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# Niagara Escarpment Erosion Project (NEEP) March 2023

**McMaster University & the City of Hamilton**

**OVERVIEW:**

The Niagara Escarpment is an integral feature of the City of Hamilton and provides the city with exceptional sites of natural beauty including numerous waterfalls and exposed rocky cliffs. However, the escarpment is also a geomorphic feature formed by ongoing erosion processes that create many challenges for the city and its residents. Unfortunately, there is very little information or quantitative data regarding the nature of erosion processes or the rates at which they operate along the escarpment in the Hamilton region, yet there is a growing urgency to understand these active processes given recent and predicted future impacts of climate change in the region. Climate is a major factor controlling both the types and rates of erosion processes that operate along the escarpment given that precipitation and temperature determine the effectiveness of runoff, groundwater seepage, freeze-thaw, undercutting and mass movement of exposed rock, and also the removal of weathered material. In order to fully understand the effect of climate change on these processes and on erosion rates along the Niagara Escarpment in the Hamilton area, a multi-year study (2023-2027) involving the investigation of multiple geological, hydrological, and historical factors is proposed.

The Niagara Escarpment Erosion Project (NEEP) is a collaborative venture between McMaster University and the City of Hamilton, that focusses on identifying the processes involved in erosion of the escarpment face and the controls that influence the rate at which these processes occur. These investigations involve the use of digital UAV photography, airborne/terrestrial remote sensing techniques, and the field recording (logging) of rock types and structures to identify vertical and horizontal variability in rock properties that may influence erosion processes and rates. Detailed documentation of joints, fissures and fractures on the escarpment face allows spatial patterns and possible controls on their development to

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be identified. In addition to field-based investigation, historical photographs, satellite and Google Earth images, and maps are being examined to establish former positions of the escarpment face in order to establish retreat rates. Past climate data and future climate models will also be examined to allow predictions of future changes in precipitation and temperature values to be made.

The initial phase of the NEEP project (2017-20) involved 4 undergraduate students, one MSc and one PhD student and three faculty members from the School of Earth, Environment and Society (SEES). The continuation of this work will involve Dr. Carolyn Eyles, Dr. John Maclachlan, Dr. Alex Peace, and Dr. Elli Papangelakis (McMaster faculty), 1 postdoctoral fellow, 3 full-time graduate (2023-2027), and 6 undergraduate students. The next phase of the project will include additional work on surface water hydrology and its relationship to erosional processes along the escarpment.

## McMaster University: work completed

**To gain quantitative data regarding erosion rates and processes the initial NEEP study (2017 – 2020) focused on:**

**Photogrammetry** – (to July 2020)
Ground-based and UAV photogrammetry was completed at 10 study sites (see Figure 1) during the summer of 2018 in order to establish a record of 'baseline conditions'. Subsequent photogrammetric surveys were conducted during the fall (2018) and winter/spring of 2019 to identify areas of material loss. Photographic images are being modelled using Agisoft Metashape software with change detection techniques identifying areas particularly susceptible to erosion. Best practices suggest at least 5 years of imagery are required for effective change detection analysis. Terrestrial-based LiDAR data collected by the City will augment these data. Initial results of the change detection study have established an effective methodology for determining the location and size of erosional events and a first order approximation of volume of change at one location (Albion Falls). (See Manuscripts – submitted).
**This can be extended to additional sites of importance along the Niagara Escarpment to allow documentation of erosion rates and processes at various sites along the escarpment.**

**Lithological analysis** – (to July 2020)
Detailed lithological analysis and assessment of the Niagara Escarpment in the Hamilton area documenting facies types, unit architectures, vertical and lateral variability. This involved detailed field logging of exposures along the Niagara Escarpment and spatial analysis of lithological changes along section and between sections. Additionally, two cores (40m and 45m long) from Sam Lawrence Park were logged to provide further lithological details leading to a more robust analysis. Data on the physical properties of lithological units is available and can be integrated into this work. Future work will involve field assessment of additional exposures along the escarpment (2023-2026). (See Theses – submitted).
**This would allow assessment of the potential geological controls on progressive and 'catastrophic' erosion processes (undercutting, collapse etc.) and of lithological variability along the escarpment.**

**Historical data analysis –** (B.Sc thesis, April 2020)
Change analysis of land use (Landsat imagery and additional data) in the Hamilton region over 34 years was conducted to identify the rate of urban expansion of the City and the location of areas that are at

