Perspectives on Determining Flood Size for Risk Assessment at Smurfit-Stone

Sam Carlson, Clark Fork Coalition Staff Scientist
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Introduction

Although we have nearly 100 years of flow records for the Clark Fork River, it is difficult to understand the likelihood and frequency of large floods. This challenge is not unique to the Clark Fork River. Across the western United States and across the world, floods have exceeded our predictions and our imagination. History shows that extreme floods happen, and that century-long datasets may not prepare us for the size or severity of future floods. Despite the difficulty, it is necessary to predict the magnitude of future floods in order to safeguard critical infrastructure, human life, and environmental quality.

The Smurfit-Stone site is a former paper mill located adjacent to the Clark Fork River near Frenchtown, Montana. Areas of the site are known to contain toxic contaminants such as heavy metals and persistent organic pollutants, and an investigation of the extent of contamination at the site is currently underway as a part of the superfund process. A major flood at the Smurfit site could have catastrophic effects on both the downstream ecosystem and human health by exposing and eroding contaminated sediments and pushing toxic material into the Clark Fork River.

The largest flood measured by the nearby USGS gauge (Clark Fork below Missoula, 12353000) was 55,100 cfs in 1997, but fully characterizing the risk of catastrophic flooding at Smurfit requires consideration of much larger floods. This 1997 flood is understood as an event with a 25 year average recurrence interval, or a 4% chance of happening each year (Allied Engineering Services 2022). Risk assessments commonly include much larger floods, such as 100-year (1 in 100 annual chance) and 500-year (1 in 500 annual chance) events. Further, as many of the contaminants present at Smurfit are extremely persistent in the environment, a risk assessment needs to consider large floods possible under future climate conditions. Estimating the size of these floods requires extrapolation beyond the historical record, and the use of climate forecasting tools to represent expected changes in local hydrology.

Understanding and interpreting the findings of any flood risk assessment requires consideration of the broader context of what we do (and don't) know about the frequency of extreme flood events. This document provides some of this context, and is intended to compliment flood risk and climate vulnerability assessments of the Smurfit site and associated clean-up effort.

Historical Floods on the Clark Fork

The 1908 flood of the Clark Fork River predates flow recordings at USGS gauge near Smurfit and was the largest known flood on the river. Peak flow during this flood was estimated at 48,000 cfs above Missoula, which is nearly 50% greater than the largest recorded flow of 32,500 cfs in 2018 (U.S. Geological Survey 2024). Based on the observed relationship between peak flows above and below Missoula (and implicitly, the contribution of the Bitterroot River), I estimate that flow at the Smurfit site peaked around 70,000 cfs during this flood.

PO Box 7593
Missoula, MT
59807

T: 406.542.0539
F: 406.542.5632

The 1908 flood provides a few lessons that are directly relevant to the current situation at Smurfit:

The amount of mine waste dispersed by this flood is simply astonishing. We are still in the midst of a grueling effort to clean up this waste, and a complete cleanup of the affected area from Butte to Missoula is not possible. And while some concerns had been noted about the influx of mine waste material into the river, it would have been very difficult to anticipate the catastrophic outcome of the 1908 flood.

Although the 1908 flood occurred before the beginning of systematic streamflow measurements in this country, the flood was well documented in other ways. Historical photographs show the inundation of portions of Butte and Missoula, and newspaper records describe widespread destruction and the threat presented to the then-new Milltown dam in detail. The breadth of flood-deposited mine sediment provides another clear indication of the size of the flood. If this flood had occurred a few decades earlier, we might have no written records of its magnitude. The timing of this flood underscores the difficulty in understanding the size or likelihood of large floods. While the 1908 flood is the largest we know of, we have no written record and limited natural evidence to help us understand the occurrence of even larger floods.

Our intuitive understanding of the Clark Fork is shaped by what have seen, yet the 1908 flood demonstrates the possibility of larger floods. In considering the risk of a catastrophic flood at the Smurfit site, it is important remember that we have a lot of experience with common small and medium floods, but we cannot expect to have an intuitive understanding of extreme floods which are, by definition, rare. The 1908 disaster was un-imaginable at the time, but we must imagine extreme floods in the future in order to understand the risk of a catastrophic flood at Smurfit.

The Yellowstone River Flood

The 2022 flood of the Yellowstone River is an example of a recent extreme event in a nearby system, and it provides a contemporary perspective on the limitations of our ability to anticipate the likelihood of extreme floods. Peak flow during this flood was measured at 54,700 cfs at the Corwin Springs gauge (USGS 06191500), almost twice as large as the previously observed largest flow of 32,200 cfs in 1997.

