Flood Inundation Extent and Volume Mapping of the 2021 Nooksack River and Sumas Prairie Floods using Remote Sensing and GIS

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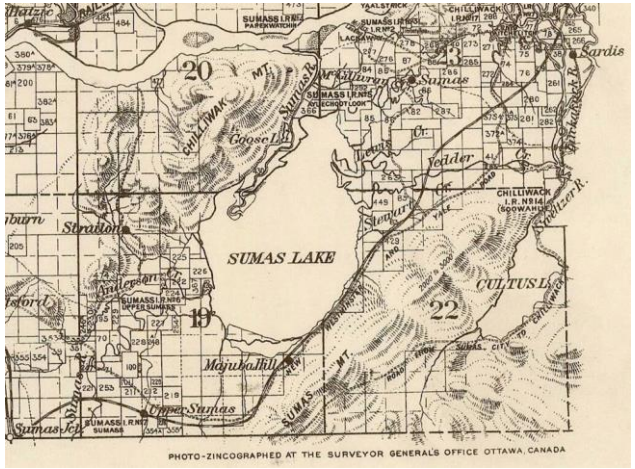
Jonathan McIntyre (i-Open Technologies)

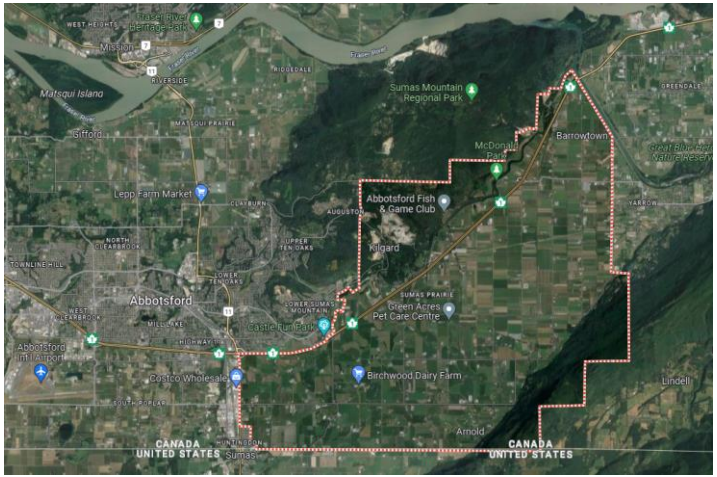
Land Acknowledgment

Simon Fraser Burnaby is located on the unceded traditional territories including, the Sḵwx̱wú7mesh Úxwumixw (Squamish), səl̓ilw̓ətaʔɬ (Tsleil-Waututh) and kʷikʷəƛ̓əm (Kwikwetlem), xʷməθkʷəy̓əm (Musqueam) Nations, on which SFU Burnaby is located.

Sumas Prairie is located on the unceded traditional territory of the Sumas First Nation. The Semá:th people's relationship with this land goes back time immemorial. Sumas Prairie is located on the former site of Sumas Lake which served as a central gathering place and food source for the Semá:th until it was drained for settler agricultural practices just over 100 years ago (Sumas First Nation)



Map of former Sumas Lake (City of Vancouver Archives)



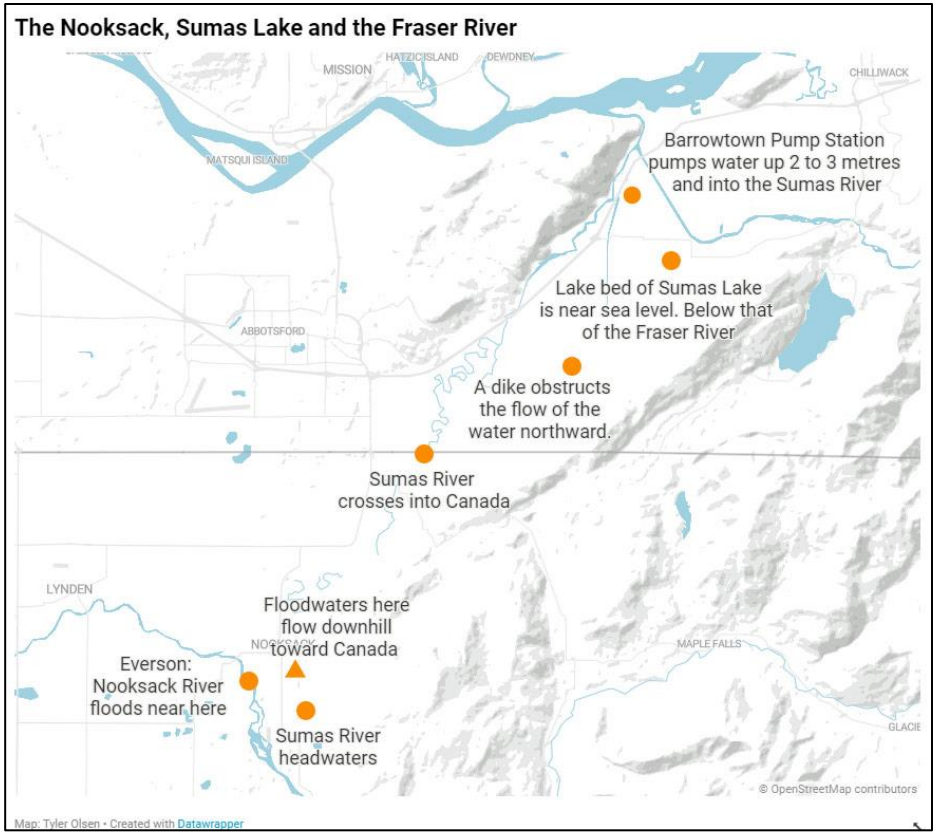
Map of Sumas Prairie (Google Maps)

Order of Presentation

- Background
- Methods
- Results
- Discussion/Conclusion
- References
- Questions

Background

- Sumas Prairie in Abbotsford B.C. experienced a severe flooding event from November 15th to December 8th, 2021
- This event was caused by a series of atmospheric rivers that led the Nooksack River spilling over into the Sumas River
- The series of floods in Abbotsford resulted in over a billion dollars of damage and the loss of thousands of farm animals (Globe and Mail)



Flood water movement (Tyler Olsen, 2021)

Research Questions:

- What areas were inundated by flood waters?
- How did the flood inundation extent change over time?
- What was the volume of flood water inside of Sumas Prairie?
- How and why do different areas have different drainage rates?

