JD2 and Miller Bay Project Team

Meeting Agenda

Monday, November 16th, 2026 | 9:00 a.m. to noon
Sauk River Watershed District Office
642 Lincoln Road, Sauk Centre, MN 56378

Meeting Preparation: Review agenda and packet.

Time	Agenda Item	Lead	Action
9:00	**Introductions, and Agenda Approval & Agenda additions**.	SRWD	Decision
9:05	**Previous Meeting Notes** Review and approve the October 19th, 2026 meeting notes.	SRWD/Steve	Decision
9:10	**SRWD Judicial Ditch 2 Sediment Basin Technical Review** • Design, Performance, Cost, & Monitoring methodology.	Moore Eng, Abigail	Discussion
10:00	**Osakis Alternatives Analysis Exercise Results** Review rating distributions, unsure responses, top-three priorities, and member comments. Clarify measures using Table 1 on page 14 and Sections 4–7 of the USACE PAS report.	SRWD/Steve	Information & Decision
11:00	**Open Discussion, Adjournment**	All	Informational

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JD2 and Miller Bay Project Team Meeting Minutes

October 19, 2026 | 9:00a- noon

Sauk River Watershed District Office, 642 Lincoln Road, Sauk Centre, MN 56378

Attendees: Steve Zeece III, Allison Pfingsten, Abi Borgerding, Susan Capitola, Bruce Magnus, Garrett Monson, Shane Finck, Emily Siira, and Troy Bednarz.

Call to Order and Prior Meeting Notes

- Steve Zeece III called the meeting to order shortly after 9:00 a.m. Introductions were completed; no agenda changes were requested.

Osakis Outlet Modification

- Construction remains planned for 2027; permitting is ongoing.

Crooked Lake Wetland Restoration and Branch 3 MS103E Petition

- The September 28 public hearing was recessed. It resumes December 30, 2026, at 1:00 p.m. at the Douglas County Public Works Building. Rinke Noonan will provide SRWD legal representation.
- The project primarily provides temporary water storage and flood reduction, with habitat and water-quality benefits. It is not designed as a sedimentation pond.
- Discussed a preliminary $5,000 annual budget for staff time and outlet operation. The proposed plan is for the landowner to maintain the basin & vegetation; while SRWD inspects and maintains project infrastructure. The O&M plan has yet to be finalized.
- The grant is reimbursement-based, with an original expiration of June 30, 2027. An extension may be possible.

SRWD Sediment Ponds Water Quality (TSS &Turbidity) Monitoring Methodology

- Discussion around previous and current SRWD monitoring methodology of JD2 including the County Road 3 monitoring station, JD2 pond surveys, and sediment-removal records.
- Additionally discussed were inconsistent flows, lake tailwater, and groundwater inputs complicating monitoring and downstream sediment daily and annual loading calculations/estimates.
- SRWD staff and engineer will consider practical monitoring methods.
- Douglas SWCD's Supervisor Rutten volunteered to grab turbidity tubes samples above and below the Sed ponds. No formal plan was achieved. Further discussion on this item should occur in November.

Lake Osakis Alternatives Ranking Exercise

- As of this meeting eight participants submitted responses. Additional responses were encouraged between the October and November meetings.
- Preliminary priorities: Septic compliance and monitoring ranked highest; shoreland ownership education was one point behind.
- Channel stabilization, public engagement, and outlet modification also ranked highly. JD2 pond expansion and stabilization ranked lowest.
- Osakis Lake Association septic-screening results were pending. Discussed county parcel and septic-system information, shoreland practices, and the Lake Stewardship Program as an education partner.
- Potential channel work includes the reach between Otter Tail Trail and County Road 85 and the steep reach toward the ponds. Drainage capacity and drainage-authority approvals remain important. Stabilization work was supported, with strong concerns around construction expressed.
- Funding and long-term maintenance costs remain unresolved. Stormwater stewardship, focused dredging, and wetland restoration remain under discussion.
- No formal actions were taken. The Committee advised to request and acquire more responses before moving into the next implementation actions.

Follow Up Items

- Steve/SRWD- Request additional ranking responses and update the tally for a future Project Team discussion and implementation actions
- SRWD Monitoring Staff and Moore engineering: Continue evaluating practical monitoring options for JD2 and SRWD Sediment Collection Basin.
- Project Team: Continue alternatives and feasibility discussions in November. Adjournment
- The meeting adjourned at approximately 10:50 a.m.

THE JOINT BOARD OF COUNTY COMMISSIONERS OF DOUGLAS AND TODD COUNTIES AS THE JOINT DRAINAGE AUTHORITY FOR DOUGLAS AND TODD COUNTY JUDICIAL DITCH #2

Findings of Fact and Order Acknowledging Placement of a Legal Obstruction in Judicial Ditch #2

FINDINGS OF FACT

1. The District Court established Judicial Ditch #2 by Order on January 22, 1909.

2. Construction of the ditch increased the watershed of Lake Osakis from 10 square miles to 53 square miles.

3. To ensure the efficient operation of Judicial Ditch #2 and to reduce the flood impacts on Lake Osakis, the Court established Judicial #2 over the outlet of the lake for a distance of approximately 1/4 mile downstream from the first highway bridge below the lake.

4. The original petition for establishment of Judicial Ditch #2 was for the purpose of draining Crooked, Grandlin, and Handford Lakes, and the low, wet and marshy land adjacent to those lakes and adjacent to Fairfield Creek. The petition stated that these lakes were normally shallow and grassy and of marshy characteristic, and that none were of a sufficient depth or volume to be capable of any beneficial public use.

5. The level of Lake Osakis at the time of construction of the ditch was 1,324.05 feet mean sea level (msl). The original engineering profiles show a plan bottom of the ditch at the point of the outlet into Lake Osakis at an elevation of 1,318.08 feet msl. The design of the grade of the ditch at the time of construction was based upon the assumption that the level in Lake Osakis would be lowered by 3 to 5 feet.

6. Beginning in about 1919, landowners on the lake began to complain of low lake levels and requested the construction of a dam at the outlet of the lake to help retain water in the lake.

7. In 1925 the State Department of Game & Fish investigated the lake. Their engineer's report found that Lake Osakis had been low for several seasons. The engineer identified the only bad effect of the low water was to create a wide sandy beach around the shores which interfered with the landing of boats and decreased the beauty of the lake from the shore.

8. The State's engineer specifically found that the channel of the Sauk River for approximately 1/4 mile below the lake shore road had been improved as a drainage ditch as part of Judicial Ditch #2. The report states that the Sauk River below the road was

straightened, widened and deepened between 1 and 2 feet with a 14 foot ditch bottom width.

9. On the date of the engineer's inspection, the lake was unaffected by the improved channel as there was no outflow from the lake through the channel. The improved outlet combined with successive drought years had promoted the reduced lake levels.

10. The engineer recognized that the outlet of the lake was part of a legally authorized drainage project that had been constructed for a number of years. The engineer further recognized that there was no known authority for obstructing a legally constructed drainage ditch for any purpose.

11. The engineer concluded that it might be possible to control in the outlet by mutual agreement with the court that established the ditch and with the consent of the interested landowners.

12. On May 5, 1931 the State's Department of Game & Fish issued an opinion that it was deemed inadvisable by the Department to proceed with any improvement on Lake Osakis or even to establish a water level until the status of the lake had been clarified by the district court. The Department recommended no action until all claims for damages were quieted in the courts.

13. On several occasions throughout the late 20s and early 30s landowners along Lake Osakis petitioned the State Game & Fish Department for a dam at the outlet of the lake (headwaters of the Little Sauk River) to retain water in Lake Osakis.

14. By the mid-1930s severe and prolonged drought in the region had left Lake Osakis with extremely low water levels. Various agencies were considering the construction of a diversion channel from the Long Prairie River to bring fresh water into Lake Osakis and a dam at the outlet of Lake Osakis to retain waters in the lake.

15. In 1938 the United States Engineer approved a project to construct a channel to divert water from the Long Prairie River into Lake Osakis. The project included a dam at the outlet of Lake Osakis. The project was to be constructed by the Works Progress Administration (WPA) to promote water conservation within the lake.

16. On September 6, 1938, the Todd County Board of Commissioners resolved that the Conservation Department of the State of Minnesota be given permission to construct a controlled dam within the State Aid Road #3 right-of-way, west of the double box culverts of the Sauk River in Lot 6, Section 16, Township 128, Range 38. The permission was granted in connection with the Lake Osakis diversion project that had been undertaken by the Corps of Engineers.

17. The state accepted the WPA dam constructed in the outlet of Lake Osakis on October 3,

1939. The structure was a stop log box with a crest elevation of approximately 1,321.5 feet msl.

18. In 1942 the state undertook to establish a natural ordinary high water (NOHW) level in Lake Osakis. The NOHW level of Lake Osakis was established at 1,323.20 feet msl. The state determined it should maintain a summer pool elevation of the lake of 1,321.74 feet msl.

19. No appeals were taken from the Commissioner's 1942 decision.

20. In 1951 a group of landowners farming land near Osakis brought a legal action against the state claiming that the state was maintaining a water level in Lake Osakis higher than that level ordered by the commissioner in his 1942 determination. The judge in the case ruled that the State Department of Conservation had not violated its 1942 Order and that the structure should remain at its current crest elevation, approximately 1321.5 feet msl.

21. Between 1955 and 1962 the state received several petitions to either raise or lower the level of Lake Osakis. In each instance the state adhered to the prior Order of the commissioner establishing a NOHW level and a summer pool elevation for the lake.

22. By 1964 the diversion channel from the Long Prairie River had been abandoned and the inlet structure blocked to prevent the movement of water and fish between the river and Lake Osakis. Though the diversion project had been abandoned, the dam in the outlet to Lake Osakis remained in place.

23. Throughout the late 1960s and 1970s both lake shore landowners and agricultural producers in the region inquired of the State regarding either raising or lowering the outlet structure.

24. In 1969 unknown individuals dynamited the structure causing minor damage that the State later repaired. The repairs to the structure resulted a cementing of the stop logs and a fixed crest structure with crest elevation of approximately 1321.5 feet msl.

25. On July 25, 1980, during proceedings to redetermine benefits on Judicial Ditch #2, Mr. Carroll Henning provided a memorandum to the Joint Drainage Authority stating:

> "Your Ditch Inspector, Clarence Sperling, and I have had a quick look at the original profiles of this ditch. As we interpret the plan profile, the bottom of the ditch at the outlet of Lake Osakis was 3.4' below the water level of the lake that year, 1914. . . . Since that time, a dam fixing the out flow elevation has been constructed at the outlet of Lake Osakis. . . . We believe that the benefit to some lands adjacent to the ditch have decreased because the seasonal high of Lake Osakis may be higher now than in 1914."

