Comparing Paleohydrograph Reconstructions from Topography and Subsurface Stratigraphy at the Sault Ste. Marie Strandplain

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Abstract:

The Great Lakes are currently at high water levels, which are negatively impacting coastal infrastructure, coastal ecosystems, and stakeholders that rely on the lakes. To better understand natural fluctuations which includes high lake levels geoscientists study ancient shorelines to reconstruct paleohydrographs. Reconstructing past lake-level elevations from a specific subsurface sedimentary contact or foreshore base (FSB) contact is the most accurate way to gain insight into ancient lake levels. The objective of this thesis is to establish an alternative method to use topographic elevations as a proxy for the FSB in the reconstruction of inferred paleohydrographs from the Sault Ste. Marie (SSM) strandplain. Light detection and ranging (LiDAR) data was used to obtain topographic elevations for this topographic reconstruction. Topographic elevations measured in the field were compared to LiDAR data and these topographic elevations were also compared to FSB elevations measured in cores. Elevation trends and patterns were statistically analyzed and visually analyzed in graph to justify that topographic elevations from LiDAR could be used as a proxy for the FSB or past lake level elevation, but so far this only applies to the SSM strandplain deposited during the Nipissing phase. The field measured topographic swale elevations could be used as an alternative to FSB elevations when a correction factor of 1.49 m was subtracted from each individual swale elevation. LiDAR data was then used to obtain one swale elevation for every beach ridge in the SSM strandplain and then a correction factor of 1.49 m was applied to the LiDAR swale elevations. Results from this thesis found that an inferred paleohydrograph reconstructed from LiDAR swale elevations was an appropriate alternative to infer ancient lake level elevations and trends. However, this has only been shown to apply for Nipissing phase beach ridges in the SSM strandplain. Further comparisons at different sites and for different ages of strandplains need to be investigated. In summary, this thesis determined that LiDAR swale elevations can potentially provide an alternative method to reconstruct paleohydrographs, and thus gain valuable insight into natural lake level trends and patterns to help place current high levels and potentially future lake level fluctuations into context for stakeholders.

Objective:

The objective of this project is to compare paleohydrograph reconstructions from topography and subsurface stratigraphy at the Sault Ste. Marie Strandplain (Figure 1). This comparison will aim to determine if paleohydrographs derived from LiDAR topography can be used as an alternative to paleohydrographs derived from FSB elevations.

Goals:

- Reconstruct a paleohydrograph from LiDAR topography
- Develop guidelines to apply LiDAR topography paleohydrograph reconstruction method
- Create new opportunity to reconstruct paleohydrographs for areas that have not been cored