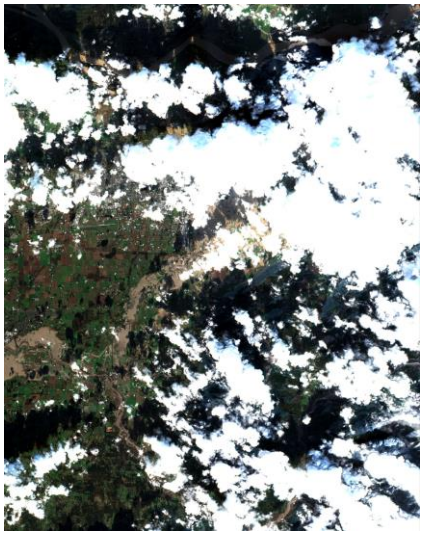
Inundation along the Nooksack River (Larry McCarter)

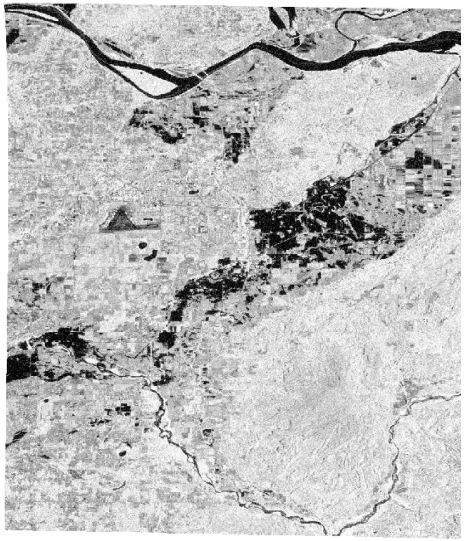
Inundated areas (Darryl Dyck)

Why Synthetic Aperture Radar (SAR)?

- Measures surface structure backscatter rather than passive reflection.
- Data can be collected day or night and under most weather conditions
- Radar wavelengths are also long enough to penetrate cloud coverage
- Sentinel-1 that collects SAR images has a 5-10 day revisit time

Sentinel-2 (true color) image of Sumas Prairie taken on November 16th, 2021

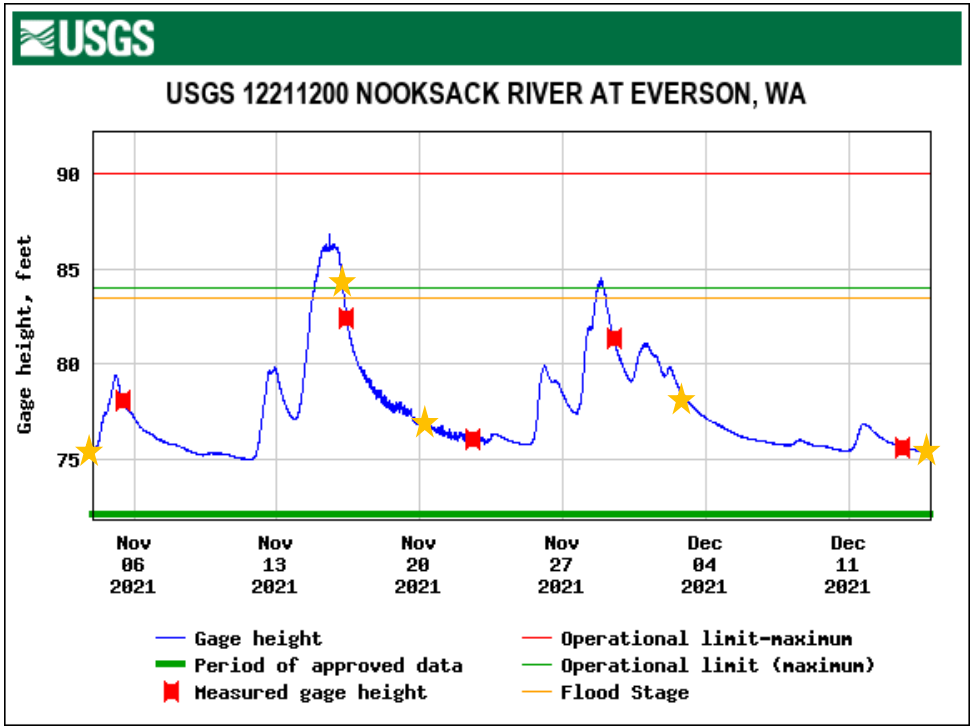




Sentinel-1 (SAR) image of Sumas Prairie taken on November 16th, 2021

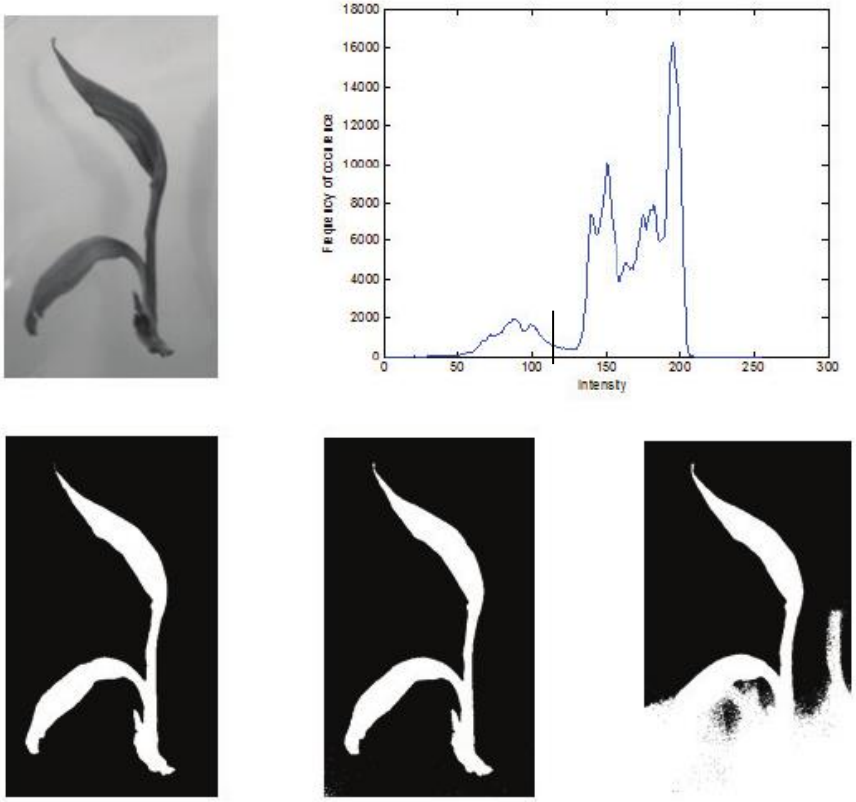
Flooding Timeline

Dates of SAR Image Acquisition
November 4th (Pre-flood)
November 16th
November 20th
November 25th
November 28th
December 2nd
December 7th
December 14th (Post-flood)



