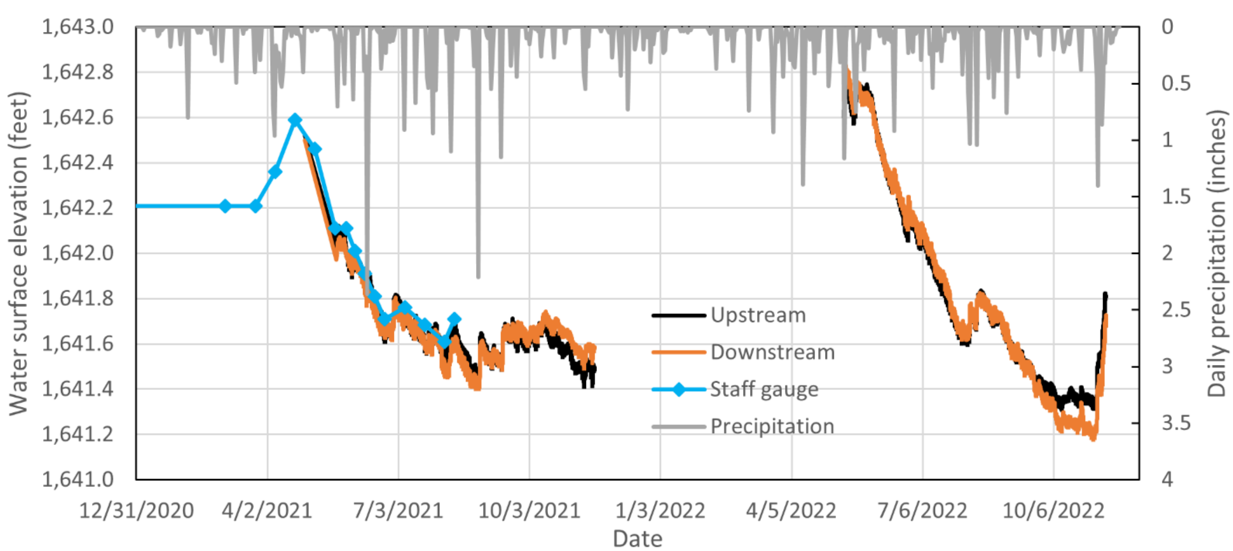

Figure 2. Trophic State Index Graph for Spur Lake. Displays average summer (July-August) Trophic State Index values for Secchi, total phosphorus, and chlorophyll a by year.

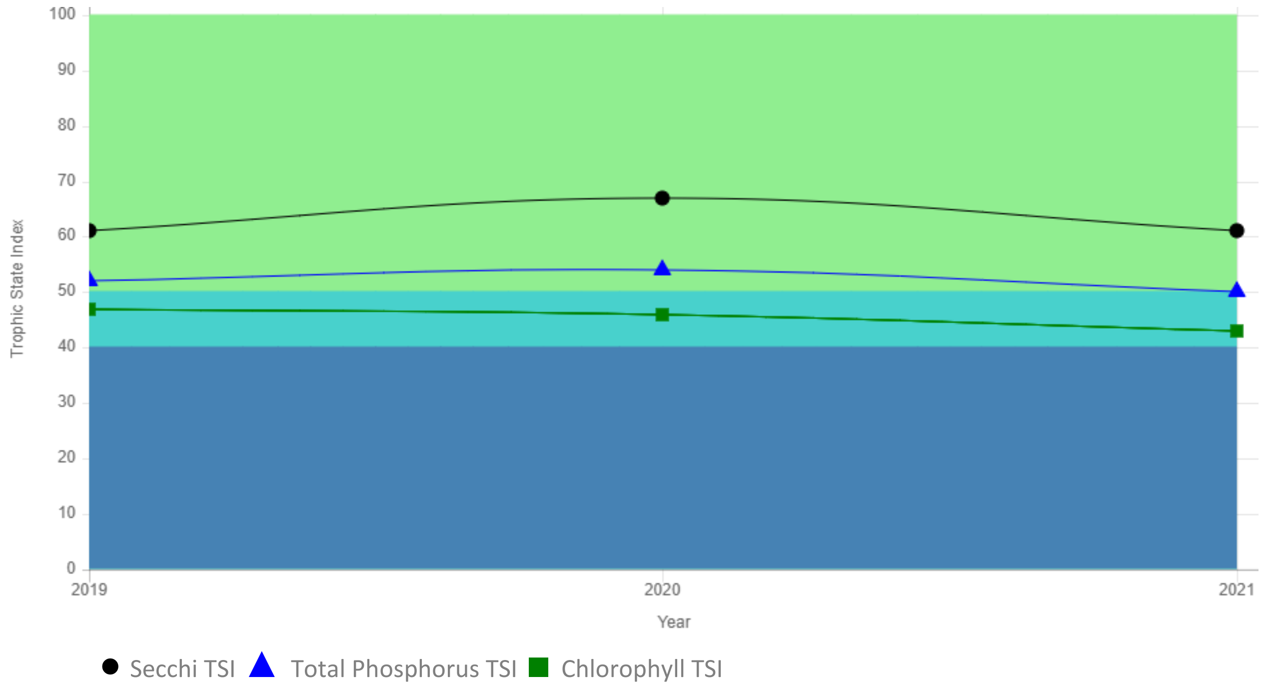

Table 3. Past Secchi averages in feet (July and August only).

Year	Secchi (ft) Mean	Secchi (ft) Min	Secchi (ft) Max	Secchi Count
2019	3	2	4	2
2020	2	2	2	2
2021	3	3	3	2

Table 4. Average annual summer chlorophyll on Spur Lake from 2019-2021.

Year	Chlorophyll (ug/L) Mean	Chlorophyll (ug/L) Min	Chlorophyll (ug/L) Max	Chlorophyll Count
2019	5.3	3.1	7.5	2
2020	4.2	3.2	5.2	2
2021	3.0	1.1	4.1	3

Table 5. Average annual summer phosphorus totals on Spur Lake from 2019-2021.

Year	Phosphorus (ug/L) Mean	Phosphorus (ug/L) Min	Phosphorus (ug/L) Max	Phosphorus Count
2019	24.4	21.0	27.3	3
2020	25.2	22.7	26.6	3
2021	18.6	14.4	23.9	4

Table 6. Additional water quality parameters taken in 2021 and 2022 on Spur Lake.

Additional Water Quality Parameters	
Alkalinity (mg/L)	27.5
Calcium (mg/L)	7.2
Chloride (mg/L)	1.43
Color	70
Hardness (mg/L)	35.2
Magnesium (mg/L)	4.19
Nitrogen (mg/L)	0.798
Ph	6.74

- Aerial Imagery
    - GLIFWC has conducted annual wild rice inspections via fixed-wing aircraft since the 1980's and has captured photos to document variability over the years and the absence of wild rice.
- Seedbank study
    - A seedbank pilot study was done by GLIFWC in 2019. Sediment samples were taken from the lake bottom and then tested for the presence of residual viable wild rice seed. No seeds were found, just empty hulls.
- Hydraulic Study
    - In 2021, SCC obtained grant funds (Brico Foundation via the Natural Resources Foundation of Wisconsin) and contracted Fish Creek Restoration, LLC to conduct a hydraulic study of Spur Lake and Twin Lakes Creek (See Appendix C: Spur Lake & Twin Lakes Creek Assessment Report).
        - Report Summary:
            - High water levels on Spur Lake are the result of human alterations (i.e., roads, culverts, artificial riffles, and a former railroad) of Twin Lakes Creek and beaver population recovery since the 1950's.
            - A dye tracer study determined that the lake has minimal water movement or inflow/outflow from surface to groundwater.
            - Climate change factors (increased annual rainfall events >2", decreased duration of winter ice cover) likely catalyzed the ultimate demise of wild rice.
            - Wild Rice is unlikely to re-establish to previous levels on its own without intervention (restoration)
        - Management recommendations
            - Eliminate the artificial riffle at downstream private property.
            - Replace the failing culvert on downstream private property.
            - Replace East Stella Lake Road culverts with larger structure to minimize backwater impacts, facilitate flow, and reduce potential for woody material entrapment.
            - Continue to remove beavers and beaver dams.

Historical Management

Man-made alterations to Twin Lakes Creek since the early 1900's have slowly changed the water levels and flowage of Spur Lake and Twin Lakes Creek. East Stella Lake Road was installed adjacent to Spur Lake, disrupting the surrounding wetlands; artificial riffles were added in Twin Lakes Creek; a former railroad once ran through the watershed and has since been removed; and multiple culverts have been installed and replaced over the years. Recent management has been focused on restoring hydrology in the Spur Lake system. Highlighted below is a timeline of relevant management on and around Spur Lake:

1997: A second culvert was added adjacent to an existing culvert on East Stella Lake Road.
1980's-present: United States Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) has been contracted annually by WDNR to remove beavers and dams.
2008: Both culverts on East Stella Lake Road were replaced, reportedly lower than the original culverts (by approximately 6 inches). Adding the second culvert may have reduced water movement, and in recent high-water years, the culverts have generally been completely underwater. Another undersized culvert is present and in poor condition on private property downstream, and further downstream there are 5 additional stream crossings on local town roads, 3 of which have culverts with major to severe deterioration (MDNR 2023).
2016-present: Manual vegetation and beaver dam removal in Twin Lakes Creek has been done 2-3 times per year since 2016 to increase downstream water flow.
2018: Stream work restoration was conducted on downstream private property. The bank was widened and stream bed lowered and regraded, allowing for better water flow. Post construction water levels dropped briefly (approximately 7 cm) but rose again following precipitation events in October and stayed high.
2022: A rice restoration pilot was initiated. Vegetation was cut and removed from 6x1 acre plots on Spur Lake in early August, and roughly 300 lbs. of wild rice was seeded into 3 cut and 3 uncut plots in September. The plots will be seeded for at least three years, and aquatic vegetation will be monitored within the plots for at least four years (1 before cutting and three after initial cutting and seeding).

Management

To maintain Spur Lake as an important shallow, muck-bottomed lake, and to promote wild rice reestablishment, a variety of management actions are recommended. Management actions were identified for both Spur Lake and Twin Lakes Creek. Most of these management actions were identified during the Climate Adaptation Workshop in 2019 and in follow-up meetings with the Spur Lake Working Group. Recommendations are as follows:

Spur Lake	Twin Lakes Creek
Replace the culverts on East Stella Lake Road to optimize flow and prevent blockages.	Continue to trap beavers and remove beaver dams and other obstructions from the stream as long as water levels remain high on Spur Lake.
Implement a pilot wild rice study during a low water period to understand if wild rice restoration is possible.	Replace the failing culvert on downstream private property and further restore the stream hydrology immediately up and downstream.
Monitor for invasive species and implement control measures if any are found.	Continue to manually remove vegetation from Twin Lakes Creek near the Spur Lake outlet to improve water flow.
Conduct a snow removal study on the lake to examine the impact of increased ice thickness on perennial aquatic species and wild rice.	Monitor for invasive species and implement control measures if any are found.
	Plug railroad ditches to improve channelization of Twin Lakes Creek and improve stream flow.

Alternatives Analysis

Additional management objectives were considered but not recommended. These are as follows:

- Replace all downstream culverts with ones that are appropriately sized for maximum flow rates within the watershed to further restore hydrology and reverse long-term high-water levels. This would be costly and outside of our realm of control of the Spur Lake Working Group.
- Take peat cores to ascertain historic plant communities, past water levels, past nutrients, and fire history to better understand the historic conditions of Spur Lake. This would be costly, and it is not necessary to achieve current management goals, so it is not recommended at this time.

Broader impacts

This management strategy involves the collaboration of a variety of stakeholders and partners that are involved in the Spur Lake Working Group. This group arose from a Climate Adaption Workshop hosted by NIACS in 2019 that utilized the Wetland Adaptation Menu and an early draft of the Tribal Adaptation Menu (Staffen et al., 2019; Tribal Adaption Menu Team, 2019).

Management actions to restore Spur Lake's hydrology and to promote wild rice reestablishment will have a broader impact on scientific understanding of this specific ecosystem. Wild rice has declined across its range, and it is considered highly to extremely vulnerable in the face of climate change (GLIFWC Climate Change Team 2023). Many factors that may contribute to wild rice decline are being addressed by the current and planned work at Spur Lake. Lessons learned from this effort could be used to inform restoration on other shallow lakes in the Upper Midwest and aid in conservation both ecologically and culturally.

This management plan has been reviewed by the Spur Lake Working Group and their constituents and underwent a public review and comment period in March 2024. Comments and input received have been incorporated into this final draft.

Implementation Plan

Management Goal 1: Lake monitoring

<u>Management action: Monitor for and control aquatic plants/AIS; monitor water quality, and water levels.</u>

Time frame: Ongoing, indefinite
Facilitator: WDNR, Citizen Lake Monitor, UMN
Description: Monitoring will occur on an annual basis, or as determined to be appropriate, and will consist of point-intercept aquatic plant surveys conducted by WDNR, ground and surface-water sensors deployed by UMN, and water depth and clarity measurements collected by a Citizen Lake Monitor.
Action steps: Continue the work that has already been initiated.

Management Goal 2: Control beaver

<u>Management action: As long as water levels remain elevated, trap and remove beavers and remove beaver dams annually.</u>

Time frame: Ongoing, indefinite
Facilitator: USDA – APHIS, WDNR
Description: As long as water levels remain elevated on Spur Lake, beavers will continue to be trapped and removed. Dams will be removed on an annual basis by both facilitators.
Action steps: Continue with beaver control as needed.

Management Goal 3: Remove in-stream obstructions.

<u>Management action: Remove obstructions from Twin Lakes Creek channel to improve water flow.</u>

Time frame: Ongoing, indefinite
Facilitator: WDNR, with the assistance Spur Lake Working Group partners
Description: Hold annual workday(s) to accomplish manual work in Twin Lakes Creek.
Action steps: Focus more on true obstructions (beaver dams and associated sediment) and less on vegetation.

Management Goal 4: Wild rice restoration study

<u>Management action: Conduct a pilot study to actively restore wild rice on Spur Lake.</u>

Time frame: Ongoing, minimum of 3 years but likely longer
Facilitator: Spur Lake Working Group, especially WDNR, SCC, GLIFWC
Description: Trial a series of experimental plots with different combinations of vegetation removal and wild rice seeding. Monitor for wild rice restoration results and waterfowl herbivory impacts, and experiment with methods for preventing herbivory. If certain treatments are successful for either wild rice restoration and/or waterfowl herbivory prevention, they could be considered for broader implementation on the lake.
Action steps: Acquire proper permits, identify and mark plot locations, sample vegetation, remove vegetation with a weed harvester, seed wild rice, address rice herbivory as needed/practical, and sample vegetation again.

Management Goal 5: Restore the habitat and hydrology of the stream channel and riparian areas on Twin Lakes Creek, including infrastructure improvement.

Management action 1: Replace failing culvert on private property downstream on Twin Lakes Creek with a more appropriate structure (at minimum) if a structure is still desired and needed; restore stream channel in same location by removing man-made riffle/restriction point.

Time frame: Ongoing, nearly complete
Facilitator: WDNR, USDA Natural Resources Conservation Service
Description: Restore hydrology in Twin Lakes Creek by replacing the failing culvert and restore the man-made alterations to the stream bed and stream channel in the same location. Project was delayed but is still moving forward.
Action steps: Complete project 2023-2024.

Management action 2: Conduct activities to improve and restore natural hydrology and ecosystem connectivity along Twin Lakes Creek, including, but not limited to, plugging/filling perpendicular railroad grade channels on both sides of the grade where they intersect the creek to encourage channelization of in-stream flows, decrease artificially created backwater storage and ponded areas, and improve overall streamflow and velocity.
Time frame: Unknown
Facilitator: Unknown
Description: Currently there is not an implementation plan in place for this management goal.
Action steps: Currently there is not an implementation plan in place for this management goal.

Management Goal 6: Restore Spur Lake hydrology impacted by East Stella Lake Road and existing infrastructure.

Management action: Conduct management activities to improve watershed hydrology and promote restored hydrologic connection among wetland and aquatic communities, including, but not limited to, replacement of the culverts (at minimum) at the outlet of the lake (East Stella Lake Road).

Time frame: 3-5 years
Facilitator: WDNR, Town of Piehl, SCC
Description: Work with the Town of Piehl to identify an acceptable replacement design, fund, and implement the replacement of the culverts or conduct other appropriate alterations as needed that allow for hydrologic connectivity improvement on East Stella Lake Road with designs that are more appropriate for the situation and ongoing, modeled, and anticipated climate change events.
Action steps: Culvert design has been drafted by Fish Creek Restoration, LLC. Work with the town to identify and apply for funding to pay for the culvert replacement.

Management Goal 7: Experiment with snow removal on lake.

Management action: Plow snow off lake ice during winter.

Time frame: Unknown
Facilitator: Unknown
Description: Snow removal from lake ice has been shown anecdotally to reduce perennial vegetation and improve wild rice growth from similar shallow lakes in Minnesota. This allows lake ice to get thicker and even freeze to the bottom of the lake, killing the perennial tubers. If carried out, it would likely be a pilot experiment to document the effectiveness of this action.
Action steps: Currently there is no ramp access to Spur Lake. Timber mats placed over the bog would be required to provide driving access for an ATV with a plow. Currently, there is not an implementation plan in place for this management goal.

Management Goal 8: Additional adaptive watershed management activities as informed by timely and updated water quality monitoring, reports, and planning efforts.

<u>Management action: Consider conducting additional management actions related to hydrologic restoration, wetland restoration, and other areas as identified through ongoing WDNR, tribal, academic, and other efforts.</u>

Time frame: Unknown
Facilitator: Unknown
Description: WDNR and partners are planning to conduct comprehensive holistic watershed monitoring (lake, stream, and wetland) throughout the Twin Lakes Creek HUC12 starting in 2024. Management goals, suggested actions, or activities to alleviate or improve stressors or other concerns may be identified in watershed monitoring reports and watershed planning efforts as related to Spur Lake directly or deemed to have substantial connection or potential for improvement to Spur Lake, Twin Lakes Creek, and their numerous and vast associated wetland complexes and may be considered for implementation on a case-by-case basis as deemed appropriate by the Spur Lake Working Group.
Action steps: Currently there is not an implementation plan in place for this management goal.

Plan Update Strategy

This management plan will be re-evaluated annually by the Spur Lake Working Group. Additionally, an updated draft will be provided for public review approximately every 5-10 years to remain eligible for DNR Surface Water Grant funding. If any structures such as culverts are replaced with WDNR funding, a long-term maintenance plan will be developed.

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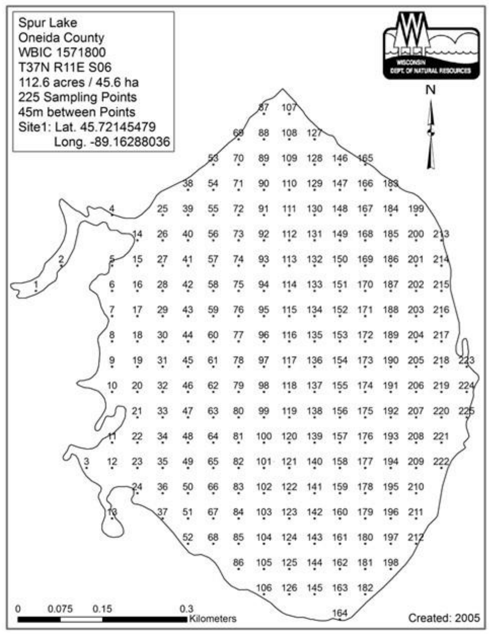
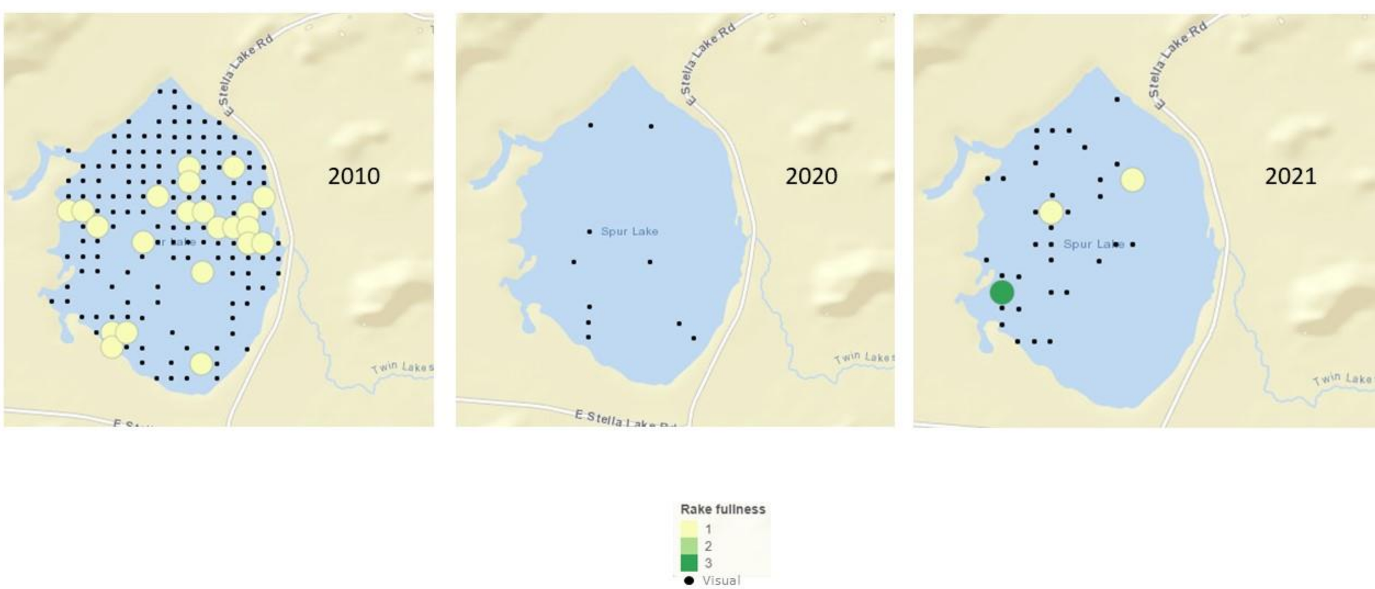
Appendix A: Spur Lake Aquatic Plant Maps

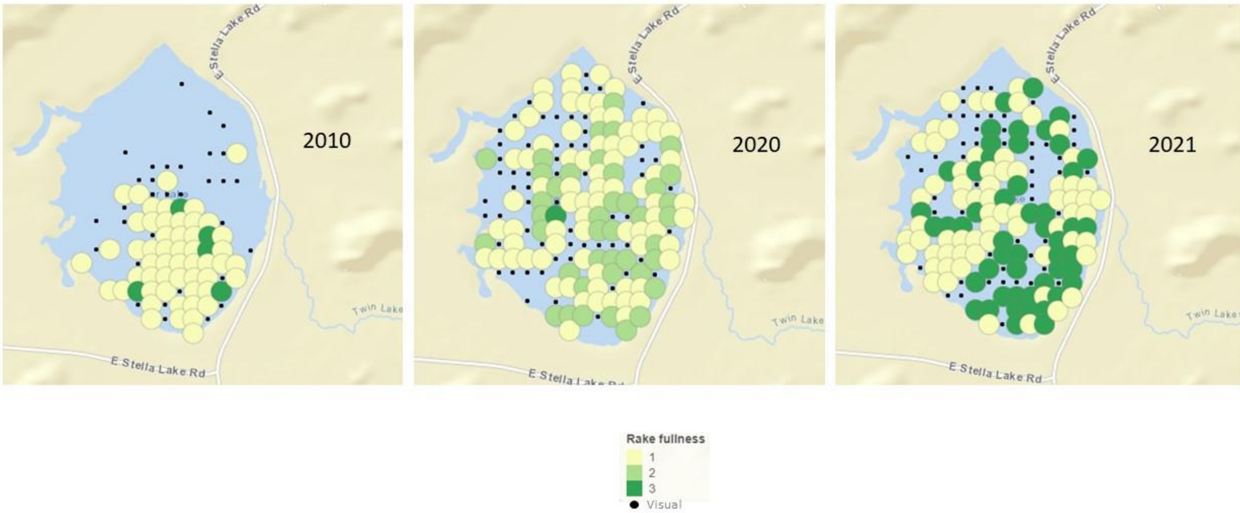
Point-intercept Aquatic Plant Survey Grid



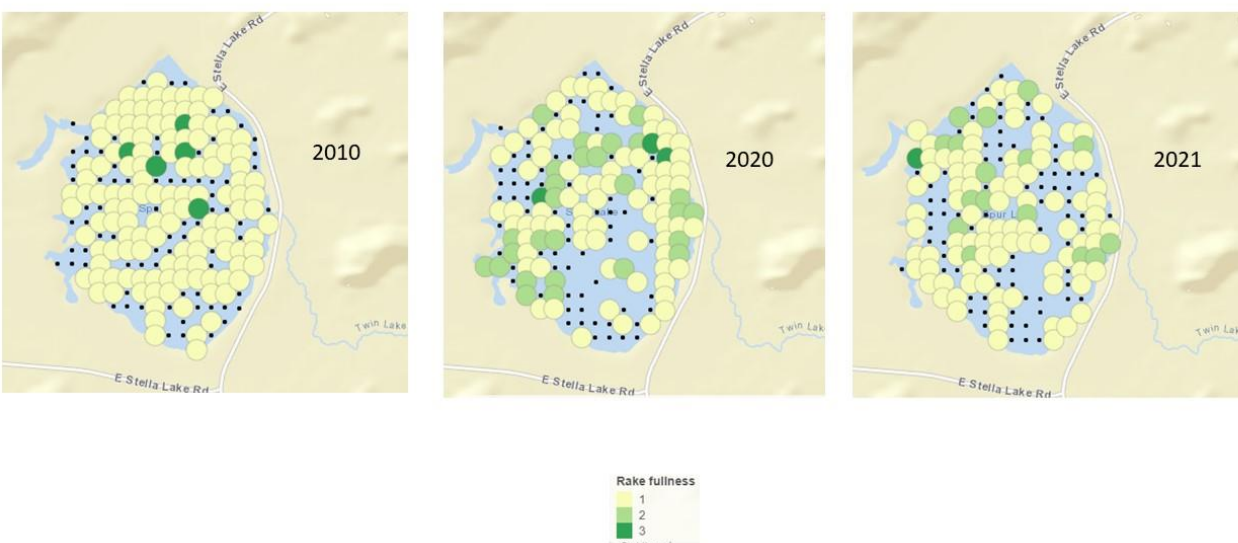
Zizania palustris – wild rice or Manoomin



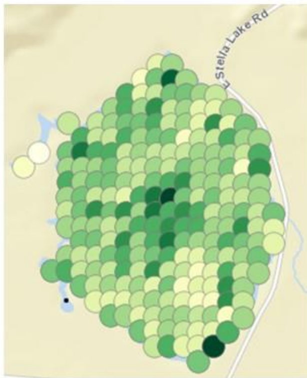
Brasenia schreberi - watershield



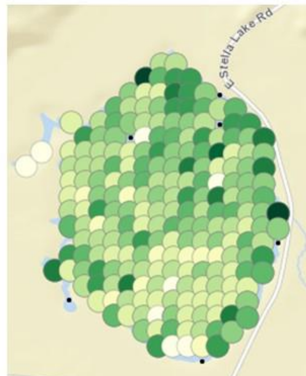
Nymphaea odorata – white water lily



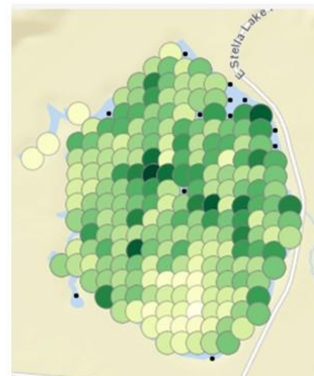
Species Richness



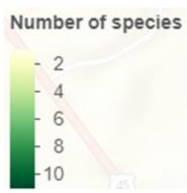
2010

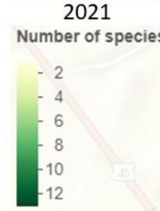


2020



2021





Appendix B: Spur Lake Report (2018-2022). *Kawe Gidaa-naanaagadawendaamin Manoomin.* First we must consider Manoomin/Psiŋ (wild rice) Research Collaboration

SPUR LAKE REPORT
(2018 - 2021)

Kawe Gidaa-naanaagadawendaamin Manoomin

First we must consider Manoomin / Psiŋ (wild rice) Research Collaboration

In partnership with the Great Lakes Indian Fish & Wildlife Commission

May 2022

Table of Contents

Introduction

Manoomin, the Ojibwe word for wild rice (Psiŋ in Dakota, scientific name: *Zizania palustris*), grows in shallow lakes and streams and provides physical, spiritual, and cultural sustenance as a sacred food and relative for Ojibwe/Anishinaabe, Dakota, and other Indigenous peoples across the Great Lakes region of North America (David et al. 2019; Great Lakes Wild Rice Initiative 2020). Manoomin abundance across North America has unfortunately been declining due to multiple environmental stressors since the onset of Euro-American colonization (LaDuke 2005; Drewes and Silbernagel 2012). In 2018, an interdisciplinary group from the University of Minnesota-Twin Cities came together with natural resource managers from tribes and inter-tribal organizations to study Manoomin within its socio-environmental context. The collaborative that formed was given the Ojibwe name: Kawe Gidaa-naanaagadawendaamin Manoomin—or First, We Must Consider Manoomin.

This report details the data and analysis generated in collaboration with one of our partners, the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), on Spur Lake. Resource managers at the Sokaogon Chippewa Community Mole Lake Band of Lake Superior Chippewa (SCC) and the Wisconsin Department of Natural Resources (WIDNR) were also involved in fieldwork and data analysis. This report was written to reflect knowledge generated through this partnership during collaborative field work and data analysis discussions to be shared with the communities of the Great Lakes Indian Fish and Wildlife Commission.

Partnership Agreement

Our intention in Kawe Gidaa-naanaagadawendaamin Manoomin is to respect tribal sovereignty through our partnerships. GLIFWC submitted a letter of support for the grant proposal titled "Wild Rice in Minnesota and the Great Lakes region: A flagship for environmental preservation and Indigenous resource sovereignty" for what has since become this project (2017). After receiving this grant and through relationships built between UMN researchers and GLIFWC resource managers and TEK and outreach specialists, a protocol of responsible and accountable research was developed and researchers committed to following it (2018). As advised by GLIFWC partners, no memorandum of understanding was signed because Spur is on ceded territory, but permits for research were obtained through the WIDNR. Partnership development and lessons learned are detailed in Matson et al. (2021).

