Eel Point Road Restoration and Resilience

Picture of Eel Point Road after rainfall.

December 15, 2023

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An interactive Qualifying Project submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

December 15, 2023

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Abstract

The goal of this project was to research, identify, and recommend solutions to mitigate the effects of continued flooding and erosion on Eel Point Road (EPR) on Linda Loring Nature Foundation (LLNF) property. We assessed and documented EPR conditions, identified EPR users, and surveyed and interviewed key personnel. Then, we integrated our research with pre-existing data from the LLNF and recommended both near- and long-term solutions for flooding and erosion control to the LLNF. We determined that regular maintenance is required in identified problem areas on EPR.

Authorship

Section Name	Author(s)	Editor(s)
Abstract	KP	ALL
Acknowledgements	KP	ALL
Executive Summary	JP, MR	ALL
Introduction	JP	ALL
Background	MR	ALL
Goals and Methods	MR	ALL
Results	MR	ALL
Recommendations	JP	ALL
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2.0 Background	MR	ALL
2.1 Unpaved Roads	MR	ALL
2.2 Conditions on Unpaved Roads	KP, MR	ALL
2.3 Unpaved Road Repair and Maintenance	AD	ALL
2.4 Eel Point Road	JP	ALL
2.5 Background Summary	MR	ALL
3.0 Goals and Methods	MR	ALL
3.1 Road Condition Assessments	MR	ALL
3.2 Vehicle Traffic Composition	KP	ALL
3.3 Community Perceptions	KP	ALL
3.4 Impact of Road Conditions on Usability	KP	ALL
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Acknowledgements

We would like to extend our appreciation to everyone that helped our team throughout the entirety of our project. We would like to specifically thank these individuals for their guidance:

- Professor Fred J. Looft and Professor Susan Jarvis for everything that they have done for our team from improving our academic skills to providing us with a positive experience on Nantucket for which we are grateful.
- Kathryn K. Pochman, Sarah T. Bois, and Seth I. Engelbourg for being wonderful sponsors and providing us with a great project, a positive experience, guiding and helping us the whole way.
- Kristin Bullet and Libby Buck for creating social media posts to promote our survey and giving us advice throughout the project.
- Andrew Patnode, Arthur Dwyer, and Mike Burns for meeting with our team and sharing their expert opinions that were a great help for our report.
- All our interviewees for their willingness to meet with us and share their experiences that helped our findings in the report.

Executive Summary

Introduction

The Linda Loring Nature Foundation (LLNF) is a 275-acre land trust and conservation foundation located on Nantucket. It was established in 1999 by Linda Loring and became operational in 2007 with a mission to preserve the natural landscape of Nantucket ("*History*"). The Linda Loring Nature Foundation building, located on 110 Eel Point Road (EPR), is dedicated to preserving and researching the biological diversity of their property and in prioritizing its resiliency. This includes monitoring rare and endangered species and the control of invasive species. In addition, weather data is collected through weather stations on the property. The LLNF provides education for the Nantucket community through academic and community programs, workshops, and special events ("*Education*").

The only point of vehicle access to the LLNF property is the unpaved section of EPR. The road is prone to flooding and heavy erosion that alters its shape, and by 2070, EPR is expected to experience up to 6 inches of flooding daily during high tides ("Nantucket Coastal" 4). The flooding and erosion of EPR has resulted in the fragmentation of habitat protected by the LLNF; if the flooding and erosion problems are not addressed, habitat loss and damage will increase (S. Bois, personal communication). Access to the LLNF and surrounding properties may become limited.

Background

Unpaved roads are composed of three structural layers: the road surface, gravel, and subgrade (Shtayat et al. 632) The surface and gravel layers are often composed of stone, rock, or sand, while the subgrade is formed from compacted native soil (ibid). These layers are shaped to form the road crown, which allows water to drain off the road surface ("Crown & Cross-Slope" 1).

Unsurfaced roads experience seven types of distress that impact their functionality: improper cross section, inadequate roadside drainage, corrugations, dust, potholes, ruts, and loose aggregates (Saha & Ksaibati 4). The erosion of unpaved roads is affected by the composition of the surface and subgrade, as well as from traffic flow across the road surface (Alvis et al. 183-188). If the surface or subgrade layers are improperly constructed, the rate of erosion on the road increases (ibid). The impact and flow of rainwater across the road surface also contributes to the erosion of unpaved roads (Ngezahayo et al. 2-3). The rise in relative sea level (RSL) is projected to increase the effects of water-based erosion: flooding frequencies are expected to increase by 5 times their current amount by 2050, from 0.04 severe flooding events per year to 0.2 severe flooding events per year ("Sea Level Rise Scenarios" xiii).

To directly address distresses on unpaved road surfaces, blading and reconstructive grading are used. Blading is the practice of smoothing the road surface by redistributing loose aggregates, while reconstructive grading involves the removal, redistribution, and compaction of the road surface (Kearley 3-4). Additionally, multiple structures can be installed as part of an unpaved road to mitigate the effects of flooding and erosion on the road. These structures include ditches, culverts, outlet structures, and bank stabilizations (Kearley 11-24).

Eel Point Road (EPR) is a partially paved road on the west end of Nantucket, with access to points of interest including Eel Point, Dionis Beach, the Linda Loring Nature Foundation (LLNF), and 40th Pole

Beach. Erosion on EPR is caused by multiple factors, including heavy summer traffic, construction vehicle use, and repeated grading of the road (S. Bois, personal communication). Additionally, rising sea levels may result in up to 6 inches of daily flooding on EPR by 2070 ("Nantucket Coastal" 4). Increased volumes and frequencies of flooding on EPR are expected to increase the erosion of EPR (S. Bois, personal communication).

Goals and Methods

The goal of this project was to research, identify, and recommend solutions to mitigate the effects of continued flooding and erosion of Eel Point Road (EPR) on Linda Loring Nature Foundation (LLNF) property in both the near and long term. To achieve this goal, the research team developed the following objectives:

1. Assess and document current conditions on EPR[1] via road surface condition indexing, photography, and qualitative observations of the road.
2. Identify users of EPR by analyzing the composition of vehicle traffic.
3. Survey and interview key personnel how road conditions are perceived by the community.
4. Assess and document how road conditions impact the usability of EPR.
5. Integrate research with pre-existing data from the Linda Loring Nature Foundation (LLNF) via updating GIS mapping and documentation of research data.
6. Recommend flooding and erosion control, and maintenance solutions implementable by the LLNF on EPR over varying timelines based on research data.

To achieve this goal, the research team assessed current conditions on EPR through photography and the Unsurfaced Road Condition Index (URCI). Vehicle traffic composition on EPR was determined through a trail camera placed on LLNF property that recorded the types of vehicles used on EPR over a two-week period. Through social media, flyers, e-mail, and local news, an online survey was distributed to identify user demographics of EPR and how these users perceived road conditions on EPR. A series of 15-minute targeted interviews were conducted with town employees, first responders, fishers, and residents to learn about how specific road conditions on EPR impacted its usability. The data collected from these methods were then integrated with GIS data from the LLNF and public databases to fully visualize road conditions on EPR. Finally, this data was used to produce and recommend both short- and long-term erosion and flooding control solutions for EPR to the LLNF that could be applied across multiple potential timelines.

Results

In assessing the current condition of EPR, determining the composition of vehicle traffic on EPR, surveying and interviewing EPR users, and integrating our data with data from the LLNF and public databases, the research team learned the following:

[1] From the area of 69 Eel Point Road to the 40th Pole Beach parking lot: this is the section of EPR bordering LLNF property and is a private road.

- The most severe distresses on EPR are improper cross sections, corrugations, and loose aggregates.
- The main form of vehicle traffic on EPR is from passenger vehicles. During the study window in early November, EPR experienced a traffic volume of approximately 81 vehicles per day, with peak traffic occurring at 11:00 AM.
- Over 50% of survey respondents rated the road condition and maintenance of EPR poorly or very poorly. Of the respondents familiar with EPR, 55% rated its condition as being worse than other unpaved roads on Nantucket.
- The conditions on EPR negatively affected resident and first responder access to locations on the road. Interviewees expressed interest in regrading EPR and establishing a consistent road height and width.
- Two sections of EPR are projected to experience severe potential flooding yearly by 2070. The GIS map of EPR allowed the research team to identify sections of EPR at risk for future flooding and erosion and to target road repair and maintenance solutions to specific sections of EPR.

Recommendations

The research team recommends that the Linda Loring Nature Foundation (LLNF) perform the following actions on EPR to reduce the effects of flooding and erosion of the road on foundation property:

- Regrade Eel Point Road to address potholes, corrugations, ruts, and loose aggregates that impact the usability of EPR. This will also allow water to drain from the road surface into the surrounding environment.
- Install an artificial wetland area in sections of EPR to hold large amounts of water runoff from storms and reduce the effects of flooding.
- Establish a consistent road width on Eel Point Road to prevent traffic hazards.

The research team recommends that the LLNF perform the following actions on EPR to supplement the recommendations listed above:

- Establish a road path on Eel Point Road to create a set layout of the road.
- Implement a civic association to address maintenance, funding, and organization of the repairs on Eel Point Road.
- Install warning signs on Eel Point Road to inform EPR users of current road conditions.

Future research concerning EPR should be conducted in the following areas:

- Conduct additional trail camera studies to determine how frequently EPR is used during different seasons.
- Survey abutters of Eel Point Road to determine which road repair and maintenance solutions should be implemented.

- Continue indexing the conditions of Eel Point Road annually by utilizing the Unsurfaced Road Condition Index (URCI).

1.0 Introduction

The Linda Loring Nature Foundation (LLNF) is a 275-acre land trust and conservation foundation located on Nantucket. Linda Loring started the conservation effort in 1957 when she began to purchase and connect a total of 270 acres of land between Madaket and Eel Point Road ("*A Woman of Vision*"). In 1999, Linda Loring established the Linda Loring Nature Foundation ("*History*"). The foundation became operational in 2007 with a mission to preserve the natural landscape of Nantucket (ibid).

Shown in Figure 1 is the Linda Loring Nature Foundation building located on 110 Eel Point Road (EPR)[2]. The LLNF is dedicated to preserving and researching the biological diversity of their property and in prioritizing its resiliency. This includes monitoring rare and endangered species and the control of invasive species. In addition, weather data is collected through weather stations on the property. The LLNF provides education for the Nantucket community through academic and community programs, workshops, and special events ("Education").

Figure 1. The Linda Loring Nature Foundation building.

As shown in Figure 2, the only point of vehicle access to the LLNF property is the unpaved section of EPR. As shown in Figure 3(a) and 3(b) (on following page), the road is prone to flooding and heavy erosion that alters its shape, and by 2070, EPR is expected to experience up to six inches of flooding daily during high tides ("Nantucket Coastal" 4). The flooding and erosion of EPR has resulted in the fragmentation of habitat protected by the LLNF; if the flooding and erosion problems are not addressed, habitat loss and damage will increase (S. Bois, personal communication). Access to the LLNF and surrounding properties may become limited.

Figure 2. Part of the unpaved section of Eel Point Road. (https://tinyurl.com/3yjz7wcj)

The goal of this research study was to research, identify, and recommend solutions to mitigate the effects of continued flooding and erosion of EPR on LLNF property in both near and long term. To achieve this goal, the following objectives were developed.

1. Assess and document current conditions on EPR[3] via road surface condition indexing, photography, and qualitative observations of the road.
2. Identify users of EPR by analyzing the composition of vehicle traffic.
3. Survey and interview key personnel how road conditions are perceived by the community.

[2] All sources within this report are cited. Pictures, graphs, tables, or other components not cited are derived from our own work.

[3] From the area of 69 Eel Point Road to the 40th Pole Beach parking lot: this is the section of EPR bordering LLNF property and is a private road.

4. Assess and document how road conditions impact the usability of EPR.
5. Integrate research with pre-existing data from the Linda Loring Nature Foundation (LLNF) via updating GIS mapping and documentation of research data.
6. Recommend flooding and erosion control, and maintenance solutions implementable by the LLNF on EPR over varying timelines based on research data.

The following sections of this report will present the background information and methodology used to gather research data. We will then present our results and the research-based recommendations for flooding and erosion mitigation on EPR.

Figure 3. Images of flooding and erosion on Eel Point Road.
A. A depression on EPR flooded with water.
B. Erosion on the road shoulder of EPR.

2.0 Background

This section provides information needed to understand the goals, objectives, results, and recommendations of this report. Specifically, this section provides information on unpaved roads, how road conditions are evaluated, and how unpaved roads are maintained and repaired. The section also presents information on Eel Point Road and its current condition.

2.1 Unpaved Roads

The structure of unpaved roads can be summarized in terms of their structural layers and their component elements. As shown in Figure 4, unpaved roads are comprised of three structural layers: the road surface, gravel, and subgrade (Shtayat et al. 632). The surface layer is dependent on geographic soil conditions and is often composed of stone, rock, or sand[4]. The subgrade consists of native soil compacted to support traffic loads; gravel is used to improve water drainage and load distribution across the road surface (ibid).

