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## **Geomorphology of Presumpscot Formation landslides**

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# Geomorphology of Presumpscot Formation Landslides

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**ABSTRACT:** Landslides in the Presumpscot Formation have been witnessed around Maine for at least 150 years and documented back to 13,500 years ago. With 2010 lidar data, we identified 216 possible landslides in the greater Portland area. Geomorphology shows multiple earth movements that resulted in relatively flat valleys on the order of 5-15 m lower than the surrounding undisturbed Presumpscot Formation. These lowlands have hummocky ridges that imply a direction of upland displacement. One of these features, the Fuller Flowslide, predates the nearby 1869 Westbrook landslide, lowered 25 hectares of land, and discharged sediment into the Presumpscot River. The morphology of many of the greater Portland landslides suggests a fluid-like earth movement different from the retrogressive block failures common in many other Maine landslides. We hypothesize that the GM-D (draped Presumpscot Formation) facies may lead to retrogressive movements while the GM-P (ponded) facies may contribute to the larger flow slides.

## 1 INTRODUCTION

### 1.1 *Maine landslides*

Landslides have been known to occur in Maine since early deglaciation (Thompson, 1997; Thompson et al., 2011), through the colonial period (Morse, 1869) up to the present (Berry et al., 1996). In his study of the Presumpscot Formation, Bloom (1963) recognized instability in the silt and clay sediments in southern Maine. Numerous site-specific investigations of both coastal and inland sediments have documented high water content, low permeability, low shear strength, and sedimentary thicknesses of tens of meters in the Presumpscot Formation.

An inventory of Maine landslides by Novak (1987) noted about 20 slope failures in and around the greater Portland area. To understand the potential for future landslides, the Maine Geological Survey examined high-resolution topography (lidar; Light Detection and Ranging) to confirm the geomorphology of known

landslides and to locate additional features that resemble documented landslides.

## 2 IDENTIFICATION OF LANDSLIDES WITH LIDAR

### 2.1 *Data analysis*

In order to visualize the geomorphology of known landslide sites, lidar bare-earth topography (relief with buildings, bridges, trees removed) was examined. Multiple eye-witness accounts of slope failures in both coastal and inland locations were available for examination (e.g. Berry et al., 1996; Foley, 2010; Morse, 1869; Novak, 1987; Thompson, 2008; Weddle & Berry, 2004; among others) in a geographic information system using aerial photographs and shaded relief imagery available from the Maine Office of GIS. Metadata for the 2010 lidar is available from the MEGIS web site. This analysis of documented landslides provided the basis for additional geomorphic identification of similar features and potential landslide sites.

## 2.2 Data sources

In the past, geomorphic analysis was done with stereo-pairs of air photographs, topographic maps, field work, and a questionnaire survey Novak (1987). Prior research was able to compile accounts of about 50 slope failures in the greater Portland area. Additional records and Open-File reports and maps at the Maine Geological Survey, as well as landslides we have visited, allowed additional identification of known or potential landslides to a total of about 180 in and around Portland (Novak, 1990). Our analysis is focused on features we presume to be natural in origin. There have also been landslides associated with human activity that we did not analyze in this study. To date, very little age control exists for some landforms that appear to have been the result of landslides, so the frequency of natural landslides has yet to be determined accurately.

## 2.3 Geography & geomorphology

For this study, we used GIS to examine the shorelines of Casco Bay from Orrs Island west to Cape Elizabeth and inland to the extent of lidar data (including portions of the Towns of Westbrook and Falmouth and the City of Portland). The geomorphology of Rockland Harbor landslides (Berry et al., 1996) was also used for reference. The distinctive characteristics of potential landslide sites include (a) steep hill slopes, (b) often arcuate relief along slopes, (c) hummocky terrain below the steep slopes, and (d) lobate morphology on the intertidal zone or fluvial valley adjacent to steep slopes. Combinations of these features seen in detailed lidar relief are quite distinctive and relatively easy to identify in areas not altered by development.

# 3 RESULTS

## 3.1 New landslide sites

This analysis confirmed prior landslide sites and also identified additional areas with similar geomorphology. A total of 216 possible and former sites are now known in and around the greater Portland area. These sites occur in areas

where the surficial geology was mapped as the Presumpscot Formation (Figure 1). The preponderance of these areas is within the Presumpscot River, Stroudwater River, and Fore River valleys.

## 3.2 West End, Portland

The best documented late Pleistocene landslide in the Presumpscot Formation occurred in Portland near Bramhall Hill and along what now is the Fore River. Investigations by Thompson et al. (2011) determined the age of the landslide to be 13,520  $\pm$  95/-20 calendar years before present when sea level may have been 37 meters above the present; this may have been a submarine landslide that affected uplands and incorporated land loss that included trees at the top of the hill. While little geomorphology remains of this area due to extensive earth reworking from urbanization, the area affected by the landslide may have affected 500 meters from shore (Figures 2 & 3).

## 3.3 Bunganuc Bluff, Brunswick

Bunganuc Bluff slope failures have resulted in lobate morphology as discrete sedimentary deposits remained intact and were deposited on the intertidal zone out to a distance of 50 meters (Weddle & Berry, 2004). Sedimentary layers in the Presumpscot Formation were noted at post-landslide exposures at Bunganuc Bluff in Brunswick (Kelley & Kelley, 1986; Weddle & Berry, 2004). This stratigraphy is thought to be what makes up the GM-D (glaciomarine-draped facies) of the Presumpscot Formation (Belknap & Shipp, 1991). The coastal bluff and embankment produced by shallow-depth slides is one of a remarkably linear shoreline (Figure 4). A shore-perpendicular transect shows a slope of 30° above the slumped sediment at the toe (Figure 5).

## 3.4 North Shore, Rockland Harbor

In Rockland, both the 1973 and 1996 landslides occurred in stratified Presumpscot sediments (Berry et al., 1996). The 1996 Rockland landslide affected 1.4 hectares and resulted in bluff retreat

of 40 meters. Post-landslide deposition extended 80 meters onto the intertidal zone and disturbed 100 meters of shoreline. Stratigraphic analysis of exposed sediments of the landslide headwall and cores landward of the headwall found centimeter-scale sand layers and pebble-sized dropstones (Berry et al., 1996). Glacial sediment thickness in undisturbed upland adjacent to the 1996 slide varied from 8-18 meters in thickness. Topographic relief through the displaced Presumpscot Formation documented a headwall slope of 40° and discrete blocks in the failure zone (Berry et al., 1996). Similar discrete blocks occurred in the 1973 landslide, where relief still remains as seen in 2010 lidar (Figures 6 & 7).

### 3.5 *The Great Landslide of 1868, Westbrook*

Sediment outflow from the 1868 Landslide was into the Presumpscot River on the night of November 22 (Morse, 1869). Morse estimated that 8 hectares (20 acres) of sediment was displaced, infilled a 60 meter-wide cross-section of the Presumpscot River and dammed the river for over 800 meters along the thalweg (Dickson, 2014). In 1954 John E. Warren (quoted in Devin & Sandford, 1990) estimated the volume of the 1868 landslide to have been over 600,000 m<sup>3</sup>.

