July 2023 storm: preliminary analyses

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Vermont Citizens Advisory Committee
November 13, 2023
- Rain
- River flow
- Phosphorus delivery
- Lake level
- Lake water quality

Observations and statistics

Compare to
- Typical
- Tropical Storm Irene
- TMDL
• Important impacts **not covered** in this talk
  • Loss of life and property
  • Displacement, evacuations
  • Farms – crop loss and contamination
  • Infrastructure
  • Wastewater discharges and overflows
Results are provisional
• 48-hour rainfall: 3 – 9 inches
• Highest 48-hour rainfall: **9.20 inches** (Calais, VT)
• Montpelier stats:
  • Broke **daily rainfall record** with **5.28 inches** (previous record Irene; 5.27 inches)
  • Broke **monthly rainfall record** with **12.06 inches** (previous record 10.69 inches in August 1989; average 3.86 inches)

Stats from NOAA
• Widespread flooding
• Winooski, Lamoille, Otter reached major flood stage
• Flash flooding from smaller rivers and streams

Montpelier, VT on July 11, 2023 (NASA)
Latest observed value: 19.34 ft at 1:45 PM EDT 11-Jul-2023. Flood Stage is 15 ft
Total measured water flow to Lake Champlain
19 tributaries combined; represents roughly $\frac{3}{4}$ of watershed

Instantaneous peak flow: 109,397 cubic feet per second
7pm on July 11, 2023
Daily average flow from each tributary

7-day water flux:
- Top five delivered 80%
- 219 billion gallons
- 829 million cubic meters
Stats dating back to 1990
July 11, 2023 daily average flow was:
• greater than 90th flow percentile for all tributaries
• Highest ever for Lamoille River
• Second highest ever for Winooski River
• highest flow ever for this date for nearly all tributaries (2nd for 2)
Total measured water flow to Lake Champlain
17 tributaries combined; all years since 1991
Total measured water flow to Lake Champlain
17 tributaries combined; all years since 1991

July 11 peak daily flow all-time rank is 13th
Total measured water flow to Lake Champlain
17 tributaries combined; all years since 1991

100,000 cubic feet per second

10,000

1,000

Oct-1  Feb-1  Jun-1

2023  2011
Total measured water flow to Lake Champlain
17 tributaries combined; all years since 1991

- Especially high flow for this time of year
- Average flow is about 7,000 cfs
Context: **timing and distribution of flow is changing**
Winooski River – discharge trends by quantile

Annual flow quantile

- Lower flows
- Higher flows

Likelihood of trend

- Very likely
- Likely
- Uncertain
Winooski River – discharge trends by quantile and season

**Annual flow quantile**

- **Lower flows**
- **Higher flows**

**Likelihood of trend**
- Very likely
- Likely
- Uncertain
Daily phosphorus load from each tributary to Lake Champlain

175.4 metric tons of phosphorus delivered on July 11*

7-day load:
- Top five delivered 90%
- 359 metric tons*
- 62 - 85% of full-lake TMDL*

Legend:
- Winooski
- Missisquoi
- Lamoille
- Otter
- Pike
Stats dating back to 1990

**July 11, 2023 daily phosphorus load was:**

- **greater than 90th percentile** for all tributaries
- **Highest** daily load ever for Pike River
- Second highest ever for Winooski River
- **Highest load ever for this date** for all but two tributaries
- **Third largest daily load ever** delivered to Lake Champlain
  - Highest: Irene (586.9 mt)
  - Second: Halloween storm 2019 (187.7 mt)
Context: Cumulative phosphorus delivered to Lake Champlain; all years since 1991
Cumulative phosphorus delivered to Lake Champlain
17 monitored tributaries combined; all years since 1991

2,000 metric tons of phosphorus

average
Cumulative phosphorus delivered to Lake Champlain
17 monitored tributaries combined; all years since 1991

2,000 metric tons of phosphorus

Oct-1 Feb-1 Jun-1

average 2023
Cumulative phosphorus delivered to Lake Champlain
17 monitored tributaries combined; all years since 1991

![Graph showing cumulative phosphorus delivered to Lake Champlain from 1991 to 2023. The graph indicates a significant increase in the amount of phosphorus delivered in 2011 and 2023.](image)
Next: Cumulative **phosphorus** delivered to Lake Champlain **by lake segment**
- all years since 1991
- adjusted for unmonitored area
- compared to TMDL allocations
metric tons of phosphorus

Cumberland Bay

TMDL allocation
average

Main Lake

Malletts Bay

Missisquoi Bay

Oct-1  Feb-1  Jun-1

Oct-1  Feb-1  Jun-1
Cumberland Bay

Main Lake

Malletts Bay

Missisquoi Bay

2011 metric tons of phosphorus TMDL allocation

Oct-1 Feb-1 Jun-1 2011 2023
Next: how did **July 2023 storm** phosphorus load compare to **annual** phosphorus loads?
Ratio of 7-day July 2023 storm phosphorus loading to annual loading

During July storm, Lamoille River delivered 1.2 times annual 2022 load, 0.6 times typical (median) annual load.
During July storm, Winooski River delivered 1.3 times typical (median) annual load.
Ratio of 7-day July 2023 storm phosphorus loading to annual loading
Context: high flows are always important for nutrient delivery
Winooski River
Portion of phosphorus load contributed

From the biggest...

- 30 days
- 10 days
- 5 days
- Single day
Lamoille River discharge (cfs)

pH

Specific conductivity (uS/cm)

Turbidity (fnu)
Next: lake level and water quality
Lake Champlain level, Burlington (ft above sea level)
All years, starting 1907

Oct-1  Feb-1  Jun-1

Average

2023
Lake Champlain level, Burlington (ft above sea level)
All years, starting 1907
Malletts Bay
Secchi depth 0.4 m on July 20
Typically about 2.5 m

Photo: Kelsey Colbert
Adapted from Peter Isles’ presentation
Turbidity (fnu)
Lamoille River discharge (cfs)

Lamoille river turbidity (fnu)

Malletts Bay turbidity (fnu)
Summary

Historic **rainfall** amounts
- 48-hour totals: **3 – 9 inches**
Summary

Very high river flows

• > 90\textsuperscript{th} daily flow percentile for all tributaries
• daily record for Lamoille, 2\textsuperscript{nd} for Winooski
• Unusually high for the time of year
• Consistent with climate change trends
Summary

**Phosphorus** delivery

- Preceded by a dry spring
- Five tributaries delivered 90% of 7-day storm flux
- **More than half** of full-lake annual **TMDL** delivered in 7 days
- Esp. significant for **Main Lake**
- Consistent with **climate change** trends (time of year)
Lake level

- Rose about 3 feet
- From average to record high for season, near normal for spring
Summary

Lake water quality

- High turbidity
- Primary productivity likely suppressed
- Dissolved nutrients available for later season growth
- Short-term bacteria impacts; not widespread
- Waiting on 2023 data
Resources

- **July 2023 flooding summary**
- Real-time data: [data.lcbp.org](data.lcbp.org)
- Science blog: [lcbp.org/science-blog](lcbp.org/science-blog)

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