Acknowledgments

Updates to this 2021 report on Spur Lake were written by Maddy Nyblade (PhD student, UMN), June Sayers (MS student, UMN), Gigi Voss (PhD student, UMN), Hima Hassenruck-Gudipati (postdoc, UMN), and Crystal Ng (Earth and Environmental Sciences professor, UMN) in collaboration with our GLIFWC partners, Dawn White and Amy Cottrell, as well as Nathan Podany (Sokaogon Chippewa Community) and Carly Lapin (WIDNR), who provided feedback through a data analysis meeting in spring of 2021. Emily Green (Manoomin project coordinator,

UMN) provided editorial assistance. Other contributors to the previous, 2020 version of the report, which serves as the basis for this 2021 report, include: Peter David (GLIFWC), Melonee Montano (GLIFWC), Cara Santelli (UMN), and Dan Larkin (UMN).

General fieldwork, lab work, and data analysis for Kawe Gidaa-Naanaagadawendaamin Manoomin has been conducted by the following UMN affiliates: Alex Waheed, Josh Torgeson (former MS student, UMN), Patrick O'Hara (MS student, UMN), McKaylee Duquain (MS student, UMN), Abi Barlett (undergraduate intern), Kellen Cooks (undergraduate intern), Christopher Villarruel (undergraduate intern), Trinaty Caldwell (undergraduate intern), Jamie Kay (undergrad intern), Riley Howes (undergraduate intern), Lilah White (undergraduate intern), Susannah Howard (undergraduate intern), LeAnn Charwood (undergraduate intern), Brena Mullen (undergraduate intern), Riley Schmitter (undergraduate intern), Gracelyn McClure (undergraduate researcher), Rachel Runzheimer (undergraduate researcher), Sairoong Brunner (undergraduate researcher), Hannah Jo King (PhD student, UMN), Sirena Torres (MS student UMN), Sarah Dance (PhD student, UMN), Mae Davenport (Forest Resources professor, UMN), Mike Dockry (Forest Resources professor), Gigi Voss, June Sayers, Maddy Nyblade, Hima Hassenruck-Gudipati, Crystal Ng, Cara Santelli, and Dan Larkin; help was also provided by Chris Schuler (PhD student, UMN), Harsh Anurag (PhD student, UMN), Shaoqing Liu (post-doc, UMN), Leila Saberi (PhD student, UMN), Brayden Kuester (undergraduate, UMN), Aubrey Dunshee (MS student, UMN), and Andy Wickert (Earth and Environmental Science professor, UMN).

At Spur Lake, Nathan Podany, Carly Lapin, Joe Graveen (Lac du Flambeau), and Bill Wildcat (Lac du Flambeau) also contributed to fieldwork.

Manoomin Background

Manoomin Life Cycle

Manoomin germinates in the early spring, reaches the water surface during the floating-leaf stage through June, emerges out of the water and flowers in mid-July, and reaches full maturation in September when it is consumed by waterfowl and harvesters (Aiken et al. 1988). Manoomin is wind-pollinated, with most cross-pollination occurring between nearby plants (Lu et al. 2005). In addition, Anishinaabe harvesting practices, waterfowl, and wind knock ripened seeds back into the water, reseeding the beds for the next year (Moyle 1944, Moodie 1991). Seed falling into the water near parent plants leads to generally short dispersal distances (Kjerland 2015), though waterfowl may contribute to longer-distance dispersal (Vivian-Smith and Stiles 1994, Diller et al. 2018). Together, short-distance pollination and dispersal limit gene flow between watersheds and give rise to unique, locally adapted genotypes, or strains, of Manoomin (Lu et al. 2005, Xu et al. 2015, but see Diller et al. 2018). The seeds require a period below or near freezing to induce germination (Atkins et al. 1987). Manoomin commonly exhibits an approximately 4-year cycle of abundance where years of low yield follow high ones (David et al. 2019). This has been attributed to microbial immobilization delaying availability of nitrogen from decaying Manoomin litter (Walker et al. 2010). However, other environmental factors, notably water levels, also influence abundance, leading to several consecutive good or bad years for Manoomin (Moyle 1944, shared by D. Vogt, 1854 TA, during data discussion 2021) as well as longer 10-30 year cycles (shared by K. Hanson, Lac du Flambeau [LDF], during data discussion 2021). Its seeds can stay dormant for 5 years or longer waiting for the right conditions to germinate (David et al. 2019). Manoomin's population has always been annually variable at each waterbody and regionally variable each year. This diversity has ensured Manoomin's availability for the Anishinaabe through human movement and trade (shared by Zhaashiigid Nooding/R. Shimek from White Earth during conference discussion 2020).

Figure 1. Life cycle of Manoomin reproduced from David et al. (2019).

Manoomin Habitat and Threats

Manoomin requires certain environmental conditions to thrive and not be displaced by other aquatic vegetation, including native perennial species such as pickerelweed (*Pontederia cordata*), cattails (*Typha* spp.), and water lilies (*Nymphaea* and *Nuphar* spp.) (Pillsbury and McGuire 2009). It grows in the glaciated Upper Great Lakes region now dominated by inland lakes often hydrologically connected through both surface and groundwater, as seen in Figure 2 (Webster et al. 2006). The direction of water flow up or down through the bottom of the lake can be significant in driving changes in surface-water levels and geochemical conditions in shallow streams or lake beds (Boano et al. 2014). The geochemistry of the overlying surface water can be quite distinct from the geochemistry of the deeper groundwater. Surface water, compared to groundwater, is typically enriched with dissolved oxygen, and can contain higher concentrations of contaminants that enter lakes or streams through runoff. Groundwater, on the other hand, likely contains higher concentrations of ions dissolved from the underlying sediment and bedrocks.

Optimal water levels range from 1 to 3 feet with a slight current (Stewart 1969). Hydrological changes caused by culverts, dams, drainage systems, or other human modifications can push water levels outside this range. Within optimal ranges, abrupt water level changes (fluctuations roughly > 4 inches / 7-day period) and strong currents during the floating-leaf stage can uproot the plant. However, consistently stable water levels from year to year create conditions more favorable for competitive perennial vegetation, which can displace Manoomin (NRCS 2009; David et al. 2019). Years with high Manoomin abundance have been observed to follow harsh winters and low water levels through the early growing season (shared by P. Bunting and C. Weiss from Mille Lacs during fieldwork at Ogechie Lake 2020; others have shared similar observations, including R. Labine). Manoomin beds are enhanced by sediment influx (Meeker 1996) and mixing, such as that caused by muskrat activity, according to tribal members (David et al. 2019). Higher water temperatures and low water clarity also correlate with lower Manoomin abundance (Myrbo et al. 2017).

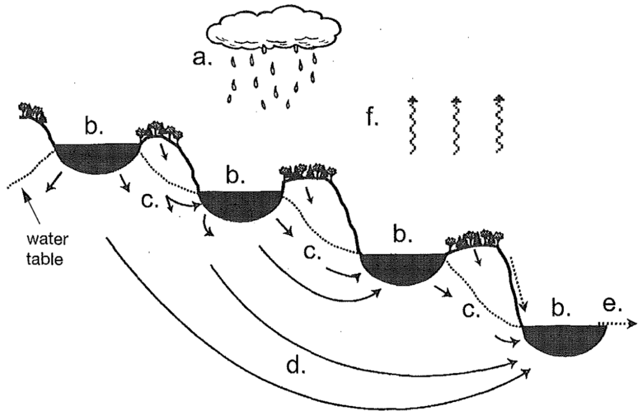


Figure 2. Diagram of water flow paths through a series of lakes reproduced from Webster et al. (2006): "Precipitation (a) falls onto the land and enters the groundwater system or directly falls on lakes (b) and streams. Within the groundwater system, water can follow short, local flow paths (c) or long, regional flow paths (d). Water leaves the basin through stream flow at the terminal discharge point (e) or through evaporation from either land or water surfaces (f). Solid arrows = groundwater flow."

Manoomin generally does not grow in water bodies with high sulfate concentrations (>10 ppm), including those polluted by mine or other industrial drainage and those in the western and southern regions of present-day Minnesota with naturally sulfate-rich groundwater, lower precipitation, and higher evapotranspiration (Moyle 1945; Moyle 1956; Myrbo et al. 2017). Recent studies have shown that combinations of high sulfate and organic carbon and low sediment iron elevate sulfide concentrations in lake/stream sediment pore-spaces (Myrbo et al. 2017; Pollman et al. 2017), which causes decreased seed mass, seedling survival, and maturation (Pastor et al. 2017; Johnson et al. 2019). When iron is also present, iron sulfide can precipitate on Manoomin roots, which is associated with reduced nitrogen uptake, poorer plant development, and lower nutrient allocation to seeds (LaFond-Hudson et al. 2018, 2020).

Generally, nitrogen and phosphorus are important limiting nutrients for Manoomin growth, especially in the early part of the growing season (Grava and Raisanen, 1978). Studies have shown Manoomin to be most sensitive to insufficient levels of nitrogen, but it can also be adversely affected by low phosphorus (Walker et al. 2010; Sims et al. 2012). Additionally, Manoomin has been noted to need soft, organic sediment, although excessively loose and watery sediment is not favorable (Lee 1986; Lee and Stewart 1984; Day and Lee 1989, Waheed 2021).

According to recent climate change vulnerability reports from the 1854 Treaty Authority (Stults et al 2016), GLIFWC (Panci et al. 2018), and Lac du Flambeau (Abel et al. 2019), recent and projected warmer winters with thinner ice cover and earlier ice-out may contribute to declines in Manoomin seed germination and create conditions more favorable to perennial vegetation. Warmer winter conditions may also increase rice worm (*Apamea apamiformis*) overwintering survival, leading to increased populations that consume Manoomin seeds and deplete seed banks for the following year's growth. Changes in growing season conditions from climate change may also contribute to Manoomin decline. More frequent high-intensity rain events associated with climate change have and will continue to threaten Manoomin by potentially uprooting or drowning out plants during the floating leaf stage (e.g., the floods of 2012 detailed by Moons 2016). Manoomin is classified as vulnerable to climate change based on assessments of the 1854 Treaty Authority (medium vulnerability, Stult et al. 2016), GLIFWC ("highly to extremely vulnerable", Panci et al. 2018), and Lac du Flambeau (extremely vulnerable, Abel et al. 2019).

Brown spot fungal infections (sometimes presenting as stem rot) can afflict Manoomin during hot, humid summer days, decreasing photosynthesis and seed production (David et al. 2019). Additionally, dry heat stress during flowering may cause flowers to fracture, causing "ghost rice" with empty Manoomin hulls (shared by T. Howes from Fond du Lac during conference discussion 2020). Ghost rice was observed just a few miles away from ponds with healthy Manoomin in the fall of 2020, suggesting that other lake-specific factors besides regional heat stress may also contribute to ghost rice occurrence (shared by T. Moilanen from Mille Lacs during data discussion 2021). Calm weather during flowering may also prevent pollination and thereby contribute to empty hulls (David et al. 2019).

Animals also play a role in Manoomin abundance. Beaver dams can cause high water levels that prevent the growth of Manoomin (David et al. 2019), but the year-to-year variability in damming they create may provide variability in water levels that prevent Manoomin from being out-competed by dominant vegetation. Since their reintroduction to present-day Minnesota and recent population growth, swans have become a threat to Manoomin, consuming and physically damaging significant portions of the Manoomin beds on some lakes on the Fond du Lac Reservation (Howes 2020). Geese can also pose a threat by consuming large amounts of Manoomin and interfering with seeding and restoration efforts (David et al. 2019, Vogt 2020). Invasive common carp (*Cyprinus carpio*) also disturb sediments during feeding, decreasing water clarity and uprooting Manoomin (Johnson and Havranek 2012, David et al. 2019). In a statewide Minnesota analysis of the effects of carp on aquatic plants, Manoomin was one of the species most sensitive to carp invasion (Larkin et al. 2020). A strong correlation between Sturgeon and Manoomin stands has also been observed in Michigan by Little River Band of Ottawa Indians' A. Smart, where her elders shared their TEK "where you find sturgeon, you find rice" (shared by K. Hanson, LDF, during data discussion 2021). Increased shoreline development also causes Manoomin declines, as residents often uproot plants with boat traffic and dredging (Pillsbury and McGuire 2009).

Emerging Models and Hypotheses

Our collaboration thus far has brought forth several frameworks for understanding Manoomin socio-ecological systems. As seen in Figure 3, this first model attempts to capture the interconnections between the many different beings and elements within this system: Manoomin is linked to people and ecosystems (outer ring) through multiple social dimensions and biophysical processes (middle ring), which together encompass a coupled socio-environmental manoomin system. Manoomin, according to Anishinaabe traditions, relies on human relationships. Harvesting and ecosystem conservation are two traditional and contemporary ways Anishinaabe people steward manoomin.

Our second conceptual model, seen in Figure 4, represents the dynamics surrounding the ecological niche in which Manoomin thrives. Specifically, we have conceptualized a Venn diagram of factors aligning or misaligning to determine the likelihood or abundance of Manoomin. Three of these factors on which we are currently focusing are water levels, sediment, and nutrients; however, these are not the only factors influencing Manoomin presence at any given site.

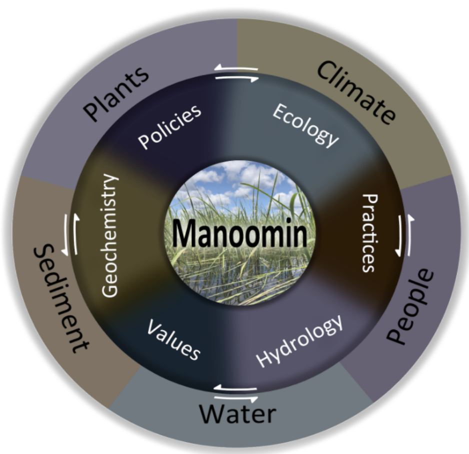


Figure 3. Manoomin socio-ecological system.

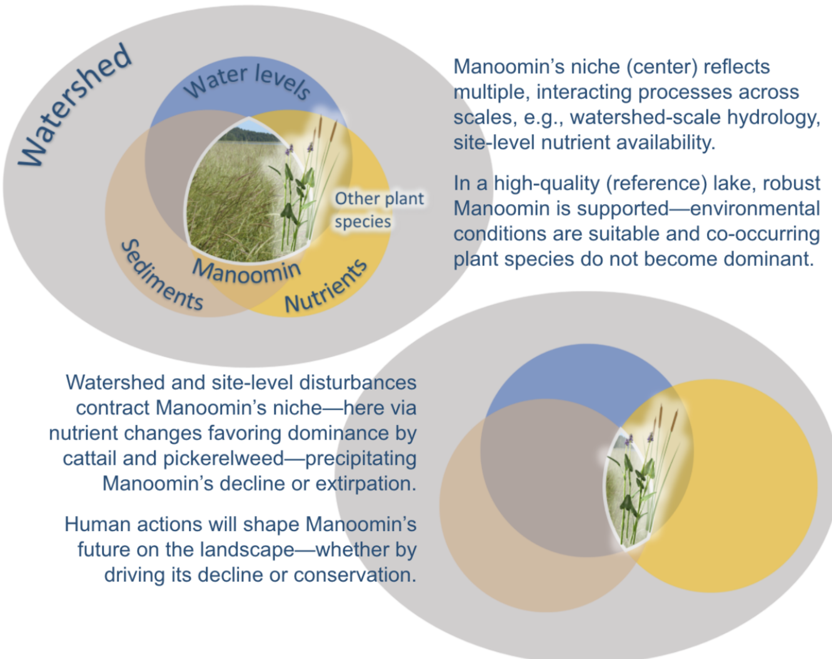


Figure 4. Manoomin niche model.

A project goal is to eventually move the Manoomin niche conceptual model (Figure 4) to include the interconnected relationship with people, as captured in the Manoomin socio-ecological systems model (Figure 3). During the 2020 December conference, Kate Hagsten, resource manager for the Leech Lake Band of Ojibwe, posed one particular hypothesis that brings these two ways of looking at the Manoomin community together. She proposed that the decline in Manoomin harvesting may have increased the likelihood of brown spot disease and presence of rice worm, because with less harvesting, more seeds germinate, increasing stem density and stand humidity, factors that correspond with brown spot disease (David et al. 2019) and rice worm abundance (Dahlberg and Pastor 2014).

Site Overview

Prior to a sharp decline in 2003, Spur Lake had abundant Manoomin that brought three different tribal communities together to harvest. Spur Lake has a surface area of 113 acres, mucky sediments that support dense beds of aquatic plants (emergent, submerged, and floating leaf), and is surrounded by a mostly undeveloped watershed (NIACS 2021). Spur Lake is also designated as a Wisconsin State Natural Area.

Figure 5. Spur Lake site map. Hydrologic monitoring and surface water sampling conducted at point marked in yellow.

The cause of Manoomin decline is unclear, but is likely related to higher water levels since the late 1990s (NIACS 2021), possibly from climate change and increased groundwater inputs according to Peter David, GLIFWC biologist. According to the Fish Creek Restoration study report, alterations made to the outlet creek from 1960 - 1980 may have been one of the causes of increasing water levels in this system, along with the repopulation of beaver. This was determined by examining historic aerial photos of Twin Lakes Creek dating back to the 1930s. Over time, the stream and its surroundings appear to have gotten wetter, which is evident in the graduate reduction of trees from the surrounding wetlands (Lee 2022).

Culverts at the outlet of the lake and further downstream are undersized. At times throughout the summer, culverts at the outlet are completely submerged, a clear indication of inadequate sizing. Water is typically slow moving on either side of the culverts and significant sediment has built up 200-300 feet downstream of the lake outlet. Over the last several decades, vegetation has encroached on Twin Lakes Creek (Spur Lake's outlet stream) as its velocity has decreased. GLIFWC, several tribes (LDF, Lac Vieux Desert, and the SSC Mole Lake Band of Lake Superior Chippewa), and the Wisconsin Department of Natural Resources have been collaborating to restore Manoomin on Spur Lake.

Current management plans include plowing snow off of the ice to increase lake freezing to suppress competitive perennial plant species, controlling beaver populations and removing their dams, removing select vegetation at the outlet to encourage better streamflow, installing culverts, and possibly regrading old railroad beds upstream to restore hydrology (NIACS 2021). The downstream landowner, in coordination with the WIDNR, received an NRCS grant to replace the downstream culvert with a larger one. This work is still moving forward. WIDNR has been working to remove vegetation and sediment from Twin Lakes Creek and restore it to its historic state (Meyer, 2020). They have also hired a contractor to conduct a hydraulic study of Twin Lakes Creek and will continue performing their annual vegetation surveys and lake monitoring, including having citizen science volunteers record water depth and clarity measurements. SSC is planning to conduct a dye study this year to examine flow, and collect upstream and downstream water level data from Twin Lakes Creek.

In 2018, a riffle structure was removed from the outlet (~1 mile downstream) in the early fall and, in 2019, a spill-over dam was removed at the outlet and 12 beavers were trapped from Twin Lakes Creek (Nyblade field notes 2020, may need additional verification). Beaver dam removal occurred July 9-10 in 2019 (shared by N. Podany, SCC, during data discussion 2021). Further removal of multiple beaver dams and improvement of the downstream channel (to facilitate outflow) took place in 2021, coinciding with a drought year. Specifically, USDA-APHIS removed ~10 beavers and ~7 beaver dams in April/May of 2021. At the Spur Lake Working Group workday (7/13/21), 12 people helped remove vegetation from the stream channel immediately downstream from Spur Lake (just down from the E. Stella Lake Road culverts). Additional old beaver dams were removed from Twin Lakes Creek on 8/5/21 and 9/8/21 (Laplin, C. email correspondence, 2022).

It is possible that there is no longer a viable seed bank in the Spur Lake sediments. Carly Lapin shared with us that interns previously working with Peter David were unable to find or germinate seeds in sediment samples taken from the lake-bed.

Manoomin Threats

Since the late 1990s, Spur Lake has been subject to abnormally high water levels that have likely contributed to Manoomin declines (NIACS 2021). Potential causes for these increased water levels include local infrastructure alterations, increased vegetation clogging outlets, and beaver dams (NIACS 2021). Heavy rain events have also increased over the past several years, and may have damaged Manoomin beds by uprooting plants during the floating leaf stage (NIACS 2021). One hypothesis is that climate change (including heavier rains) may be causing higher water levels through groundwater inputs (P. David during the data discussion 2021). However, groundwater contributions to Spur Lake are uncertain and have not been measured prior to this study.

Perennial aquatic plant species (such as native cattails and water lilies) that compete for habitat with Manoomin may also be preventing Manoomin growth (NIACS 2021). Shorter winter seasons and warmer and wetter summers may further contribute to the decline in Manoomin by reducing germination and seed production and increasing brown spot fungus and abundance of other aquatic plants and algae that can displace Manoomin (NIACS 2021).

Sampling Effort

Both a surface water gauge and a groundwater well were deployed at Spur Lake during the 2018, 2019, 2020, and 2021 seasons, and surface water samples were analyzed for geochemistry during summer 2019. No surface water samples were taken in the 2020 field season due to our limited capacity during the COVID-19 pandemic.

Table 1. Data Collection Overview

Site	Years	Measurements
Spur	2018 - 2021	Groundwater and surface levels, surface water chemistry (2019)

Fieldwork Protocol

Communication with Peter David (GLIFWC) and Carly Lapin (WIDNR) has been maintained throughout the development of the fieldwork plan. We have also included Joe Graveen from Lac du Flambeau and Roger LaBine from Lac Vieux Desert in many of our communications. Nate Podany from Mole Lake helped to carry out the fieldwork in 2020. Fieldwork permits were obtained from WIDNR. At all field sites in the project, UMN researchers follow tribal partners' instructions regarding appropriate cultural protocol before collecting data on their Manoomin waters, such as offering Asema or speaking with knowledge holders or elders.

Water Levels

To monitor groundwater flow and surface water levels, hydrologic monitoring equipment was deployed over the summers of 2018, 2019, and 2020 in Spur Lake. Automated water level sensors called "pressure transducers" (sometimes referred to as "data loggers") were deployed in groundwater wells (or "piezometers") and surface water gauges. The sensors were commercial units (Schlumberger Barologger or Solinst Levelogger Jr. Edge). Measurements were made at regular sub-hourly intervals (15 minutes or 30 minutes) in both surface water and groundwater wells.

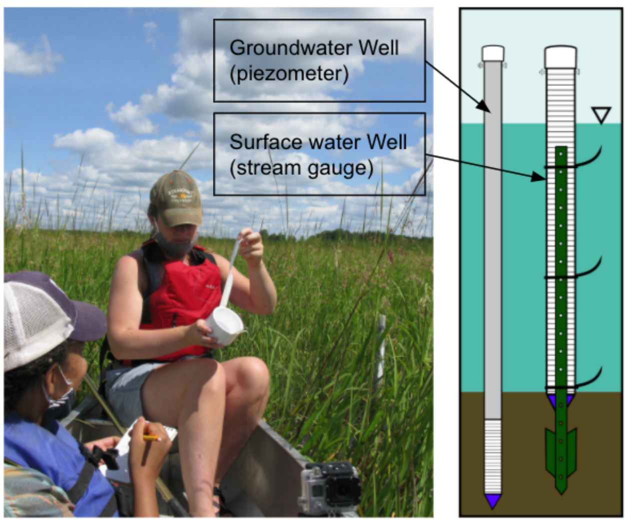
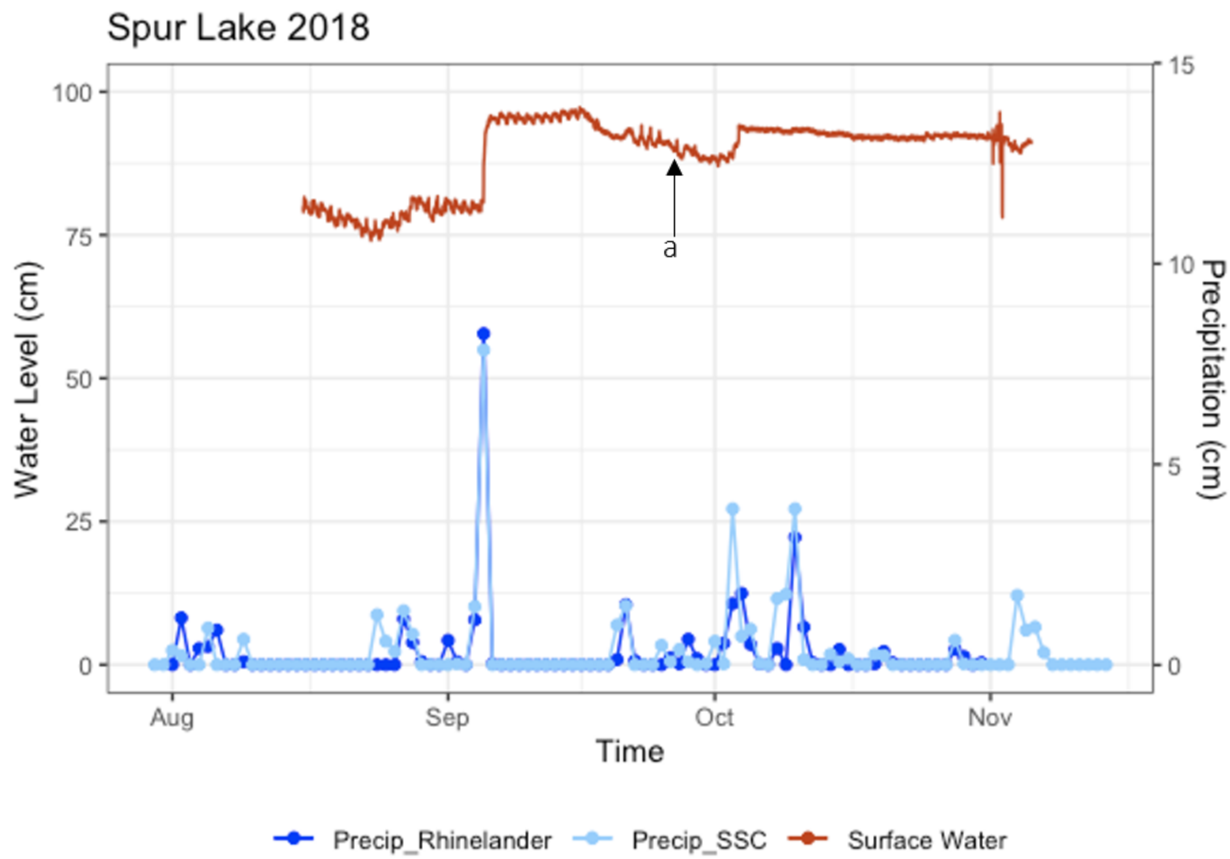


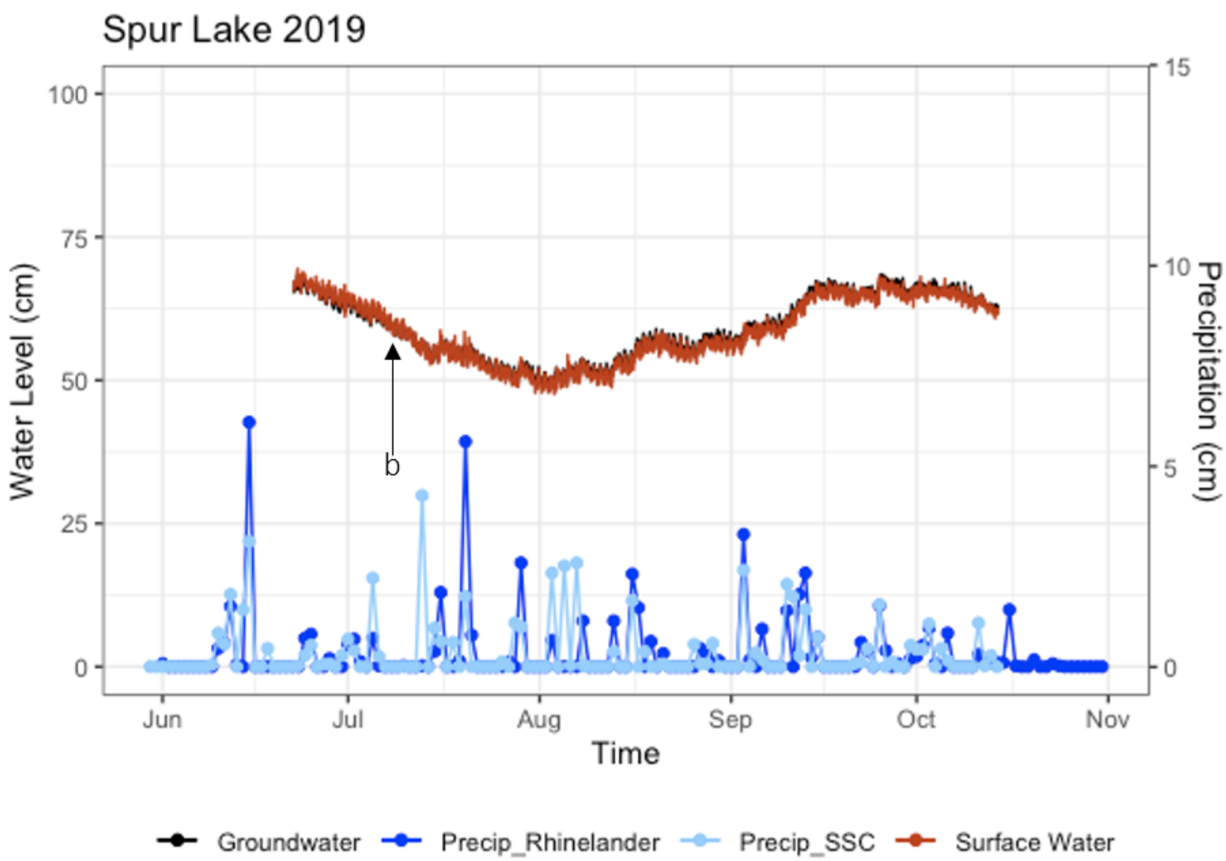
Figure 6. Maddy and Hannah Jo checking sensors in a Perch Lake groundwater well in July 2020. Groundwater wells (piezometers) were constructed from PVC pipe with open screening below the lake bottom. Water filling this well reflects the groundwater level (groundwater hydraulic head). Surface water wells (stream gauges, pipe diagram on the right) were constructed from PVC pipes with screening throughout their length, so the water level within these wells reflects the surface water level (surface water hydraulic head).

