

# Data Analysis for Conceptual Model of Ice-Jam Formation in Lithuania– Results and Uncertainties

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# Data Analysis for Conceptual Model Methodology

Data analysis for conceptual model was performed on data collected according to a common template agreed upon by Latvia and Lithuania project partners.

## Hydrological Parameters:

- H (beginning, maximum, ending);
- Q max;
- Stream velocity;
- Ice thickness;
- Other derived parameters, e.g.  $\Delta H$ , ice-jam duration days, ice-jam volume, etc.

# Data Analysis for Conceptual Model Methodology

## Meteorological Parameters:

- Negative Degree Sum (NDS) of air temperature during the 30 days prior to ice-jam;
- Positive Degree Sum (PDS) of air temperature during the 30 days prior to ice-jam;
- Number of Positive Degree Days (PDD) during the 30 days prior to ice-jam;
- Positive Degree Sum (PDS) during the 5 days prior to ice-jam;
- Positive Degree Sum (PDS) during the 2 days prior to ice-jam;
- Number of Positive Degree Days (PDD) during the 5 days prior to ice-jam;
- Number of Positive Degree Days (PDD) during the 2 days prior to ice-jam.
- Monthly air temperature compared to normal during the 30 days prior to ice-jam;
- Monthly air temperature compared to normal during ice-jam;
- Monthly precipitation compared to normal during the 30 days prior to ice-jam;
- Monthly precipitation compared to normal during ice-jam.

# Data Analysis for Conceptual Model Methodology

After testing various analytical approaches, the correlation matrix method was selected. This method proved effective in identifying variables whose interrelationships suggest a potential influence on the likelihood of ice-jam formation. Correlation coefficients equal to or greater than 0,70, as well as those equal to or less than  $-0,70$ , were considered significant.

- **For Mūša – Ustukiai HS**, the strongest and most numerous correlations were obtained by analyzing ice-jam events without categorizing them into types (freeze-up, mid-winter, spring). The analysis focused solely on events for which ice thickness data were available. A total of 17 ice-jam events were examined, occurring in the years: 1972 (3 events), 1978, 1980 (3 events), 1986–1988, 1993 (2 events), 1994, 1998, 1999, 2010, and 2013.
- Similarly, for **Lėvuo – Bernatoniai HS**, correlation matrix analysis was conducted based on 19 ice-jam events. These events occurred in the years: 1970, 1980, 1984, 1985, 1987, 1988 (3 events), 1989, 1991, 1993 (3 events), 1994 – 1996, 1999, 2006, 2010.

## Correlation Matrix Results (A total of 28 significant correlations were identified)

### Correlations with H beginning of ice-jam:

$r = 0,99$  (H max of ice-jam);  
 $r = 0,95$  (Q max of ice jam);  
 $r = 0,90$  (stream velocity);  
 $r = 0,87$  (PDD during 2 days prior to ice-jam);  
 $r = 0,85$  (PDS during 2 days prior to ice-jam);  
 $r = 0,82$  (PDS during 5 days prior to ice-jam);  
 $r = 0,77$  (NDS during 30 days prior to ice-jam);  
 $r = 0,70$  (PDD during 5 days prior to ice-jam).

### Correlations with H max of ice-jam:

$r = 0,93$  (Q max of ice-jam);  
 $r = 0,87$  (stream velocity);  
 $r = 0,83$  (PDD during 2 days prior to ice-jam);  
 $r = 0,80$  (PDS during 2 days prior to ice-jam);  
 $r = 0,78$  (PDS during 5 days prior to ice-jam);  
 $r = 0,73$  (NDS during 30 days prior to ice-jam).

## Other Significant Correlations of Parameters

### Correlations with Q max of ice-jam:

$r = 0,89$  (PDS during 2 days prior to ice-jam);  
 $r = 0,87$  (PDD during 2 days prior to ice-jam);  
 $r = 0,86$  (PDS during 5 days prior to ice-jam);  
 $r = 0,81$  (stream velocity);  
 $r = 0,76$  (NDS during 30 days prior to ice-jam);  
 $r = 0,73$  (ice-jam volume);  
 $r = 0,70$  (PDD during 5 days prior to ice-jam).

### Correlations with streamflow velocity:

$r = 0,85$  (PDS during 2 days prior to ice-jam);  
 $r = 0,82$  (PDD during 2 days prior to ice-jam);  
 $r = 0,81$  (PDS during 5 days prior to ice-jam).

### Correlations with ice thickness:

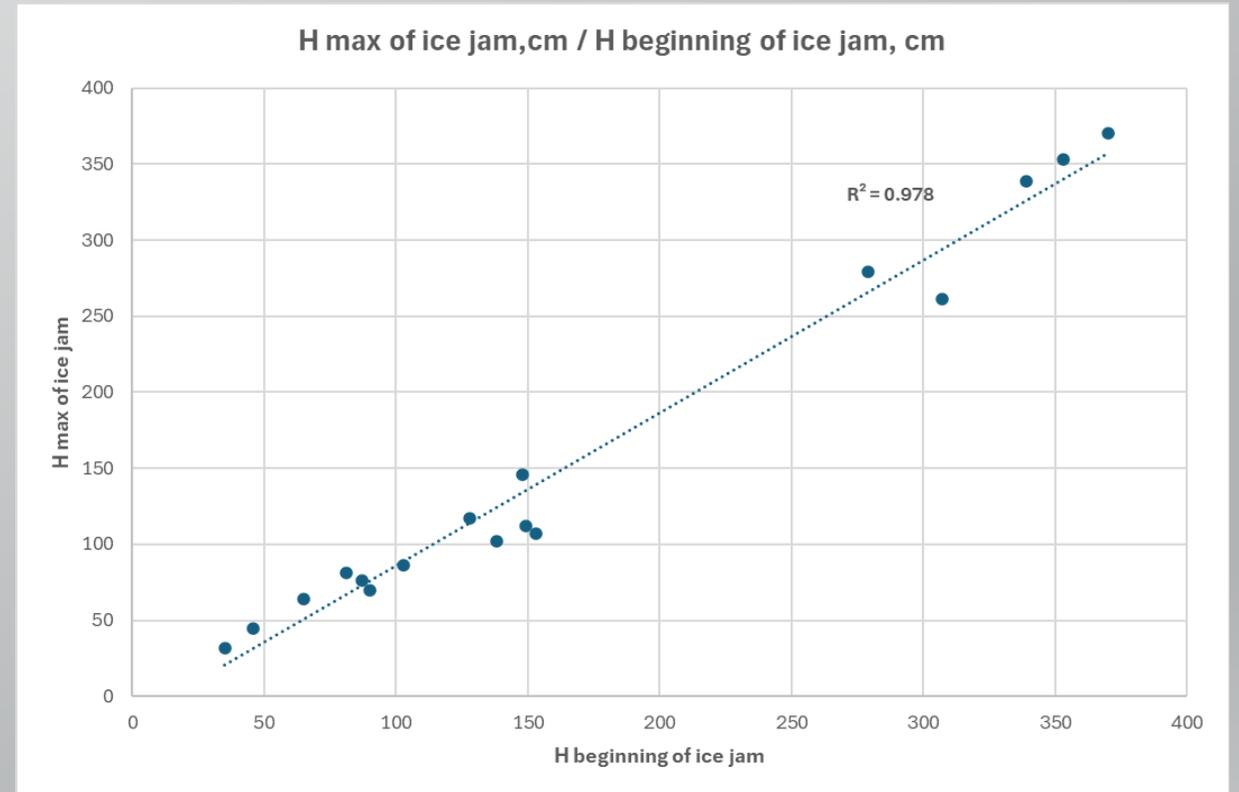
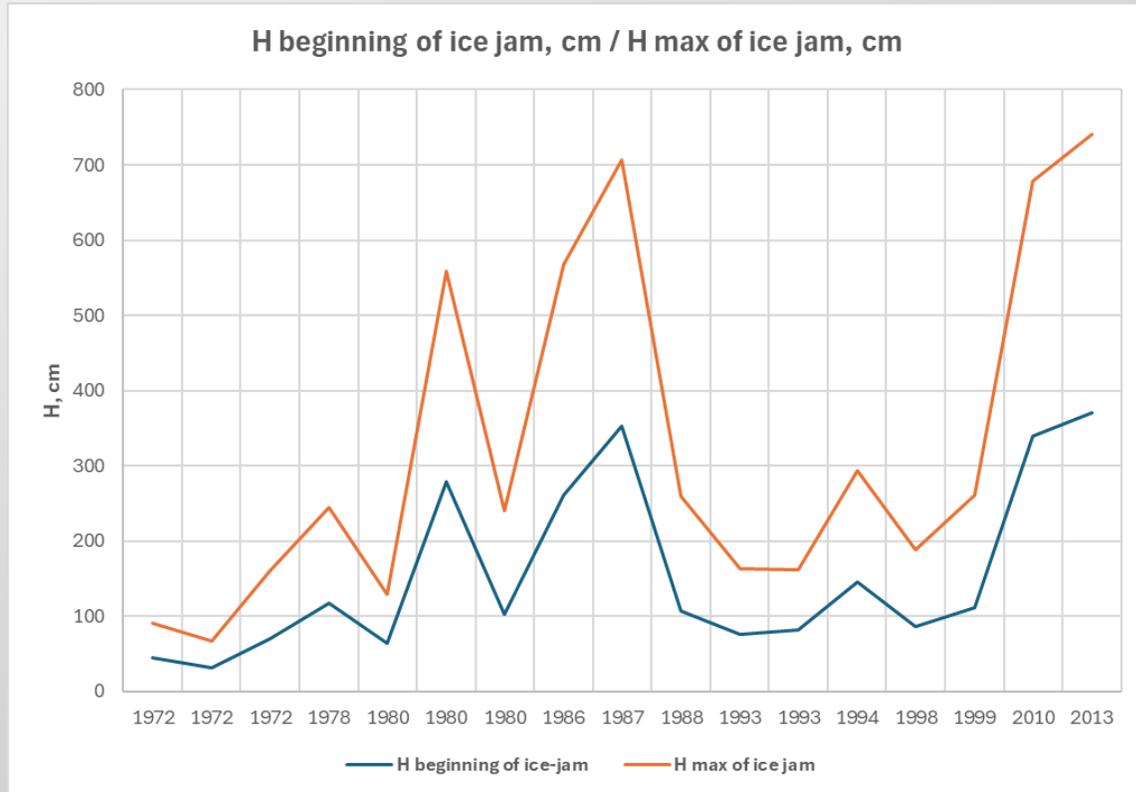
$r = 0,95$  (ice-jam volume);  
 $r = 0,87$  (NDS during 30 days prior to ice-jam);  
 $r = -0,73$  (PDD during 30 days prior to ice-jam).

