12/18-12/19 2023 Mount Washington ROS:

A Case Study

Abstract:

This case study is a subsection of a larger paper, concerning ROS trends at the summit of Mount Washington, which found the frequency of these events to be increasing. This case study examined the meteorologic setup, snow composition, and subsequent runoff of the December 2023 ROS flooding event. While this event fit within the average time frame of ROS events examined, fell on a below average depth of snowpack, and did not generate significantly rainfall higher than any other large runoff events studied, it generated the highest daily discharge values from a non-spring ROS event in the adjacent gauge's records. Causing major flooding at a majority of the studied gauges as well as generating recurrence intervals of close to 800 years, this event is an example of the potential size of modern ROS events, particularly those occurring outside of the spring runoff season, in and around Mount Washington, relevant as the frequency of their occurrence increases.

Introduction:

Anthropogenic climate change is having discernible effects on both global and local weather patterns and climates. Worldwide, there's a notable increase in the frequency and intensity of hot extremes, alongside a general decline in the frequency and intensity of cold extremes (Pörtner 2023). As the trend of global warming continues, the variability and intensity of the global water cycle is projected to increase. Additionally, there is projected to be increased potential for abrupt shifts in regional weather patterns (Pörtner 2023). At the regional level, climate extremes in the Northeast US have shown similar trends. An analysis of temperature indices from 1870 to 2005 have shown intense warming alongside an increased frequency of warm weather events and decreased frequency of cold weather events (Brown et al. 2010). This warming has already been observed in the form of increased heat waves, decreased snowpack, and more extreme flooding and droughts (Young and Young 2021). Climate change has even been observed at the summit of Mount Washington, regardless of the summit's location in the alpine zone. Since 1935, the summit has warmed an average of 0.1ºC per decade. Winter months have been found to warm even faster, at a rate of 0.14ºC per decade (Murray et al.). There is also doubt concerning whether previous studies on climate variability at the summit have accurately captured extreme event trends. Multiple studies on snowpack at the Mount Washington summit have found little change in summit winter snowpack (Seidel et al. 2009), however these studies have failed to examine the impacts of warming events and ROS, which have detrimental impacts on snow cover. These studies have also neglected to examine overall precipitation frequency and type changes at the summit.

This case study is only a subsection of a larger study examining ROS events at the summit of Mount Washington. This study will isolate winter precipitation events occurring over a definable snowpack, to see if there has been a change in frequency of ROS events at the summit. These results will help determine whether winter precipitation has been increasing on Mount Washington while warmer temperatures allow this precipitation to fall as rainfall, increasing icing events and runoff to neighboring ravines and gullies. Determining how winter is impacting Mount Washington will increase understanding of how climate change is impacting the region, while also informing how fragile high alpine zones will be impacted by a changing climate[1].

ROS events have a history of causing highly impactful flooding events. As of 2015, the 2013 South Saskatchewan and Elk River Basin ROS flood was the costliest natural disaster in Canadian history, requiring over 100,000 people to evacuate and raising water levels to their highest peak in 60 years (Pomeroy et al. 2016). A 2017 ROS event in California severely damaged the Oroville Dam resulting in the evacuations of almost 200,000 people (Vahedifard et al. 2017). Some of the most damaging storms recorded in the Sierra Nevada have been ROS events, with uncertainties in runoff forecasting impeding downstream flood mitigation efforts (Kattelmann 1996). A more local example comes from Pennsylvania, where rain falling on an unusually deep snowpack resulted in the largest midwinter flood in the state's history (Kroczynski 2004). While the majority of ROS studies have been conducted in North America, these floods have also been reported in Europe, Japan, and New Zealand (Rössler et al. 2013).

The high flood generation potential of these ROS events is largely due to snowmelt contributions and timing of water release from the snowpack (Kattelmann 1996). Generally, water from rainfall can be stored in snowpack until reaching the liquid water holding capacity (generally ~10% SWE) before being released, however, melting energy from liquid precipitation can increase snowmelt and decrease water holding capacity which has the potential to enhance runoff generation (Rössler et al. 2013). In thick snowpacks, where the melting energy is low, precipitation generated runoff can be reduced as the water is held within the snowpack, but in thinner snowpacks, such as those seen in early winter on Mount Washington, precipitation induced snowmelt can have a greatly amplifying effect on runoff and flood generation potential. The main driving factors of a ROS flood are extent of snow cover, freeze/thaw elevations, SWE of the snowpack, and duration and intensity of liquid precipitation (Mccabe et al.).

Kroczynski's PA case study is a fantastic example of the difficulties of forecasting for ROS floods, as high intensity precipitation falling onto a preexisting snowpack will not always result in flooding. Snowpack composition plays a large role in determining runoff generation. The impeding characteristics of ice layers can double the holding capacity of a snowpack, while preconditioning can increase flow rates through a snowpack (Singh et al. 1997). After a

[1] Paraphrased from currently unpublished Charlie Peachey Mount Washington ROS Paper

snowpack has been conditioned rainfall intensity has minimal impact on runoff timing and may prevent the snowpack from holding any additional water (Würzer et al. 2016). Spatial variability of snowpacks as well as limited SWE data complicate hydrological prediction of these ROS events, particularly their response times and runoff generation, essential information for flood mitigation.