The geomorphology of this earth movement is unusual in that a rather linear valley with steep walls formed (Figure 8). Relief on the west margin is about 3 meters higher than on the east (Figure 9). The basin floor is relatively flat with only a meter of relief over 500 meters (Figure 10).

To this day, there appears to be hummocky topography in the valley floor. This earth movement with a relatively fluid displacement of sediment is termed a flowslide (Devin & Sandford, 1990). Liquefaction of subsurface Presumpscot Formation seems a likely means of mobilizing such a large sediment volume and producing a relatively flat post-slide morphology from disturbed sediment with little strength.

The account by Morse attributed the slide to a single day. The cross-section area shown in Figure 9 is about 1350 m<sup>2</sup> and a relatively narrow valley through which much of the slide had to pass. Morse suggested that the deposit from the

slide affected 170% more surface area than the source area so there was lateral spreading once the mobilized sediment reached the river.

The depth affected by the landslide is unknown. However, the depth to bedrock is on the order of 25 meters below the post-slide valley floor (Locke, pers. comm.) so disturbance within the deeper Presumpscot Formation could have been on the order of several meters below the present surface. This seems plausible if flow into the Presumpscot River became impeded during the event and sediment was prevented from reaching the infilled river.

### 3.6 *The Fuller Flowslide, Westbrook*

According to accounts in Morse (1868) there were “bottomlands” near the 1868 landslide that were pre-existing. This lowland basin was described by a Mr. Fuller to Mr. Morse yet there is no documentation or eye-witness records of when it presumably occurred. Topographic contours on an 1891 USGS map hint at a depression but do not resolve the extent this lowland feature. Consequently, this landform is inferred to have been a landslide in the colonial period or earlier, based solely on the geomorphology that exists today.

Lidar data show the geographic extent of what we call the “Fuller Flowslide” to be about 25 hectares (63 acres; Figure 11; Dickson, 2014). Using a lidar-estimated thickness of 21.5 m, this landslide may have displaced 5,500,000 m<sup>3</sup> of the Presumpscot Formation. Lidar relief shows, in addition to the large size, that this particular movement appears to have exited through a relatively narrow gap of approximately 700 m<sup>2</sup> that leads to the floodplain of the Presumpscot River and between uplands that remain (Figures 12-14).

There are at least three sets of en echelon relict ridges of down-dropped blocks within the slide zone. Ridge-normal vectors can be used to infer flow direction toward the narrow opening. The central slide zone has very little relief and could be a result of more fluid flow or post-slide surficial erosion of former ridges. Across the floor of the slide is a minor dendritic drainage channel leading to the outlet gap. Lastly, lidar

topography in the Presumpscot River valley shows very little downstream geomorphic expression of the large volume of displaced sediment from the Fuller Flowslide in Westbrook (Figure 15). River channel meanders and point bars are relatively symmetrical as is the channel width downstream of the slide outlet.

#### 4 DISCUSSION

Earth movements, as seen with lidar, appear to have ranged from simple shallow slope failures (e.g. Bunganuc Bluff) to deep-seated rotational block slides (Rockland Harbor) to fluid-like vertical displacements of large sediment volumes. In all accounts, these events happened in hours, not days or weeks. Preliminary estimates of the sediment released through a narrow gap adjacent to the Fuller Flowslide suggest an additional area of disturbance from sedimentation in the Presumpscot River valley affecting 2500 meters or more along the river's course.

The 1868 Landslide resulted in a deposit within the Presumpscot River valley of 14 hectares (34 acres) or a depositional area 170% of the land displaced. Based on accounts from the time, and summarized by Morse, this event took place in a matter of hours, displaced the course of the Presumpscot River, and caused flooding in Westbrook. If this same proportion were true for the Fuller Flowslide, 42 hectares (107 acres) could have been affected by Presumpscot Formation redeposition of over 5,000,000 m<sup>3</sup> of mud in the Presumpscot River valley. If this event were to have occurred in 24 hours, the sediment accumulation rate would have been over 200,000 cubic meters per hour. It seems probably that this event, as in 1868, would also have created a sediment dam in the river and led to significant flooding upstream.

The Presumpscot River has numerous meanders and a relatively flat valley floor (Figure 1) so deposition of sediment from the Fuller Flowslide may have led to aggradation of the river floodplain and adjacent terraces. Alternatively, the fine sediment could have been reworked through the fluvial system and contributed to the thick estuarine sedimentary

sequences of the lower Fore or Presumpscot Rivers. Sediment borings and seismic stratigraphy of inner Casco Bay show extensive strata associated with the Presumpscot Formation and Holocene estuarine mud (Kelley et al., 1987; 1989).

Accounts of additional landslides are provided in Morse (1869) and include the "Saccarappa Slide" that he and others thought altered the course of the Presumpscot River to turn to the east. They postulate that the Saccarappa Slide diverted what was previously drainage into the Fore River to the Presumpscot River. Colonial excavations exhumed buried trees from depths on the order of 10 meters below the ground elevation suggesting deep-seated earth displacement.

Topographic and lidar data in Westbrook show a potentially slide-infilled drainage path about 1 kilometer across between the Presumpscot River and the Stroudwater River channel. To the north of this position, the Presumpscot River takes a sharp bend from flowing south to east. South of this position the Stroudwater River flows east then turns south to join the Fore River (Figure 16).

Based on early surveys, Morse estimated that the Saccarappa Slide affected 74 hectares (183 acres). If this estimate is correct, the Saccarappa Slide may have been the largest yet identified to have occurred in the Presumpscot Formation. Based on lidar data, it is difficult to determine if this slide was a single event or a series of landslides that affected such a large area (Figure 16).

The distribution and extent of Presumpscot Formation sediments prone to flowslides is important, yet little is known of terrestrial sub-facies of the formation. Understanding of the original depositional setting of the Presumpscot Formation may be helpful. In the greater Portland area, some ice-proximal deposition of Presumpscot sediment may have been at very high sedimentation rates followed by later sedimentation and reworking when the ice margin had retreated from the region (Thompson, 1997). These ice-proximal deposits may correlate with the GM-M (glaciomarine-massive; Belknap and Shipp, 1991) facies of the Presumpscot Formation that appear to have minimal seismic stratigraphic

reflectors but have isolated hyperbolic acoustic reflectors that may be from glacial dropstones.

The seismic stratigraphic signature of the GM-P (glaciomarine-ponded) facies is also one with few internal acoustic reflectors and few hyperbolic returns that occur stratigraphically over GM-D and GM-M and infill bathymetric – or formerly topographic – depressions (Belknap & Shipp, 1991). It seems plausible that the basinal depositional setting for GM-P would also be favorable to retaining high water content silt and clay of the Presumpscot Formation following sea-level regression and subaerial exposure in the Holocene.

## 5 CONCLUSIONS

Analysis of landforms at historical landslides sites in the Portland, Brunswick, Rockland, Westbrook, and surrounding areas allowed the geomorphic characterization of landslides with lidar data. Additional areas with similar geomorphic features suggest that there are over 200 former landslide sites in the greater Portland area. These sites occur predominantly in areas where the surficial geology is mapped as the Presumpscot Formation.

The Fuller Flowslide occurred at an unknown date in the past. The relict geomorphology suggests that over 5,000,000 cubic meters of earth were displaced and sediment was discharged into the Presumpscot River. Based on existing lidar data and historical records, the Fuller Flowslide is one the largest landslides known in the Presumpscot Formation.