Figure 4 additionally shows the structures that direct water from the road surface: the road crown, road shoulder, and ditches ("Gravel Roads Construction" 1). Ditches redirect and transport water collected from the road to culverts and road outlet structures ("Unpaved Roads BMP Manual" 15). This prevents standing water from infiltrating the subgrade layer and contributing to road destabilization and collects eroded road materials (ibid).

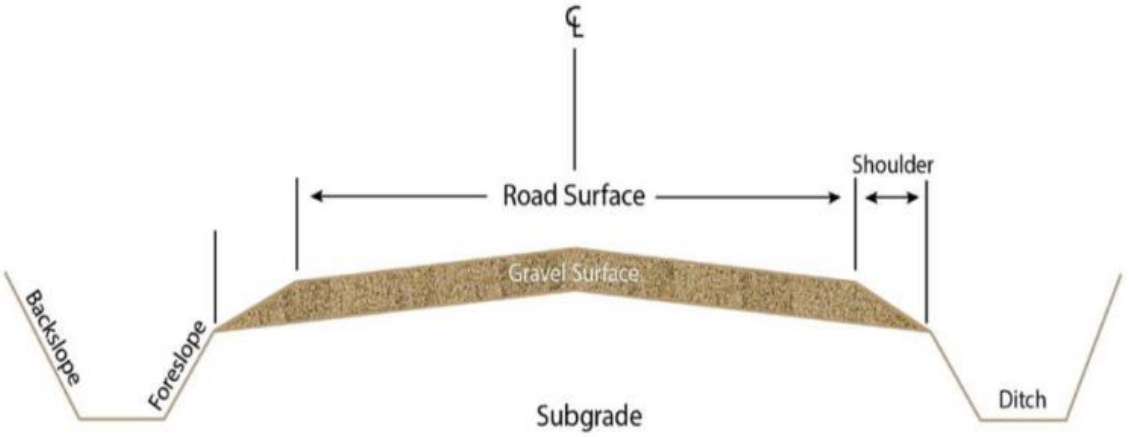


Figure 4. Generalized road surface cross-section illustrating the following: road surface, gravel surface, and subgrade; the location of the road shoulder and ditches; and the centerline of the road (represented by centerline symbol ℄).
(https://cset.uaf.edu/media/222562/1706_cset_final-report_ibrahim.pdf)

[4] The native soil of Nantucket is composed of sandy loam with a fine grain ("Nantucket Series" 1). For more detail, see the Nantucket Series (1).

As shown in Figure 5, the road crown is the cross-section elevation of the road, divided into centerline crowns, in-slopes, and out-slopes ("Crown & Cross-Slope" 1). Material displacements and compaction from vehicle travel can alter the road crown and result in pooling water on the road surface (Crown & Cross-Slope" 2). The road shoulder refers to the sloping sides of the road crown, which direct the flow of water away from the road surface and into ditches ("Unpaved Roads BMP Manual" 10).

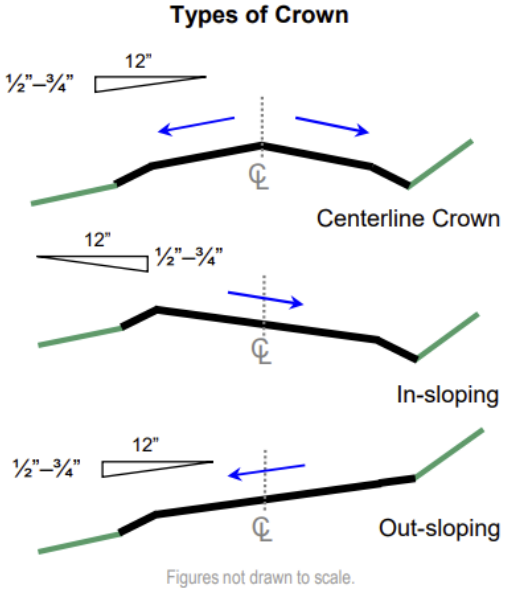


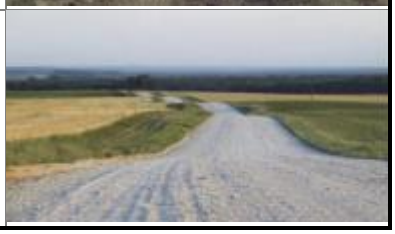
Figure 5. Road surface cross-sections illustrating the three types of road surface crown. (https://dirtandgravel.psu.edu/wp-content/uploads/2022/06/TB_Crown_and_Cross_Slope.pdf)

2.2 Conditions on Unpaved Roads

Unsurfaced roads experience seven distress conditions that impact their functionality (Saha & Ksaibati 4). Table 1 (on following page) lists each distress condition, their descriptions, and the sources of the distress. Structural erosion on unpaved roads is impacted by the flow of traffic across the road surface (Alvis et al. 183). The structure and composition of the road surface and subgrade further affect how traffic flow erodes the road (Alvis et al. 188). Poor aggregate materials break down under stress (i.e., traffic, air flow, water flow) (ibid). Improperly compacted subgrades, or subgrades constructed using stress-intolerant materials, also lead to increased erosion rates (ibid). Table 2 (page 6) names, describes, and identifies the source of types of structural erosion caused by traffic on unpaved roads.

Water-based erosion on unpaved roads is categorized into splash, sheet (inter-rill), rill, and gully erosion (Ngezahayo et al. 2-3). These conditions are caused by the impact and flow of rain and floodwater across the surface of the road. Table 3 (page 7) lists the types of water-based erosion, their descriptions, their source, and a diagram of each.

Table 1. Distress conditions of unpaved roads (Eaton B1-B13)

Distress Condition	Description	Source of Distress	Image[5]
Improper cross section	• Road not sufficiently sloped to carry water off road surface • Water pools on road surface	• Improper road shape • Lack of maintenance on road surface	
Inadequate roadside drainage	• Drainage structures unable to transport water runoff • Collection of water in & around drainage structures	• Vegetation and/or debris blocking water flow • Improper drainage structures • Erosion of drainage structures into road surface	
Corrugation	• Ripples in road surface perpendicular to flow of traffic	• Acceleration & deceleration of vehicles • High speed vehicle traffic[6]	
Dust	• Clouds of loose soil produced by vehicle travel	• Loosening of soil particles • Vehicle traffic	
Potholes	• Depressions in road surface, typically circular or bowl-shaped	• Loose surface material • Soft spots under road surface • Vehicle traffic	
Rutting	• Depressions in road surface parallel to traffic flow • Follows wheel paths formed by traffic flow	• Deformations in road structure • Repeated vehicle traffic along soft spots & deformations	
Loose aggregate	• Loose soil & road material	• Loose surface material • Vehicle traffic	

[5] https://www.researchgate.net/publication/318015991_Developing_an_Optimization_Model_to_Manage_Unpaved_Roads

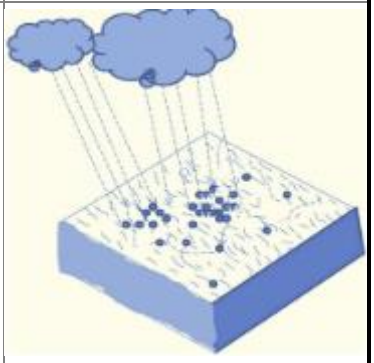
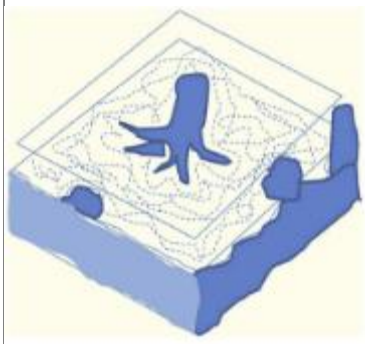
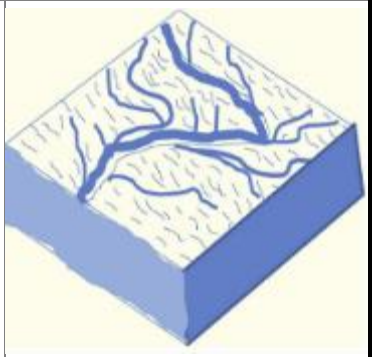
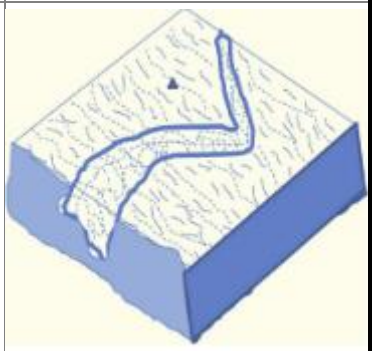
[6] From Rehmeyer (1). For a description on how vehicle speed affects the formation of corrugations, refer to Rehmeyer (1).

Table 2. Types of structural traffic-based erosion on unpaved roads (Alvis et al. 183-186)

Structural Erosion Type	Description	Source of Erosion	Image[7]
Crushing	• Breakdown of surface aggregates	• Heavy loads/vehicles pushing downwards onto road surface	
Pumping	• Fine sediments displaced to road surface • Displacement of subsurface road materials	• Vehicle traffic	
Scattering	• Displacement of large road sediments • Exposure of fine sediment layers	• Vehicle traffic	
Flow rerouting	• Water flow paths diverted/altered by erosion	• Vehicle traffic • Water flow across road surface	

[7] https://cdnsciencepub.com/doi/10.1139/er-2022-0032

Table 3. Types of water-based erosion on unpaved roads (Ngezahayo et al. 2-3)

Water-based Erosion Type	Description	Source of Erosion	Image[8]
Splash	• Road absorbs kinetic energy from rainfall • Soil detached from road surface by rainfall impact	• Rainfall • Loose soil	
Sheet/inter-rill	• Water collects on road surface & forms sheet flows • Sheet flow detaches soil particles	• Heavy rainfall	
Rill	• Flowing water detaches soil particles & puts shear stress on road surface • Sediment from road surface flows & collects downstream	• Water streams across road surface	
Gully	• Water flow across & through pre-existing rills • Cracks & cliffs form across road layers	• Rill erosion	

[8] https://www.researchgate.net/publication/342799551_Soil_and_Water_Conservation_Measures_for_Agricultural_Sustainability

The severity of water-based road erosion is based on the amount, intensity, velocity, and duration of rainfall (Zhang et al. 2). As an example, the effect of rainfall conditions on soil erosion were analyzed in 2017, when a heavy rainstorm on the Loess Plateau in north-central China resulted in 1.65 cm of soil erosion (Wang et al. 7)[9]. As shown in Figure 6, four catchment sites across the Loess Plateau recorded erosion intensities above the area average due to the effect of the rainstorm on soil erosion (Wang et al. 8).

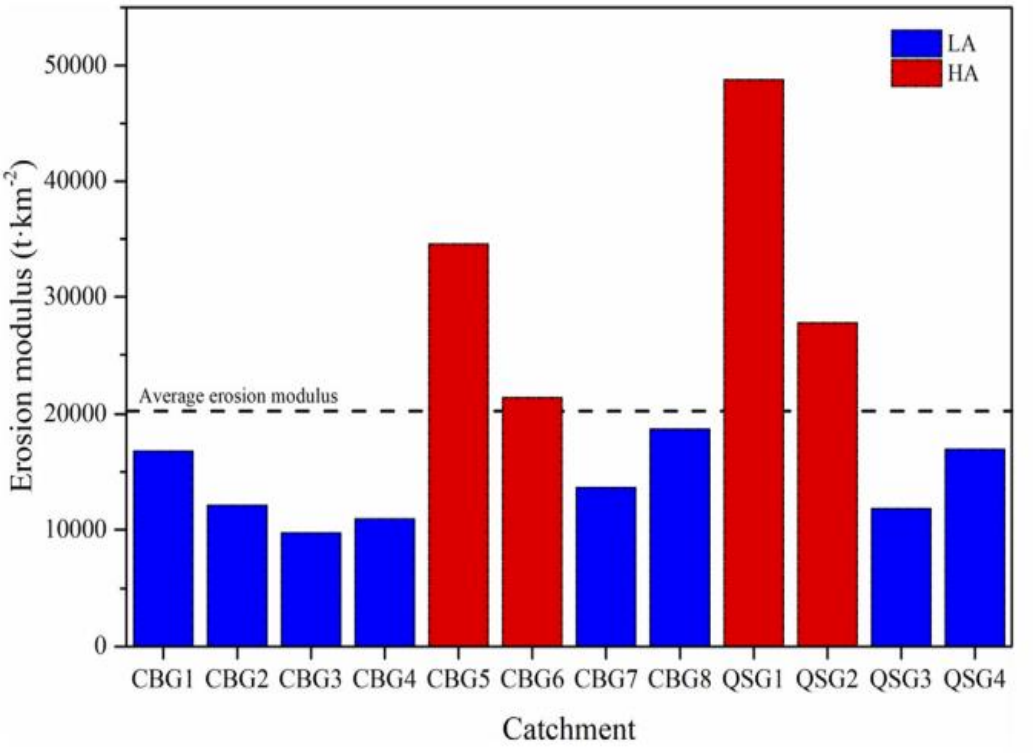


Figure 6. A bar graph showing erosion intensities from 12 sediment catchments across the Loess Plateau. The x-axis shows each catchment and their names; the y-axis shows the erosion modulus (degree of erosion). Catchments in blue (LA) represent degrees of erosion lower than the area average, while catchments in red (HA) represent degrees of erosion higher than the area average. (https://www.sciencedirect.com/science/article/pii/S0341816220303301)

A contributing factor to water-based erosion is the rise in relative sea level (RSL). Table 4 (on following page) demonstrates how RSL has risen in the past, and that future projections show a larger rise in RSL. As the RSL rises, the space between the sea level and land begins to shrink. According to *Global and Regional Sea Level Rise Scenarios*, the rise in RSL will bring tide and storm surge heights closer to inland within the next 30 years. As the RSL increases the number of opportunities for storms to reach inland, this then impacts storm surges, high tides, coastal erosion, and wetland loss ("Sea Level Rise Scenarios" 2) The increase in flooding increases the impacts to unpaved roads as there are larger amounts of water impacting the road and how usable it is.