By comparing surface water and groundwater measurements, direction of flow between the two can be determined. If water level (or hydraulic head) is higher in groundwater, groundwater flows up to the surface water. If water level is higher in surface water, surface water flows down into the groundwater. There could be different groundwater and surface water interactions at different parts of the lake, although the greatest magnitude fluxes generally happen close to shore in lakes. A schematic of instruments used is shown in Figure 6.

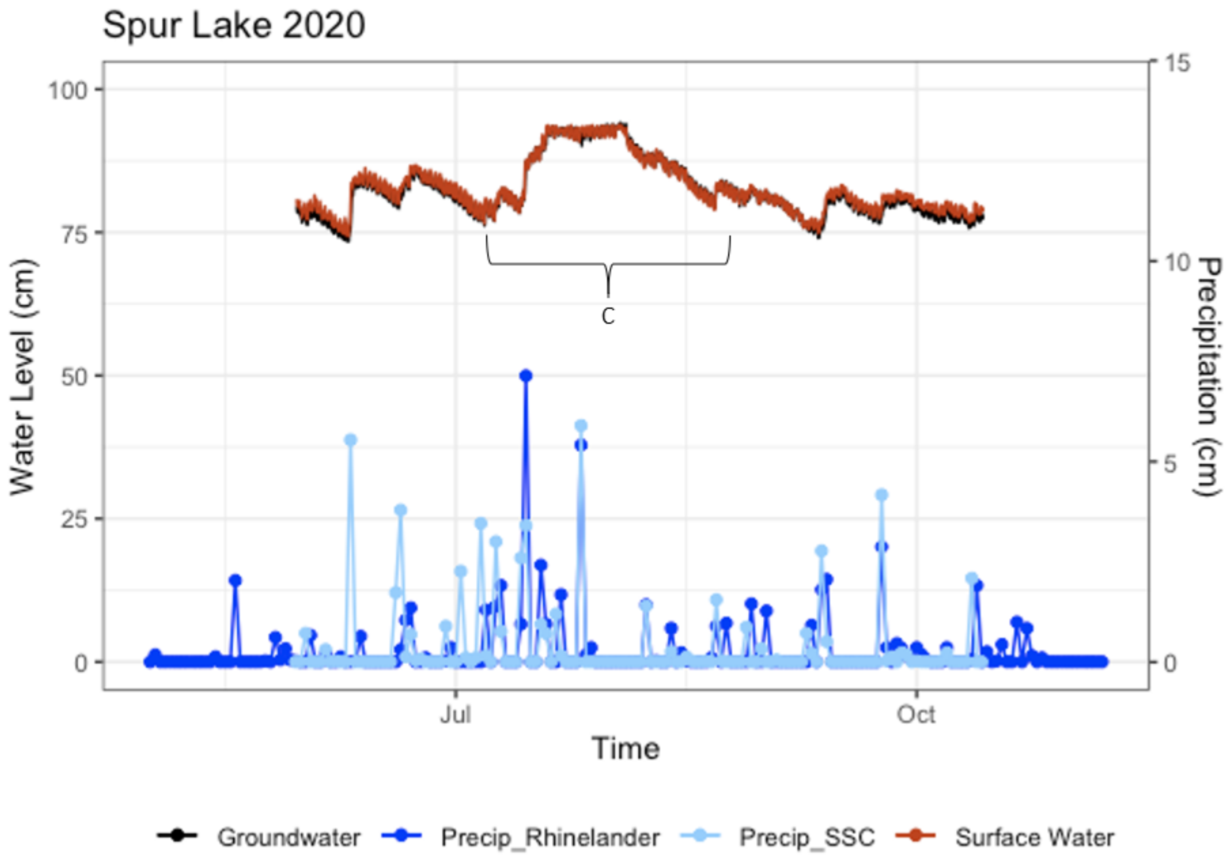
The following include all monitoring locations, water level data, and brief interpretations.

Water Level Data





Spur Lake 2019
Water Level (cm)
100
75
50
25
0
b
15
10
5
0
Precipitation (cm)
Jun
Jul
Aug
Sep
Oct
Nov
Time
Groundwater
Precip_Rhinelander
Precip_SSC
Surface Water


Spur Lake 2020
Water Level (cm)
100
75
50
25
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15
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Precipitation (cm)
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Jul
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Time
Groundwater
Precip_Rhinelander
Precip_SSC
Surface Water

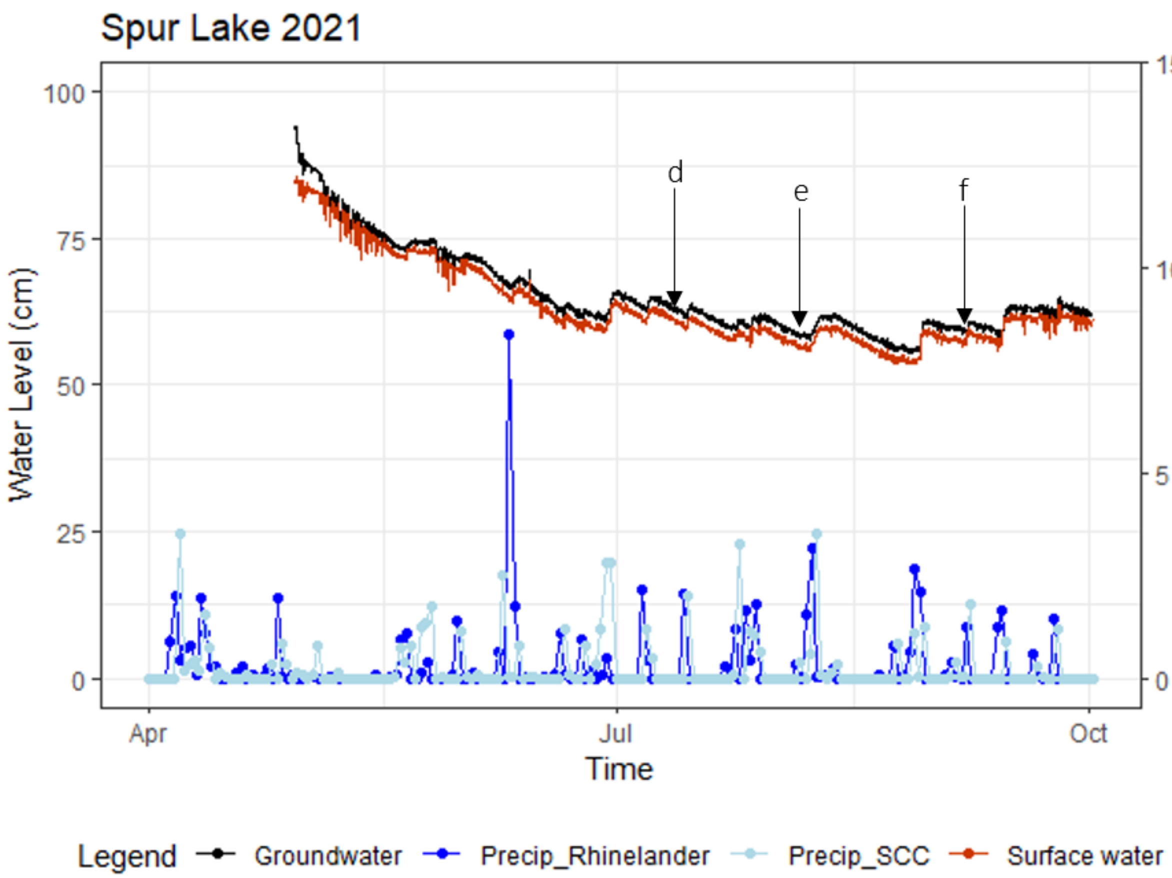

Figure 7. 2018-2021 surface water levels, groundwater levels (2019-2021), and precipitation for Spur Lake. Groundwater and surface water levels (hydraulic head) are plotted in centimeters above the lake bed. The precipitation record was collected from the nearest station Rhinelander-Oneida County Airport Station (~25 miles west) (obtained from weatherunderground.com (2018-2020) and Midwest Regional Climate Center's CliMATE dataset (2021)), and from the Sokaogon Chippewa Community (SCC) rain gauge (~30 miles to the south). Arrows indicate management actions undertaken during 2018-2021: a) riffle structure removed from outlet channel, b) spillover dam, beaver dams, and vegetation and sediments in Twin Lakes Creek removed, c) vegetation and sediments removed from Twin Lakes Creek multiple times in July and August, d) vegetation removed from stream channel downstream of Spur Lake, e/f) old beaver dams removed from Twin Lakes Creek. [Note we will switch all precipitation data to data from the Midwest Regional Climate Center's CliMATE dataset in the future]

Preliminary Interpretations

- **Water level plateaus**: The water level plateaus in both 2018 and 2020 at around 90 cm are likely due to accidental submersion of our air pressure sensor deployed inside the well. This would have comprised air pressure measurements, which are used for processing water level data. If this is the case, actual water levels above around 90cm would not have been recorded. We put the air pressure sensor on a tree in 2021 so that it would not be submerged. This plateau was not seen in 2021.

- **Removal of riffle structure**: In 2018, a riffle structure in the outlet channel of Spur Lake was removed on September 27. The water level declined briefly at this time, but it then rose again after rain events in early October and stayed elevated.
- **Groundwater measurement potential errors**: The groundwater and the surface water level measurements seem almost the same for both 2019 and 2020. There is a bit more of a difference in 2021. In 2019, we suspect that this could have been because the groundwater well was not fully sealed from the surface water, due to challenges in the installation (unsteady footing on the bog due to high water level conditions). However, Nathan Podany reports pounding in the groundwater well deeper in 2020, when there was also negligible difference detected between the surface water and groundwater levels. Wells were lengthened and redeployed in 2021, so the groundwater well likely had a better seal.
- **Groundwater flow**: The groundwater in 2020 is very slightly lower than the surface water in the earlier and later parts of the growing season. This possibly suggests a very slight flux of water flowing from the surface water into the groundwater, but it is difficult to be confident due to the very small difference in head levels. In 2021, the groundwater level was clearly higher than the surface water level throughout the summer. This indicates with greater confidence that there was a small flux of water from the groundwater to the surface water in 2021. The upward flux measured in 2021 with the longer (more robust) piezometer is consistent with Peter David's previous hypothesis of groundwater upwelling at Spur Lake, which could be contributing to high surface water levels that impair Manoomin growth.
- **Early Season Groundwater flow**: Piezometers were deployed early in 2021. Groundwater levels were significantly above surface water levels in the early season, and this gap shrunk throughout the spring and then remained constant for the rest of the summer. This indicates more groundwater flux into Spur in the early season, possibly from snow-melt contributing to higher groundwater levels and therefore flux into the lake.
- **Daily oscillations**: The daily oscillations are caused by plants taking up water during the day but not during the night.
- **Water level responses to precipitation**: In 2019, the water level does not change dramatically in response to precipitation events. In contrast, in 2020, the water levels do change noticeably in response to precipitation events. And water levels in 2021 change a bit more than in 2019 but less than in 2020. This change may be from the removal of the spillover and beaver dams on July 9-10, 2019, which would have allowed faster drainage of water during precipitation events in the rest of the season. The more subtle water level changes in 2019 may also be related to smaller rain intensities that year, which would be less likely to trigger water level rises.
- **Water level patterns**: In 2020, water levels were higher than in 2019 but similar to water levels in 2018. The low water levels in 2019 after the start of July probably resulted from the removal of the spillover and beaver dams on July 9-10. The 2020 water levels

approached the maximum range for Manoomin growth. In 2021, water levels started at a similar high level as in 2020, likely due to early spring rainfall, but they dropped throughout the season. This pattern is different than the other seasons we have monitored and may have resulted from a combination of factors that occurred in 2021: the regional drought, removal of multiple beaver dams, and further work to improve the channel at the lake outlet. Although we recorded even lower water levels in early July to late August 2019 compared to 2021, local residents reported that 2021 water levels were the lowest they experienced in a long time, and Nathan Podany notes that the water was too low to go through the channel. This could be because we are not using a fixed datum (0-water level elevation) in our plots; instead we are using the lake-bed level where our gauge is located, but this changes slightly between years, and the lake-bed level is likely very hummocky.

- **Impacts of restoration work**: WI-DNR removed vegetation and sediment from Twin Lakes Creek (the outlet stream) on 07/09/19, 07/07/20, 07/15/20, 07/16/20, 07/30/20, 08/25/20 to improve water outflow from Spur Lake. In 2019 this (along with the spillover and beaver dam removal) may have allowed for the overall lower water level in late July to early August compared to other years. In 2020, the outlet maintenance may have resulted in the moderate decline in water level over July-September, but overall the water levels were high compared to in 2019 and 2021.
- **Surface water study**: Work was done in 2021 to assess the channel downstream of the outlet and culvert, including installation of surface water gauges before and after the culvert, drawing of a longitudinal profile of the channel, and modeling of the relative water level elevations before and after the culvert. Groundwater was not considered in this work. The project has concluded, although the surface water wells will be kept in place for one more year.

Physical Sediment Data

Muck Depth

Sediment density matters to Manoomin health. Manoomin does not grow well in very loose sediments. This is a concern at some of our field sites, so we decided to take measurements across all of our sampling locations. We recorded the depth that two different instruments sunk into the sediment: a Secchi disk and a 4-m drive rod. Both the drive rod and the Secchi disk were placed into the water and allowed to sink until they stopped moving. We specifically chose not to push in the drive rod and instead let it sink itself in order to standardize the measurement. (We found in the past that different people were able to push in the drive rod with different forces, so it was not a consistent measurement.)

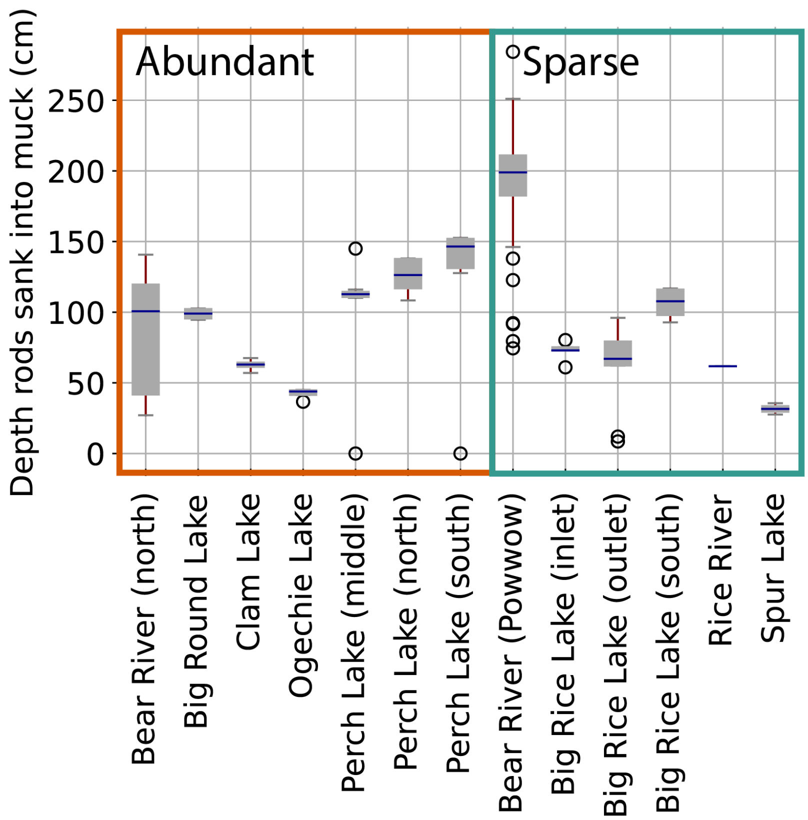

Figure 8. 2021 Depth that a 4m drive rod sank to across field sites, including abundant and sparse sites.

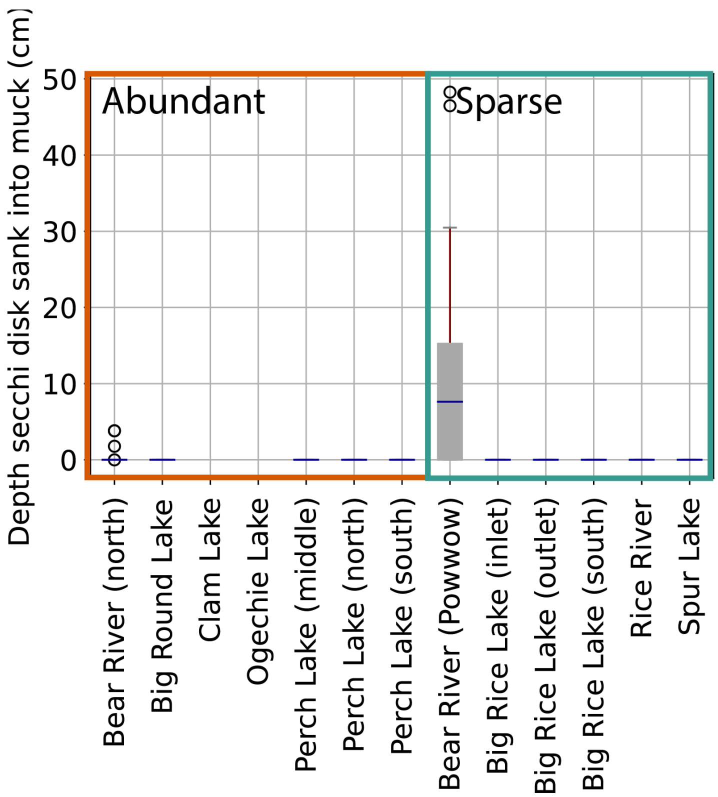

Figure 8. 2021 Depth that a secchi disk sank to across field sites, including abundant and sparse sites. This measurement reflects how much the muck compacted.

Preliminary Interpretations

- One sample of muck depth was taken from each of the water level gauge sites. For these sites the muck depth was 28 and 38 cm, as measured by 2 drive rods sinking into the lake bed.
- This is less than most other sites that also have sparse manoomin but comparable to Ogechi Lake, which is an abundant site.
- The secchi disk did not sink below this muck, as it did at Bear River.
- Spur Lake appears to have plenty of muck that is not too loose for Manoomin to thrive.

Geochemical Data

To monitor water quality and geochemical differences between sites, twelve different aqueous and sediment analytes were measured as part of our geochemical analysis overall in the project. Aqueous ion analytes in surface water and porewater samples included: calcium, chloride, iron, potassium, magnesium, nitrate, nitrite, phosphate, sodium, and sulfate. Sediment geochemical analytes included acid volatile sulfide and total organic carbon. Surface water chemistry mostly reflects conditions in incoming streamflow, rain, and other surface water run-off, as well as groundwater chemistry where there is upwelling of groundwater.

At Spur Lake, there has not been a strong interest or directive from tribal partners to collect water and sediment samples for geochemical analysis, in part because hydrology is believed to be the most likely reason for Manoomin impairment. For that reason, together with time constraints for the UMN field crew, we have only taken one easy-to-collect surface water sample in 2019 to provide some background conditions.

Background

- Manoomin needs sufficient **nitrogen** and **phosphorus** to grow (especially nitrogen), but not too much. High nutrient levels may allow other plants to out-compete Manoomin, and excessive amounts can cause large algal blooms that deplete the water of oxygen and disrupt healthy ecosystems (eutrophication). We measured dissolved nitrate (NO_3^-) plus nitrite (NO_2^-), as well as dissolved phosphate (PO_4^{3-}). These are major forms of nitrogen and phosphorus that plants can readily take up through their roots from the water. However, there are other nitrogen and phosphorus forms used by plants that we did not have the ready capacity to measure in our lab facilities. For example, for nitrogen, plants can take up ammonium, amino acids, and other organic nitrogen forms, especially in anoxic conditions such as those found around Manoomin roots (Näsholm et al. 2019; Maathuis, 2009). For phosphorus, some of the phosphate available to plants may be sorbed (stuck) to sediments rather than dissolved in the water (Jungk 2001), and organic matter may be holding an important source of phosphorus that can be released for plants to use (Shen et al. 2011).

- The cations **calcium** (Ca^{2+}), **magnesium** (Mg^{2+}), and **potassium** (K^+) are released from the weathering of soils and bedrock and other anthropogenic sources, and in addition to nitrogen and phosphate, these are other vital nutrients needed in relatively significant amounts for plant growth.

- **Chloride** (Cl^-) and **sodium** (Na^+) ions were also measured to examine the possible impact of road salt (NaCl) at certain locations. The impact of salt on Manoomin is not known.

- Sulfur readily undergoes geochemical reactions in the sediments of shallow lakes and streams, and we are measuring different major sulfur (S) forms that are generated from this. Manoomin is particularly sensitive to dissolved **sulfide** (HS^-) in porewater. Samples were collected for dissolved sulfide analysis, but this has not yet been completed due to lab protocol issues. Sulfate (SO42-) was also measured because it is the “source” of sulfide - sulfate can transform to sulfide under oxygen-free conditions in organic-rich sediments when certain types of bacteria are present. When sufficient **iron** (Fe) is present in the sediment, it can react with the HS^- to produce solid-phase iron sulfide (FeS) on sediments, which is measured in this study as **AVS (acid volatile sulfide)**. Iron sulfide / AVS in the sediment has not been found to affect Manoomin directly, but it may become a source of dissolved sulfide if the conditions in the environment change. Some studies have found high concentrations of iron sulfide/AVS minerals collecting on Manoomin roots at the same time that there is impaired nutrient uptake and seed generation (LaFond-Hudson et al. 2018; 2020). However, iron sulfide/AVS build-up on roots does not seem to correspond to a simultaneous increase in iron sulfide/AVS in sediments, which is what we are measuring. (Out of respect for Manoomin, we will not take destructive samples of Manoomin roots unless widely asked by tribal partners to do so.) Further, it is not yet known whether iron sulfide/AVS accumulation on roots directly impacts Manoomin, or whether it is simply a side-effect of high sulfide porewater concentrations, which is known to be toxic to Manoomin. Porewater sulfide concentrations depend on three separate variables: higher sulfate concentrations, lower sediment Fe concentrations, and higher total organic carbon (TOC) (Pollman et al. 2017).

Surface water collected from Spur Lake on June 21, 2019.

Species	**Measurement**
Chloride	0.188 ppm
Sulfate	0.431 ppm
Phosphate	0 ppm
Nitrite + Nitrate	0.57 ppm
Calcium	6.425 ppm
Magnesium	2.819 ppm
Potassium	1.099 ppm
Sodium	1.320 ppm

Preliminary Interpretations

- All concentrations are low in comparison with other lakes sampled on this project, except for nitrite and nitrate concentrations. Spur Lake had higher nitrate and nitrite than all other waters sampled except for Sand River and Twin Lakes, both sites impacted by wastewater from mine tailings.
- Spur Lake is a shallow lake without agricultural run-off or wastewater inputs from the surrounding watershed, so the high nitrate and nitrate may be related to internal nutrient

cycling from organic matter. We only have one data point, so we would need more data to verify these high nitrate and nitrite levels.
- Algal blooms are present on Spur Lake.

Discussion

This discussion summarizes the knowledge shared during our collaborative data analysis meetings in the winter of 2021 and spring of 2022.

Spur Lake water levels have increased and Manoomin has declined since 2003.
- Observations: Higher water levels have been observed at both Spur Lake and its outlet to Twin Lakes Creek, along with Manoomin declines. Heavy rains have been noted over the past years. Culverts at the outlet of Spur Lake are sometimes completely filled, indicating they are undersized for the volume of water flowing out. A culvert downstream of Spur Lake is also undersized.
- Questions: What is driving the higher water levels?
- Hypothesis: Climate change with increasing precipitation, along with human alterations to the landscape, have increased water levels. Culverts are undersized and prevent enough water from flowing out of the lake. Higher water levels could also be a result of climate-driven increases in groundwater inputs. Long term effects of this include sediment buildup and vegetation encroachment in the lake outlet to the Twin Lakes Creek channel, which now contribute to keeping Spur Lake water levels high.
- Current Efforts: WIDNR conducted a hydraulic modeling study of the outlet stream, and they have been removing beaver dams and clearing sediment and vegetation from the outlet stream. SCC is monitoring the outlet and inlet streams as well as conducting a dye tracer test to study flow.
- Possible Measurements: Continue measuring water levels (surface and groundwater). Consider deploying groundwater well(s) at different locations where there is more likely to be groundwater inputs to the lake. Process and plot water level data based on an absolute elevation datum and tie our measurements to other data collected at Spur Lake (e.g., past water levels and water level monitoring before/after the culvert). Determine the elevation of the culvert top.
- Possible Analysis: Compare long-term precipitation records with water level records and GLIFWC aerial photos shared with us by P. David. Look into long-term groundwater trends in the region as well. Relate water level data to the height of the culverts.

Manoomin recovery has been hampered by a sub-viable seedbed and thick growth of perennial plants
- Observations: Although since 2003, small stalks intermittently appear, attempts by GLIFWC to detect and germinate seeds in sediment samples have generally not been promising (shared by Carly Larpin). Although this does not confirm that there is no viable seedbed, WIDNR point intercept surveys from 2010/2012 show dense competing

vegetation (water lilies and watershield) that likely would not allow Manoomin to grow even if there were seeds. Dense root mats were also found.
- Current Efforts: New in summer 2022, WIDNR in collaboration with the Spur Lake working group (includes GLIFWC and Sokaogon Mole Lake) will conduct a pilot study using a "Swamp Devil" to remove competing vegetation over 12 acres (including control areas). The Swamp Devil is made by Aquarius systems, and it is similar to the "cookie cutter" used by Fond du Lac and MN-DNR: it is a watercraft propelled by blades that chops up vegetation. They will also be reseeding Spur Lake, although the source of the seeds is still not decided.
- Possible Measurements: WIDNR will be continuing their point intercept vegetation surveys but are open to coordination for our group to help conduct further surveys. The working group would like us to continue our groundwater measurements and possibly start nutrient and water chemistry sampling and analyses, as these are efforts that they are not themselves doing (unclear: will GLIFWC no longer be doing surface water sampling at Spur Lake?). There is an interest in looking at nutrients and sediments, because presumably the cutting will result in increased decomposition of organic matter and sediment disturbance.

Next Steps

These next steps were developed collaboratively during our collaborative data analysis meeting in the spring of 2022.

Fieldwork 2022

- Late April / Early May:
  - Hydro plan: Deploy groundwater and surface water well at Spur Lake. Survey the hydro equipment, culvert, and staff gauge near the culvert.
  - Who: Nathan Podany can deploy these, but we need to bring or ship to him new PVC pipes, because these were removed at the end of the last season. Maddy and possibly June have the most availability in the early season (April/May); Hima can join mid-May.
- Other Potential Fieldwork Plans:
  - Vegetation surveys - coordinate with WIDNR's planned point intercept surveys
  - Porewater sampling - for nutrients and other water and sediment chemistry, especially considering the impacts of the vegetation cutting.
- October: Partners retrieve sensors and mail them back to UMN team

Further Data Analysis

- Coordination:
  - Connect with Dawn about GLIFWC's geochemical analysis parameters, and compare them with our analysis plan.

    - Check if Three Lakes rain gauge data is available and closer than Rhinelander. Carly will also check if the WIDNR has a closer rain gauge.
    - Connect with WIDNR and SCC about data on their hydraulic study and dye and flow measurements.
    - Connect with Carly to get the report for the planned wild rice pilot restoration project (vegetation cutting and reseeding)
    - Connect with Jon Simonson (WIDNR) to get staff gauge data
    - Connect with Ben (? ask Nathan) to get water level sensor data before and after the culvert
    - Connect with Scott (? ask Carly) to get WIDNR's vegetation data
    - Facilitate connections with Fond du Lac and/or MNDNR about vegetation cutting
    - Connect with Nathan to get the report on the assessment of the channel (by the outlet)
- Data presented by UMN team:
    - Plot several years for each site on one graph so we can easily compare them. If the well location has changed, then the datum has also changed, making the data not directly comparable between years.
    - Create water level plots with a common datum between years. Use either our nail in the road (although, this was lost in 2021, and a new nail was put in) or maybe the top of the staff gauge or top of the culvert.

Further Projects and Directions

- Check back in with Melonee about how we can support and stay connected with her TEK work around Spur Lake.
- UMN team could collect porewater samples here. There is interest.

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Appendix C: Spur Lake & Twin Lakes Creek Assessment Report

Spur Lake & Twin Lakes Creek Assessment Report

February 25, 2022

Prepared for: Sokaogon Chippewa Community

Prepared by: Ben Lee, PE
Fish Creek Restoration LLC
Madison, WI

Contents

1. Introduction

Spur Lake was a historically productive wild rice (*zizania palustris*) habitat. Anecdotal evidence from Sokaogon Chippewa Community (SCC) members indicates that in the early 2000s, the abundance of rice dropped substantially. The reason for the decrease has not been apparent. To identify reasons for the drop in productivity, the SCC obtained funds to conduct a hydrologic study of the lake.

The 104-acre Spur Lake is in the Wisconsin Department of Natural Resources (DNR) Spur Lake State Natural Area in eastern Oneida County, Wisconsin. According to the DNR website, the "lake and surrounding wetlands provide habitat for black ducks, ring-necked ducks, osprey, and common loons." They also note that "use by migratory waterfowl is heavy." Wild rice presumably provided an important food source for the birds.

Several causes for the decrease in wild rice have been suspected. Human alterations to Twin Lakes Creek, the stream draining the lake, have been speculated to have caused increased water levels. In glaciated landscapes of the region, small changes to hydraulic conditions can lead to substantial changes in water depths and drainage. For sensitive species with specific habitat requirements like wild rice, these alterations can be profound. Therefore, the primary goal of this study was to identify if changes to Twin Lakes Creek have contributed to the loss of wild rice in Spur Lake. Secondarily, we sought to identify potential other climate and watershed factors that may be contributing to changes in physical habitat for wild rice in the lake.

This report documents the assessment of the existing conditions and describes management recommendations to improve conditions for wild rice.