Additional synthesis of known geological and geotechnical characteristics of the Presumpscot Formation is recommended in order to understand better the sedimentary and acoustic facies for better prediction of the types of landslides that might occur in Maine.

Compilation of site-specific sedimentary stratigraphy and structures, of the Presumpscot Formation could lead to better subdivision of sedimentary facies and potentially correlate the geology with the seismic stratigraphy of the GM-M, GM-D, and GM-P facies. Integration of geotechnical properties from cores and surface

excavations with geology and geophysics is essential to understand the origin of landslides.

All historical accounts of slope failures in the Presumpscot Formation indicate rapid earth movements in a matter of hours with little advance notice. Three documented by Morse (1869, p. 240) all occurred in a span of 37 years. Further research into dating individual landslide events (e.g. Thompson et al., 2011) could provide greater insight into the geological and historical timing of landslides.

Geochronology is important to determine if most of the earth movements occurred during post-glacial isostatic rebound, pre-colonial time, or have been episodic throughout the Holocene. Timing may also help understand processes that trigger failures such as ground vibration via earthquakes, slope steepening from toe erosion or fluvial incision, groundwater and the hydrological cycle, or land-use patterns.

Landslide investigation is multidisciplinary, multivariate, and of great societal relevance (Turner & Schuster, 1996). The chronological, geomorphic, sedimentary, hydrological, and geotechnical characteristics are all significant variables that need to be synthesized to estimate better the risk of geohazards that the Presumpscot Formation poses to people and development in Maine.

## 6 REFERENCES

- Belknap, D.F. & Shipp, R.C. 1991. Seismic stratigraphy of glacial marine units, Maine inner shelf, in: *Glacial marine sedimentation; Paleoclimatic significance*, Anderson, J.B. & Ashley, G.M. (eds.). Boulder: Geological Society of America Special Paper 261, 232 p.
- Berry, H.N. IV, Dickson, S.M., Kelley, J.T., Locke, D.B., Marvinney, R.G., Thompson, W.B., Weddle, T.K., Reynolds, R.T. & Belknap, D.F. 1996. *The April 1996 Rockland Landslide*. Maine Geological Survey Open-File Report 96-18, 55 p., 1 plate.
- Bloom, A.L. 1963. Late-Pleistocene fluctuations in sealevel and post-glacial crustal rebound in coastal Maine. *American Journal of Science*, v. 261, p. 862-879.
- Devin, S.C. & Sandford, T.C. 1990. *Stability of natural slopes in the Presumpscot Formation*. Maine Geological Survey Open-File Report 90-24, 75 p.
- Dickson, S.M. 2014. "The Great Landslide of 1868, Westbrook, Maine." Maine Geological Survey web site. <<http://www.maine.gov/dacf/mgs/hazards/landslides/facts/may14.pdf>> (Aug 8, 2015).

- Foley, M.E. 2010. "Landslide susceptibility mapping in Maine." Maine Geological Survey web site. <<http://www.maine.gov/dacf/mgs/hazards/landslides/facts/nov10.pdf>> (Aug 8, 2015).
- Kelley, J.T. & Kelley, A.R. (eds.) 1986, *Coastal Processes and Quaternary Stratigraphy, Northern & Central Coastal Maine*. SEPM Eastern Section Field Trip Guide Book, May 15-18, 1986, 95 p.
- Kelley, J.T., Belknap, D.F., Shipp, R.C., & Miller, S.B. 1989. An Investigation of Neotectonic Activity in Coastal Maine by Seismic Reflection Methods, in: *Neotectonics of Maine*, Anderson, W.A. & Borns, H.W. Jr. (eds.). Maine Geological Survey, p. 157 – 204.
- Kelley, J.T., Belknap, D.F., & Shipp, R.C. 1987. *Geomorphology and Sedimentary Framework of the Inner Continental Shelf of South Central, Maine*. Maine Geological Survey Open-File Report 87-19, 76 p.
- Locke, D.B., 2015, personal communication of Maine Geological Survey 12-channel seismic investigations.
- Morse, E.S. 1869. On the land-slides in the vicinity of Portland, Maine, in: *Boston Society of Natural History, Proceedings*, v. 12. p. 235-244, 1 map.
- Novak, I.D. 1987. *Inventory and bibliography of Maine landslides*. Maine Geological Survey Open-File Report 87-3, 27 p., 1 map.
- Novak, I.D. 1990. *Air photo reconnaissance of slope failures in the Presumpscot Formation, Cumberland County, Maine*. Maine Geological Survey Open-File Report and Map No. 90-22, 4 p., 1 map.
- Thompson, W.B. 2008. *Surficial geology of the Portland West quadrangle, Maine*. Maine Geological Survey Open-File Map 08-16.
- Thompson, W.B. 1997. *Surficial geology of the Portland West 7.5 minute quadrangle, Cumberland County, Maine*. Maine Geological Survey Open-File Report 97-66, 10 p.
- Turner, K.A. & Schuster, R.L (eds.) 1996. *Landslides: investigation and mitigation*. Special Report 247. Transportation Research Board, National Research Council, 675 p.
- Thompson, W.B., Griggs, C.B., Miller, N.G., Nelson, R.E., Weddle, T.K. & Killian, T.M. 2011. Associated terrestrial and marine fossils in the late-glacial Presumpscot Formation, southern Maine, U.S.A., and the marine reservoir effect on radiocarbon ages. *Quaternary Research*, 10.1016/j.yqres.2011.02.002.
- Weddle, T.K.W. & Berry, H.N. IV. 2004. "Coastal landslide with outrunner blocks, Bunganuc Bluff." Maine Geological Survey web site. <<http://www.maine.gov/dacf/mgs/hazards/landslides/facts/dec04.pdf>> (Aug 8, 2015).