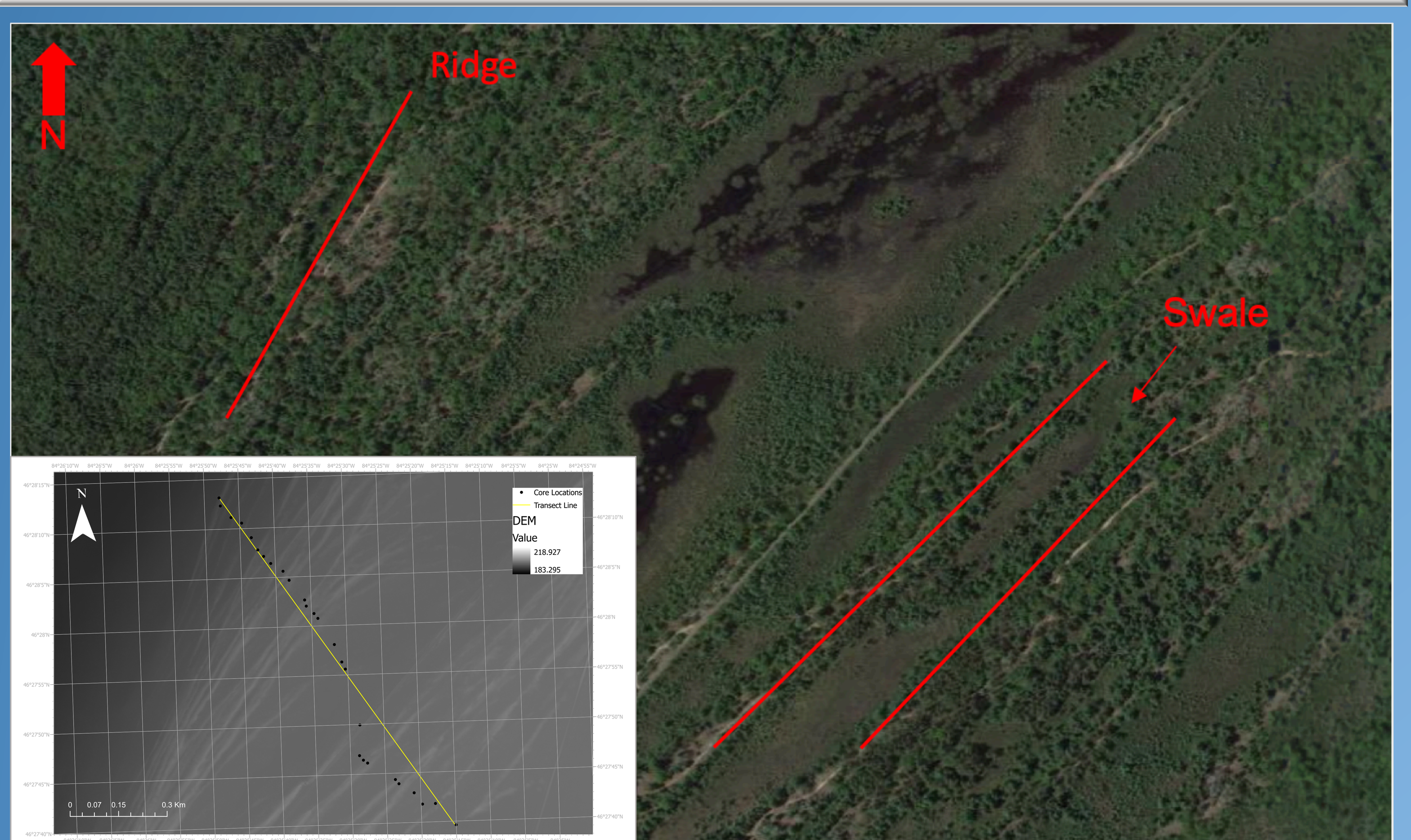

Figure 1. Satellite image of Sault Ste. Marie strandplain site (Google Earth, n.d.) Each ridge is a relict shoreline. Areas between ridges are swales. DEM of SSM inset. Transect line used for topographic profile is represented by yellow line, locations of cores from Johnston et al. (2012) are black circles.

Introduction:

- The Great Lakes water shed is home to more than 30 million people in Canada and the United States. This transboundary watershed supports a vital environment, society and economy (US EPA, 2019).
    - Stakeholder interest for: drinking water, shipping, power generation, fishing, and tourism (Rau et al. 2020)
- We are currently near record high water levels in the Great Lakes (Gronewold and Rood, 2019)
    - Threatening Infrastructure, coastal erosion and flooding
- Geologic lake levels have been reconstructed from subsurface sedimentary contacts inside ancient shorelines (Thompson, 1992, Johnston et al. 2012)
    - Lateral chronosequence of beach ridges preserving ancient water levels
- Can topographic elevations be used to reconstruct paleohydrographs?
    - Potential method for areas that have not been visited or cored
- Ancient trends used alongside modern measurements can provide context to understand modern levels and will provide a foundation for stakeholders to plan for future fluxes

Literature Summary:

Variable approaches:

- Many methods have been used to reconstruct past lake levels
    - Included topography of beach ridges, Larsen (1994) for example collected sediments not directly related to lake level

A new consistent approach:

- Developed in Thompson (1992)
    - Subsurface basal foreshore contact used to reconstruct ancient water level

Opportunities:

- Investigate one recent application (Johnston et al., 2012) that briefly used the subsurface contact method along with topographic elevations
    - One correction factor was applied to topographic data to create one short paleohydrograph
    - Similarities were found between the two types of paleohydrographs
- Potential to create paleohydrographs from topography to compare with subsurface sedimentary contact paelohydrographs