### Correlations with ice-jam volume:

$r = 0,89$  (NDS during 30 days prior to ice-jam).

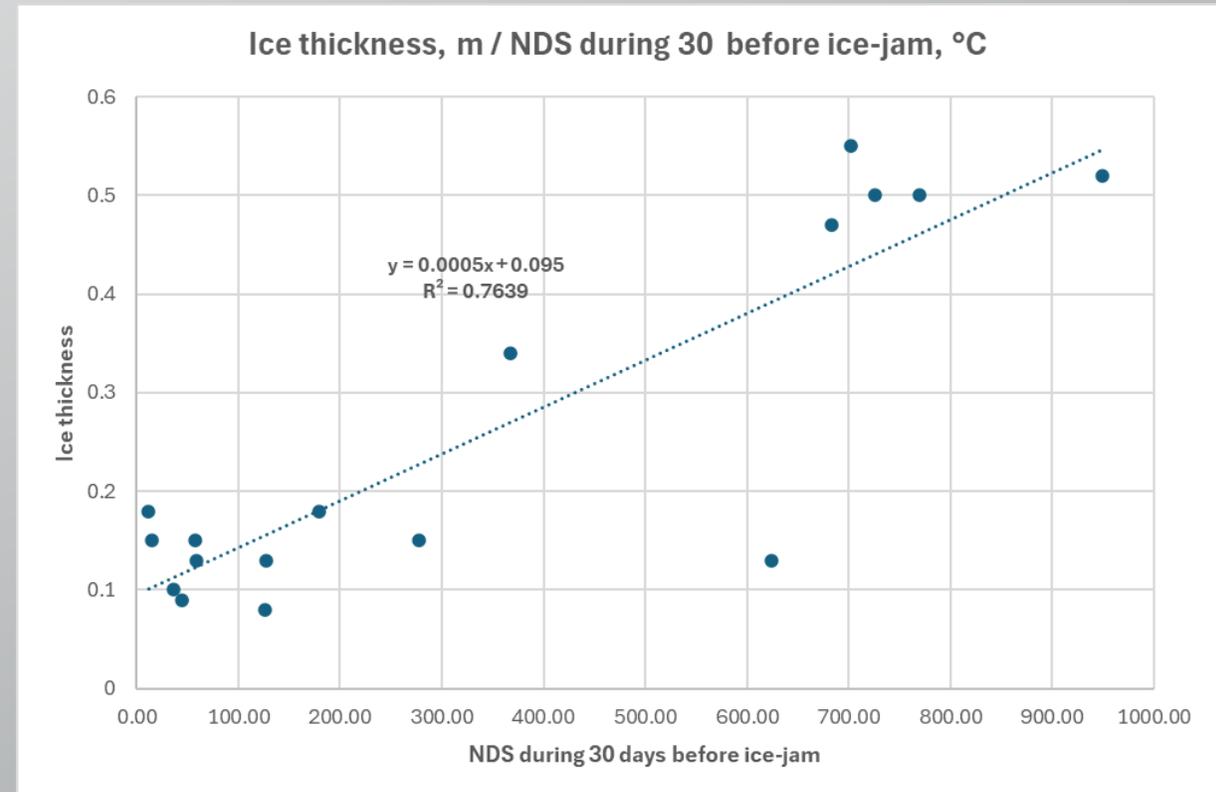
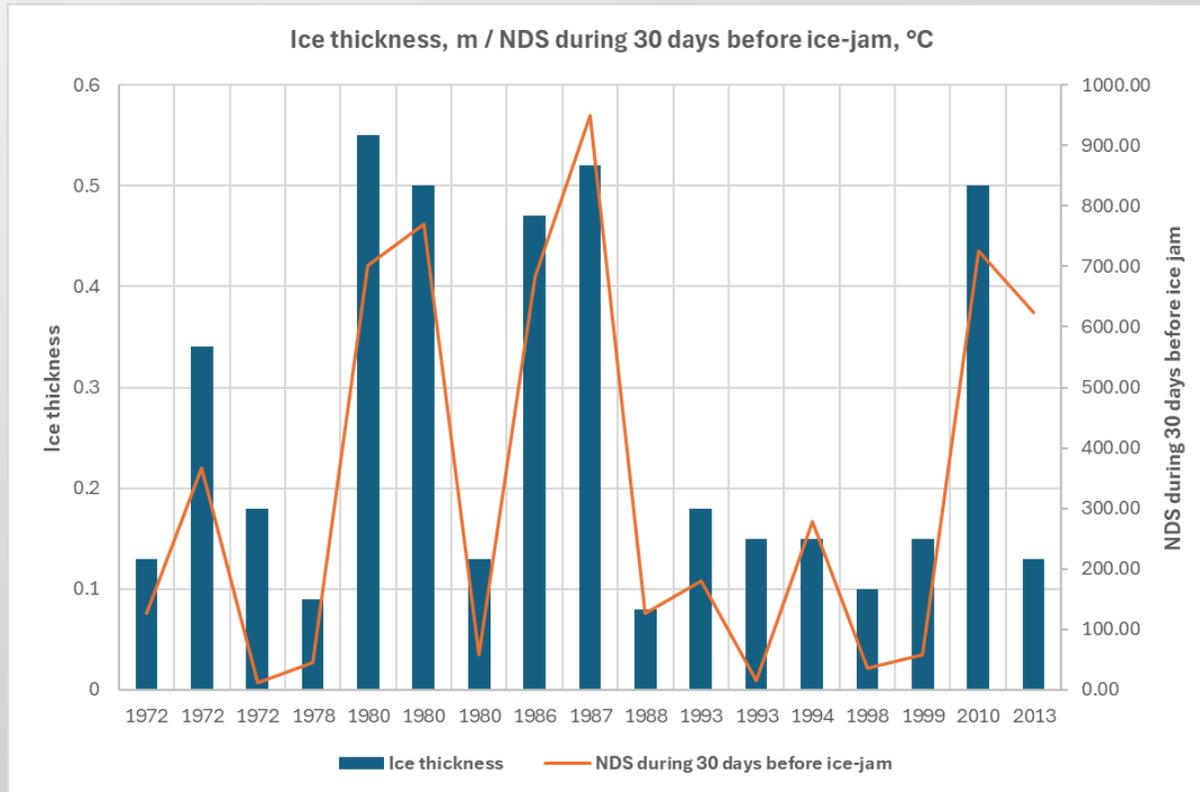
# Data Analysis for Conceptual Model Results (Mūša – Ustukai HS)