## 7. FIGURES

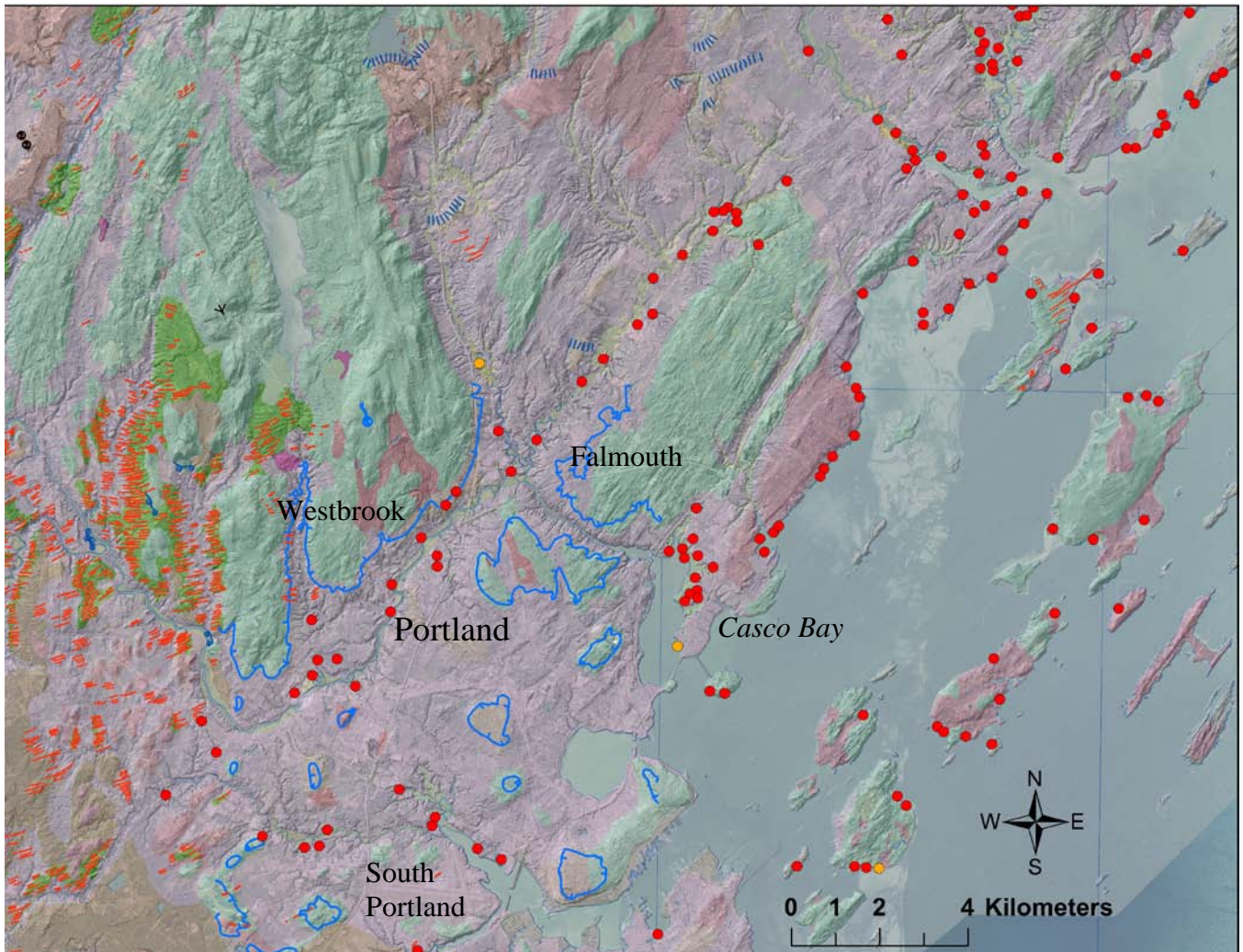


Figure 1. Shaded relief location map of greater Portland and Casco Bay. Red circles denote locations where geomorphology visible in lidar data suggests the location of a landslide. The orange dots are areas with steep headwalls. The black symbols are where glacial striations were measured. The glaciomarine Presumpscot Formation is shown in lavender and Pleistocene glacial till is in light green. Other Pleistocene marine deposits are illustrated in dark green and tan. Blue lines indicate late Pleistocene “shorelines” when sea level was higher than present, red lines are glacial moraines (for a more detailed legend and a geographic base map, see Thompson, 2008). Shaded relief based on lidar and courtesy of the Maine Office of GIS.



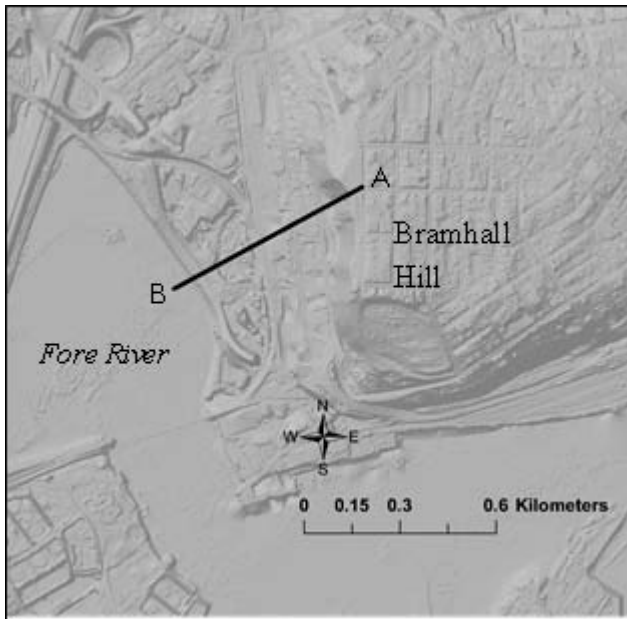


Figure 2. Shaded relief of Portland's West End, Bramhall Hill, and the Fore River. The black line shows a transect from the top of an embankment at the corner of Pine Street and Western Promenade (A) to the Fore River (B) and shown in Figure 3. Note the bare-earth lidar data does not show part of Memorial Bridge across the Fore River.

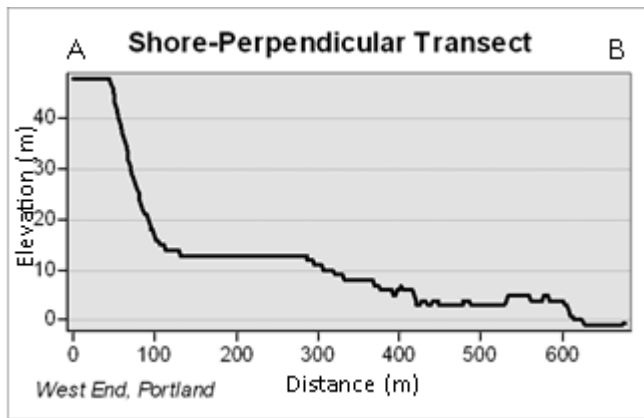


Figure 3. A topographic profile from Portland's Western Promenade at the intersection with Pine Street (A) down a steep embankment and across level urban areas and into an excavation (approximately 400-530 m) in the vicinity of the late Pleistocene landslide some 13,500 years ago described by Thompson et al. (2011). The tidal Fore River and mid-tide level are on the right at 0 m elevation (B). Distances and elevations are in meters NAVD88. Note vertical and horizontal axes are not equal.

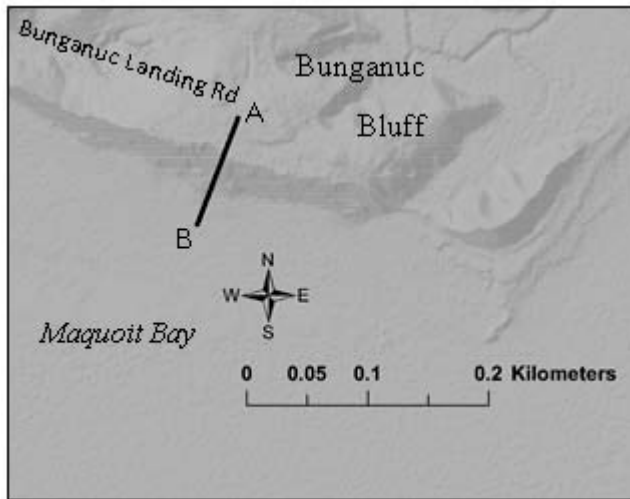


Figure 4. Shaded relief of Brunswick's Bunganuc Bluff and the Maquoit Bay. The black line shows a north-south transect perpendicular to the shoreline from the top of an embankment (A) to tidal flats (B). Elevations along the transect are shown in Figure 5.