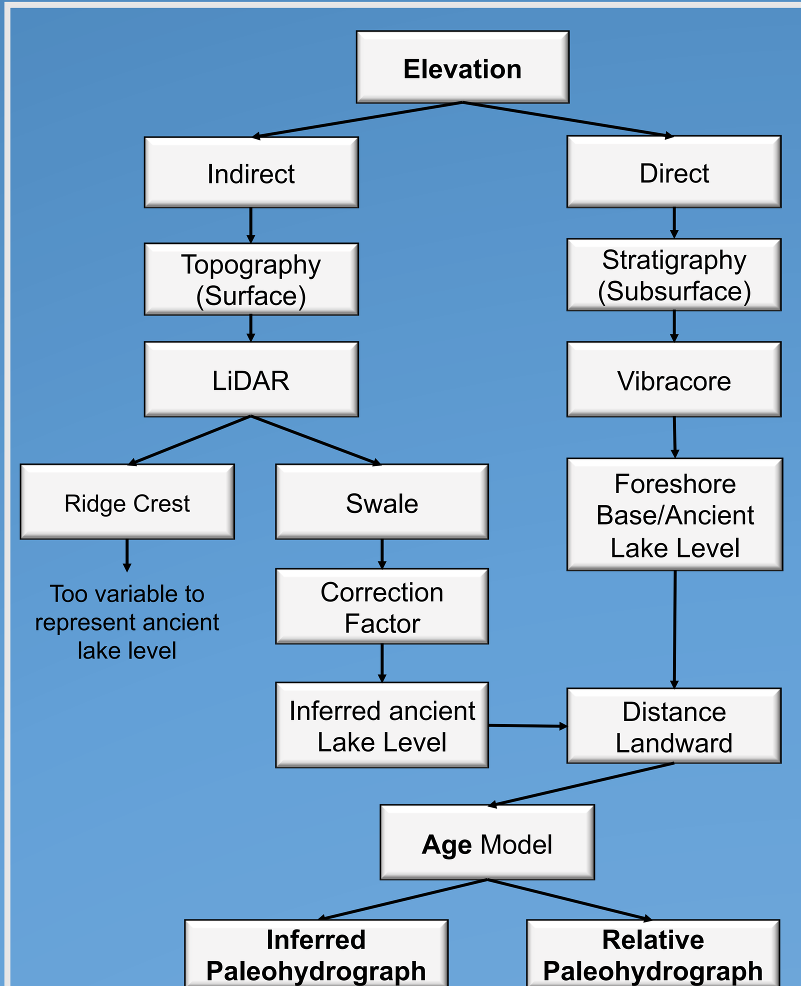

Figure 2. Flow chart of the methods used to reconstruct cross inferred and relative paleohydrographs.

Methods:

- Reconstructing relative **paleohydrograph** requires an **elevation** and an **age**
- **Elevations** (field measured)
    - **Direct** elevations from **stratigraphic** contact at **FSB**(Johnston et al., 2012)
    - **Indirect** elevations surveying **ridge crest** and **swale** (Johnston et al., 2012)
- **LiDAR** elevations
    - **Indirect Swale** elevations and corresponding **distance landward** collected from cross-strandplain topographic profile (Figure 4)
- **Ages**
    - **Age model** for SSM from radiocarbon applied to **distance landward** of ancient ridges to obtain **age of ridges**
- **Paleohydrographs**
    - **Relative paleohydrograph** reconstructed using **FSB** elevations and **age model**
    - **Inferred paleohydrograph** reconstructed using corrected **LiDAR swale** elevations and **age model**
- **Correction factor**
    - Statistical analyses found mean difference of swale and FSB elevations creating **correction factor**
    - **Correction factor of 1.49 m** subtracted from LiDAR swale elevations

Results:

- Paired t-tests showed difference of field measure swale and ridge crest elevations both separately have statistically significant difference when compared with FSB elevations
- Mean difference between field measured swale elevations and FSB elevations is **1.49 m**
    - 1.49 m can be used a **correction factor** to allow swales to represent ancient lake level