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particular risk from erosion issues. Data from topographic maps, air photos and media reports were integrated into this study and analysed by an undergraduate thesis student (Ashley Wray) from September 2018 to April 2019. (See Theses – completed).
**This work began to identify areas of greatest urban change and potential high risk from erosion.**

**Vegetation analysis –** (M.Sc thesis, April 2022)
M.Sc student Allie Ellis investigated the effect of vegetation growth on erosion of the escarpment. Her research focused on the role that tree root growth plays in the expansion of bedrock fractures and the loosening of surface blocks. She conducted experimental work using digital accelerometers that measured tree sway and quantified the impact of this movement on fracture development. (see Theses – completed, Presentations).
**This work investigated the impact of tree growth on erosion process along the escarpment and may be used to inform vegetation management strategies.**

## McMaster University: work ongoing

**Fracture analysis –** (B.Sc theses completed April 2020, April 2021)
Initial analysis of fractures (September 2019 – April 2020) identified appropriate analytical techniques to be used in further study of fracture patterns in lithological units exposed along the escarpment. Work completed by an undergraduate thesis student (D. Joshi) from September 2019 to April 2020 determined the most effective methodology for computer-generated fracture analysis of the escarpment face which will provide information on erosional block size, water penetration, and frost weathering potential. The study used a semi-automated procedure to identify fractures based on photogrammetric models. Further work determining fracture orientation, density and aperture in the field was subsequently completed by S. Formenti, an undergraduate thesis student (2020 – 2021). The field-based measurements were compared to the semi-automated computer-generated fracture maps to determine the most accurate and efficient methodology for this work. (See Theses – completed; Manuscripts – published).
Future work could document fracture patterns in different lithologic units and at different sites along the escarpment and has the potential to form the basis of an M.Sc project (M.Sc student #1). A second potential MSc project could investigate regional tectonic stresses that influence fracture development and earthquake potential in the Hamilton region (M.Sc student #2).
**The distribution of fractures has a significant impact on erosion processes operating on the escarpment and understanding this variability will aid in assessing erosion potential.**

**Hydrological analysis** – (B.Sc theses, April 2020, April 2023)
Patterns of surface and groundwater movement in and around the escarpment were investigated by an undergraduate thesis student (S. Jivani) from September 2019 to April 2020. Initial results of this study have identified regional trends in water table elevations and possible seasonal effects on these elevations. (See Theses - completed). An ongoing study of Spencer Creek by undergraduate thesis student Shania Ramharrak-Maharaj aims to identify segments of the river network that are at high risk for riverine erosion using specialized hydrologic parameters calculated from a custom GIS toolbox. Collaboration with another undergraduate thesis student (E. Davies) aims to link results to the underlying geological patterns to provide a better picture of the controls on riverine erosion potential in the watershed and its relationship to other erosion processes along the escarpment. The effects of future land-use development and climate change on surface water systems crossing the escarpment, as well as continued investigation into the relationship between geology and surface water could be incorporated into future analyses (2023 – 2027).

These directions will further assess the importance and spatial variability of hydrological factors on erosion processes along the escarpment. (MSc student #3).
**The movement of water on and through the escarpment has a significant control on the effectiveness of weathering processes (such as freeze-thaw, the removal of weathered material), and direct riverine erosion of the escarpment.**

**Weathering susceptibility/ Climatic Data Analysis –** in progress (to April 2023)
Seasonal and diurnal temperature changes on the escarpment face can instigate the processes of thermal expansion, thermal shock, and freeze-thaw weathering, particularly in heavily fractured lithological units. Ongoing undergraduate research projects (Henry Gage & Julia Nielsen) are conducting in-situ thermal monitoring of escarpment rocks and fracture aperture changes to determine whether the necessary conditions for these weathering processes are occurring and to what degree. Continued climate change may increase the intensity of daytime temperature fluctuations and the length and number of freeze-thaw weathering cycles in the year, further enhancing the risk of fracturing and destabilizing the rock face. Future work will analyze historical climate records to identify trends in both precipitation and temperature values for the Hamilton region and their relationship to the frequency of failure events along the escarpment. Future climate models will also be examined to determine the potential impact of changing precipitation and temperature on erosion processes and rates.
(See Manuscripts – published; Presentations). Future BSc thesis. Future PhD thesis
**This work will determine the prevalence of thermal weathering processes occurring in Hamilton and its potential impact on fracturing and slope stability. This work will also identify the potential impact of future climate change on erosion of the escarpment.**