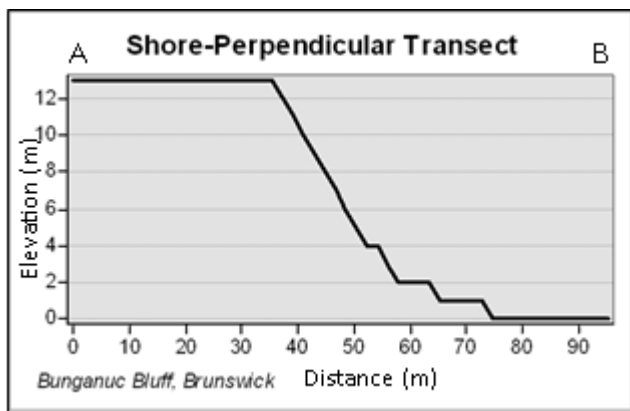


Figure 5. A shore-perpendicular transect of elevations across Bunganuc Bluff in Brunswick. Transect points A to B are shown in Figure 4. The bluff face has a linear slope with slump blocks at the toe from 4 m and below MHW at 1.5 m elevation. Distances and elevations are in meters NAVD88. Note vertical and horizontal axes are not equal.

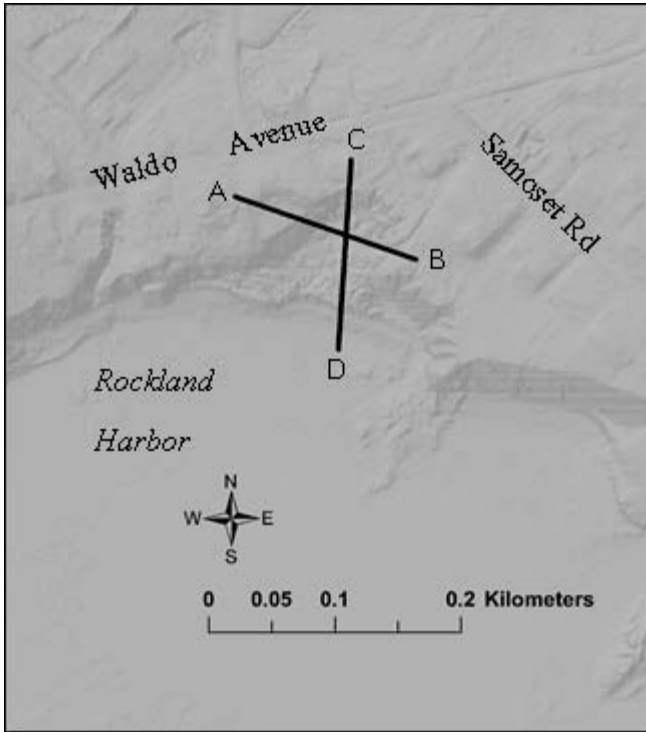


Figure 6. Shaded relief of the north shore of Rockland Harbor in Penobscot Bay. The east-west black line shows a transect across the 1973 landslide site. The north-south line is an axial transect from the headwall in the north to the intertidal zone in the south. Elevations along the transect are shown in Figures 7a, b.

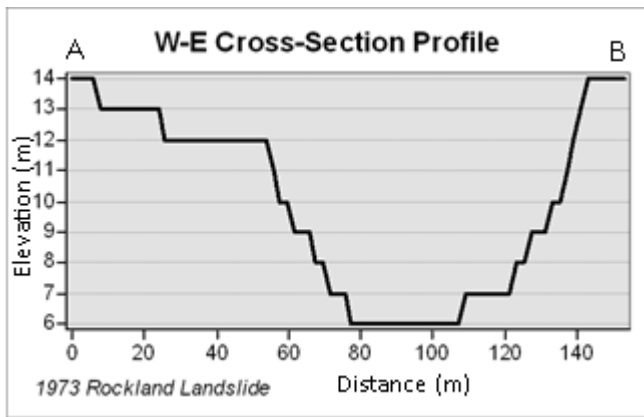


Figure 7a. A cross-section of topography across the 1973 Rockland Landslide. Sidewalls (flanks, A & B) show terraces on both sides below 10 m elevation. The west side (A) also shows a pair of 1 m terraces between 11 and 14 m. In this transect, the base of the section is 6 m in elevation above the highest tide level. Transect location is shown in Figure 6. Note vertical and horizontal axes are not equal.

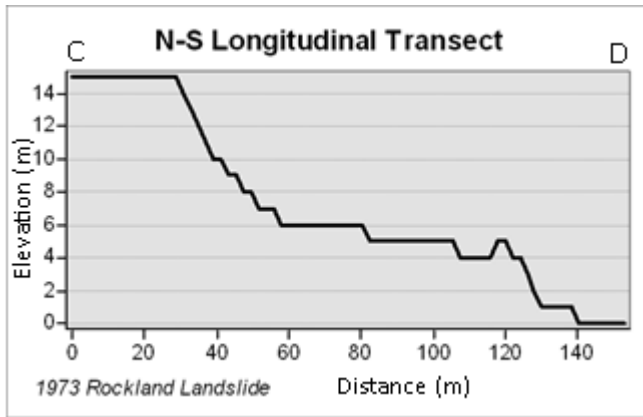


Figure 7b. An illustration of the axial profile of elevations through the 1973 Rockland Landslide. The headwall (C) has an even slope down to 10 m elevation below which 6 terraces remain in the displaced Presumpscot Formation. The toe of the slide reaches the ocean at 130 m distance where there is an intertidal terrace of mud (D). Transect location is shown in Figure 6. Note vertical and horizontal axes are not equal.