26. In 1989, the Todd County Board of Commissioner passed a resolution regarding the outlet structure. The resolution stated in whole:

> "WHEREAS, Lake Osakis has a low water level due to drought for the past several years; and
>
> WHEREAS, the outlet control structure to the Sauk River has not been in full use for several years; and
>
> WHEREAS, the Todd County Highway Department is preparing plans for the replacement of bridge #1913 on C.S.A.H. #37 which is an integral part of the present control structure; and
>
> WHEREAS, the Lake Osakis Resort Association, through the representative Mr. Roger Holder, w/Hoffman's Hideaway Resort has requested the Todd County Board of Commissioners to pass this resolution requesting the DNR to take the necessary steps to raise and maintain an adequate lake level, then now be it resolved that this Board requests the Department of Natural Resources to take the necessary action for a more permanent control structure for Lake Osakis along with an appropriate water level.
>
> Dated this 1st day of August, 1989
>
> //s// Robert Dorosh, Chairman
> //s// Mr. Joyce Rosenow, Auditor."

27. That same month the Douglas County Board of Commissioners passed the following resolution:

> "WHEREAS, many area lakes, including Lake Osakis, currently have low water levels due to drought conditions prevailing since the winter of 1986-1987; and
>
> WHEREAS, the Lake Osakis Resort Association, through their representative, Mr. Roger Holder/Hoffman's Hideaway Resort, has requested the Todd County Board of Commissioners and the Douglas County Board of Commissioners to pass a resolution requesting the Minnesota DNR to take steps necessary to raise and maintain an adequate lake level, and.
>
> WHEREAS, the Douglas County Board of Commissioners shares concern for declining lake levels, being also aware of the integral relationship of

changing lake levels and satisfactory operation of the systems of county ditches.

NOW, THEREFORE, LET IT BE RESOLVED, that the Douglas County Board of Commissioners does hereby support a request from the Minnesota Department of Natural Resources to conduct a study to determine an appropriate control water run out elevation for Lake Osakis. Be it further resolved, that any recommendation resulting from such a study will be compatible with the goals and objectives of the Sauk River Watershed District and also with the continued satisfactory operation of the county ditch system, specifically Douglas - Todd Joint Ditch #2 which discharges into Lake Osakis.

Dated in Alexandria, Minnesota, this 22nd day of August 1989.

BOARD OF COUNTY COMMISSIONERS
DOUGLAS COUNTY, MINNESOTA
//s// Bill Collins, Chairman
Attest:
//s// William J. Anderson, County Auditor"

28. In 1996 the Todd County Highway Engineer applied for a DNR Protected Waters Permit for the replacement of the box culverts under C.S.A.H. #37 and for the placement of a 23 foot long fixed crest concrete weir (the existing outlet control in Lake Osakis).

29. On April 8, 1996 the Department of Natural Resources issued Permit #96-3061 to the Todd County Highway Department to remove the existing two lines of 10' by 6' concrete box culvert and the associated 23' long fixed crest concrete weir and replace the structure with two lines of 12' by 7' concrete box culvert, including end sections with precast concrete weirs placed in each end section. Each weir shall have a fixed crest elevation of 1,321.52, consistent with the in-place condition. As constructed, the control structure has a crest elevation of 1,321.45 feet msl.

30. The crest elevation of the current structure generally corresponds to the summer pool elevation of 1,321.74 feet established by the Commissioner's 1942 Order.

31. The average surface elevation of Lake Osakis since installation of the original structure in 1939 is approximately 1322.20 feet msl.

32. Construction of the new structure in 1996 has not changed the average surface elevation.

33. Construction of the new structure in 1996 has not produced any new damages to properties on Judicial Ditch #2.

34. There is no evidence in the Ditch record to indicate that the court or the Joint Drainage Authority ever authorized placement of the original structure in the ditch.

35. The original structure was lawfully placed in a cooperative effort between the State and Federal governments, and Todd and Douglas Counties.

36. The new structure was placed to replicate as closely as possible the function of the original structure.

37. Any damages resulting from the placement of the original structure in 1939 were either accounted for in the 1980-83 redetermination of benefits on Judicial Ditch #2, or have been waived by the passage of 60 years time.

38. The Joint Drainage Authority is authorized by Minnesota Statutes Sections 103E.011 and 103E.015 to allow the construction or placement of dams, structures, and improvements to impound and release flood water to prevent damage, to conserve soil, water, forests, wild animals, and related natural resources, or to protect other public interests. The drainage authority must consider whether its actions will be of public utility, benefit, or welfare.

39. The Joint Drainage Authority finds that the original structure was lawfully placed in Judicial Ditch #2 and therefor makes the following:

ORDER

1. The Joint Drainage Authority recognizes the lawful placement of an obstruction on the channel of Judicial Ditch #2.

2. The obstruction as it exists today is the 23 foot long fixed crest weir constructed onto the twin 12 by 7 foot box culverts placed by Todd County under C.S.A.H. #37 in Southwest Quarter of Section 16, Township 128 North, Range 35 West, Todd County, Minnesota.

3. The crest elevation of the structure is recognized at 1321.45 feet msl.

4. The records of Judicial Ditch #2 shall be amended to reflect the existence of the obstruction and to reflect a legal grade of the ditch at the structure of 1321.45 feet msl.

5. The viewers, currently conducting the redetermination of benefits on Judicial Ditch #2, shall consider the existence of the structure when determining benefits and shall complete their viewing with all haste.

6. The engineer, currently evaluating the petitioned repair of Judicial Ditch #2, shall

consider the existence of the structure when preparing his repair report and shall complete his report with all haste.

Dated this 6th day of March, 2000.

Gerald Tomfohr
Chairperson, Joint Drainage Authority

The foregoing Findings of Fact and Order were made by the Joint Board of County Commissioners of Douglas and Todd County, as Joint Drainage Authority for Judicial Ditch #2, at a public hearing held March 6, 2000, at 9:30 a.m. in the Douglas County Public Works Center, Alexandria, Minnesota.

Filed this 9th day of March, 2000.

County Auditor, Douglas County

MEMO

To: Board of Managers

From: Abigail Borgerding, Environmental Monitoring Manager

Re: Monitoring of Judicial Ditch 2 System and Sediment Ponds

Date: September 9, 2026

During the past several Judicial Ditch 2 (JD2) Project Team meetings and during SRWD board meetings, there have been more questions about the current and past monitoring on the JD2 system and the sediment retention ponds. This memo is meant to clarify and synthesize what monitoring has been attempted in the past and the current status. Intensive monitoring on the JD2 system began in 2016 with 3 sites (CR73, CR3, and the Mouth at County Hwy 10). A Crooked Lake Area Monitoring Plan was put together in 2017. By 2018, there were 5 monitoring sites along the JD2 system, each with varying success. A table below outlines why each site was abandoned. The table also mentions the sediment pond inlet and outlet, which have not been monitored since 2009.

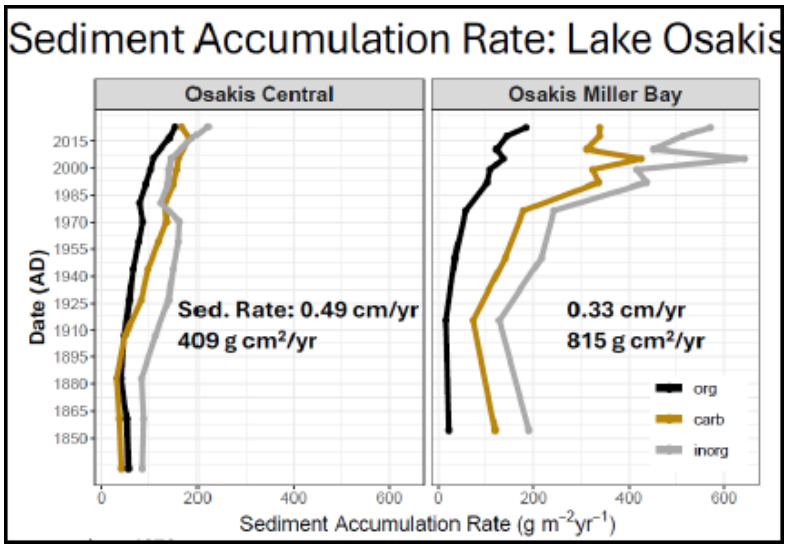
Site Name	Last Monitored	Challenges that Prohibited Usable Data
JD2@CR82	2018	Extreme sediment fluctuation, required a lot of shifting in data analysis, time intensive to monitor and analyze.
JD2@Hope Road	1997	Too much flooding influencing data collection.
JD2@CR73-2 (near CR74 intersection)	2018	Low flow/shallow site, captured downstream at CR3.
JD2@CR73	2018	Review of data indicates poor site conditions due to stagnate water and large amounts of vegetation buildup, data unreliable.
JD2@CR3	2021	Currently monitored for samples and flows.
JD2@CR85	2016 (sonde only), 2013	Difficult to capture flows due to depth.
Sediment Pond Inlet	2009	Access issues, no cross section for flows.
Sediment Pond Outlet	2009	Access issues, no cross section for flows.
JD2Mouth (CR10)	2018	Backwater influence from lake, large amounts of vegetation and sediment interference with equipment, dangerous parking, data quality poor.
Lake Osakis Outlet (CR37)	2021	Currently monitored for samples and flows.

This table was taken from the January 2022 JD2 Project Team meeting presentation that Sarah Jo Boser put together. Monitoring is still ongoing at the CR3 site because it is downstream of much of the system and is not as influenced by the tailwater effect from Lake Osakis. However, it is still not an ideal site for flow conditions since there is often stagnant water and excessive vegetation growth.

During early Project Team meetings, there was much discussion about challenges to monitoring on JD2 and what could be done as an alternative. Since the SRWD had been tracking sediment accumulation in the retention ponds with sonar equipment, it was suggested to collect sediment core samples in the ponds and at Miller Bay. As the SRWD started coordinating with the US Army Corps of Engineers (USACE) for the Alternatives Analysis study, it was decided to include the Miller Bay core samples with the rest of the study, along with sediment cores in central Lake Osakis, to determine the current sediment conditions

of the lake. The answer to determining the impact of the retention ponds and the JD2 system itself on Lake Osakis are largely found in the results of the Alternatives Analysis, along with the Sediment Ponds Efficacy Review conducted by Moore Engineering.

