Geo-INQUIRE Transnational Access Project Report: *Tsunami hazards posed by sublacustrine landslides in Lake Quinault, Washington State,* from SeanPaul La Selle (U.S. Geological Survey)

Geo-INQUIRE installation: BingClaw - Model for simulating dynamics of cohesive landslides (TA2-532-1)

Project title: Tsunami hazards posed by sublacustrine landslides in Lake Quinault, Washington State (original proposal title: Tsunami hazards posed by the Santa Cruz Basin submarine landslide complex, southern California)

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Project acronym:

Project report ID: C2_TA2-532-1_2 (2nd Call)

Transnational access team: Dr. Finn Løvholt and Dr. Steven J. Gibbons (Norwegian Geotechnical Institute, Oslo, Norway)

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Project report:

Recent bathymetric surveys[1] of Lake Quinault in Washington State reveal evidence of slope failures, many of which may have been induced by intense ground motion from ruptures of the Cascadia Subduction Zone (CSZ) and other active local crustal faults. The tsunami hazard posed by these sublacustrine landslides to low-lying shorelines remains unquantified, as no direct evidence (such as tsunami deposits) has been found. To assess these risks, we employ the numerical landslide model (BingClaw[2]) to generate initial hydrodynamic conditions for the dispersive tsunami propagation and inundation model GeoClaw[3].

Training on the use of BingClaw and GeoClaw was provided by Dr. Finn Løvholt and Dr. Steven Gibbons at the Norwegian Geotechnical Institute (NGI) in Oslo and conducted over five days. The result of this course was the development of a complete modeling workflow that encompasses a landslide's initial source generation through its resultant tsunami inundation, which was completed in the first week of the Geo-INQUIRE TA.

We decided to model a characteristic slope failure imaged along the northern shore of Lake Quinault, WA, at the mouth of McCormick Creek because the bathymetric data exhibit the minimum runout distance on the lake floor (Figure 1a) that can be used to tune BingClaw model parameters. High-resolution bathymetry of the lake bottom was used to estimate, in rough terms, the initial landslide volume and thickness distribution, which were used as initial conditions in the BingClaw landslide model. Sensitivity to key sedimentological model parameters was explored to estimate a range of possible tsunamigenic landslides that recreate the geomorphic expression of landslide runout observed in the bathymetry. Most default sedimentological parameters in BingClaw are empirically based on modeling studies of the Storegga Slide[2]. We found that using a remolding coefficient of 0.005 while lowering the default values of yield stresses and friction coefficients was necessary to match the observed runout (Figure 1b, 1c). A preliminary landslide source model was selected that generally matched the observed runout below McCormick Creek.

Using the outputs of landslide thickness from the preliminary BingClaw model as inputs to the GeoClaw model, we produced various models of tsunami propagation from this one landslide. We tested the effects of wave dispersion during tsunami propagation by running GeoClaw with the depth-averaged shallow water equations (SWE) and the dispersive depth-averaged Serre-Green-Naghdi (SGN) equations[3]. Initial results suggest that the net inundation and runup agree between the SWE and SGN models. The SWE model may be missing a high-frequency component of propagating waves that may pose a significant hazard to boats and infrastructure in the water (i.e., docks), but this component would be less important for structures on land (Figure 2).

Further work would be needed to assess the utility of tsunami generation using empirical equations[4] that predict dipole tsunami sources based on bulk landslide dimensions. A comparison of the tsunamis generated by dipole sources vs the dynamic runout in BingClaw is essential to determine the applicability of these models. We also identified the need to continue testing dispersive tsunami model implementations such as the Madsen-Sorenson equations[3] and to produce longer runs of the tsunami models to assess if seiching can be generated by a sublacustrine landslide.

Our initial model setup files and simulation results are published and publicly available in a U.S. Geological Survey data-release[5] and the Simulation Data Lake[6].