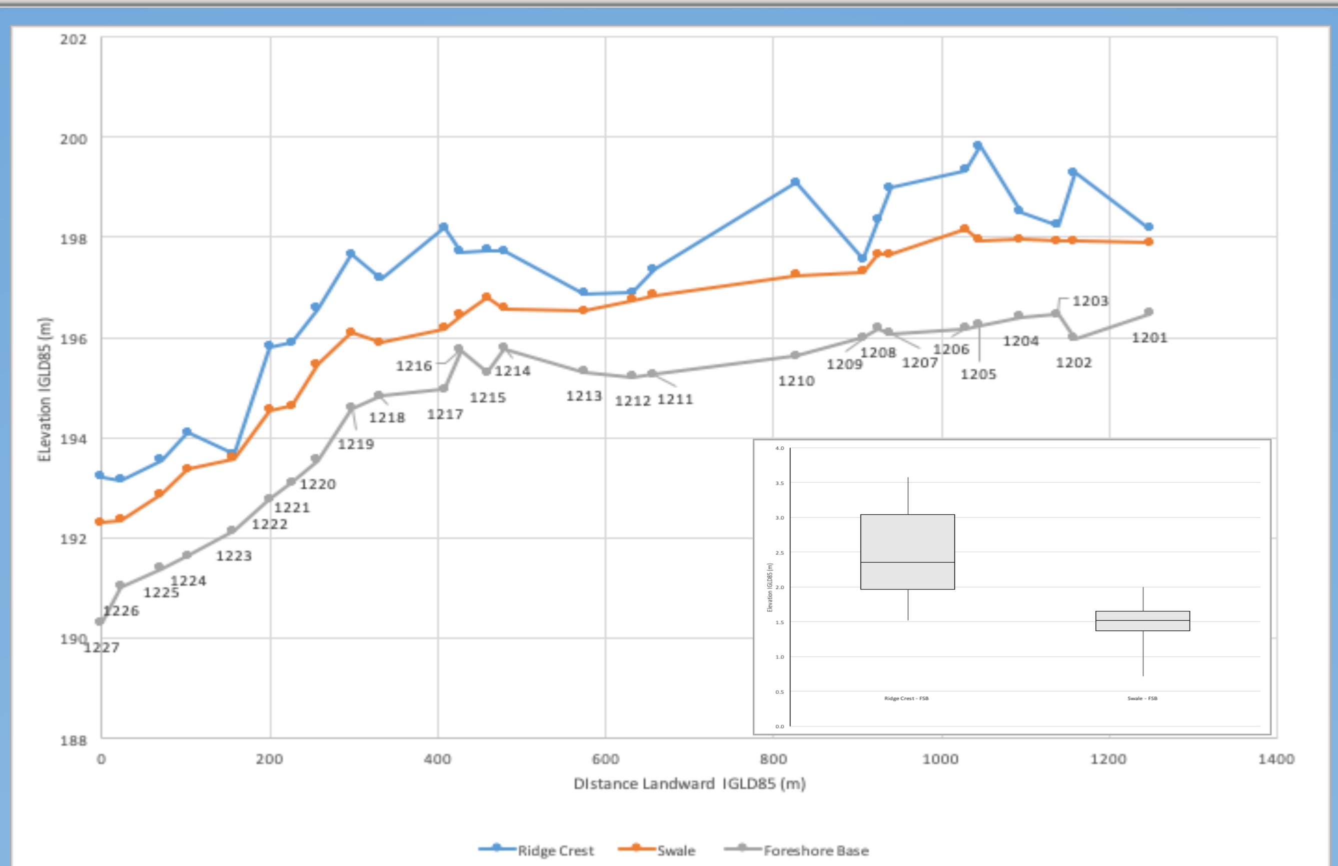

Figure 3. FSB relative paleohydrograph and cross strandplain topographic trends for SSM. Inset shows box plots of average difference in elevation between ridge crest and FSB and swale and FSB. Swales have less deviation and are more symmetrical to the mean

Results-Figure 3

- Field measured topographic elevation trends have similar trends to FSB relative paleohydrograph
- Swale trend is less variable than ridge crest trend when compared to FSB
- Field measured swale to FSB elevation differences have lower standard deviation, lower range, and more symmetrical spacing around median
- Topographic elevations of swales are best proxy for FSB elevations