Study Area:

Stream Area:

Primary meteorological observations used in this case study were collected at the Mount Washington Observatory, located at the summit of Mount Washington. The national Geologic Survey places the summit elevation at 6286 ft NAVD88. The Mount Washington Summit marks an intersection between three watersheds, Headwaters Ammonoosuc River, Peabody River-Androscoggin River, and Ellis River. Given that there is currently no stream gauge located in the Ellis River watershed, the Headwaters Saco River watershed is also included as it drains directly from the summit, though its border falls short of the true summit. These three watersheds are each contained within distinct hydrologic units; Headwaters Ammonoosuc in the Upper Connecticut unit, Peabody-Androscoggin in the Lower Androscoggin unit, and Headwaters Saco in the Saco unit.

Two stream gauges are located along the Saco river, in the Saco hydrologic unit, one in Bartlett and one in Conway NH. Located in the Headwaters Saco watershed, the Bartlett gauge has an elevation of 660ft NAVD88, 5626ft lower than the summit. Mean basin slope was calculated to be 30 degrees and drainage area to be 91sq mi. Summit runoff to this gauge occurs primarily through the Dry River, on the south facing side of Mount Washington. Located further to the south, in the Conway Lake-Saco River watershed, the Conway gauge has an elevation of 418ft NAVD88, placing it 5868ft below the summit, with a mean basin slope of 23 degrees. This gauge has a much larger drainage area, of 385sq mi. Despite its distance, the Conway gauge also drains from the Mount Washington summit, though its summit runoff comes by way of the Ellis River and Rocky Branch, in addition to the Dry River.

The Ammonoosuc gauge, situated in Bethlehem, NH, receives most of its summit runoff from the Ammonoosuc River, which flows along western aspects of the mountain. It also receives water from Clay and Jefferson Brooks via the Ammonoosuc and Burt Ravines. This gauge is located at an elevation of 794ft NAVD88, 5492ft below the summit, with a mean basin slope of 22 degrees. This is the smallest drainage examined, with a drainage area of 87.6sq mi.

The Peabody-Androscoggin gauge, located in Gorham NH, receives most of its summit runoff from the West Branch Peabody River through the Great Gulf area, giving it a mostly northern aspect. Unfortunately, headwater storage and various flood mitigation strategies employed along the Androscoggin have the potential to artificially increase discharge values; as such, the gauge and its data has been removed from this study.

Summit Area:

Mount Washington can be separated into four distinct areas of surficial deposits. The summit cone, where precipitation data is recorded, consists of upper slope diamicts. These are angular, heavily weathered cobble to boulder sized clasts of alpine metamorphic lithologies, sitting atop bedrock. While this setup is conducive to producing runoff, the holding capacity of this alpine region is quite low. Most precipitation falling on the summit will therefore runoff to lower elevations (Dethier et al. 2022). The ravines, existing in the subalpine region below the summit, are composed of two surficial units, both colluvial debris but distinguished by their location either on or below the unstable and rockfall prone slopes of the ravines. This debris consists of cobble to boulder sized clasts, matrix dominated diamicts and talus. Middle elevations outside of the ravines are composed of lower slope diamicts of variable size and weathering, likely originating from the higher elevations. This is the highest elevation on the mountain with significant areas of silt and clay, treeline is also located in the middle elevations at roughly 4500ft (Leak and Graber 1974). Water infiltration in this region is limited by the small amounts of clay and silt overlying bedrock (Heath et al. 2004). Lower elevations, below ravine level, consist of till, with variable clasts and silt, sand, and clay. These deposits are generally less than 20ft deep but can reach up to 100ft beneath hillocks and moraine features (Fowler 2010).

Methods:

The December 2023 ROS event will be characterized using a combination of meteorological, snowpack, and hydrologic data. Initially, the synoptic evolution of this event will be analyzed using historic surface analysis charts, created from local sounding and observational data, from the National Weather Service. Localized development of this event will be analyzed primarily using Mount Washington Observatory archival data. Hourly present weather codes will be obtained from the MWOBS's B-16 archives. Snowfall amounts, snow depth, and liquid precipitation totals, collected every six hours by summit observers, will be obtained from MWOBS's archive of synoptic weather reports. Mount Washington summit data will be supplemented with weather data from the North Conway NCON3 weather station, and observations from the Hermit Lake snow plot, located at the base of Tuckerman Ravine on Mount Washington. MWOBS summit data will be used as a primary data source, with NCON3 and Hermit Lake data used to inform event development at elevations below the summit.

Hermit Lake snow plot observations, in conjunction with observations submitted by the USFS Mount Washington Avalanche Center, will be used to characterize snowpack development in the month preceding this event. MWOBS B-16 hourly weather data and 6 hourly synoptic weather data will be used to confirm MWAC observations. These data are limited to locations above 3,000 ft, so Community Snow Observations will be used for an approximation of lower elevation snowpack in Carroll NH, located adjacent to the western side of Mount Washington.