2. Project Goals

Several causes for the drop in wild rice have been suspected. Nevertheless, there have been no distinct changes observed in channel conditions, watershed conditions, or climate that could be easily correlated with the reduction in wild rice abundance. For this study, our goal was to determine if physical habitat characteristics in Spur Lake have been negatively impacted by humans. Changes to water depth and changes to the disturbance regime in the lake are probably the two most important habitat components for wild rice, and alterations to the outlet channel from wild rice lakes are often the cause of these changes.

To begin the study, we identified several important variables that define habitat conditions that may have changed in recent decades. Assessment methods were developed to detect changes in each of the following variables:

- Water depths exceeding wild rice habitat suitability which may be caused by:
  - East Stella Lake Road culverts – Causing backwater that increases upstream water depths in Spur Lake
  - Gunder Paulsen culverts – Causing backwater that increases upstream water depths in Spur Lake
  - Beaver Dams in Twin Lakes Creek – May have increased in size or abundance to increase upstream water depths
  - Changes in the intensity, duration, frequency, or timing of precipitation

        - Higher groundwater levels
    - Aquatic vegetation density increases in Twin Lakes Creek
    - Changes in drainage area contributing surface water runoff
- Lack of disturbance that reduces nutrient availability in sediments including:
    - Reduction in ice cover duration or thickness
    - Higher water levels reduce ice contact on the lakebed
    - Reduced lake mixing due to altered flow patterns by the East Stella Lake Road culverts

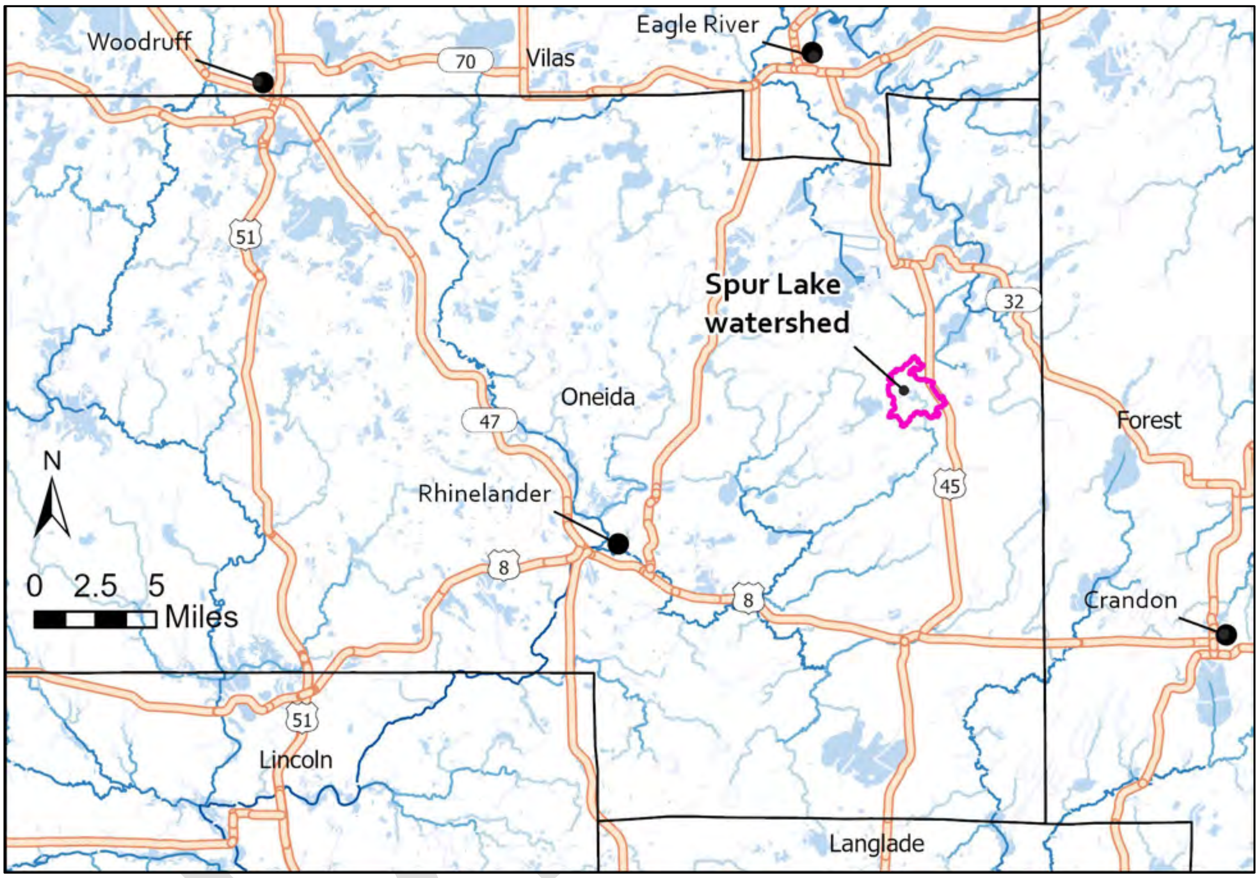

Figure 1. Location map of Spur Lake. Higher-order rivers and streams have darker blue shades.

3. Background on Wild Rice

To identify impacts on wild rice habitat, it is important to first understand the life history and define the ideal conditions conducive to growth. The plant is relatively sensitive as it has adapted to a specific ecological niche in lakes and rivers.

3.1 Phenological Traits and Life-History

Wild rice is an annual aquatic plant growing from seed each year. It grows from the beds of slow-moving rivers and lakes (David et al., 2019). The seed typically germinates in April as the water is warm and oxygen levels are low. The seed pod remains anchored in the substrate while developing a submerged leaf that grows upward towards the water surface. The submerged leaf is present between late May and early June. The leaves are flexible and free to bend with the water flow. Wild rice collects energy from both photosynthesis and nutrients in the sediment during the submerged leaf stage. As the plants are flexible to move with water flow, they are susceptible to uprooting with sudden changes in water level or strong currents. Greater water depths may inhibit survival as the plants need to focus more energy on leaf elongation.

In late June, wild rice leaves reach the top of the water and lay flat across the surface. The floating leaf stage allows the plants to gain more energy from photosynthesis to begin stem growth. Thomas and Stewart (1969) indicate that the floating leaf stage is "when the plants are most susceptible to mechanical damage by wind and wave action."

Aerial shoots begin to form at the end of June and July. Panicles begin to form in August when a male and female flower are produced (Dore, 1969). The male flower is located on the lower, more flexible branches which drop off within two days of shedding their pollen. The female flower remains at the top of the panicle until it becomes firm. After the female is fertilized, the grain fills the void space inside the hull and remains until the grain becomes firm. Finally, in September, after the grain fills the hull for a few days, it falls off the plant into the water. The seeds do not float but fall quickly to the bed nearby the parent plant where they remain until the next spring (Dore, 1969). If the seeds do not germinate, they can remain viable for up to 5 years (David et al., 2019).

3.2 Habitat Requirements - Depth

Water depth is often a limiting constraint that dictates habitat suitability for wild rice. Large depths can inhibit sunlight penetration into the water which will reduce potential photosynthesis during the submerged leaf stage. Shallow depths may not necessarily be unsuitable for wild rice; however, other emergent aquatic plants can out-compete wild rice for habitat. Therefore, the depth range that wild rice most often inhabits is relatively narrow.

In a comprehensive study of 60 wetlands with natural wild rice habitat in Minnesota and Wisconsin, Pillsbury and McGuire (2009) found that the densest wild rice beds had depths averaging 2.0 feet (0.8-foot standard deviation). Rice density decreased significantly when water depths exceeded 2.5 feet or greater. The authors concluded that shallower depths provided better habitat. Part of the reason for the low density in deeper water may have been due to human disturbance.

Meeker (1993) also found that shallower depths were beneficial to wild rice. In his three-year study in the Kakagon Slough of Lake Superior, he found that wild rice inhabited depths between 1.2 and 3.6 feet. As lake levels dropped at the end of the study, wild rice abundance increased, and rice even grew in some areas that were exposed briefly above the water surface. He concluded that wild rice was an opportunistic species that could quickly colonize new habitats if other plants were not already established.

Several other researchers have investigated suitable wild rice depth habitats. Thomas and Stewart (1969) and Stevenson and Lee (1987) studied southern wild rice (*Zizania aquatica*). Although it is a different species, the phenological traits, life history, and habitat are very similar to northern wild rice (*Zizania palustris*). Results from those studies should correlate with northern wild rice requirements. Thomas and Stewart (1969) tested water level fluctuation in a controlled laboratory setting. They found that fluctuating (increasing) water levels led to reduced plant height, leaf area, and plant weight. They also found that various life stages were delayed as water depths increased.

Stevenson and Lee (1987) also tested the influence of water level fluctuation. They established seedlings in 1.5-foot deep water then increased depths 0, 0.5, 1.0, and 1.5 feet during each life stage of wild rice. With the 1.0-foot and 1.5-foot depth increases, all phenological stages of development were adversely affected. On the other hand, the 0.5-foot depth increase resulted in greater production compared to the control where water depth was held static at 1.5 feet. The authors indicated two possible explanations: (1) the optimal depth for wild rice might be 2.0 feet, not the initial 1.5-foot depth; and/or (2) the light intensity was so great at the smaller depth that it impeded plant growth. Regardless, the results indicate an optimal depth for wild rice between 1.5 and 2.0 feet, while greater depths were detrimental to production.

3.3 Habitat Requirements – Sediment and Nutrient Supply

Nutrient supply is often a limiting factor in the growth of wild rice (Dore, 1969). Each growing season, wild rice will deplete a portion of the available nutrients in the lake or riverbed it occupies. In riverine environments, the nutrient supply may be replenished regularly by sedimentation of fine silt particles that have phosphorus and/or nitrogen adhered. For this reason, Meeker (1993) hypothesized that wild rice favors river environments. Nevertheless, wild rice is also present in many lakes without substantial flow through. In lake environments, wild rice can be productive for several years as it draws nutrients from the lakebed. Once the nutrients are depleted, the abundance may drop significantly for a year. The buildup of thatch from other aquatic plants may rejuvenate the nutrient supply, and the wild rice crop may bounce back. In other cases, disturbance of the lakebed may stir up sediments to make nutrients available for growth. Ice movements, humans, and other animals can create disturbances.

3.4 Historical Presence of Wild Rice in Spur Lake

The Great Lakes Fish and Indian Wildlife Commission (GLIFWC) has monitored wild rice on Spur Lake annually since 1985 (David, 2020). The acres of wild rice on the lake were measured using both ground and aerial surveys. A qualitative measure of the density was multiplied with the area to create an index. The data indicate that abundance remained high in the 1980s then was nearly absent between 1990 and 1991 (Table 1). Abundance increased for a few years from 1992 to 1994 before dropping off again. One more slightly abundant year occurred in 2003. After that, abundance has remained low with no rice detected for a couple of years.

Older historical information on Spur Lake wild rice is sparse. GLIFWC compiled the journal entries from a nearby resident, Paul Munninghof, who harvested wild rice on the lake between 1956 and 1985. The journal notes indicate the amount of rice harvested and when/if the season was open at the lake in a particular year. Nevertheless, the entries do not represent consistent data on the presence or abundance of wild rice. In general, the notes provide an indication that the lake cycled with multiple years of high abundance interspersed with periodic lows. From

1956 to 1985 there were no extended periods in low rice abundance as has been observed in the 16 years from 2005 to 2021.

Table 1. Wild rice abundance in Spur Lake between 1985 and 2014. Data were collected by GLIFWC (2020).

Date	Acres	Density	Index	Date	Acres	Density	Index
1985	110	5	550	**2000**	25	1	25
1986	110	5	550	**2001**	45	2	90
1987	96	3	288	**2002**	30	2	60
1988	100	5	500	**2003**	68	3	204
1989	100	5	500	**2004**	65	2	130
1990	15	1	15	**2005**	18	2	36
1991	0	0	0	**2006**	8	2	16
1992	110	2	220	**2007**	3	3	9
1993	110	4	440	**2008**	70	1	70
1994	80	5	400	**2009**	0	0	0
1995	70	4	280	**2010**	1	1	1
1996	85	5	425	**2011**	1	1	1
1997	85	4	340	**2012**	2	1	2
1998	95	4	380	**2013**	1	1	1
1999	56	3	168	**2014**	0	0	0

4. Existing Conditions

4.1 Watershed Surficial Geology

Landforms in the Spur Lake watershed are the result of the last glaciation that occurred between 30,000 and 14,000 years ago (Attig et al., 2011). Most of the surface features were created around 20,000 years ago as the glacier was receding towards the north. Glacial retreat occurred slowly with various re-advances. During the retreat, meltwater from the end of the glacier deposited many of the sediments in the region. Around Spur Lake, there are no remnant sub-glacial deposits like drumlins or moraines. Meltwater deposits and features are everywhere. Many areas contained remnant ice that later melted to produce a hummocky surface topography ("sc" in Figure 2). Kettle depressions formed where large blocks of ice remained after the glacial retreat and later melted. Vegetation encroachment eventually filled the depressions with peat ("p" in Figure 2). In some places, channels formed beneath the glacier that carried substantial sediment loads. After glacier retreat, the sediment remained to create high ridges along the general direction of glacial movement (eskers, labeled "se" in Figure 2).

4.2 Modern Watershed Conditions

Before EuroAmerican settlement in the 1800s, the region generally consisted of a mesic mixed hardwood forest (Cottam et al., 1965). Survey notes from the general land office in the 1850s indicate swamps throughout the landscape that were predominantly tamarack with some spruce. Upland forests contained sugar maple, hemlock, and spruce. After the EuroAmerican settlement, many forests in the region were cut over for lumber with harvesting activities primarily taking place between 1870 and 1920 (Rhemtulla et al., 2009). Following the cutover, early successional species became established, and the forest transitioned to dominance by deciduous species.

Aerial photos between 1938 and 2010 show that uplands north and west of Spur Lake have been harvested for timber. Several tracts of land have been clear cut, and some have been replanted with row trees – presumably red pines. A few unpaved roadways and utility corridors were constructed between 1960 and 1980. Nevertheless, because most of the watershed consists of wetlands, there has been little development since the 1938 air photos. Impervious surfaces (roads, buildings, etc.) that cannot infiltrate water have remained less than 10% of the watershed area.

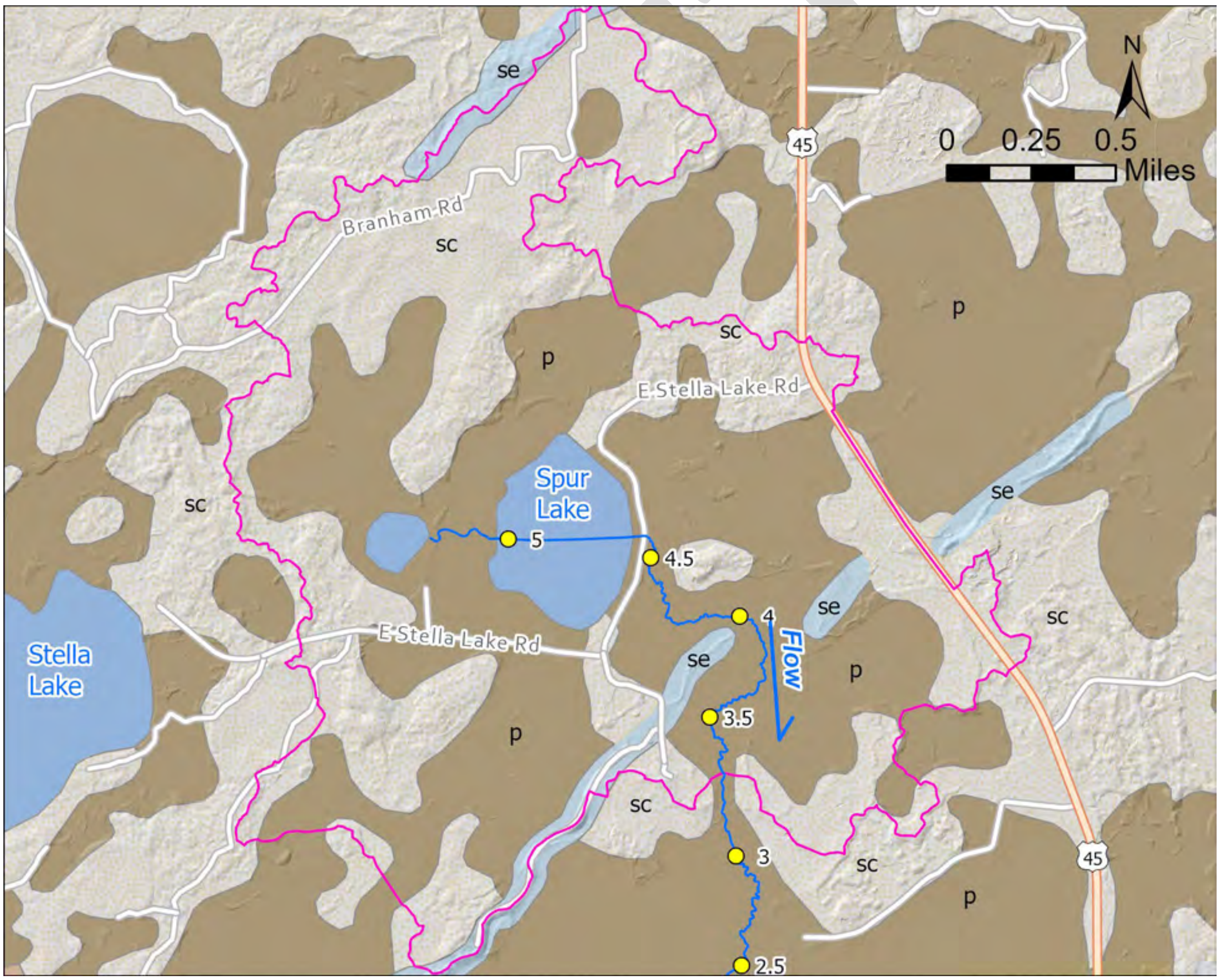

Figure 2. Surficial geology of the Spur Lake watershed (from Attig and Rawling, 2020). Map unit "p" indicates organic peat sediment in wetlands; "sc" indicates collapsed meltwater stream sediment from the previous glaciation; "se" indicates eskers.

4.3 Lake Geomorphology

Spur Lake was formed by the melting of an ice block that was lodged in the ground after the glacier receded. The cavity was likely larger than the surrounding low-lying depressions because vegetation has not encroached from the perimeter to create a vegetated wetland. Peat surrounds the entire perimeter of the lake except at the eastern edge. Most of the eastern perimeter of the lake butts up to coarse sediment along a ridge. East Stella Lake Road was constructed along the ridge with some additional fill likely needed around the Twin Lakes Creek outlet from Spur Lake. The sediment consists of mostly sand with a few gravels. The material is present about 3 feet under the lakebed. Adjacent to the road crossing, the coarse material is exposed. The sand and gravel may have provided some historical control in water levels at Spur Lake.

Within Spur Lake, the lakebed elevation is relatively consistent throughout with the deepest portion around 1638.5 feet and the shallower perimeter around 1640 feet (see Appendix A: Spur Lake Bathymetry). During the 2021 growing season, the average water level was 1,641.7 feet and the average depth was 2.3 feet. The area of the lake within the ideal wild rice depth range of 1.5-2.0 feet was mapped for various 0.5-foot water level increments.

Water surface elevation (feet)	Area with depths between 1.5 and 2.0 feet
1640.0	3.5
1640.5	15.8
1641.0	39.5
1641.5	31.1
1642.0	13.9
1642.5	0.5
1643.0	0.0
1643.5	0.0
1644.0	0.0

Since 1937 there have been subtle changes in the shoreline around Spur Lake. Air photos indicate that chunks of peat have broken off from the shoreline several times (see Appendix B: Historical Spur Lake Aerial Photos). For example, a nearly half-acre piece of peat detached from the western shore sometime between 1960 and 1980. In the same period, a piece of ground nearly the same size lodged at the north end of the lake. Presumably, the peat broke away from the western shore and drifted north. During the same time, another one-third acre size block of peat broke from the southwestern shoreline and lodged on the eastern shore just south of the Twin Lakes Creek outlet. Both peat blocks remained in place until the most recent air photos in 2010. No other substantial changes in the shoreline were apparent in the air photos; however, smaller pieces could likely have shifted around. It is unknown what caused the large peat blocks to break away. Rainfall data do not indicate any unusually high water years between 1960 and 1980. The journal notes from Paul Munninghof also do not note any unusual water levels.

Potential reasons for the peat movement could be attributed to ice forces or human modifications.

4.4 Fluvial Geomorphology

Channel forms and processes in Twin Lakes Creek are dictated by remnant glacial features. Throughout most of its course, the stream traverses glacial kettles that have filled with peat. Between the kettles are collapsed meltwater outwash and subglacial river (esker) sediment. In some cases, the coarse glacial meltwater material provides grade control that is manifest in a steeper longitudinal stream profile (Figure 3). The steep channel at Gunder Paulsen's property exemplifies this scenario. The channel immediately upstream from the north Gagen Road crossing is also relatively steep due to coarse outwash deposits.

In some cases where Twin Lakes Creek traverses coarse meltwater deposits, there is no substantial change in stream elevation. At stream mile (SM) 3.7, the channel dissects an esker deposit (Figure 4). The wetland peat surface that filled upstream and downstream from the esker is nearly the same elevation. Nevertheless, the sand and gravel sediment are locally present on the stream bed. The coarse channel bed material is a stark contrast to the silt and peat channel bed that is extensive in the adjacent reaches. Refusal probing data indicate that the peat channel bed is soft and does not provide grade control.

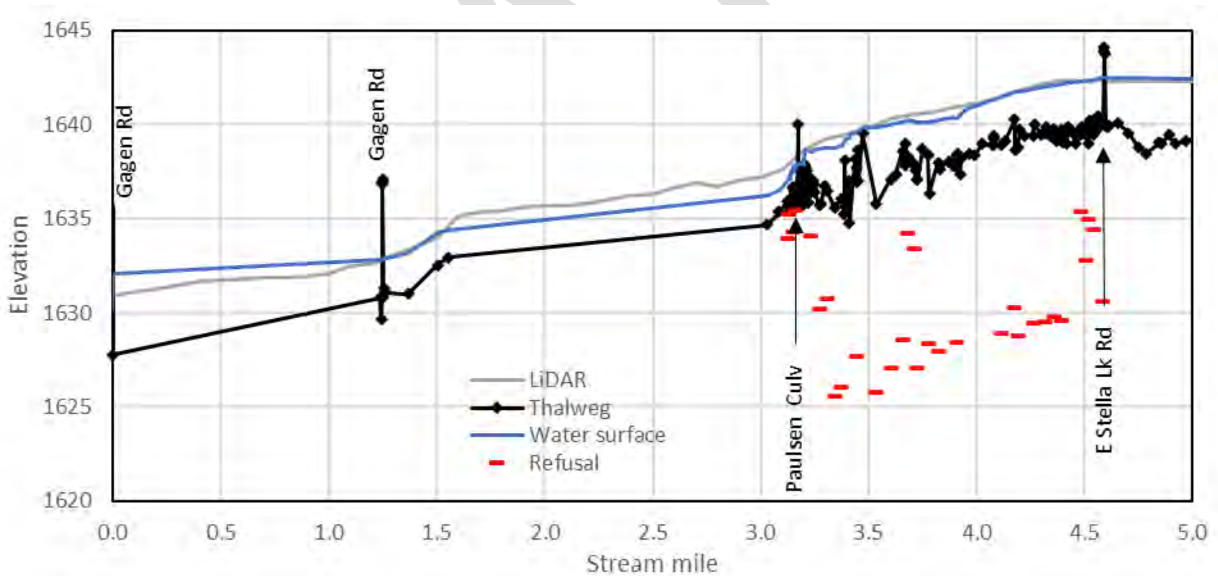

Figure 3. Longitudinal profile of Twin Lakes Creek between Gagen Road and Spur Lake.

In addition to glacial deposits, beaver dams provide a major control on the stream profile. The influence of beaver dams was characterized in 2021 when a water surface profile was surveyed before and after the removal of several beaver dams. Between April 26th and August 2nd, 2021, the water surface between Gunder Paulsen's property and East Stella Lake Road dropped 1-2 feet. Stream discharge reduced from 7.3 cubic feet per second (cfs) in April to 0.6 cfs in August at the Paulsen property. The reduced flow rate probably explains a large portion of the water level drop; however, the beaver dams appear to have caused about one foot of drop locally. More specifically, the water surface profile is about 0.75 feet lower and nearly parallel between RM 4.0

and 4.6 where beaver dams were not removed. Between RM 3.4 and 3.8 at the former beaver dams, however, the drop was larger between 1.5 and 2.0 feet.

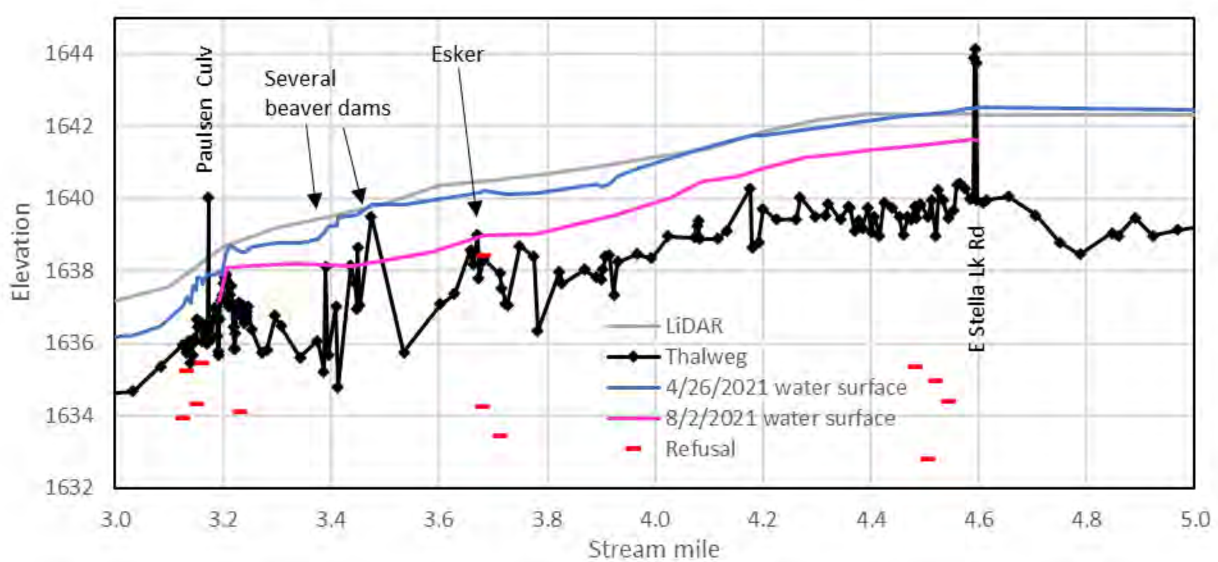

Figure 4. Longitudinal profile of Twin Lakes Creek between Gunder Paulsen's property and Spur Lake. Several beaver dams were removed between the 4/26/2021 and 8/2/2021 surveys.

Historical aerial photos indicate notable changes in the composition of the riparian vegetation since the 1930s. In 1937, the floodplain between RM 3.2 and 4.2 appears to consist of forests with larger trees (Appendix C: Twin Lakes Creek Historical Aerial Photos). In 1960, the channel width appears wider, though it is possible there was recent rainfall that resulted in greater inundation. By 1980, however, many of the trees were absent in the reach, and some areas of the channel appear somewhat wider. The lack of trees indicates the larger channel width was not just due to recent rainfall but due to persistent high water. In the same 1980 air photo, a new pond was constructed downstream at Gunder Paulsen's property at RM 3.2. Field observations in 2021 indicate that the channel may have been modified to direct water into the ponds. The channel bed adjacent to the former ponds was in a relatively straight alignment with a grade drop of over one foot in about a 100-foot reach. The channel bed was likely elevated to maintain the stable pond water surface elevation. Consequently, water levels in the reach upstream were increased. The low gradient of Twin Lakes Creek resulted in elevated water levels for at least several hundred feet upstream. It is unknown if the stream water levels were lowered back to their historical level after the ponds were deactivated.

Around the 1980s, beaver populations in northern Wisconsin increased substantially compared to the early 20th century when populations were decimated (Johnson-Bice et al., 2018; Figure 5). The new pond at Paulsen's property may have enticed the beavers to colonize the upstream reach. The flooded upstream land would have provided a food source with the increase in aquatic vegetation. Similarly, the absence of mature trees (likely white cedar and tamarack before 1980) probably led to the increase in shrubs like speckled alder and willow that provide food and dam-building material. Air photos from 1991 through 2010 indicate a strong beaver

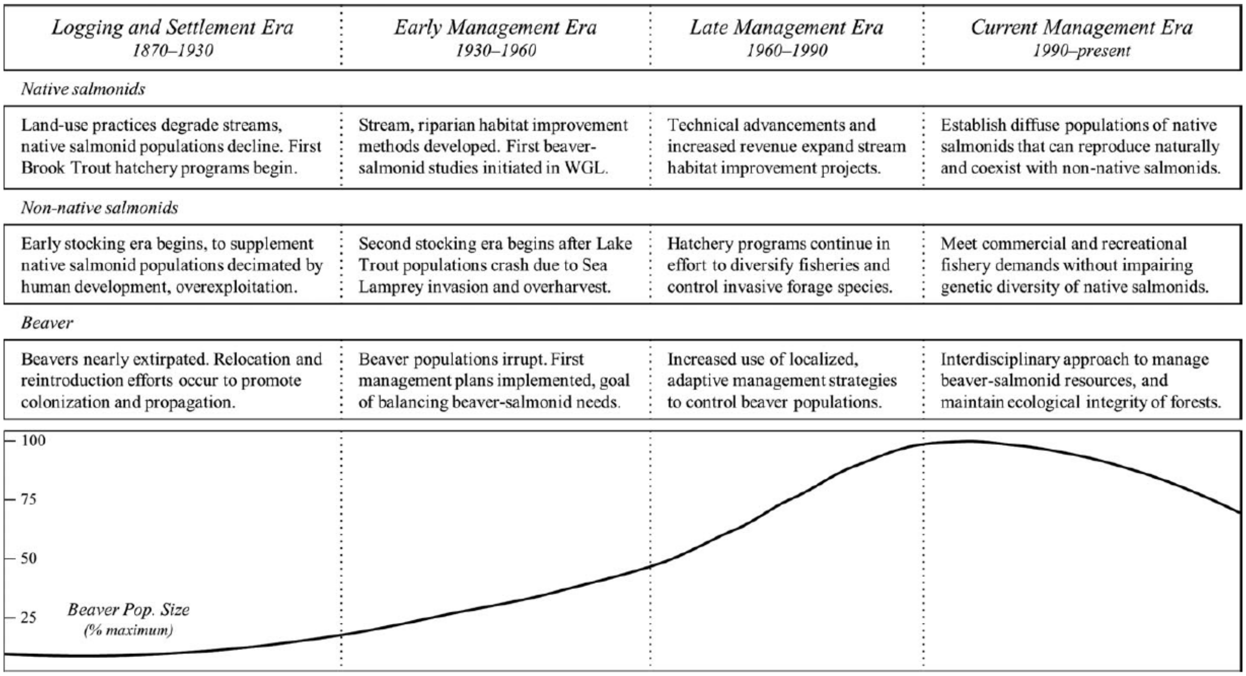

Figure 5. Changes in beaver population size across the western Great Lakes region in relation to trout management actions from Johnson-Bice et al., 2018.

presence as the channel planform was punctuated by abrupt changes in wetted width that were likely caused by beaver dams.