[9] 252.3 mm/9.9 inches of rainfall: see Zhang et al. (2).

Table 4. Past statistics and future projections of Relative Sea Level (RSL) and flooding

	RSL Statistics	Flooding Statistics
Past	• RSL increased ~28 cm between 1920-2020 ("Sea Level Rise Scenarios" 1)	• Flooding frequency increased 75% from 2000-2015 ("Patterns and Projections" viii). • 3.4 days/year to 6 days/year high tide flood frequency ("Patterns and Projections" viii).
Future	• RSL to increase 2-5 mm yearly ("Patterns and Projections" 1) • RSL estimated to increase 10-12 inches in 30 years ("Sea Level Rise Scenarios" xii)	• Severe flooding to increase by 5 times current amount by 2050: from 0.04 events/year to 0.2 events/year ("Sea Level Rise Scenarios" xiii).

2.3 Unpaved Road Repair and Maintenance

Techniques to directly address unpaved road surfaces are blading and reconstructive grading. As shown in Figure 7, blading is the practice of smoothing the road surface by pulling loose aggregates from the road across surface deformations (Kearley 3). As shown in Figure 8, reconstructive grading is the practice of cutting, redistributing, and compacting the road surface to reshape the road (Kearley 4). Reconstructive grading also involves the addition and distribution of new road surface material to address rutting, potholes, corrugations, and erosion caused by standing water (ibid). Table 5 (on following page) lists structures used to mitigate the effects of flooding and erosion on unpaved roads, their function, where on the road the structures are placed, and images of each structure.

Figure 7. Blading being performed on an unpaved road. The moldboard is used to drag loose sediment across the road surface. (https://www.fhwa.dot.gov/construction/pubs/ots15002.pdf)

Figure 8. Grading being performed on an unpaved road. The road grader (tractor) cuts the surface of the road and refills the cut surface with aggregate materials. (https://bouldercounty.gov/transportation/road-maintenance/road-grading/)

Table 5. Flooding and erosion mitigation structures for unpaved roads (Kearley 11-24)

Structure Type	Function	Installation Location	Example Image[10]
Ditch	• Transport water from road surface • Reduce speed & turbulence of flowing water	• Roadside • Typically placed uphill to prevent water flowing onto road surface	
Culvert	• Transport water between locations • Drain water from other installations	• Installed alongside other flooding and erosion installations • Underneath road surface	
Outlet structure	• Reduce speed & turbulence of water • Remove sediment & pollutants from runoff	• Areas of high velocity/turbulent water discharge • Ditch & culvert outlets	
Bank stabilization	• Resist erosion of slopes & embankments • Improve slope stability	• Road slopes & embankments	

[10] http://www.culpeperswcd.org/wp-content/uploads/Dirt-and-Gravel-Road-BMP-Guide-Final-January-28-2019.pdf; https://waynecountynysoilandwater.org/culvert-enhancement-services/; https://megamanual.geosyntec.com/npsmanual/outletstructures.aspx; https://docs.nzfoa.org.nz/live/nz-forest-road-engineering-manual/5-road-and-landing-construction/5.10-stabilising-cut-and-fill-slopes-during-construction/

2.4 Eel Point Road

Eel Point Road is a partially paved road on the west end of Nantucket with access to points of interest including Eel Point, Dionis Beach, the Linda Loring Nature Foundation (LLNF), and 40th Pole Beach. As shown in Figure 9(a), the road transitions from paved to unpaved and users must drive through a mix of fine sand, dirt, and chunks of rock in the unpaved section to access the LLNF, 40th Pole Beach, and Eel Point. As shown in Figure 9(b), desire paths have been created along EPR by drivers. These desire paths have caused different sections of EPR to have varying widths and thicknesses (S. Bois, personal communication).

Erosion on EPR is caused by multiple factors including heavy summer traffic, construction vehicle use, and the use of grading on the road (S. Bois, personal communication). Increased volumes and frequencies of flooding on EPR are expected to increase the erosion of EPR (S. Bois, personal communication). The rise in relative sea level (RSL) discussed in Section 2.2 may result in up to 6 inches of daily flooding on EPR by 2070 ("Nantucket Coastal" 4). Increased volumes and frequencies of flooding on EPR are expected to increase the erosion of EPR (S. Bois, personal communication).

Figure 9. Four images of EPR.

A. The transition between the paved and unpaved sections of EPR.

B. Desire paths on EPR created by vehicle and pedestrian traffic.

C. The improper cross-section of EPR. The road is flat and does not slope to the sides.

D. Water-filled potholes and loose aggregate on EPR

2.5 Background Summary

Unpaved roads consist of structural layers that define the shape and strength of the road surface. Changes to the road surface from vehicle traffic, flooding, and erosion result in distresses that degrade the road over time. This degradation can be mitigated by timely maintenance and repair solutions that improve the stability of road materials, direct water across and away from the road surface, and that address specific distresses in the road. Heavy traffic and past, infrequent road work have degraded the structure of EPR. This may make the road vulnerable to future sea level rise and climate change events. Road maintenance and repair solutions applied to EPR must consider these future projections, as well as the current status of the road and its position within the Nantucket community.

3.0 Goals and Methods

The goal of this research study was to research, identify, and recommend solutions to mitigate the effects of continued flooding and erosion of Eel Point Road (EPR) on Linda Loring Nature Foundation (LLNF) property in both the near and long term. To achieve this goal, the research team developed the following objectives:

1. Assess and document current conditions on EPR[11] via road surface condition indexing, photography, and qualitative observations of the road.
2. Identify users of EPR by analyzing the composition of vehicle traffic.
3. Survey and interview key personnel how road conditions are perceived by the community.
4. Assess and document how road conditions impact the usability of EPR.
5. Integrate research with pre-existing data from the Linda Loring Nature Foundation (LLNF) via updating GIS mapping and documentation of research data.
6. Recommend flooding and erosion control, and maintenance solutions implementable by the LLNF on EPR over varying timelines based on research data.

3.1 Road Condition Assessments

Conditions on EPR were assessed via photography and the Unsurfaced Road Condition Index (URCI) assessment, an assessment technique developed by the U.S. Army to index unpaved roads. These provided a baseline that could then be referenced by the proposed solutions to mitigate continued flooding and erosion on EPR. These assessments were also utilized to produce a comprehensive view of EPR conditions and usability.

3.2 Vehicle Traffic Composition

A trail camera was placed on LLNF property along EPR. This camera was used to assess the types of vehicles used to access EPR and the frequency with which EPR was accessed.

3.3 Community Perceptions

A cross-sectional survey was proposed and implemented to identify user demographics on EPR and how conditions on the road are perceived by the Nantucket community. The end of the survey also provided a space for participants to indicate their interest in being interviewed regarding their experiences with EPR (see Appendix A for survey questions). The survey was distributed via QR code (flyer and card), LLNF e-mail list, local news (*DayBreak Nantucket*), and LLNF social media (see Appendix B for flyer design; see Appendix C for card design).

[11] From the area of 69 Eel Point Road to the 40th Pole Beach parking lot: this is the section of EPR bordering LLNF property and is a private road.

3.4 Impact of Road Conditions on Usability

A series of 15-minute targeted interviews were conducted with town employees, first responders, fishers, and residents. Interview questions addressed how specific road conditions on EPR impacted its usability to users (see Appendix D for interview questions). Interviews were conducted in locations accessible to participants. Time was allotted for follow-up probing based on interviewee responses. Audio during interviews was recorded with the permission of the interviewee, and a scribe was present.

3.5 Data Integration

Data from surveys, interviews, and road condition assessments were integrated with pre-existing GIS data from the LLNF to produce a full visualization of road conditions on EPR and how these conditions affect the road's usability. The ability to highlight specific areas of concern regarding road conditions, as well as visualizing these areas in detail, allowed us to match specific road areas and conditions with the examples and experiences of EPR users.

3.6 Recommendations

Data documentation was used to produce and recommend both short- and long-term erosion and flooding control solutions for EPR to the LLNF. These solutions could then be applied across multiple potential timelines. Additionally, referring to secondary literature for ideas of possible solutions and reviewing such solutions in the context of EPR enabled the research team to analyze the viability of each solution. A set of recommended solutions was constructed and provided alongside it to the LLNF to inform them of possible strategies to improve conditions on EPR. These solutions included budgets, work prioritizations, and preliminary environmental assessments to inform the LLNF on how to implement each solution.

4.0 Results

This section presents the results from the methods outlined in Section 3.0. These results present the data collected from each method and how the data was organized, analyzed, and presented.

4.1 Results from Objective 1

The research team assessed current conditions on Eel Point Road (EPR) through the photography of road conditions, satellite imagery, and by the Unsurfaced Road Condition Index (URCI).

Road Condition Photography and Satellite Imagery

Conditions on EPR were photographed with a Nikon D3300 camera and organized according to Appendix B of *Unsurfaced Road Maintenance Management*. As shown in Table 6 (on following page), 6 of the 7 distress conditions[12] identified in *Unsurfaced Road Maintenance Management* were found to occur on EPR. As shown in Table 7 (page 17), additional distresses not recorded in *Unsurfaced Road Maintenance Management* were documented on EPR: desire paths, variations in road height, entrenchment of the road, and variations in the width of the road were identified and photographed.

Pre-existing satellite imagery from Google Earth was collected to identify where and when desire paths and variations in the road width occurred on EPR. As shown in Figure 10, one such desire path was formed from a pre-existing walking path, and residential infrastructure has developed along the formed path.

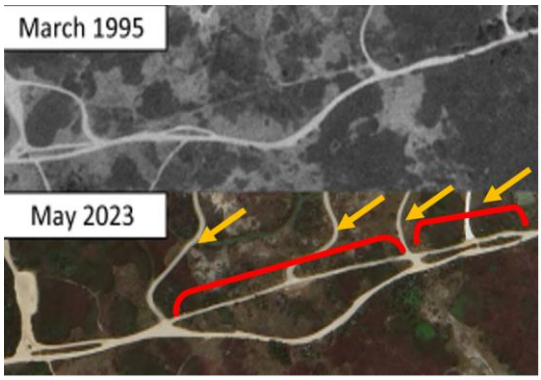


Figure 10. Satellite images of EPR from March 1995 and May 2023. The desire paths on EPR are indicated in red, and driveways are indicated in yellow. (https://tinyurl.com/yaj9pdne)

Unsurfaced Road Condition Index

After documenting the conditions affecting EPR, the Unsurfaced Road Condition Index (URCI) was used to measure the severity of these conditions. The surface of EPR was designated as a single branch. As shown in Figure 11 (page 18), this branch was divided into 19 additional sections according to the general structural composition and surface conditions of the road. Each section was considered as a sample unit. The distresses of each sample unit were measured for their severity as per Appendix B of *Unsurfaced Road Maintenance Management*. A numeric rating from 0-100 was then assigned to each sample unit, and these scores were averaged to assign EPR a total URCI score of 65 with a rating of good, as per Paragraph 3-4 of *Unsurfaced Road Maintenance Management*. The full URCI assessment for EPR is located in Appendix H.

[12] Improper cross section, inadequate roadside drainage, corrugations, potholes, ruts, and loose aggregates: dust was not identified as occurring on EPR during the study period.

Table 6. Photographs of road distress conditions on Eel Point Road.

Distress Type[13]	Description	Photograph
Improper cross section	The W-shape of the road prevents water from flowing off the road surface. The slope of the road surface is insufficient to carry water off the road.	
Inadequate roadside drainage	Water is prevented from moving off the road surface due to a lack of drainage and entrenching of the road into the surrounding land.	
Corrugation	Ripples have formed in the road surface due to damage from heavy vehicles and high-speed vehicle traffic (S. Engelbourg, personal communication).	
Potholes	Large, water-retaining potholes have formed in areas of soft surface material. Traffic and water inundation contribute to the growth of potholes along the road.	
Rutting	Vehicle traffic has caused rutting in areas of the road surface where surface materials are soft and easily erodible.	
Loose aggregate	Loose road surface materials have been pushed onto the road shoulder from vehicle traffic and erosion.	

[13] For descriptions and causes of each distress condition, see Table 1 in Section 2.2 of this report.

Table 7. Photographs of miscellaneous road conditions on Eel Point Road.

