To: Middlesex Roads Committee, Conservation Commission, and Planning Commission
From: Mike Kline, River Scientist, Middlesex resident
Date: July 14, 2025
Re: Great Brook Futures Project, Year 1 data collection and field observations

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Since the 2024 flood in Middlesex, I've been acting as a member of the Middlesex Roads Committee (formed by the Selectboard) to pursue a Great Brook Futures Project, which has the stated objective to:

> Create a more naturally stable Great Brook in Middlesex that allows for the feasible maintenance of Brook Road and stream embankments along the road and next to homes accessed along Brook Road. To reduce landslides and bank failures through a reduction of channel incision processes with stream bed grade controls and floodplain restoration where feasible.

The Roads Committee has thus far been unsuccessful in getting the project fully funded from different FEMA grant programs, but has made some progress with assistance from the State and UVM in gathering information that will be very useful in the future planning and design work we've outlined in the proposal. I will in attempt in this report to outline the work and assessments that have been completed to date. Some bullet points simply state the facts, others are technical observations that I am offering as a professional river scientist, having spent much of my career working on flood hazard assessments. Lastly, I've made some recommendations for future restoration designs and watershed-scale planning that I think would benefit Middlesex and its residents.

Only once in this report did I make specific reference to a street address along Great Brook, and that was to give the reader a geographic reference point. Any discussion of current/future erosion vulnerabilities are made in connection to the road and other town infrastructure.

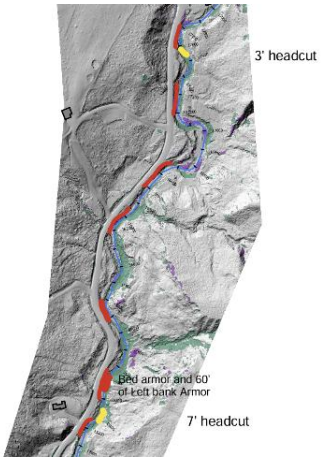
Erosion of the road, private lands, and infrastructure

- The Brook Road provides access to 26 Middlesex homesteads and is traveled daily by many Middlesex residents enroute to and from I-89 and Route 2 state highway. Old Brook Road provides access to five Middlesex homesteads.
- Of those 31 homesteads, 13 are located between the roads and Great Brook and two are located across the Brook and accessed with bridges off Brook Road over the Brook.
- Segments of both roads were washed out, road embankments were lost, and streambanks adjacent to some homes experienced severe erosion during one or both of the 2023 and 2024 floods. Large rock revetments have been placed on multiple streambanks (17 so far, averaging between 150 and 200' in length) in an attempt to save the road and homes. At least several more revetments may be needed.
- Brook Road crosses Great Brook two times over metal culverts. Old Brook Road crosses once over a bridge. None of these crossings failed during the recent floods. There are two private bridges over Great Brook and both were damaged or failed during the 2023 and 2024 floods. There are 24 cross-culverts that carry ditch storm water runoff under the road and directly into

the Brook. At least eight culverts were replaced after the 2024 flood. Brook Road also has a concrete box culvert that carries it over a larger Great Brook tributary and it survived the floods as well.

- Some rip-rapped embankments and private bridges have suffered repeated damage or failure. After floods in 2023 and 2024 approximately $2.5M was spent repairing the Brook Road, cross-culverts, and streambanks along Great Brook, much of which had been previously repaired. Fortunately, much of the money spent on repairs these last two years was or will be funded by the Federal Government. Diligent and dedicated town residents and officials have spent countless hours and sleepless nights to the efforts to return these town assets and personal properties to their pre storm condition and in some cases to upgrade them to a more storm-resilient condition. Additional work is ongoing.

Why the erosion is getting worse



- The Vermont Geologic Survey and the DEC Rivers Program have been documenting stream instability and landslide activity along Great Brook for 20 years. Recent LiDAR data have provided the means for creating fine-scale topography, as well as stream profiles and cross-sections. With these the Rivers Program has created maps with 100-foot stationing (markings) along Great Brook to help us communicate specific locations where stream erosion and structure damage is occurring. The stationing starts at the Old Brook Road bridge, continues upstream, and ends at the culvert where the Center Road crosses Great Brook. The full PDF of the LiDAR base map of the Brook with stationing and landmarks is provided in a separate document. Upload and enlarge the PDF to see the stationing numbers along the Brook.
- Detailed topographic maps created before and after the 2023 and 2024 floods show changes in elevation that confirm what we can plainly see from the road—the extent of landslides in the valley has increased dramatically, particularly along what will be referred in this writing as the upstream segment of Great Brook above Station 10800 (~ 325 Brook Road).
- The two types of erosion that have been described along Great Brook are the downward erosion of the stream bed, and the lateral erosion of the stream banks including the landslides. Both types of erosion increase when the power of the flowing water exceeds the ability of the bed and bank materials to resist that power.