In the reach immediately downstream from Spur Lake between RM 4.2 and 4.6, fluvial and riparian changes were not as clear. The observed channel in 2021 was defined by the presence of tussock sedges. They bordered both sides of the channel, and remnant organic matter, probably from sedges, was present throughout the streambed. The air photos between 1937 and 2010 also indicate herbaceous vegetation within an approximately 70-foot wide corridor. The sedges likely dominated the riparian vegetation along the channel through the period. Beyond the 70-foot herbaceous corridor, larger size trees or shrubs appear in the air photos. It is difficult to distinguish exactly where the herbaceous to tree transition occurs; however, it appears that the line moved away from the stream through time. If the trees have receded towards the valley edge, it could be an indication of the elevated water levels from downstream beaver dams. Nevertheless, we could not make a definitive judgement because distinct features like beaver dams were not observed in the reach in any of the photos.

4.5 Hydrology

Along with changes in land use and human modifications to the outlet channel, changes in the hydrologic regime could explain part of the decline in wild rice in Spur Lake. Water supply to Spur Lake is provided by precipitation and groundwater flow. Of these two variables, precipitation changes are probably the only factor influencing water levels and depths in Spur Lake. Water levels in the lake are the surface manifestation of the groundwater table. Because Spur Lake is not a closed system (it contains an outlet channel), water levels are dictated by downstream channel hydraulics. In other words, substantial increases in groundwater flow to the lake should not increase lake levels because the excess water can be quickly drained through an open channel (rather than through the groundwater system).

4.5.1 Long-Term Climate Data

To understand if there have been changes in precipitation or temperature, climate data from the Rhinelander airport (National Weather Service Coop number 477113) were analyzed. Daily and annual data were available for 1908 through 2020. The annual data were plotted and qualitatively assessed for trends in annual precipitation, annual temperature, and annual snowfall. The data did not indicate major changes in the annual average or the standard deviation in precipitation or temperature since 1908 (see Appendix D: Climate Data). The lack of a detectable precipitation or temperature trend over the last century was similar to the findings of the Center for Climatic Research at the University of Wisconsin-Madison (accessed online at https://wicci.wisc.edu/wisconsin-climate-trends-and-projections/). They found some small changes in precipitation and temperature; however, Dr. Daniel Vimont (email communication 12/1/2021) indicated that the annual "trends in Northern WI are generally not statistically significant."

Although there were no major changes in annual climate data, the minor year-to-year annual precipitation fluctuations were somewhat correlated with the wild rice index between 1984 and 1992 (Figure 6). Low rice abundance was somewhat associated with high annual precipitation and vice versa. Between 1992 and 1998, the wild rice index remained generally high as annual precipitation remained relatively consistent around 30 inches/year. Starting in 1999, the wild rice index dropped drastically even though annual precipitation did not increase markedly. Even with relatively low annual precipitation around 27 inches/year between 2003 and 2009 (potentially lower water depths that were more suitable for rice), there was almost no rice in the lake.

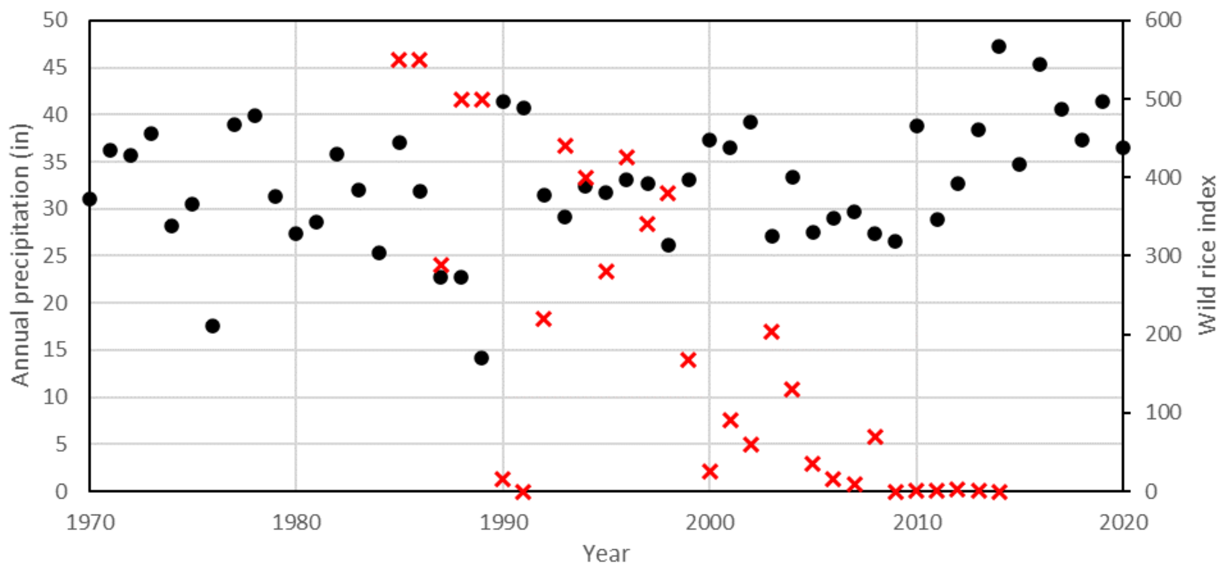

Figure 6. Annual precipitation in Rhinelander (NWS Coop 477113) and wild rice index measured by GLFWC for Spur Lake.

Daily precipitation data from Rhinelander were also analyzed for potential changes. The number and magnitude of precipitation events exceeding 2 inches in 24 hours were plotted. After 1990, the number of events exceeding 2 inches within a year increased. From 1908 to 1990, there were only two years with three 2+ inch precipitation events. After 1990, there were four different years when there were three or more 2+ inch precipitation events. The largest daily rainfall recorded was on July 8, 2000, when 8.65 inches fell in a single event (Figure 7). According to the National Oceanic and Atmospheric Administration's Atlas 14 (Perica et al., 2013), the event was larger than a 500-year recurrence interval. The wild rice index that year dropped substantially from the previous years.

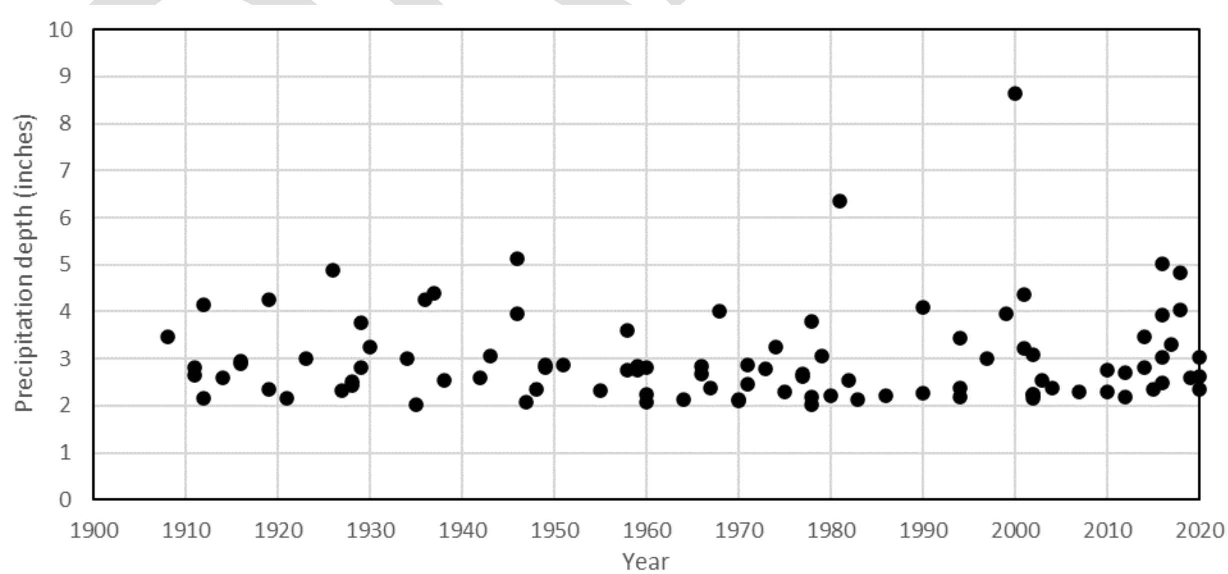

Figure 7. Daily precipitation events that exceeded 2 inches in Rhinelander (NWS Coop 477113).

The season when the heaviest precipitation occurred did not appear to change through the climate record (see Appendix D: Climate Data). Similarly, the daily snowfall amounts remained relatively consistent through the record.

The duration and thickness of ice cover was also investigated for potential correlation with the wild rice index. The nearest long-term, systematic record for lake ice was found at the University of Wisconsin-Madison's Center for Limnology Trout Lake Research Station (Magnuson et al., 2021). The research station is located about 33 miles away, and the data record began in 1982 which covered the period of record for the wild rice index measurements. We assumed that the data would be representative of the year-to-year variation in ice conditions for the region. Data from four different lakes around the research station were plotted. They represent lakes with areas from 1.5 acres to 3,867 acres and mean depths from 5.5 feet to 48 feet. The maximum ice thickness and duration each year were relatively consistent across the spectrum of lake sizes, indicating that climate likely dictates the data more than site-specific characteristics. Therefore, extrapolating the data to represent general year-to-year variations in Spur Lake may be reasonable.

The wild rice index appeared to have some correlation with the duration of ice cover and the maximum ice thickness. For example, the wild rice index was low in the years between 2003 and 2009. Over that time, 2003 had the maximum ice thickness and one of the longest ice cover durations. 2003 stood out with the highest wild rice index for the period. Similarly, 1996 had the longest ice cover duration and one of the greatest ice thicknesses on record, and the wild rice index increased notably from the lower years before and after.

Although there were some correlations, there were many years without any apparent influence by ice. For example, the duration of ice cover was relatively consistent between 1985 and 1990; however, the wild rice index fluctuated greatly. After 2008, wild rice was practically absent from Spur Lake even though the greatest ice thickness on record was measured in 2014.

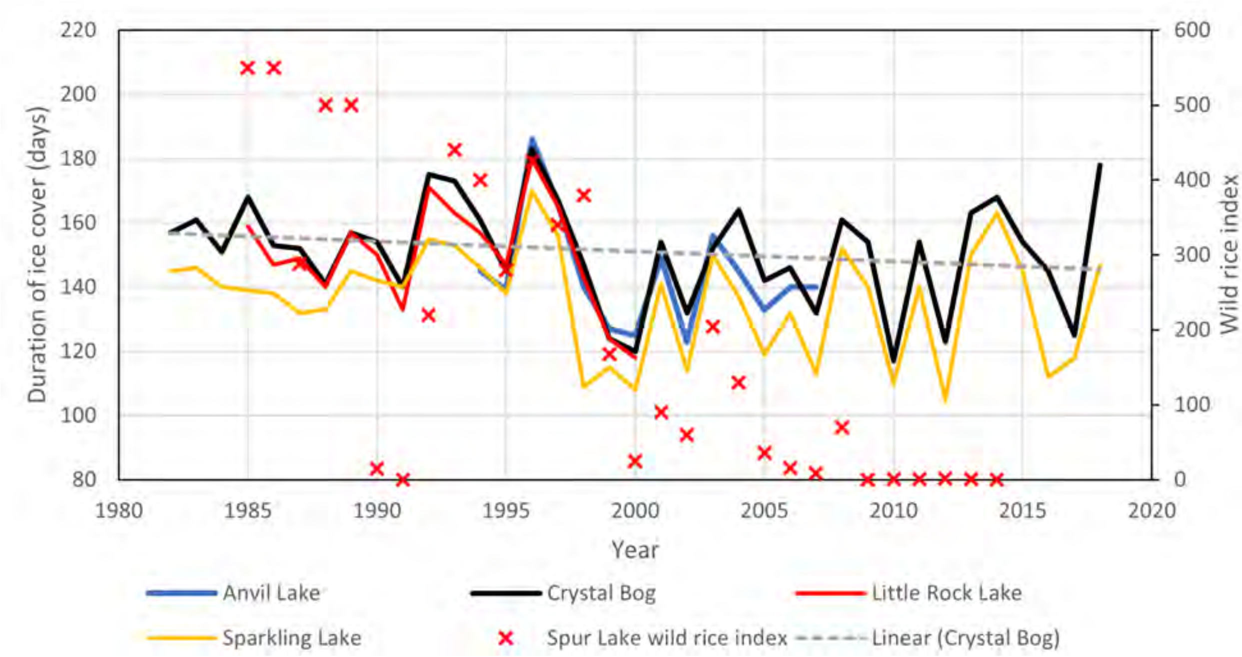

Figure 8. Duration of ice cover at the Trout Lake Research Station lakes (Magnuson et al., 2021) and the wild rice index at Spur Lake (David, 2020).

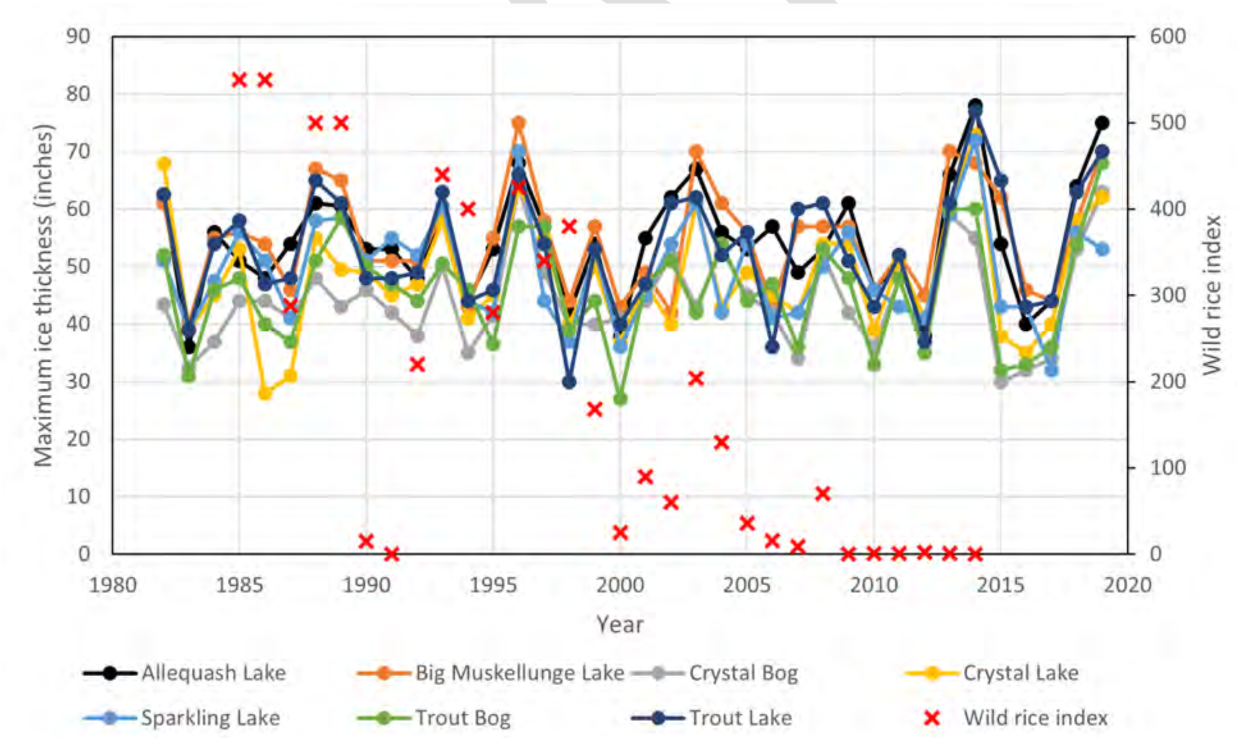

Figure 9. Maximum ice thickness at the Trout Lake Research Station lakes (Magnuson et al., 2021) and the wild rice index at Spur Lake (David, 2020).

4.5.2 Flood Frequency

Peak discharges for annual exceedance probabilities (AEP) were estimated to model the hydraulic conditions in Twin Lakes Creek. The peak AEP discharges were estimated using regression equations developed for the State of Wisconsin (Walker et al., 2017). The equations were developed by correlating flood magnitudes with longer-term U.S. Geological Survey (USGS) flow gaging stations in similar physiographic regions. Twin Lakes Creek is in an area where AEP floods are correlated with drainage area and percent of land classified as water. The stream gauges used for the regression equations, however, have drainage areas substantially larger than the drainage area at the Spur Lake outlet. Consequently, results from the regression equations should be considered extrapolation. Multiple years of water level monitoring and flow measurements would be required to develop a better estimate of flood frequencies in the stream. For now, the regression equations represent the best estimate of flow conditions.

To apply the regression equations, we first delineated the drainage areas to multiple locations along Twin Lakes Creek. Drainage areas were delineated manually in ArcGIS Pro using LiDAR data for Oneida County.

Table 2. Drainage area characteristics at various locations on Twin Lakes Creek.

Location	Drainage area (square miles)	Land under water
Spur Lake outlet	2.31	7.27%
Gunder property	3.53	5.46%
Gagen Road north	8.09	2.82%

Table 3. Peak discharges for AEPs at locations on Twin Lakes Creek.

AEP	Recurrence interval (years)	Discharge (cubic feet per second)		
		Spur Lake outlet	Gunder property	Gagen Road north
50%	2	12.3	19.3	47.4
20%	5	16.9	26.6	66.5
10%	10	20.1	31.8	80.0
4%	25	24.4	38.7	98.3
2%	50	27.9	44.3	112.9
1%	100	31.4	50.1	128.1

4.5.3 Water Level Monitoring

The existing culverts that convey Twin Lakes Creek under East Stella Lake Road have been suspected to impact water levels in Spur Lake. In recent years, the two parallel 30-inch diameter culverts have been submerged on either side of the road. We installed water level loggers on each side of the roadway to detect if there was a water surface increase caused by the culverts. The loggers were installed on May 20, 2021, and were set to collect data at 30-minute intervals. The loggers were deployed in stilling wells to reduce noise from wave action, and the elevations were surveyed with an rtkGPS to relate to a vertical datum. The loggers were removed on November 17, 2021, before ice cover.

The water level dataset indicates that there was no substantial difference on either side of East Stella Lake Road. During precipitation events, the water surfaces increased about 0.1 feet on the upstream side. The water level receded after a couple of days to match the downstream side of the culverts. The 0.1-foot increase probably has no major effect on water depth suitability for wild rice in Spur Lake. The lack of water level change also indicates that there is little potential energy to drive water downstream through the culverts. Over multiple field visits in 2021, very little water velocity was observed, confirming the lack of flow.

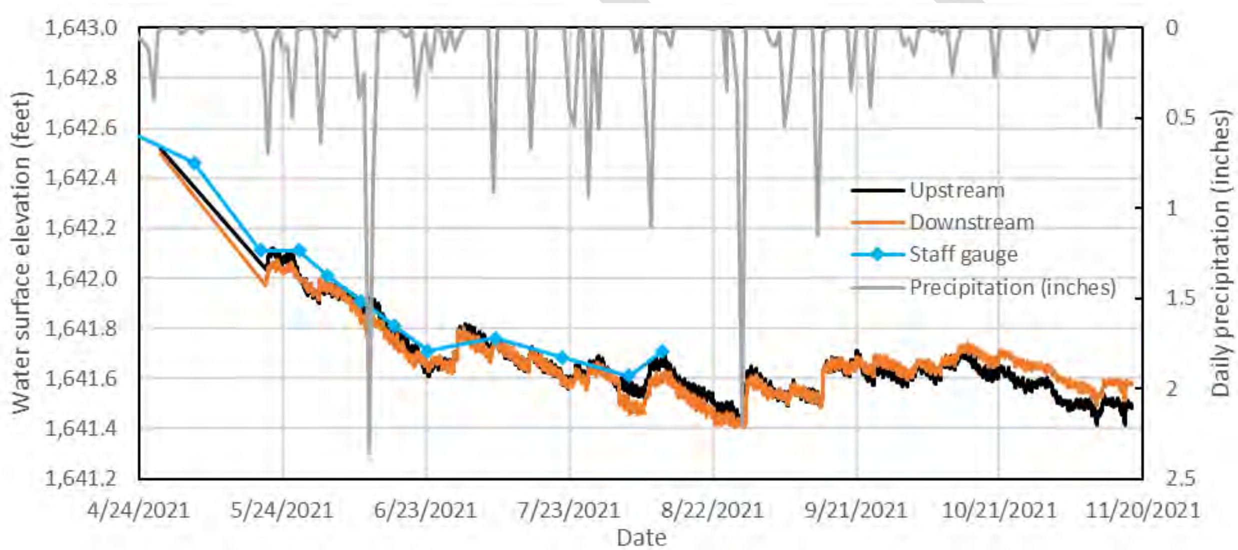

Figure 10. Water levels upstream and downstream from East Stella Lake Road. Periodic staff gage measurements are shown in blue. Precipitation is shown for reference on the secondary axis. Note the lack of difference in water level on either side of the road even during the larger 2-inch rainstorms.

4.6 Hydraulics

4.6.1 Spur Lake Tracer Study

A dye tracer was injected into Spur Lake to understand water circulation patterns in the lake. The intent of the experiment was to detect potential groundwater inflows or outflows that would direct flow patterns. We initially hypothesized that the East Stella Lake Road fill and culvert would influence water movement through the wetlands discharging water from the lake. Similarly, we suspected that elevated water levels would disperse water inflows. The dispersion would reduce the potential for flow to cause disturbance and mixing of sediments on the lakebed sediments.

Rhodamine WT dye was injected into one location on the west side of Spur Lake on April 27, 2021. The spring test date was intended to reduce the potential for aquatic vegetation to deter flow patterns. The injection location was about 300 feet east from the surface water inflow channel draining Gust Lake to the west. Winds were generally less than 5 miles per hour so wave action would not drive the dye across the lake. A fluorometer was set up at the outlet from Spur Lake at East Stella Lake Road to measure the residence time in the lake. Aerial photos were collected over several days after the injection to qualitatively monitor the movement of the dye through the lake.

After the dye injection, dispersal through the lake was very slow. The aerial photos did not indicate a specific direction of movement. Instead, the dye diffused slowly outward in all directions. Two days after the injection, the dye had mixed with enough water that it was hardly detectable in the aerial photos. No dye was detected over the period by the fluorometer.

The dye injection results indicate that surface and groundwater flows to the lake are minimal. The injection was designed to occur in the spring near the end of snowmelt so that potential groundwater inflows would be maximized while aquatic vegetation would provide little resistance to circulation. The lack of dye movement indicates that the residence time of water in Spur Lake is very long, and there is probably little disturbance provided by water inflow. Consequently, the lake is probably subject to cycling in wild rice abundance every few years as nutrients are depleted. The cycling may be more prominent than in other lakes where some surface water inflows create erosion and deposition of sediments in at least parts of a lake.

4.6.2 Twin Lakes Creek Hydraulic Model Setup

A one-dimensional (1-D), steady-state hydraulic model was created for Twin Lakes Creek using the program HEC-RAS (Brunner, 2016). An existing conditions model was set up for calibration and to estimate water depths for flood flows. Multiple proposed conditions models were developed to understand the influence of the culverts and the Gunder Paulsen riffle on water levels.

Geometry for the existing conditions model was based on survey data for the channel merged with LiDAR data for the overbank areas. Cross sections were spaced about 1,300 feet apart, on average, between Spur Lake and Gunder Paulsen's property. Additional cross sections were placed around the East Stella Lake Road culverts. Cross sections were spaced about 100 feet apart on Gunder Paulsen's property due to the more rapid changes in floodplain width and channel bed grades.

The downstream end of the model was about 50 feet downstream from the north Gagen Road crossing. The road was included as the top of the roadway elevation was about the same elevation as the Gunder Paulsen culvert. If the Gagen Road crossing overtopped, it would define upstream hydraulic conditions onto the Paulsen property. Several additional cross sections were surveyed just upstream from the north Gagen Road crossing because the reach was relatively steep. The reach between SM 1.6 and 3.0 was not surveyed because the channel traverses a flat kettle that likely provides little hydraulic influence.

Culvert and bridge geometry data were based on 2021 survey data. The downstream boundary condition for the model was specified as a normal depth based on the measured water surface slope from the survey data. The downstream end of the model was located much further than the area of interest so that the model would not be sensitive to errors in boundary conditions. The upstream boundary condition was specified as steady flows.

Contraction and expansion coefficients were specified as 0.3 and 0.5, respectively, adjacent to the structures. In all other cross sections, contraction and expansion coefficients were specified to be 0.1 and 0.3, respectively. Ineffective flow areas were specified at cross sections adjacent to culverts.

Roughness coefficients for the channel were calibrated so that modeled and measured water surfaces matched for measured flow rates. The calibration was focused on the reach in and immediately upstream from Gunder Paulsen's property. Calibration in the other reaches was not possible because hummocky vegetation and wood from beaver dams controlled water levels. The high complexity and frequency of the features were not possible to characterize with survey data. Roughness values were estimated in the other channel areas based on the method of Arcement and Schneider (1989) which involves partitioning various components of a stream that contribute to roughness (e.g., degree of meandering, aquatic vegetation, obstructions, etc.). The Arcement and Schneider (1989) method was also used to estimate the floodplain roughness coefficients.

The impact of the culvert and the artificial riffle on Gunder Paulsen's property was investigated by modifying the geometry of the HEC-RAS model. The cross sections representing the riffle were eliminated, and the culvert was removed from the geometry. Ineffective flow areas were omitted from the cross sections near the culvert.

Table 4. Roughness coefficients in Twin Lakes Creek.

Reach/location	Manning's n-value
Channel – SM 4.8 to 4.6	0.068
Channel – SM 3.2 to 4.8	0.059
Channel – SM 3.1 to 3.2 (Gunder Paulsen property)	0.037
Channel – SM 1.2 to 3.1	0.059
Floodplain – SM 1.2 to 4.8	0.119

Additional model geometries were created to investigate the required size of a new culvert at Gunder Paulsen's property to eliminate the upstream hydraulic influence. A pipe arch structure was specified to maximize flow width while minimizing overhead cover requirements. Multiple culvert cross sectional areas were modeled to determine the size just large enough to minimize backwater during the 50% AEP flood and avoid overtopping during the 1% AEP flood.

4.6.3 Twin Lakes Creek Hydraulic Model Results

The existing conditions HEC-RAS model results indicate that the Gunder Paulsen culvert and the Gagen Road increase upstream water levels during all flood events. At the Paulsen Culvert, the backwater is 0.58 feet during the 50% AEP flood, 1.06 feet at the 10% AEP flood, and 0.94 feet at the 1% AEP flood. Backwater due to the Gagen Road culvert is also substantial. The water surface profile indicates that flood peak discharges greater than the 50% AEP may backwater the channel nearly 2 miles upstream to the Paulsen Culvert.

The East Stella Lake Road Culverts have a relatively small influence on water surface elevations in Spur Lake according to the model results. During the 50% AEP flood, the backwater is only 0.04 feet. The water surface elevation increases somewhat during the 10% AEP flood to 0.13 feet, and it increases further during the 1% AEP flood to 0.31 feet.

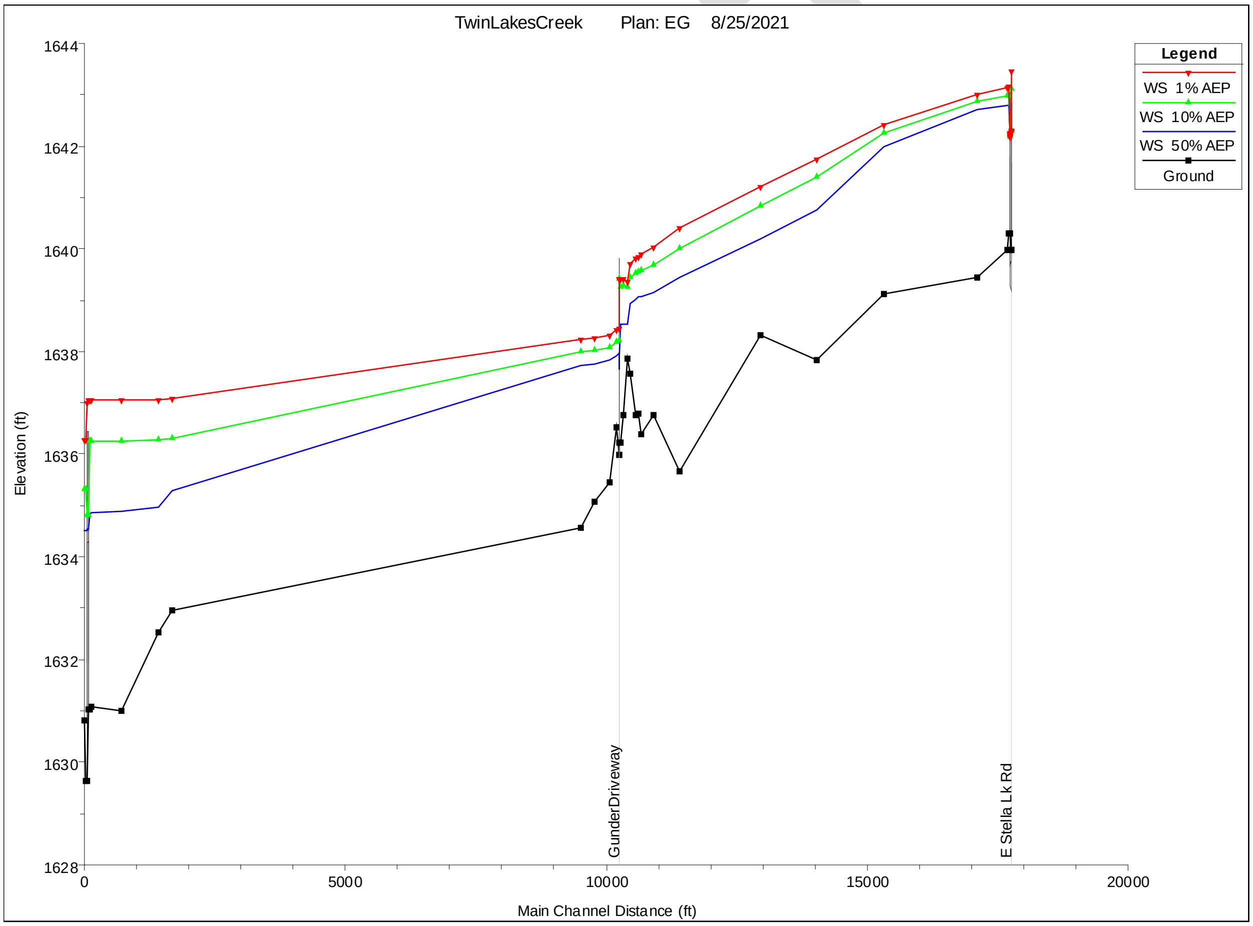

Figure 11. Existing conditions HEC-RAS model results.