Condition	Description	Photograph
Desire paths	Traffic over time has produced additional paths along EPR. These paths fragment surrounding habitat and cause variations in road width.	
Road height	Large variations in the height of the road are inconsistent with surrounding terrain elevation.	
Entrenchment	Erosion of the road surface has depressed the elevation of the road below the surface of surrounding terrain.	
Width variation	Traffic has irregularly expanded the width of EPR. Expansion of the road surface encroaches into surrounding habitat and contributes to erosion.	

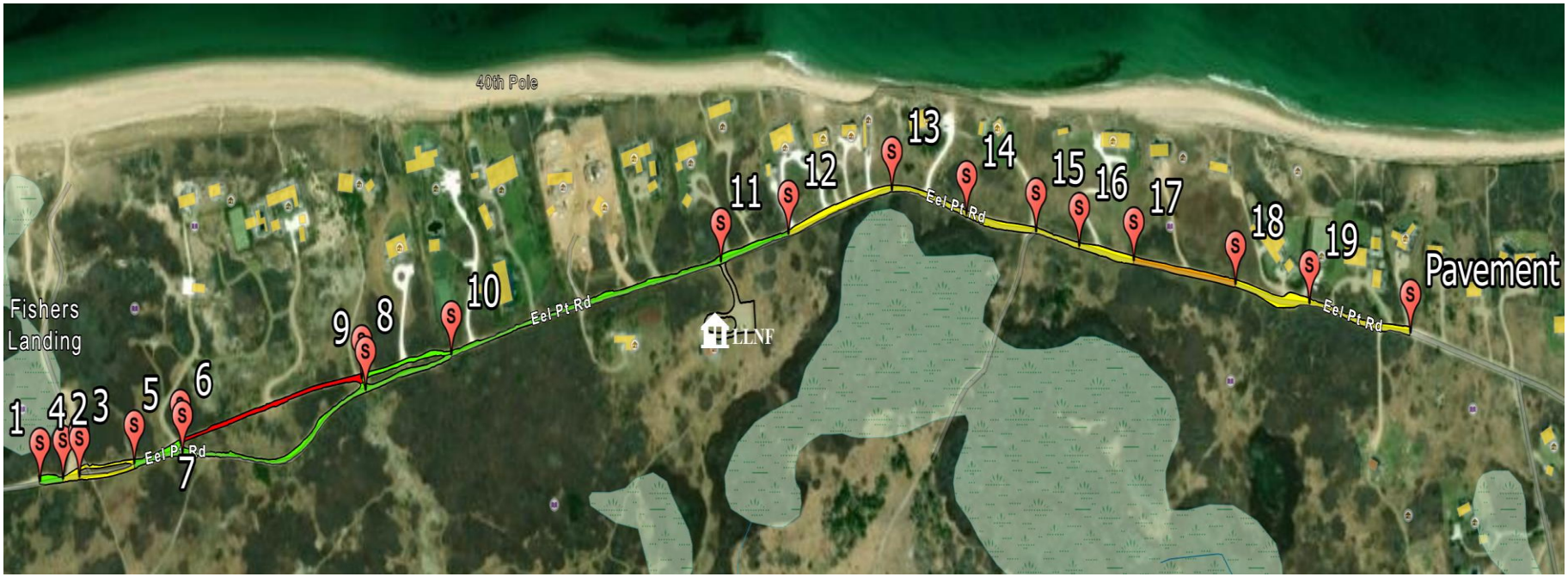


Figure 11. A map of the 19 segments that EPR was divided into with ratings designated as follows (Eaton 11):

Red: Poor (URCI rating of 25-40)

Orange: Fair (URCI rating of 40-55)

Yellow: Good (URCI rating of 55-70)

Green: Very Good (URCI rating of 70-85)

4.2 Results from Objective 2

As shown in Figure 12, a trail camera facing EPR was installed on LLNF property[14] to record the frequency of use and vehicle traffic composition of EPR between October 27, 2023 and November 10, 2023. Additionally, 1 question on the survey asked respondents to identify which forms of transportation they used to access EPR.

EPR was utilized 1216 times during the 2-week study period by passenger vehicles, heavy equipment, bicycles, walkers, and motorcycles/mopeds. The top counts included 1010 passenger vehicles, 102 heavy equipment, and 76 bicycles. Shown in Figure 13 are the percentages of transportation types recorded from the trail camera and survey.

As shown in Figure 14 (on following page), EPR experienced the largest volume of traffic between 7:00 AM and 6:00 PM (18:00). Peak traffic on EPR occurred at 11:00 AM with an average of 53 vehicles recorded. Overall, EPR experienced a traffic volume of approximately 81 vehicles per day.

Figure 12. A photograph of the trail camera and notice posted on EPR.

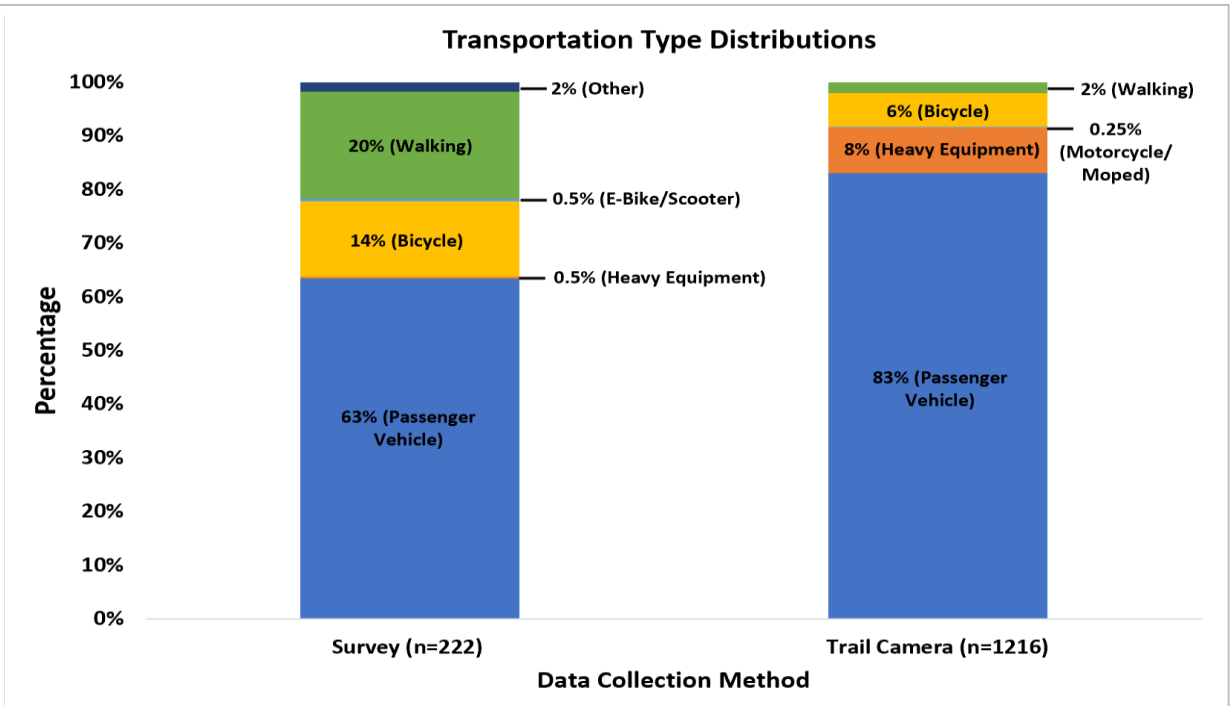


Figure 13. A stacked column graph showing the percentage distribution of transportation types recorded on Eel Point Road across the survey and trail camera results.

[14] Between 93 and 99 Eel Point Road.

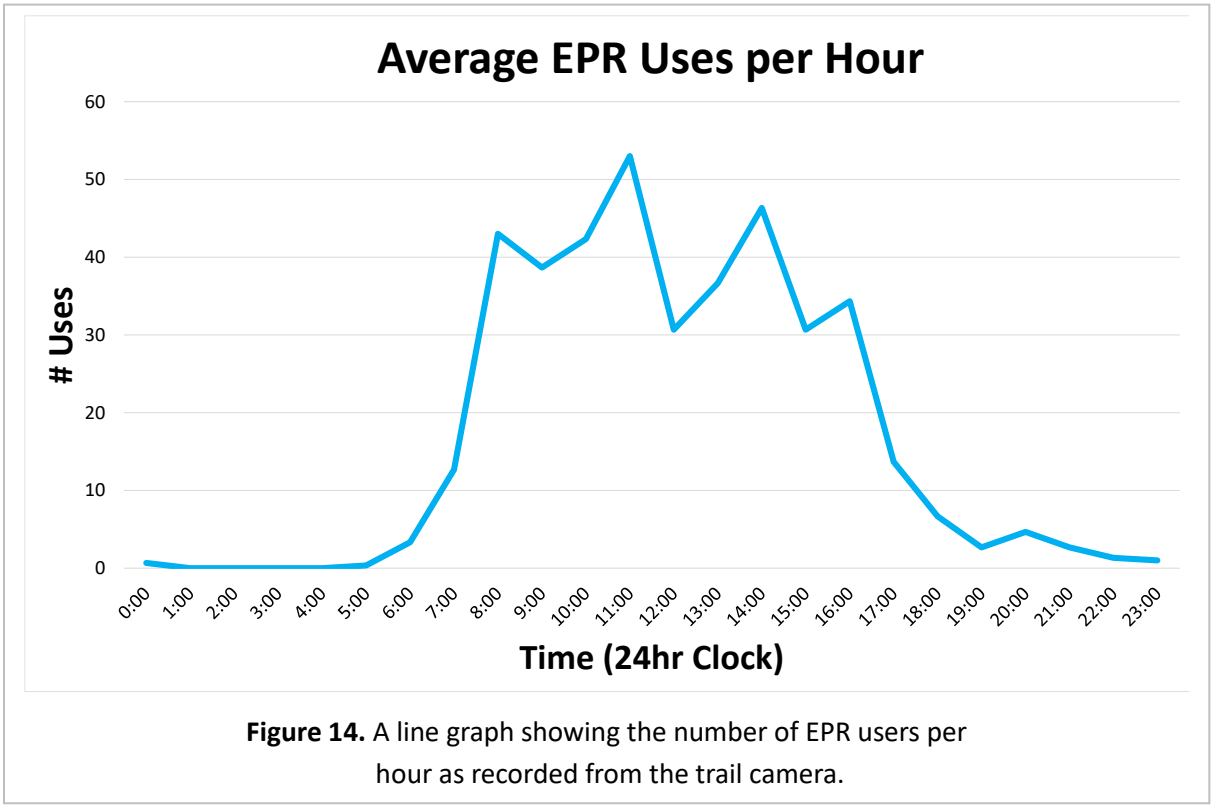


Figure 14. A line graph showing the number of EPR users per hour as recorded from the trail camera.

4.3 Results from Objective 3

The online survey was open for responses from October 27, 2023 to November 26, 2023. The survey, located in Appendix A, collected data on how respondents rated the conditions and maintenance of EPR and their perception of EPR in relation to other unpaved roads on Nantucket. At the conclusion of the survey period, 160 responses were collected: 153 responses through an anonymous link[15], 6 responses through QR code[16], and 1 response through preview.

Survey Demographics

Respondents identified themselves as part of the following group(s): year-long Nantucket resident, seasonal Nantucket resident, fisher/angler, tradesperson, visitor/tourist, town employee, first responder, or other. The respondents selected all that applied to them. The top three percentages of these groups were year-long residents (47%), seasonal residents (28%), and fishers (9%).

Approximately 90% of the respondents were familiar with or very familiar with EPR. Respondents' frequency of travel on the road included daily, weekly, monthly, certain seasons, or other. These percentages included 40% who travelled on EPR during certain seasons, 23% who travelled on the road weekly, 16% who travelled on the road monthly, and 10% who travelled on the road daily.

[15] From LLNF social media and advertisements.
[16] Flyer and recruitment card.

EPR Conditions and Maintenance Ranking

Shown in Figure 15(a) are respondents' ratings of EPR's condition, in which 64% of respondents rated the road surface conditions of EPR poorly or very poorly. Shown in Figure 15(b) are the respondents' ratings on EPR maintenance, in which 57% of respondents rated the maintenance of EPR as poor or very poor.

Table 8 (on following page) shows how specific respondent demographics rated the conditions and maintenance of EPR, and their perceptions of EPR in relation to other unpaved roads on Nantucket.