<u>Bed and Bank Resistance</u>

- When Great Brook was first surveyed in 2005, the stream bed was more consistently armored with cobbles and boulders, and more resistant to the power of flood flows than the predominant gravels and clay materials found along the bed today, especially in the upper segment. While decades of bed erosion (downcutting) have been documented along the Brook, the rate and extent of bed erosion has increased, with several steep head-cuts migrating upstream and further

deepening the channel up from Station 15000 through the clay substrates. Headcuts now appear as near vertical drops in the stream bed.

- The resistance of natural stream banks to erosion is a function of the chemical, physical, and biological conditions of the bank materials. One of the primary failure modes of erosion and landslides along the banks of Great Brook is caused by their physical steepness. The banks along the upper segment of the Brook have become over-steepened, almost vertical, due to the scouring and erosion of the bed materials at the toe of the slope below them. The layers of clay in the banks become saturated and fall down in large blocks, bringing with them many trees from the hillslope forests above. The varved (or layered) clays and rocky unconsolidated bank soils, when laid bare of vegetation, are also susceptible to the erosive force of water flowing against them (this is called hydraulic erosion).



Stream Power

- The power of Great Brook during floods has increased for several reasons. The first has been discussed above: the loss of a consistent layer of natural bed and bank armoring (cobbles and boulders) that would otherwise create friction and slow the water down. The exception in Great Brook is the large number of trees that are now in the path of flood flows. Noting the concern that trees and debris jams may divert flows toward homes and infrastructure, they also create a very significant source of friction during floods and can be beneficial in mitigating the increase of stream power during floods.
- An increase in the erosive power of a flood also occurs when there is an increase in either the slope or depth of its flow, which explains much of what we are seeing along upper segment of Great Brook at his time. The abandoned floodplains and terraces, such as the flatter bottom area of the valley where the Brook Road was constructed and widened over time, provide ample evidence that Great Brook once had more room to meander in the valley and therefore had a lower gradient (slope), and, when a storm occurred, the depth of the flood flow was lower because it could spread out onto its small but functioning floodplains. Flood flows are now steeper and much deeper and therefore increasingly powerful to erode the Brook's bed and banks.
- Flows in the upper segment of the Great Brook are so steep and so deepened within an entrenched channel that a larger flood in the Brook can move cobbles and boulders of nearly any size. At the height of a flood, with the channel in this condition, most of the natural bed armoring in this upper segment would be scoured and carried within the flow. As the flood recedes, the trees and rocks being tumbled downstream begin to deposit, especially in the lower segments, where the gradient flattens and floodplains slow the flood velocities. This rapid deposition of

sediment and debris can cause blockages to the flow that redirect the floodwater causing erosion of lands along the lower segment of Great Brook.

Existing and future vulnerability



- Erosion is the brook's attempt to adapt to increased rain and runoff in the narrower channel that remains on the valley floor after human activities, roads and structures. The question is: can our management of structures and lands along Great Brook be modified to give the brook what it needs to adapt to present hydrologic conditions?
- While there have been large investments to upgrade town road infrastructure, secure embankments with rock, and protect residences against future floods, there are still serious concerns about future flood damage along the Brook Road and Old Brook Road. The increase in stream power coupled with the lowered resistance of the Brook's bed and banks to the increased erosive forces means we will see ongoing landslide activity and ongoing stream bed erosion that will undermine the road embankments and stream banks, including those armored with rock.
- In highly erodible stream channels, rock revetments have a more limited life-span than those with bedrock controls or with ample floodplains that attenuate the forces of a flood. What makes a rock revetment especially vulnerable to failure is when it is designed to treat the erosion that just happened on a short segment of the embankment. Primarily due to expense and access, they are often not extended upstream or downstream far enough to go beyond the inflection points in the flow path where the stream is crossing over, for instance, from the left bank to the right bank. During a walking survey of the Brook in May, 2025, those road embankments armored with rock during the summer/fall of 2024 were evaluated, and it is estimated that at least 8% of the new revetments were already failing. Three modes of failure were noticed: the Brook is outflanking the revetment, causing rocks on the upstream end to fail; the clay bed under the revetment is eroding and undermining the rock; and/or flows were accelerating off the rocks at the downstream end of the revetment causing them to roll downstream from where they were originally placed. It should be noted that the vertically stacked walls of large rock used to revet the road embankment is a technically correct and favored treatment compared to dumping smaller rock as a blanket over an embankment. The latter more traditional revetment design would likely have a significantly higher failure rate, at this point, given the dramatic landslide changes happening along the upper segment of the Brook.
- In the past year, since the 2024 flood, there has not been another significant flood in the Great Brook watershed. Given the factors discussed above, Middlesex should expect some number of the road embankments to fail again possibly taking portions of the road with them when another larger flood does occur. The Road Committee is planning to monitor the road embankments on

at least an annual basis in hopes of establishing the need for pre-disaster mitigation funding to treat areas and head off complete failures.