Sediment cores were collected in Miller Bay and a central location on Lake Osakis by the St. Croix Watershed Research Station as part of the Alternatives Analysis study through the USACE. The Central site showed a gradual increase in sedimentation. After 1970, the sediment increasingly consisted of carbonates and **organic** material, which points to in-lake productivity. At Miller Bay, the sedimentation rate has been increasing more rapidly since 1900. The sediment increasingly consisted of **inorganic** materials, meaning it was derived from the watershed, not in-lake sources. There was then a sharp drop in accumulation in the 2010s. For context, the ponds were constructed from around 2003-2005. A graph is included that displays the accumulation rates at each site and the make-up of the material.



As stated in the Moore Engineering Sediment Ponds Efficacy Review presented by Garrett Monson, the sedimentation rate in Miller Bay has dropped during the 2011-2023 time period compared to past accumulation rates. From 1976-1992, the increase per year was **0.0025**, while from 2011-2023, it had reduced to **0.0017**. The reduction was found to be around 30%, which is similar to the load reduction calculated when the ponds were cleaned out in 2019.

For the Sediment Ponds Efficacy Review, there were 2 sediment core samples collected in the primary pond in February 2026. It was found that the sediment was high in P flux, which could indicate internal loading from the bottom sediments. The core samples were dominated by iron-bound phosphorus, meaning under anoxic (no oxygen) conditions, there is potential of phosphorus being released by anaerobic bacteria metabolizing the attached iron. However, it was also found that the organic content was very low at both sampling sites, which suggests that the deposited sediment was likely primarily inorganic clays, resulting in the dense hard-pan like texture.

To determine the current oxygen conditions in the ponds, SRWD staff have started taking dissolved oxygen (DO) readings in the ponds during each site inspection. DO readings are taken at the inlets and outlets of both the primary and secondary ponds. This will provide a baseline of DO levels and whether the ponds do indeed become anoxic or not. If anoxic conditions are found to be a problem, a potential solution would be an alum treatment, which may reduce the possibility of the ponds becoming a source of phosphorus under those conditions. One consideration would be how to dispose of materials removed from the ponds after they have undergone an alum treatment.

From: Garrett Monson
To: Jon Roeschlein
Cc: Abigail Borgerding; Steve Zeece III; Allison Schugel; Scott Wittkop
Subject: JD 2 Sed Pond Sampling
Date: Wednesday, October 28, 2026 12:11:34 PM
Attachments: image.png
image.png

Jon,

I want to circle back on something that came up through the recent JD 2 Project Team meeting and Board Meeting. It sounds like members of the project team and public are requesting monitoring upstream and downstream of the JD 2 Sed Ponds. The majority of conversation to date has been around this not being consistent with the District's monitoring plan due to previous failed attempts to establish monitoring sites in this vicinity. The more recent conversations have brought clarity to the request for "grab samples."

A few notes about the general discussion:

- Regarding long term monitoring in the JD 2 Sed Pond vicinity - this is an impractical area to evaluate long-term monitoring data due to the occurrence of backwater flow from Lake Osakis up JD 2 due to the shallow ditch grades and fluctuating lake elevations.
- Regarding "grab samples" - while technically possible, special care needs to be given to ensure they are captured during positive flow conditions when water is flowing from the ditch into the lake and when a meaningful amount of the flow is diverting into the sed ponds (i.e. not large events that a majority of the flow bypasses the sed ponds).
- Also regarding "grab samples" it is important to know what type of sample is being taken and its limitations.
    - T-tubes - these are focused on measuring turbidity of the water which is then used as an analogue for TSS and sediment loading. There is no evaluation of nutrients.
    - Bottle/Jar samples - can be used for turbidity and/or nutrient sampling when properly collected. These require more skill and cost.

From the most recent conversations it sounds like members of the public are wanting sediment and nutrient monitoring. Additionally, members of the public are willing to volunteer to collect t-tube samples. I think volunteer sampling is a great approach, but just want to make sure SRWD is effectively communicating:

1. proper sampling technique and timing, and
2. the limitations of t-tubes (they do not monitor nutrients).

For additional context, due to the channel having flow go both ways, sampling becomes much more difficult to evaluate. So while I support gathering data, I think close documentation of context at the time of collection and reviewing the data in the larger context will be important.

Thanks,
Garrett

Sedimentation rate study of Lake Osakis and Faille Lake

Adam J. Heathcote

St. Croix Watershed Research Station
Science Museum of Minnesota
16910 152nd St N
Marine on St. Croix, MN 55047
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Final Report submitted to:
Bruce Magnus
Osakis Lake Association

Recommended citation: Heathcote, A.J. 2025. Sedimentation rate study of Lake Osakis and Faille Lake. Final report submitted to the Osakis Lake Association. St. Croix Watershed Research Station, Science Museum of Minnesota, Marine on St. Croix, Minnesota, 55047

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a Vistal company

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55447
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Memorandum

Date: 7/21/2026

Prepared By: Quentin Scott, PE
Garrett Monson, PE

Project: Judicial Ditch 2 Sediment Ponds Efficacy Review

Prepared For: Sauk River Watershed District

Narrative:

The Judicial Ditch 2 Sedimentation Ponds (JD 2 Sed Ponds) have been in operation for 20 years. During that time, the ponds have been cleaned out multiple times, reconstructed, and modified. During recent discussions of the factors affecting sediment loading in downstream Lake Osakis, the public and other partners expressed curiosity about the efficacy of the JD 2 Sed Ponds. The Sauk River Watershed District (SRWD) hired Moore Engineering, Inc. (Moore) to review the past clean-out of the ponds, complete sediment core sampling within the ponds, and the review overall sediment and nutrient removal of the ponds.

Background

The JD2 Sed Ponds are located in the northern half of Section 6, Gordon Township, Todd County, Minnesota. These ponds serve a drainage area of approximately 26,000 acres, predominantly agricultural land, and were designed to mitigate sediment runoff into Osakis Lake. The original construction occurred during the winter of 2002-2003. However, following embankment failure during a significant rain event, the ponds were reconstructed in the winter of 2004-2005. As-built drawings were not completed following the 2004-2005 project. However, the ponds were cleaned out in 2019 to the original bottom based on the sediment/virgin material interface. Following the 2019 project, as-built drawings were completed, which are assumed to reflect the original design plans of the 2004-2005 project.

There is a primary pond, 0.75 acre footprint, and a secondary pond,10 acre footprint. The primary pond is intended to collect larger sediments and debris while the secondary pond was designed to settle finer sediment particles. Water flows from JD2 into the primary pond, then to the secondary pond, and then is discharged to back to JD2 through an outlet in the southeast corner of the secondary pond. The outlet at this location is a 48-inch CMP, which was installed after the 2019 cleanout. The original outlet, located in the southwest corner, was also a 48-inch CMP but was replaced due to failure.

Past Cleanout

Based on calculations taken after the JD2 ponds were cleaned out in 2019, 17,600 cubic yards of sediment were removed. Of the 17,600 cubic yards, there was an estimated 13,736 pounds of phosphorus removed in 2019. On average the ponds annually removed 1,057 pounds of phosphorus

between their reconstruction in 2005 and the cleanout in 2019. The TMDL for Lake Osakis requires a reduction of 3,330 pounds of phosphorus per year, which means the JD2 ponds account for roughly 32% of the TMDL reduction amount. The cost of the cleanout, excluding SRWD time, was $512,819.56 for construction and $61,660.96 for engineering for a total of $574,480.52. The cost per cubic yard of sediment was $32.64 and $41.82 per pound of phosphorus removed, with an annual cost of $2.51 sediment removal and $3.22 per pound of phosphorus, see the table below. This is an extremely cost effective method of removing phosphorus as the typical cost can be hundreds to thousands of dollars per pound.

	Unit Cost for Removal	Annual Cost
TSS (CY)	$ 32.64	$ 2.51
TP (LB)	$ 41.82	$ 3.22

Table 1: Removal Cost

Current Conditions

Since 2019 SRWD staff have been conducting annual sonar surveys of the JD 2 ponds. Sonar data has varied throughout the years, with some years showing little to no accumulation, but based on the data captured in the Spring of 2026, the ponds have a volume proportional to pre-cleanout levels. Based on the volume removed in 2019 it is assumed that the pond has an average annual removal of 1,354 cubic yards of sediment from JD2. Based on that rate, the expected 2026 volume was 8,123 cubic yards and the Spring 2026 sonar data showed the JD2 ponds currently have 7,235 cubic yards of accumulated sediment, so less than expected but within the error of the sonar's measurement.

Sediment samples were also collected in February of 2026 and tested for diffusive P Flux under both oxic and anoxic conditions. The samples were tested by University of Wisconsin-Stout and showed the sediment within the ponds had relatively high P fluxes. While it is not believed that the JD2 ponds are a constant source of phosphorus, there may be conditions in which phosphorus is leached from the ponds. The sediment was dominated by iron-bound P, which means under anoxic conditions there may be potential of the phosphorus being released by anaerobic bacteria metabolizing the iron binding the phosphorus.

Sediment Delivery to Lake Osakis

JD2 drains approximately 45% of Lake Osakis' watershed. A sedimentation study was conducted by the St. Croix Watershed Research Station within Lake Osakis, with one monitoring location within Miller Bay, which includes the outlet of JD2. The study dated the sediment within Lake Osakis to determine the sediment mass accumulation rate from 1855 to present day. The study noted that sedimentation was relatively stable until 1900 when it began increasing, and between 1976 and 1992 there was a sharp increase in sedimentation. Then in 2004 there was a large rain and flooding event that skewed the data, but post 2004 to present while sediment was still depositing, the rate in which it was increasing had decreased. See the table below for the sedimentation rates.

Years	Sediment Mass Accumulation	Increase per Year
1854	0.0332	0.0001
1950	0.0391	
1976	0.0478	0.0025
1992	0.0877	
2011	0.0886	0.0017
2023	0.1094	

Table 2: Increases in Sediment Mass Accumulation

The JD2 ponds were constructed and reconstructed between 2003 and 2005, and the sedimentation rate post 2005 has dropped when compared to the 1976-1992 window. The decrease is also around a 30% reduction, which is similar to the load reduction calculated when the ponds were cleaned in 2019.

Recommendation

Based on the volume and cost of sediment and phosphorus removed in 2019, the current volume of sediment within the ponds, and the reduced increase of sedimentation rates within Lake Osakis, the JD2 ponds are recommended to stay functioning as-is. The ponds should continue to be monitored and have sediment removed when necessary, as detailed in the operations and maintenance plan. Based on the findings of the 2026 inspection, periodic dredging of the JD2 ponds has been shown to be a cost effective method of preventing the discharge of sediment and phosphorus to Lake Osakis.