At Mūša – Ustukai HS, a strong positive correlation was identified between the initial and maximum water levels during ice-jam events ( $r = 0,99$ ). This suggests that continuous and precise water level monitoring is essential for effective early warning of potential ice-jams and risk mitigation.



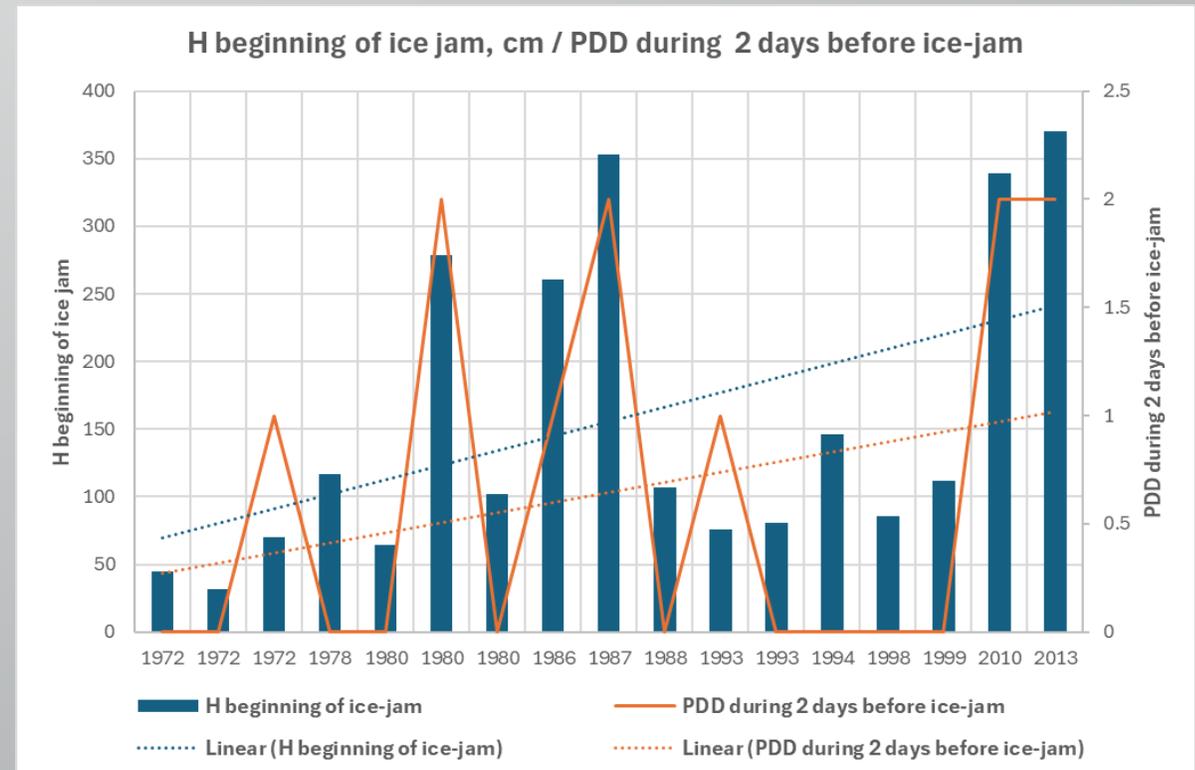
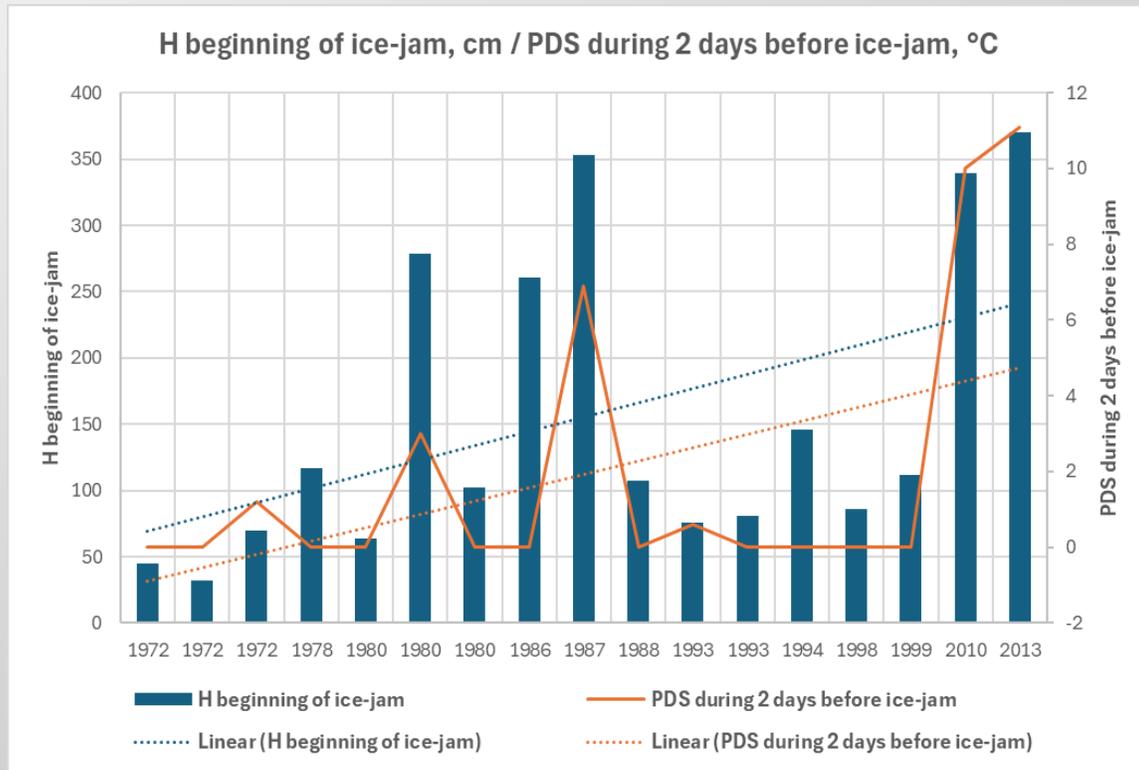
# Data Analysis for Conceptual Model Results (Mūša – Ustukiai HS)

Temperature patterns are reliable predictors of ice condition ( $r = 0,89$ ). Greater ice thickness, such as 0,5–0,55 m in 1980, 0,52 m in 1987, and 0,5 m in 2010, was observed when the NDS during 30 days prior to ice-jam exceeded  $-700\text{ }^{\circ}\text{C}$ . This demonstrates that prolonged cold periods significantly contribute to ice growth, thereby increasing the potential for ice-jam formation.