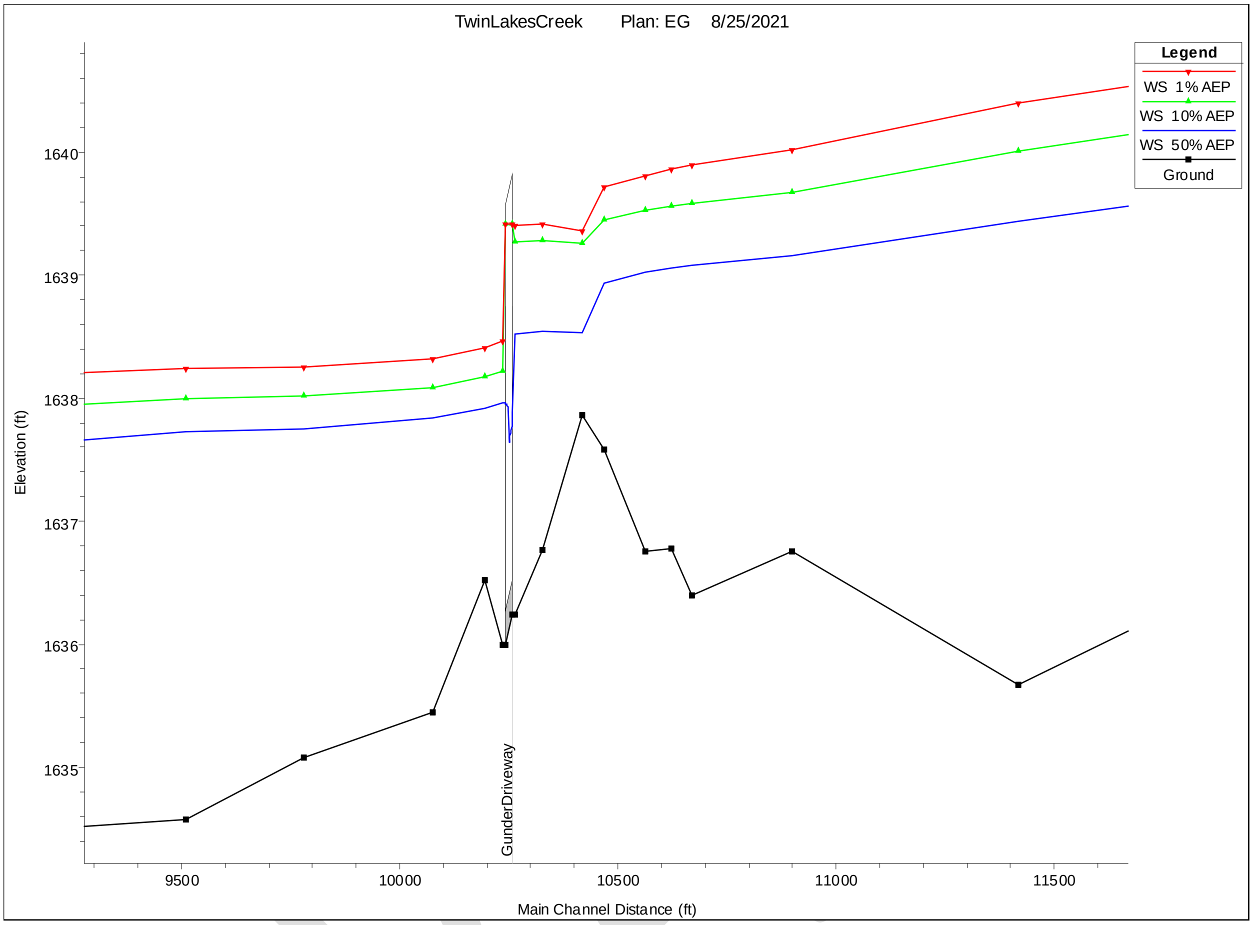

Figure 12. Existing conditions HEC-RAS model results around the Gunder Paulsen property.

The influence of the small culvert on Gunder Paulsen's property is limited to the reach within 150 feet from the culvert (Figure 13). During the 50% AEP flood, the water surface elevation immediately upstream drops substantially with the culvert removed. Nevertheless, the steep artificial riffle controls water levels further upstream. Similar patterns are evident in the larger flood discharges.

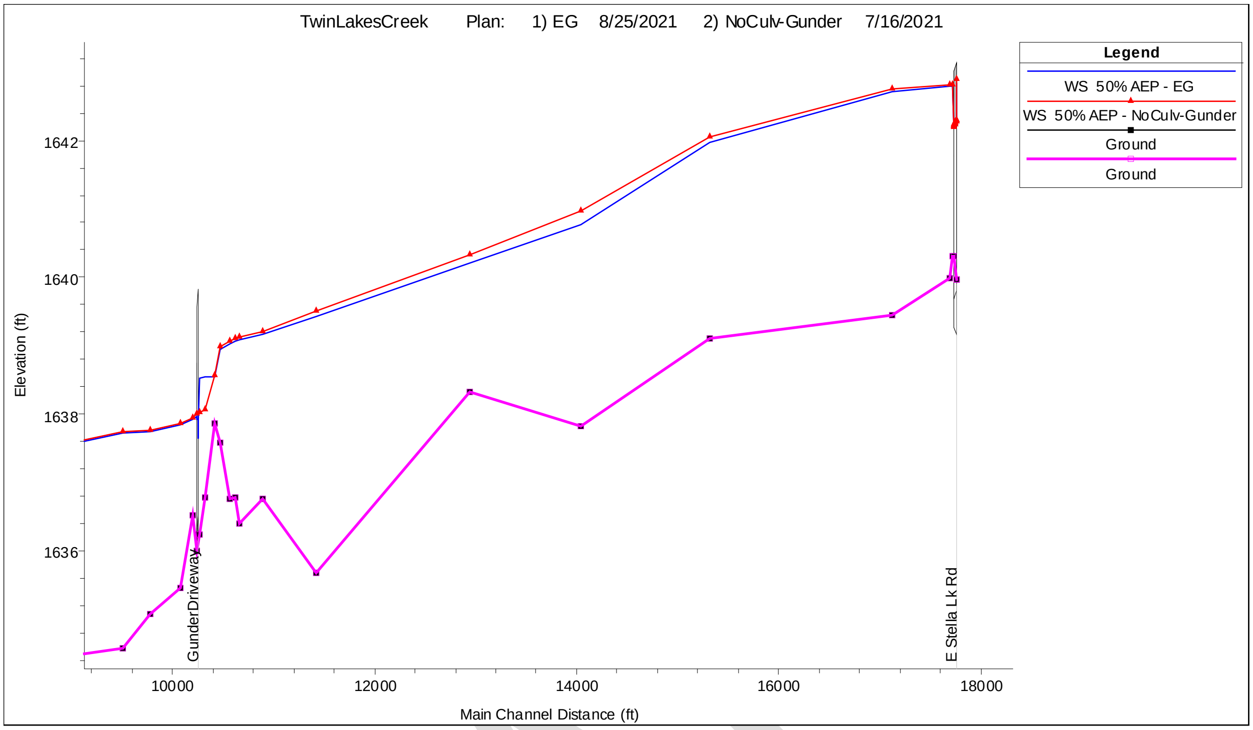

Figure 13. Water surface profile during the 50% AEP flood under existing conditions (blue line) and with the Paulsen Culvert removed (red line). The only substantial difference is limited to the first 150 feet upstream from the culvert.

Water surface elevations drop throughout a longer reach with both the culvert and the artificial riffle eliminated on Gunder Paulsen's property. During the 50% AEP flood, the water levels decrease an average of about 0.27 feet between the riffle and the esker crossing at SM 3.7. Shear stresses in the reach increase by about 20% indicating that the loose channel bed silts may mobilize more readily. Similar drops in water surface were predicted during larger floods up to the 1% AEP.

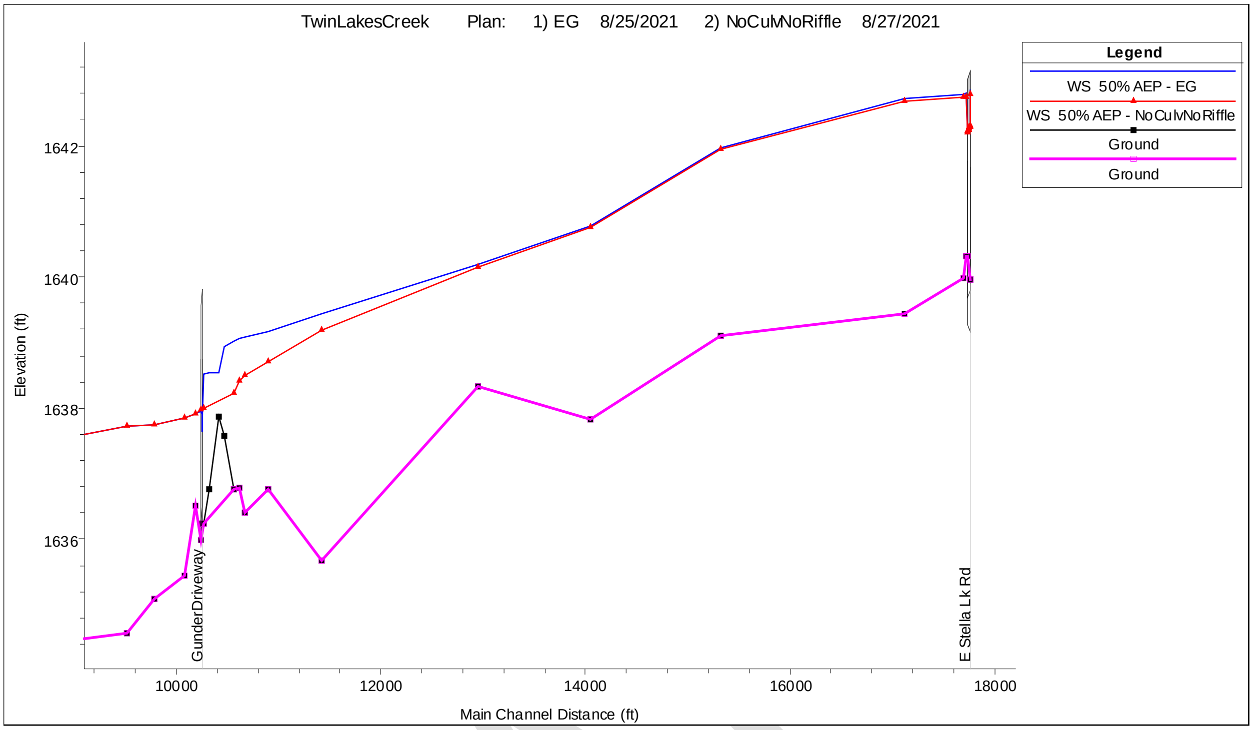

Figure 14. Water surface profile during the 50% AEP under existing conditions (blue line) and with the culvert and artificial riffle removed from Gunder Paulsen's property (red line).

5. Discussion

There was no clear, singular cause for the decrease in wild rice abundance in Spur Lake over the last few decades. Multiple factors probably contributed to worsening habitat conditions including human alterations, wildlife populations and management, and climate. The cumulative impact of the factors may have led to the passing of a threshold beyond which wild rice could flourish; however, the impact level of each factor alone is unknown.

To begin with, beaver recolonization of Twin Lakes Creek probably set the stage for changing habitat conditions in Spur Lake. After near extirpation from the state around 1900 (Knudsen, 1963), populations increased dramatically until reaching a peak around 1990 (Johnson-Bice et al., 2018). After that, populations came down somewhat with increased awareness of potential habitat changes to trout streams. The Wisconsin DNR first published a beaver management plan in 1990 (WIDNR, 1990), and the U.S. Department of Agriculture-Animal and Plant Health Inspection Service (APHIS) ramped up management of beavers in the region in the years following (FCPC, 2010). Aerial photos of Twin Lakes Creek indicate that beavers were establishing a presence between 1960 and 1980. The aerial photos in 1991, 1997, and 2010 show a peak in inundation due to beaver dams. Presumably, water levels increased in Twin Lakes Creek and possibly in Spur Lake.

It is interesting to note that wild rice abundance did not drop in 1990, the apparent peak in beaver activity based on the work of Johnson-Bice et al. (2018) and as indicated by aerial photos. Nevertheless, as beavers elevated water levels in the stream, conditions were probably ripe for other perturbations to potentially change Spur Lake habitat conditions to favor other species. Climate change may have been the catalyst. In 1998, there was a change in the average duration of ice cover from about 150 days/year to about 130 days/year. Coupled with the water level increases, there may have been little time when ice was anchored to the lakebed to kill competing perennial water lily roots (white water lily [*Nymphaea odorata*], spadderdock [*Nuphar variegata*]).

Additional climate-induced change to wild rice habitat may be due to extreme rainfall events. In 2000, over 8 inches of rain fell on July 8th just after aerial shoots formed. If water levels had risen substantially and remained high for more than a few days, it is possible that most of the wild rice was killed that year. David et al. (2019) described a similar-size rainfall event in Duluth in 2018 that led to “complete failures of the rice crop.” The 2000 high water would have come right on the heels of decreasing ice cover duration in the prior 1-2 years.

In the two years following 2000, annual precipitation amounts were relatively high and ice duration remained shorter. The result may have been less mortality of water lily roots and greater water depths that favored the lilies. The very thick ice in 2003 may have kept lily roots in check for a year as wild rice abundance increased. Nevertheless, the rice did not recover to an abundance near those 10-20 years prior. High water was probably still present that may have also limited the area in the lake with suitable water depths.

To re-establish wild rice abundance in Spur Lake under current conditions would likely require an unusual change in the climate. Multiple long, cold winters with lower annual rainfall and no extreme rain events may result in some improvement in wild rice. Given the unlikely nature of those conditions, other management actions will probably be needed.

5.1 Historical Wild Rice Presence

The presence of wild rice in Spur Lake prior to the 20th century is unknown. Conditions that led to abundant wild rice in the 20th century may not have been indicative of pre-EuroAmerican presence conditions. For example, beavers were nearly absent from the region which may have led to lower water levels over most of the last century. On the other hand, beaver populations may have been limited by available habitat. Late-successional, old-growth trees such as white cedar and hemlock may have been prevalent in the riparian corridor. They would not have provided a food source for beavers which could have limited their interest in establishing dams on Twin Lakes Creek.

Determining the presence or abundance of wild rice could be investigated to provide a reference for future efforts. Sediment cores would need to be sampled from the lakebed and tested for wild rice DNA (or other indicators such as pollen or seeds). The DNA indicators could then be correlated with various dating techniques to understand when rice was present. Regardless of the historical results, project partners may desire to manage the lake for wild rice if it is determined feasible.

5.2 Study limitations

For this study, we assumed that physical habitat changes were the cause of the decline in wild rice in Spur Lake. The correlation between the wild rice index data and the beaver dam indicators, climate, and ice data appear to tell a coherent story. Beaver dams and increased rainfall were assumed to increase water levels so that water depths were beyond the suitable range for wild rice. Nevertheless, there were no data on water level prior to 2016 to corroborate the assumption.

It is possible that factors other than water level change led to the decline in wild rice. Herbivory by geese and swans can be dramatic in some places (David et al., 2019). Humans can disturb rice beds by boat wake. Water and sediment quality changes can also be severely detrimental to wild rice. Increased sulfate concentrations can lead be toxic (Myrbo et al., 2017). Diseases and insects may also decimate wild rice populations.

Finally, climate change can induce stress to wild rice plants or exacerbate other issues. We did not find a correlation between wild rice abundance in Spur Lake and temperature, but the effects may be obscured by other factors. For example, if suitable water depths and winter anchor-ice could be re-established, year-to-year fluctuations in wild rice abundance may then start to depend on heating degree days in the growing season. The potential for brown spot disease could increase.

To re-establish ice contact on the lakebed, water levels will need to be lowered. Beavers would likely need to be controlled on a regular basis, and any dams dismantled. Lowering water levels may be sufficient to increase the duration and frequency that ice anchors to the lakebed and kills lily roots; however, it may be helpful to manually increase ice thickness by scraping snow off the surface. The effectiveness of the method is unknown, but there is some evidence that it may help (David, 2019).

6. Management Recommendations

To improve habitat for wild rice in Spur Lake, historical conditions should be restored to the extent possible. Human impacts on Twin Lakes Creek should be minimized. Ideally, re-establishing natural conditions would result in Spur Lake water levels around elevation 1641.5 feet (staff gage measurement 4.90 feet) which maximizes the area with water depths between 1.5 and 2.0 feet.

The decline in wild rice habitat appeared to initiate with the channel modifications at the Gunder Paulsen property, and we recommend starting restoration efforts at that site. **The steep riffle should be lowered to decrease upstream water levels.** Probing to historical channel bed material in the floodplain indicates that historical elevations were lower, though a somewhat steeper channel was always present.

The new, lower channel bed at the Paulsen property would create drier conditions in the upstream floodplain. Consequently, vegetation may shift away from a tag alder and willow-dominated system. Tree planting activities could be conducted in the floodplain to promote a faster transition to a later-successional vegetation community.

The lower channel bed could also mobilize sediments. The steeper energy gradient would likely extend from the Paulsen property at SM 3.2 up to at least the esker at SM 3.7. The hydraulic model results indicate the water surface elevations would drop through this reach during the 50% AEP flood. A similar drop would likely occur during base flows. It is also possible that some downcutting through the reach would steepen the energy gradient through the reach further upstream. The change may not propagate upstream to cause a major change in Spur Lake; however, the change should provide some benefit.

The existing culvert at the Gunder Paulsen property should also be replaced with a new, larger structure. The new culvert should ideally be set to match the bankfull channel width of about 12-15 feet. The culvert should be designed according to U.S. Forest Service Stream Simulation Guidelines (FSSWG, 2008), if possible. If the larger culvert is cost-prohibitive, a smaller culvert could be specified to at least eliminate upstream backwater during most flood events. The culvert should be embedded into the channel bed profile to allow for some vertical adjustments. A rock-lined ford crossing could also be considered as a low-cost alternative.

The East Stella Lake Road crossing over Twin Lakes Creek should also be replaced with a new, larger structure. Although we detected a small impact on water levels, the effect should be minimized. It is also possible that if the existing culverts have a larger impact than what we detected in this study. For example, if the downstream water levels can be reduced substantially, the existing small openings may hold back more water during large, intense rainfalls. The new culvert should be about 8 feet wide to match downstream channel widths. The invert should also be embedded below the stream profile to avoid artificially raising water levels during dry periods.

Beavers and beaver dams will need to be eliminated in Twin Lakes Creek to lower water levels in Spur Lake for wild rice habitat. It is possible that active management may not be needed if the floodplain can be revegetated with trees that do not favor beavers; however, that condition will likely require multiple decades.

Aquatic vegetation removal appeared to have little effect on Spur Lake water levels. The water surface profile between April and August 2021 showed little to no difference in the reach immediately downstream from the lake where vegetation was removed. Flow rates are very small so even with high roughness values in the channel, the aquatic vegetation probably is not a primary control. If downstream water levels are lowered by removing beaver dams, water levels should be minimized.

These recommended management actions should help maximize the potential wild rice habitat in Spur Lake. Nevertheless, climate change may continue to produce conditions that are not favorable for wild rice habitat. Short winters with little ice may allow perennial vegetation like lilies to persist. Extended warm periods in the summer could favor other aquatic vegetation or lead to increased disease.

7. References

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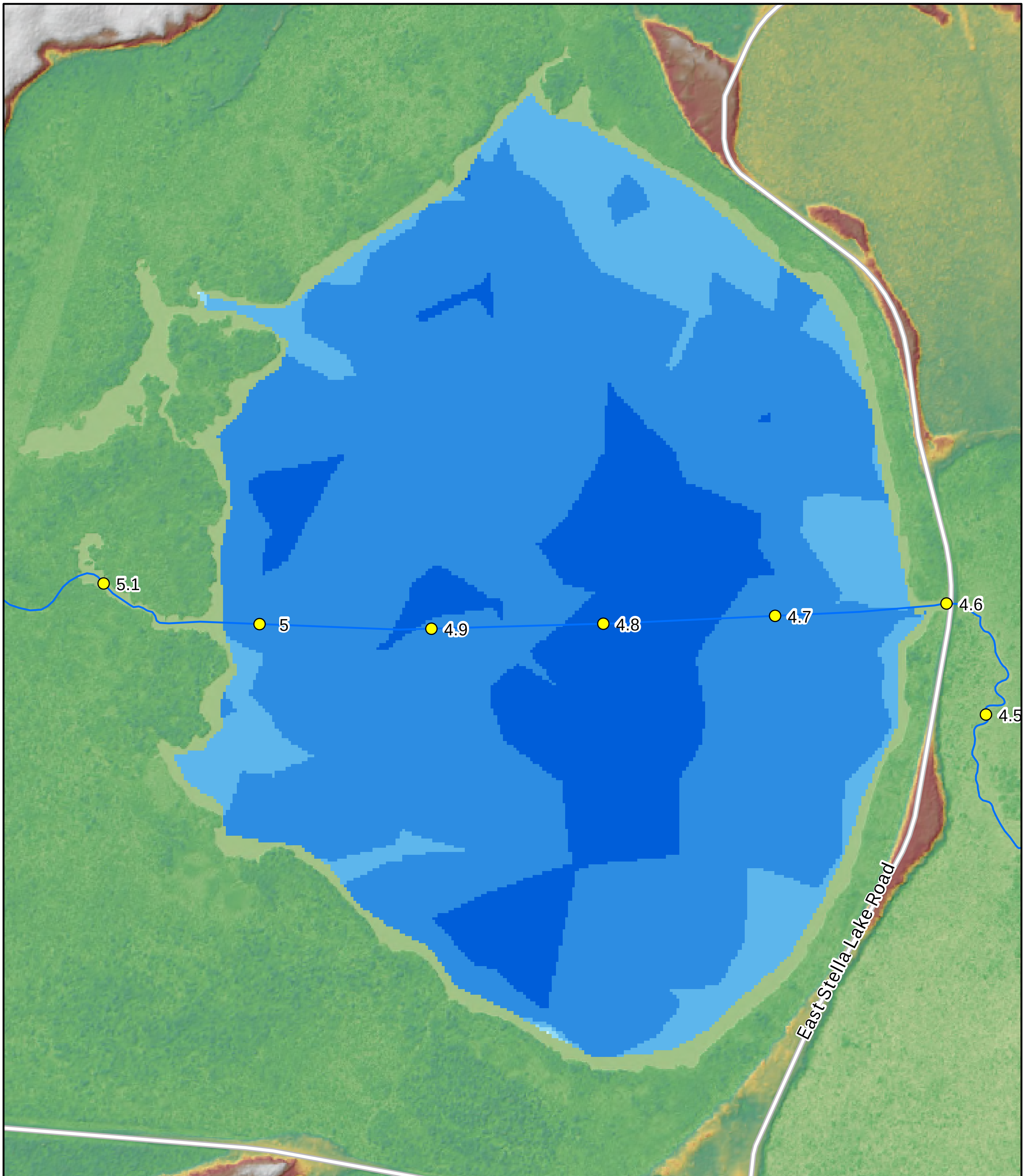
Appendix A: Spur Lake Bathymetry



