Design Guidance for Wetland-Road Crossings to Reduce Blanding's Turtle Mortality Risk

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CHaRT
Coastal Habitat Restoration Team

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Foreword

We recognize that the more we study and understand flora, fauna and their ecosystems, the more we realize that their needs should be considered in the process of infrastructure design. Roads in particular tend to disconnect natural systems. There is the ability therefore to connect wetland and stream systems in the presence of roads. In this document, we present variables to be considered for turtle habitat disconnected by roads. New wetland and stream crossings may be designed with these metrics in mind. Existing wetland and stream crossings may be assessed to evaluate their potential for turtle mortality, as well as gather the metrics needed to redesign high risk wetland and stream crossings.

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INTRODUCTION

SCOPE OF DOCUMENT

Fragmentation of aquatic networks caused by dams and road crossings is one of the primary threats to aquatic species in the United States. The Northeastern United States has the highest density of dams and road crossings in the country (Collier et al, 1997; Graf, 1999; Anderson and Olivero Sheldon 2011; Fuller et al 2015). It is estimated there are at least 26,000 road crossings in the State of New Hampshire, many of which are not compatible with the geomorphology or hydrology of the site and are barriers to aquatic organism passage (AOP). Based on 9,500 state-wide stream crossing surveys managed by The New Hampshire Stream Crossing Initiative (NHSCI), about 78% of road crossings do not have full AOP in New Hampshire (Statewide Asset Database Exchange System (SADES), 2021). The NHSCI is a multi-agency partnership of NHDES, New Hampshire Department of Transportation (NHDOT), Homeland Security and Emergency Management (HSEM), NHFG, and UNH that manages stream crossing surveys across the state to support data-driven decisions on replacements that will improve aquatic connectivity and flood resiliency. To date, approximately 40% (9,500) of the state's crossings have been assessed statewide using a single, consistent protocol. While this is a significant accomplishment, the focus of these surveys has been mainly on passage for brook trout and anadromous fish and geomorphic processes, not wetland connectivity or passage issues for semi-aquatic species such as turtles.

Several turtle species in New Hampshire are threatened or endangered due to fragmentation and loss of wetland habitats, nesting sites, and migratory corridors resulting from development and land use modifications. Mortalities from road crossings can have a significant impact on turtle populations. Disconnections between streams, wetlands, wetland floodplains, and the riparian environment from roads and deficient crossings restricts access to habitats required for one or more life stages of semi-aquatic turtle species. For example, perched culverts limit aquatic migrations of freshwater turtles that cannot jump into the culvert for passage, forcing them to travel overland and increasing their risk of predation and road mortality. Therefore, there is a compelling need to focus on methods for assessing areas where turtles and vulnerable species typically cross roads and develop crossing designs that reduce the mortality risk at these locations.

New Hampshire has a diversity of aquatic environments, including wetland complexes that are critical to support the life history activities of semi-aquatic wildlife. Many turtle species are migratory and require different aquatic and terrestrial habitat types, and continuity between these patches, for nesting, foraging, overwintering, and estivation. Blanding's turtles require large mosaics of wetland and upland habitats with relatively limited development, and therefore they are an important umbrella species for wetland habitat and species protection in the Northeast.

Human population density and development is rapidly increasing in southern New Hampshire (Thorn, et al, 2017) and increases in wetland fragmentation and road densities pose direct threats to semi-aquatic turtles. Blanding's turtles are especially vulnerable to wetland fragmentation and are slow to cross wide roads. Many Blanding's turtle records from New Hampshire are individuals observed on roads.

The intent of this document is twofold: to develop a method of assessing a road-wetland crossing as to the risk of turtle mortality and to provide design guidance for wetland-road crossings to reduce Blanding's turtle mortality risk. To support the design guidance the document demonstrates a method and metrics to evaluate and prioritize road crossings to focus restoration activities that will improve wetland connectivity and migration corridors for semi-aquatic wildlife, such as turtles, vulnerable to wetland loss. The information collected from field surveys of road crossings and spatial analyses were used to develop a data-driven prioritization scheme (rubric) to determine the comparative turtle mortality risk of a road-wetland crossing as well as to then identify key restoration projects to improve aquatic connectivity for aquatic and semi-aquatic wildlife, with a focus on state-endangered turtles (i.e., Blanding's turtle, *Emydoidea blandingii*).

BLANDING'S TURTLE BACKGROUND

In New Hampshire, the state-endangered Blanding's turtle uses a variety of wetland types including marshes, vegetated ponds, forested and shrub swamps, fens, oxbows, vernal pools, and terrestrial habitat, and will travel extensively among them. Habitat use may shift seasonally and vary geographically: for example, Blanding's turtles may forage on amphibian eggs in vernal pools during the spring, lay eggs in upland habitats (sandy, loam, gravel open areas) between late May and early July, and overwinter in permanent wetlands. Upland habitats suitable for turtle nesting are open and sunny, clear of vegetation, with loose bare soil or sand that is well drained.

Blanding's turtles are capable of dispersing long distances through upland habitats (Innes et al. 2008, Babbitt and Jenkins 2003, Joyal et al. 2000). Roads that intersect turtle home ranges increase the chance of individuals being killed on the roads and the presence and intensity of roads is a major threat for Blanding's turtles. Models have shown that road densities as low as 1 km/ km^2 (1.6 mi/mi^2) with fewer than 100 vehicles per lane per day may affect turtle populations (e.g., *Emydoidea*, Gibbs and Shriver 2002). Low population densities and skewed age and sex ratios have raised concerns over the effect of road mortality on turtle populations in the region, where losses of only a few adult Blanding's turtles per year may result in local population extirpation (Joyal et al. 2000, Marchand and Litvaitis 2004a, Gibbs and Steen 2005). Since females move more often than males (due to migrating to nesting grounds) and do not sexually mature until 14-20 years old, the loss of adult females greatly exacerbates their population declines (Congdon and van Loben Sels 1993, Gibbs and Shriver 2002). Thus, the death of even one adult Blanding's turtle can have a significant impact on populations. Because Blanding's turtles are a wetland-dependent migratory species, restoration efforts to improve habitat connectivity to meet their life history needs will also improve overall wetland conditions to benefit other aquatic and semi-aquatic wildlife in New Hampshire (Willey and Jones 2014).

A less frequently implemented approach to Blanding's turtle conservation is to restore/improve semi-aquatic organism passage within key movement corridors. For example, the risk of mortality may decrease when there is a suitable passage structure (culvert or bridge) under a road. Turtles are more likely to pass through a structure that is large and bright, providing a clear line of sight to the other end of the structure. Culverts that are screened, perched, or less than 2 feet in diameter are not likely to be passable by turtles, forcing them to attempt crossing over the road. Road mortality may also be decreased if access to the road is limited by fences, walls, or steep road embankments; however functional connectivity of habitats is only maintained if a suitable passage structure is present.

POTENTIAL AREAS FOR RESTORATION

Blanding's turtles occur in southern New Hampshire (Figure 1). When developing projects in this region of the state it is important to consider whether Blanding's turtles should be part of the project planning process. To guide your consideration it is recommended that you: (1) look at the landscape and adjacent habitats; (2) check with the NH Natural Heritage Bureau (NHB) using the DataCheck tool to see if there are known records; and/or (3) contact a NHFG biologist.

(1) Habitat: Blanding's turtle habitat includes wetland habitats with permanent shallow water and emergent vegetation such as marshes, swamps, bogs, and ponds. Blanding's turtles use vernal pools extensively in spring and while traveling through the landscape. They may use slow rivers and streams as mechanisms for dispersal between wetlands and use terrestrial habitats for nesting and travel among wetlands. While Blanding's turtle movements are dispersed and extensive, a likely hotspot for road crossings is where a road bisects a wetland (Figure 2).
(2) NHB DataCheck tool The New Hampshire Natural Heritage Bureau (NHB) keeps records of known locations of rare species and natural communities. The DataCheck Tool can check if your property/project location is near any known records[1].
(3) Contact a NHFG Biologist: NHFG biologists can provide technical assistance. Joshua Megyesy, wildlife biologist/turtle projects, Joshua.megyesy@wildlife.nh.gov, 603-271-1125

If based on these factors, or other information sources, Blanding's turtles are part of your project planning process then follow the site consideration guidance in this document to determine the potential road mortality risk.

[1] https://www4.des.state.nh.us/nhb-datacheck/

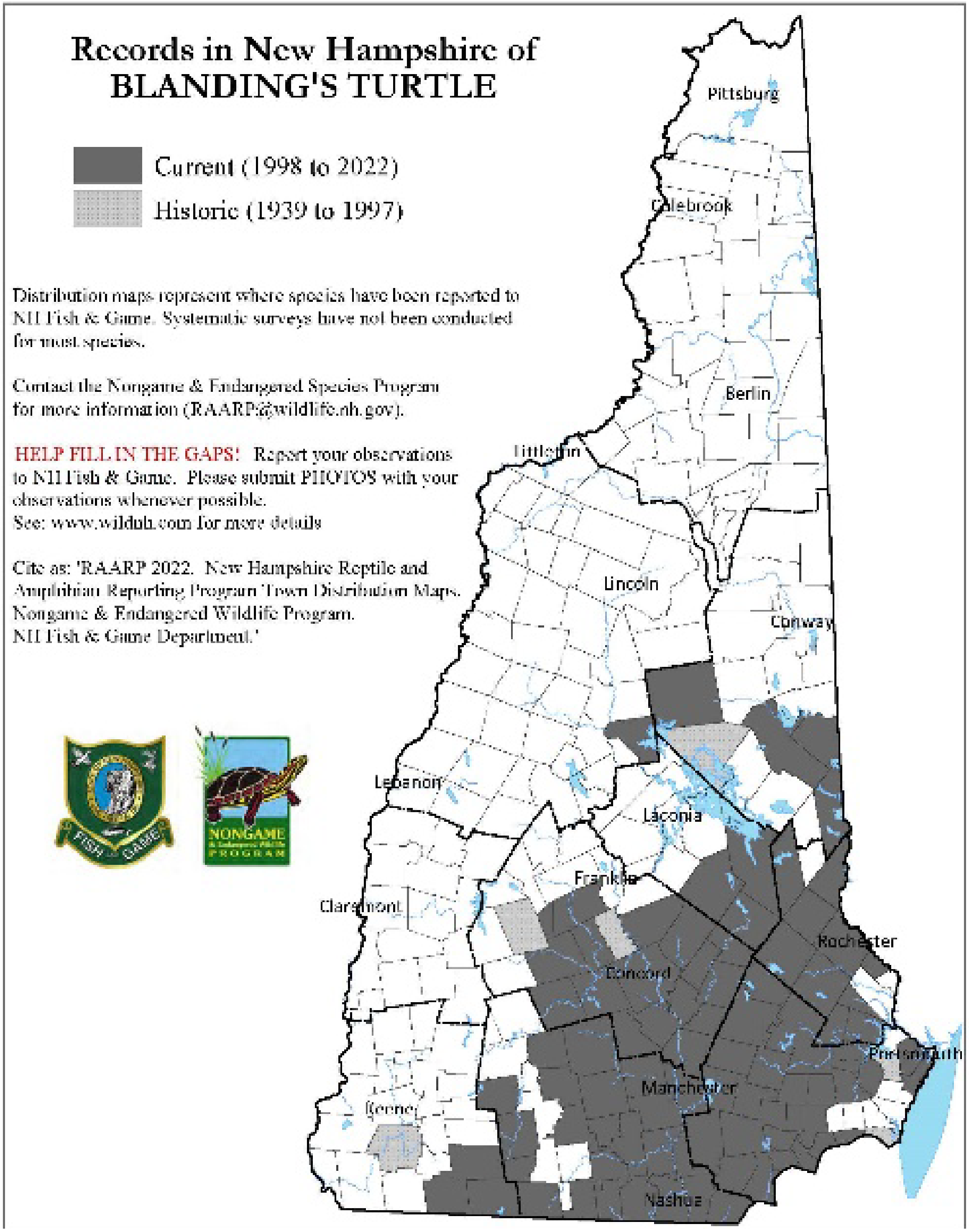

Figure 1. Blanding's turtle records in New Hampshire.