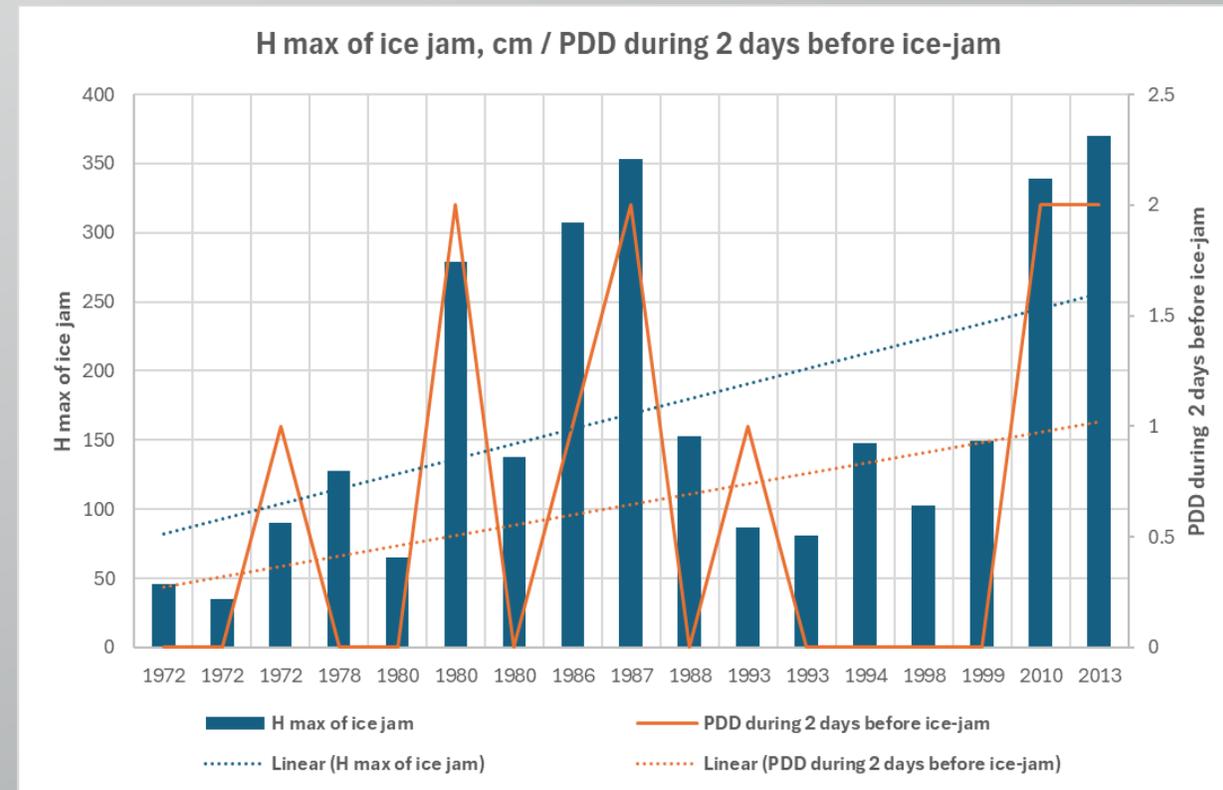
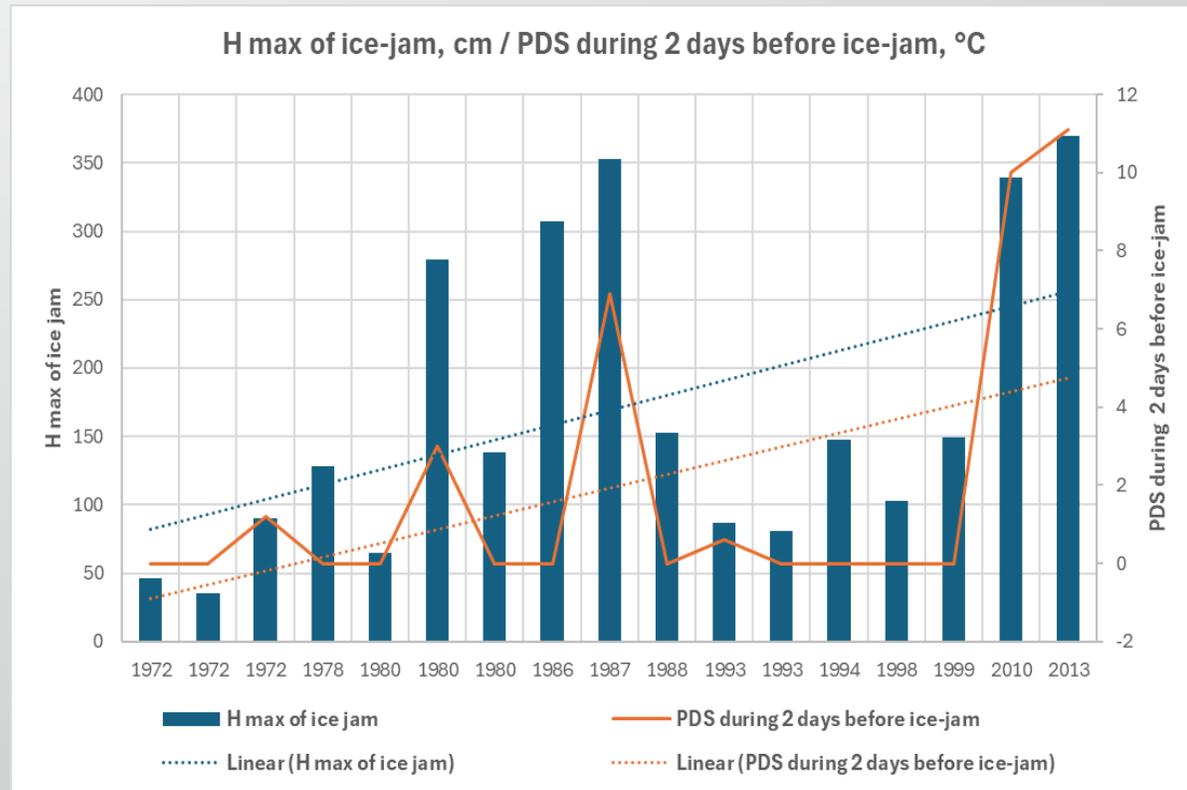
# Data Analysis for Conceptual Model Results (Mūša – Ustukiai HS)

Ice-jams consistently formed at high water levels (e.g., 279 cm in 1980, 353 cm in 1987, 339 cm in 2010, and 370 cm in 2013) when either 1–2 days of positive air temperatures occurred or the 2-day sum exceeded 3 °C (e.g., 6.9 °C in 1987, 10 °C in 2010, and 11.1 °C in 2013), indicating that even short warming periods can contribute to ice-jam onset.