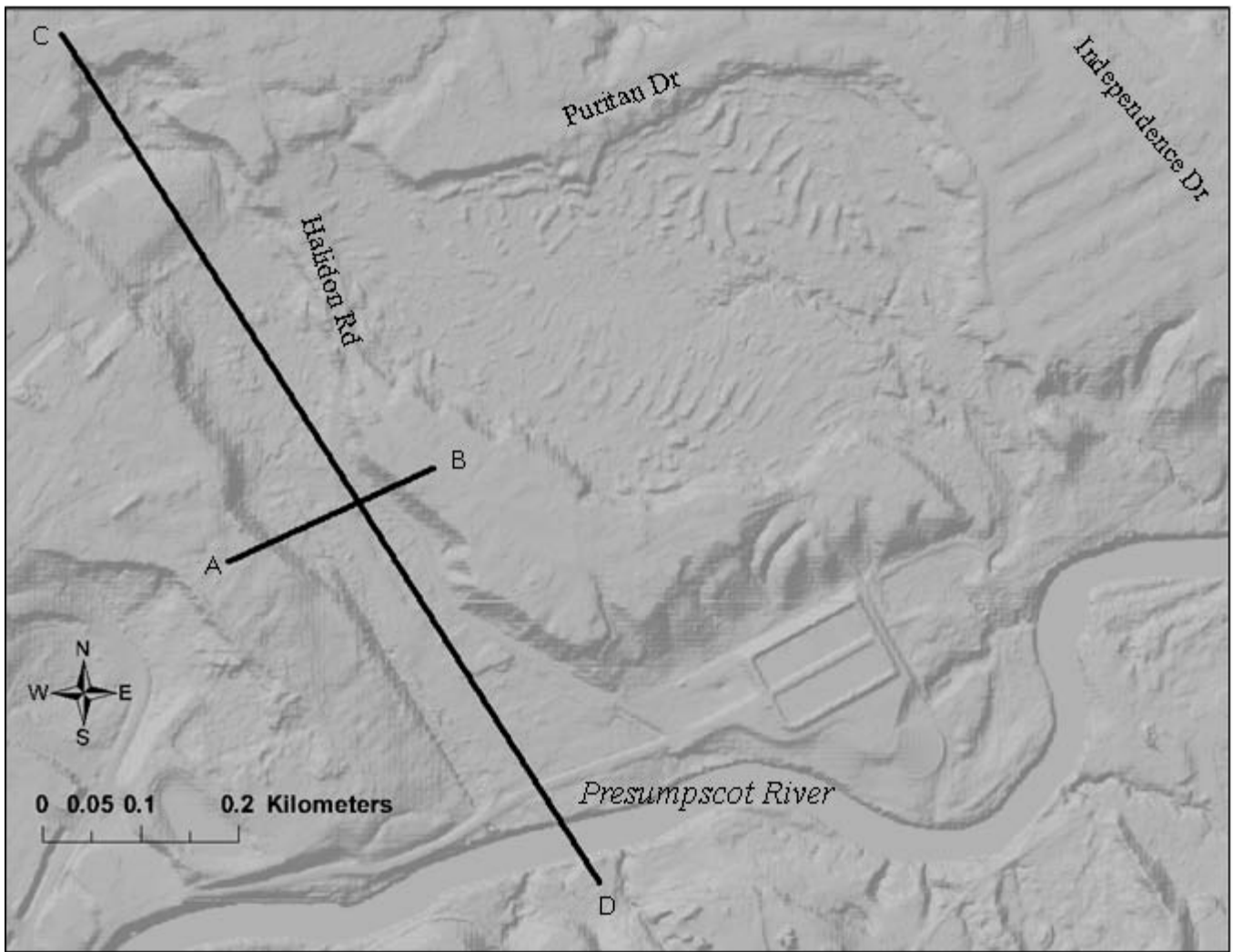


Figure 8. Shaded relief Westbrook along the Presumpscot River. The east-west black line (A to B) shows a transect across the 1868 landslide site. The northwest-southeast line (C to D) is an axial transect from the headwall in the north to the river in the south. Elevations along the transects are shown in Figures 9 and 10.

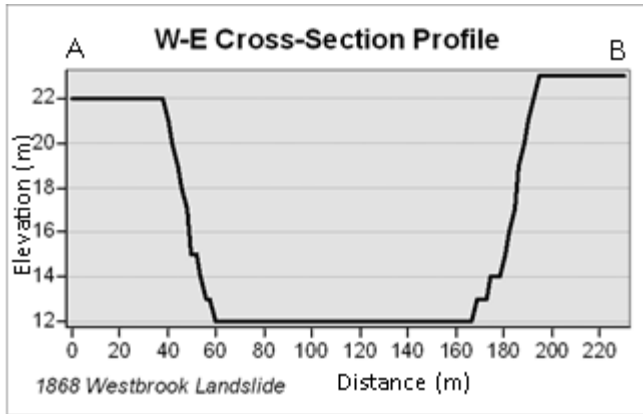


Figure 9. This figure illustrates a cross-section transect of the 1868 Westbrook Landslide showing steep valley walls and a flat depression in the area affected by the event. This section is inland of outlet point at the Presumpscot River. The east ending point (B) is the starting point of the profile across the Fuller Flowslide in Figure 11 (point A). Distances and elevations are in meters NAVD88. Note vertical and horizontal axes are not equal.

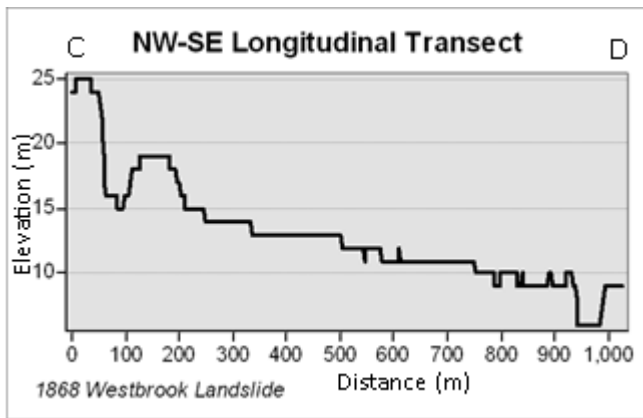


Figure 10. This figure shows an axial transect through the valley created by the 1869 Westbrook Landslide. Relief drops from above the headwall (C) to the Presumpscot River (D). There is an elevated mound in the basin down slope from the headwall that is anthropogenic. Farther down the valley relief drops 10 meters over 800 meters for an overall basin dip of about one degree. Distances and elevations are in meters NAVD88. Note vertical and horizontal axes are not equal.