Furthermore, there may be other practices or BMPs that could help further reduce the sediment load from JD2 to Lake Osakis. The US Army Corps of Engineers conducted the Lake Osakis Sediment Analysis and Comprehensive Plan, in which they recommend adding storage and restoring wetlands. Maintaining the JD2 ponds is consistent with that recommendation.

Finally, another recommendation would be to explore alum treatment of the JD2 pond. While alum treatment can have variable effects when applied in open waters, the JD2 ponds are a separate system where alum is less likely to track downstream. Alum treatment may reduce the likelihood that the JD2 ponds become a source of phosphorus under anaerobiotic conditions, which would increase the removal efficiency of the JD2 system, and potentially further increase the cost effectiveness of sediment and phosphorus removal.

Attachments

1. Examination of Sediment in JD2 Sediment Ponds Report

Examination of sediment characteristics and diffusive phosphorus fluxes in the JD2 sedimentation pond, Lake Osakis, MN

5 April 2026

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SUMMARY

1. Diffusive phosphorus (P) fluxes from sediment (at 20 C) collected in JD2 sedimentation pond were relatively high under both oxic and anoxic conditions, ranging between 1.7 and 2.3 mg/m^2 d (oxic diffusive P flux) and 8.0 and 13.1 mg/m^2 d (anoxic conditions). These rates were also high relative to some other lake sediments in the region, falling near or above the 75% quartile.
2. Sediment in the upper 10-cm layer exhibited very low moisture content, high wet density, and low organic content, suggesting fine clay-dominated and compacted sediment texture.
3. Mobile (i.e., subject to recycling and internal loading) P fractions in the upper 10-cm sediment layer were dominated by iron-bound P. Concentrations of loosely-bound P, iron-bound P, and labile organic P were modest when compared to some other lakes in the region. However, mobile P mass (i.e., as g or g/m^2) was high due to the high density of sediments in the pond.

1.0 PURPOSE.

The objectives of this research were to evaluate sediment chemistry and diffusive P flux under both oxic (i.e., oxygenated) and anoxic conditions in the JD2 sedimentation pond, which traps sediment from the Crooked Lake Ditch before it flows into Miller Bay, Lake Osakis, MN (Fig. 1). Specifically:

1. quantify rates of oxic and anoxic diffusive P flux at 2 stations in the sedimentation ponds and
2. examine sediment physical-textural characteristics and mobile P fractions in the 0-5-cm and 5-10-cm sediment layer at each station.

2.0. APPROACH

Sediment coring stations

Sediment coring stations are shown in Figure 2. Two intact sediment cores were collected at each station for determination of rates of P release under oxic and anoxic conditions. An additional sediment core was collected at each station to examine sediment physical-textural and chemical characteristics.

A gravity sediment coring device (Aquatic Research Instruments, Hope ID) equipped with an acrylic core liner (6.5-cm ID and 50-cm length) was used to collect sediment in late February 2026. The core liners, containing both sediment and overlying water, were immediately sealed using rubber stoppers and stored in a covered container in a cool location until analysis. Additional lake water was collected for incubation with the collected sediment. Sediment cores were sectioned and processed within 24 hours of collection.

Laboratory-derived rates of P release from sediment under oxic and anoxic conditions

In the laboratory, sediment cores were carefully drained of overlying water and the upper 10 cm of sediment transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from each lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature of 20 C. The oxidation-reduction environment in the overlying water was controlled by gently bubbling air (oxic or aerobic) or nitrogen (anoxic or anaerobic) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 μm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2011). Rates of P release from the sediment (mg/m^2 d) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Evaluation of sediment chemistry

An additional sediment core collected at each station was sectioned over the 0- to 5-cm and 5- to 10-cm intervals for analysis of the variables listed in Table 1.

Table 1. Textural-physical variables and biologically labile sediment phosphorus pools.

Moisture content (%)
Sediment wet and dry bulk density (g/cm^3)
Organic matter content (%)
Loosely-bound P (mg/g)
Iron-bound P (mg/g)
Labile organic P (mg/g)
Aluminum-bound P (mg/g)

Subsamples were dried at 105 °C to a constant weight and burned at 550 °C for determination of moisture content, sediment density, and organic matter content (Avnimelech et al. 2001, Håkanson and Jensson 2002). Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (1 M NH_4Cl; loosely-bound P), bicarbonate-dithionite-extractable P (0.11 M BD; iron-bound P), and sodium hydroxide-extractable P (0.1 N NaOH; aluminum-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P.

3.0. RESULTS AND INTERPRETATION

Sediment diffusive phosphorus flux

Soluble P concentrations and P mass (i.e., mg/L x L of water in the incubation system) increased linearly in the overlying water column of sediment incubation systems under both oxic and anoxic conditions (Fig. 3, *please note y-axis scale differences between oxic and anoxic conditions*). Soluble reactive P concentration increases were much greater under anoxic conditions versus oxic conditions. At the end of the incubation period, soluble P concentrations were relatively high, ranging between 0.79 mg/L (St 1) and 0.434 mg/L (St 2) under anoxic conditions and 0.147 mg/L (St 1) and 0.088 mg/L (St 2) under oxic conditions (Fig. 3).

This pattern difference between oxic and anoxic conditions is typical and related to iron-phosphorus chemistry. Under oxic conditions at the sediment-water interface, iron is in the oxidized Fe^{3+} state as Fe~OOH (i.e. iron oxyhydroxide) and binds P, limiting its release into the water column. Under anoxic conditions, anaerobic bacteria reduce iron the Fe^{2+} during metabolism, which breaks the bond between Fe and P, resulting in P release into the water column.

Rates of P flux under anoxic conditions were relatively high at both stations, indicative of eutrophic sediments (Table 2). Under anoxic conditions, anoxic diffusive P fluxes ranged between 8 and 13 mg/m^2 d. In particular, anoxic diffusive P fluxes for JD2 sediments fell above the median and exceeded the 75% quartile at St 1 compared to other lakes in the region (Fig. 4). Diffusive P fluxes were also relatively high under oxic conditions, ranging between 1.7 and

Table 2. Variations in diffusive phosphorus (P) flux under oxic and anoxic conditions in JD2.

Station	Diffusive P flux (mg/m^2 d)	
	Oxic	Anoxic
1	2.27	13.08
2	1.70	7.99

2.3 mg/m^2 d (Table 2). Oxic diffusive P fluxes for JD2 sediments fell above the 75% quartile compared to other lakes in the region (Fig. 4).

Sediment characteristics

Moisture content was less than 50% in the upper 5-cm sediment layer at each station and it declined in value in the deeper 5-10-cm section (Fig. 5). Sediment bulk density exhibited the opposite pattern; it was ~ 1.5 g/m^2 in the surface section and increased within the deeper section. Organic content was very low (i.e., < 10%) at both stations, ranging between 2.5% and 6.7%. These patterns suggested that sediment deposited in the pond was likely composed primarily of inorganic clays that were compacted, resulting in dense hard-pan like texture.

Table 3. Variations in sediment physical-textual characteristics and concentrations of loosely-bound phosphorus (P), iron-bound P, labile organic P, and aluminum-bound P in JD2 sediments.

Date	Station	Section		Moisture Content	Wet density	Dry Density	Organic Content	Loosely-bound P	Fe-bound P	Labile organic P	Al-bound P
		(cm)		(%)	(g/cm3)	(g/cm3)	(%)	(mg/g)	(mg/g)	(mg/g)	(mg/g)
2/4/2026	Hole 1	0	5	37.8	1.585	1.009	3.6	0.026	0.120	0.029	0.041
2/4/2026	Hole 1	5	10	19.8	1.927	1.592	2.5	0.016	0.055	0.003	0.019
2/4/2026	Hole 2	0	5	47.3	1.434	0.779	6.7	0.022	0.127	0.027	0.059
2/4/2026	Hole 2	5	10	37.9	1.565	1.003	5.5	0.016	0.149	0.008	0.084

Loosely-bound P and iron-bound P concentrations, fractions that are typically associated with internal P loading and diffusive P flux from sediment, were modest at both stations (Fig. 6). Loosely-bound P ranged between 0.016 mg/g and 0.026 mg/g while iron-bound P ranged between 0.055 mg/g and 0.149 mg/g (Table 3). These concentration ranges generally fell below the 25% quartile when compared to other lakes in the region (Fig. 7). However, the overall P mass (i.e. g/m^2) in the upper 10 cm sediment layer was high due to the high sediment density (Table 4).

Table 4. Area-based concentration of redox P (i.e., the sum of loosely-bound P and iron-bound P) in the upper 10-cm sediment layer at various stations in JD2 pond.

Station	Redox P (g/m^2)
1	12.7
2	13.7

Because the sediment stored in the pond was very dense with low organic content, labile organic P concentrations (i.e., P that can be mineralized via bacterial breakdown) were very low (Fig. 6). In addition, JD2 labile organic P concentrations were very low relative to concentrations observed in regional lakes (Fig. 7).

4.0. ACKNOWLEDGMENTS

Conor Dougherty and Andrew Schneyer, University of Wisconsin – Stout, are gratefully acknowledged for participating in the analysis of diffusive P flux and analysis of sediment characteristics. Analyses were conducted out of the University of Wisconsin – Stout, Center for Limnological Research and Rehabilitation.