Three USGS stream gauges are located in watersheds directly adjacent to the summit. The Ammonoosuc river gauge, in Bethlehem NH, the Peabody River gauge, a tributary of the

Androscoggin River, in Gorham NH, and the Saco River gauge, in Bartlett NH. Data from the Peabody gauge will be omitted since head water storage and flood mitigation measures occurring along this river have the potential to create artificially inflated stream flow values. Both daily stream discharge and gauge height values will be used for the two remaining gauges; discharge as an indicator of conditions along the entire river, and gauge height as an indicator of local flooding conditions. These data will be used to determine duration, onset, and intensity of event runoff. Another gauge, further downstream on the Saco River, located in Conway NH, will be used to supplement historic discharge data, with a daily discharge record dating back to 1903. While this gauge is not located in an immediately summit adjacent basin, it is fed directly by flow from the higher summits and has the longest record of any of the available gauges. A Pearson 3 function will be run over the Conway and Bethlehem discharge data sets to determine a recurrence interval for the December 2023 flooding event. Additionally, daily discharge values for this event from the gauges will be directly compared to daily discharge values from previous major hydro-meteorological events in the region.

Results:

Weather Conditions/Meteorologic Setup:

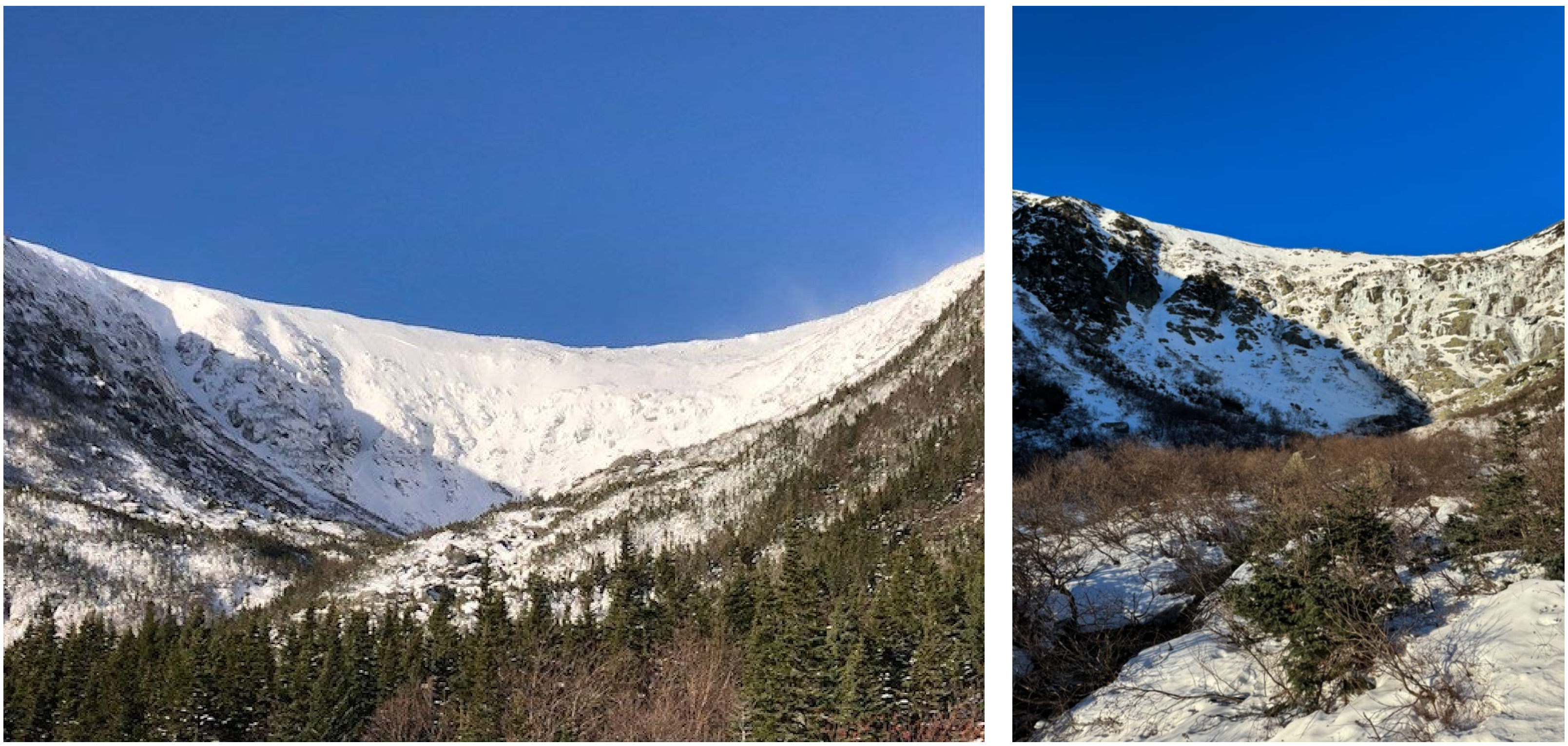
The weather in the three days preceding the December 2023 ROS event was characterized by generally clear conditions. No precipitation fell at the summit between the 2am observation on Dec 14th and the 4pm observation on December 17th. No precipitation was recorded at the NCON3 station for December 14th through the 17th.

The December ROS event began in the late afternoon of December 17th 2023. The 4pm EST summit observation reported freezing drizzle, becoming a combination of freezing rain/drizzle, ice pellets, and rain, which continued until the 1am EST observation on December 18th. At this observation, summit temperatures rose to 35ºF and precipitation transitioned to rain, which continued for the next 18 hours before becoming a combination of rain and freezing rain at 7pm on December 18th. Precipitation ended completely by the 10pm EST observation that same day. From December 17th to 18th, across 31 hours, this system dropped a total of 4.1 inches of precipitation at the Mount Washington summit. The lower elevation NCON3 station recorded 3.71 inches of precipitation from the same event.