**Proposed Research Activities (May 2023 – May 2027)**

Our ongoing research into lithological and fracture analysis, weathering susceptibility, and riverine erosion potential will continue at various sites along the escarpment and will provide important information about factors affecting erosion processes and rates along the escarpment face. Some of these study sites will not be on access routes (e.g. Devil’s Punchbowl, Tiffany Falls, Chedoke Radial Trail). In addition to this research we will collect photogrammetric data using drones and/or SLR cameras at regular intervals (monthly/seasonally) on critical rock faces along the following access routes:

- Claremont
- Kenilworth
- Sydenham Road
- Beckett Drive
- Hwy 8 (Dundas)
- Sherman
- McNeilly Road
- Jolley Cut

These photographic images, taken at different times, will be used to identify areas of change on the rock faces and can be used to calculate volumes of rock material lost or gained. To supplement these photographic data, we will place ‘rock traps’ at the base of selected slopes to collect debris released from the rock face. These traps will be emptied at regular intervals to gain additional information on the size, shape and volume of material lost from the rock face over a specified time period. The majority of this work can be conducted along the margins of the active roadways at times of low traffic volume. However, we have budgeted for 8 hours of road closure per year to allow for data collection along Beckett Drive.

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All of the data (described above) collected by the team will be used to conduct a multi variate analysis taking into account factors such as slope angle, natural and anthropogenic water sources, and loading of the upper slope, to create a three-dimensional map identifying areas of high erosion potential along the escarpment in the Hamilton area. This map will be created collaboratively by a PhD student, a Post-Doctoral Fellow and all faculty involved.
**This work will contribute toward a comprehensive analysis of erosion risk along the escarpment in the Hamilton region.**

**Role of Part-Time Post-Doctoral Fellow** – (2 days/week - May 2023 – May 2027)
We will seek a part-time (2 days/week) Post-Doctoral Fellow (PDF) to co-ordinate and manage this project. They will be responsible for data integration, data preservation and metadata, report writing, manuscript preparation/publication, coordination/communication with the City, and public outreach. During and at the completion of the project, all project data will be accessible to the City of Hamilton and personnel training (where necessary) will be provided for ongoing monitoring of the Niagara Escarpment. The PDF will also be responsible for the coordination and scheduling of regular consultation meetings between the City and McMaster researchers to ensure effective communication is maintained between the collaborative teams. At least one of these meetings per year will involve presentation and discussion of all data collected/analyzed to date together with implementation strategies.

**PROPOSED DELIVERABLES:**

| Deliverable | Description | Format | Proposed Date of Completion |
|---|---|---|---|
| Photogrammetric imagery | Dataset - including all images used in photogrammetric modelling process completed in Agisoft Metashape | JPEG (any standard photo viewer will be sufficient) | Continuous data collection will continue from beginning of project to 2027 |
| Photogrammetric models | Each photogrammetry dataset will be processes into 3D models using Agisoft Metashape. Dense point clouds generated will be compared to compute change detection | The models can be shared in an .obj file (useable with Windows default 3D viewer, freeware CloudCompare, Meshlab, or any SfM software) or other file types (can be integrated with CAD software if needed) | Winter 2025 (first set of complete models) followed by ongoing through 2027 |
| Fracture density and distribution Report | Details of the collection methodology and resulting analysis of extensive field data to quantify the orientation and density of fractures in the Niagara Escarpment. | Report | Summer 2024 |