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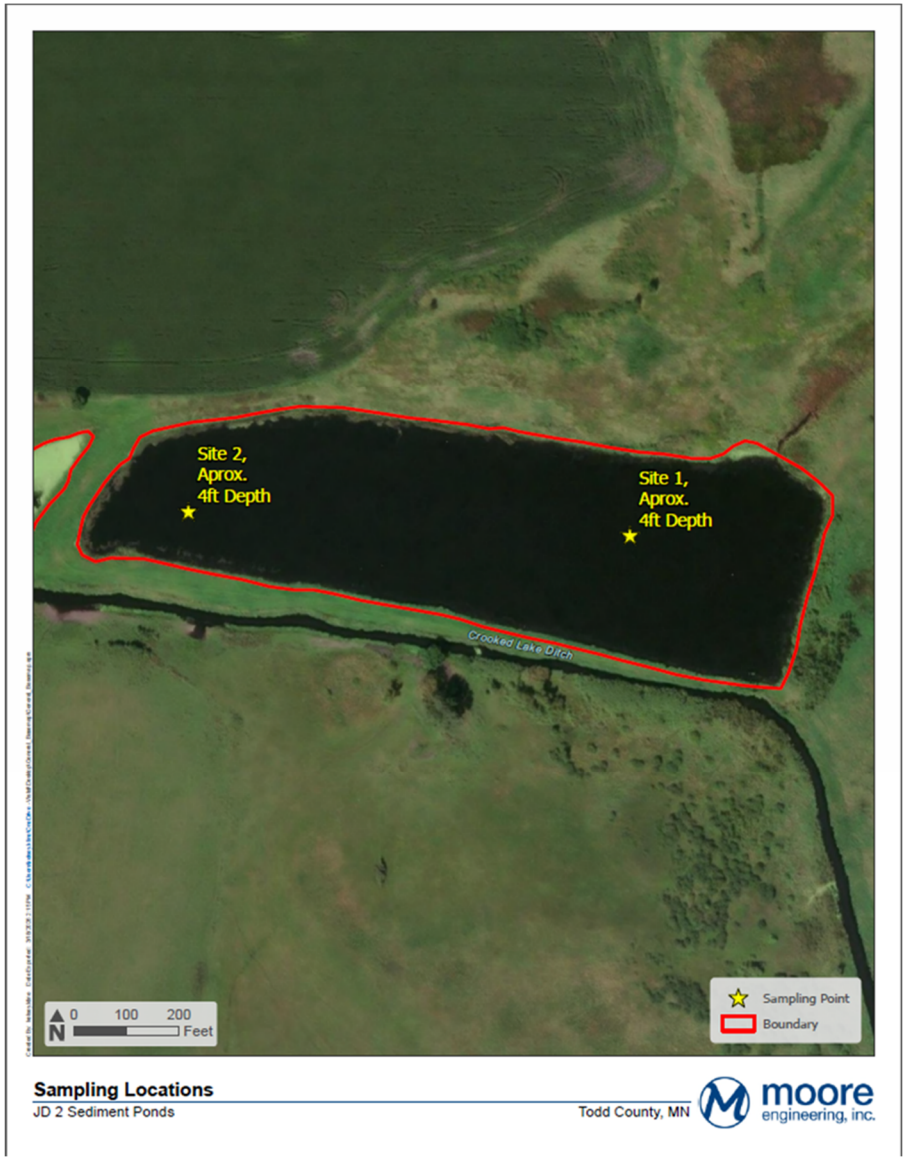
Psenner R, Puckso R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch Hydrobiol Biel Erg Limnol 30:43-59.



Figure 1. Location aerial phto (Google Maps) showing Lake Osakis, Miller Bay, and JD2 sedimentation pond.

Figure 2. JD2 sedimentation pond with sediment core sampling locations.



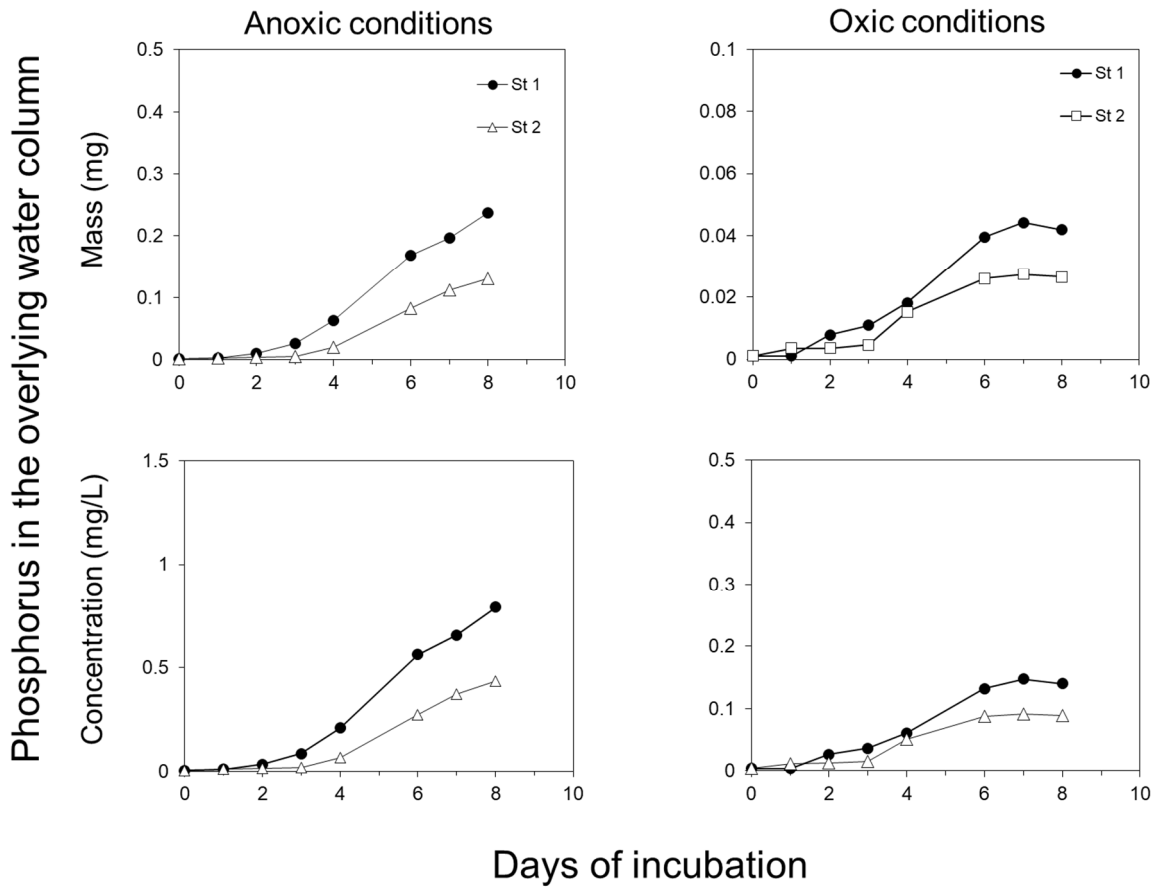


Figure 4. Changes in phosphorus mass (upper) and concentration (lower)in the overlying water column of sediment cores incubated under oxic and anoxic conditions.

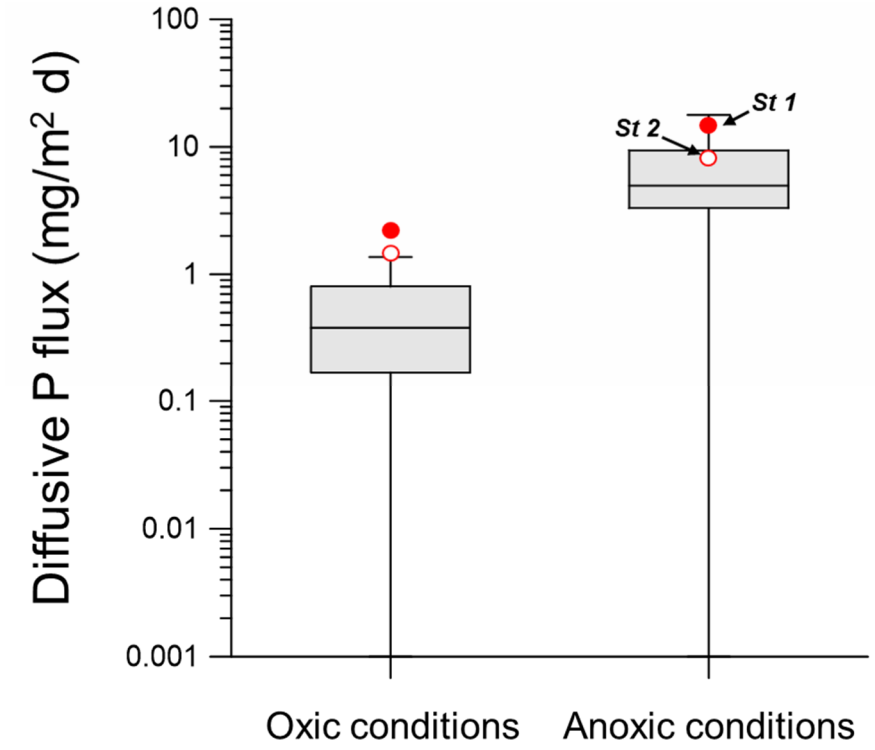
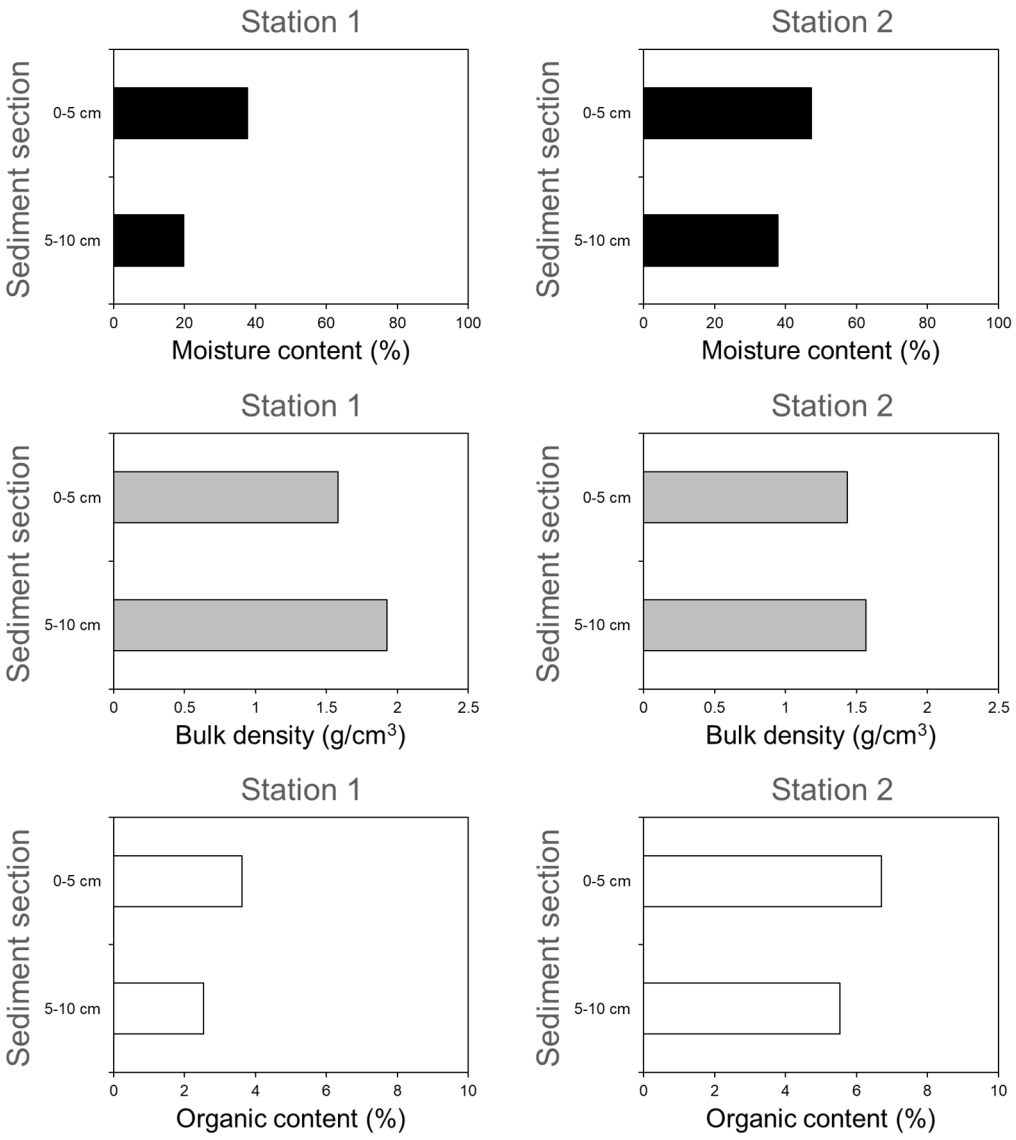


Figure 4. Box and whisker plots of oxic and anoxic P flux for JD2 versus other lakes in the MN-WI region.