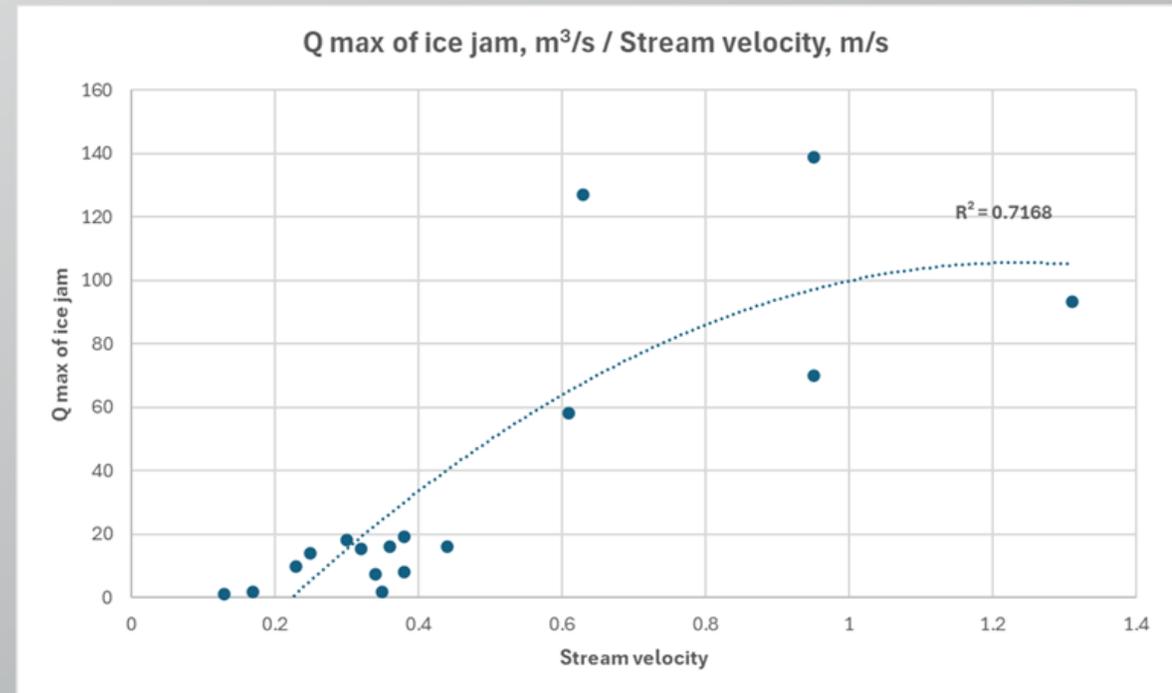
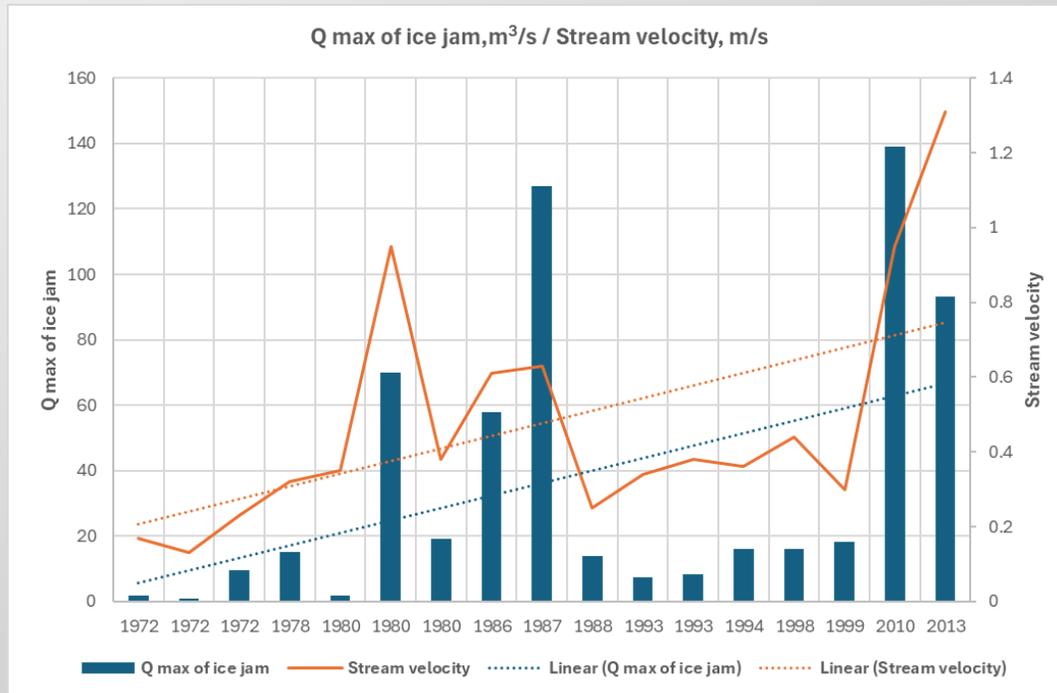
# Data Analysis for Conceptual Model Results (Mūša – Ustukiai HS)

The highest ice-jam water levels such as 279 cm in 1980, 307 cm in 1986, 353 cm in 1987, 339 cm in 2010, and 370 cm in 2013 were consistently preceded by short-term warming events. These typically involved 1–2 days of positive air temperatures and with the 2-day sum exceeding 3 °C (e.g., 6.9 °C in 1987, 10 °C in 2010, 11.1 °C in 2013), highlighting thaw events as triggers of ice-jams.



# Data Analysis for Conceptual Model Results (Mūša – Ustukiai HS)

The most extreme ice-jam discharges, such as 127 m<sup>3</sup>/s in 1987, 139 m<sup>3</sup>/s in 2010, and 93,3 m<sup>3</sup>/s in 2013, were associated with high stream velocities exceeding 0,9 m/s (up to 1,31 m/s in 2013), indicating that stronger flows during breakup can intensify ice-jam dynamics and increase flood risk. However, while higher stream velocity is a factor, other environmental conditions (e.g., ice thickness, air temperature) may also play a role in extreme ice jam events.



## Main factors for ice-jam formation in the Mūša river

- **Colder air temperatures before ice-jams** lead to thicker ice, larger ice-jam volumes, and stronger river blockages. When the **30-day negative degree sum (NDS)** exceeds **100°C**, **ice thickness typically reaches 0,18–0,34 m**, and **ice-jam volumes** can exceed **1,0 mln. m<sup>3</sup>** (e.g., in 1972). These conditions often correspond to **initial water levels (H beginning)** between **70–117 cm**, and maximum levels can reach **128 cm**.
- **Short-term positive air temperatures (PDS) in the 5–2 days prior to ice-jam** strongly influence both **discharge (Q max)** and **water level rise (ΔH)**:
  - When **PDS (5 days) ≥ 10°C**, jams tend to become more intense, with **Q max reaching 9,68 m<sup>3</sup>/s** and **water level rising by 20 cm** (e.g., from 70 cm to 90 cm in 1972).
  - Even smaller thaws (PDS ~3–4°C ) can lead to high flow and backwater effects: in **1978, PDS = 3,9°C**, and the water level rose from **117 cm to 128 cm**, with **Q max = 15,2 m<sup>3</sup>/s**.
- **Streamflow velocity > 0,25 m/s** is consistently associated with high ice-jam discharge. For example, in years with velocities around **0,23–0,32 m/s**, **Q max ranged from 9,7 to 15,2 m<sup>3</sup>/s**, with ice-jam water levels reaching up to **128 cm**. This confirms that **faster flows increase ice transport and jam intensity**.
- **Monthly precipitation** during and before ice-jam events showed **no consistent impact** on either **Q max** or **water level changes**. This supports the conclusion that **air temperature and river hydraulics** are the primary factors influencing ice-jam development in the Mūša river.

## Uncertainties and deviations in the Mūša River

- **Relatively short data set (17 events) may be limiting for long-term statistical analysis.**
- **Temperature threshold exceptions:** most major ice-jams coincide with short-term warming (sum of  $+T > 3$  °C in 2 days), but 1986 stands out with  $Q_{\max} = 58 \text{ m}^3/\text{s}$  and  $H_{\max} = 307 \text{ cm}$  despite 0 °C warming over the last 2 days. This deviation emphasizes that not all jams are thermally induced, and external triggers (e.g., precipitation, upstream melting, or channel configuration) may also play a role.
- **Uncertainty from precipitation influence:** despite efforts to analyze monthly precipitation vs. norm, the values are scattered (e.g., 0,38 to 1,02 during ice-jams) and show no consistent correlation with jam formation. This reinforces that precipitation is a secondary or negligible factor under the specific conditions at Ustukiai HS.
- **Limited observational resolution:** Some parameters like H rising duration (days) and  $\Delta H$  (beginning to max) vary widely from 1 to 4 days and 1 to 46 cm, introducing uncertainty into the time available for early warning. Such temporal variability may reflect differences in ice strength, channel geometry, or data resolution, and highlights the need for real-time monitoring.

# Data Analysis for Conceptual Model Results (Lėvuo – Bernatoniai HS)

Correlation Matrix Results (a total of 16 significant correlations were identified)

## Correlations with H beginning of ice jam:

$r = 0,91$  (stream velocity);

$r = 0,86$  (H max of ice-jam);

$r = 0,79$  (NDS during the 30 days prior to ice-jam);

$r = 0,72$  (PDS during the 5 days prior to ice-jam);

$r = 0,72$  (PDS during the 2 days prior to ice-jam).

## Correlations with H max of ice-jam:

$r = 0,89$  (NDS during the 30 days prior to ice jam);

$r = 0,79$  (streamf velocity);

$r = 0,76$  (Q max of ice jam);

$r = 0,73$  (ice-jam volume).