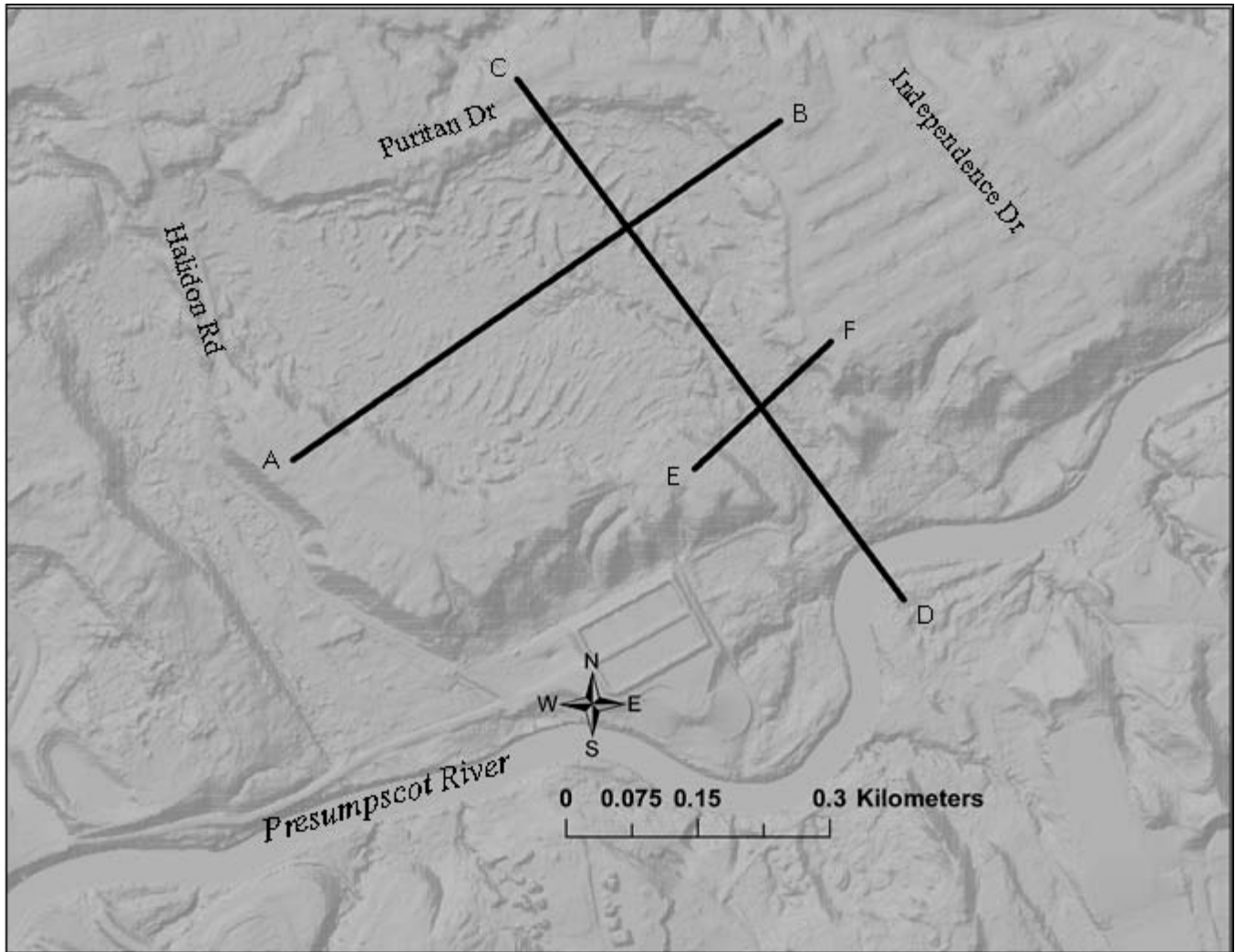


Figure 11. A shaded relief map of Westbrook along the Presumpscot River. The upper east-west black line shows a transect A-B across the width of the Fuller Flowslide. The northwest-southeast line (C-D) is an axial transect from the headwall in the north to the river in the south. The third transect (E-F; west-east) shows the narrow opening through which sediment is inferred to have moved out of the slide zone and into the Presumpscot River. Elevations along the transects are shown in Figures 12-14.

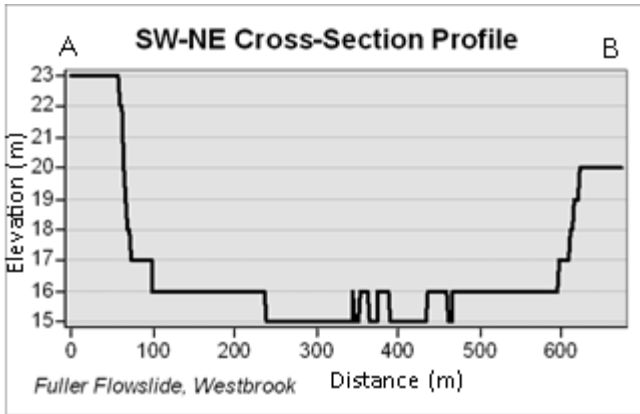


Figure 12. A topographic profile of elevations across the center of the Fuller Flowslide in Westbrook. The starting point of the western transect (A) is the easterly ending point of the cross-section of the 1869 Landslide shown in Figure 9 (point B). Distances and elevations are in meters NAVD88. Note vertical and horizontal axes are not equal.

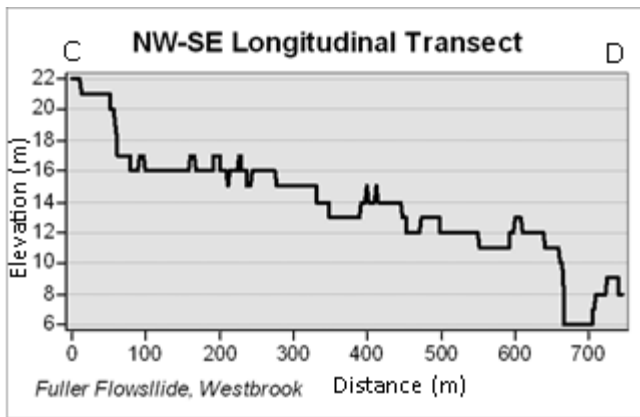


Figure 13. This illustration shows a transect (C-D) from the headwall (at 70 m) through the slide zone (from 100-600 m) of the Fuller Flowslide. Within the slide zone there are multiple ridges with about a meter of relief. These ridges can be seen in Figure 11. From the headwall to the toe of the slide there is about a 5 meter drop in elevation over 500 meters. This represents a slope of about 0.6 degrees. The slide is incised by the Presumpscot River (at 680 m). Distances and elevations are in meters NAVD88. Note vertical and horizontal axes are not equal.



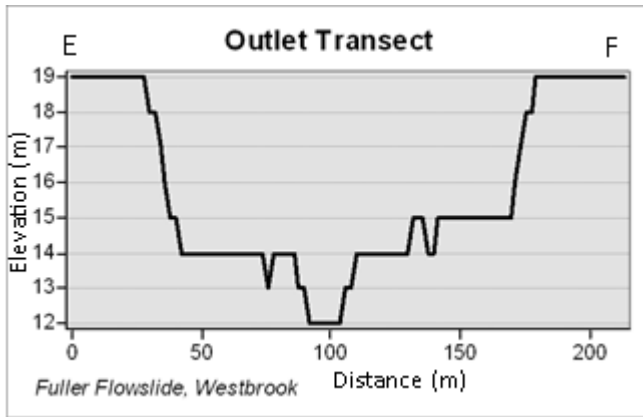


Figure 14. A cross-section of relief in the narrow constriction (E-F) that the Fuller Flowslide is thought to have passed through. The opening has a single, incised modern stream drainage with 2-m relief (at 100 m) and two flanking terraces with elevations of 14 and 15 m. The transect is located on Figure 11. Distances and elevations are in meters NAVD88. Note vertical and horizontal axes are not equal.