Figure 2. A likely turtle crossing hot spot is where a road bisects a wetland or aquatic system.

SITE CONSIDERATIONS FOR TURTLE CROSSINGS

A rubric was developed to assess the relative risk of turtle road mortality at wetland crossing structures. Informed by a literature review and iterative discussions with experts, this rubric scores a crossing structure based on three major categories: physical barriers to turtles, road accessibility to turtles, and structure visibility. It is intended to be useful in determining relative risk amongst a given set of crossing locations to prioritize efforts and resources for renovation that will improve passage and decrease vulnerability.

The goal of the rubric is to organize a select group of road crossing structures into the four categories found in Figure 3: a spectrum of road mortality risk for Blanding's turtle.

Figure 3. Stream-Road Crossing Classification for Risk of Turtle Mortality

This rubric only assesses physical site characteristics and not the turtle population in the surrounding area when calculating risk. For this reason, the use of this rubric to support the prioritization of projects that reduce risk should be supplemented with data on target species' range, habitat preferences, and observed presence.

Site Consideration for Turtle Crossings

As presented in the section, "POTENTIAL AREAS FOR RESTORATION", before a site is assessed for risk of Blanding's turtle road mortality based on physical site characteristics, the possibility of Blanding's presence at this site should be considered. If a specific site is not near turtle populations or turtle habitats, the site may not be high risk for Blanding's turtle mortality. The site turtle assessment includes the three previously mentioned sources: the NHDES Mapper[2], the NHB DataCheck[3], and contacting an NHFG biologist. When using this rubric to assess the risk of stream crossing structures, it is important to seek out further information on Blanding's turtles' presence and habitat preferences.

Each road-wetland crossing (culverted) site under consideration should be individually measured prior to using the rubric. It is suggested that measurements begin with arrival at a site, and taking time to observe and search for turtles, noting species and number of individuals present when possible. In order to have enough input data to effectively use the turtle mortality scoring rubric (Figure 4) the following information should be collected at each site:

- The presence of screens at a structure's inlet and outlet
- Width of structure inlet
- Presence of an outlet drop
- The presence of other blockages (i.e. crushed inlet, sediment, debris)
- Embankment slope at inlet and outlet
- The presence of a barrier wall or fence on the upstream or downstream side
- Riparian continuity upstream and downstream of the culvert
- Road length along the wetland on the upstream and downstream side
- Turtle nesting habitat upstream and downstream of the crossing

The specific assessment instructions for field measurement of these nine variables are outlined in Appendix A.

With the collected data, each road crossing may be individually assessed by employing the flowchart rubric (Figure 4) to determine which of the four turtle levels of mortality risk that specific location presents: high risk, medium-high risk, medium-low risk, or low risk. The risk of road mortality in this context increases with the possibility of a turtle gaining access to a road surface.

[2] https://www.des.nh.gov/resource-center/data-and-mapping
[3] https://www4.des.state.nh.us/nhb-datacheck/

Rubric Flowchart:

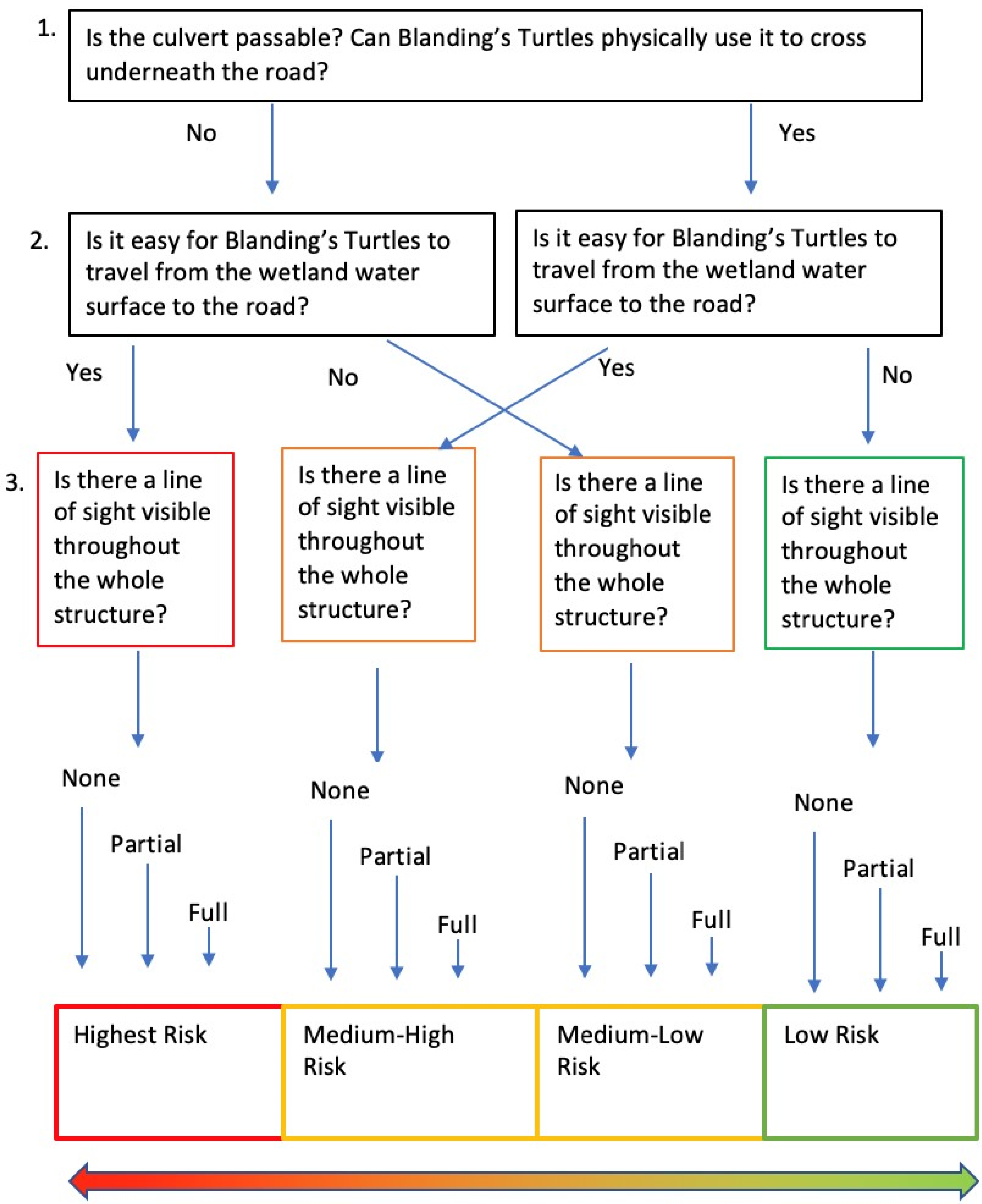

Figure 4. Mortality Risk Scoring Rubric for wetland-Road crossings.

At rubric question #1 (Is the culvert passable?), each culvert is assessed for a physical passage barrier through that culvert. Outlet perching (a drop from the structure outlet invert to the water surface), structure screening, or culvert blockage are physical barriers that prevent Blanding's turtles from traveling through the road crossing structure. Perching poses a vertical climbing challenge and prevents turtles from accessing the structure. A physical screen at either end of a culvert blocks the inlet or outlet and prevents entrance/exit to/from the structure. Blocking similarly prevents entrance/exit to/from the structure, defined in the field dataset as either the inlet or outlet being buried in sediment or otherwise without an opening. Additionally, culvert openings less than 2 feet in width (span) or diameter are too small for Blanding's to comfortably pass through (insufficient light) and are designated as not passable.

To use the rubric, the first effort is to determine if the culvert itself is passable. If any of the following in Table 1 is true, the culvert is marked as "*No, not passable*". If all elements of Table 1 are false, the culvert is marked as "*Yes, passable*".

Table 1. Culvert passability

Variable	**Not Passable if…**
Presence of screens	Yes
Width of structure inlet	< 2.0 ft
Outlet drop	> 0.0 ft
Presence of other blockages	Yes

Following the corresponding arrow to the first question (yes or no regarding passability) on the flow chart, the second rubric question assesses road accessibility by asking "Is it easy for a Blanding's turtle to travel to the road from the water surface/wetland?" To develop the response to this question, five variables need to be scored using the elements in Table 2. Each of the Table 2 variables has a range of their physical dimensions that relate to how easy or difficult it may be for a turtle to get onto the road. The ranges of each of these Table 2 variables were binned, and these bins appear in Table 3.

Table 2. Road accessibility variables

Variable	Description
Embankment Slope	Slope of the road embankment (horizontal to vertical).
Fence or Wall	Fence or (retaining) wall parallel to the road that prevents turtle movement. For low risk: height > 16 inches, curves back into wetland, and have opening sizes less than one inch. Medium risk is a fence that does not meet any of the low-risk criteria. High risk is no fence.
Riparian Continuity	Riparian continuity exists when the vegetation and substrate makeup is consistent across the shelf and onto the banks of the water body. A site with no continuity could have boulders, riprap, or other obstacles that can impede turtle movement across the embankment.
Road Length (ft)	The distance of the wetland along the intersected the road.
Roadside Nesting Habitat	Sandy or gravelly nesting habitat located on the embankment or along the shoulder of the road (up and downstream) for the length of the wetland. Where there is nesting habitat on the road embankment, there is higher risk of turtles attempting to reach it.

In accordance with Table 3, points are assigned to each of the Table 2 variables and then summed for each culvert's road accessibility assessment. Low Risk variables account for 1 point, Medium Risk for 2 points, and High Risk for 3 points. An example using the rubric and this scoring matrix is presented in Appendix B.

Table 3. Scoring for road accessibility variables

Variable	Low Risk +1pt	Med Risk +2pts	High Risk + 3pts
Embankment slope upstream (US*)	<1:1	1:1 to 1:2	>1:2
Embankment slope downstream (DS)	<1:1	1:1 to 1:2	>1:2
Fence or wall (US)	Turtle-proof	Present	Not present
Fence or wall (DS)	Turtle-proof	Present	Not present
Riparian continuity (US)	-	No US continuity	US continuity
Riparian continuity (DS)	-	No DS continuity	DS continuity
Road Length (US)	<50ft	50-100ft	>100ft
Road Length (DS)	<50ft	50-100ft	>100ft
Nesting habitat	No nesting habitat US nor DS	Nesting habitat US or DS	Nesting habitat US and DS

*US – upstream   DS - downstream

After assigning points to each variable associated with the road crossing, the totals are added. This total is then used to determine Blanding's turtle road accessibility in line 2 of the rubric (Figure 4):

Sums less than 18 are considered "No, the road is not easily accessible"

Sums greater than 18 are considered "Yes, the road is easily accessible"

Following the corresponding arrows in the flow chart for question #2, the crossing is now sorted into one of the four output categories of risk: High (red), Medium-high (orange), Medium-low (yellow), or Low (green).