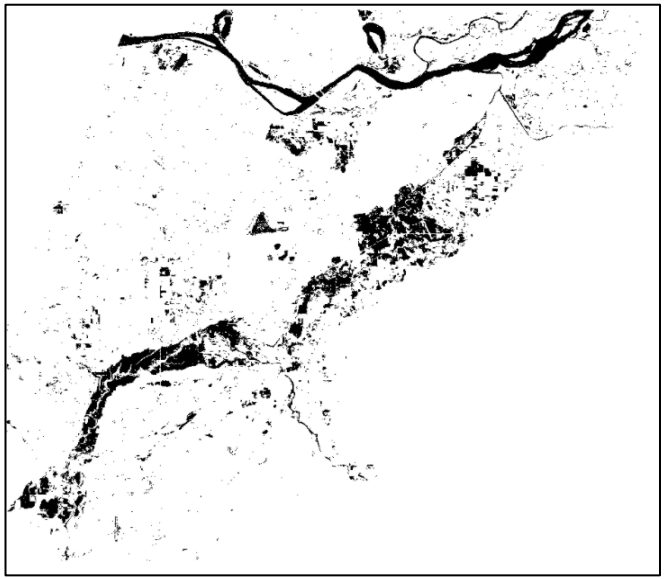
Nooksack River Elevation

Method for Delineating Flood Water: Edge Otsu “Threshold”



Otsu Threshold Histogram
(Ismail et al., 2009)

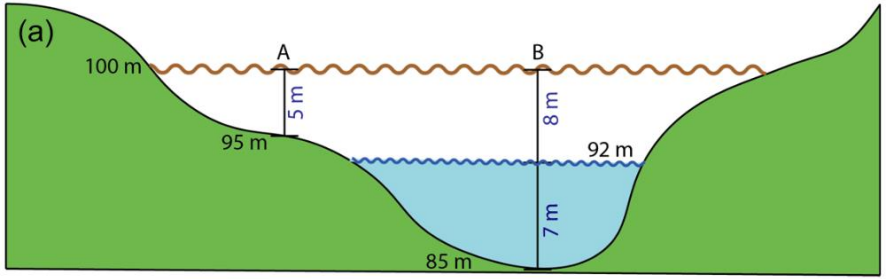
Otsu Thresholding is a technique that segments into two classes based on maximizing the variance between classes.



November 16 Water Inundation Map

Method for Determining Flood Inundation Depth and Volume

The Flood Water Depth Estimation Tool (FwDET) created by Cohen et al. (2017) uses digital elevation models (DEMs) to calculate flooding depth for each cell by calculating surface water elevation (based on local maxima) and subtracting it by each cell's terrain elevation

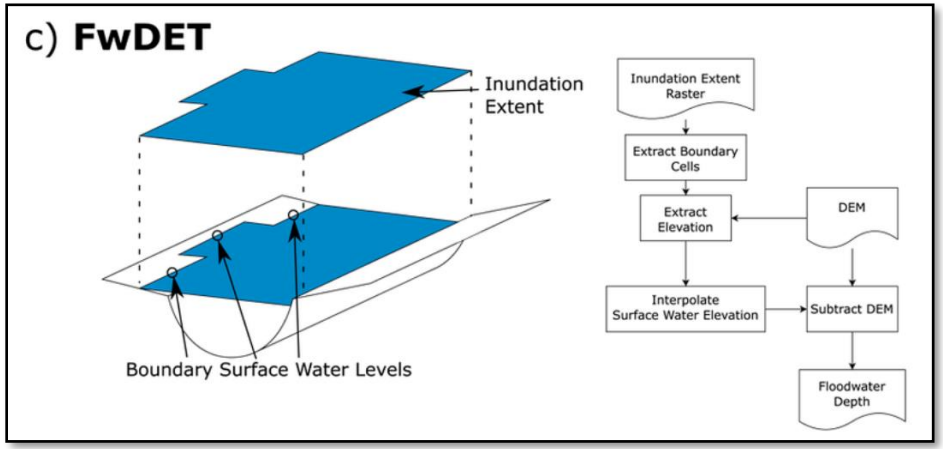


FwDET visualized (Cohen et al., 2019)

Flood Volume Calculation

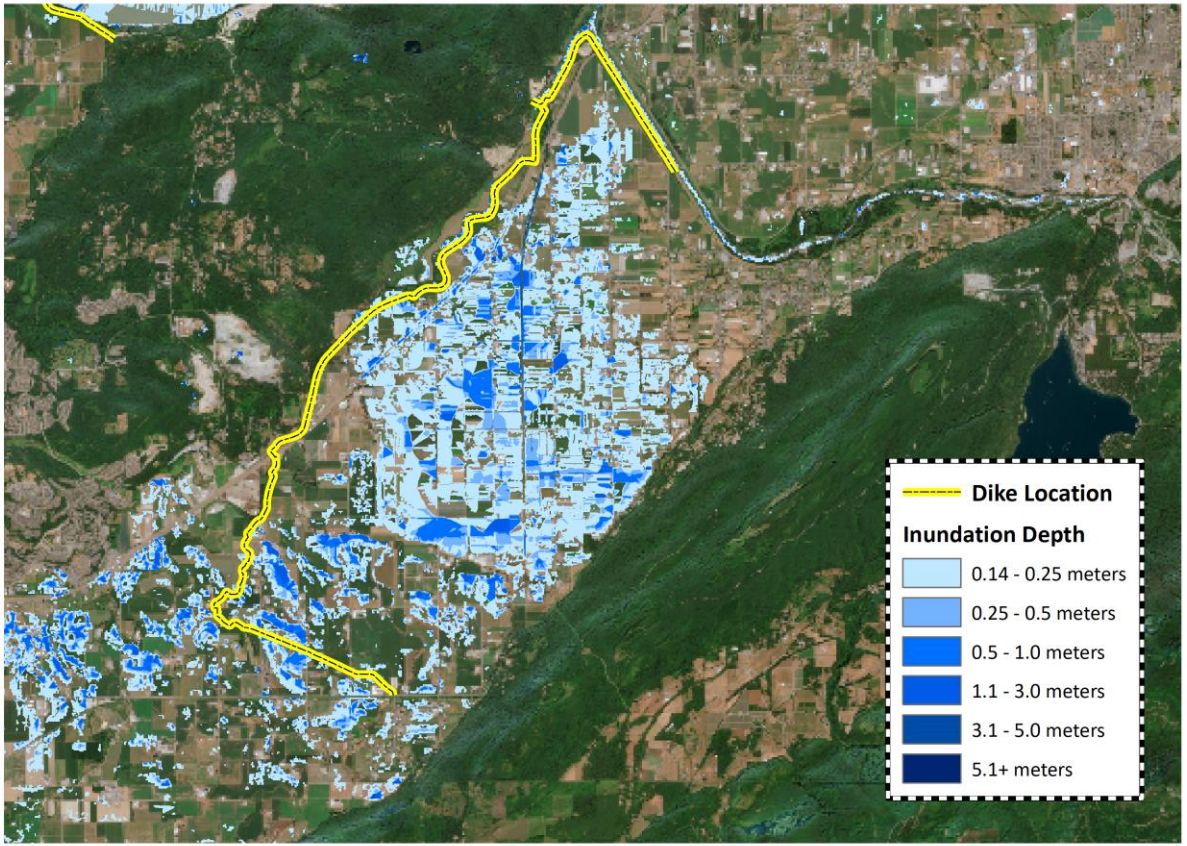
Cell Volume = Cell Depth x Image Spatial Resolution