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|---|---|---|---|
| Surface waters characterization inventory | Dataset containing physical characteristics of surface water systems gathered from monitoring sites included in the study (e.g., slope, channel widths, material size) | Dataset | Summer 2025 |
| Methodology Report | Detailed breakdown of the methodology used in data collection and analysis for the change detection. | Report | Summer 2025 |
| GIS datasets | GIS datasets created during each stage of research will be compiled, standardized, and shared (e.g. riverine erosion risk maps). | Shapefile, Raster (will require GIS program to use such as ArcGIS) | Continuous creation and sharing |
| Risk assessment model of outcrops | Integration of numerous existing data sets normalized with data collected for this study within a multi-criterion analysis model to create a risk assessment of the escarpment face | Report | Summer 2026 |
| Risk assessment model of rivers | Synthesis of analysis on surface water features along the escarpment to create a risk assessment along the escarpment face | Report | Summer 2026 |
| Public Outreach initiatives | Public lectures or another format of public outreach. Timing and format to be determined at a future date in conjunction with both City and McMaster partners | TBD | ongoing |
| Methodology Manual | A manual explaining the methods used in the project and how they may be applied moving forward by the City of Hamilton. | Report and in-person training where relevant. | Spring 2025 and ongoing. |
| Consultation | Coordination and scheduling of regular meetings between City and McMaster personnel | In person and virtual meetings, presentations, field visits | Continuous from beginning of project to 2027 |

**NOTE: All data collected and compiled and work completed under this project, including B.Sc and M.Sc thesis work conducted by students, will be shared with the City. Students will be allowed to publish the results of their research, with approval from the City where necessary.**

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**Manuscripts – published**

- Formenti, S., Peace, A., Eyles, C., Lee, R., & Waldron, J. (2022). Fractures in the Niagara Escarpment in Ontario, Canada: Distribution, connectivity, and geohazard implications. Geological Magazine, 1-16. https://doi.org/10.1017/S0016756822000462
- Gage, H., Eyles, C., & Peace, A. (2022). Winter weathering of fractured sedimentary rocks in a temperate climate: Observation of freeze–thaw and thermal processes on the Niagara Escarpment, Hamilton, Ontario. Geological Magazine, 1-22. https://doi.org/10.1017/S0016756822000887

**Manuscripts – to be submitted (March 2023)**

- Lee, R.E., Maclachlan, J.C. and Eyles, C.H., Application of change detection to the analysis of erosion processes in an urban environment. Quaternary Science Advances.
- Lee, R.E., Maclachlan, J.C. and Eyles, C.H. Accuracy of change detection and volume calculations using UAV-based imagery of sedimentary rock outcrops of the Niagara Escarpment, Hamilton, Ontario, Canada. Quaternary Science Advances.

**Presentations and Articles**

- Ramharrack-Maharaj, S., Davies, E., Papangelakis, P., Peace, A., 2023. Linking surface water and geology: A case study of the Niagara Escarpment, Hamilton, Ontario. GAC/MAC Annual Meeting, Sudbury (submitted).
- Nielsen, J.P, Gage, H.J.M. and Eyles, C.H., 2023. Influence of Fracture Aperture on Thermal Weathering Processes in Fractured Sedimentary Rockwall. GAC/MAC Annual Meeting, Sudbury (submitted).
- Gage, H.J.M., Nielsen, Julia P. & Eyles, C. H., 2022. Seasonality of Rockwall Thermal Regimes in a Temperate Climate. Geological Society of America Abstracts with Programs, v.54, no. 5, https://doi.org/10.1130/abs/2022AM-383361
- Nielsen, J.P., Gage, H.J.M. and Eyles, C. H., 2022. Fracture Aperture Moderates Thermal Weathering Processes in Fractured Sedimentary Rockwalls. Geological Society of America Abstracts with Programs, v.54, no. 5, (https://doi.org/10.1130/abs/2022AM-383121)
- Gage, H., Eyles, C.H., Lee, R., Peace, A. 2021. Observations and Projections of Thermal Factors Affecting Weathering of Fractured Sedimentary Rocks of the Niagara Escarpment. GAC/MAC Annual Meeting, London. Abstracts, v. 44, p. 97.
- Gage, H., Eyles, C.H., Lee, R., and Peace, A., 2021. Contemporary Climatic Factors Affecting Thermal Weathering of Fractured Sedimentary Rocks of the Niagara Escarpment. American Geophysical Union Fall meeting, https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/845737
- Ellis, A. and Eyles, C.H., 2021. The influence of tree sway on erosion processes along the Niagara Escarpment, Hamilton, Ontario. American Geophysical Union Fall meeting. https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/996375
- Formenti, S., Peace, A., Waldron, J., Eyles, C., and Lee, R., 2021. The influence of fracture networks on stability and geohazards of the Niagara Escarpment in southern Ontario, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9094, https://doi.org/10.5194/egusphere-egu21-9094
- Gage, H., Eyles, C., and Lee, R., 2021. Thermal controls on the development of fractures in dolostones of the Niagara Escarpment, Hamilton, Ontario, Canada, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9140, https://doi.org/10.5194/egusphere-egu21-9140