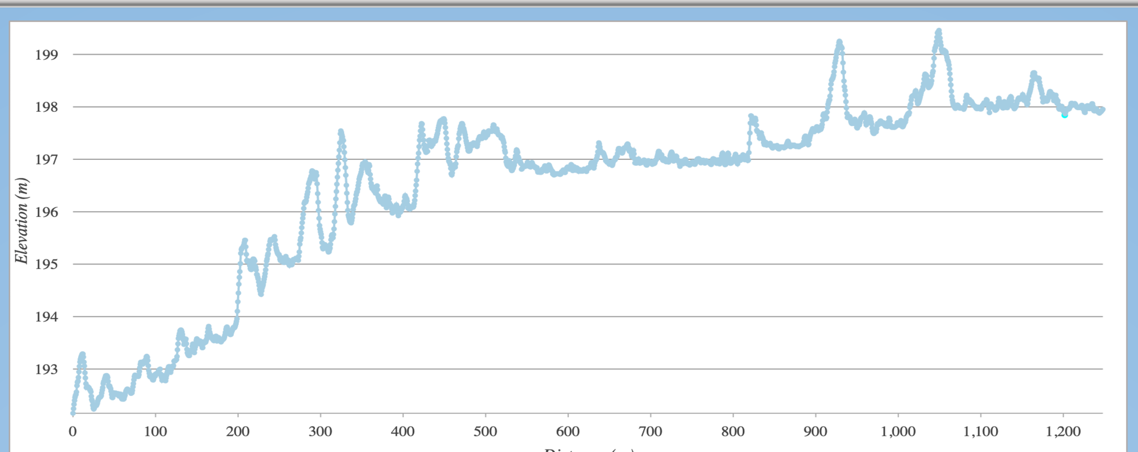

Figure 4. Cross-strandplain topographic profile derived from transect (Figure 1) across SSM strandplain.

Results-LiDAR

- Figure 4 - Cross sectional topographic profile showed similar trend to FSB relative paleohydrograph but is too variable to use on its own
- Figure 5A - Swale elevations extracted from topographic cross section have much less variable trend than figure 4
- Figure 5B - Inferred paleohydrograph with corrected swale elevation and calendar year BP of ridges
    - **Correction factor** of **1.49 m** subtracted from LiDAR swale elevation
- **Inferred paleohydrograph** from LiDAR swale elevations shows strong similarities with FSB relative paleohydrograph