Area Inundation Volume= Sum of each cell's volume in an area



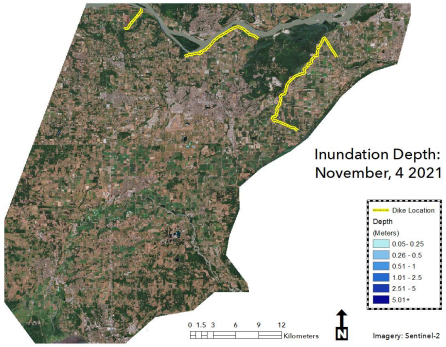
FwDET methodology (Teng et al., 2022)

Flooding Inundation Depth- November 20th

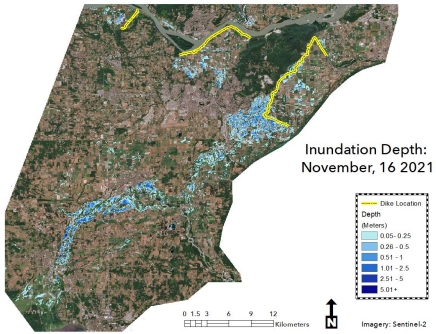


Imagery: Sentinel-2

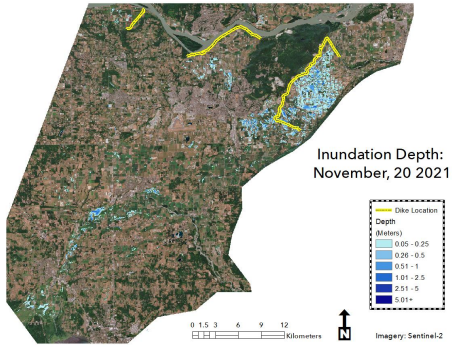
Tracking Changes in Flood Inundation Depth