Working with nature at the watershed scale

- The federal government, the state of Vermont, Middlesex, and Brook Road property owners have spent over $2.5 M to repair Brook Road and protect homes, with more invoices from the 2024 flood forthcoming. Given the high potential for more erosion, Middlesex should have a plan that explores the benefits of alternative response and recovery actions, including their relative costs.
- The Great Brook valley along the Brook Road is widening in response to more frequent and intense storms pushing powerful floods through a narrow, constrained, and highly erodible geologic setting. Middlesex is not alone in trying to manage such large-scale forces with small man-made structures. Other Vermont towns are also struggling to maintain spot-fixes of stone with no real foundation (think bedrock) to try and get to a sustainable co-existence with their brooks. Right now, we're engineering against nature, pushing back where the Brook is working to create new floodplain. While public safety and homesteads are of primary concern, our plan for Great Brook needs to look for ways to restore the natural features that reduce stream power and increase resistance. While we're applying band aids to eroding spots along the road, we need to be working at the watershed scale to slow the flow. If we are successful, then nature will take care of most of the maintenance cost.

Create a Watershed-Scale Flood Recovery and Resilience Plan to:

Avoid New Hazards

Setback development and infrastructure to less vulnerable places
Sponsor buyouts at the request of homeowners
Adopt zoning bylaws to limit any further development along the Brook

Arrest further stream downcutting (if possible)

Create space for floodplain restoration

Restore and protect floodplains and wetlands
Build flood benches along road embankments
Shift driveways, roads, and infrastructure

Restore wooded stream riparian areas

Spread, slow, and infiltrate stormwater

Create more road ditch turnouts
Arrest gully formations

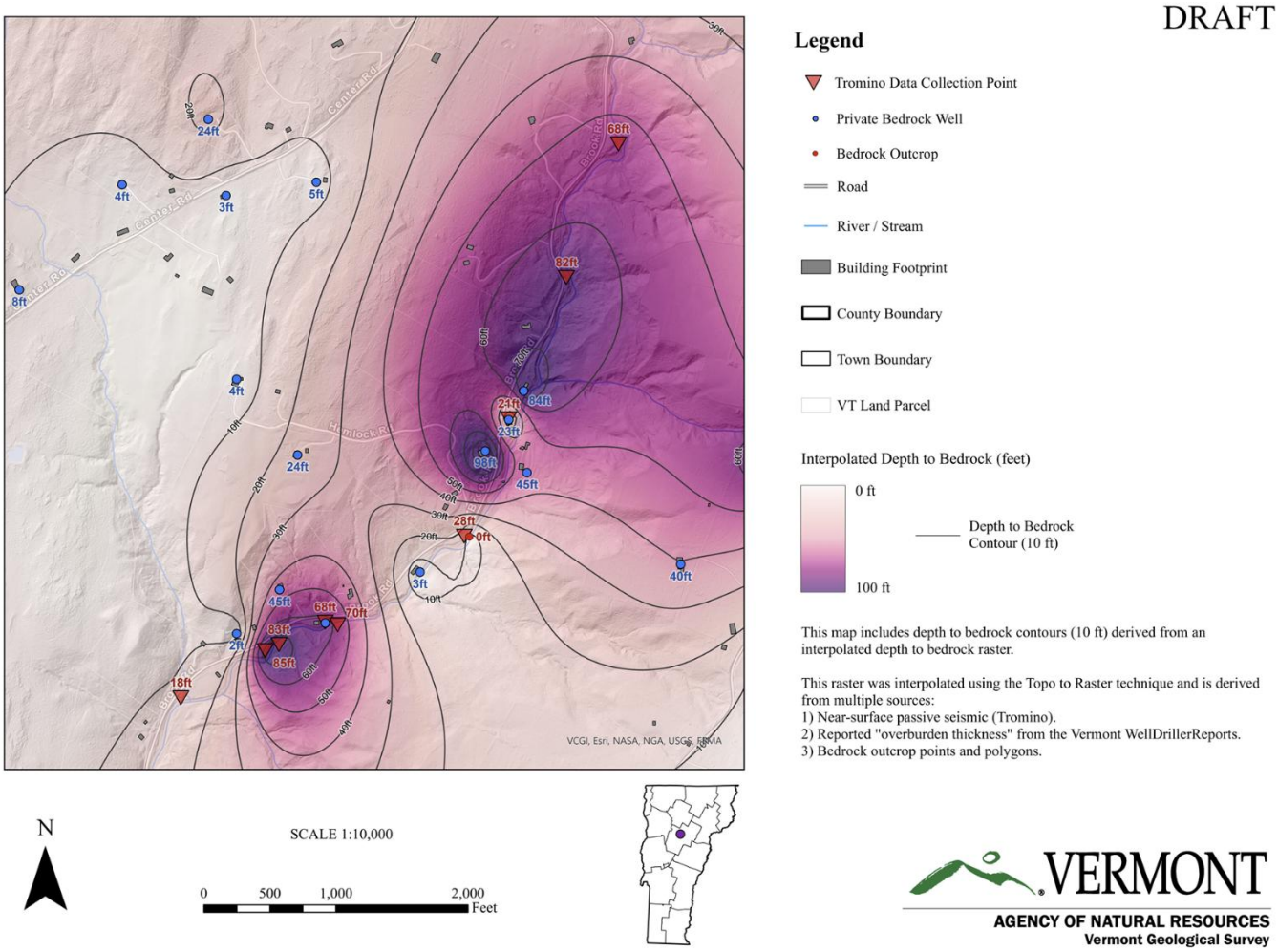
Upsize and manage driveway and road culverts