A strengthening low-pressure system moving north along the eastern seaboard resulted in increasing temperatures and precipitation throughout the region. The elongated shape of this low resulted in an extended wind field over the ocean, contributing significant moisture to the system and driving up precipitation totals. By 11am EST on December 18th, the low was centered over New England, with a pressure of 982mb, a 16mb drop from 24 hours prior. Rainfall peaked in intensity at the summit around 1pm EST on December 18th, with lighter rainfall continuing for hours afterward. The passage of repeated warm fronts spinning off this low drove temperatures up to a new daily record high of 41ºF at the Mount Washington summit before decreasing back below freezing by 6pm EST on December 18th. Primarily clear conditions dominated the week following this event, with only trace precipitation recorded.

<u>Snowpack Composition:</u>

From December 17th to 19th elevations below the summit, specifically Hermit Lake and Carroll, saw a near complete eradication of snowpack. On December 17th, Carroll reported 4.5 inches and Hermit Lake reported nearly 18 inches of snowpack, both of which were reduced to 0 by the morning of December 19th. The summit saw a similar pattern, with 5 inches of snow and ice reported at 4PM EST reduced to 1 inch by December 19th.



View of Tuckerman Ravine before and after ROS event (photos courtesy of Eli Hanschka)

On December 15th, Tuckerman ravine reported up to 83 inches of snow on eastern aspects, with variable depths around the remainder of the bowl. This snowpack was characterized by a substantial layer of wind transported snow over multiple crusts with damp, granular snow underneath. This observed granular snow would suggest a general absence of ice beneath the ravine snowpack. By the next MWAC observation on December 21st, the snowpack was undermined by audibly running water and snowpack had been visibly reduced with bare rock newly visible around a majority of the ravine.

Ground Conditioning/Almanac Data:

The 2023 year was the 4th wettest on record at the NCON3 station, with a total of 61.7 inches liquid equivalent recorded by the end of December. December alone netted 7.35 inches liquid equivalent precipitation, 2.8 inches higher than average. However, the fall season preceding this event was cooler and drier than is typical, with only 10.44 inches liquid equivalent precipitation recorded for the September to November period, 3.16 inches below average. November alone saw 1.84 inches liquid equivalent precipitation less than average.

Stream Conditions:

This event's hydrologic response occurred shortly after the onset of steady rain and resulted in major flooding in the drainages surrounding Mount Washington. Gauge height measurements exceeded the threshold for major flooding at every gauge excepting that of the Amonoosuc River at Bethlehem which reached moderate levels. These flood heights were reached by midday on December 18th and had reduced back below the threshold for even minor flooding by December 19th. This response was intense, immediate, and relatively short lived[2].

This event produced the largest daily streamflow value (9810 ft3/s) ever recorded by the Saco River gauge in Bartlett, exceeding those of Hurricane Irene, Tropical Storm Philippe, and any other snowmelt event with the last decade. At the Ammonoosuc River at Bethlehem Gauge, this event (4760 ft3/s) ranks as the fourth largest recorded since 1939. The Saco River at Conway gauge has the longest record of the three, dating back to 1903, with the December 18, 2023 streamflow of 24300 ft3/s ranked sixth, exceeding that produced by Hurricanes Irene, Agnes, and Sandy. No larger out-of-season rain-on-snow event has ever been recorded at this gauge.

A log pearson function for the Ammonoosuc and Saco at Conway gauges yielded high recurrence intervals for both December 18th and 19th daily streamflow values. Streamflow at the Ammonoosuc gauge on the 18th produced an almost 800 year recurrence interval, followed by a 125 year recurrence interval for the 19th. The Conway gauge had similar results, 795 years for December 18th and 485 years for December 19th.

Discussion:

While the December 2023 rain-on-snow event occurred too recently to be included in the climatology used by this paper, it serves as an example of the potential magnitude of ROS events in the region. The December event resulted in the 6th highest runoff recorded by the Saco River gauge (Conway) since 1903. With the exception of Tropical Storm Philippe, the December event, lasting nearly 2 days, stands out as the shortest duration event to trigger daily runoff surpassing 21,000ft3/s at this stream gauge. Considering that the average duration of ROS events analyzed in this study is 1.7 days, it's noteworthy that an event fitting within this average ROS timeframe yielded runoff comparable to that of much longer events. These results are mirrored in the

[2] Graphs in appendix

shorter records of the two other gauges located in more immediate subbasins. Of the larger recorded events, only two occurred without the influence of snowmelt, receiving 11.35 inches and 6.37 inches of liquid precipitation over four and two days, respectively, much higher totals than that of the December 2023 event. This is especially relevant given that the December snowpack was thinner than average at only 45cm and, regardless, rainfall has been found to be the more significant contributor to ROS runoff generation (Wayand et al. 2015). Each larger event saw either much higher precipitation totals or the addition of spring snowmelt, typically much deeper and denser than the early season snowpack of this 2023 event.