EST. 2019
FISH CREEK RESTORATION LLC

Legend

TwinLakesCreek_Route

CountyAndLocalRoads

Bathymetry

1,638.14 - 1,639

1,639.01 - 1,640

1,640.01 - 1,641

1,641.01 - 1,642

1,642.01 - 1,643

LiDAR

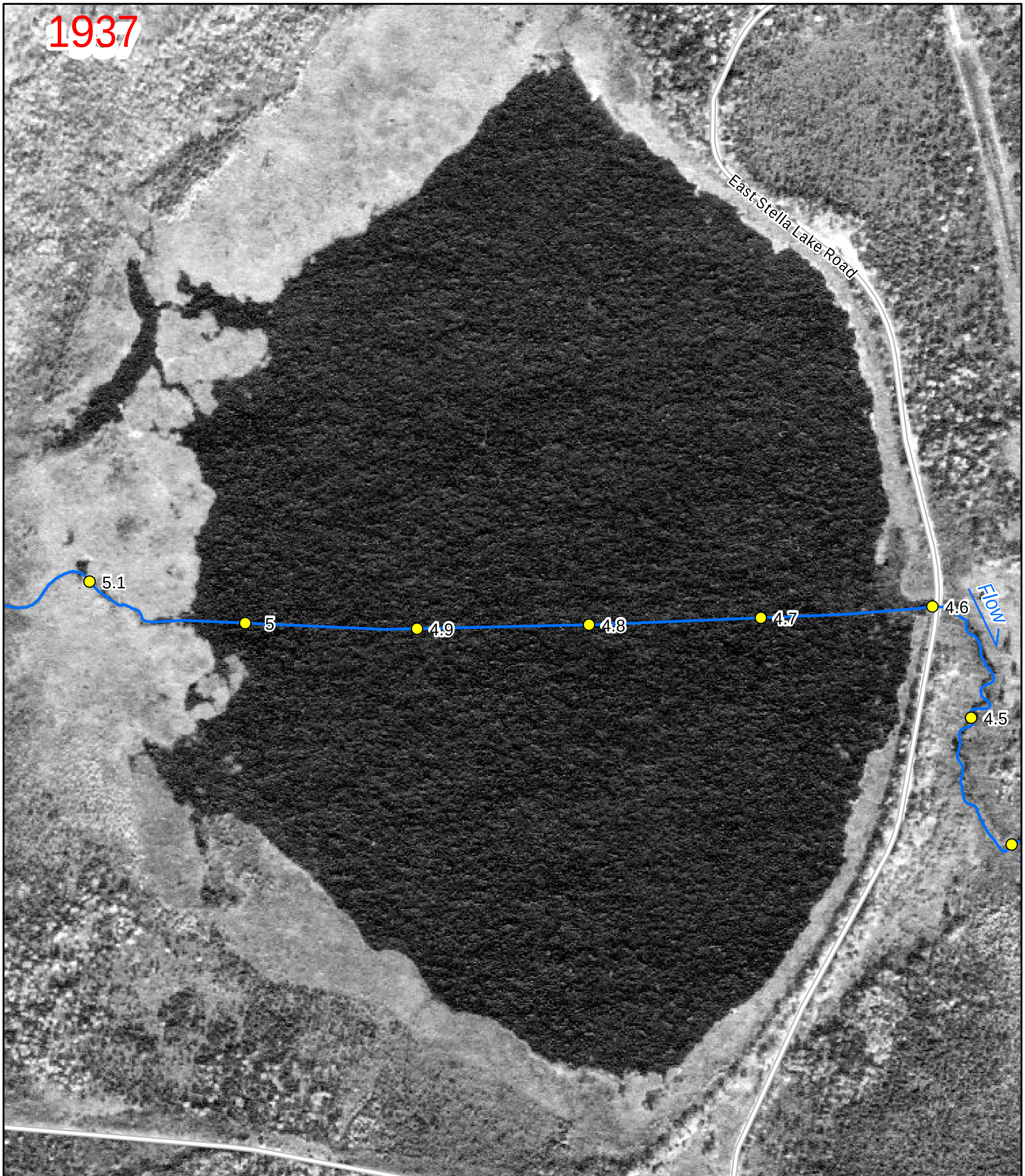
1660

1638

N

0 250 500 Feet

Appendix B: Historical Spur Lake Aerial Photos



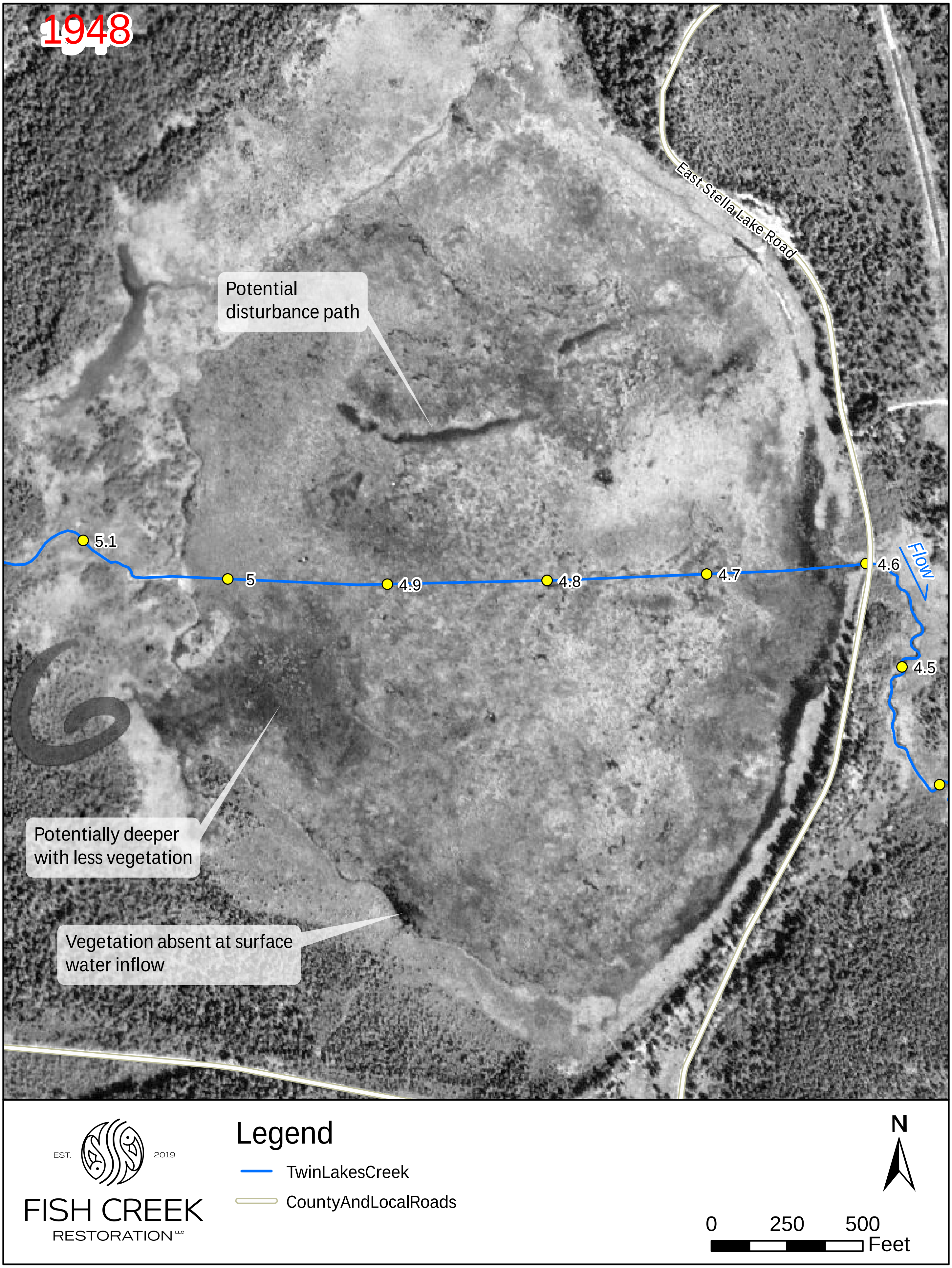
FISH CREEK RESTORATION LLC
EST. 2019

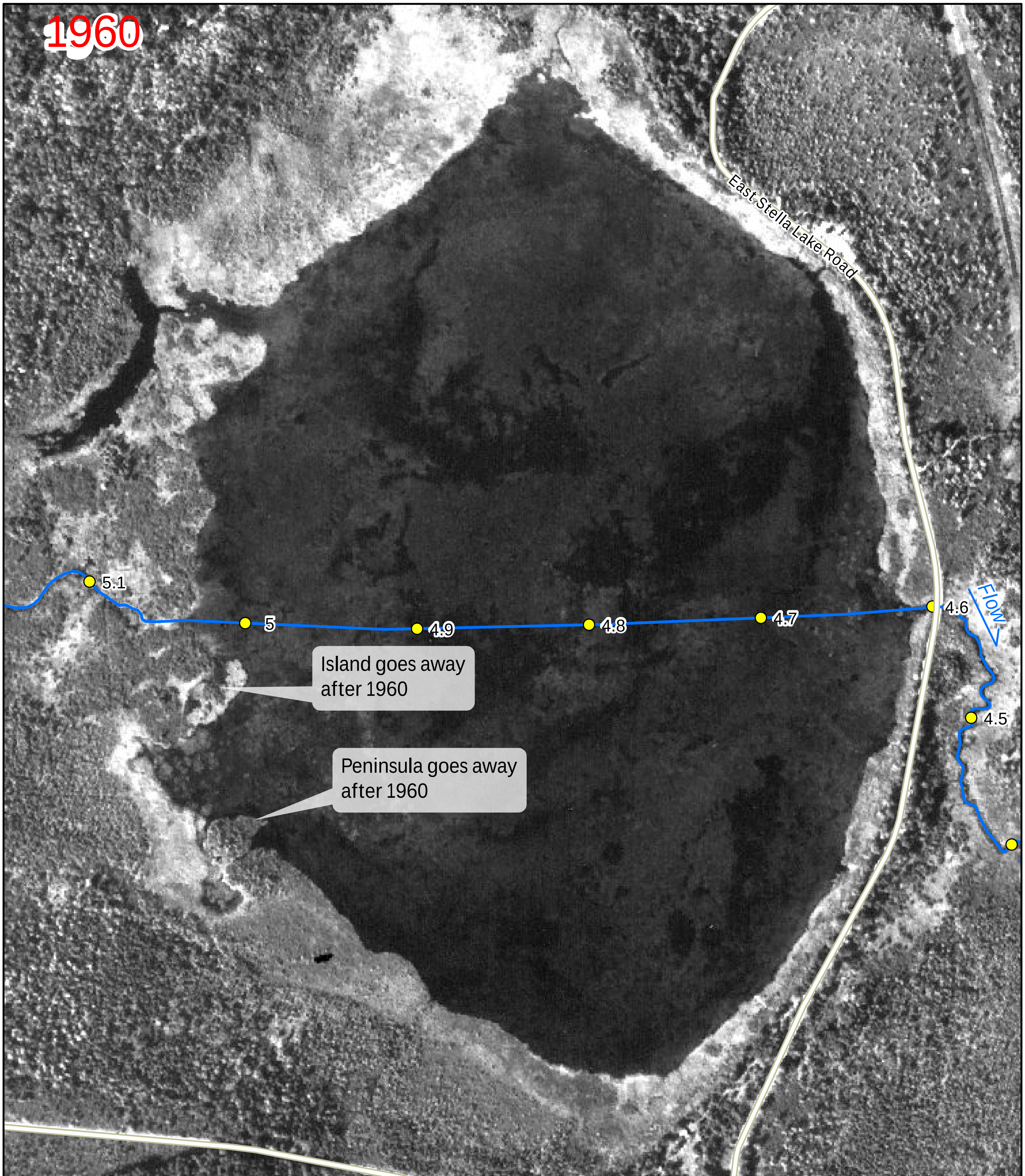
Legend

- TwinLakesCreek
- CountyAndLocalRoads

N

0 250 500 Feet


1948
East Stella Lake Road
Potential disturbance path
Potentially deeper with less vegetation
Vegetation absent at surface water inflow
Flow
5.1
5
4.9
4.8
4.7
4.6
4.5
Legend
TwinLakesCreek
CountyAndLocalRoads
N
0
250
500
Feet
EST. 2019
FISH CREEK RESTORATION LLC



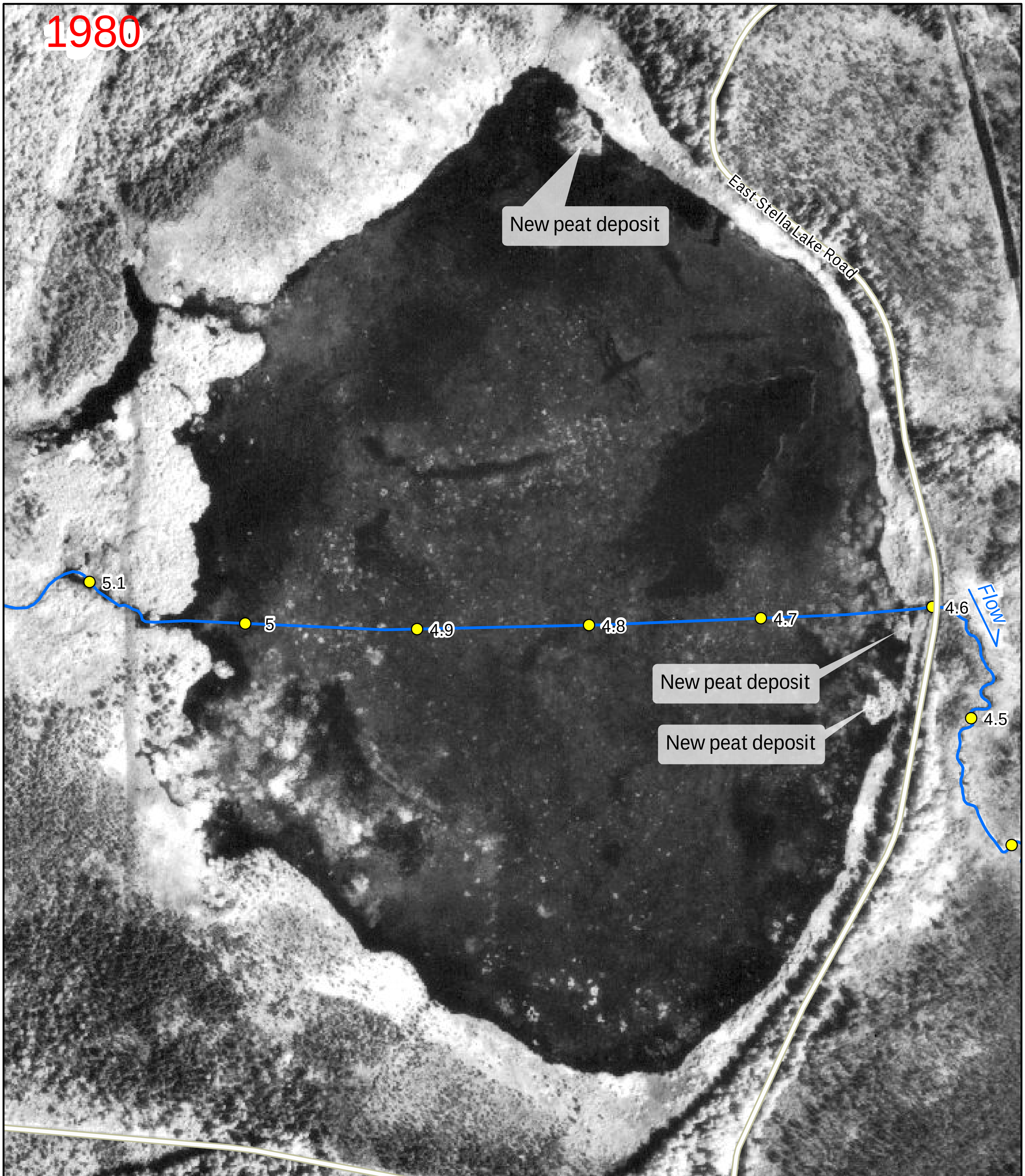
EST. 2019
FISH CREEK RESTORATION LLC

Legend

- TwinLakesCreek
- CountyAndLocalRoads

N

0 250 500 Feet



FISH CREEK RESTORATION
EST. 2019

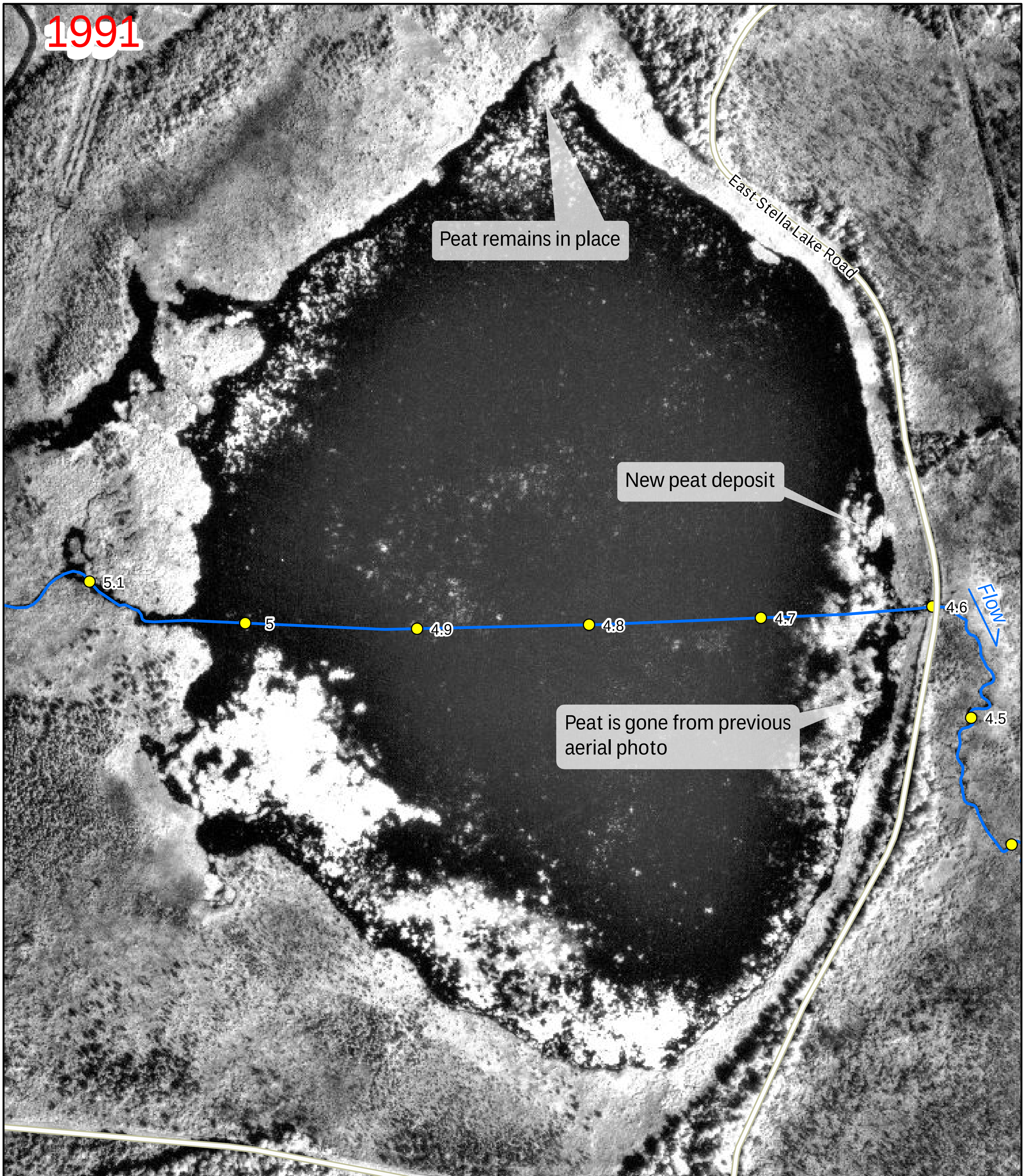
Legend

TwinLakesCreek

CountyAndLocalRoads

N

0 250 500 Feet



EST. 2019
FISH CREEK RESTORATION LLC

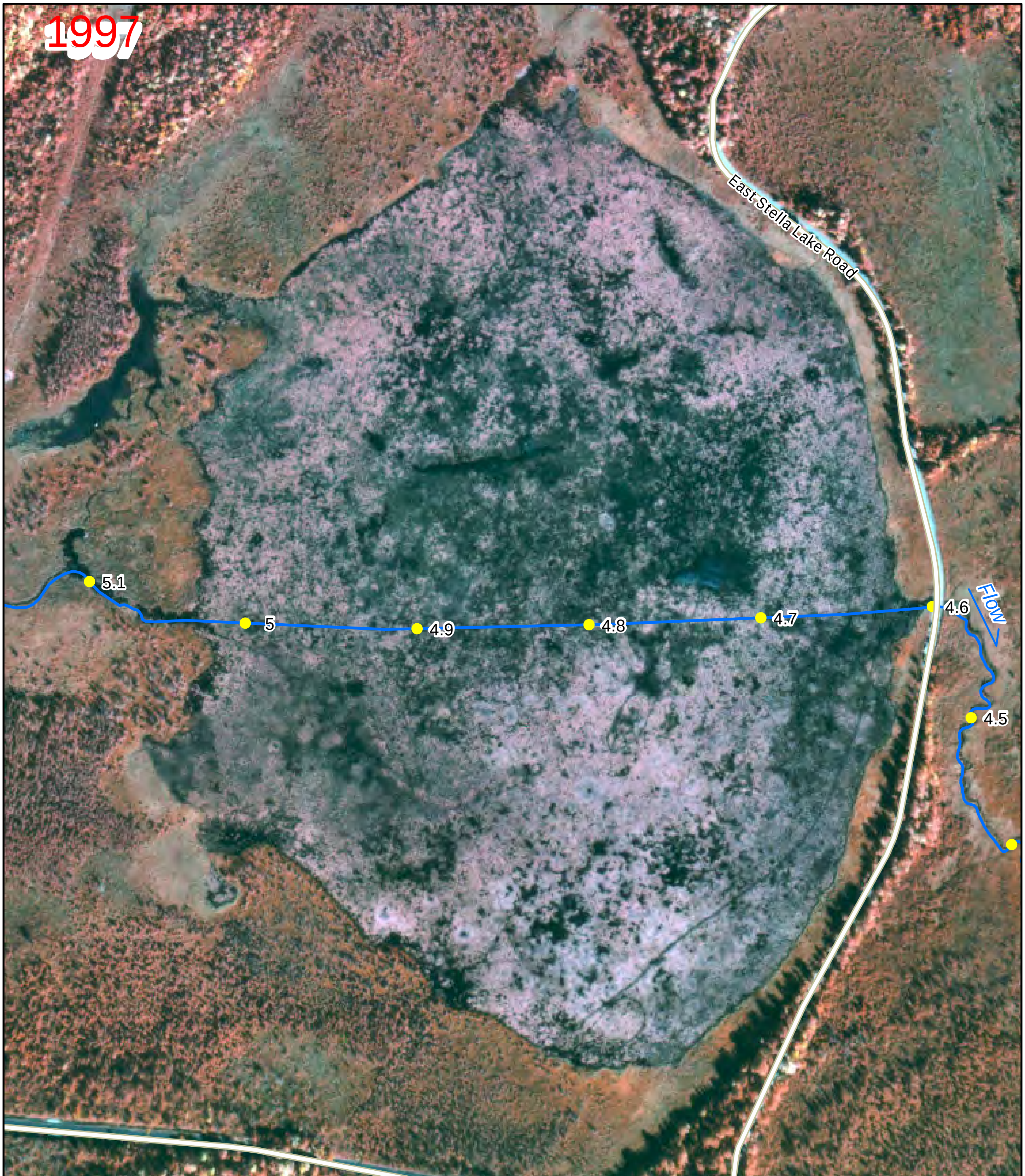
Legend

TwinLakesCreek

CountyAndLocalRoads

N

0 250 500 Feet



EST. 2019
FISH CREEK
RESTORATION LLC

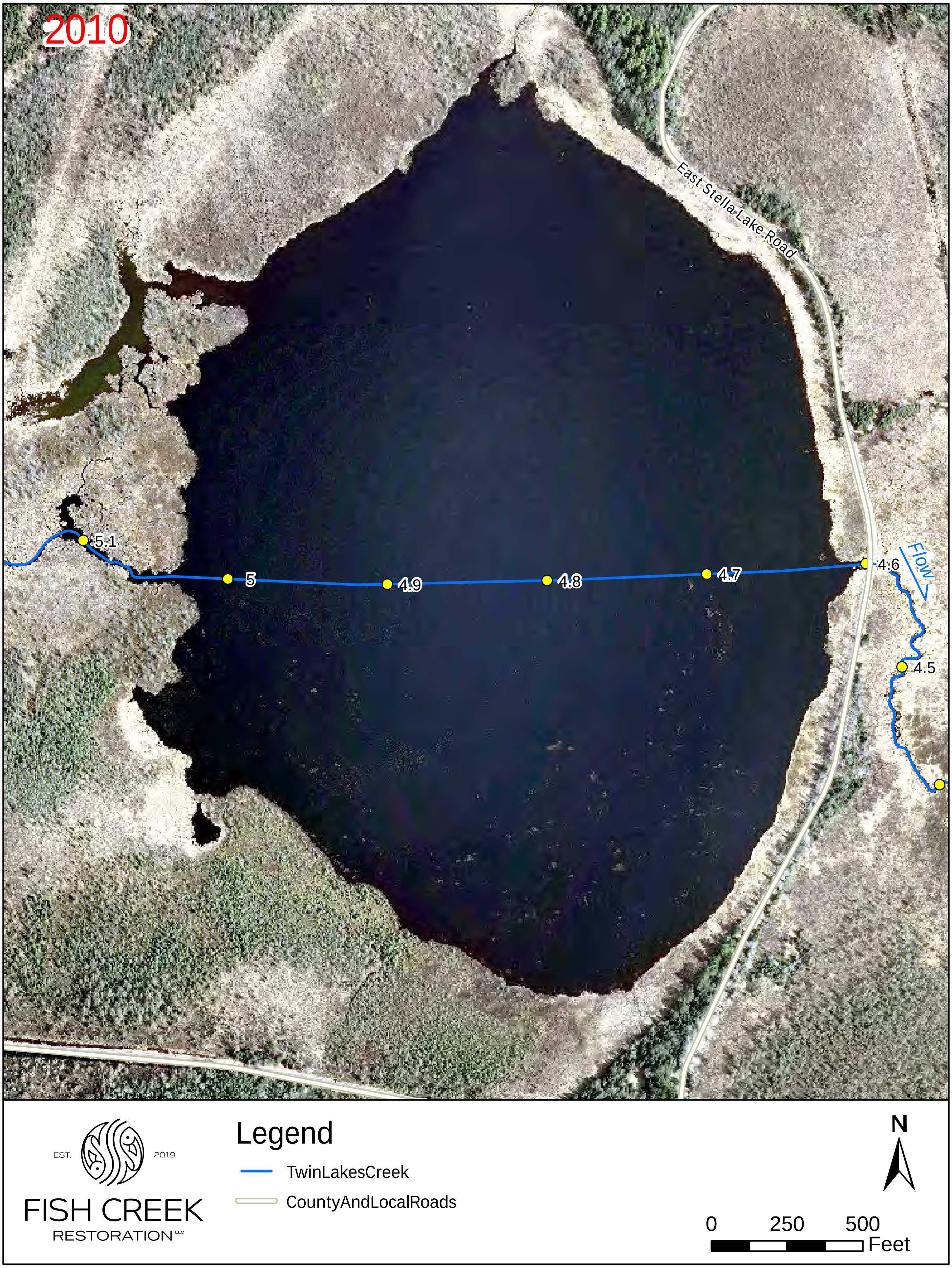
Legend

TwinLakesCreek

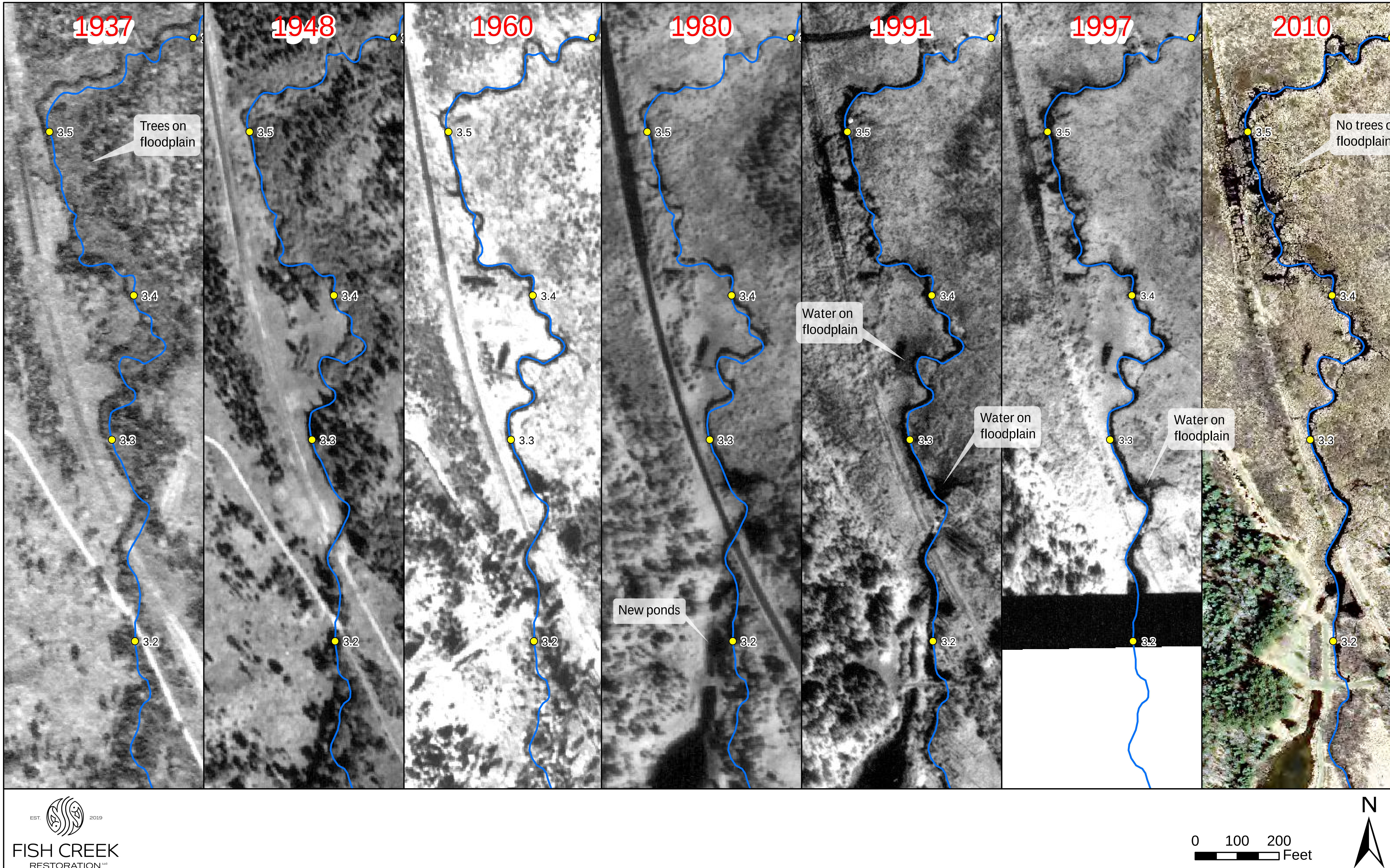
CountyAndLocalRoads

N

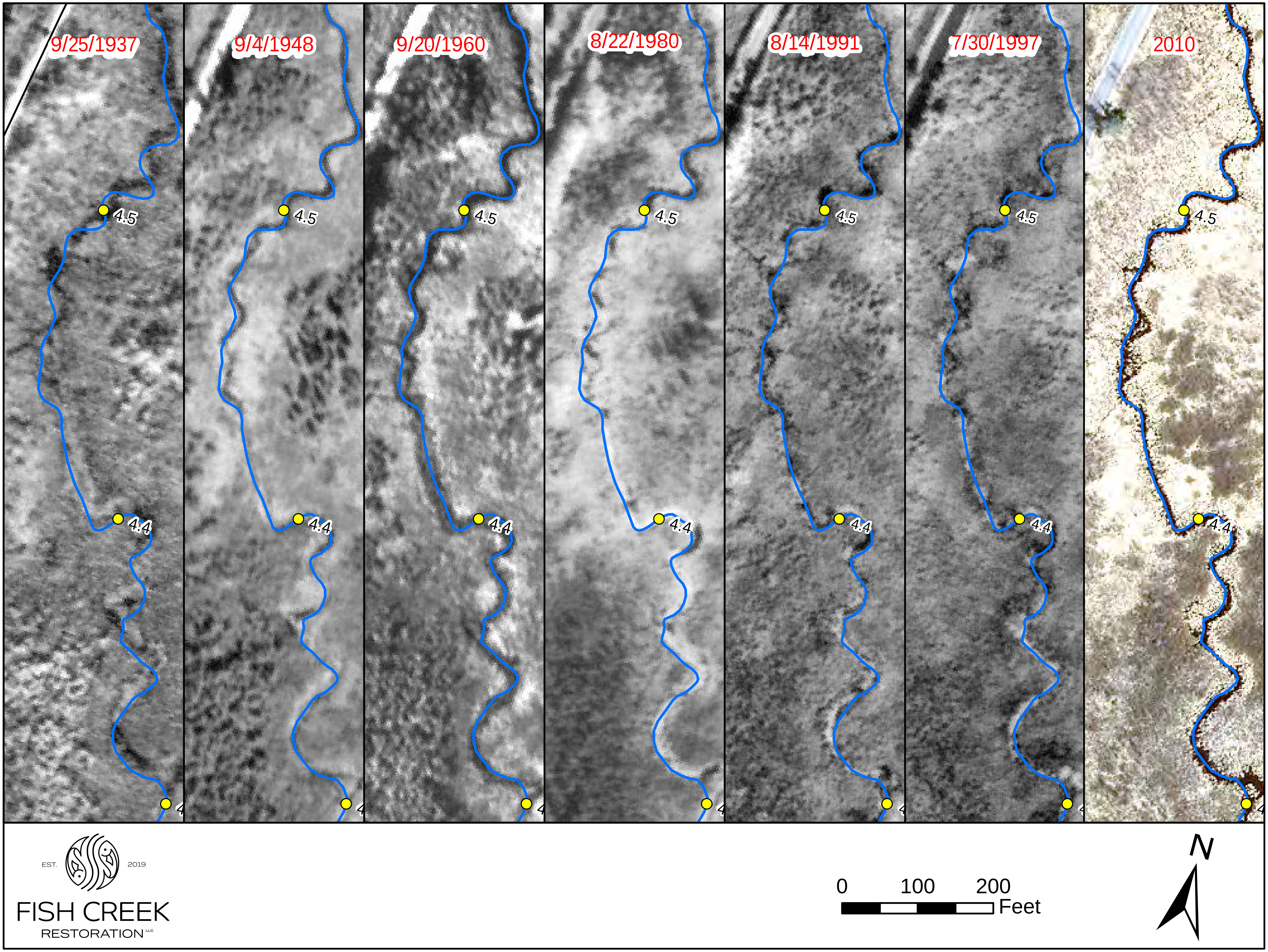
0 250 500 Feet


2010
East Stella Lake Road
5.1
5
4.9
4.8
4.7
4.6
4.5
Flow
Legend
TwinLakesCreek
CountyAndLocalRoads
N
0
250
500
Feet
EST.
2019
FISH CREEK
RESTORATION LLC