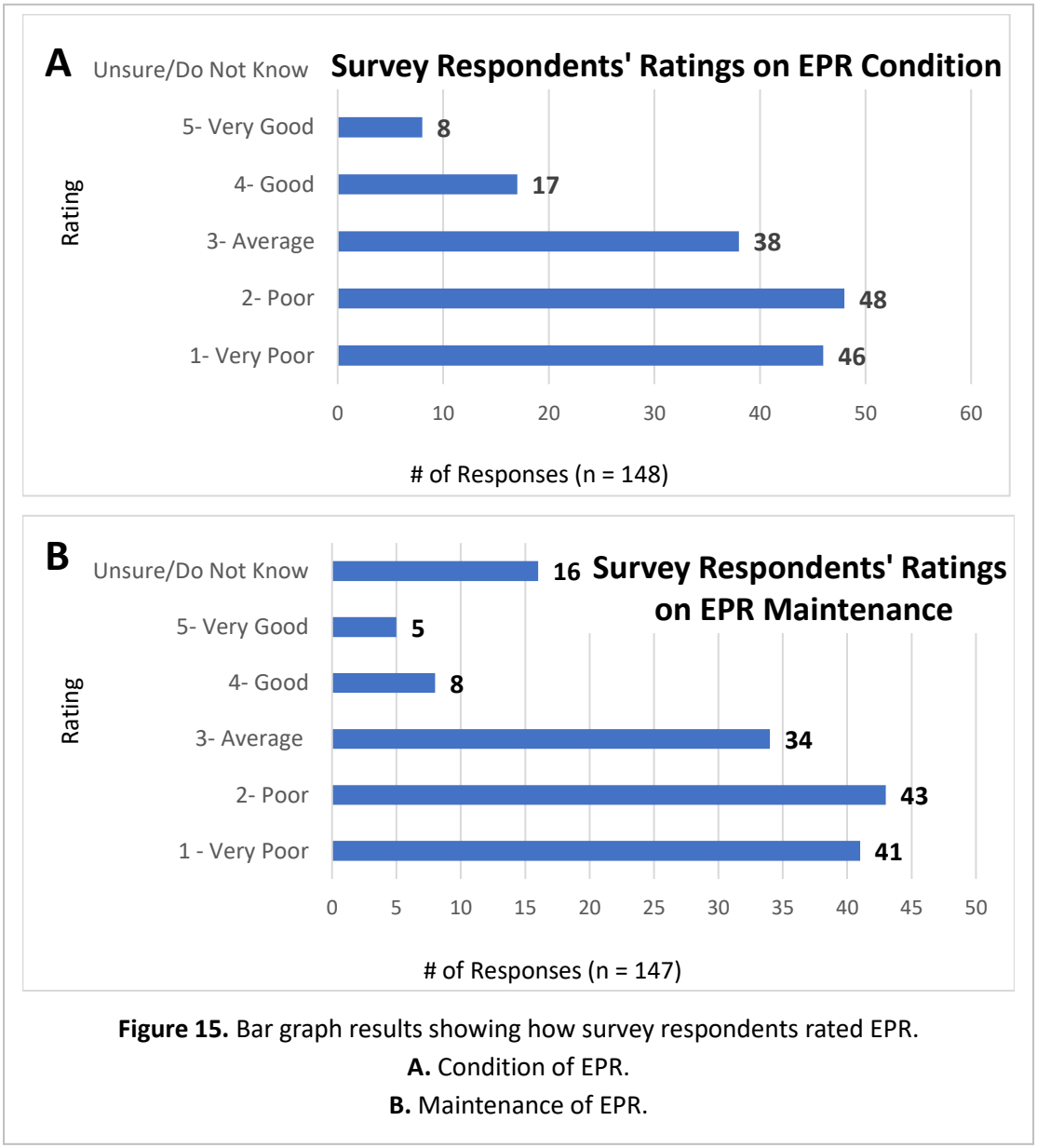
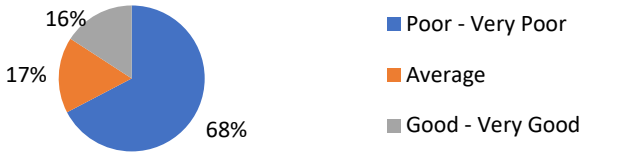
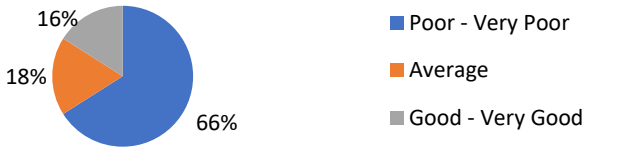
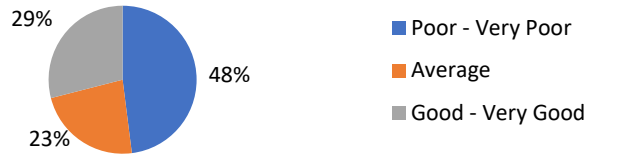
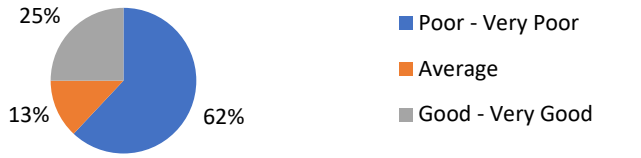
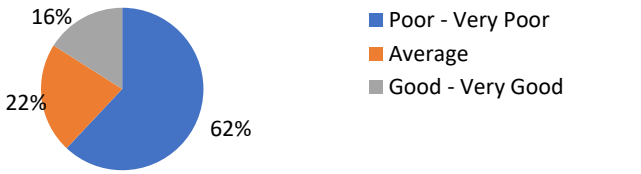
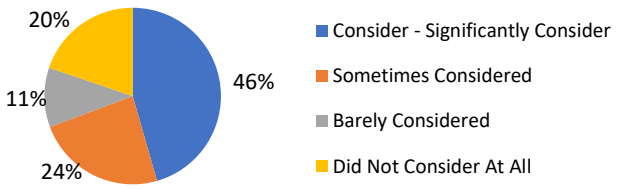
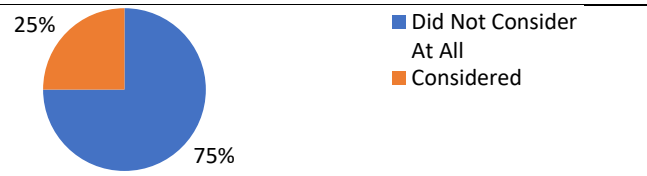
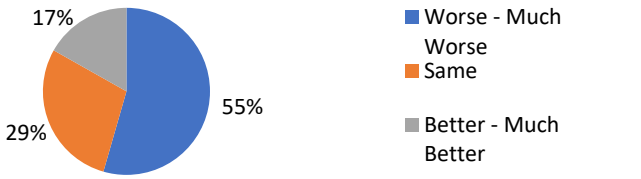


Figure 15. Bar graph results showing how survey respondents rated EPR.
A. Condition of EPR.
B. Maintenance of EPR.

Table 8. Pie charts showing the percent distribution[17] of responses to selected survey questions.

Title	Description	Chart	Count
Familiar – Very Familiar with EPR Rated EPR Conditions	Percentages of how survey respondents familiar to very familiar with EPR rated the condition of EPR.		**n = 132**
Passenger Vehicle Users Rated EPR Condition	Percentages of how survey respondents that use passenger vehicles on EPR rated the condition of EPR.		**n = 140**
Bicycle Users Rated EPR Condition	Percentages of how survey respondents that use bicycles on EPR rated the condition of EPR.		**n = 31**
EPR Walkers Rated EPR Condition	Percentages of how survey respondents that walk on EPR rated the condition of EPR.		**n = 45**
Familiar – Very Familiar with EPR Rated EPR Maintenance	Percentages of how survey respondents familiar to very familiar with EPR rated the maintenance of EPR.		**n = 132**
Year-long Residents Rated Extent Which Consider Avoiding EPR	Percentages of how year-long residents rated the extent in which they consider avoiding EPR due to road conditions.		**n = 81**
Visitors/Tourists Rated Extent Which Consider Avoiding EPR	Percentages of how visitors/tourists rated the extent in which they consider avoiding EPR due to road conditions.		**n = 4**
Familiar – Very Familiar with EPR Rated EPR Compared to Other Unpaved Roads	Percentages of how survey respondents familiar to very familiar with EPR rated EPR compared to other unpaved roads on Nantucket.		**n = 140**

[17] Percentages rounded to nearest integer.

4.4 Results from Objective 4

The research team interviewed a total of 17 individuals during 15[18] interview sessions. Of the 17 people interviewed, 6 were residents living on EPR, 6 were local experts in erosion, roads, and right of ways, 2 were first responders, and 3 were conservation specialists. A full interview guide can be found in Appendix D. Interviews were conducted to collect data on how interviewees perceived impacts to EPR's usability from flooding and erosion.

Resident Interviews

Of the 6 residents the research team was able to interview, only 2 residents claimed to use Eel Point Road year-round. The other 4 only visit the island during certain seasons. Of the residents interviewed, 2 of the 6 believed that road conditions on Eel Point Road are worse during certain seasons: specifically, autumn, spring, and winter were cited as times of increased flooding due to rainfall and slush accumulation on the road surface. All 6 residents noted potholes, puddles, and the width of EPR as factors that limited the road's usability. Other issues discussed in resident interviews included the corrugations and loose aggregates present on EPR.

Resident concerns regarding EPR included speeding on the road, traffic from tourists during the summer, and the ability of emergency vehicles to access their residence in the event of an emergency. Of the 6 residents interviewed, 1 resident reported being unable to access their residence via Uber or taxi, as these services refused to drive on EPR due to the risk of damaging the vehicle. Multiple residents expressed concern that the use of construction vehicles on EPR caused damage to the road surface.

When asked about work they'd wish to see performed on EPR, residents expressed a desire for EPR to be graded more frequently to repair distresses in the road surface. Residents also expressed a desire to change the layout of EPR, with 2 of the 6 residents interviewed wishing for the road to be widened to account for two-way vehicle traffic. Additionally, 1 of the 6 residents interviewed expressed a desire for a civic association to be established on EPR: another resident informed the research team that, while a homeowner's association used to exist for EPR, it has since become defunct after the resident in charge of the association passed away.

Through these interviews, the research team was able to learn the history of EPR. While residents were aware of attempts to pave EPR in the past, all 6 interviewed residents were strongly opposed to paving the road surface.

Expert Interviews

Interviews were conducted with 6 experts: while interviewing these experts, the research team found that their responses were targeted towards solutions and changes they wanted to see implemented on EPR. Possible solutions mentioned during these interviews included grading and widening of the road, which was also mentioned by residents of EPR as possible solutions to mitigate EPR's flooding and erosion. The interviewed experts also discussed specific solutions such as culverts and catch basins, as well as the addition of fill material to increase the height of EPR. Of the 6 experts interviewed, 1 expert

[18] Two interviews were held with two participants and were counted as a single interview each.

recommended the creation of a civic association on EPR in order to effectively implement proposed flooding and erosion control solutions.

First Responder Interviews

An interview was conducted with 2 first responders, who both expressed concern over being able to assist citizens on EPR due to its current condition. Both stated that, if the flooding on EPR is not mitigated, their response times to emergencies on the road would increase. Both first responders also mentioned their concern with winter storms, specifically referencing times in the past where conditions on EPR due to the storms prevented access to certain locations on the road. Of the 2 interviewed, 1 first responder mentioned that the section of EPR from 99-135 Eel Point Road became inaccessible after heavy rains due to flooding on the road. As of late November 2023, there were 58 EMS and fire calls on EPR in 2023: this shows that there is a need for EPR to be accessible to first responders. The lack of fire hydrants on EPR was cited as a concern by both first responders. The closest fire hydrant to EPR was out of service as of November 2023 due to damage from car collisions: this limits the access firefighters have to water when responding to a potential emergency on EPR.

Conservation Specialist Interviews

To learn the history of past work on EPR performed by conservationists on Nantucket, 3 Nantucket conservation specialists were interviewed. The Nantucket Land Bank (NLB) and LLNF had both paid for EPR to be graded in the past, but neither had seen success in creating a consistent maintenance schedule for grading of the road. The interviewed specialists expressed interest in adding material to and reshaping the structure of EPR to improve drainage and reduce entrenchment of the road, citing rising sea levels as an imminent flooding concern on EPR. The research team was also informed that the NLB established a separate walking trail on EPR, as they believed the area past 40th Pole Beach was too narrow for pedestrians to use safely.

Interview Conclusions

Of the 17 interviewees, only 6 expressed concerns regarding the effect of flooding and erosion of EPR on the surrounding environment and on protected species. Of those 6 interviewees, 1 interviewee was able to identify water runoff into surrounding wetlands as a current environmental issue caused by flooding on EPR. From this sample of interviewees, it was made clear that more information regarding the effects of flooding and erosion on the surrounding environment should be shared with the public. Increasing awareness of these issues may help to increase public support for road repair and maintenance on EPR.

When asked to identify roads on Nantucket similar to EPR, 10 respondents listed roads including Pocomo, Squam, Somerset, Redbarn, Madaquecham, Rugged, and Milbrook Road. While interviewees expressed that the conditions of these roads were worse than those of EPR, they believed that the conditions on EPR were more concerning due to the level of traffic on the road. When asked about previous work performed on EPR, 9 interviewees were aware of grading being performed on the road in the past. Of those 9 interviewees, 1 also claimed that the road had been oiled to reduce dust, and 1 claimed that the road had been filled with crushed and reclaimed concrete known as ACK-Pack. Of the 17 interviewees, 8 were unable to recall previous work performed on EPR.