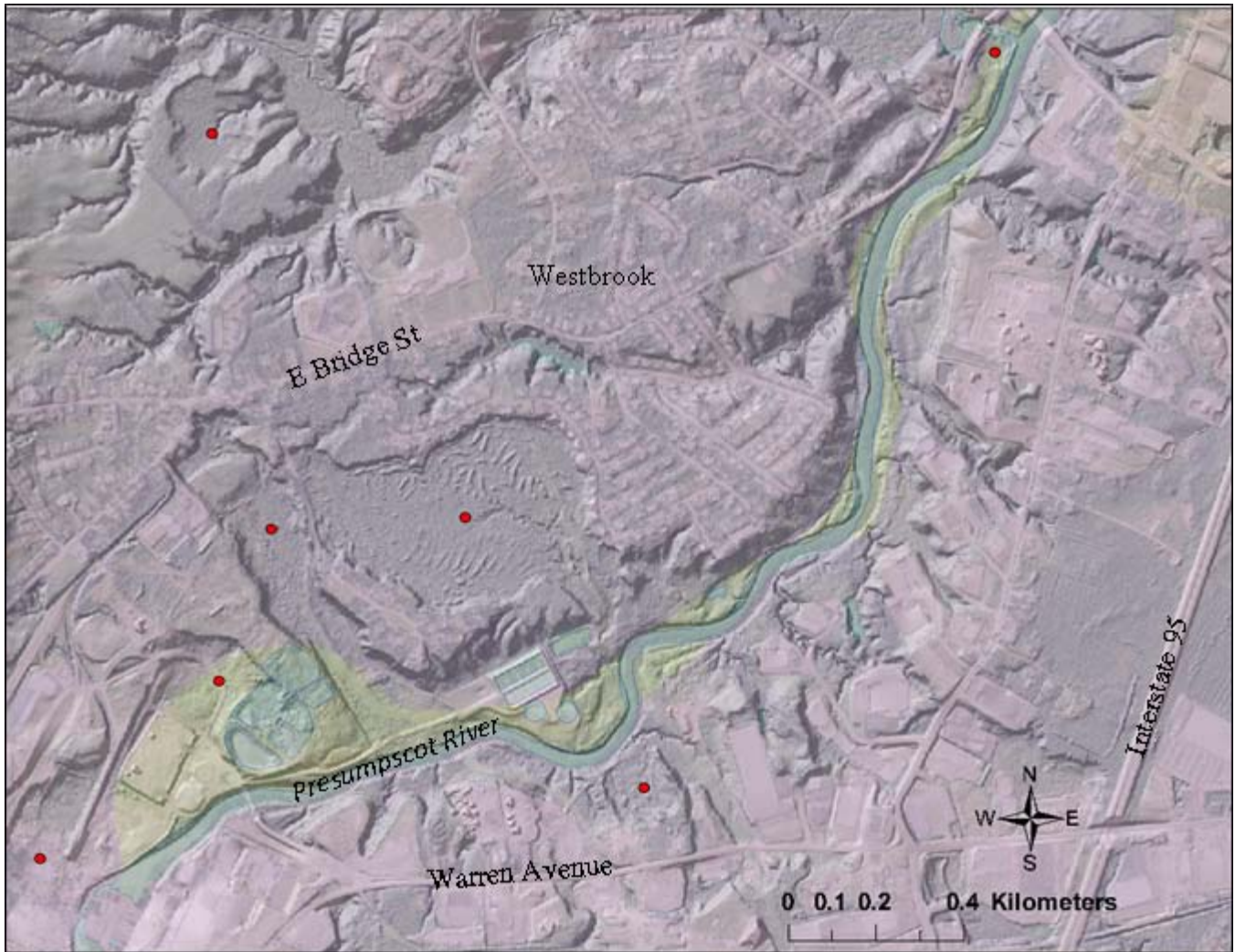


Figure 15. A shaded relief map of known and potential former landslide sites in Westbrook, Maine. Red circles denote locations where geomorphology visible in lidar data suggests the location of a landslide. The glaciomarine Presumpscot Formation is shown in light purple, river alluvium in light tan, water in light blue. Map units are based on the surficial geology mapped by Thompson (1977; 2008). Shaded relief based on lidar and courtesy of the Maine Office of GIS.

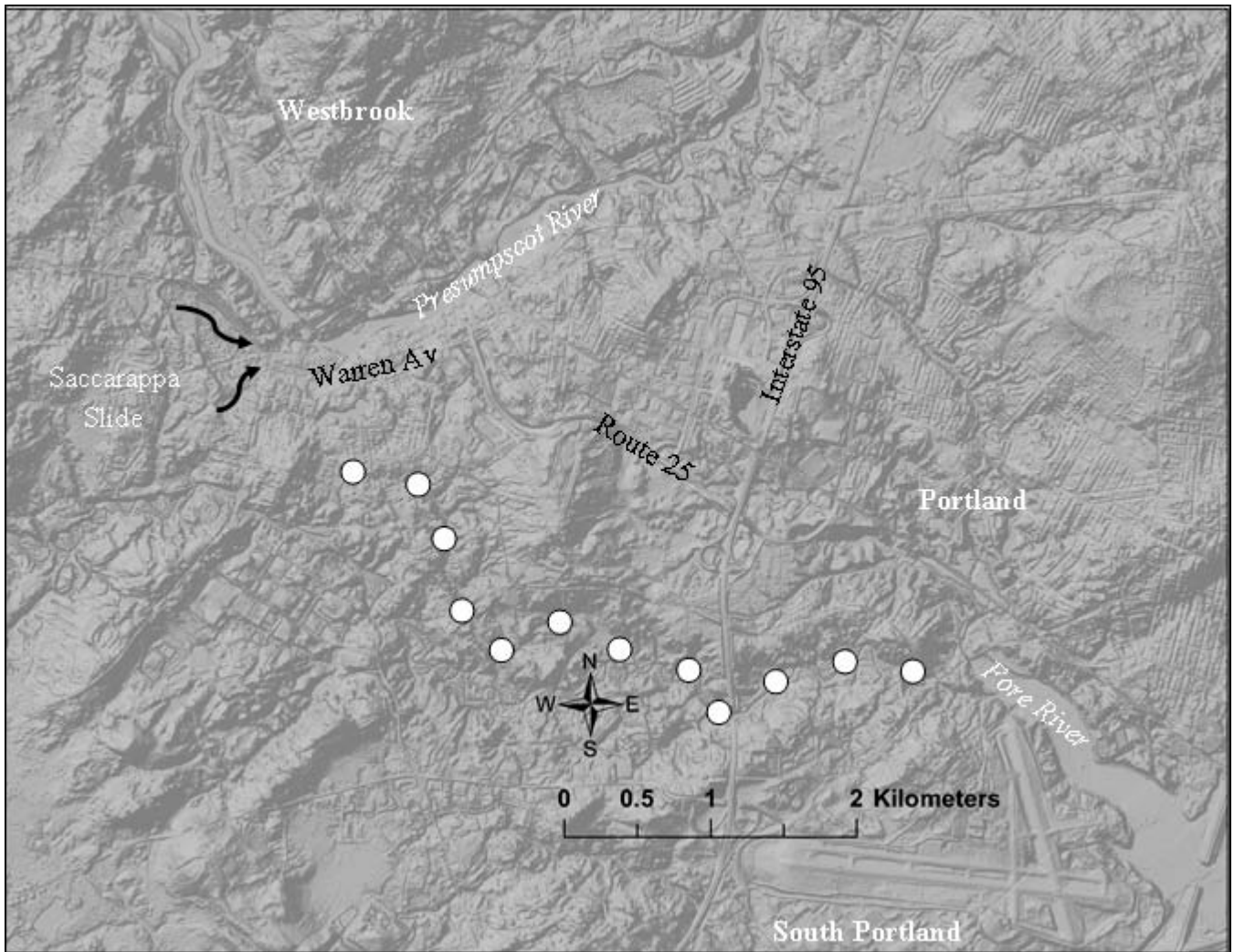


Figure 16. Shaded relief map of the greater Portland area showing the location of the Saccarappa Slide (black arrows) where the Presumpscot River abruptly changes course from SSE to ENE in Westbrook. Morse (1869) and others at the time surmised that clay from the Saccarappa Slide altered the course of the river that once continued to flow SSE to connect to the Fore River. Lidar relief indicates the Stroudwater River channel location (thalweg highlighted with white circles) that could have connected the Presumpscot River to the Fore River prior to the landslide. Today, the Saccarappa Slide zone still has a tributary that flows south to the Stroudwater River, rather than east to the Presumpscot River.