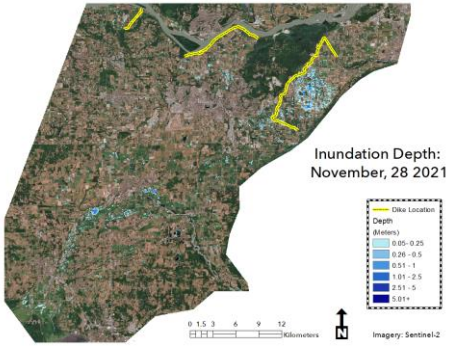
November 4, 2021



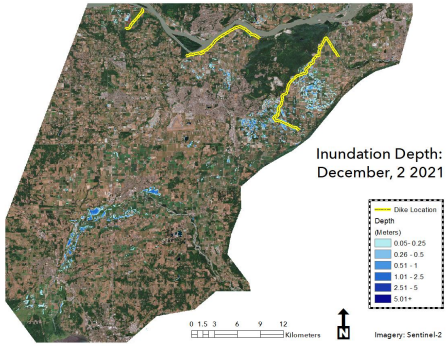
November 16, 2021



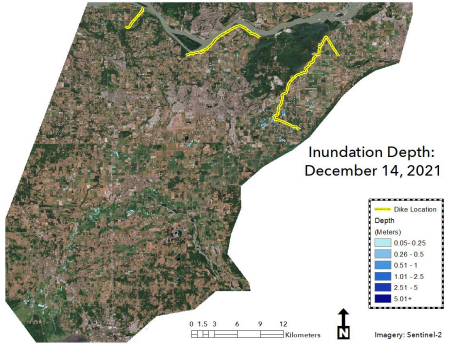
November 20, 2021



November 28, 2021



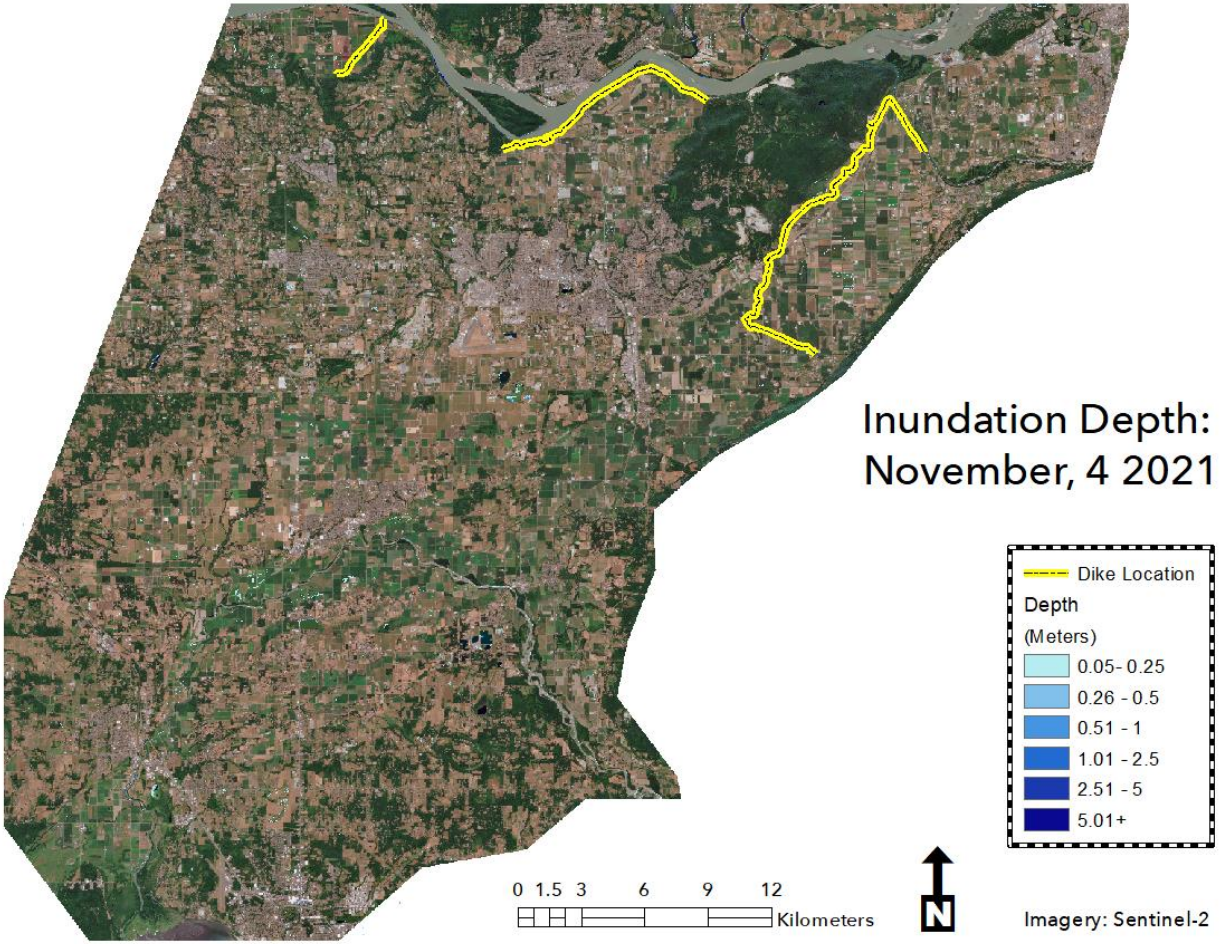
December 2, 2021



December 14, 2021

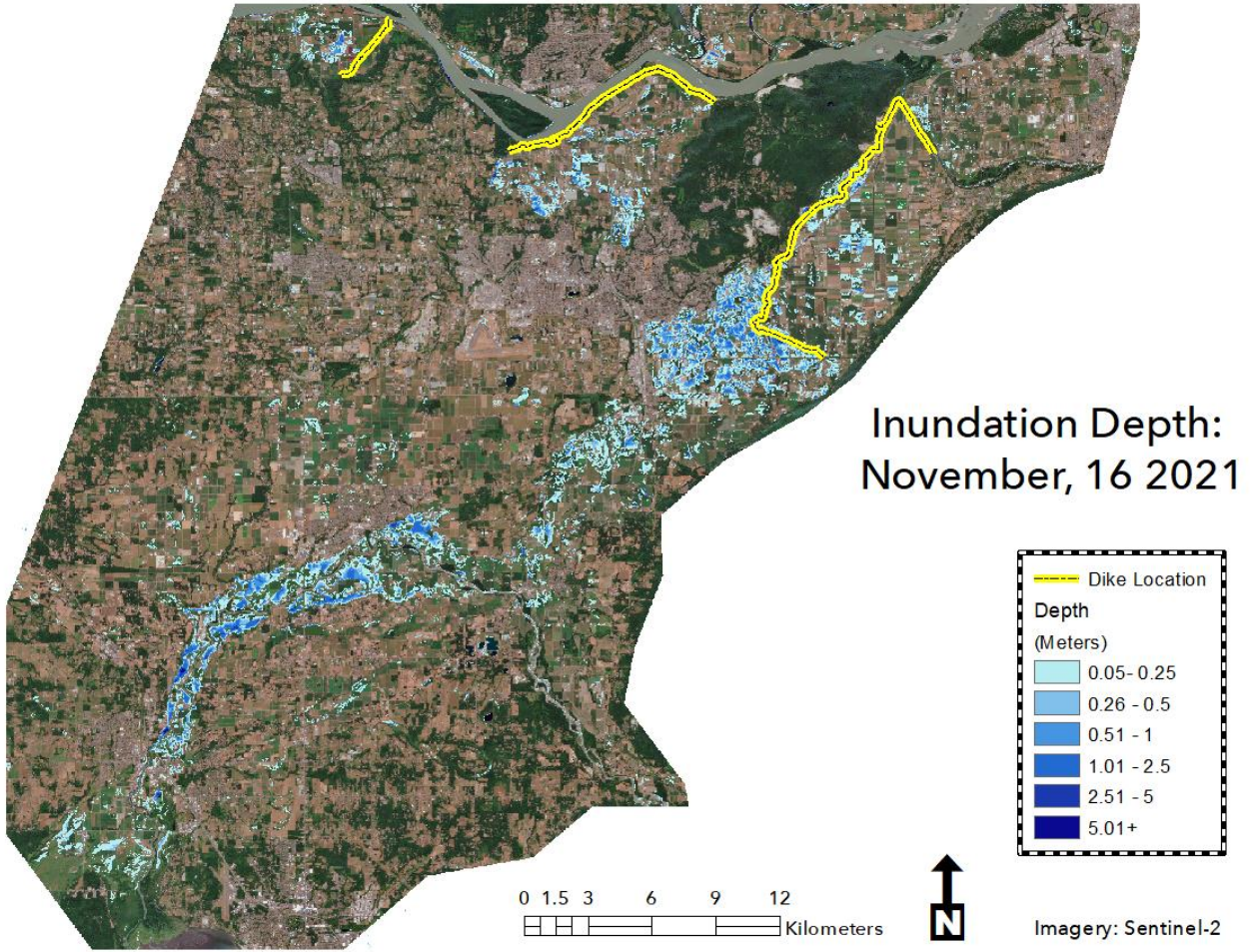
November 4, 2021

Preflood Image