To form a broader perspective on the difficulty of anticipating large floods, it is worth considering our understanding of flood frequency on the Yellowstone prior to the 2022 flood. As of the end of 2021, there were peak flow observations for 1890 – 1893 and from 1911 on at the Corwin Springs gauge. The flood frequency distribution from this period of record can be used to calculate the likelihood of large flood events, producing estimates of a 1 in 100 annual chance of a 33,000 cfs flood (similar to the largest observed flood in the record), a 1 in 500 chance of a 38,000 cfs flood, and a 1 in 1000 chance of a 40,000 cfs flood. In recognition of the uncertainty around these estimates, confidence intervals can also be calculated for these floods. The 95^{th} percentile of the confidence interval surrounding these estimates suggests a 1 in 100 chance of a 37,000 cfs flood, a 1 in 500 chance of a 42,000 cfs flood, and a 1 in 1000 chance of a 44,000 cfs flood. The 2022 flood was substantially larger than all of these.

Our quantitative understanding of the Yellowstone River in 2021 did not prepare us for the 54,700 cfs 2022 flood. Based on the statistical understanding of flood frequency at that time, the chance of a flood of this size was well under 1 in 1000, and perhaps closer to 1 in 100,000. Even using the high limit of the confidence interval, the estimated likelihood of the 2022 flood was infinitesimal.

The difficulty of understanding large but rare floods is a fundamental limitation of a data-driven approach and is not unique to any one statistical method. The estimates I use in this document are calculated using the methodology from Bulletin 17B (Interagency Committee on Water Data 1982) instead of the more complex methodology of Bulletin 17C (England Jr. et al. 2019), but the predicted frequencies of high flow events are not substantially different between these two methods in this system. It is inevitable that data-driven, statistical methods perform well for small and medium floods that are commonly observed, but that extrapolating beyond the bounds of historical observations yields far greater uncertainty.

Despite the statistical improbability, the Yellowstone flood of 2022 happened. Was it really an incredibly unlikely event, or was it a result of changing climate conditions? When the 2022 flood is incorporated into the dataset, this new information changes the calculated flood frequency distribution, generating estimates for the likelihood of a flood of this size between 1 in 500 and 1 in 1000. Should we have confidence in this updated model of flood frequency, or does it still suffer from the same fundamental limitations as the pre-2021 model? What lessons can we learn from this monumental flood, and can these lessons help us to understand flood risk at Smurfit?

Evaluating Future Flood Risk

The 2022 Yellowstone flood was caused by a combination of unusually heavy rain on an already-melting snowpack. Although the precise future climate conditions for this region are difficult to predict, a warming atmosphere has long been predicted to drive a general ‘intensification’ of the water cycle and an increase in the frequency of extreme precipitation events (Huntington 2006), and these predictions are increasingly clear in recent observations (Fischer and Knutti 2016). The 2022 Yellowstone flood may be an indication of the increasing frequency of large floods, and a specific example of the risks associated with increased precipitation intensity. There are numerous other examples of precipitation intensity driving a large flood, including the massive and unusual rainfall event during September 2013 that lead to flooding of multiple streams and rivers along the Colorado Front Range (Yochum 2015).

Our understanding of how a warming climate intensifies the water cycle challenges the use of historical records to anticipate future flood frequency. In areas where this intensification of precipitation is substantial, historical records may represent flood frequency for a fundamentally different system. As modern computational climate models gain greater precision and resolution, we have an increasing opportunity to form flood risk assessments that incorporate historical information along with the effects of current and future climate conditions. Recent studies confirm a substantial increase in the frequency and size of large floods (Swain et al. 2020), and suggest that future flood frequency may meet or exceed the upper confidence interval limit of a flood frequency analyses based on historical records (Quintero et al. 2018).

The upper limit of the confidence interval for the historical flood frequency distribution can be used to form a rough estimate of future flood frequency at Smurfit. Including the 1908 flood as a 70,000 cfs event in the historical record and considering only the upper (95%) confidence limit of the resulting prediction, I calculate a 1 in 100 chance of a 75,000 cfs flood, and a 1 in 500 chance of a 90,000 cfs flood. These estimates are based only on the limited historical record, and it is inevitable that this method provides limited insight into floods beyond the bounds of historical observations or the specific effects of a warming climate. Given these limitations, I suggest that these simplistic estimates should be considered minimum values for the reasonable range of extreme floods in the future. If the nearby Yellowstone provides any indication, floods much larger than these estimates may be expected.

To adequately assess the risk of flooding at Smurfit, it is necessary to look beyond the historical record at the nearby USGS gauge and consider the likelihood of extreme floods. Extreme floods may not fit with our intuitive or statistical understanding of the Clark Fork, yet history demonstrates that unimaginable floods do happen and can cause widespread devastation to communities and ecosystems. Further, flood size and frequency are increasing, driven by the connection between warming climate conditions and increased precipitation intensity. Preventing a disastrous flooding incident at Smurfit requires us to err on the side of caution, to use modern scientific approaches that consider both historical records and future climate conditions, and to anticipate the possibility of substantially larger future floods.

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