Figure 5. Variations in moisture content (upper), sediment wet density (middle), and organic content (lower) in the 0-5-cm and 5-10-cm sediment layer for various stations in JD2.



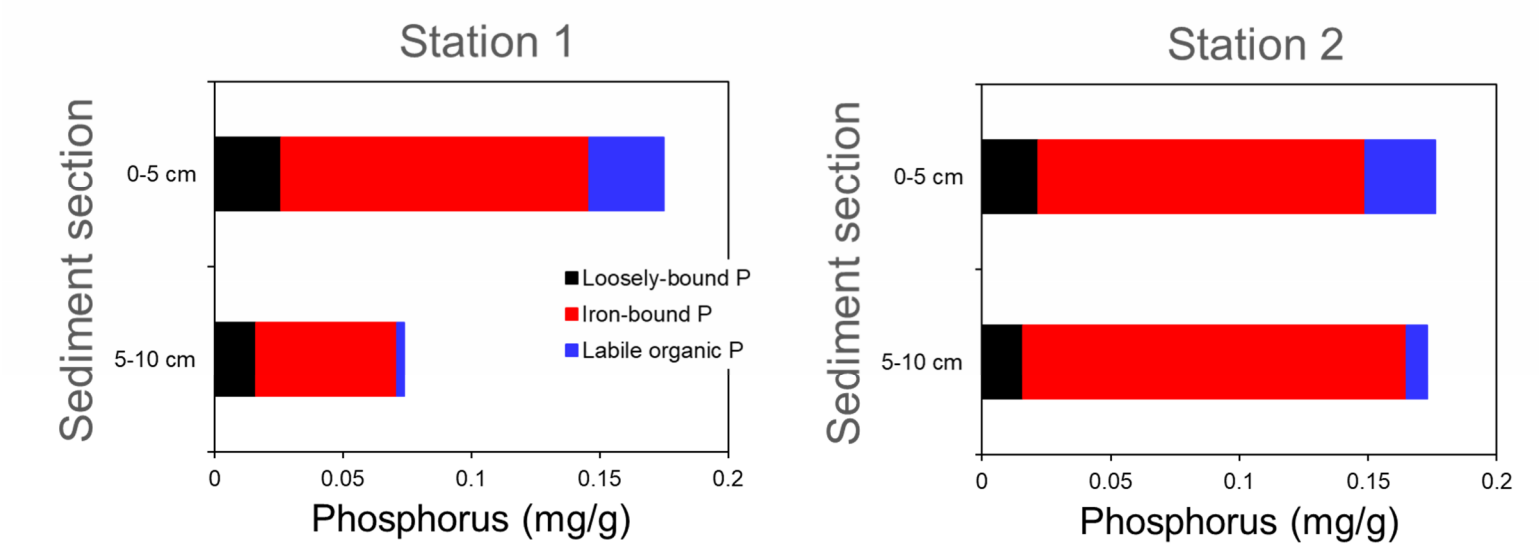


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Figure 6. Variations in loosely-bound phosphorus (P), iron-bound P, and labile organic P concentrations in the 0-5-cm and 5-10-cm sediment section at station 1 and 2, JD2 sedimentation pond.

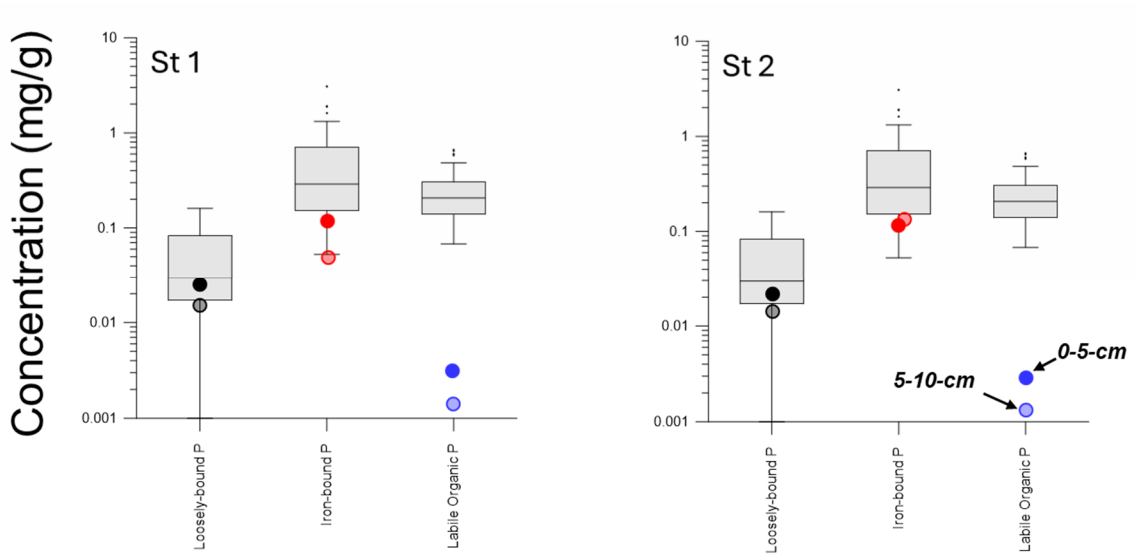

Figure 10. Box and whisker plots of loosely-bound phosphorus (P), iron-bound P, and labile organic P in the 0-5-cm and 5-10-cm sediment layer at station 1 and 2, JD2 sedimentation pond versus other lakes in the MN-WI region.

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SUMMARY

1. The Osakis Lake Association contracted with the St. Croix Watershed Research Station to estimate sedimentation rates at four sites of interest in Lake Osakis and nearby Faille Lake. Two sediment cores were collected from Lake Osakis at a central location and in Miller Bay and two were collected from Faille Lake in a backwater area and near the outlet on either side of Highway 27.

2. Cores were analyzed for sediment geochemistry via loss-on-ignition and radio-isotopically dated, if possible. The Faille Outlet core could not be dated likely due to the drying of the region, so sedimentation was estimated based on the cumulative dry mass and a basal date of the core determined from aerial imagery to be ca. 1938.

3. Central Osakis site has been slowly increasing in sedimentation since Euro-American settlement (pre-1900). After 1970 that sediment has been increasingly made of carbonates and organic material, indicating more in-lake productivity (algae and aquatic plants).

4. Miller Bay sedimentation has been increasing more rapidly than the Central Osakis site since 1900, and especially since ~1975. Sediment is increasingly inorganic, meaning it is derived from the watershed rather than in-lake sources. Carbonates and organics also increase, indicating some productivity, however correlation of carbonates with inorganics in Miller Bay could also point to chemical weathering from the watershed.

5. Both Faille Lake sites are primarily filling with sediments from the watershed, with some increasing in-lake production seen in the Faille Backwater core (algae and plants) after 1940. The Faille Outlet had the highest sedimentation rate across all four sites despite being a long-term average and the Faille Backwater was the second highest sedimentation site.

6. There is evidence of increased erosional deposition at Miller Bay relative to the rest of the lake supporting the possibility of a local source of sediment from the nearby tributary. This is especially evident after 1975 and also could explain the large spike seen in 2005. The Faille Lake outlet is another possible source of sediment to Lake Osakis as sedimentation rates near this site are high and appear to have increased in the latter part of the 20th century.

INTRODUCTION

Local stakeholders in the area surrounding Lake Osakis, collectively represented by the Osakis Lake Association, have concerns about the rates of sedimentation in the lake. This is especially the case in an area which receive significant inputs from a canalized tributary known as Judicial Ditch #2 where a portion of the flow runs through a series of constructed or otherwise manipulated sedimentation ponds on the west side of the lake into Miller Bay. Additionally, there is interest in better understanding the sedimentation rates in Faille Lake, a relatively small shallow lakes whose outlet runs into the south end of Lake Osakis but has been significantly re-engineered with the routing of Highway 27 in the late 1950's across the outlet.

With any lake management plan, it is important to have a basic understanding of natural fluctuations within the system. Reliable long-term data sets, on the order of 30 - 50 years, are generally not available for most regions of the country. Through the use of paleolimnological techniques we can estimate past conditions and natural variability, identify timing of ecological changes, and determine rates of change and recovery in lakes and wetlands. For this project, we have estimated the long-term (e.g., 100-year) sedimentation rates at multiple sites in both Lake Osakis and Faille Lake using radio-isotopically dated sediment cores and geochemical analyses. The results of this research will inform management goals for the Osakis Lake Association and their work to protect and preserve this valuable natural resource.

METHODS

Coring

Coring sites were selected based on guidance from the Osakis Lake Association, personnel from the Sauk River Watershed District, and analysis of bathymetric maps. Two sediment cores were collected from separate basins of Lake Osakis to understand the heterogeneity of sedimentation rates across the lake in relation to specific sites of possible sediment input (Figure 1). This included a site in Miller Bay as well as another more central location that would represent a more lake-wide average.