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- Lee, R. E., Maclachlan, J. C. and Eyles, C. H. (2020). Determining the applicability of change detection for quantification of erosion on the Niagara Escarpment, Hamilton, Ontario, Canada. Geological Society of America Abstracts with Programs. Vol 52, No. 6.
- Formenti, S., Peace, A., Eyles, C. H., and Lee, R. E. (2020). An analysis of fracture controlled erosion and rockfalls in the Niagara Escarpment in southern Ontario. Geological Society of America Abstracts with Programs. Vol 52, No. 6, 2020 [Poster presentation]. doi: 10.1130/abs/2020AM-354729
- Ellis, A.J. and Eyles, C.H., 2020. Quantifying the impact of vegetation on erosion processes along the Niagara Escarpment in the Hamilton region of southern Ontario. Geological Society of America Abstracts with Programs. Vol 52, No. 6, doi: 10.1130/abs/2020AM-357459
- Weiland, L., Lee, R., Narro Perez, R. and Eyles, C.H. (2019). Investigation of the influence of lithological variability on erosion of the Niagara Escarpment in Hamilton, Ontario, Canada. Geological Society of America Annual Meeting, Phoenix, United States.
- Weiland, L., Lee, R. and Eyles, C.H. (2019). Creation of a Virtual Field Experience of the Niagara Escarpment in Hamilton, Ontario, Canada. Geological Society of America Annual Meeting, Phoenix, United States.
- Wray, A, Lee, R. and Maclachlan, J.C. (2019). Urbanization and the Niagara Escarpment: Anthropogenic Factors Influencing Erosion Rates. Geological Society of America Annual Meeting, Phoenix, United States.
- Lee, R. E., Eyles, C. H., Narro Perez, R. and Maclachlan, J. C. (2018) Utilizing photogrammetry to analyze variation in the lithology and structure of the Niagara Escarpment in Hamilton, Ontario, Canada. Geological Society of America Annual Meeting, Indianapolis, United States. Abstracts.

**Student Theses & Reports**

- Ellis, A.J., 2022. Assessing the Impact of Vegetation on Erosion Processes on the Niagara Escarpment in the Hamilton Region, Canada. McMaster University, M.Sc thesis, 71pp. http://hdl.handle.net/11375/27565
- Lee, R.E., 2022. Delineation and Analysis of Active Geomorphological Processes Using High Resolution Spatial Surveys. McMaster University, PhD thesis. 233pp. http://hdl.handle.net/11375/27445
- Ahmed, Zargham (2022) Geologic fractures at Fletcher Creek and their relationship to fluid flow and local geohazards. McMaster University, BSc thesis.
- Formenti, Serena (2021) Control of fracture distribution, style and orientation on stability of the Niagara escarpment in Hamilton. McMaster University, BSc thesis.
- Joshi, D., 2020. Fracture Analysis, Sampling Methodology and Influence on Erosion of the Niagara Escarpment in Hamilton, Ontario. McMaster University, BSc thesis, 58pp.
- Jivani, S., 2020. A Hydrogeological Investigation of the Niagara Escarpment in Hamilton, Ontario. McMaster University, BSc thesis, 47pp.
- Wray, A., 2020. Urbanization and The Niagara Escarpment: Anthropogenic Factors Influencing Erosion Rates, BSc thesis, 34pp.
- Weiland, L, 2020. An Investigation of the Mineralogical Composition of the Lockport Dolostone and Rochester Shale exposed along the Niagara Escarpment in Hamilton, Ontario. Independent Project Report, 57pp.

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**FUTURE INITIATIVES:**

**Planned work for short term (6 months – 1 year)**

- Photogrammetry and drone imagery collected at selected study sites (Summer 2023; see Figure 1) including the Kenilworth access route, Beckett Dr, and Claremont access;
- Conduct change detection analysis of imagery to document erosion processes and rates at selected sites;
- Continue analysis of lithological variability along the escarpment – vertical and lateral;
- Continue monitoring of temperature changes in fractures and on rock faces at selected sites;
- Continue compilation of hydrological/hydrogeological data and analysis of water impacts on erosion processes and rates;
- Photographic image analysis, preparation of manuscripts and summary diagrams.