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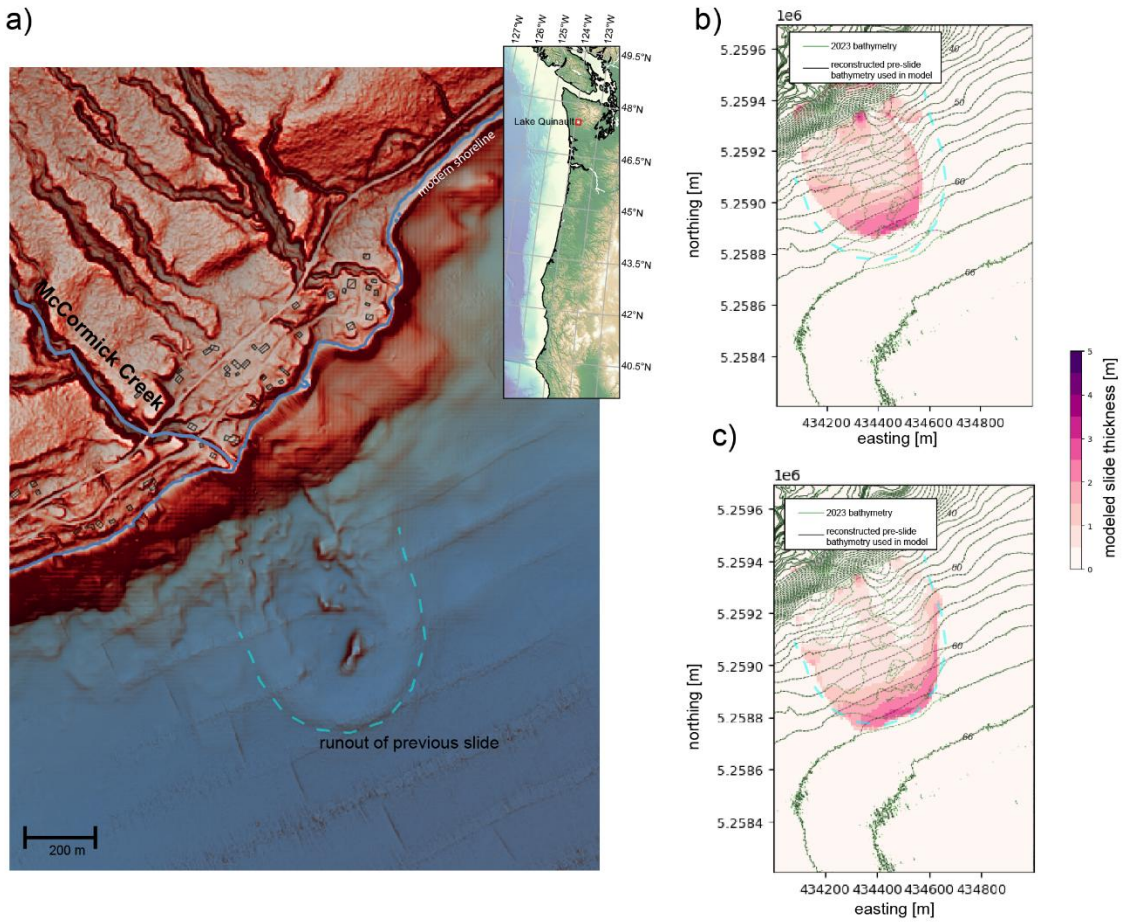

Figure 1: a) Red-relief image of combined topography and bathymetry along the north shore of Lake Quinault at McCormick Creek. The runout of a previous landslide (cyan dashed line) is visible in the lake bathymetry, and this geomorphic expression was used to evaluate landslide models. b) BingClaw[2] model output of slide thickness in meters after sediment comes to a stop. 2-meter contour intervals, green contours show the original bathymetry surveyed in 2023, with the toe of the slide debris visible. Black contours show the smoothed bathymetry used in the BingClaw model. Model parameters in this panel used an initial yield strength of 10 kPa, a residual yield strength of 1 kPa, and a remolding coefficient of 0.01. c) Newly modeled runout[5] that more accurately matches observed runout and requires lower yield strengths—initial yield strength of 5 kPa, residual yield strength of 0.5 kPa, remolding coefficient of 0.005.