To further assess relative risk within categories, the culverts may be assessed for Line of Sight, or visibility throughout the structure. Line of sight (LOS) indicates the visibility (light characteristics) through the structure. Line of sight is divided into the categories of 'None (N)', 'Partial (P)', and 'Full (F)'. None indicates no light seen/observable, Partial indicates that some light is visible through the structure but is faint, and Full indicates that the entire tunnel is visible due to light infiltrating from each end. Sievert et al. (2015) found that Blanding's Turtles were more likely to successfully pass through a tunnel structure when light was visible at the other end. In their study, 89% of Blanding's Turtles passed through a tunnel with 100% ambient light, compared to the 8% that passed through a tunnel with 0% light. While an absence of light is not a complete barrier to passage, it is clearly a deterrent.

An example application of this rubric may be found in Appendix B.

DESIGN GUIDANCE & CONSIDERATIONS

For new or restoration road crossing designs, the following sections detail how to address individual site design elements in order to reduce turtle mortality risk on roads. In addition, while the focus of this design guidance is wetland crossings, where there is an associated stream, a crossing should be designed to also meet the NH Stream Crossing Guidelines (May 2009) so as "to be hydraulically and geomorphically transparent" to the environment.

The variables that result in a high turtle mortality risk in the previous section are often those that may be addressed in designs to lower risk. Risk mitigation measures to reduce turtle road mortality and maintain habitat connectivity include barrier fences and walls, passage structures, signs paired with other measures, and the creation of safe nesting sites.

ROAD CONSIDERATIONS

CURB

Steep curbing can trap turtles on roadways and decrease the chance of turtles successfully crossing a road. Steep curbs should be avoided on roads adjacent to turtle habitats, such as wetlands. If curbing is necessary, the height should be less than 4 inches and a slope no greater than 3:1 to allow turtles to climb them.

RIPARIAN CONTINUITY

Combined, the effects of embankment slope and riparian continuity can make road accessibility easy or difficult for wildlife moving from the wetland to the road surface. A steep embankment slope paired with a lack of riparian plant cover can prevent an individual from climbing up the side of the road and gaining access to the road. Large diameter rocks such as rip rap (Figure 5) can act as a barrier to travel for wildlife such as turtles and steep slopes, while passable, represent high turtle energy costs when climbing uphill. A low-sloped embankment paired with riparian continuity (described as consistent vegetation and substrate across a water edge/wetland), can allow easy passage for a turtle from the wetland to the road (Figure 6). Such a setting provides very little barrier and results in greater vulnerability for turtles at the crossing.

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Figure 5. Relatively steep embankment slope by the culvert inlets with rip rap on the embankment, reducing riparian continuity. In this instance, passage from the water to the road is relatively difficult compared to Figure 6 and would likely take more energy, or potentially be a barrier.

Designing a crossing that prevents turtle road mortality requires both putting barriers between the wetland and the road as well as maintaining riparian continuity leading into and through structures. This may be accomplished with efficient fencing, or with high slopes and coarse, non-vegetated surfaces for embankments. However, rip rap is not always an advisable design characteristic due to concerns of erosion, the potential for scour, costs, maintenance, and the fact that native vegetation provides more suitable habitat and ecological benefits in its place.

Figure 6. An embankment with a low slope and riparian continuity, making the travel from the water surface to the road easy and accessible.

Figure 7. Lack of riparian continuity leading into and through a structure due to cobble and rip rap placed on banks.

FENCING/GUIDEWALLS

To prevent turtles from accessing a road, and therefore reduce the number of turtles killed on a roadway, a barrier feature such as a wall or fence is recommended. The barrier/fence serves two purposes: to prevent turtles from accessing the road and to guide turtles into a crossing structure under the road. Appropriately located, designed, and maintained barriers have been shown to significantly reduce turtle road mortality (Aresco 2005, Langen 2011, Crawford et al. 2017, Markle et al. 2017, Boyle et al. 2021, Read & Thompson 2021). Ideally, the wall or fence also guides turtles to a passage structure or underpass, such as a culvert or bridge, thus maintaining functional habitat connectivity. Barrier features are a simple and effective way to upgrade a crossing structure for turtle passage. Figures 8a and 8b display various turtle barrier examples.

<u>The design guidance for fencing/guidewalls may be found in the following bullets:</u>

- The barrier height should be at least 2 feet high above ground level (Figure 8a and b). Note that any wall 2 feet or higher should be outside of the road clear zone.
- The barrier base should be buried at least 6-8 inches into the ground to prevent turtles from digging under the barrier.
- A 4-inch overhang at the top of the barrier will inhibit turtles from climbing over the fence/wall and entering the roadway (Figure 9).
- There should be no gaps along the barrier length that allow turtles to access the road (Figure 10).
- The barrier feature should be long enough to encompass the full segment of roadway that turtles regularly encounter. The barrier should be installed the length of the turtle crossing hotspot (e.g. the distance of the wetland along the road) and 20 meters (65 feet) beyond.
- Features to prevent turtles from moving around ends of the barrier include:
- Ending the turtle barrier to an existing barrier (e.g. bridges, rock faces, walls, natural obstruction such as a rock outcropping);
    - Long wings heading away from roadway (25 meters);
    - Short end return loop (200-degree loop at the end of the barrier turned back towards the interior of the barrier for 2 meters (curve/hook). (Figures 10 and 11)
- Ideally, the barrier should be opaque. If turtles can see through the wall/fence they may spend a long time trying to push through, climb, or pace along the barrier and risk overheating, dehydration, poaching, and predation.
- If a mesh fence is used as the barrier, add a 1” by 1” or finer mesh at the base to prevent hatchling turtles from passing through the fence and onto the roadway
- The barrier may be combined with other road barriers such as a guard rail (Figure 12). It should be noted that attaching a fence to a guard rail as depicted may not meet local or state design codes.

Include features to prevent turtles from getting trapped on the road. For example, a barrier built into the slope at grade on the road side so that an animal may drop over the lip from the road (Figures 9 and 11). Additional advantages of a barrier wall built into the slope are aesthetics (not visually conspicuous from roadway), easy vegetative maintenance, uninterrupted water flows, and increased durability.

Figure 8a. Various turtle barrier strategies.

Figure 8b. Various turtle barrier strategies.

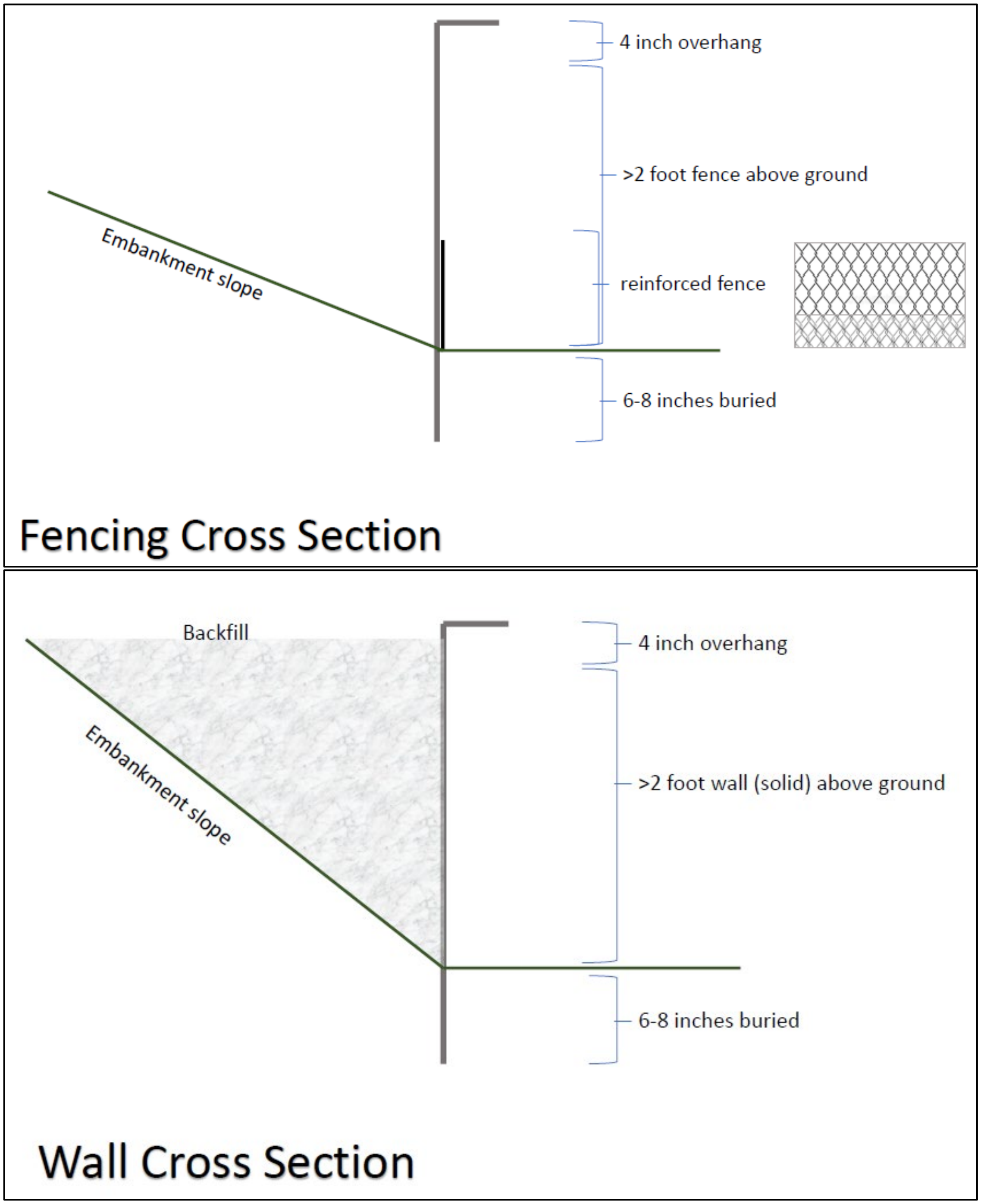

Figure 9. Turtle-proof fence and wall cross section views. Note: backfill on road side of wall (lower figure) enables turtles and wildlife that reached the road to get back to the riparian lands.