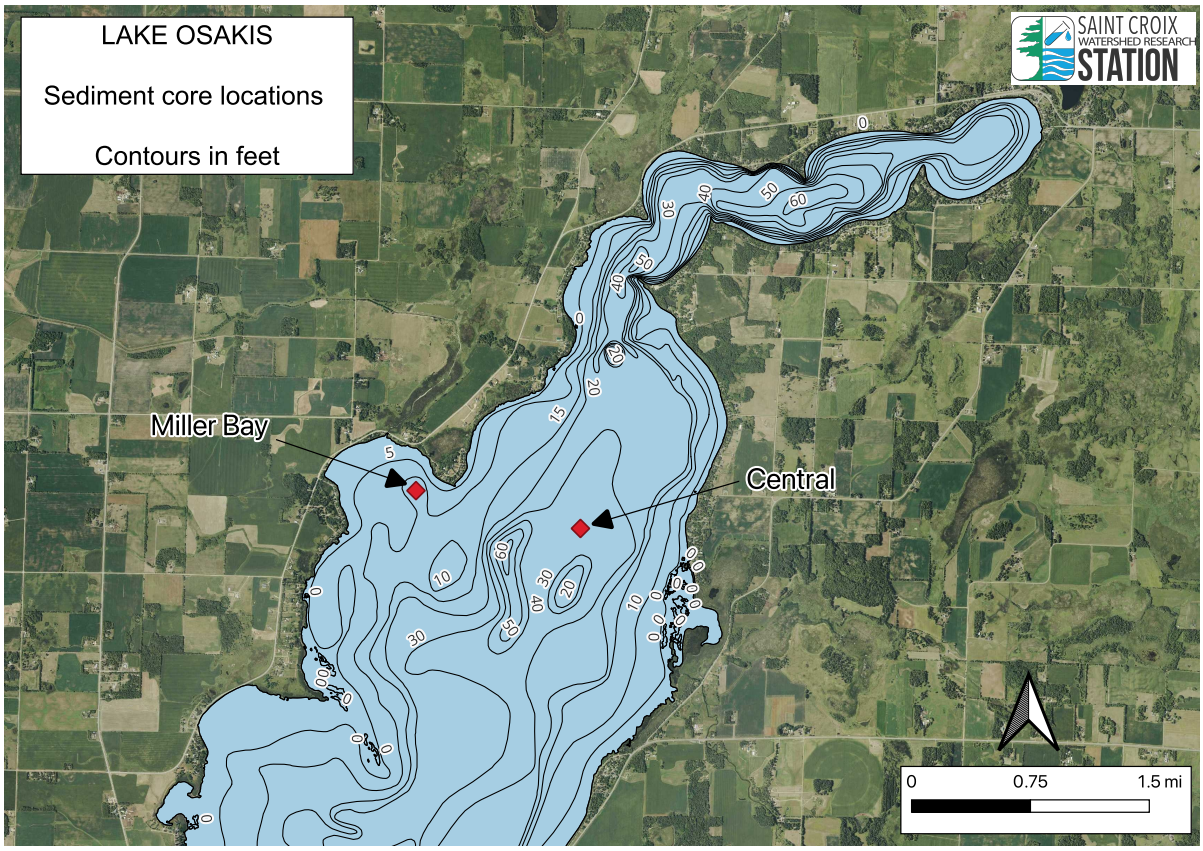

Figure 1 Map of coring locations (red diamonds) on Lake Osakis.

Two additional cores were collected from Faille Lake (Figure 2). The first core was collected in a shallow backwater area just south of Highway 27 and the other was collected on the north side of Highway 27 in a small, isolated arm of Faille Lake that was bisected by the highway and is now connected via a culvert under the road. Both areas were extremely shallow (< 3 feet in depth) and core sites were selected for maximum sediment thickness based on soft sediment probing while on site.

Each sediment core was retrieved using a modified piston-type corer (Wright Jr., 1991) with a 6.5-cm diameter polycarbonate core barrel, operated from the lake surface by Magnesium-alloy drive rods. Sediment cores were vertically extruded, sectioned at 1 cm increments, and stored in polypropylene jars for subsequent analyses at 4°C.



Figure 2 Map of coring locations (red diamonds) on Faille Lake.

Radioisotopic dating

Each sediment core was analyzed for ^{210}Pb activity to determine age and sediment accumulation rates for the past 150 to 200 years. The activity of ^{210}Pb was measured from its daughter product, ^{210}Po, which is considered to be in secular equilibrium with the parent isotope. Aliquots of freeze-dried sediment were spiked with a known quantity of ^{209}Po as an internal yield tracer and the isotopes distilled at 575°C after treatment with concentrated hydrochloric acid (HCl). Polonium isotopes were then directly plated onto silver planchets from a 0.5 N HCl solution. Activity was measured for 1-3 x 10^5 s using an Ortec alpha spectrometry system. Supported ^{210}Pb was estimated by mean activity in the lowest core samples and subtracted from upcore activity to calculate unsupported ^{210}Pb. Core dates and sedimentation rates were calculated using the constant rate of supply model (Appleby & Oldfield, 1978). Dating and sedimentation errors represented first-order propagation of counting uncertainty (Binford, 1990).

Geochemistry

Bulk-density (dry mass per volume of fresh sediment), water content, organic content, carbonates, and non-carbonate inorganic matter of each of the sediment intervals were determined by standard "loss-on-ignition" techniques (Dean Jr., 1974). Each of these components can inform us about watershed changes and internal limnological dynamics over time. Weighed sediment subsamples were dried at 105°C for ~16 hours to determine water content and dry bulk

density, then heated at 550°C and 1000°C, for 1 hour each, to calculate organic and carbonate content, respectively. These data were used in combination with ^{210}Pb dating to calculate sedimentation rates as dry mass accumulation rates (DMAR; g cm^{-2} yr^{-1}) for each core section and its sediment constituents.

RESULTS

Sediment core collection and sectioning

All sediment cores were successfully collected on July 16th, 2024. Core length varied between sites. The longest core was collected from the Lake Osakis Central site at 97 cm. The core from Miller Bay was 50cm and was truncated due to us hitting a layer of coarse gravel. The Faille Lake backwater and outlet cores were 46 and 32 cm long, respectively, and both were limited by a dense sandy layer at the bottom.

Dating and geochemistry

We constructed dating models using radioisotopes that allowed us to estimate the age of individual sediment intervals for three of the four sediment cores (Figure 3). We were unable to date the core from the Faille Lake outlet because the ^{210}Pb inventory was missing from the bottom of the core. This prompted further analyses of historic aerial imagery of the site which revealed that in addition to the re-engineering of the outlet, the shallow region closest to Lake Osakis had completely dried out during extreme drought conditions in Minnesota in the late 1930s (Figure 4). Using the confirmed date of drying from historic photography (ca. 1938), we instead interpolated the average dry mass accumulation rate by taking the total mass of sediment accumulated in the core from 1938 to present and estimated an average dry mass accumulation rate of 0.1115 g cm^{-2} yr^{-1} over that time. We then used the cumulative dry mass accumulation at each sediment slice to estimate the approximate age while assuming this average rate.

Loss on ignition results show the variability in the sediment composition of calcium carbonate minerals as well as inorganic and organic matter which indicate changes in watershed land use or in-lake primary productivity (Figure 5). To convert the relative proportion of each geochemical constituent to an annual flux, we multiplied the proportion by the dry mass accumulation rate of sediment at each section. These fluxes give us the temporal trajectory and absolute magnitude of the sedimentation rate of each type over time. In general, an increase in organic matter is often correlated to in-lake production in the form of phytoplankton or aquatic plants, although some portion of this can also be attributed to watershed inputs. Increases in inorganic matter are derived from terrigenous watershed inputs and are an indicator of increased erosional inputs. Carbonates are generally precipitated out of the water in areas with high alkalinity and can be a sign of increasing primary production by aquatic plants and phytoplankton as the uptake of dissolved CO_2 by photosynthesis increases lake pH and stimulates the formation of particulate $CaCO_3$. However, these carbonates may also be derived from chemical weathering of carbonate-rich rock and soils in the watershed, delivered as particulate or dissolved inorganic carbon from stream inputs.

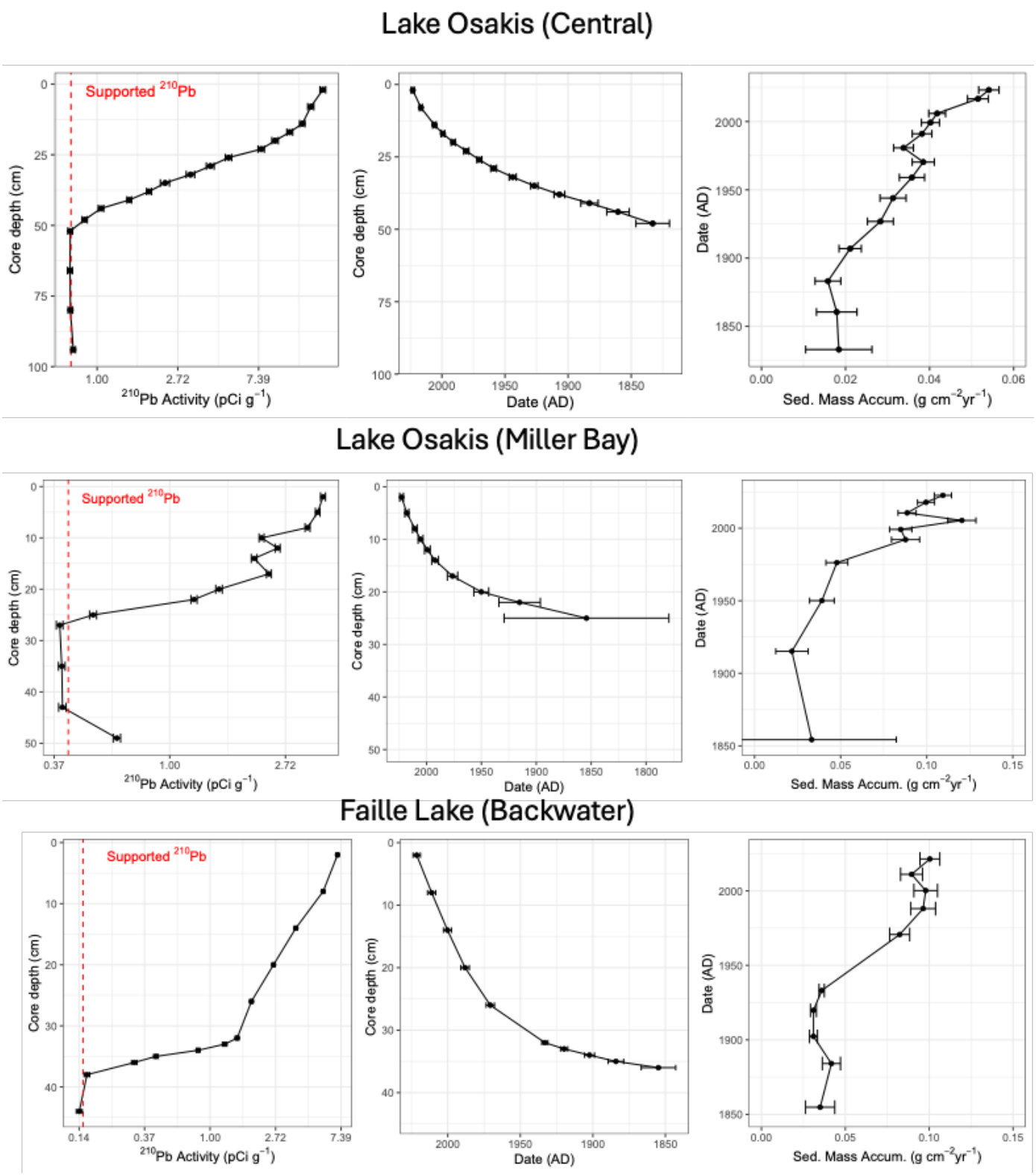

Figure 2 Lead-210 dating results for Lake Osakis Central, Miller Bay, and the Faille Lake Backwater cores. For each core, the right figure shows the ^{210}Pb activity vs core depth with the red-dashed line indicating when background (supported) ^{210}Pb was reached. The middle figure shows core depth vs date and the left most figure shows date vs the sediment mass accumulation rate. Error bars designate one standard deviation.