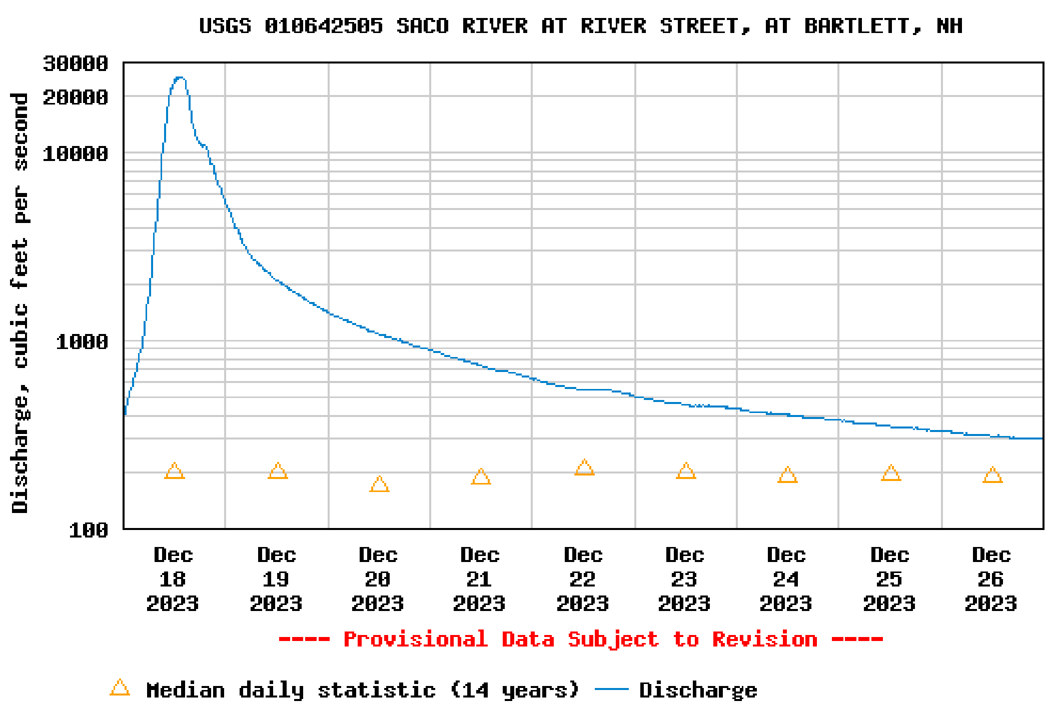
Relatively thin snowpack in December 2023 (as compared to that in the spring) in conjunction with the lack of ice within this snow created conditions favorable to a rapid runoff response, as seen in the stream gauge data (Singh et al. 1997; Würzer et al. 2016). Relatively thin snow cover also allowed for the near complete eradication of snowpack at all elevations on Mount Washington. It's likely that this snowmelt, particularly the near complete melting made possible by thin early season snowpack, allowed the 4.1in of liquid precipitation falling across 31 hours to result in a hydrologic forcing comparable to that caused by 6.37in of liquid precipitation falling across 32 hours during Tropical Storm Philippe. There exists space to examine why this event, falling on a thinner than average December snowpack, resulted in runoff values surpassing those of any other out of season rain on snow event in the region since 1903. As SWE, extent of snow-cover, and freeze/thaw elevations are named as primary driving forces behind ROS flooding, further investigation into these variables would be beneficial in developing a more thorough understanding of the development of this event (Rössler et al. 2013). Additionally, an examination of ground saturation, snowpack conditioning and the runoff generating potential of thin snowpacks would also increase understanding of this event. As upland basins are the most heavily influenced by ROS events (Freudiger et al. 2014), an increase in of ROS events in the region, as indicated by this study, have the potential to greatly impact Mount Washington and it's immediate subbasins. This event serves as an example of the high runoff and subsequent flooding potential resulting from an increasing frequency of out of season ROS events, even those falling on thin snowpacks, in the Mount Washington region.

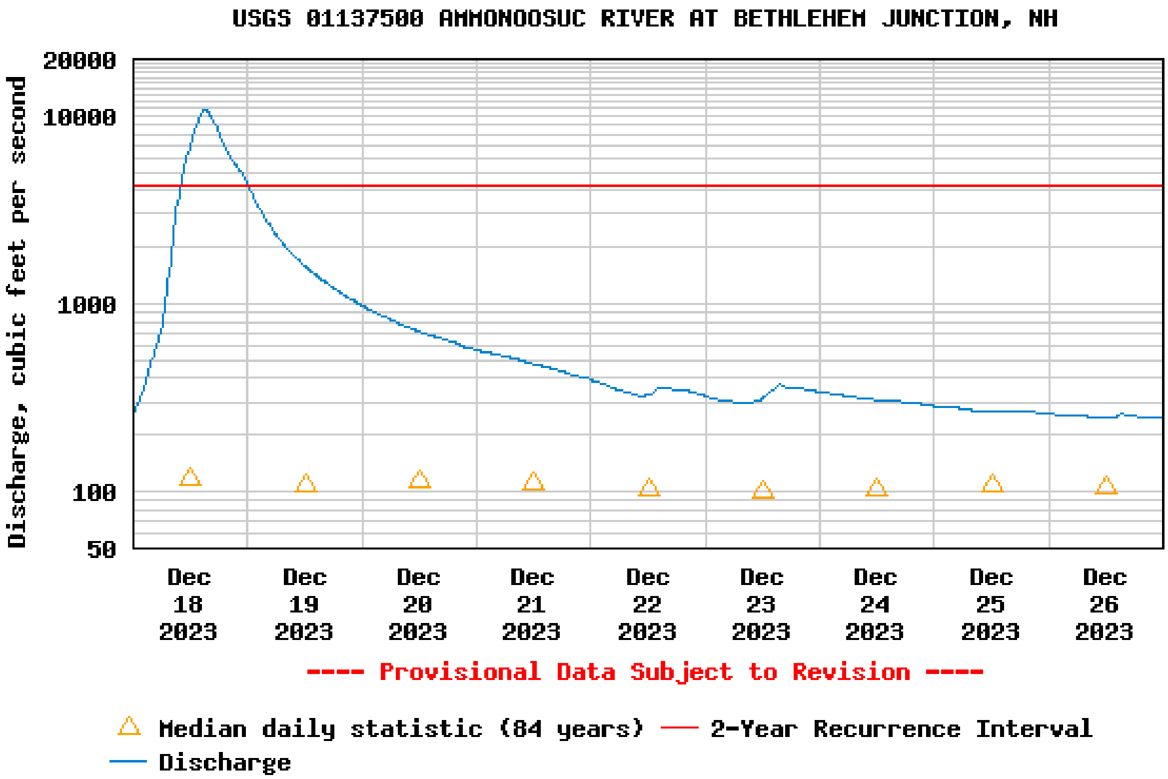
Conclusions:

The potential impacts of an increasing frequency of ROS events, as shown by the larger study, of which this case study is only a section, is given greater context through this analysis of the December 2023 ROS event. Taking place over the course of 31 hours, this event produced 4.1 inches of rainfall at the Mount Washington summit, almost completely eradicating snowpack at all elevations. The event caused major flooding at a majority of the examined gauges and generated daily runoff numbers higher than any other non-spring ROS event in over a century. Calculated recurrence intervals for these discharge values reached nearly 800 years. Given the below average snowpack and less than extreme rainfall which led to this event, as the frequency of ROS events increases in the region, it is possible that ROS floods of this magnitude will begin to become more common. This is especially relevant given projected intensity increases in the global water cycle and extremely wet weather resulting from anthropogenic climate change (Pörtner 2023). Given the extent of damages caused by this event, the implications of increased frequency of these floods could be significant for those communities and ecosystems on and below Mount Washington. As this event produced one of the largest runoff responses ever seen by each of three adjacent stream gauges, with rainfall totals noticeably lower than the majority of events with comparable runoff, and the majority of ROS induced runoff occurs as a direct result of rainfall, with snowmelt contributing minimally (Wayand et al. 2015), further work examining the factors contributing to this historic runoff would greatly benefit understanding of ROS flooding in the Northeast.

Appendix:

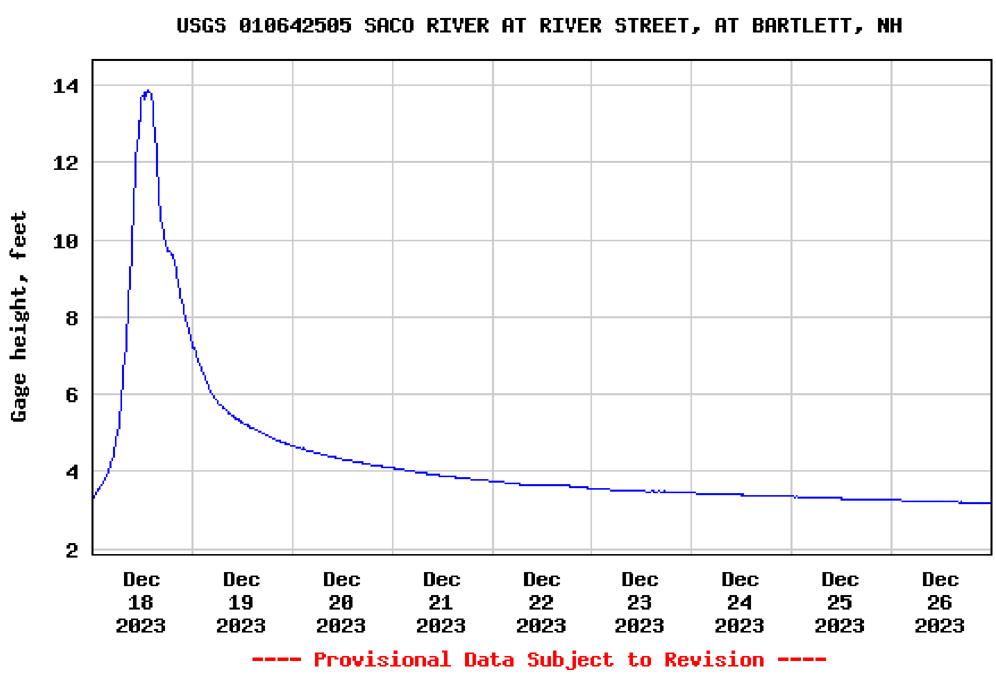
Stream Discharge Graphs:

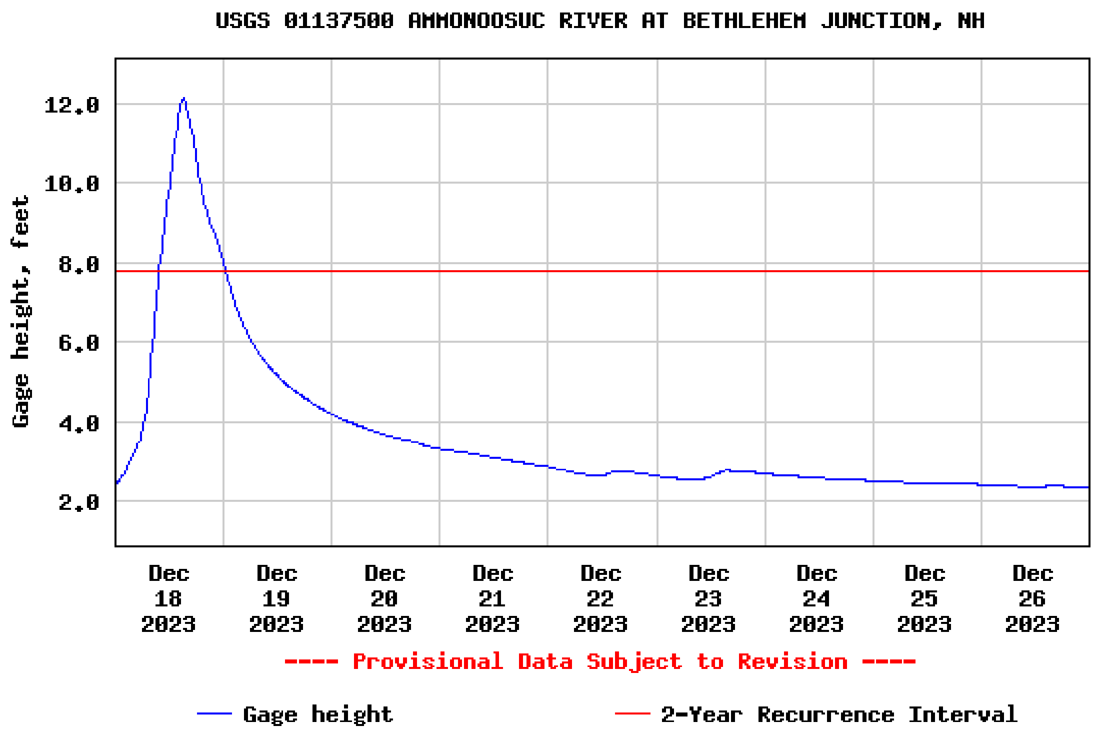




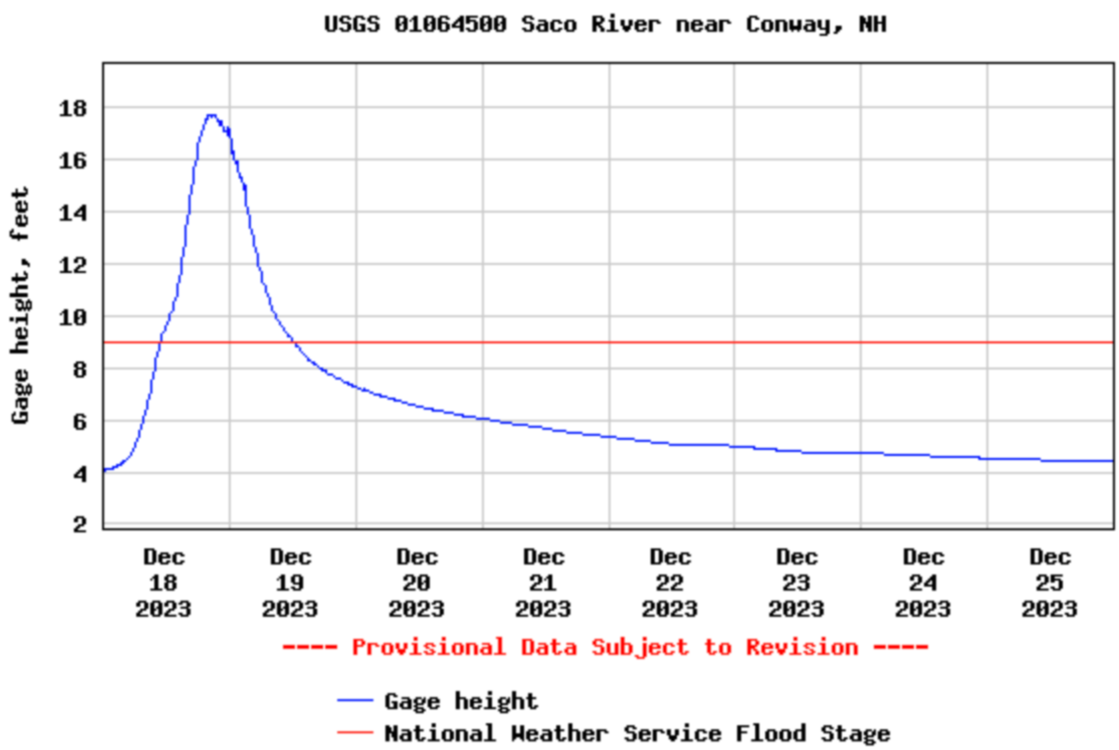
Only daily discharge data available for Saco at Conway stream gauge

Flood Stage Data:





USGS 01137500 AMMONOOSUC RIVER AT BETHLEHEM JUNCTION, NH
Gage height, feet
12.0
10.0
8.0
6.0
4.0
2.0
Dec 18 2023
Dec 19 2023
Dec 20 2023
Dec 21 2023
Dec 22 2023
Dec 23 2023
Dec 24 2023
Dec 25 2023
Dec 26 2023
---- Provisional Data Subject to Revision ----
Gage height
2-Year Recurrence Interval



USGS 01064500 Saco River near Conway, NH
Gage height, feet
18
16
14
12
10
8
6
4
2
Dec 18 2023
Dec 19 2023
Dec 20 2023
Dec 21 2023
Dec 22 2023
Dec 23 2023
Dec 24 2023
Dec 25 2023
---- Provisional Data Subject to Revision ----
Gage height
National Weather Service Flood Stage

Works Cited

Brown, P. J., R. S. Bradley, and F. T. Keimig, 2010: Changes in extreme climate indices for the Northeastern United States, 1870-2005. *J Clim*, **23**, 6555–6572, https://doi.org/10.1175/2010JCLI3363.1.