4.5 Results from Objective 5

A Trimble Juno 5B GPS unit was used to construct a GPS perimeter of EPR. This GPS perimeter was then mapped and integrated into GIS mapping of EPR and its surrounding environment to establish the current layout of EPR. A GIS map of EPR was constructed using ArcGIS Pro to integrate pre-existing GIS data on EPR from the LLNF and from public databases for flooding, erosion, and sea level rise predictions with the URCI assessments performed by the research team. The full GIS map of EPR can be found in Appendix I of this report.

As shown in Figure 16, it was found that multiple points on EPR will be subject to severe annual flooding by 2070. Construction of the GIS map of EPR allowed the research team to identify which sections of EPR may be subject to increased levels of flooding and erosion, and to identify the causes of this flooding and erosion. By identifying these at-risk sections, recommendations were then be targeted towards specific sections of EPR to reduce the impact of flooding and erosion in those areas.

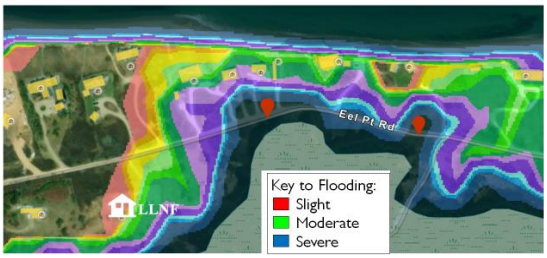


Figure 16. A GIS layer of EPR showing where flooding is projected to be slight, moderate, or severe in 2070. The red pins show where flooding on EPR may become most severe.

4.6 Results from Objective 6

Based on the results shown above, recommendations for road repair and maintenance were made to address current road conditions on PER, and to address current and projected flooding and erosion on EPR. A full list of recommendations can be found in Appendix J of this report. Section 5.0 below lists the top recommendations for EPR's repair and maintenance.

5.0 Recommendations

This section presents the recommendations of the research team from the methodology and results outlined in previous sections. This section also presents recommendations for future research regarding the flooding and erosion of Eel Point Road (EPR).

5.1 Recommendations for Road Repair and Maintenance

The research team recommends that the Linda Loring Nature Foundation (LLNF) perform the following actions on EPR to reduce the effects of flooding and erosion of the road on foundation property.

Regrade Eel Point Road

The LLNF should regrade EPR using the current road surface as the subgrade layer. As shown in Figure 17, a road crown with a cross slope of ½”-¾” per foot should be established on EPR on all structural layers to allow water to drain from the road surface (Crown & Cross-Slope” 2). During the regrading process, additional fill should be introduced to sections of EPR that have become entrenched in the surrounding terrain to raise them above the level of surrounding terrain. This will allow water to flow off the road surface into the surrounding environment. Regrading EPR will also address potholes, corrugations, ruts, and loose aggregates that impact the usability of EPR. Based on contractor estimates, regrading EPR will cost the LLNF approximately $100,000 for labor, overhead, and materials costs (A. Dwyer, personal communication).

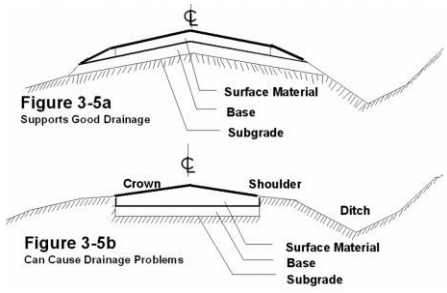


Figure 17.A generalized diagram illustrating the shape of the road cross-section that should be established on EPR. (https://tinyurl.com/ms79hx2z)

Artificial Wetland Installation

The LLNF should create artificial wetland areas in sections of EPR projected to experience high levels of flooding. Wetlands can hold large amounts of water runoff from storms and tidal flooding (Madsen et al. 7-8). After taking on water, wetlands are then able to release the water slowly to prevent additional flooding (ibid). By installing artificial wetlands along sections of EPR that are projected to experience increased flood rates from sea level rise, the effects of this flooding on EPR can be reduced. While the construction of artificial wetlands along EPR may disrupt native plant and animal populations in the short-term, their ability to moderate flooding will help reduce the costs of future road repair and maintenance on EPR and may reduce the strain on the surrounding environment from rising sea levels. The initial cost for installing artificial wetlands on EPR would average $45,000 per acre of wetland created (Crites and Ogden 1). The operational cost of these wetlands would average $0.10-$0.30 per 1,000 gallons of water processed by the wetland (ibid).

Establish a Consistent Road Width on Eel Point Road

The LLNF should establish a consistent road width on EPR. GPS mapping of the road perimeter showed large variations in the width of EPR, which creates a traffic hazard for vehicles and pedestrians passing on opposite sides of the road. The American Association of State Highway and Transportation Officials establishes a minimum road width of 22 feet (Un 1). As a temporary measure until a consistent road width of 22 feet is established, sections of EPR wider than 22 feet in length should be designated as passing spaces for vehicles and pedestrians. These spaces will allow for vehicles and pedestrians moving in opposite directions on EPR to pass each other without encroaching on the surrounding environment. The base cost of excavating sections of EPR to establish consistent road width would be $42.50 per cubic yard of soil removed ("Lovers Lane Reconstruction"). This cost does not include additional costs from the transportation of removed material. The cost of imported material to establish a proper road cross section in these areas would be about $110 per ton of added material, and the grading of the road during and after the reconstruction of road sections would cost $4,200 per day of labor (A. Dwyer, personal communication).

5.2 Additional Recommendations

The research team recommends that the LLNF perform the following actions on EPR to supplement the recommendations listed above.

Establish a Road Path on Eel Point Road

The LLNF should establish a single road path on EPR by blocking off the additional road paths that have been created over time. By establishing a single road path for EPR, a set boundary of the road can be created for which regular maintenance can be performed. As shown in Figure 17, this can be done by installing snow stakes or wooden bollards at the sides of EPR to block vehicle traffic from moving off the established road. These installations should be monitored and replaced as needed.

Figure 18. Snow stakes and wooden bollard as they could be installed on the sides of EPR. (https://tinyurl.com/ycrc62j7; https://tinyurl.com/2p9mha8f)

Implement a Civic Association for Eel Point Road

The LLNF should work with other abutters of EPR to establish a civic association for the road. The civic association could address issues such as irregular maintenance on EPR and help to establish funding for road repair and maintenance.

Install Warning Signs on Eel Point Road

The LLNF should install warning signs on EPR to inform EPR users of current road conditions, and how these road conditions may affect vehicle access on the road. Areas to place warning signs include the beginning of the unpaved section of EPR, before 40th Pole Beach, and after 40th Pole Beach. These

warning signs will provide information as to the conditions affecting EPR and caution users of EPR who may be unfamiliar with the road's condition.

5.3 Future Research Recommendations

Future research concerning EPR should be conducted in the following areas.

Trail Camera Data Collection

The LLNF should conduct additional trail camera studies to determine how frequently EPR is used during different seasons. The trail camera studies should be conducted for a two-week period during the winter, spring, and summer. The data will allow the LLNF to determine any differences in user frequency on EPR. The data will help determine what maintenance should be done on EPR and when the maintenance should occur.

Survey Abutters of Eel Point Road

The LLNF should survey all abutters of EPR to determine which road repair and maintenance solutions should be implemented based on community support. The recommended solutions located in Appendix I should be listed in the survey for abutters to rank their preferred repair and maintenance solutions. Each recommendation should include a description of the recommendation, its cost, and the environmental impact of the recommendation. At the conclusion of the survey, the LLNF should then use the collected data to determine what solutions should be implemented on EPR.

Continue Indexing of Eel Point Road

Indexing of EPR's condition should be performed annually using the Unsurfaced Road Condition Index (URCI). Continued indexing of EPR's condition will allow the LLNF to assess the effectiveness of implemented road repair and maintenance solutions on the road. Establishing annual indexes of EPR's condition will also allow the LLNF to track the effects of sea level rise on EPR over time.

6.0 Conclusion

The goal of this project was to research, identify, and recommend solutions to mitigate the effects of continued flooding and erosion on Eel Point Road (EPR) on Linda Loring Nature Foundation (LLNF) property. After we assessed and documented EPR conditions, identified EPR users, surveyed and interviewed key personnel, and integrated our data, we compiled a list of recommendations for the LLNF. We highlighted 3 road repair and maintenance solutions, 3 additional steps, and 3 future research recommendations to the LLNF.

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Appendix A. Survey

This survey was created and used to collect data regarding how conditions along Eel Point Road (EPR) affect community access to resources and locations.

Link to survey: https://tinyurl.com/yp8r43dc

1) Select all the following groups that describe you.
    a) Year-long Nantucket resident
    b) Seasonal Nantucket resident
    c) First responder
    d) Town employee
    e) Tradesperson (landscaper, construction worker, etc.)
    f) Fisher/angler
    g) Visitor/tourist
    h) Other [Open response option]
2) How often are you on the island of Nantucket every year?
    a) Less than a week
    b) 1 week – 1 month
    c) 1 – 3 months
    d) 3 – 6 months
    e) Year round
    f) Other [Open response option]

The following statements will reflect your views of Eel Point Road.

3) Rate your familiarity with the location and characteristics of Eel Point Road.
    a) 1 – very unfamiliar
    b) 2 – unfamiliar
    c) 3 – average
    d) 4 – familiar
    e) 5 – very familiar
4) Rate the **layout** (width, positioning) of Eel Point Road.
    a) 1 – very poor
    b) 2 – poor
    c) 3 – average
    d) 4 – good
    e) 5 – very good
    f) Unsure/ do not know

5) Rate the **condition** (surface, material) of Eel Point Road.
    a) 1 – very poor
    b) 2 – poor
    c) 3 – average
    d) 4 – good
    e) 5 – very good
    f) Unsure/ do not know
6) Rate the **maintenance** (frequency, methods) of Eel Point Road.
    a) 1 – very poor
    b) 2 – poor
    c) 3 – average
    d) 4 – good
    e) 5 – very good
    f) Unsure/ do not know
7) Rate Eel Point Road in relation to other unpaved roads on Nantucket.
    a) 1 – much worse
    b) 2 – worse
    c) 3 – the same
    d) 4 – better
    e) 5 – much better
    f) Unsure/ do not know

The following statements will reflect how often you use Eel Point Road.

8) Characterize your frequency of travel along Eel Point Road.
    a) Daily
    b) Weekly
    c) Monthly
    d) During certain seasons
    e) Never
    f) Other [Open response option]
9) Select all types of transportation you use to access Eel Point Road.
    a) Passenger vehicle (car, truck)
    b) Heavy equipment vehicle (dump truck, bulldozer, landscape trailer, etc.)
    c) Motorcycle/moped
    d) Bicycle
    e) E-bike/scooter
    f) Walking
    g) Other [Open response option]

The following statements will reflect your impression of Eel Point Road.

10) Rate the extent to which road conditions on Eel Point Road have **limited** your access to points of interest along the road.
    a) 1 – severely limited
    b) 2 – limited
    c) 3 – sometimes limited
    d) 4 – barely limited
    e) 5 – did not limit at all
    f) Unsure/do not know
11) Please describe the specific road conditions that have limited your access.
    a) [Open response]
12) Rate the extent to which road conditions on Eel Point Road have **prevented** your access to points of interest along the road.
    a) 1 – severely prevented
    b) 2 – prevented
    c) 3 – sometimes prevented
    d) 4 – barely prevented
    e) 5 – did not prevent at all
    f) Unsure/do not know
13) Please describe the specific road conditions that have prevented your access.
    a) [Open response]
14) Rate the extent to which you have considered **avoiding** Eel Point Road due to road conditions.
    a) 1 – significantly considered
    b) 2 – considered
    c) 3 – sometimes considered
    d) 4 – barely considered
    e) 5 – did not consider at all
    f) Unsure/do not know

The following statements are open-ended responses regarding conditions and travel along Eel Point Road.