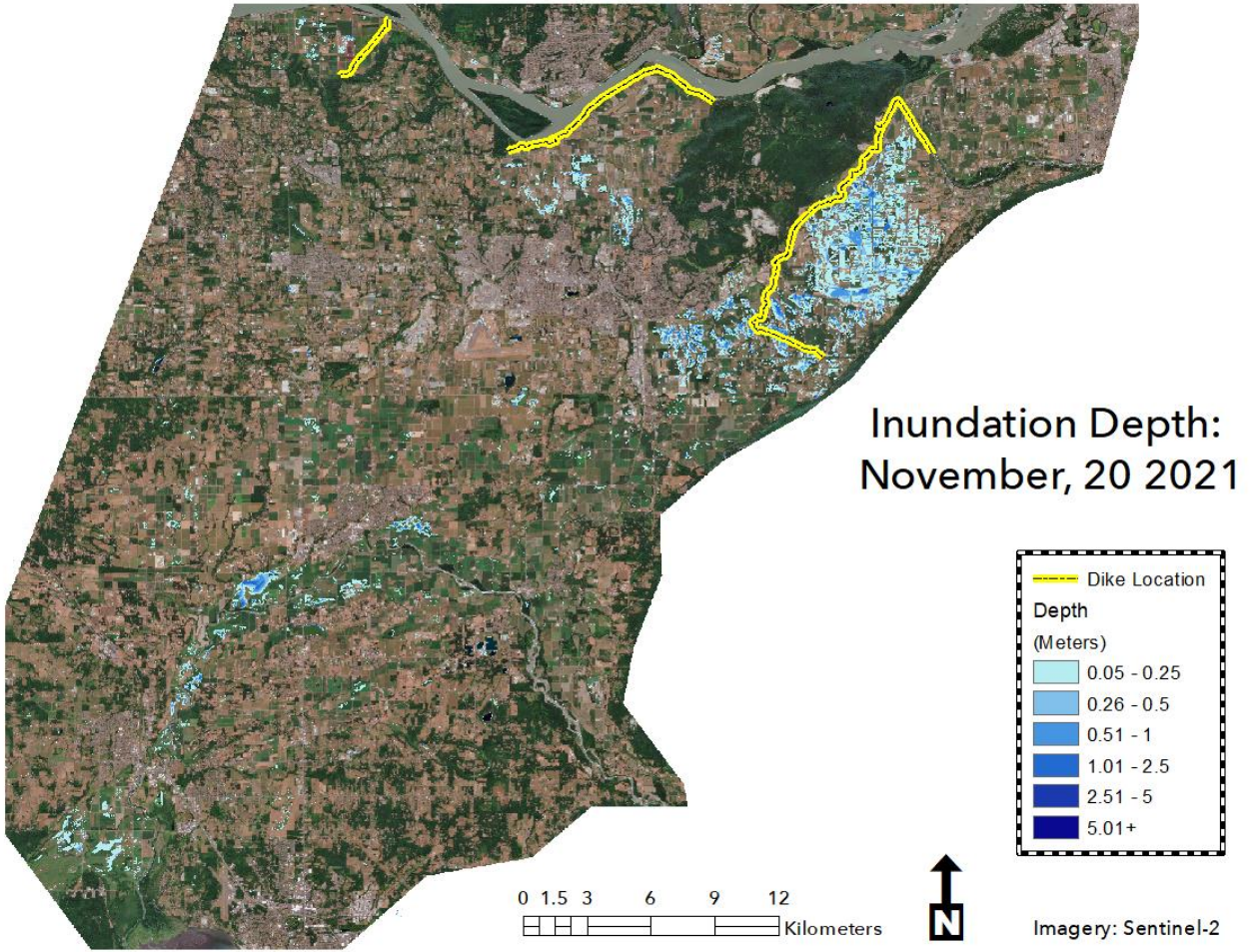
November 16, 2021

Image taken 1 day after the Nooksack River spilled over its bank



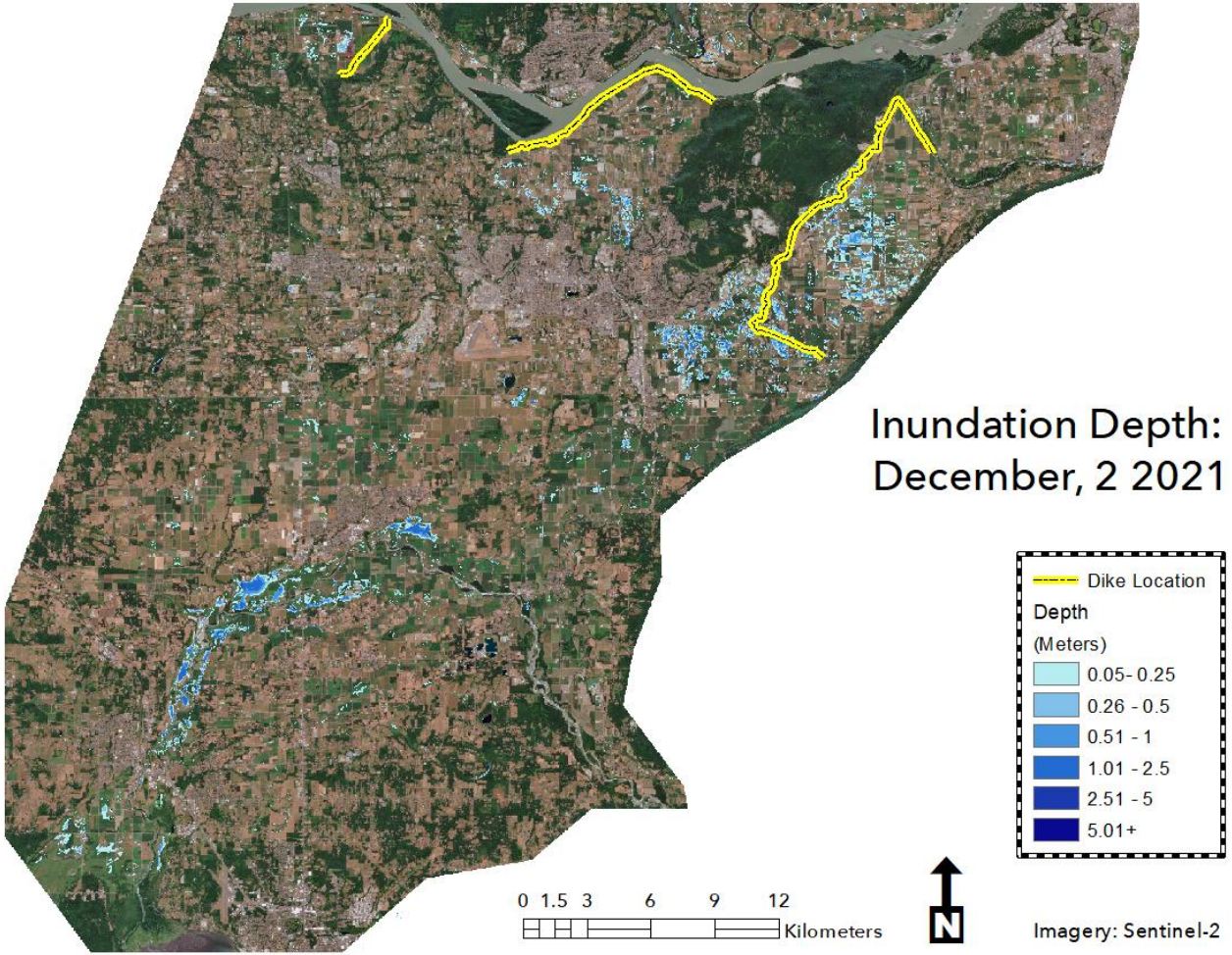
November 20, 2021

Image taken 5 days after Nooksack River flooded. The flood waters of the Nooksack have receded. However the spillover waters flowed into the Sumas River which flooded Sumas Prairie