Dethier, D. P., N. Williams, and J. F. Fields, 2022: Snowmelt-Driven Seasonal Infiltration and Flow in the Upper Critical Zone, Niwot Ridge (Colorado), USA. *Water (Switzerland)*, **14**, https://doi.org/10.3390/w14152317.

Fowler, B., 2010: Interim Surficial Geologic Map Mt. Washington 7.5 Minute Quadrangle. *USGS Statemap.*

Freudiger, D., I. Kohn, K. Stahl, and M. Weiler, 2014: Large-scale analysis of changing frequencies of rain-on-snow events with flood-generation potential. *Hydrol Earth Syst Sci*, **18**, 2695–2709, https://doi.org/10.5194/hess-18-2695-2014.

Heath, R. C., North Carolina. Department of Natural Resources and Community Development., and Geological Survey (U.S.), 2004: *Basic ground-water hydrology*. U.S. Geological Survey, 86 pp.

Kattelmann, R., 1996: *Flooding from rain-on-snow events in the Sierra Nevada*. IAHS Publ.

Kroczynski, S., 2004: *A COMPARISON OF TWO RAIN-ON-SNOW EVENTS AND THE SUBSEQUENT HYDROLOGIC RESPONSES IN THREE SMALL RIVER BASINS IN CENTRAL PENNSYLVANIA*.

Leak, W. E., and R. E. Graber, *Forest Vegetation Related to Elevation in The White Mountains of New Hampshire*.

Mccabe, G. J., M. P. Clark, and L. E. Hay, RAIN-ON-SNOW EVENTS IN THE WESTERN UNITED STATES. https://doi.org/10.1175/BAMS-88-3-3l9.

Murray, G. L. D., and Coauthors, *Northeastern Naturalist Climate Trends on the Highest Peak of the Northeast: Mount Washington, NH*. 11 pp.

Pomeroy, J. W., R. E. Stewart, and P. H. Whitfield, 2016: The 2013 flood event in the South Saskatchewan and Elk River basins: Causes, assessment and damages. *Canadian Water Resources Journal*, **41**, 105–117, https://doi.org/10.1080/07011784.2015.1089190.

Pörtner 2023: Summary for Policymakers. *Climate Change 2022 – Impacts, Adaptation and Vulnerability*, Cambridge University Press, 3–34

Rössler, O., P. Froidevaux, U. Börst, R. Rickli, O. Martius, and R. Weingartner, 2013: A non-forecasted rain-on-snow flood in the Alps Retrospective analysis of a non-forecasted rain-on-snow flood in the Alps-a matter of model-limitations or unpredictable nature? A non-forecasted rain-on-snow flood in the Alps A non-forecasted rain-on-snow flood in the Alps. *Hydrol. Earth Syst. Sci. Discuss*, **10**, 12861–12904, https://doi.org/10.5194/hessd-10-12861-2013.

Seidel, T., D. Weihrauch, K. Kimball, A. Pszenny, R. Soboleski, E. Crete, and G. Murray, 2009: Evidence of climate change declines with elevation based on temperature and snow records from 1930s to 2006 on Mount Washington, New Hampshire, U.S.A. *Arct Antarct Alp Res*, **41**, 362–372, https://doi.org/10.1657/1938-4246-41.3.362.

Singh, P., G. Spitzbart, H. Hübl, and H. W. Weinmeister, 1997: Hydrological response of snowpack under rain-on-snow events: A field study. *J Hydrol (Amst)*, **202**, 1–20, https://doi.org/10.1016/S0022-1694(97)00004-8.

Vahedifard, F., A. Aghakouchak, E. Ragno, S. Shahrokhabadi, I. Mallakpour, 2017: Lessons from the Oroville Dam. *Science,* **355**, 1139-1140, DOI: 10.1126/science.aan0171.

Wayand, N. E., J. D. Lundquist, and M. P. Clark, 2015: Modeling the influence of hypsometry, vegetation, and storm energy on snowmelt contributions to basins during rain-on-snow floods. *Water Resour Res*, **51**, 8551–8569, https://doi.org/10.1002/2014WR016576.

Würzer, S., T. Jonas, N. Wever, and M. Lehning, 2016: Influence of initial snowpack properties on runoffformation during rain-on-snow events. *J Hydrometeorol*, **17**, 1801–1815, https://doi.org/10.1175/JHM-D-15-0181.1.

Young, S. S., and J. S. Young, 2021: Overall warming with reduced seasonality: Temperature change in New England, USA, 1900–2020. *Climate*, **9**, https://doi.org/10.3390/cli9120176.