## Other Significant Correlations of Parameters:

### **Q max of ice-jam:**

$r = 0,90$  ( $\Delta H$  beginning – max);

$r = 0,78$  (ice thickness);

$r = 0,72$  (ice-jam volume).

### **Streamflow velocity:**

$r = 0,75$  (NDS during the 30 days prior ice-jam);

### **$\Delta H$ (beginning – max):**

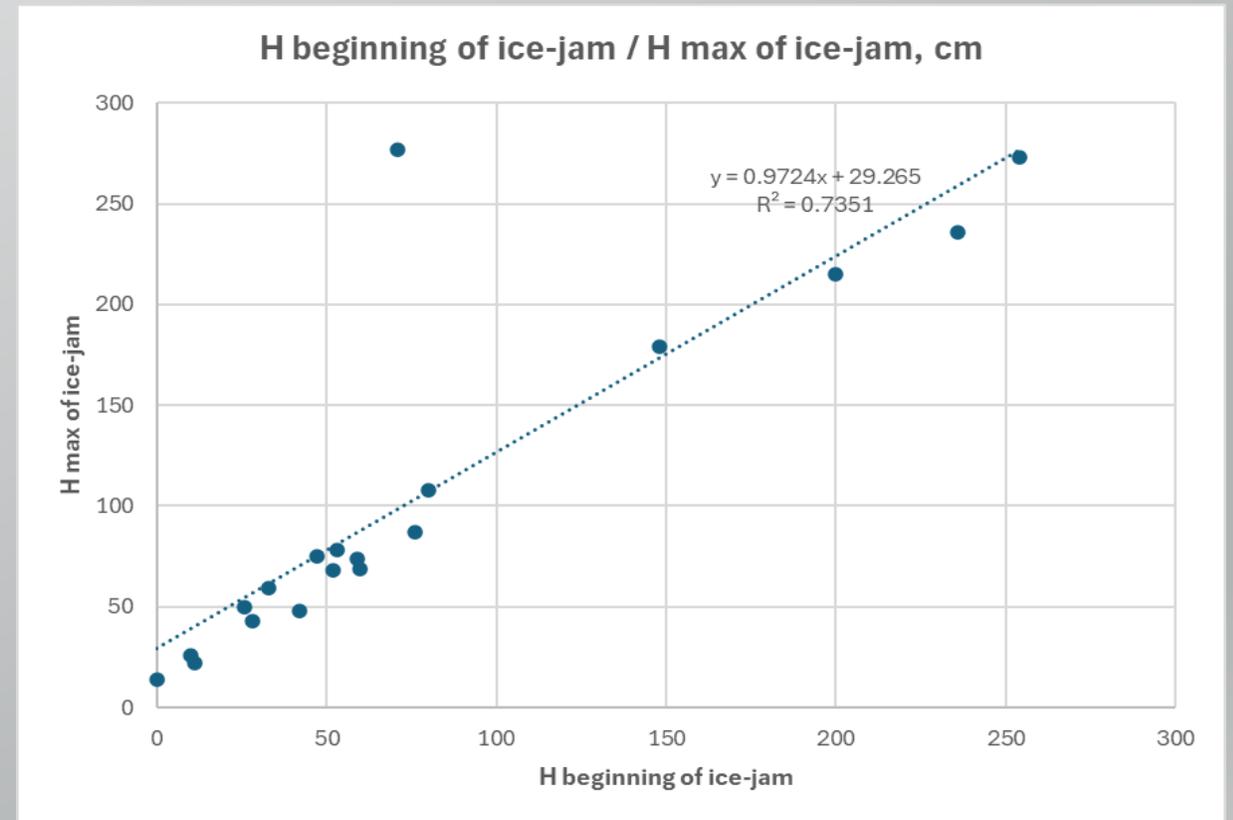
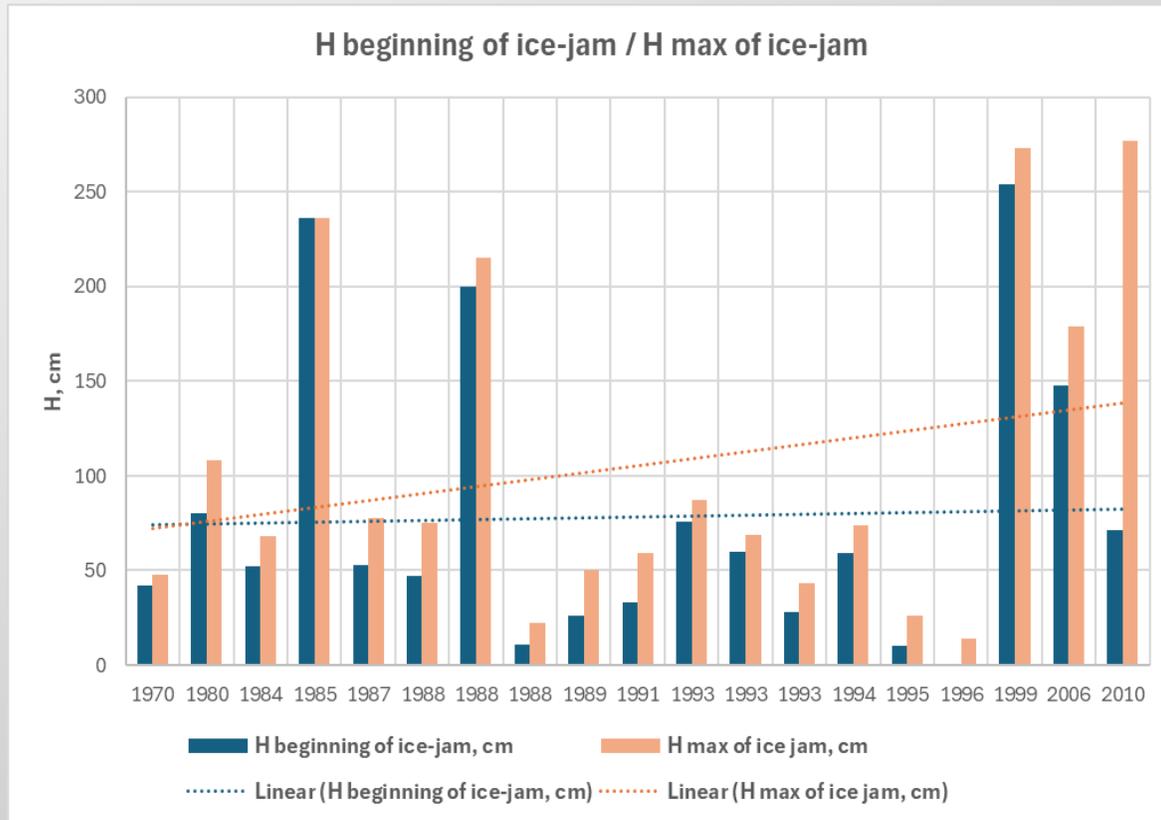
$r = 0,70$  (ice thickness).

### **Ice-jam volume:**

$r = 0,79$  (NDS during the 30 days prior ice-jam).