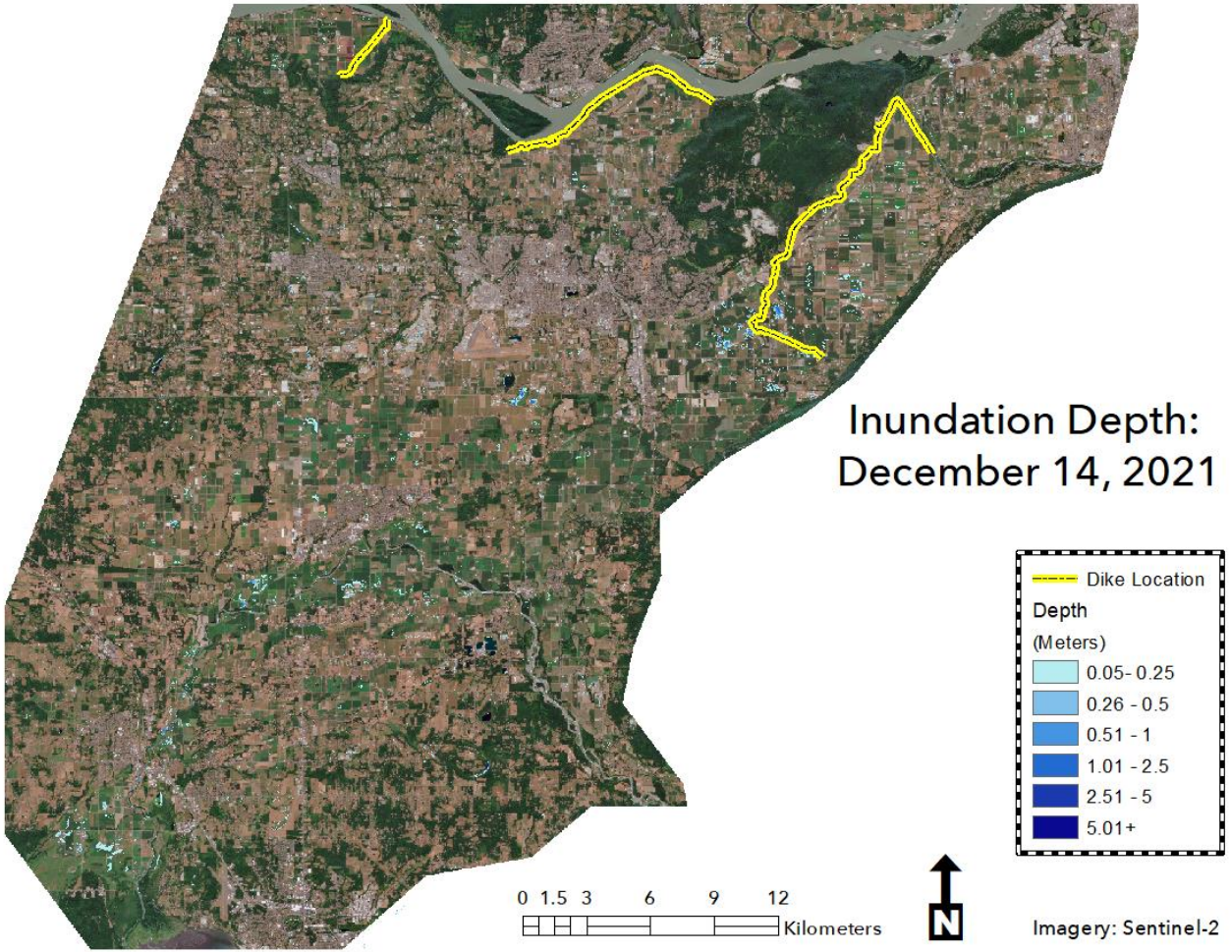
December 2, 2021

A second round of Atmospheric rivers cause the Nooksack River to flood again. However, the duration of the flooding was shorter and with less magnitude

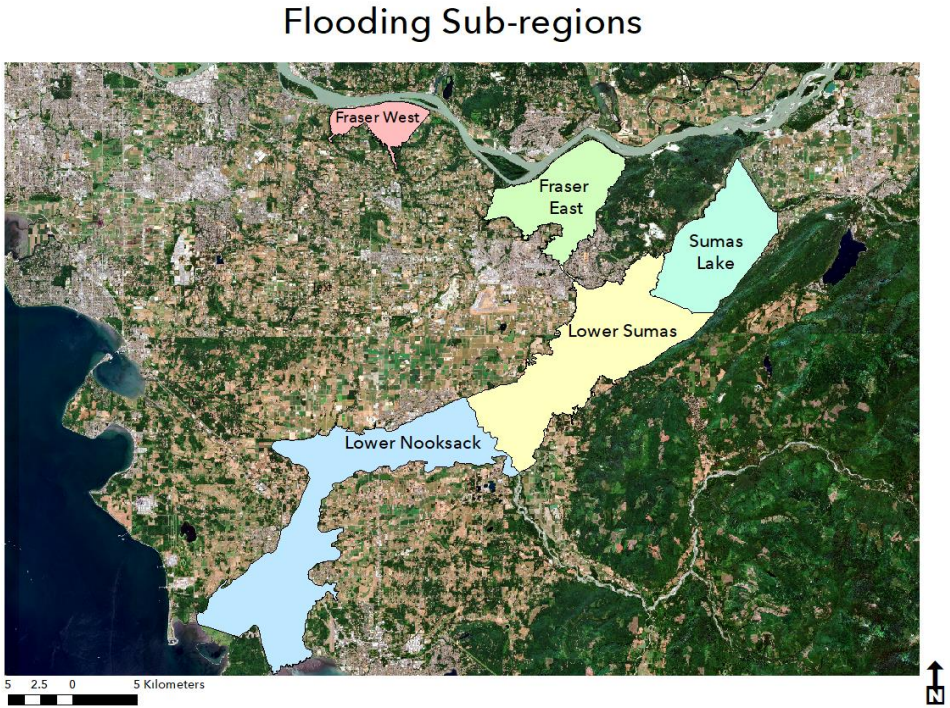


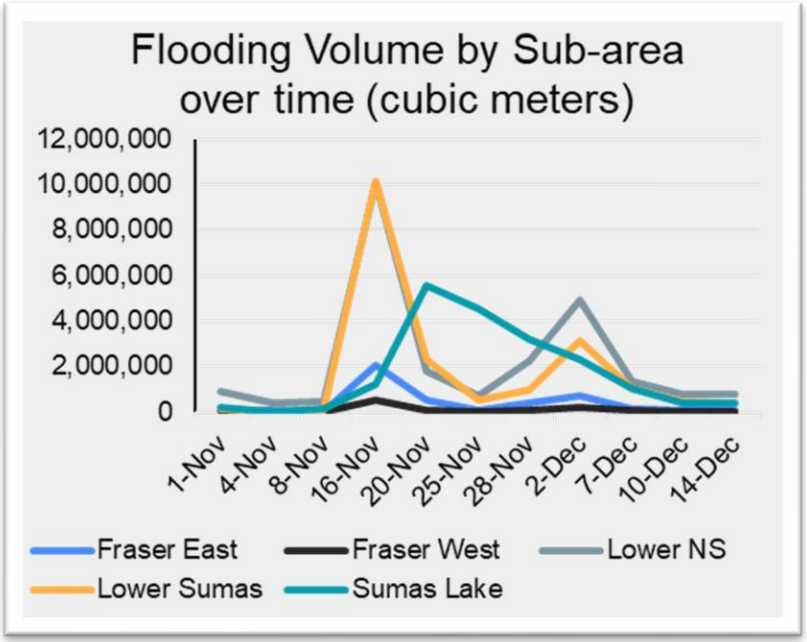
December 14, 2021

By December 14th, Sumas Prairie and its surrounding area have mostly returned to its pre-flood conditions