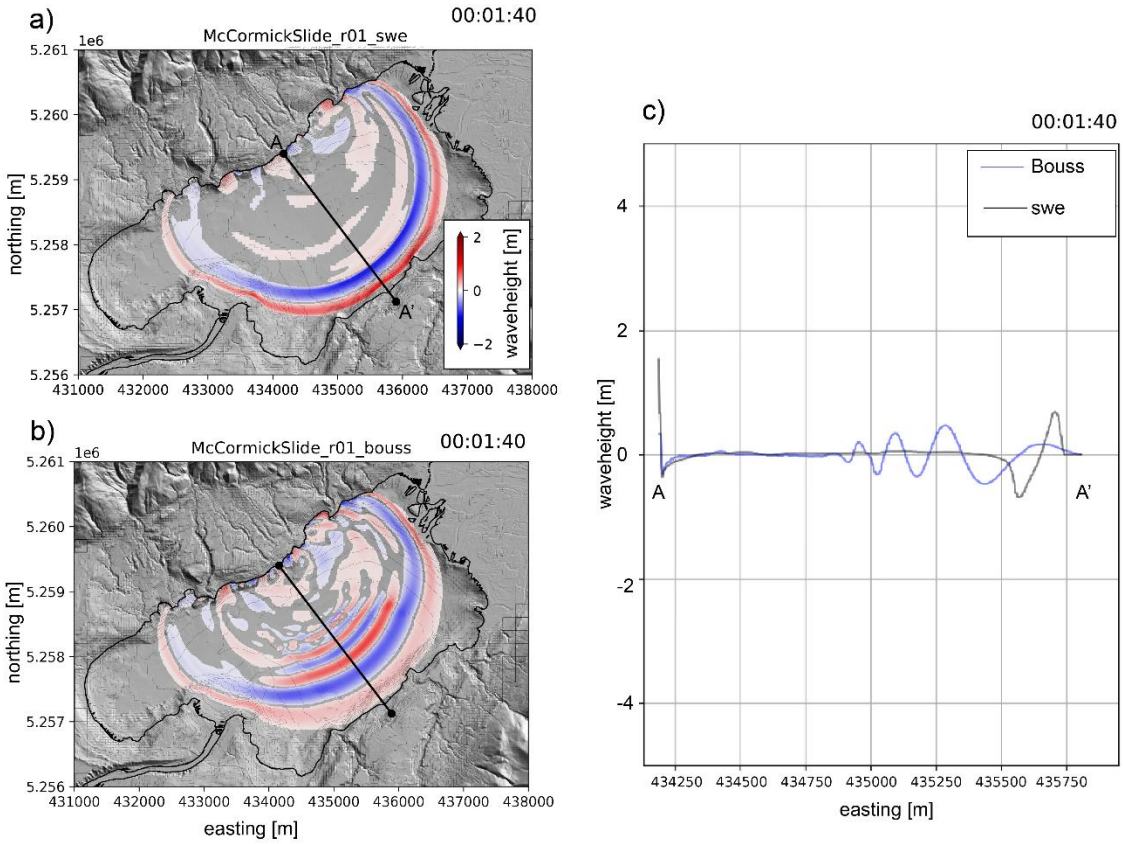

Figure 2: Modeled tsunami in GeoClaw[3], generated by a preliminary model of a sublacustrine landslide along the northern shore of Lake Quinault[5]. a) 1 minute and 40 seconds after the start of the landslide, map view of modeled tsunami wave heights in the non-dispersive, shallow water equation (SWE) model b) Boussinesq model. c) Modeled tsunami waveheights along the transect A-A' in panel a. Blue line (Bouss) is from the Boussinesq model, black line is from the SWE.

References:

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