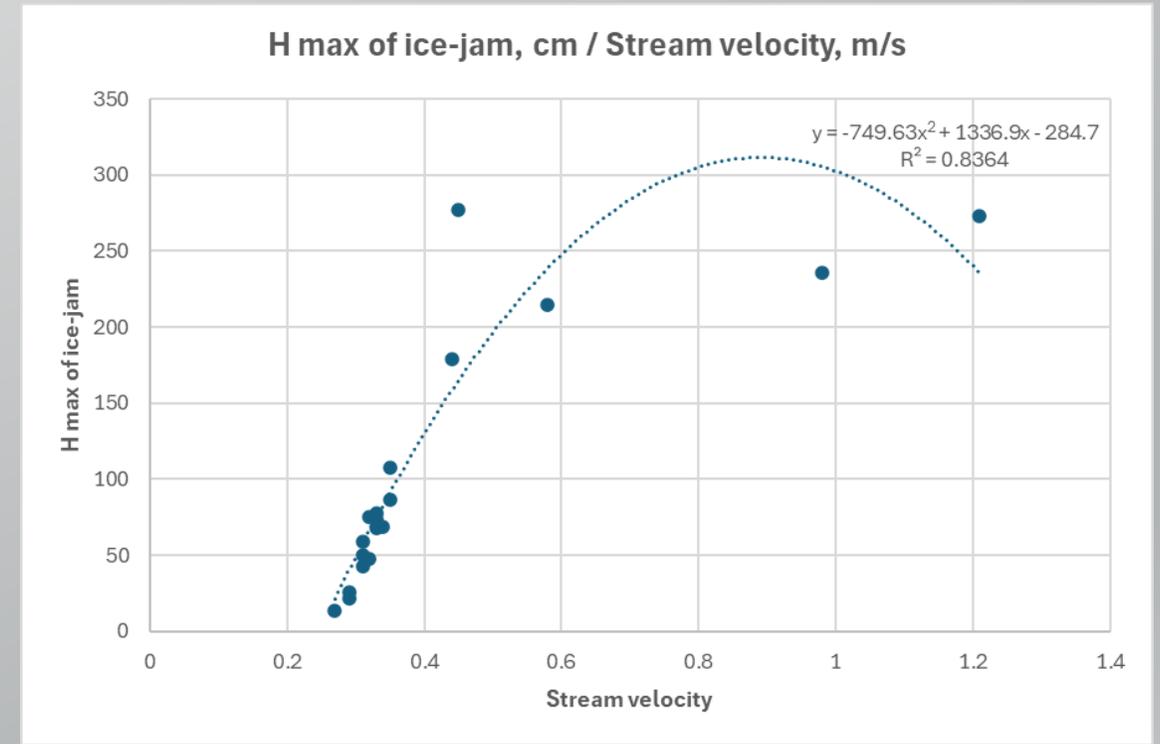
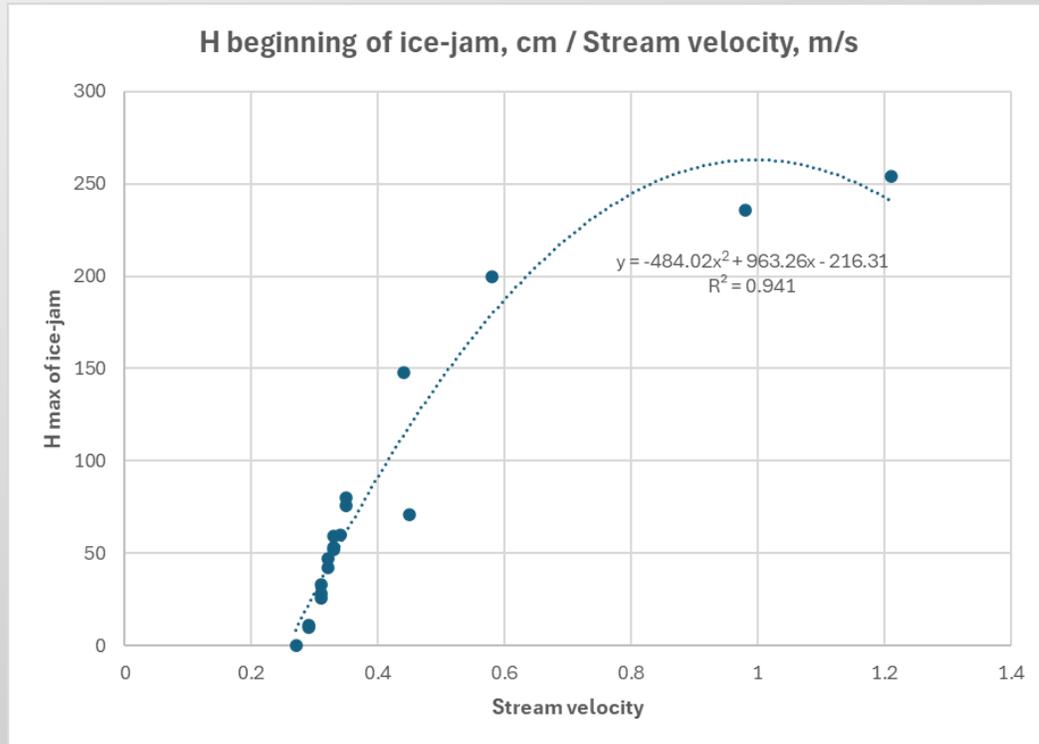
# Data Analysis for Conceptual Model Results (Lėvuo – Bernatoniai HS)

Just like in Mūša – Ustukiai HS, a strong correlation ( $r = 0,86$ ) was obtained between the initial and peak water levels of ice-jams at **Lėvuo – Bernatoniai HS**. This supports the idea that water level monitoring is one of the most important factors in an early warning system for ice-jam events.



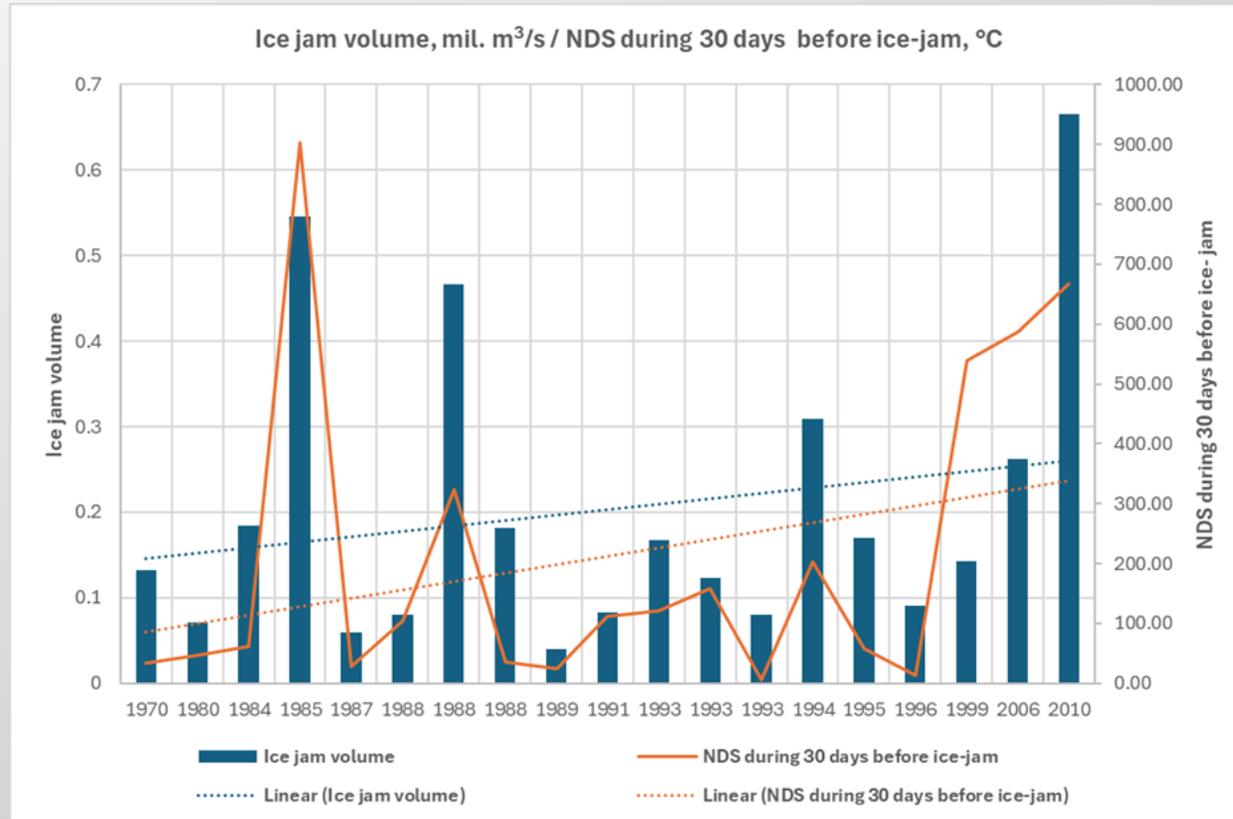
# Data Analysis for Conceptual Model Results (Lėvuo – Bernatoniai HS)

The correlation between **streamflow velocity** and **water levels at the beginning and peak** the ice jam ( $r = 0,91; 0,79$ ) suggests that higher stream velocities contribute to increased ice accumulation. As stream velocity increases, both  $H$  beginning and the  $H$  max also increase. At low stream velocities (around 0,3 m/s), ice jams can start at water levels as low as 10 - 80 cm, and the maximum level during the jam reaches about 50 - 100 cm. At high velocities (around 1,0–1,2 m/s), ice jams begin at much higher levels (230–254 cm) and reach peak levels up to 277 cm.