Comparing Flood Volumes and Drainage Rates in Different Regions

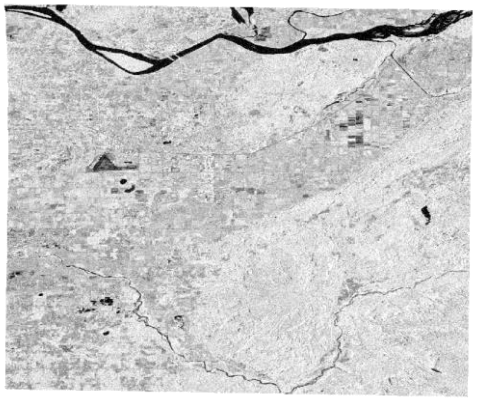




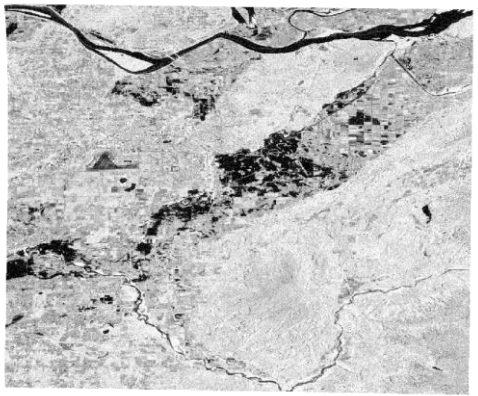
- Water drains through former Sumas Lake at the lowest rates of all regions

Conclusions and Next Steps

- SAR imagery alongside GIS is a powerful and reliable tool for mapping flood inundation throughout the duration of a flooding event and can be used by flood managers to decide if it necessary to order evacuations or built emergency infrastructure
- Work is being done to analyze flood water inundation maps alongside ancillary information (e.g. DEMs, infrastructure geospatial) to see how geomorphology and built infrastructure impact the rate of flood water drainage and water accumulation
- Imagery from additional dates will be processed to improve temporal resolution



Pre-flood SAR image



Flooded SAR image

Acknowledgements

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Works Cited

About Sumas First Nation : Sumas First Nation. http://www.sumasfirstnation.com/about-sumas-first-nation/. Accessed 12 Apr. 2023.

Cheung, Christopher. "Mapping the Flood in Abbotsford." *The Tyee*, The Tyee, 18 Nov. 2021, https://thetyee.ca/Analysis/2021/11/18/Mapping-Abbotsford-Flood/.

Climate Data Search Results - Daily Summaries | Climate Data Online (CDO) | National Climatic Data Center (NCDC). https://www.ncei.noaa.gov/cdo-web/results. Accessed 11 Apr. 2023.

Cohen, Sagy, et al. "The Floodwater Depth Estimation Tool (FwDET v2.0) for Improved Remote Sensing Analysis of Coastal Flooding." *Natural Hazards and Earth System Sciences*, vol. 19, no. 9, Sept. 2019, pp. 2053–65. *Copernicus Online Journals*, https://doi.org/10.5194/nhess-19-2053-2019.

Copernicus Sentinel-1 data [2021], processed by ESA.

Copernicus Sentinel-2 data [2021], processed by ESA.

"Figure 1. Map Showing the Location of the Abbotsford-Sumas Aquifer In..." *ResearchGate*, https://www.researchgate.net/figure/Map-showing-the-location-of-the-Abbotsford-Sumas-aquifer-in-southwestern-British-Columbia_fig1_253490522. Accessed 11 Apr. 2023.

"Habitat Program." *Nooksack Indian Tribe*, 11 Apr. 2023, https://nooksacktribe.org/departments/cultural-resources/habitat-program/.

Ismail, Abdul Halim, and Mohammad Hamiruce Marhaban. *A Simple Approach to Determine the Best Threshold Value for Automatic Image Thresholding*. Jan. 2009. *ResearchGate*, https://doi.org/10.1109/ICSIPA.2009.5478623.

'It's My Life's Work': B.C. Fruit and Vegetable Growers Face Uncertainty after Floods - Victoria News. https://www.vicnews.com/news/its-my-lifes-work-b-c-fruit-and-vegetable-growers-face-uncertainty-after-floods/. Accessed 11 Apr. 2023.

News ·, David P. Ball ·. CBC. "Flood-Ravaged Abbotsford Watching Nooksack River from U.S. 'like a Hawk' as Heavy Rains near | CBC News." *CBC*, 28 Nov. 2021, https://www.cbc.ca/news/canada/british-columbia/abbotsford-mayor-nooksack-river-heavy-rains-forecast-nov-27-1.6265548.

Photos: Record Rainfall Floods British Columbia and Washington State - The Atlantic. https://www.theatlantic.com/photo/2021/11/photos-record-rainfall-floods-british-columbia-and-washington-state/620733/. Accessed 8 Nov. 2023.

SNAP - ESA Sentinel Application Platform v2.0.2, http://step.esa.int 275

Sentinel-1 SAR Data Preparation for Extraction of Flood Footprints- A Case Study. https://www.researchgate.net/publication/338543869_Sentinel-1_SAR_Data_Preparation_for_Extraction_of_Flood_Footprints-_A_Case_Study. Accessed 11 Apr. 2023.

Teng, J., et al. "A Comprehensive Assessment of Floodwater Depth Estimation Models in Semiarid Regions." *Water Resources Research*, vol. 58, Nov. 2022. *ResearchGate*, https://doi.org/10.1029/2022WR032031.

Thousands of Animals Have Died on Flooded B.C. Farms in "agricultural Disaster" | CBC News. https://www.cbc.ca/news/canada/british-columbia/bc-flooding-2021-livestock-deaths-abbotsford-1.6252774. Accessed 12 Apr. 2023.

USGS Current Conditions for USGS 12211200 NOOKSACK RIVER AT EVERSON, WA. https://waterdata.usgs.gov/nwis/uv?site_no=12211200&legacy=1. Accessed 11 Apr. 2023.

What Is Sumas Lake? 100 Years Ago, Abbotsford Had a 134 Sq Km Lake (PHOTOS) | Urbanized. 22 Nov. 2021, https://dailyhive.com/vancouver/sumas-lake-sumas-prairie-barrowtown-pump-station-abbotsford-flooding.

Thank you! Questions?