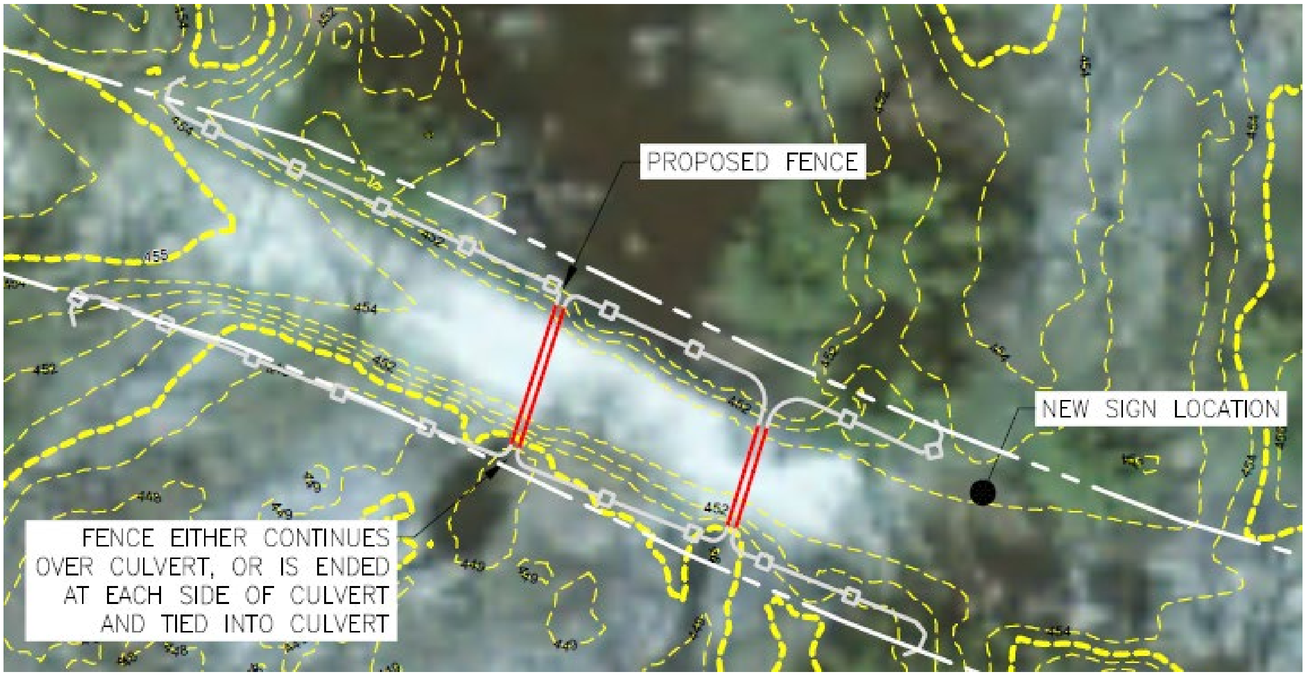

Figure 10. Example fence planform (grey lines) on design plans.

Figure 11. Curved turtle fence end to deter turtle from going around the fence. This barrier is built into the slope so it is at grade on the roadside so that an animal that is on the road is not trapped and may drop over the lip to the wetland but not move from wetland to the road.

Figure 12. Turtle fence installed behind an existing guardrail.

Other turtle barrier considerations should include:

- For motorist safety, barriers should either be behind guardrails or at least 13 feet (four meters) off the roadway and unobtrusive so as not to distract drivers or present itself as a traffic hazard.
- Drainage and high water levels should be considered in the design.
- A vegetation management plan should be developed; consider a low-growing seed mix and periodic mowing.
- Silt fencing and wood barriers are not recommended materials as they are high maintenance with limited durability.
- Fence barriers are inexpensive and easy to install but managing vegetation may be a challenge and they are not opaque.
- The turtle barrier should not present itself as an interference regarding snow removal.
- Regular maintenance may be needed, it is recommended that this need is discussed with responsible parties in the design process and a maintenance plan developed including:
    - Inspect for mammal tunnels or washouts under fence.
    - Inspect for collapsed sections from plowed snow or fallen branches/trees/
    - Inspect for collected debris against fence that turtles could use as a structure to climb over.
    - The barrier should be inspected, at a minimum in early April prior to the primary turtle movement season. Inspection should note any barrier flaws that could result in turtles getting past the barrier and onto the road and result in immediate repair or maintenance by the end of April each year.

Examples of fence and crossing suppliers include:

Animex https://animexfencing.com/turtle-fencing ;
ACO Wildlife https://acoswm.com/wildlife/

CULVERT/BRIDGE CONSIDERATIONS

LINE OF SIGHT/OPENNESS RATIO/BRIGHTNESS

The amount of light and airflow affects whether a turtle will enter and pass through a culvert. Turtles avoid dark tunnels and thus the brighter the culvert, the better to attract turtles to cross under the road. Culverts may be brightened either by (1) having a larger openness ratio or (2) openings at the top that act as skylights.

1. The openness ratio is the ratio of the culvert/crossing cross sectional area to the length of a crossing structure. For turtles, the openness ratio should at minimum be 0.2-0.25 m^2/m (0.82 ft^2/ft).
2. Grated openings on the ceiling of the structure act as a skylight and may be used to increase brightness and also allow moisture (Figures 13 and 14). Considering the use of grates is especially recommended when a culvert is longer than 80 feet. There are various prefabricated products available that provide the grate and the turtle corridor. Considerations should be made to the appropriate grate opening size so as not to become an entrapment feature, especially if the passage is not combined with a barrier feature keeping turtles off the roadway.

Figure 13. A grate in the shoulder of a roadway provides light to a culvert; installing the grate in the shoulder of the road allows it to be below road grade improving snowplow safety.

Figure 14. A dry culvert with a grated cover.

PERCHED CONDITION/OUTLET PROFILE

Perched culverts may prevent safe passage for turtles that cannot jump or climb into the perched culvert. This then forces turtles to travel overland and increases their risk of road mortality. New culverts should be set at grade or embedded at grade. For existing culverts that are perched, if replacement is not being considered, create a more gradual slope (ramp) between the culvert and the surface of the wetland using natural substrate. Existing culverts that are perched may be modified by constructing a ramp just downstream to completely eliminate the perched condition (Figure 15).

Figure 15. Perched culvert (left) and same culvert with a rock ramp (right).

SCREEN/DEBRIS/BLOCKAGE

If the opening of a culvert or bridge is blocked by debris, it reduces the likelihood of passage by turtles. For new culverts, larger culverts are less likely to fill with sediment/debris and easier to clean should they become obstructed. For existing culverts, regular inspection and maintenance should be scheduled. Debris that blocks the passage of turtles is also a potential concern for road flooding.

Placing screens in front of culverts prevents turtles from passing through the culvert. Consider alternatives including a dry passage culvert or a Beaver Deceiver or similar structure[4].

The beaver prevention device may pose a barrier to turtle passage. In these situations, it may be better to create a separate passage for turtles rather than to try to combine these competing wildlife management objectives at one location.

HYDRAULIC CAPACITY AND ASSOCIATED VELOCITY CONSIDERATIONS

Turtles in general are not strong swimmers. Some species such as Blanding's may avoid submerged culverts and prefer to move on land. Therefore submerged culverts or culverts with high velocities are not optimal components of continuous habitat. If an existing culvert is submerged, that culvert could be replaced, with one set higher, or a separate turtle crossing installed nearby. No strict guidance is available on the maximum culvert water velocity for turtle passage: however, the steam characteristics away from the effects of the culvert are the best guide. At the range of flows during the movement periods, culvert velocities should mimic those in the stream. The high water velocity problem may be avoided if there is a wildlife bench in the culvert, or, as with the water depth solution, a separate turtle crossing constructed (Figures 16 and 17).

Figure 16. Dedicated turtle crossing structure.

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[4] https://beaverdeceivers.com/wp-content/uploads/2020/11/BDI_brochure_20200227.pdf

Figure 17. Example of a dry passage culvert.

NATURAL SUBSTRATE

Natural substrate is best to entice turtles to cross under roads through culverts. Angular rock rip rap may impede turtle movement. Where there is a large amount of angular rock rip rap under a bridge it is recommended that a flat bench/pathway be created to facilitate use by turtles and other wildlife. In general for structures that require rock rip rap protection against hydraulic forces, void filled rip rap is preferred[5].

ADDITIONAL CONSIDERATIONS

SIGNS AND SIGNAGE

One method to reduce turtle mortalities on roads is to increase driver awareness (Figure 18). Road signs warning motorists that turtles may be crossing in the near distance may make drivers more aware. Signage is most effective when combined with other mitigation measures (for example barrier fencing, underpass structures, traffic calming/speed reduction, improved visibility, etc.) and it is best not to use signage exclusively, rather, it is recommended to

[5] https://www.mhfd.org/wp-content/uploads/2019/12/Combined-VFR-paper-and-appendices-4-21-11.pdf

collaborate with a NHFG Biologist on the location of signs and other measures to reduce turtle vulnerability.

Sign design guidance

- Signs should be located before the driver enters the hotspot for turtle road crossing to allow the driver to focus attention on detecting turtles.
- Seasonal signs are more likely to be effective. Signage that is only posted or activated during peak periods of turtle road encounters (e.g. nesting) functions better than signs present continuously, to which motorists quickly habituate. Seasonal signs may be hinged signs (Figure 18) that may be opened during times of the highest risk of turtles on the road such as the nesting season (late May and early July) and/or may also have flashing lights that are turned on seasonally.
- Signs should be paired with other mitigation measures.

Figure 18. Hinged turtle crossing sign that can be opened during times of highest risk of turtles on crossing roads.

TEMPORARY SPEED BUMPS

Reducing speeds and the use of temporary speed bumps may be effective at reducing turtle mortalities by traffic calming. Temporary speed bumps (Figure 19) may be placed after winter road maintenance efforts end (plowing, salting, sanding, etc.). It is recommended to use signage to warn of upcoming speed bumps.

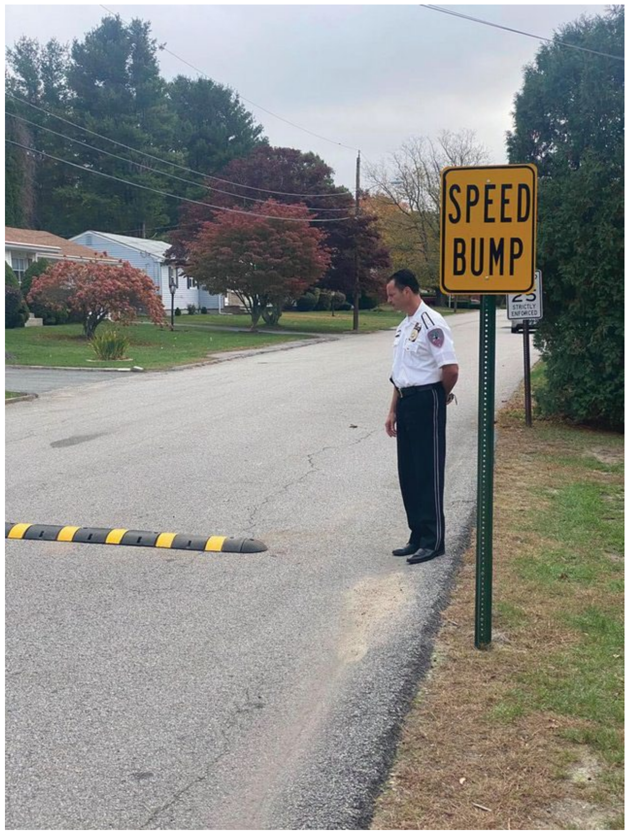

Figure 19. Temporary speed bump installation

NEST SITE CREATION

Turtles may encounter roads on their travels to nesting locations OR may be attracted to nesting sites along roadsides. The creation of safe nesting sites that allow travel from wetland habitats to nesting sites without crossing roads may reduce turtle mortality. It is recommended that you consult with a NHFG Biologist for technical assistance on the location and design of nest sites. In general, a turtle nest site habitat is open (unshaded), loose, bare soil or sand areas adjacent to or with 200 meters of wetlands (Figure 20).