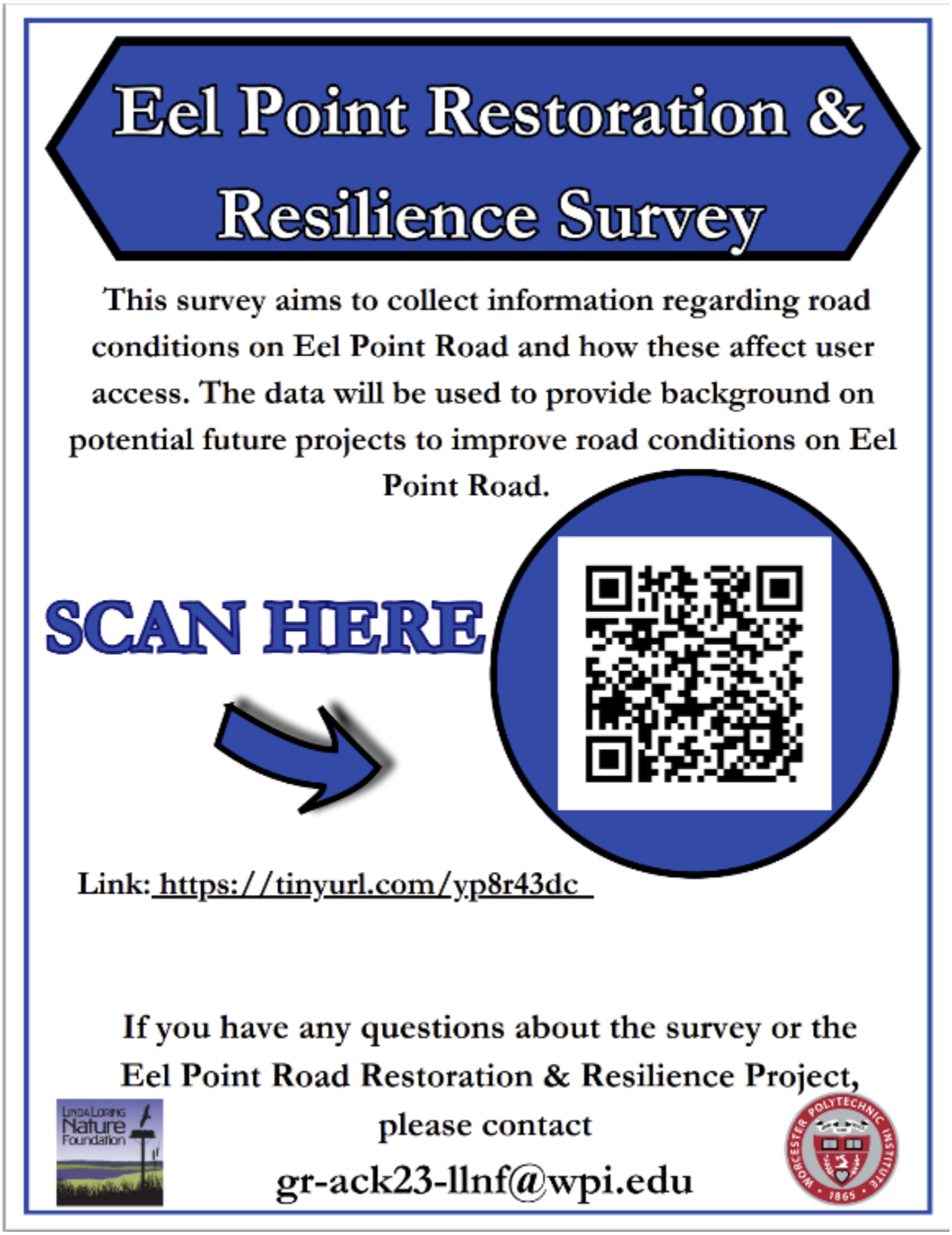
15) Please share any additional questions and/or comments regarding the **conditions** of Eel Point Road.
    a) [Open response]
16) Please share any additional questions and/or comments regarding your **travel** on Eel Point Road.
    a) [Open response]
17) We will be conducting a series of 10-to-15-minute interviews to collect qualitative data regarding specific experiences with Eel Point Road and conditions along it. These interviews will be conducted in-person at a location chosen by the interviewee (a Zoom option is also available). If you are interested in being interviewed regarding your specific experience, please enter your e-mail address and we will follow up.
    a) [Open response]

18) How did you hear about our survey?

b) Social media outlets
c) *DayBreak* advertisement
d) Community pages
e) Posted flyers on Eel Point Road
f) Posted flyers in town
g) From a friend
h) Other [Open-response option]

Appendix B. Survey Recruitment Flyer

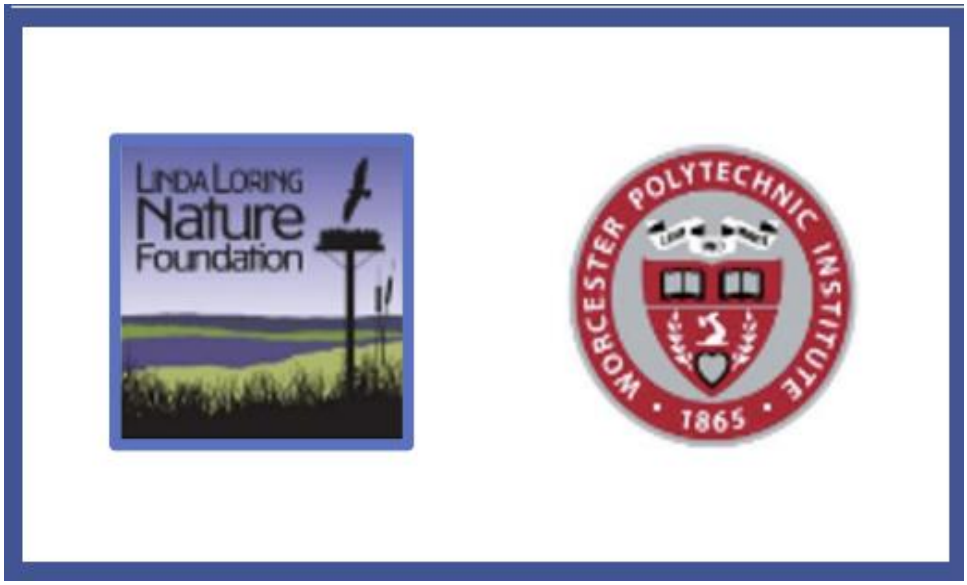
The flyer was distributed to 40th Pole Beach, the Nantucket Visitor's Center and distributed by the LLNF via e-mail, newsletter, and social media.



Appendix C. Survey Recruitment Card

The survey recruitment card was distributed to workers and drivers on EPR who showed interest in the research study.

(front)



(back)

Appendix D. Interview Guide

Interviews were conducted to collect data on specific conditions and experiences on EPR faced by its users.

Questions differed based on each group of interviewees.

- Residents, fishermen, anglers
- First responders
- Town employees (includes town officials, DPW, etc.)

Residents, fishermen, anglers, etc.

1) How often do you travel on Eel Point Road and how do you travel (by car, bike, motorcycle, walk, etc.)?
2) Can you describe any flooding and erosion problems on Eel Point Road?
    a) Probe Q1: Can you describe if the flooding and erosion problems of Eel Point Road change over different parts of the year?
    b) Probe Q2: Are you aware of any impacts on the local environment and protected species because of the flooding and erosion of Eel Point Road? Please explain.
3) Can you elaborate on any concerns you have about the flooding and erosion of Eel Point Road?
4) Can you describe other roads on Nantucket that are similar to Eel Point Road?
    a) Probe Q1: What makes the flooding and/or erosion problems of that road better or worse than Eel Point Road?
5) Can you describe what changes you would like to see made to Eel Point Road?
6) Do you have any more information about Eel Point Road flooding and erosion that you would like to share?

First Responders

1) How often do you travel on Eel Point Road and how do you travel (by car, bike, motorcycle, walk, etc.)?
2) Can you describe any experiences of flooding and erosion problems on Eel Point Road?
    a) Probe Q1: Can you expand on if there were any emergency calls where the flooding and erosion of Eel Point Road have impacted your response time?
    b) Probe Q2: Can you describe if the flooding and erosion problems of Eel Point Road change over different parts of the year?
3) Can you elaborate on any concerns you have about the flooding and erosion of Eel Point Road?
    a) Probe Q1: Can you describe changes on Eel Point Road that would help with your response time?
4) Can you describe other roads on Nantucket that are similar to Eel Point Road?
    a) Probe Q1: What makes the flooding and/or erosion problems of that road better or worse than Eel Point Road?
    b) Probe Q2: How have your emergency response calls been impacted because of flooding and erosion on similar roads?
5) Do you have any more information about Eel Point Road flooding and erosion that you would like to share?

Town Employees (Town Officials, DPW, etc.)

1) How often do you travel on Eel Point Road and how do you travel (truck, car, bike, walk, etc.)?
2) Can you describe any experiences of flooding and erosion problems on Eel Point Road?
    a) Probe Q1: Can you describe if the flooding and erosion of Eel Point Road has been a town-wide issue?
    b) Probe Q2: Can you describe if the flooding and erosion problems of Eel Point Road change over different parts of the year?
3) Can you elaborate on any concerns you have about the flooding and erosion of Eel Point Road?
    a) Probe Q1: Are you aware of any impacts on the local environment and protected species because of the flooding and erosion of Eel Point Road? Please explain.
4) Can you describe what work has already been done on Eel Point Road?
5) Can you describe other roads on Nantucket that are similar to Eel Point Road?
    a) Probe Q1: What makes the flooding and/or erosion problems of that road better or worse than Eel Point Road?
6) Do you have any more information about Eel Point Road flooding and erosion that you would like to share?

Appendix E. Informed Consent Agreement for Participation in a Research Study Survey

The survey consent form was placed at the beginning of the online survey to ensure that all participants could give their informed consent to be surveyed as part of the research study.

Investigators: Anthony DeMarco, Jonathan Pantojas, Kelly Pritchard, Madison Reiber

Contact Information: gr-ack23-llnf@wpi.edu

Title of Research Study: Eel Point Road Restoration and Resilience

Sponsor: Linda Loring Nature Foundation

Purpose of the study:

This survey is designed to collect information on how conditions along Eel Point Road (EPR) impact access to resources and locations. The data will be used to give background for the Linda Loring Nature Foundation on how to address community needs regarding potential future projects to reduce flooding and erosion rates on EPR. This survey is informational in nature and not indicative of plans for specific projects. This survey is not indicative of the opinions or attitudes of the researchers or of the Linda Loring Nature Foundation.

Procedures to be followed:

This procedure involves the completion of a ~10-minute online survey. Data is collected using multiple-choice and open-response questions. An option will be provided at the conclusion to provide an e-mail address if the participant wishes to be considered for the interview phase of this study. By providing your e-mail address at the conclusion of this survey, you consent to potentially being contacted regarding participation in the interview phase of this research study. Collected data **will not** be linked to your e-mail address if provided.

Risks to study participants:

Participants of this research study may encounter discomfort due to the discussions of topics such as flooding, loss, and any other possible topic related: these topics may involve personal losses or difficulties.

Benefits to research participants and others:

Participant data will be used to better inform potential future work plans for EPR. By identifying areas of concern and impacts to EPR users, potential road repair and maintenance solutions can be tailored to meet the needs of its users.

Record keeping and confidentiality:

All survey data will be stored and analyzed using Qualtrics. No data will be collected on the IP addresses of participants: no e-mail address information will be collected unless explicitly provided by the participant. Qualtrics encrypts all data transfers using Transport Layer Security (HTTPS), and data will be stored in password-protected electronic formats. Only the investigators of this survey will have access to your answers and email if the participant has chosen to share their email. These investigators are Anthony DeMarco, Jonathan Pantojas, Kelly Pritchard, and Madison Reiber. For a full

Qualtrics security statement, please see the Qualtrics Security Statement here or at https://www.qualtrics.com/security-statement/.

You may exercise your rights over the personal data (e-mail) collected in this survey at any point by contacting gr-ack23-llnf@wpi.edu. For a full summary of how to execute your rights to any collected personal data, please see the Qualtrics Data Protection and Privacy statement here or at https://tinyurl.com/56uxh585.

Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury:

There is no compensation in the event of injury. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

Research Investigators – Anthony DeMarco, Jonathan Pantojas, Kelly Pritchard, Madison Reiber,

Email: gr-ack23-llnf@wpi.edu

IRB Manager - Ruth McKeogh, 508 831- 6699, Email: irb@wpi.edu

Human Protection Administrator - Gabriel Johnson, 508-831-4989, Email: gjohnson@wpi.edu

Your participation in this research is voluntary.

Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. Should a participant wish to withdraw from the study after it has begun, the following procedures should be followed: all collected survey data will be deleted, and any trash folder or analogous data storage wiped. The consequences for early withdrawal for the subject and the research are: none.

By agreeing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. You also agree that you are at least 18 years of age. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

Appendix F. Informed Consent Agreement for Participation in a Research Study Interview

The interview consent form was provided to all interviewees to ensure that they were able to give informed consent to participate in the research study.

Informed Consent Agreement for Participation in a Research Study

Investigators: Anthony DeMarco, Jonathan Pantojas, Kelly Pritchard, Madison Reiber

Contact Information: gr-ack23-llnf@wpi.edu

Title of Research Study: Eel Point Road Restoration and Resilience

Sponsor: Linda Loring Nature Foundation

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study:

The interview is designed to collect information on how conditions on Eel Point Road (EPR) impact access to resources and locations. The data collected will be used to provide background for the Linda Loring Nature Foundation on addressing community needs regarding future projects to reduce the rates of flooding and erosion along EPR. This interview is informational in nature and not indicative of plans for specific projects. This interview is not indicative of the opinions or attitudes of the researchers or of the Linda Loring Nature Foundation.

Procedures to be followed:

Interviews will be conducted in-person at a location chosen by the interviewee, with a Zoom option provided if necessary. These interviews aim to collect qualitative data regarding specific experiences with EPR as well as specific examples of conditions faced on EPR.

Risks to study participants:

Participants of this research study may encounter discomfort due to the discussions of topics such as flooding, loss, and any other possible topic related. These topics may involve personal loss or difficulties.

Benefits to research participants and others:

The benefits of participation in this research study are in the usage of participant data to better inform proposed work on EPR. By identifying areas of concern to EPR users and how EPR users are impacted by the current conditions on EPR, we can better propose road repair and maintenance solutions that are tailored to the needs of its users.