**Planned work for longer term (to the end of the project)**

- Continue collection of drone imagery/seasonal photogrammetry of the selected study sites to identify lithological units and regions of the escarpment most prone to high erosion rates;
- Develop and improve change detection techniques;
- Continue analysis of past trends and future predictions of temperature and precipitation;
- Continue field-based research study the impact of thermally induced weathering processes on the escarpment;
- Expand surface water erosion risk assessment with future land-use and climate scenarios;
- Continue refinement of the erosion risk assessment model/map through incorporation of additional field data;
- Academic communication plan (papers, conferences, etc.) to be developed and implemented;
- Public communication strategy to be developed and implemented.

**Planned efforts for project continuation after completion of the grant**

- Shared methodologies developed over the course of this grant will allow for the continued collection of data and monitoring of erosion along the Niagara Escarpment using both terrestrial based imagery and UAV based imagery.

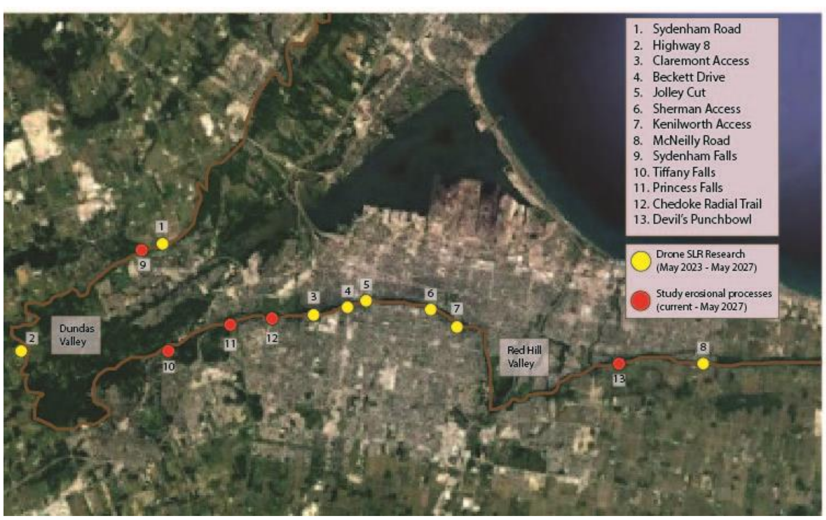


Figure 1 Study locations

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**Proposed Budget:**
To carry out this research project (May 2023 – May 2027) the following funding is requested:

| Year | Approximate Research Costs | |
|---|---|---|
| 2023-2024 (8 months) | Personnel (Post-Doctoral Fellow & graduate & undergraduate students) | *$52,000* |
| | Research Equipment | *$20,000* |
| | Consultation | *$2,000* |
| | Other Research Costs | *$4,000* |
| | **Total** | **$78,000** |
| 2024-2025 | Personnel (Post-Doctoral Fellow & graduate & undergraduate students) | *$60,000* |
| | Research Equipment | *$5,000* |
| | Consultation | *$2,000* |
| | Other Research Costs (including road closures) | *$10,000* |
| | **Total** | **$77,000** |
| 2025-2026 | Personnel (Post-Doctoral Fellow & graduate & undergraduate students) | *$60,000* |
| | Research Equipment | *$5,000* |
| | Consultation | *$2,000* |
| | Other Research Costs (including road closures) | *$10,000* |
| | **Total** | **$77,000** |
| 2026-2027 (4 months) | Personnel (Post-Doctoral Fellow & graduate & undergraduate students) | *$12,000* |
| | Consultation | *$2,000* |
| | Other Research Costs | *$2,500* |
| | **Total** | **$16,500** |

| | | |
|---|---|---|
| **2023-2027** | **NEEP project total** | **$248,500** |

**Personnel costs:**
**PDF** $60,000/year: 2 days/week $24,000/year; **Grads:** 2 x $10,000/year; **U/Grads** 2 x $8000/year
2023-24: 8 months: PDF = $16,000; Grads = $20,000; U/grads = $16,000
2024-25: 12 months: PDF = $24,000; Grads = $20,000; U/grads = $16,000
2025-26: 12 months: PDF = $24,000; Grads = $20,000; U/grads = $16,000
2026-27: 4 months: PDF = $8,000; Grads= $4,000; no undergrads

Estimated road closure costs $5000/year (2024-2026)