Figure 20. Creation of a turtle nesting site.

HELP TURTLES CROSS ROADS

Turtles on a road can always benefit from assistance in crossing the road. Cars waiting for turtles to cross, helping turtles cross, and reporting injured turtles are just a few of the ways citizen monitoring may benefit turtles. More detailed citizen efforts include:

1. Help turtles cross roads safely. If you see a turtle crossing a road, and it is safe for you to do so, help it cross in the direction it is traveling. Never create a dangerous situation for other motorists or yourself[6].

2. Do not move a turtle from where you found it. Even if a turtle is a great distance from a wetland area, they are not lost and know exactly where they are going. Moving a turtle to a different location can be stressful for the animal and may even result in death if they are unable to adjust to their new surroundings.

3. If you find an injured turtle, call NH Fish and Game's Wildlife Division at (603) 271-2461 for a list of licensed wildlife rehabilitators in your area or visit https://www.wildlife.nh.gov/wildlife-and-habitat/rehabilitators. For more information on

[6] https://www.fws.gov/story/tips-helping-turtle-cross-road

what to do if you find an injured turtle, visit https://www.wildlife.nh.gov/wildlife-and-habitat/nongame-and-endangered-species/reptiles-and-amphibians-new-hampshire/turtles-0

4. Report turtle sightings (living or deceased) to NH Fish and Game's Reptile and Amphibian Reporting Program by e-mailing details or completed form to raarp@wildlife.nh.gov; mailing a reporting slip to https://www.wildlife.nh.gov/sites/g/files/ehbemt746/files/inline-images/ngm23001.pdf; or online at http://nhwildlifesightings.unh.edu. Note the location, date, and time of observation, and include photos if possible.

CONSTRUCTION AND MAINTENANCE ACTIVITIES RELEVANT TO TURTLE MOVEMENTS

Construction Reminders

- All parties shall be notified of sensitive areas. All operators and personnel working on or entering the site shall be made aware of the potential presence of these species and shall be provided flyers that help to identify these species, along with NHFG contact information. Notes on the design plans should specifically call attention to turtle concerns at a site and risk mitigation measures.
- Silt fence (buried a minimum of 6") shall be maintained to keep turtles from entering active construction sites.
- All manufactured erosion and sediment control products, with the exception of turf reinforcement mats, utilized for, but not limited to, slope protection, runoff diversion, slope interruption, perimeter control, inlet protection, check dams, and sediment traps shall not contain plastic, or multifilament or monofilament polypropylene netting or mesh with an opening size of greater than 1/8 inches.
- Turtles are most active from April 15th - October 15th; maintain silt fences during this time.
- Turtles may be attracted to disturbed ground during nesting season (May 15th – July 15th), therefore it is important to fence off such areas if possible and inspect frequently for turtles and turtle nests. If a nest is found, please notify NHFG (Joshua Megyesy, wildlife biologist/turtle projects, Joshua.megyesy@wildlife.nh.gov, 603-271-1125)

Maintenance Notes

- Early on in the design process, it is incumbent to discuss project elements designed for turtles with whomever (Town or District Maintenance) might be responsible for the maintenance of road infrastructure. Turtle passage elements should be selected that will be readily maintained and not avoided regarding maintenance. Upon project completion, likewise, people responsible for maintenance should be walked through the project elements and instructed on inspection frequency and maintenance procedures.
- Develop a long-term maintenance and repair plan.
- Take an adaptive management approach and be prepared to make improvements.

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Appendix A: Survey Data Collection guide:

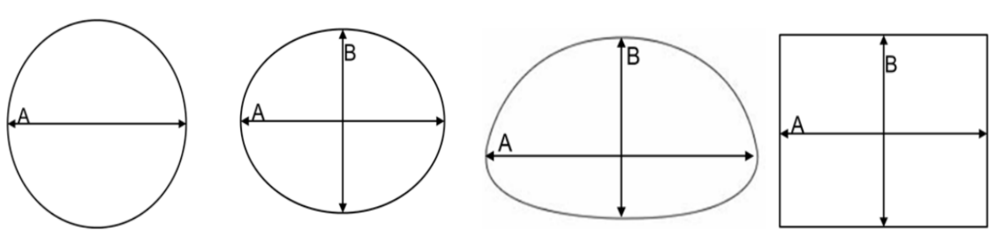
The following instructions on how to collect data on the relevant characteristics of each stream crossing site have been adapted from the New Hampshire Stream Crossing Initiative Field Manual (2019)[7] and the Wetland Crossing Turtle Assessment Handout: A Supplement to the NHSCI SADES Protocol (2022).

PRESENCE OF SCREENS

Data collection record: Yes or No
Screens at either the culvert inlet or outlet likely prevent turtles and other wildlife from accessing the culvert and prevent passage through the structure. Examples of typical screens are found in the photos below {photos taken from the New Hampshire Stream Crossing Initiative Field Manual (2019)}.

CULVERT UPSTREAM WIDTH (SPAN)

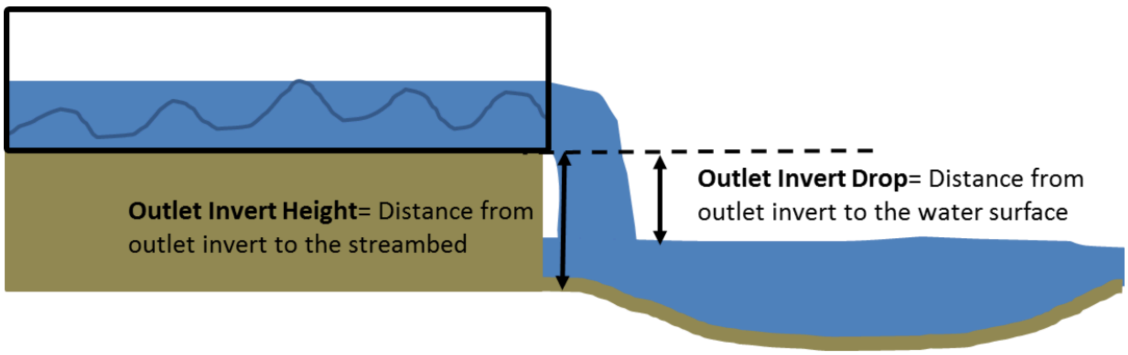
Data collection record: Width in feet
Measure the width (span) of the opening of the inlet. Follow line 'A' as drawn in the following figure. Figure taken from the New Hampshire Stream Crossing Initiative Field Manual (2019).



[7] https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/lrm-culvert-assessment-protocol.pdf

CULVERT OUTLET DROP

Data collection record: outlet drop in feet
Measure the distance from the inside of the bottom (invert) of the culvert outlet to the top of the water surface immediately downstream of the outlet. If the water is at grade (level with the invert), record a 0 ft drop. Follow the figure below for this measurement {figure taken from the New Hampshire Stream Crossing Initiative Field Manual (2019)}.



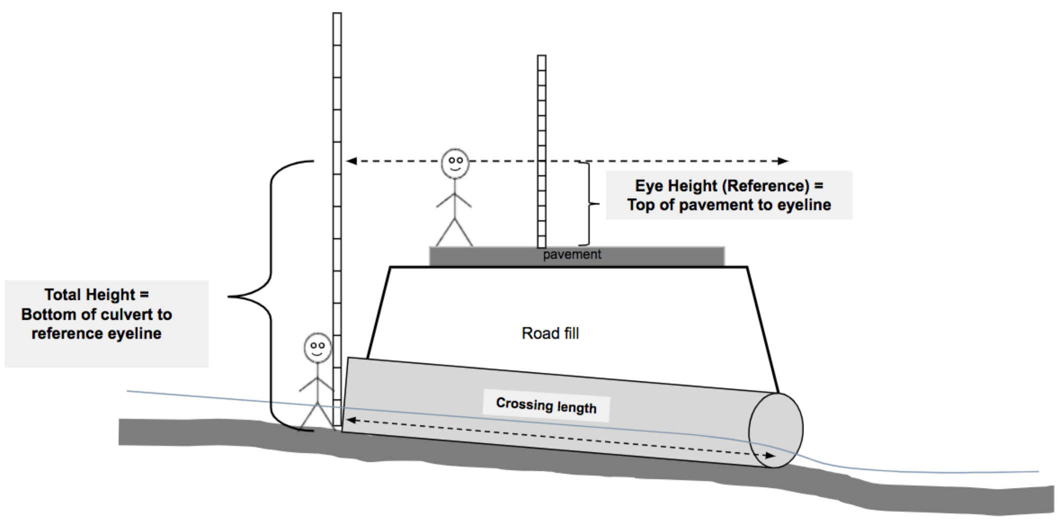
PRESENCE OF OTHER VISIBLE CULVERT BLOCKAGES

Data collection record: Yes or No
Record other abnormal visible blockages of the structure. Examples may include structural disrepair where either inlet or outlet is crushed, buried, or otherwise un-passable. The following photo shows an inlet (round corrugated pipe) that has been crushed and is blocked.

ROAD EMBANKMENT SLOPE (UPSTREAM AND DOWNSTREAM OF CULVERT)

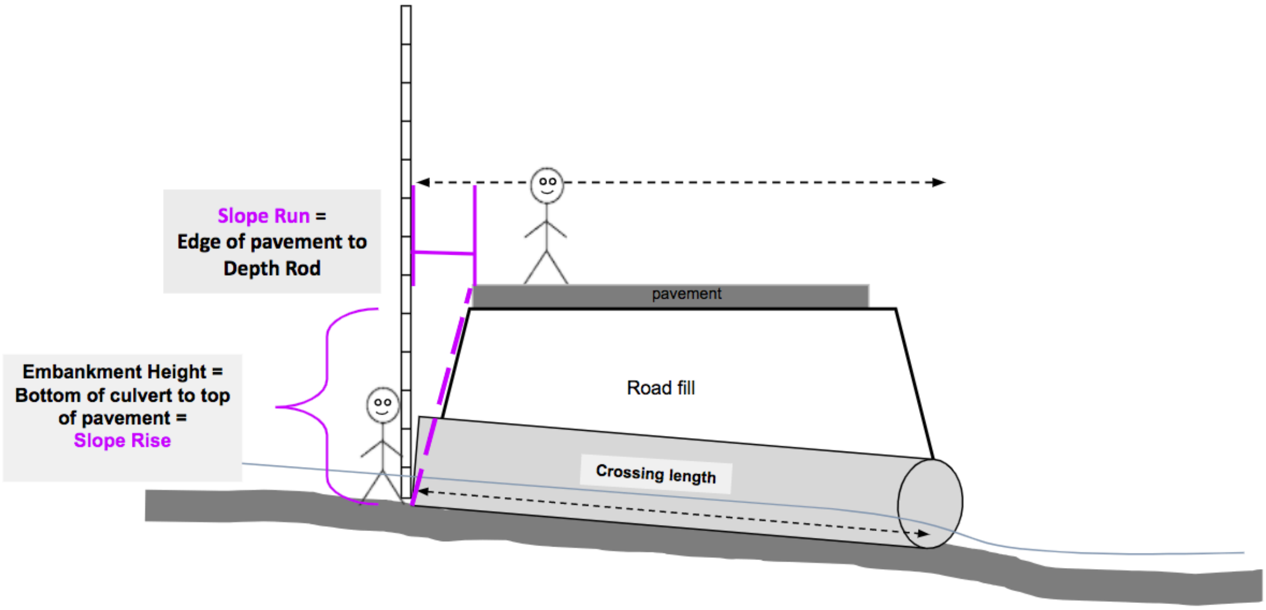
Data collection record: Slope as a ratio Rise:Run
The embankment is the area between the road and the crossing structure. It is often steep and is where a headwall may be located (yellow oval on following figure).