Record keeping and confidentiality:

Smartphones will be used to perform audio-only record in-person interviews. The same smartphone will be used to record and store all audio files corresponding to interviews and will be set to automatically lock after 30 seconds. The interview recordings will be immediately transferred to a password-protected folder on a password-protected computer: any remaining data on the smartphone regarding the contents of the interview will be deleted and the trash folder wiped. If data on the computer must be deleted for any reason (i.e., interviewee revokes consent), it will be first deleted and then the corresponding trash folder wiped. If a participant is interviewed in a Zoom call, the Zoom call recording feature will be used to collect an audio recording of the interview and the Zoom recording will be kept in the same password protected folder as phone-recorded interview audio. If the Zoom recording needs to be destroyed for any reason, it will be deleted, and the trash folder wiped. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There is no compensation in the event of injury. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

Research Investigators – Anthony DeMarco, Jonathan Pantojas, Kelly Pritchard, Madison Reiber, Email: gr-ack23-llnf@wpi.edu

IRB Manager - Ruth McKeogh, 508 831- 6699, Email: irb@wpi.edu

Human Protection Administrator - Gabriel Johnson, 508-831-4989, Email: gjohnson@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit. Should a participant wish to withdraw from the study after it has begun, the following procedures should be followed: All collected interview recordings and data will be deleted, and the trash folder will be wiped. The consequences for early withdrawal for the subject and the research are: none.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

_____ Date: _____
Study Participant Signature

_____
Study Participant Name (Please print)

_____ Date: _____
Signature of Person who explained this study

Appendix G. Unsurfaced Road Inspection Sheet

The Unsurfaced Road Inspection Sheet was used to rate and record sections of EPR based on the Unsurfaced Road Condition Index.

UNSURFACED ROAD INSPECTION SHEET

For use of this form, see TM 5-626; the proponent agency is USACE

1. BRANCH	2. SECTION	3. DATE
4. SAMPLE UNIT	5. AREA OF SAMPLE	6. INSPECTOR

7. SKETCH

DISTRESS TYPES

81. Improper Cross Section *(linear feet)*
82. Inadequate Roadside Drainage *(linear feet)*
83. Corrugations *(square feet)*
84. Dust
85. Potholes *(number)*
86. Ruts *(square feet)*
87. Loose Aggregate *(linear feet)*

8. DISTRESS QUANTITY AND SEVERITY

TYPE		81	82	83	84	85	86	87
QUANTITY AND SEVERITY	L							
	M							
	H							

9. URCI CALCULATION

DISTRESS TYPE a	DENSITY b	SEVERITY c	DEDUCT VALUE d	10. REMARKS

e. TOTAL DEDUCT VALUE	f. q =	g. URCI	h. RATING =

DA FORM 7348-R, NOV 94

*U. S. G. P. O. ; 1995- 386- 731: 150

Appendix H. Completed Unsurfaced Road Condition Index of Eel Point Road

Refer to the link for the completed Unsurfaced Road Condition Index sheets: Completed Unsurfaced Road Condition Index Sheets.

Appendix I. GIS Map of Eel Point Road

Refer to the file for the full GIS map of Eel Point Road (ArcGIS Pro required):

Full EPR GIS Map

Appendix J. Road Repair and Maintenance Recommendations

Regrade and Fill

- **Cost:** Based on contractor estimates, regrading EPR will cost approximately $100,000 for labor, overhead, and materials costs (A. Dwyer, personal communication).
- **Environmental Impact:** Low impact (EPA recommended)
- **Recommendation:** The LLNF should cut the road to the base so that additional fill material can be added and shaped to increase the overall road height, establish a proper road surface cross-section, and reduce the entrenchment of certain sections. This will also address structural issues with the road surface and subsurface such as soft spots, potholes, corrugations, rutting, and loose aggregate.

(https://bouldercounty.gov/transportation/road-maintenance/road-grading/)

French Mattress

- **Cost:** A quote from an expert will be necessary. Can refer to this document for costs for installation and material: French Mattress Cost.
- **Environmental Impact:** Low impact
- **Recommendation:** The LLNF should install French mattresses in areas of EPR where the soil becomes saturated with water. French mattresses consist of clean rock covered in geotextile fabric ("French Mattress"). Water can freely move across the mattress without saturating the road (ibid). French mattresses also help to disperse water flow through the road, mitigating rill and gully erosion (ibid).

(https://cambriaconservationdistrict.org/new-page-4)

Driver's Awareness

- **Cost:** Based on estimates, each sign can cost around $60 ("Property Signs").
- **Environmental Impact:** Low impact

(https://tinyurl.com/2y48shdm)

- **Recommendation:** The LLNF should install speed limits signs on EPR. One of the primary causes of corrugations are driving habits[19]. This includes rapid acceleration and deceleration relative to the direction of traffic and speeding. By spreading awareness to follow the speed limit will limit the worsening of existing corrugations and the creation of new formations will decrease.

Culverts in Bank

(https://waynecountynysoilandwater.org/culvert-enhancement-services/)

- **Cost:** A quote from an expert will be necessary based on how complex the installation will be.
- **Environmental Impact:** Low impact
- **Recommendation:** The LLNF should install a culvert in the bank along EPR where water pools next to the roadside. Due to EPR's bank existing multiple feet above the road's surface, it is difficult for water to percolate through the compressed soil and is trapped by the banks. Installed pipes in the banks can redirect water before it accumulates to uncompressed soil that according to ArcGIS Pro layers already is effective at drainage.

Flood Prevention Barrier

(https://www.amazon.com/Prevention-Barriers-Emergency-Protector-Protection/dp/B0C5XN98Z5?th=1)

- **Cost:** The flood prevention barriers from Garrison Flood Control that are 10 feet long and 20 inches tall are estimated around $960 ("Water Diversion Barriers"). The total cost will depend on the amount needed.
- **Environmental Impact:** Low impact
- **Recommendation:** The LLNF should place flood prevention barriers on the sides of the road in locations that are high risk flood areas prior to large storms. The barriers will prevent water from additional water sources flooding onto EPR as the rising sea level increases the opportunities for flooding to occur ("Water Diversion Barriers"). Limiting the amount of water will allow the LLNF to only address draining areas where standing water occurs from rainfall.

[19] U.S. Department of Transportation Federal Highway Administration. *Gravel Roads Construction Maintenance Guide*

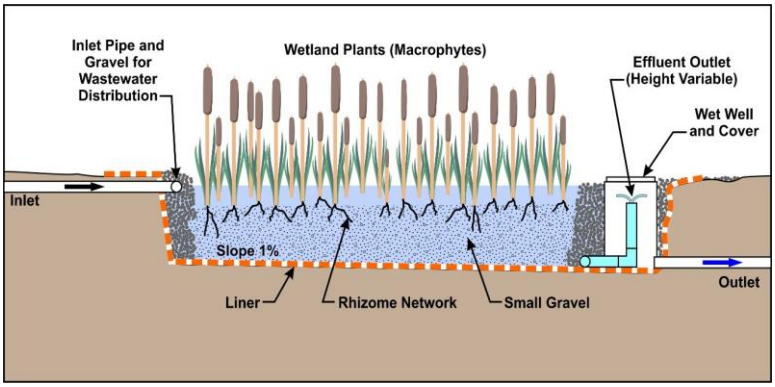
Geocell Installation

- **Cost:** The geocell grid from AgTec 8.4 feet by 27.4 feet are estimated around $130 ("AgTec Geocell Ground Grid"). The total cost will depend on the amount needed.
- **Environmental Impact:** Low impact
- **Recommendation:** The LLNF should install geocells in areas prone to flooding and erosion. The geocells would limit the impact the road experiences from heavy equipment vehicles as the geocells will maintain the structure of the road ("BaseLok Geocell Cellular Confinement"). The geocells maintaining the structure of the road will limit the impact of erosion on EPR. In addition, geocells allow locations under the road in which the water can drain (Cellular Confinement BaseLok Geocell).

(https://typargeosynthetics.com/products/geocells/)

Artificial Wetlands

- **Cost:** The initial cost for installing artificial wetlands on EPR would average $45,000 per acre of wetland created (Crites and Ogden 1). The operational cost of these wetlands would average $0.10-$0.30 per 1,000 gallons of water processed by the wetland (ibid).
- **Environmental Impact:** High impact temporarily, low impact long-term
- **Recommendation:** The LLNF should create artificial wetland areas in sections of EPR projected to experience high levels of flooding. Wetlands can hold large amounts of water runoff from storms and tidal flooding (Madsen et al. 7-8). After taking on water, wetlands are then able to release the water slowly to prevent additional flooding (ibid). By installing artificial wetlands along sections of EPR that are projected to experience increased flood rates from sea level rise, the effects of this flooding on EPR can be reduced. While the construction of artificial wetlands along EPR may disrupt native plant and animal populations in the short-term, their ability to



(https://www.frtr.gov/matrix/Constructed-Wetlands/)

moderate flooding will help reduce the costs of future road repair and maintenance on EPR and may reduce the strain on the surrounding environment from rising sea levels.

Establish Consistent Road Width

- **Cost:** The base cost of excavating sections of EPR to establish consistent road width would be $42.50 per cubic yard of soil removed ("Lovers Lane Reconstruction"). This cost does not include additional costs from the transportation of removed material. The cost of imported material to establish a proper road cross section in these areas would be about $110 per ton of added material, and the grading of the road during and after the reconstruction of road sections would cost $4,200 per day of labor (A. Dwyer, personal communication).
- **Environmental Impact:** High impact temporarily, low impact long-term
- **Recommendation:** The LLNF should establish a consistent road width on EPR. GPS mapping of the road perimeter showed large variations in the width of EPR, which creates a traffic hazard for vehicles and pedestrians passing on opposite sides of the road. The American Association of State Highway and Transportation Officials establishes a minimum road width of 22 feet (Un 1). As a temporary measure until a consistent road width of 22 feet is established, sections of EPR wider than 22 feet in length should be designated as passing spaces for vehicles and pedestrians. These spaces will allow for vehicles and pedestrians moving in opposite directions on EPR to pass each other without encroaching on the surrounding environment.

Gorilla-Snot

- **Cost:** In 1 Arizona case study, it cost around $200,000 to apply Gorilla-Snot to 320 acres of land (Lucia). According to our estimates on ArcGIS, the total area of Eel Point Road from the beginning of the unpaved portion to the 40th Pole Beach Parking lot is less than 3 acres. A true cost should be quoted from a Soilworks expert, as these are only estimates, and do not factor in base rates, rentals of devices, and other possible costs.
- **Environmental Impact:** According to the Soilworks website, Gorilla-Snot is non-corrosive, non-hazardous, non-toxic, and biodegradable ("Gorilla-Snot: An Alternative"). The long-term impacts of Gorilla-Snot have not been documented, as it was introduced to the market in 2005 ("Gorilla-Snot is Tough"). There is no documentation for how it could impact a wetland environment, which may be a concern for the vernal pools on the LLNF property.
- **Recommendation:** The LLNF should apply a layer of Gorilla-Snot to EPR. Gorilla-Snot is a liquid vinyl copolymer-based dispersion used for dust suppression and erosion control. It is made of molecular structures that link to form bonds between soils, aggregates, and particulates ("Gorilla-Snot: An Alternative").

Crushed Concrete Road Fill:

- **Cost:** $115 - $140 per yard from Toscana, a construction company on Nantucket ("Material Sales Menu").
- **Environmental Impact:** Low environmental impact
- **Recommendation:** The LLNF should fill the road with crushed recycled concrete to regain height and structure. Created from unused or wasted cement, these fills are composed of non-hydrated cement particles (Kawalec 2). Through using recycled material, waste on the island can be decreased and utilized. During the screening process, coarse[20] recycled concrete aggregate is created and can be utilized to create new fills and irregular mixtures (Kawalec 1).

Stormwater Infiltration Cell:

- **Cost:** Excluding construction and maintenance costs (i.e. clearing vegetation, excavation, site restoration), $1,500 per inlet structure and $2,500 per outlet structure ("Cost-Benefit Considerations")
- **Environmental Impact:** High initial impact (installation): infiltration measures can help reduce pollutants in runoff, but can also carry water pollutants further into the subsurface of the soil ("Overview of Stormwater Infiltration").
- **Recommendation:** The LLNF should install stormwater infiltration cells on EPR to direct and contain water from rainfall and stormwater flooding. These measures will help to reduce the volume of runoff water on EPR ("Overview of Stormwater Infiltration"). To install stormwater infiltration cells, the soil infiltration and evapotranspiration rates of EPR should be measured (ibid). These measurements will inform the LLNF of the rate at which water enters and leaves the soil on EPR due to infiltration and evaporation respectively (ibid). The stormwater infiltration cells would be able to be installed underneath the road surface and could include culverts or pipes to direct water into the cells (S. Engelbourg, personal communication).

(https://stormwater.pca.state.mn.us/index.php?title=BMPs_for_stormwater_infiltration)

[20] Coarse concrete aggregate contains particles greater than 5 mm, as opposed to fine aggregate.