Create / Implement Debris Management Plans

The Road Committee is working townwide on storm-water and culverts. A focus to slow the flow specifically in the Great Brook watershed would be prudent.

Arresting further stream downcutting (if possible)

- In June, 2025, the Vermont Geologic Survey (VGS) spent two days along Great Brook taking "depth to bedrock" measurements. This data is crucial to the success of existing and future road and stream bank revetments and stability of stream crossings. If the laid-up stone revetments placed to secure the road embankment are footed onto bedrock, then they are far less likely to be undermined and fail during future floods. If bedrock is just out-of-reach of the excavator, then perhaps metal sheet-pile could be driven to its depth. If bedrock is so deep that there is no practical way to secure a revetment to it, then the only way to reduce further bed downcutting and the risk of embankment failure is if a natural armor (cobbles and boulders) were to embed along the length of the brook. This natural bed armoring is secured when stream power is reduced as a result of flood attenuation on floodplains and lower flood depths.
- VGS has now provided Middlesex a draft map showing depths to bedrock in an area of the watershed centered on Great Brook between stations 10000 and 18000. The map shows that bedrock is shallow in the western headwaters and downstream segment of Great Brook. A few readings showing depth to bedrock at around 20 feet were made near stations 10500 and 14400, the



latter being a pocket of bedrock surrounded by areas with very deep bedrock (>80 feet). Another, very shallow depth to bedrock pocket exists at 12900. Finally, the upper segment of Great Brook (upstream of station 14500) is flowing over very deep strata of glacial lake (varved) clays and tills, with bedrock over 80 feet down from where the readings were made.

Depth to Bedrock Sites listed from Upstream to Downstream

Site	Date	Stream Station	Depth to Bedrock DBT estimate (ft)	Height above stream bed (ft)	DTB (ft) below stream bed
Tromino-Site-5	4-Jun-25	16950	68	11	57
Tromino-Site-4	4-Jun-25	15400	82	14	68
Tromino-Site-3	4-Jun-25	14400	24	10	14
Tromino-Site-7	17-Jun-25	13250	21	7	14
Tromino-Site-2	4-Jun-25	12100	70	11	59
Tromino-Site-1	4-Jun-25	12100	68	9	59
Tromino-Site-8	17-Jun-25	12100	85	5	80
Tromino-Site-9	17-Jun-25	11500	83	7	76
Tromino-Site-10	17-Jun-25	10500	18	6	12

Acknowledgements: I would like to thank Ken Davis (North Bear Swamp Road) for his help in surveying the Brook this spring and summer to get an accurate accounting of infrastructure and their condition. Ken is a quick study and really helped as a sounding board for much of what is in this report. I appreciate the interest of the Middlesex Conservation Commission: Larry Becker for his help with the geologic assessments and Adrian Magida for help with accounting for landowner bank armoring project funding. Zara Vincent took the time to gather the FEMA dollars spent so far on Brook Road and Eric Metivier was always available to help us understand the work that's been done or is ongoing. I would also like to thank Sandy and Michael Levine for their assistance with outreach and I thank the landowners along the Brook for welcoming us onto their properties to assess the Brook. Finally, a thank you goes out to Staci Pomeroy and Evelyn Bordman, DEC river scientists, Jaron Borg, DEC River Engineer, Ben Degong, State Geologist, Peter Strand, DEC Geologist, George Springston, Norwich University, and the folks at the UVM Spatial Lab for all their assistance in getting this first year of the Project off the ground. Without their time and funds we would not have achieved the data sets that we now have.