# Data Analysis for Conceptual Model Results (Lėvuo – Bernatoniai HS)

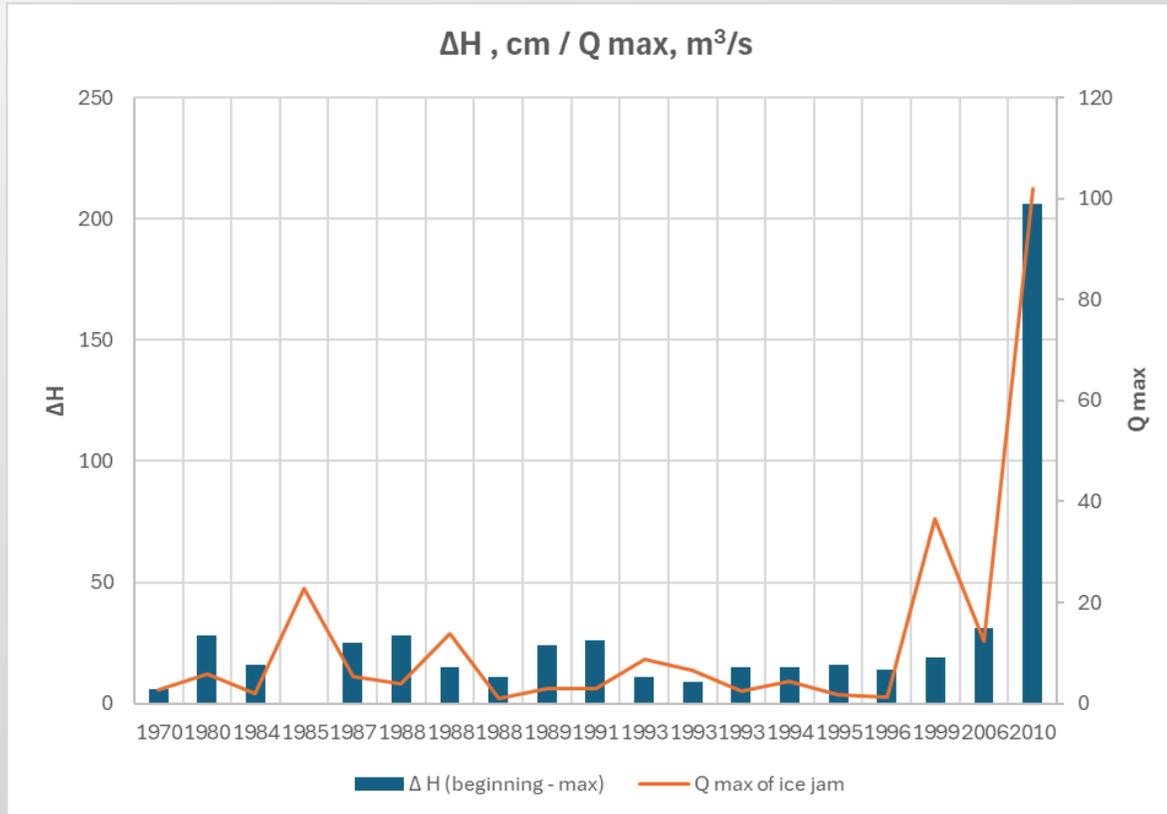
## Ice-Jam Volume and NDS during the 30 days prior to Ice-Jam ( $r = 0,79$ )



A strong correlation between the ice-jam volume and NDS during the 30 days prior ice jam formation indicates that prolonged cold conditions contribute to extensive ice buildup. These low temperatures lead to thicker ice formation, increasing the likelihood of an obstruction when temperatures begin to rise. Monitoring negative air temperatures provides an early indication of the potential severity of ice-jams.

# Data Analysis for Conceptual Model Results (Lėvuo – Bernatoniai HS)

$\Delta H$  (beginning - max) and  $Q$  max of ice jam ( $r = 0,90$ )



The change in water level from the beginning to the maximum stage correlates strongly with the maximum discharge during the ice-jam. This indicates that as ice accumulates, the potential for extreme discharge events and flooding increases significantly. The rapid increase in water levels necessitates continuous monitoring to anticipate possible flooding events.

## Main Factors for Ice-Jam Formation in the Lėvuo River

- **Cold periods prior to ice-jam** are a key driver of ice formation. When the **30-day negative degree sum (NDS)** exceeds **100°C**, ice thickness can reach **0,2–0,4 m**, significantly increasing the potential for severe ice-jams. The most extreme case occurred in **1985** with **NDS = 903,3°C** and **ice thickness = 0,4 m**.
- **Short-term warming** just before an ice-jam often triggers destabilization of ice. When the **positive degree sum (PDS)** exceeds **5°C over 5 days** or **2°C over 2 days**, the likelihood of ice-jam intensification rises. For instance, in **1999**, **PDS (5 days) = 15.6°C** and **PDS (2 days) = 8.5°C** preceded a strong jam.
- **Streamflow velocity above ~0,9 m/s** is associated with **severe ice-jams**. At these velocities, the water level at jam onset can exceed **230 cm**, and the maximum jam height may reach **250–277 cm**, as seen in **2010** (**v = 1,21 m/s**) and **1985** (**v = 0,98 m/s**).
- When **maximum discharge (Q max)** exceeds **~20 m<sup>3</sup>/s**, the water level increase during an ice jam (**ΔH**) often surpasses **20–30 cm**. The most extreme example occurred in **2010**, with **Q max = 102 m<sup>3</sup>/s** and **ΔH = 206 cm**.
- **Precipitation in the month before the ice jam** typically ranges between **0,5–1,2 times the monthly norm**, but no strong link is observed with ice-jam occurrence or severity. For example, both dry (1988: **P before = 0,82 vs norm**) and wet (2006: **P during = 3,63 vs norm**) conditions resulted in ice jams.
- Effective early warning signals arise from the **combination of**:
  - **Ice thickness ≥ 0,2 m**
  - **Streamflow velocity > 0,6 m/s** (with higher risk > 0,9 m/s)
  - **PDS ≥ 5°C over 5 days**
  - **NDS ≥ 100°C over last 30 days.**

These conditions often precede the **most significant ice-jam events**.

## Uncertainties and deviations in the Lėvuo river

### 1. Extreme outliers

Some years, like **2010**, show **unusually high values**:

- $\Delta H = 206 \text{ cm}$ ,  $Q \text{ max} = 102 \text{ m}^3/\text{s}$ , stream velocity = **1,21 m/s**.  
These are far above typical values and most likely represent **exceptional event**.

### 2. Inconsistent temperature patterns

Not all strong ice-jams follow the same pattern:

- Some years show ice-jams **without any warming** ( $PDS = 0$ ), like **1988** and **2010**, while others show significant warming, like **1999** ( $PDS \text{ 5-day} = 15,6^\circ\text{C}$ ). This suggests **multiple types of triggering mechanisms**, increasing uncertainty in forecasting.

The **negative degree sum (NDS)** varies greatly:

- From as low as **5,2°C (1993)** to over **900°C (1985)**.
- This wide range suggests high year-to-year variability in winter severity, which affects **ice thickness and jam risk** unpredictably.

### 3. Precipitation uncertainty

The effect of precipitation is inconsistent:

- High precipitation in some years (e.g., 2006) does not always result in high discharge or ice-jam height.
- This suggests **precipitation is a less reliable indicator** for ice-jam forecasting in this river.

# Thank you

Lithuanian Hydrometeorological Service (LHMS)

ICEREG Project – PP3 Role

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