To measure the embankment height, a few measurements and quick calculations are necessary. First is the Eye Height, or Reference Height, the same as the SADES protocol. This will be different for each person: using the depth rod, measure from the top of the pavement to one's eye height. Second, like the SADES elevation, measure the Total Height from the bottom of the culvert or crossing to one's eye height. Then, subtract the Eye Height from the Total Height to find the Embankment Height.



Embankment Height = Total Height - Eye Height

To measure the Embankment Slope, keep the depth rod at the bottom of the culvert or crossing. Then, determine the edge of the embankment by standing at the edge of the pavement where the road ends and the embankment substrate starts. However, if the road has a flat shoulder, mark the edge of the embankment at the site where the slope begins to change. Measure the distance from this edge to the depth rod. This will be the "Slope Run" measurement. Record this number. The slope will be determined later by dividing Embankment Height or "Slope Rise" by "Slope Run".



Slope = Rise / Run

ROAD FENCING OR WALLS (UPSTREAM AND DOWNSTREAM OF CULVERT)

Data collection record: Turtle-proof, Present but not turtle-proof, or none
Blanding's turtles have been observed to be blocked by 2-foot-tall vertical barriers as well as greater than 4-inch high, vertical road curbs. There are a myriad of potential barriers that prevent turtles from crossing from the upstream water body onto the road. Fences may be the most common, along with jersey barriers and noise barriers.

Fence (a) Mesh, metal, or vinyl continuous barrier that aims to prevent wildlife or people from crossing onto the road
Jersey Barrier (b) Solid concrete or plastic blocks used on the road to create barricades.
Noise Barrier (c) Tall, solid barriers alongside major roads to reduce noise pollution away from road.


(a)


(b)


(c)

After identifying what type of barrier exists, examine the barrier to determine if it is turtle-proof. Literature has shown that fences obstruct turtles when they are embedded in the ground, are free of any holes or maintenance issues, curve back towards the wetland at the edges, and are at least two feet tall. Guard rails or other fencing that has large open areas are not considered turtle-proof fencing.

RIPARIAN CONTINUITY (UPSTREAM AND DOWNSTREAM OF CULVERT)

Data collection record: Yes or No
Riparian continuity exists when the vegetation and substrate makeup are consistent with the wetland environment across the banks of the water body.

The example above shows a lack of riparian continuity: the cobble riprap on the left and right side of the banks disrupts the continuity of the sandy/silty substrate with young vegetation growing. The presence of a stonewall crossing the water body, banks, or embankment signals non- non-continuous riparian edge. Void-filled rip rap can improve turtle access here.

ROAD LENGTH (UPSTREAM AND DOWNSTREAM OF CULVERT)

Data collection record: Length in feet
Using vegetation and substrate indicators, identify the edges of the wetland along the road. Measure the distance between the wetland edges along the length of the road, on both the upstream and downstream culvert sides. Use indicators such as the presence/absence of ferns and other wetland vegetation, wet leaves, and water presence to determine wetland edge.

TURTLE NESTING HABITAT

Data collection record: Yes or No for both upstream and downstream
Blanding's turtles commonly nest in dry, sandy areas with no to low canopy cover (figure below). Nesting areas are often upland with grassy or little to no herbaceous vegetation. Disturbed areas such as the sides of roads (especially dirt roads) or farmlands are common turtle nesting sites. Blanding's turtles do not nest in or at the water's edge. Field surveyors

should indicate whether there are any potential turtle nesting sites near the crossing, take a photo, and identify where in relation to the structure and road the area is located.

LINE OF SIGHT

Data collection record: Full, Partial, or None
Turtles are more likely to cross through structures that have natural or artificial light throughout the structure rather than tunnels or passages that are dark. This parameter is asking the surveyor to visually assess whether there is a line of sight through the structure: when looking through the structure from the inlet, can one see the other side? If yes, the surveyor should choose whether the line of sight is full, partial, or none.

Full: The outlet is visible and enough light is able to enter the structure so that the culvert walls and water surface are visible (next figure).

Partial: The outlet is visible, but inside the culvert may be dim or not entirely clear, the culvert sides and the water surface are not visible (next figure).


None: The outlet is not visible, and no light shows through the structure (next figure).


Some structures may have a “skylight”, an opening in the ceiling of the structure that lets in natural light. Skylights may be grates, openings in the median of the road, or other structures. Surveyors should write in the type of structure that makes up a skylight if present.

Appendix B: Example Application of the Turtle Crossing Rubric to an Existing Culvert

The existing culvert conditions may be viewed in the pictures below.

INLET

OUTLET

LINE OF SIGHT

VIEW OF ROAD

In the following tables, from the turtle mortality risk rubric, the shaded cells are those applicable to the culvert for this example (figures on previous page).

Question #1: Is the culvert passable?

Variable	Not Passable if any of the following…	Example Site Data
Presence of screens	Yes	No
Width of structure inlet	< 2.0 ft	3.8 ft
Outlet drop	> 0.0 ft	0.0 ft
Presence of other blockages	Yes	None

Outcome: YES, culvert is passable

Question #2: Is it easy to access the road?

Variable	Low Risk +1pt	Med Risk +2pts	High Risk + 3pts	Example Site Data	Points
Embankment slope upstream (US)	<1:1	1:1 to 1:2	>1:2	1: 1.75	2
Embankment slope downstream (DS)	<1:1	1:1 to 1:2	>1:2	1:3	3
Fence or wall (US)	Turtle-proof	Present	Not present	Not present	3
Fence or wall (DS)	Turtle-proof	Present	Not present	Not present	3
Riparian continuity (US)	-	No US continuity	US continuity	US continuity	3
Riparian continuity (DS)	-	No DS continuity	DS continuity	DS Continuity	3
Road Length (US)	<50ft	50-100ft	>100ft	40 ft	1
Road Length (DS)	<50ft	50-100ft	>100ft	81 ft	2
Nesting habitat	No nesting habitat US nor DS	Nesting habitat US or DS	Nesting habitat US and DS	No nesting habitat US nor DS	1

Total points: 21

Total points < 18 = Road not easily accessible
Total Points > 18 = Road is easily accessible

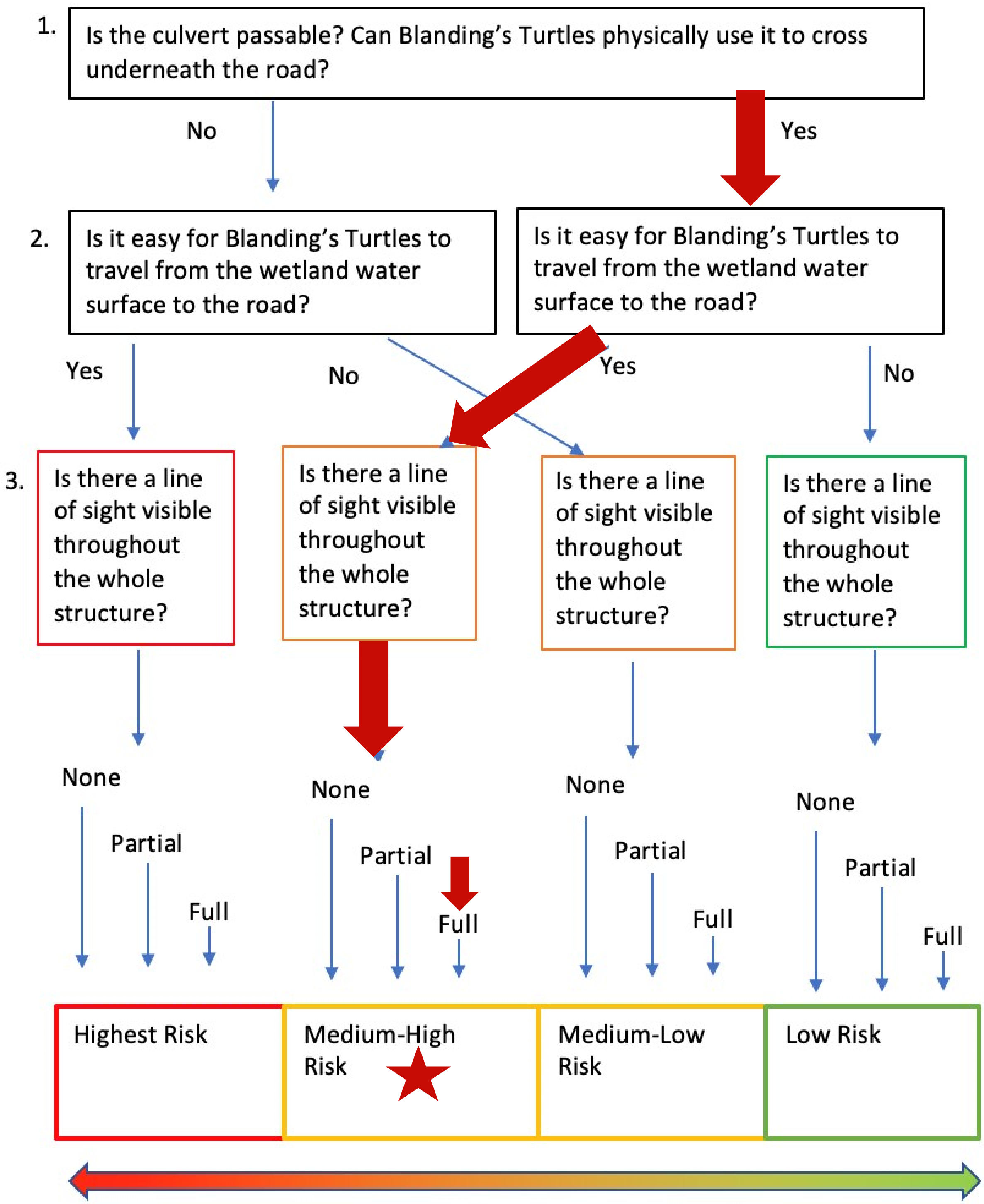
Outcome: YES, the road is easy to access

Question #3: What is the line of sight?

Outlet is completely visible from inlet

There is enough light in the structure to see the walls of the culvert and the surface of the water

Outcome: FULL, looking through the culvert there is an abundance of light shining through the other side of the culvert such that the inside of the structure is visible.