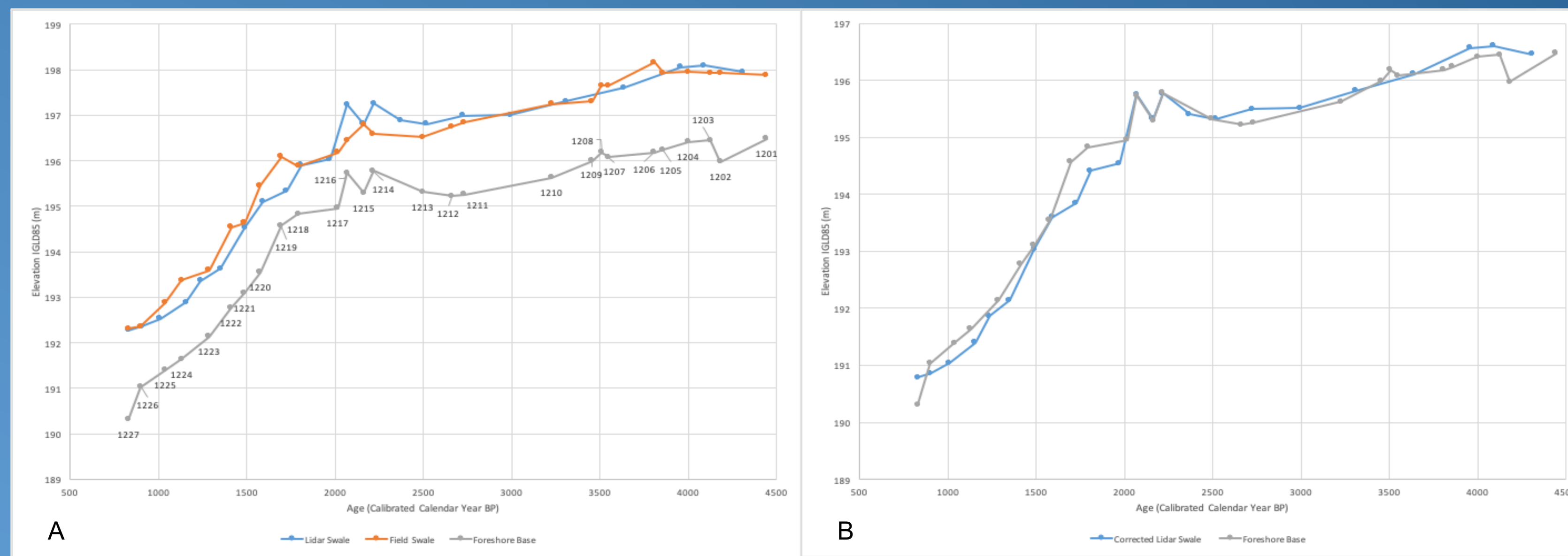

Figure 5. A. Cross strandplain elevation trends of field measured swales and LiDAR measured swales and FSB relative paleohydrograph. B. Inferred paleohydrograph from LiDAR swale elevation with correction factor applied and FSB relative paleohydrograph graphed versus Calendar year BP

Discussion:

- Swale elevation is the topographic proxy for FSB (past lake level elevation) (Figure 3)
    - T-tests, descriptive statistics, and cross-strandplain elevation trends
    - Consistent average difference between swale and FSB created one correction factor
    - Ridge crest elevations too variable to approximate FSB, aeolian processes unrelated to lake level contribute to variability
- Select LiDAR elevations can reconstruct paleohydrograph when field data is lacking
    - Reconstructed inferred paleohydrograph with correction factor applied to swales
    - Individual swale elevations associated with adjacent beach ridges need to be sampled from LiDAR cross sections (Figure 4)
    - Coastal LiDAR data in Great Lakes is becoming more accessible
- Reconstructing paleohydrographs requires age data collected in the strandplain
    - Radiocarbon has been used to create an age model for the SSM strandplain, indicating it formed during the Nipissing phase
    - Age model from radiocarbon may not be an accurate reflection of the formation of ridges (Argyilan et al., 2005)
    - Optically stimulated luminescence (OSL) needed to better reflect the age of ridges and be used to compare to other paleohydrographs
- Inferred paleohydrograph follows similar trend to FSB relative paleohydrograph (Figure 5B)
    - Inferred paleohydrograph from LiDAR swale elevations is an alternative representation of ancient lake levels from FSB relative paleohydrograph
    - Correction factor of 1.49 m required to use LiDAR swale elevations in reconstruction of inferred paleohydrograph
    - Correction factor for SSM does not currently apply to other strandplain sites
- Implications of alternative LiDAR elevation method for reconstructing inferred paleohydrographs
    - LiDAR swale elevations can be used as alternative to reconstruct inferred paleohydrographs
    - Gain insight for individual sites without cores and expands potential study sites
    - Method can help fill in gaps of time and location to help better understand entire basins lake level trends and patterns
    - Study new sites with potentially different glacial isostatic adjustment than others
- Limitations of LiDAR elevation method for reconstructing inferred paleohydrographs
    - No way to obtain remote age, still requires field work to obtain ages of ridges
    - LiDAR coverage is not complete on all of the Great Lakes coasts as of now
    - Without previous cores no way to guide transect, could result in transect that is not representative of actual strandplain formation

Conclusion:

An alternative method to reconstruct an inferred paleohydrograph has been shown using corrected topographic elevations from one strandplain of Nipissing age. This can be attempted before fieldwork to gain insight, potentially guiding fieldwork. This would help expand the knowledge of the Great Lakes ancient lake level trends and patterns by adding insight into gaps of time not previously studied and into new locations. This knowledge of the reconstructed past can help with the understanding of modern and future potential lake-level fluctuations.

Recommendations:

1. Apply methods used on SSM strandplain to other strandplains with field measured elevation data in the Great Lakes basins
    - Determine if field measured swale cross-strandplain elevation trends are similar to FSB relative paleohydrographs across many sites
    - Calculate correction factor for swale elevations at new strandplain sites
    - Determine if there is an appropriate basin wide correction factor
    - Determine if there is an appropriate multi-basin correction factor
2. Use LiDAR generated topography of a strandplain site in a Great Lake basin to reconstruct inferred paleohydrograph using appropriate basin or multi-basin correction factor
    - Collect ages in field to reconstruct paleohydrograph
    - Compare LiDAR elevation inferred paleohydrograph to other existing paleohydrographs from different strandplains in the basin
    - Determine if LiDAR inferred paleohydrographs can accurately reflect ancient lake levels with no previous cores at site

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