Appendix C: Twin Lakes Creek Historical Aerial Photos

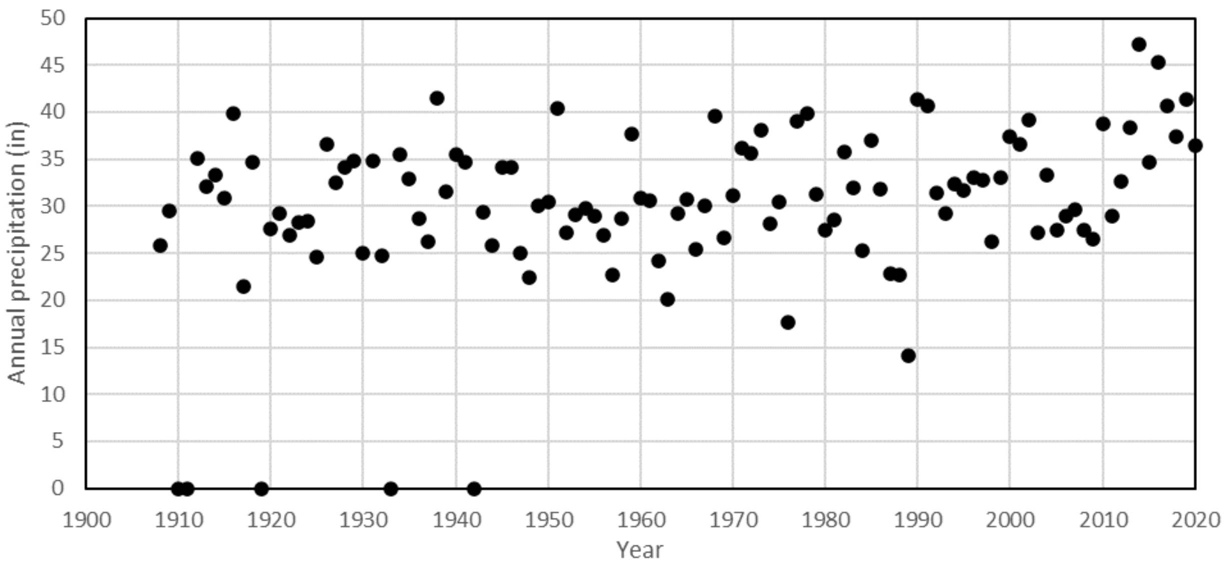


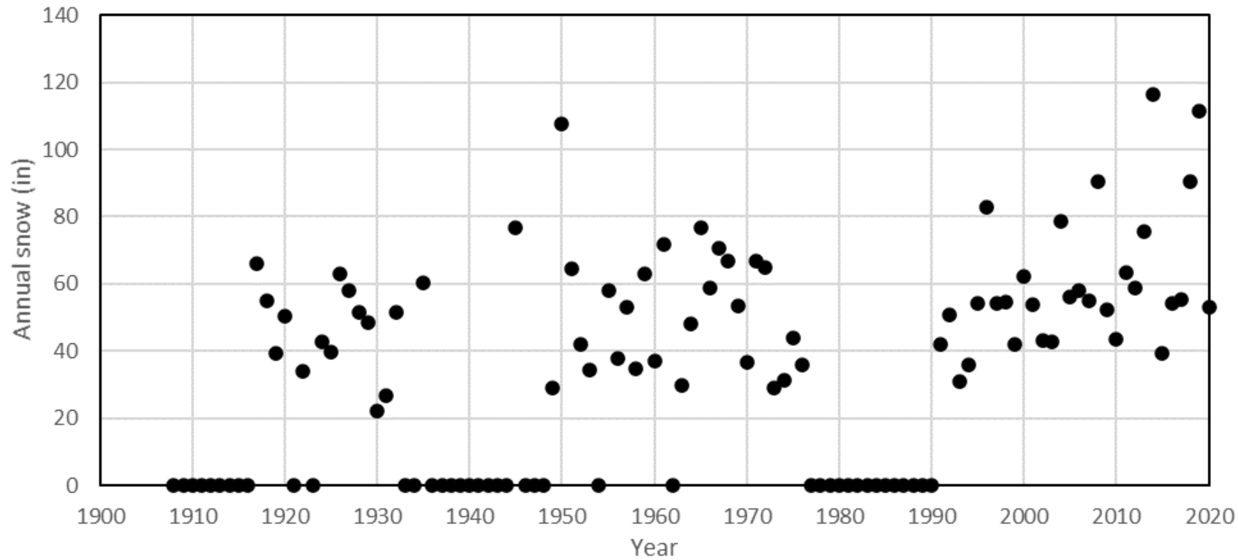
EST. 2019
FISH CREEK
RESTORATION

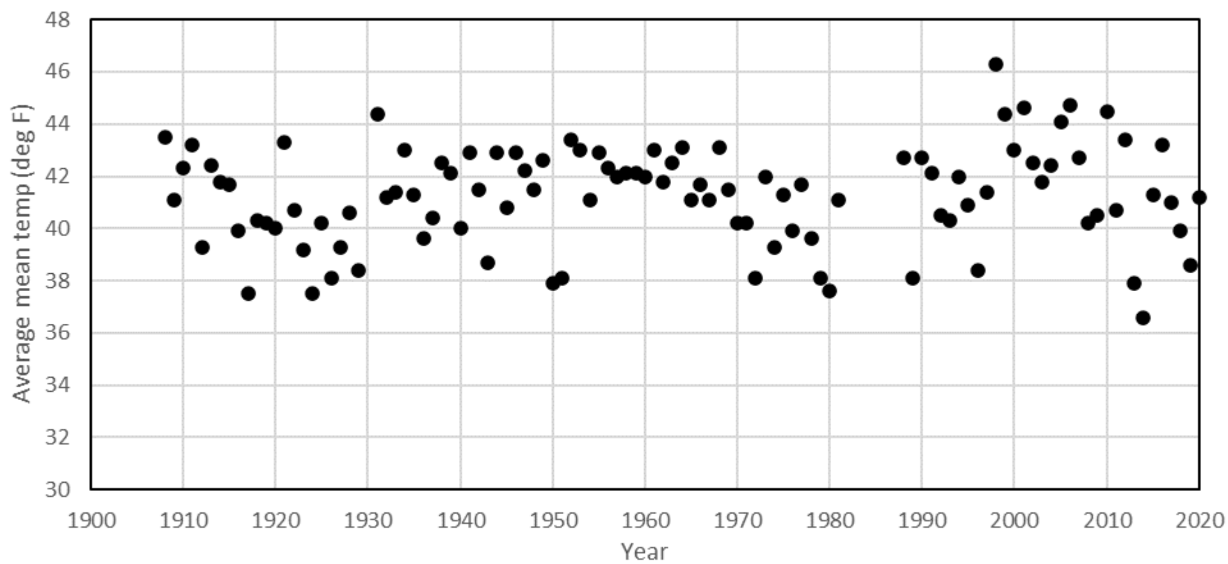


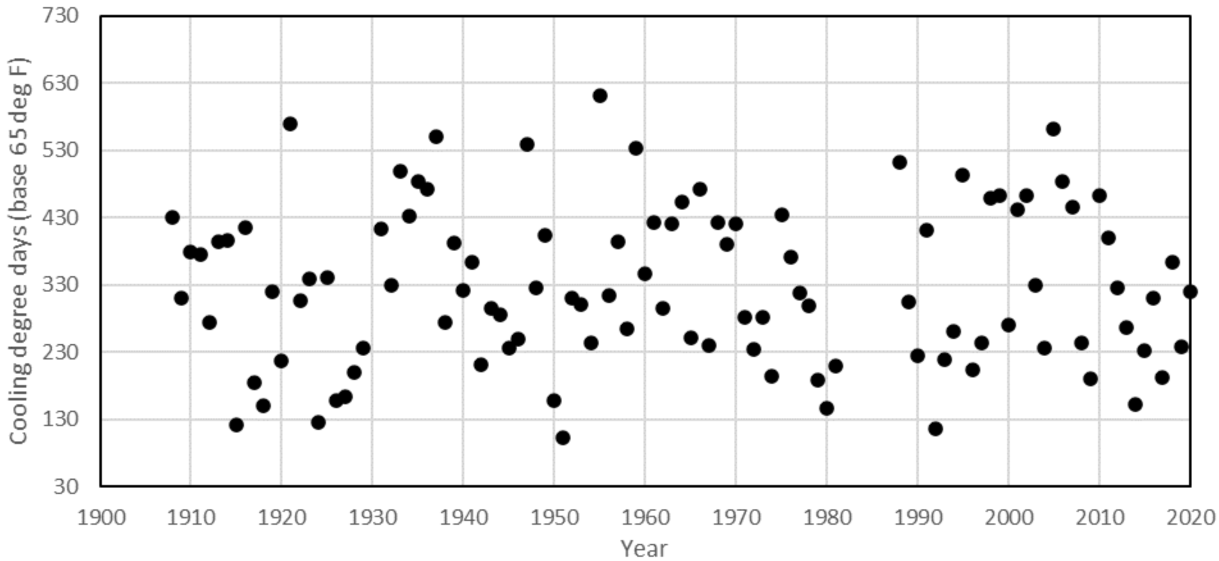
EST. 2019
FISH CREEK
RESTORATION LLC

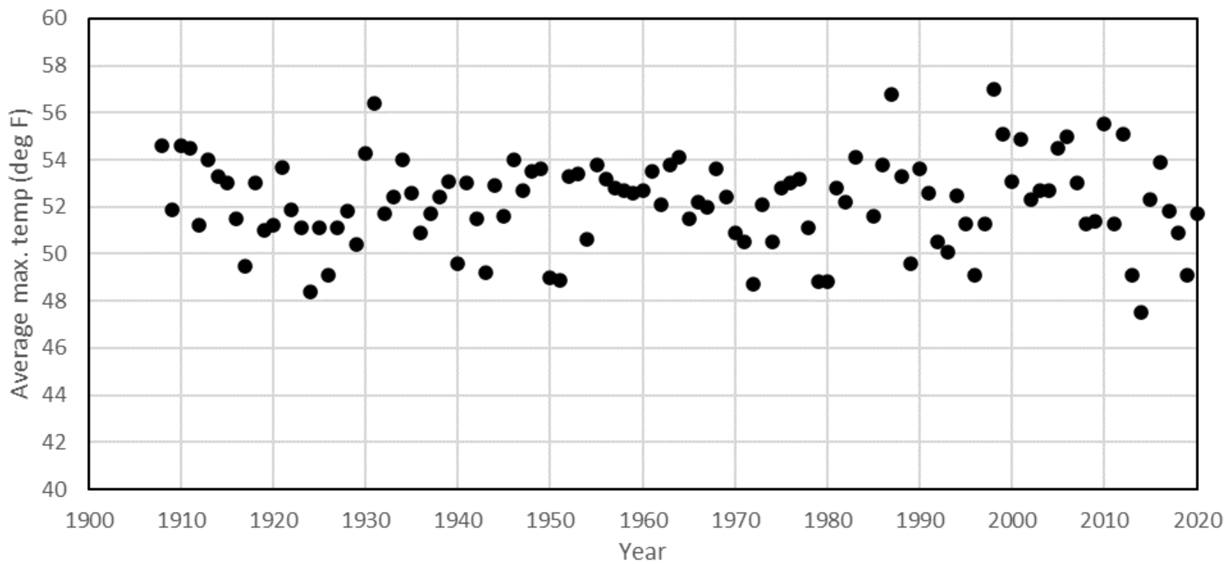
Appendix D: Climate Data

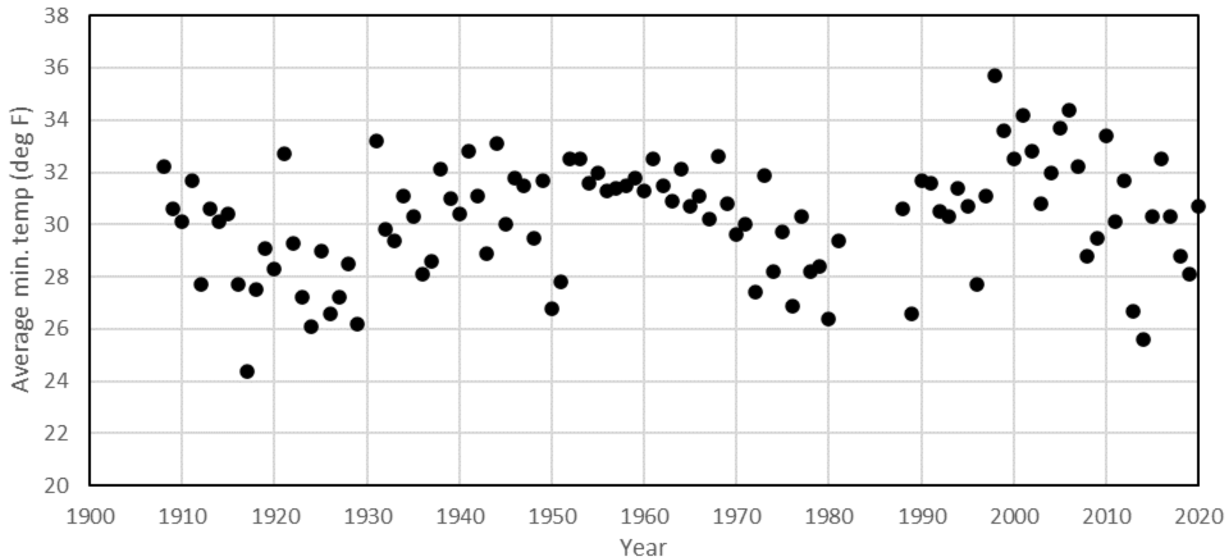


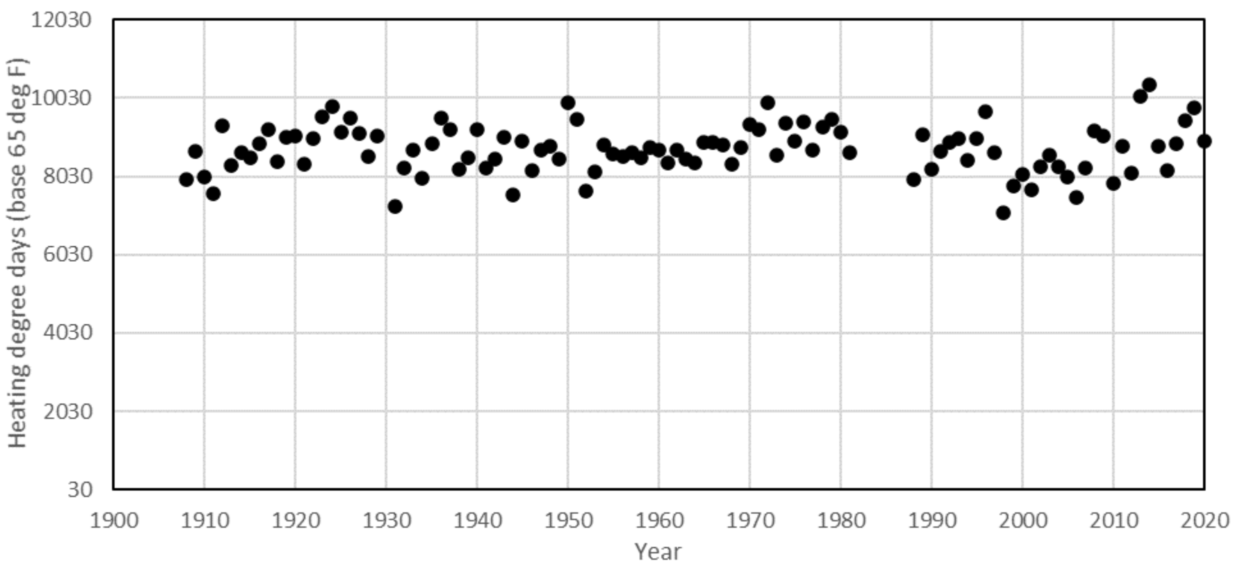

140
120
100
80
60
40
20
0
Annual snow (in)
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

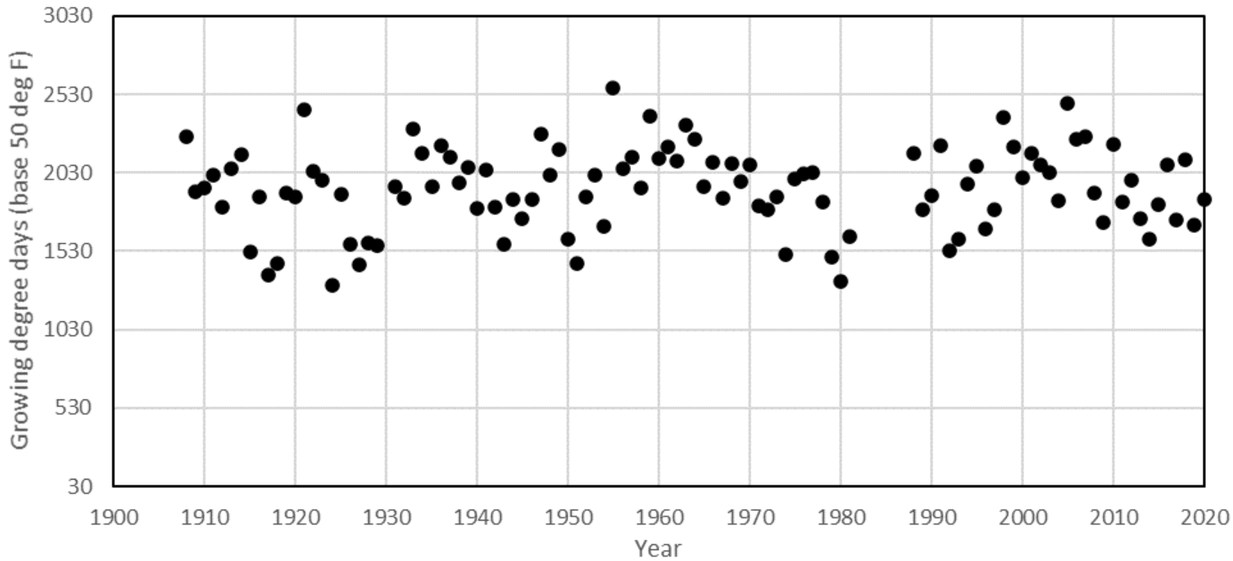

48
46
44
42
40
38
36
34
32
30
Average mean temp (deg F)
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

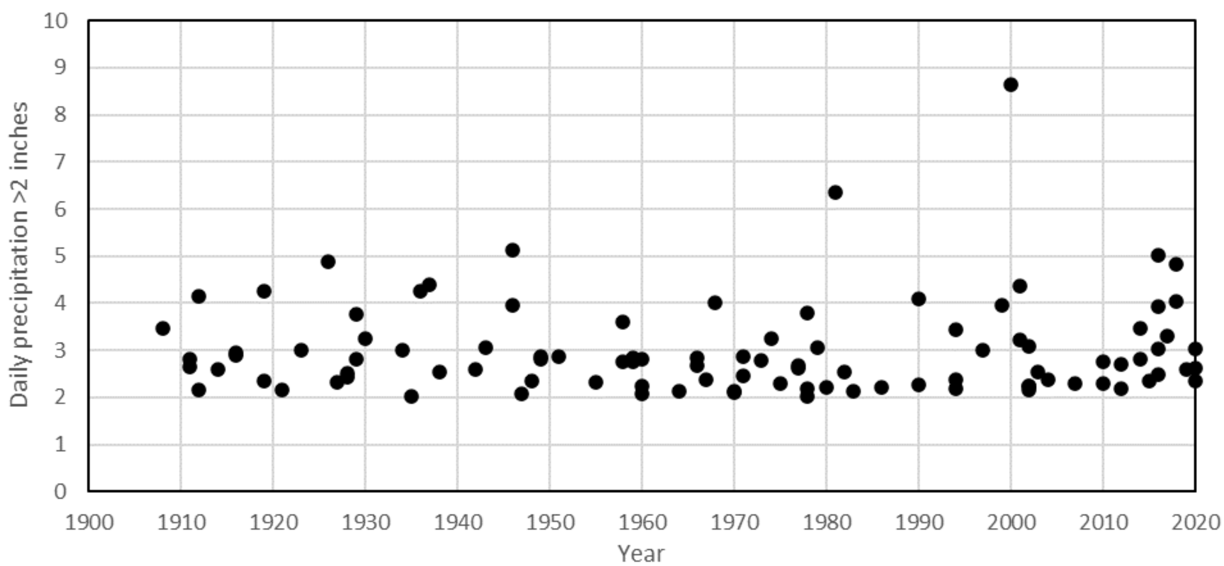

Cooling degree days (base 65 deg F)
730
630
530
430
330
230
130
30
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

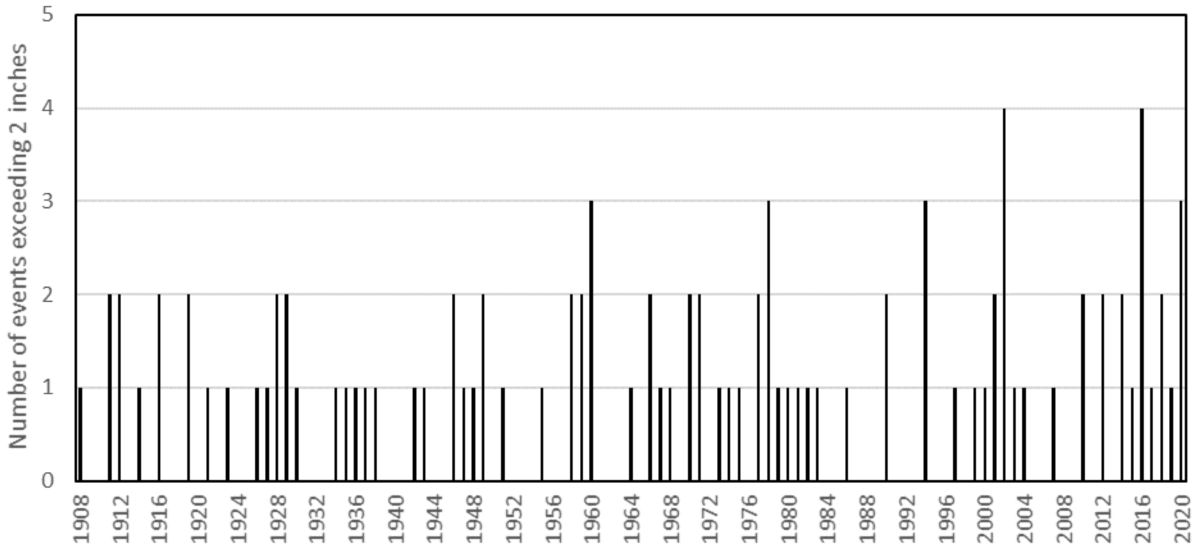

Average max. temp (deg F)
60
58
56
54
52
50
48
46
44
42
40
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

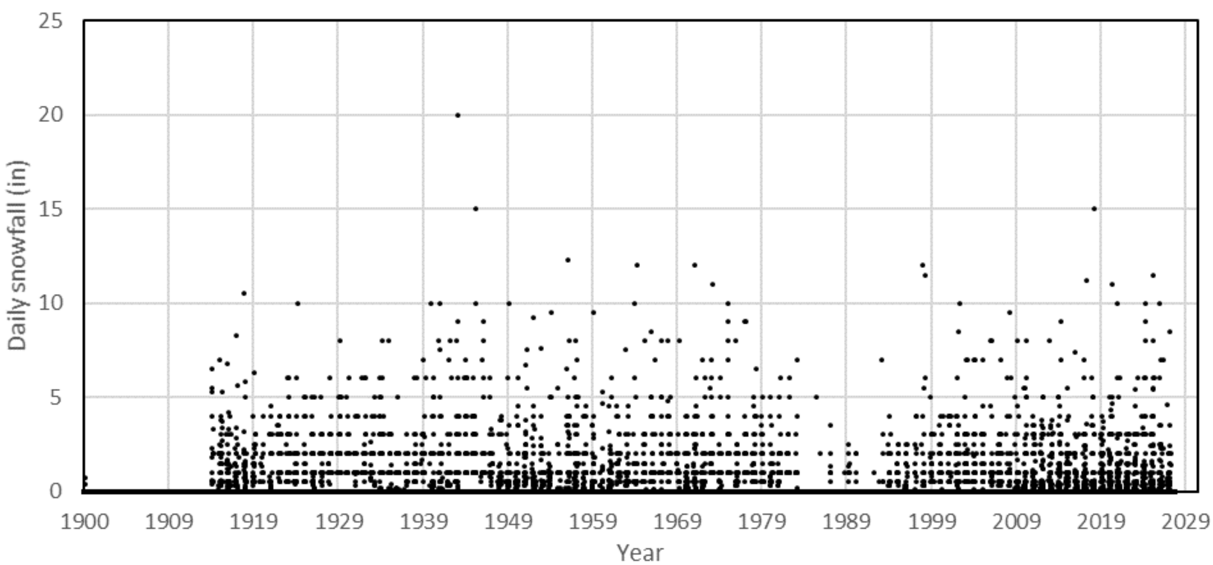

Average min. temp (deg F)
Year
38
36
34
32
30
28
26
24
22
20
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

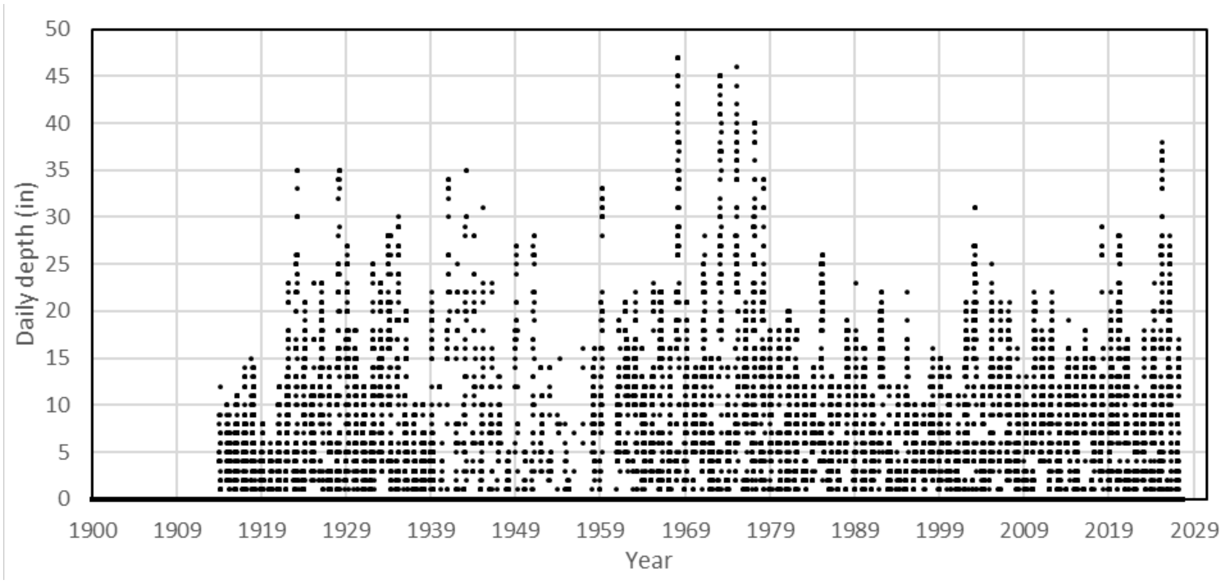

Heating degree days (base 65 deg F)
Year
12030
10030
8030
6030
4030
2030
30
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

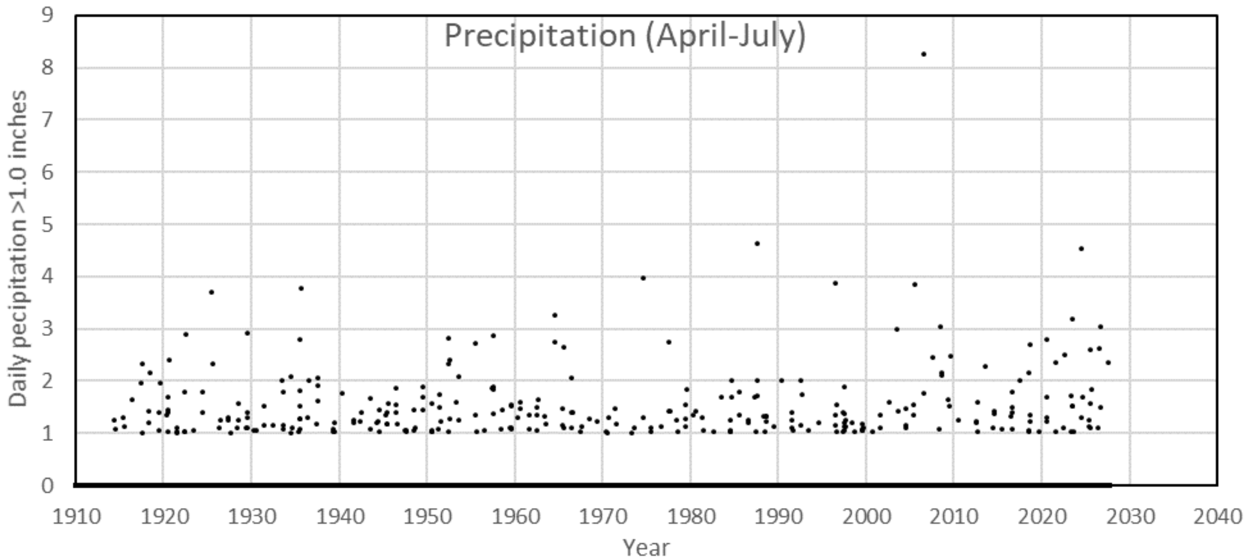

3030
2530
2030
1530
1030
530
30
Growing degree days (base 50 deg F)
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Year


10
9
8
7
6
5
4
3
2
1
0
Daily precipitation >2 inches
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Year


Number of events exceeding 2 inches
0
1
2
3
4
5
1908
1912
1916
1920
1924
1928
1932
1936
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020


Daily snowfall (in)
0
5
10
15
20
25
1900
1909
1919
1929
1939
1949
1959
1969
1979
1989
1999
2009
2019
2029
Year


Daily depth (in)
50
45
40
35
30
25
20
15
10
5
0
1900
1909
1919
1929
1939
1949
1959
1969
1979
1989
1999
2009
2019
2029
Year


Precipitation (April-July)
Daily pecipitation >1.0 inches
9
8
7
6
5
4
3
2
1
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
Year