Final outcome: Following the above flowchart, this culvert would fall into the "Medium-High Risk" category

Appendix C: Reducing Road Mortality and Creating Safe Road Crossings for Blanding's Turtles in New Hampshire

The intersection of wildlife and the human-built environment has created many vulnerabilities for animals, such as road mortality and habitat fragmentation. Roads, highways, trails, and other transportation corridors designed for vehicles are some examples of how infrastructure can cause fragmentation of habitats. When roads cut through or separate areas of land, they create interruptions in the migration and movement patterns of wildlife that use that habitat. This also occurs when roads intersect with wetlands and streams and prevent the aquatic organisms that use and live in these water bodies from migrating across the whole expanse of the wetland or from moving up or down the stream. For semi-aquatic organisms, wildlife that uses a habitat complex of both aquatic territories and dry land during their life cycle, roads and other infrastructure can be a nearly impossible feature to avoid during their migrations through and between habitat types. At the intersections between roads and water bodies, from here on referred to as road crossings, there are often structures such as culverts or bridges engineered to allow water to pass under the road for hydraulic connectivity. Many of these structures are designed as hydraulic passages only, but modifications can also allow wildlife to pass through, restoring habitat connectivity and eliminating the need for semi-aquatic animals to cross over the road and face potential road mortality. When these structures are adequately designed for successful wildlife passage, they are determined to have full AOP (Aquatic Organism Passage) in contrast to road crossings that prevent semi-aquatic animals from passing successfully through the structure (no AOP).

Many semi-aquatic organisms benefit from efforts to restore full AOP to existing stream crossings. Of the organisms that benefit from restored connectivity, animals that migrate as part of their life cycle are especially targeted for these restoration efforts: this includes many fish species, such as trout, American shad, and river herring, as well as amphibians and reptiles, including turtles. The focus of this literature review and the associated project is the Blanding's Turtle, a semi-aquatic species that has experienced population declines in the last decade and is often the victim of road mortality. Blanding's Turtles are not federally listed as an Endangered Species but are listed as Endangered or Threatened in 9 out of the 15 states their range expands across. In New Hampshire, the specific focal region for this study, Blanding's are labeled as a State Endangered Species. This designation means that their "take" is prohibited, which includes any harm, injury, harassment, or killing of this species. The New Hampshire Endangered Species Act also allows the state to manage conservation programs for threatened and endangered species that may include the acquisition of land or aquatic habitat.

The objective of this literature review is to explore the specific vulnerabilities of the Blanding's Turtle in relation to road mortality, as well as what barriers and dangers exist during their migrations across the built infrastructure. Optimal conditions for retrofitting and replacing road crossing infrastructure and other measures to increase Blanding's ecological success and population survivability will be examined. It should be recognized that he best fit design will be extremely dependent on the project type and the project area. For example, a project that is repairing existing infrastructure will not have the same level of opportunity to improve turtle passage as might a replacement.

Blanding's Turtle Population

The Blanding's Turtles range consists of two genetically distinct populations. The western population covers much of Midwest America including Nebraska, Minnesota, Iowa, Michigan, Wisconsin, Illinois, Indiana, parts of Ohio, and the southern ranges of Ontario. An eastern population located in the Northeast ranges from northern Massachusetts, through southeastern New Hampshire, Maine, and southern parts of Nova Scotia. In New Hampshire, Blanding's Turtles are located in the southeast region of the state (Figure C1).

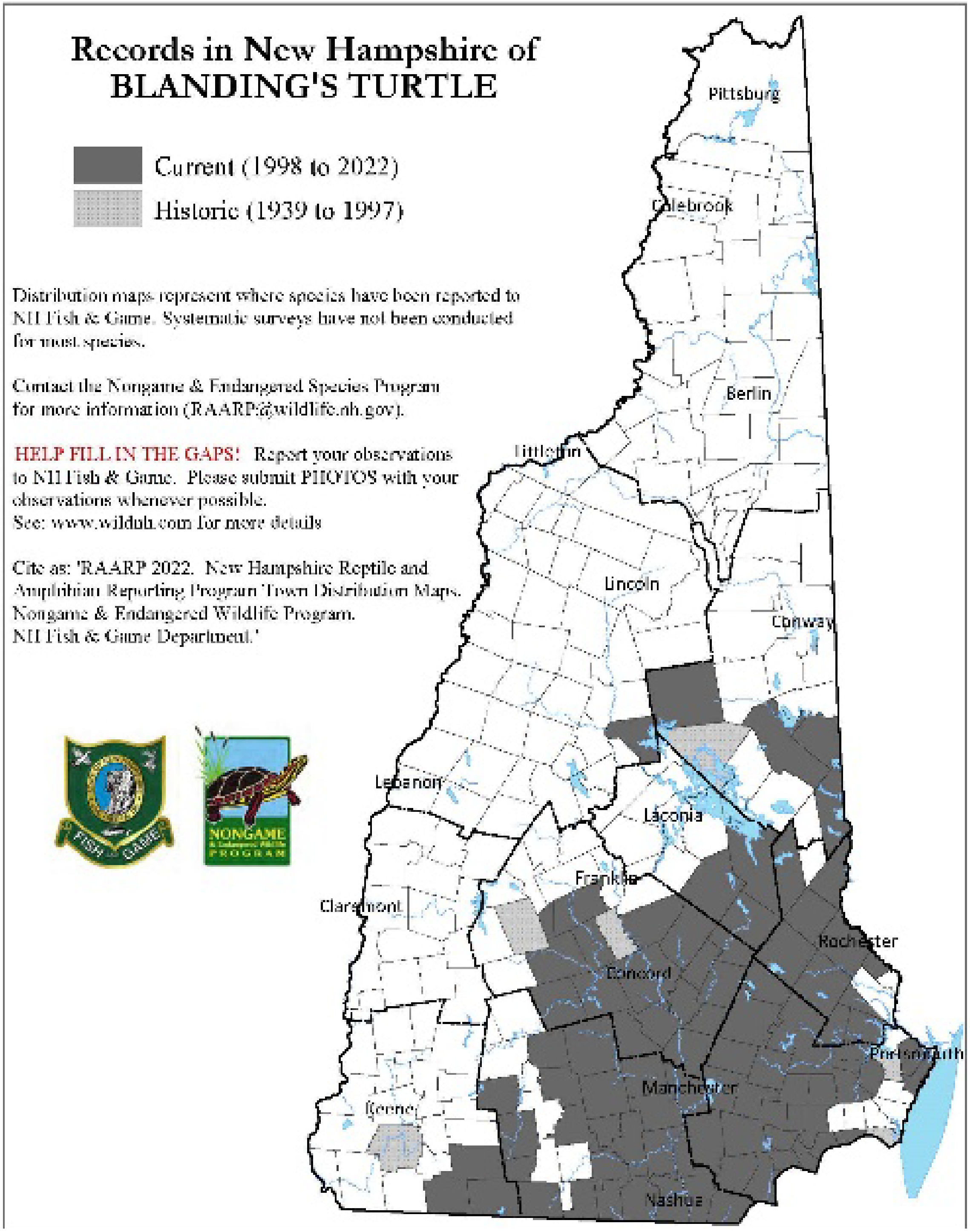


Figure C1. Blanding's Turtle range in New Hampshire. RAARP 2021. Source: New Hampshire Reptile and Amphibian Reporting Program Town Distribution Maps. Nongame & Endangered Wildlife Program. NH Fish & Game Department.

https://www.wildlife.state.nh.us/nongame/documents/blandingsturtle.pdf

Across both ranges, Blanding's populations are declining. In the Northeast, these populations are generally isolated and small, with the largest known populations numbering 450 and 85, but the majority of populations likely number less than 50 adults (Compton 2007). Though Blanding's migration routes can exceed 3km, it is understood that these populations are generally bounded by major roads, making inter-population mating or interaction unlikely. Compton (2007) reports that a single population viability model from 2000 exists for Northeastern populations of Blanding's Turtles in an unpublished Maine Department of Inland Fisheries and Wildlife report. The study uses a quasi-extinction threshold of 50 adult females. Compton concludes that at the time of publication, most of the Northeastern populations of Blanding's are quasi-extinct, meaning the species is effectively extinct (Compton 2007).

Compton (2007) also reports that in another unpublished study of Blanding's populations in Maine, populations in wetlands closer to roads were observed to be smaller than populations further away from roads, potentially suggesting that nearness to roads is associated with more rapid population decline in part to threats from road mortality.

Blanding's Turtles Life History

In populations such as the Blanding's Turtle where current numbers are already low, even small annual rates of adult road mortality can have damaging impacts on overall population survivability– especially for species with an average of 37 years between generations. Blanding's Turtles are a long-lived species, with adults aging to over 80 years old (Congdon et al. 2011). At this rate of maturation, females do not reach sexual maturity until 14-20 years (Hamernick et al 2020, Compton 2007). The slow rate of aging, sexual maturity, and production of offspring makes Blanding's Turtles a species with a slow generational turnover. This life history trait makes Blanding's more vulnerable to steep population declines with the presence of a threat like road mortality. A small annual percentage, even 1%, has a destructive effect on the long-term stability of the Blanding's population.

Targeted efforts to reduce road mortality may preserve a higher number of Blanding's adults that will then enable the population to continue. One objective of this study is to examine the efficiency and effectiveness of potential management strategies to mitigate road mortality.

Blanding's Turtle Habitat

The Blanding's Turtle is a semi-aquatic species that migrates between wetlands and uplands during their nesting and mating season. Their migration within a habitat complex makes this species especially vulnerable to road mortality in comparison with species that remain in the same habitat type for the duration of their life history. Road mortality is a leading threat to freshwater turtles

in North America, and Blanding's Turtles are especially vulnerable as a species that uses and crosses through multiple habitat types (Heaven et al. 2019).

Blanding's use wetlands as their primary habitat for mating, foraging, and basking. They also spend cold months, often November to April, hibernating by burying in the substrate of wetlands (Harper et al. 2014). The wetland in which they spend the majority of this time is often referred to as their 'resident wetland' and is where they return after migratory journeys. Both males and females use upland habitats for migrating between different wetlands areas, and females will use uplands as nesting areas. Human-disturbed areas are likely to make good nesting sites for Blanding's such as the side of a dirt road, a plowed agricultural field, or a gravel pit (Harper et al. 2014). Blanding's Turtles can nest anywhere from 2.0m to >1km away from the nearest wetland, which is often not the female's resident wetland (Harper et al. 2014, Compton 2007).

Blanding's Turtle Movements

The main active season for the Blanding's occurs between April and November, with two peak times in June/July and Sept/Oct (Beaudry et al. 2010). Male and female Blanding's Turtles have different movement and migration patterns. Through the reporting of multiple studies, it is evident that male Blanding's Turtles move more frequently and more consistently, but across lesser distances (Beaudry et al. 2010, Refsnider and Linck 2012, Hamernick et al. 2020). Female Blanding's Turtles, in contrast, move less consistently but travel further distances overall.

Gravid female Blanding's are known to move longer distances during pre-nesting movements than at any other time, averaging a minimum of 1851m (Hamernick et al 2020, Refsnider & Linck 2012). During this nesting season, female Blanding's Turtles have been reported to make more road crossings than any other season. In Refsnider & Link's study, they found that 59% of females crossed roads during this nesting foray, averaging 2.4 crossings per individual (Refsnider & Linck 2012). Walston also reports on road crossing observations, stating that in their study, the majority of females crossed a road at least once, and that specifically in New Hampshire, females crossed roads four times more than their male counterparts (Walston 2015).