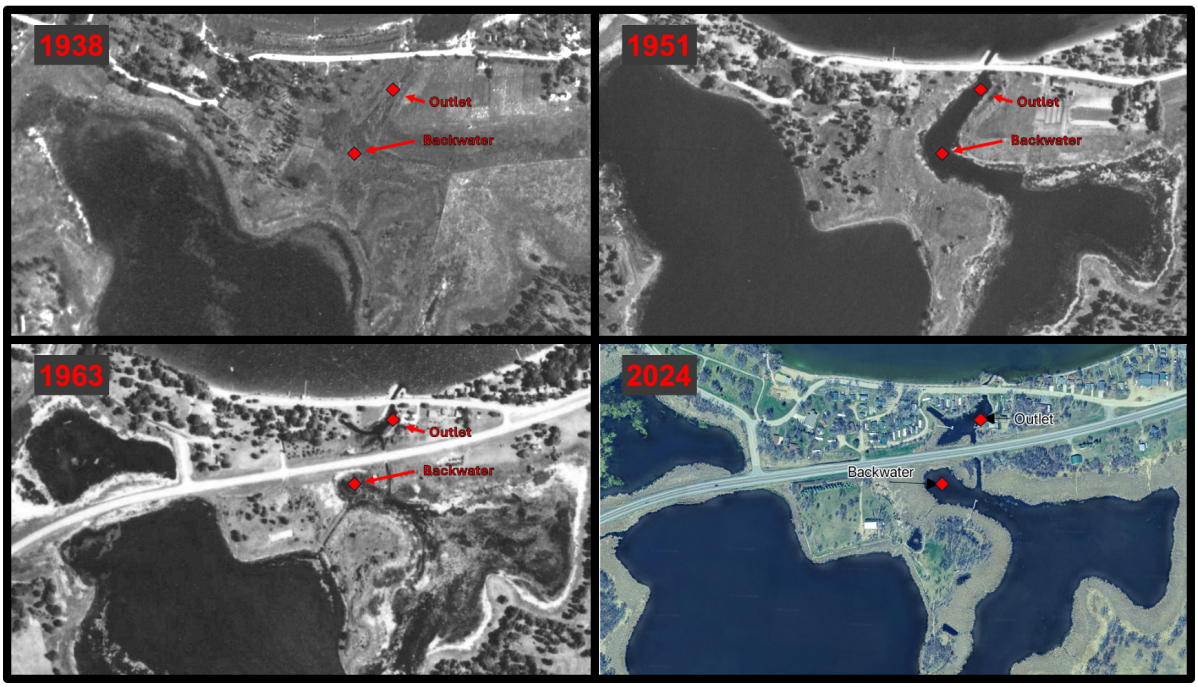

Figure 4 Historical aerial photography from Faille Lake showing the two core sites in 1938, 1951, 1963, and 2024 (the year of this study). Time series shows the drying of the lakebed in 1938 as well as the re-inundation by 1951 and the bisection of the outlet by Highway 27 in 1963. Photography was accessed from the University of Minnesota Historical Aerial Photography Online database (https://apps.lib.umn.edu/mhapo).

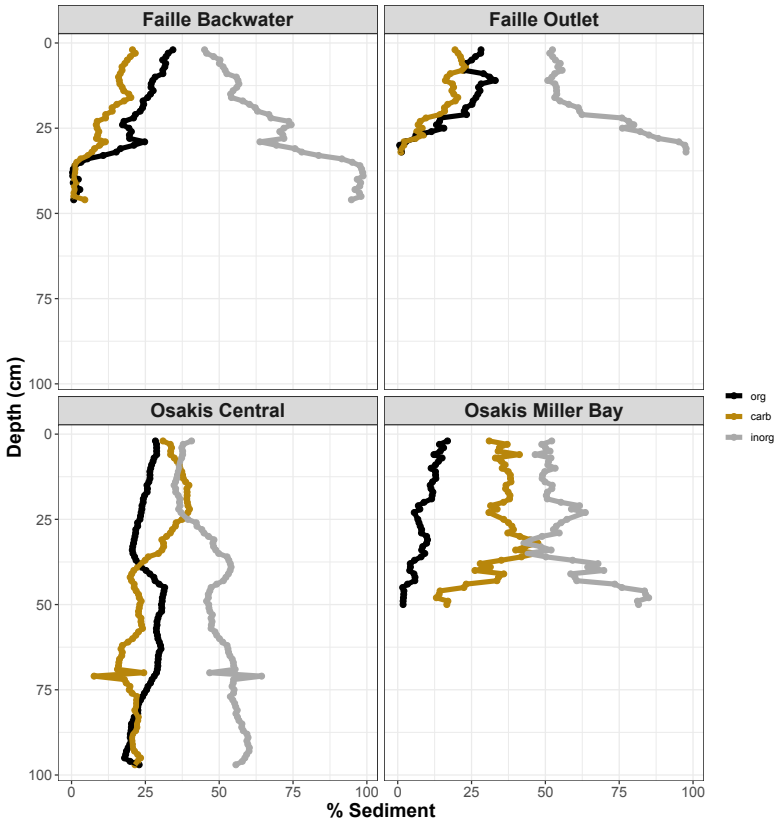

Figure 5 The percent of calcium carbonate (carb; yellow), inorganic matter (inorg; gray), and organic matter (org; black) in each section of all four sediment cores from this study.

Both cores from Faille Lake had nearly 100% inorganic matter at the bottom which corresponded to the dense sand layer (Figure 5). In both cores, this inorganic matter declined as the sand was mixed with more lacustrine like sediments which were up to 30% organic matter and 25% carbonates at the top of the core. This likely reflects increased productivity in the system by aquatic plants, with submerged aquatic vegetation being observed to cover most of the sediments in the backwater region during the coring excursion in July 2024.

Both Osakis cores also showed a majority of the sediments composed of inorganic matter at the bottom of the core. The Osakis Central core had a maximum inorganic fraction at the bottom of ~60%, however, this declined upcore with carbonates becoming the majority fraction at 25 cm before declining again towards the surface. The Miller Bay core had nearly 80% inorganic matter at the bottom, and similar to the Faille Lake sites, this was due to a dense sand layer. The proportion of inorganic matter declined upcore becoming nearly 50% carbonates at 35 cm before the inorganic fraction rebounded and once again became the dominant fraction. The rise in carbonates seen in both cores likely reflects increased primary production, and at least in the Central site, this would be attributed primarily to algal production given the water depth (~30 ft).

Sedimentation Rates

Sedimentation rates for each fraction were calculated for all cores. In the cores which were ^{210}Pb dated (Osakis Central, Miller Bay, Faille Backwater) this sedimentation rate is dynamic through time and reflects the dry mass accumulation rates calculated by the chronologic modeling. In Faille Outlet this dry mass accumulation rate is static and reflects an average from the drying event that we believe represents the basal sand layer at the bottom of this core.

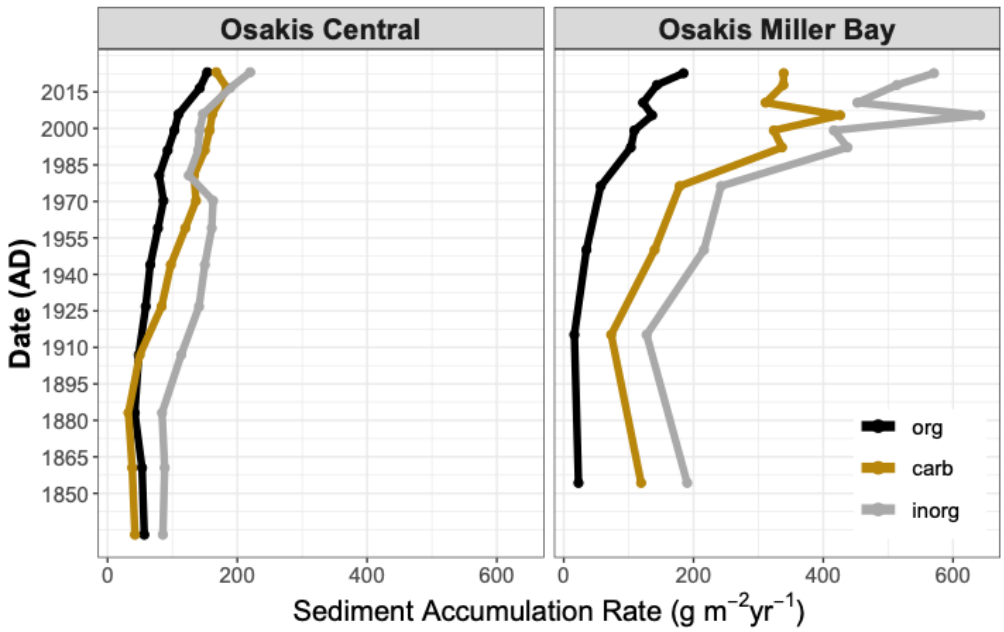

Figure 6 Sediment accumulation rates over time for the two Lake Osakis cores divided by sediment composition as calcium carbonate (carb; yellow), inorganic matter (inorg; gray), and organic matter (org; black).