Threats Associated with Road Crossing

Utilization of a large home range including numerous wetlands and uplands with many crossed by roads makes Blanding's particularly vulnerable to road mortality as they migrate throughout the mating and nesting seasons which typically occur in early June to early July in the Northeast region (Beaudry et al. 2010). Roads can bisect wetlands and are often a barrier between wetlands and uplands. **Road mortality is the leading threat to freshwater turtles, including the Blanding's (Heaven et al. 2019).** In addition to the threat of road mortality, the presence of roads leads to habitat fragmentation and genetic isolation of subpopulations. When migration movements are impeded by road and road mortality, the genetic diversity that Blanding's may be seeking through their long migrations is reduced.

In New Hampshire, Blanding's turtle range overlaps with counties seeing the highest human population growths in the state. The New Hampshire population is projected to grow by 358,000 people in the years between 2000 and 2025, increasing the need for transportation infrastructure and development, and resulting in more traffic (Innes et al. 2008). As development and road construction increase, so does the threat of road mortality and population decline for Blanding's Turtles.

Stream Crossing Structures

Blanding's Turtles are more likely to successfully and safely pass through a stream crossing structure if a few key parameters are met: 1) there is a full line of sight throughout the structure with ample lighting, 2) the openness ratio is >0.82^2 ft, 3) the bottom of the crossing consists of flat, organic materials, and 4) there is slow moving water with a consistent grade at the inlet and outlet.

In 2015, a study tested the effects of various structural factors on successful passage, introducing the importance of light and concluding that light may be critical to passage success (Sievert and Yorks 2015). In the study, only 8% of Blanding's passed through dark tunnels, while 100-75% brightness produced an 89% success rate (n=53). They claim that artificial overhead lighting may work as painted turtles responded favorably, though no mention of Blanding's specifically. Light from a median reportedly had little effect on the success of passage when compared to a fully dark tunnel, and therefore just including this light source may not result in optimal passage success. One team suggests including grated tops across a structure, stating that these openings let both light and moisture in which may encourage Blanding's passage (Heaven et al. 2019). Similarly, another team also suggests the installation of skylights for turtle crossing (Taylor et al. 2014). In their study, four wildlife culverts were installed, about 50 meters long, with three 0.6 meter square catch basin skylights, and during monitoring, ten Blanding's Turtles were observed successfully using the crossing. Taylor et al. (2014) recommend these skylights, stating that Blanding's and other turtles were observed basking on the stones in the culvert that were warmed by the sunlight.

The size of the crossing structure is also vital to a successful passage. Sievert claims that the openness ratio is an indicator of the success of passage when lighting is low or dim: the larger the ratio, the more turtles passed through, despite no lighting present. This ratio is measured by dividing the area of the opening (ft^2) by the length of the crossing (ft). Massachusetts Department of Transportation (MassDOT) issued a report in 2010 with guidelines for wildlife crossing structures. Their guidance suggests a minimum openness ratio of >0.82 ft to be effective, though a ratio > 2.45 ft would be optimal. MassDOT also offers guidance for the width of the structure, stating that a width of 1.2 times the bankful (if the water body is a river) would be optimal, with a minimum width of 5 ft. The height issued by MassDOT should be no less than 4ft.

Gunson et al. found that Blanding's Turtles "reliably" crossed through a 1.8m diameter corrugated steel culvert that was 25 meters long and half-full of water (Gunson et al. 2016). It is of note that the openness ratio of such a culvert is well below the MassDOT suggestion of 0.8 ft minimum. Blanding's in this study did not show a preference for culvert size, but show a preference for light, reinforcing Sievert's claims of brightness being critical. In this study, Blanding's crossed through tunnels with 75% ambient light emitted from an open or grated top and suggested that these tunnels be installed with a downward incline to allow drainage out. Gunson et al. maintain that the maximum length for a tunnel should be 25 m (Gunson et al 2016).

For crossing bottoms, there is consensus amongst literature that a flat, organic bottom is more likely to produce a successful passage. Minnesota Department of Natural Resources (MNDNR) and others suggest flat bottoms, filled with natural substrate (Minnesota Department of Natural Resources 2008, Gunson et al. 2016). Box culverts and round culverts should be embedded in order to allow natural materials to cover the bottom along the length of the tunnel. Taylor et al (2014) report that the topsoil used in their tunnels with skylight was a good choice and did not wash out despite the open top. They also suggested placing logs in the tunnel to mimic natural conditions (Taylor et al 2014). In areas with riprap, MNDNR recommended filling the stones with smaller pieces of gravel to allow for easier turtle passage. Presumably, filling large, jagged gaps will make the surface area slightly more consistent and easier for small wildlife to traverse.

In order to fulfill these requirements, a box culvert is often preferential to the installation of a round or even elliptical culvert. An embedded box culvert with a natural substrate bottom is prioritized over an arch tunnel with flat, natural bottom, which itself is prioritized over a round embedded tunnel (Seburn and Gunson 2016).

Fencing and Guide Walls

A well-designed culvert or other forms of crossing are most successful in facilitating safe crossing for wildlife when paired with fencing or guide walls (Woltz et al. 2008). One paper asserts that using fencing around a culvert increases the use of the culvert (Huijser et al. 2017). A 2021 study states that using a recycled plastic fence reduced road mortality by 90% in comparison to a section of road that did not have fencing present (Read and Thompson 2021). A Florida-based study claims that 95% of animals were diverted away from the highway when a 0.4-meter tall fence was installed at a road crossing (Aresco 2005).

The four studies above combined indicate that any road barriers or fencing that prevents wildlife from crossing the road in the vicinity of a road crossing is more successful when: 1) the ends of the fence are curved back towards the wetland/stream, 2) the fencing is embedded in the ground, 3) the fence has a lip on the top, and 4) when the barrier/fencing is consistently maintained.

Curving the ends of the fence attempts to prevent animals from simply walking around the fence (Aresco 2005, Taylor et al. 2014, Heaven et al. 2019). Heaven et al. placed 220 meters of continuous fencing on either side of a culvert intended for wildlife passage. In this study, there was no increased turtle mortality at the ends of the fencing, which was curved back towards the wetlands, suggesting that there was little to no circumnavigation of the fence associated with the curved edges. Taylor et al. (2014) also erected fencing with curved ends, in a U-shape, in order to prevent circumnavigation. The 2005 by Aresco study that presented a statistic of a 95% reduction in animal crossing used a fence that curved perpendicular to the road, back towards the water body. Read and Thompson (2021) installed fencing that extended beyond the wetland edge and curved back towards itself: however, the authors noted that all turtles that were victims of road mortality were located at the ends of the fences, despite the angling of the fence. They identify gaps in fencing and the edges of fences as high-vulnerability areas and urge further research to investigate effective reductions of mortality at these spots (Read and Thompson 2021).

In addition to preventing animals from walking around the fence, efforts have been made to prevent wildlife from crawling both under and over the fence. Two separate teams suggest embedding fences, especially chain link fences, in the ground to prevent them from curling upwards with time and wear and creating a hole (Paulson 2010, Read and Thompson 2021). Paulson also suggests reinforcing the bottom of a chain link fence with finer mesh or chain link to prevent burrowing. Additionally, many teams suggest using a lip at the top of the barrier or fence to prevent animals from climbing over (Woltz et al. 2008, Taylor et al. 2014, Read and Thompson 2021). Taylor et al. suggest the lip should be angled at 45° and Read and Thompson state it should be 10 cm in length. Throughout these papers, various fence heights have been used, tested, and reported to be successful. In the Woltz study, a 0.6m tall barrier was able to prevent multiple turtle species from crossing, and Paulson recommends a minimum height of 0.2m based on a turtle monitoring project. Read and Thompson found that road mortality of Blanding’s Turtles decreased by 90% when a 0.41m fence was placed along the road in comparison to control areas where no fence was used.

Consensus was formed across recent papers that examined the effectiveness of fencing to reduce turtle road mortality. Fencing or barriers need maintenance to remain an effective measure against road mortality (Read and Thompson 2021, Paulson 2010, Huijser et al 2017). Read and Thompson are most specific, suggesting repairs to fencing be done in early spring before the peak migratory period as most of the roadkill recorded in their study occurred between the months of May and June.

The results from these case studies combined present a strong argument for the installation of fencing along hot spots in turtle road crossings due to their success in statistically reducing road mortality.

Signage, Curbs, and Exclusion Gates

A few other infrastructure pieces crop up in the literature surrounding safe crossing, including signage, curbs, and beaver exclusion gates. Signage is commonly considered a low-cost, low-hanging fruit endeavor that has shown success in reducing road mortality. Since migratory peaks last May – July, temporary signage should be placed during this time period instead of year-round (Beaudry et al 2010). Having temporary signage instead of permanent may combat driver habituation and result in reduced speeds every spring and summer.

Curbs can unwittingly trap turtles on roads if they are too steep for a turtle to climb over. MNDNR suggests a ditched edge of the road instead of traditional 90-degree curbing. If curbing is needed, MNDNR suggests a max height of 4 inches and a slope no steeper than 3:1 to allow Blanding's to climb up and off the road if they are crossing it.

Unfortunately for aquatic organisms looking to use culverts as mechanisms of travel, some culverts are screened or blocked with gates in an attempt to prevent beavers from building a dam or obstructing the water flow with sticks. In these cases, McCann (2017) suggests that these beaver-exclusion gates be modified so that turtles can still pass through without impediment. Two designs are prioritized in this paper: a turtle door or a T-pipe. In these designs, two 90-degree angles make it difficult for beavers to drag sticks in but allow turtles to make these corners and pass through the culvert. Another option is a one-way door, though this is less desirable because it prevents turtles from passing both downstream and upstream (McCann 2017).

Conclusion

Myriad studies have tested several parameters to determine the best choice of culvert to allow wildlife, specifically Blanding's Turtles, safe passage where transportation corridors cross migratory paths. Facets of road crossing designs that may increase the success of Blanding's crossing span structural dimensions, presence of light, substrate material, and fencing (See Table C1). Considering these variables when designing road crossings–during restoration projects or new builds– may reduce rates of Blanding's Turtle road mortality. The existing body of research on this topic has greatly informed our understanding of Blanding's Turtle road mortality risk and opportunities to mitigate this risk and will be invaluable in helping NHDES, UNH, and NHF&G preserve the safety of Blanding's Turtles across New Hampshire.

Table C1: Variables and their Values to Increase Successful Blanding's Turtle Passage at wetland-road crossings

Variable	Optimal Conditions	Impact
Fencing and Guide Walls	Fences with edges curved in and an angled lip at the top, embedded in the soil, consistently maintained	Directs wildlife back towards waterbody and away from the road
Line of Sight (LOS)	Full LOS, able to see light all the way through the crossing; open top design	Increases success of passage as light increases
Openness Ratio (cross section/ length)	General: >0.82 ft Optimal: >2.45 ft	Increase success of passage as ratio increases
Width	1.2 x bankful width; minimum 5 ft	Smaller width increases water velocity; smaller width decreases openness ratio
Height	Minimum 4 ft	Taller structures allow more light; increase openness ratio
Length	Maximum 80 ft	Longer length decreases openness ratio
Crossing Bottom	Organic substrate; natural banks	Mimics preferred habitat
Water Velocity	Slow	Mimics preferred habitat
Water Depth	Shallow	Mimics preferred habitat

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