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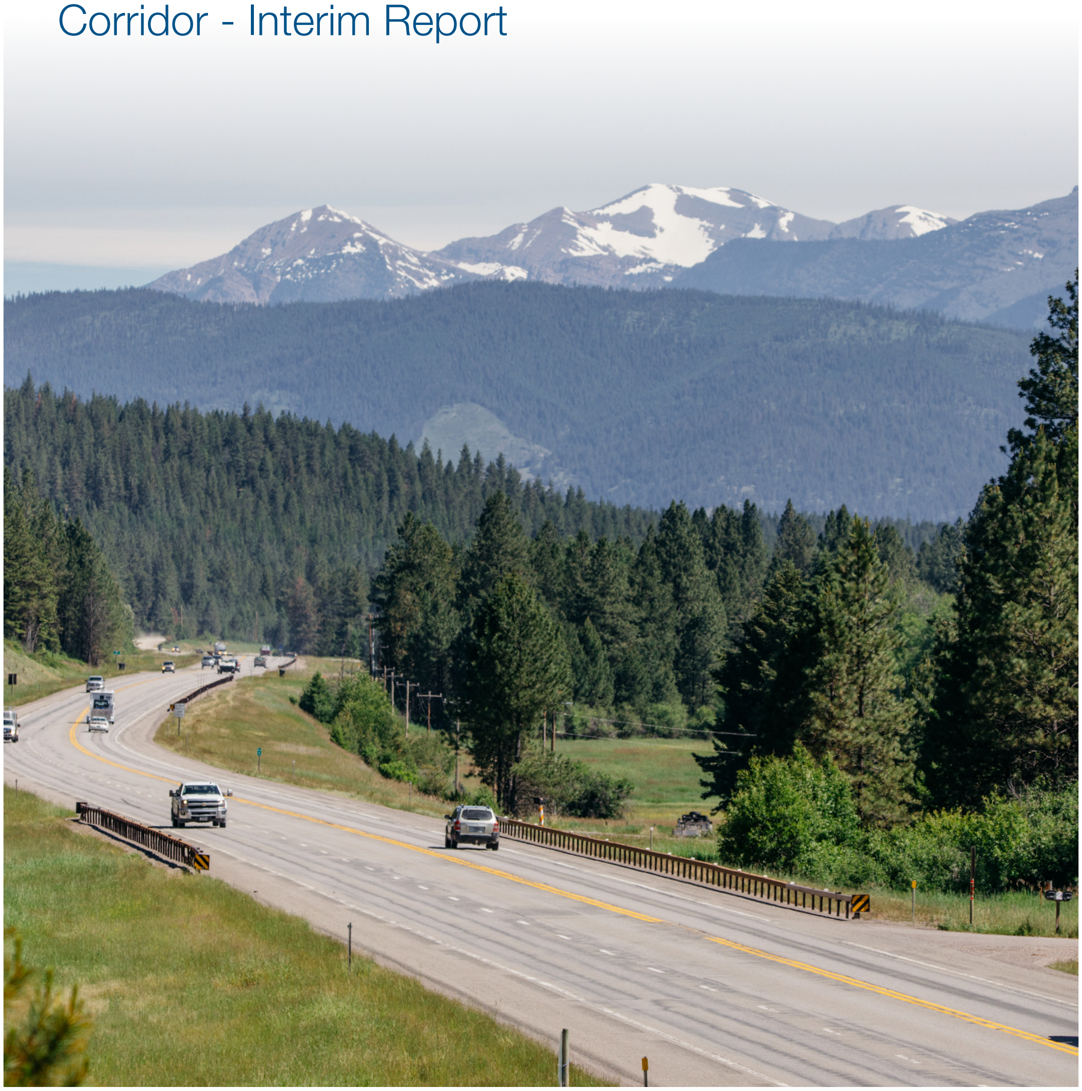
Research

EFFECTIVE WILDLIFE FENCES THROUGH BETTER FUNCTIONING BARRIERS AT ACCESS ROADS AND JUMP-OUTS

FHWA/MT-23-005/9923-808

Electrified Barriers Installed on Top of Wildlife Guards to Help Keep Large Wild Mammals Out of a Fenced Road Corridor - Interim Report



December 2023

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THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

December 2023

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Electrified Barriers Installed on Top of Wildlife Guards to Help Keep Large Wild Mammals Out of a Fenced Road Corridor

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16. Abstract
Most wildlife mitigation measures along highways are aimed at improving human safety, reducing direct wildlife mortality, and providing safe crossing opportunities for wildlife. Fences in combination with wildlife crossing structures are the most effective combination of mitigation measures to achieve these objectives. For fences to reliably reduce collisions with large wild mammals by 80% or more, at least 5 kilometers (3 miles) of road length needs to be fenced, including a buffer zone that extends well beyond the known hotspots for wildlife-vehicle collisions. Collisions that still occur within the fenced road sections tend to be concentrated near the fence-ends. In addition, gaps in fences, including at access roads, can result in concentrations of collisions inside fenced road sections. Gates are commonly used at gaps in the fence at low traffic volume access roads, but they are often left open allowing wildlife to access the road corridor. While cattle guards or wildlife guards can be effective for some ungulate species, double wide cattle or wildlife guards consisting of round bars or bridge grate material, situated above a pit, are generally recommended for ungulates. However, such guards are not a substantial barrier for species with paws, including many carnivore species. Electrified mats or electrified guards can be a barrier for both ungulates and species with paws, but to prevent animals from jumping across the mat, they need to be 4.6-6.6 m (15-22 ft)) wide. For this project, a combination of wildlife guards and electrified barriers on top of these wildlife guards was evaluated. Both electrified mats that were tested (Crosstek and BS Fabrications) on top of existing wildlife guards resulted in a near absolute barrier for both ungulates and species with paws (97.9% barrier for the 2 deer species combined, 100% barrier for coyotes and black bears); an improvement to a wildlife guard only without an electrified mat (89.3% for the 2 deer species combined, 54.5% barrier for coyotes and 45.5% barrier for black bears). Based on the images, there is evidence that a shock is delivered to the animals that touch the electrified mats and that most of the animals respond by returning to the habitat side of the barrier. Specifically for bears, if it was not for the electrified barriers, likely at least 3 black bears and 1 grizzly bear would have crossed into the fenced road corridor where they would have been exposed to vehicles.

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About the Western Transportation Institute

The Western Transportation Institute (WTI) was founded in 1994 by the Montana and California Departments of Transportation, in cooperation with Montana State University. WTI concentrates on rural transportation research; as stewards and champions of rural America, WTI also has a strong interest in sustainability. WTI research groups create solutions that work for clients, sponsors, and rural transportation research partners. WTI Research Centers include the Montana Local Technical Assistance Program, the National Center for Rural Road Safety, the Small Urban, Rural and Tribal Center on Mobility, the Federal-Public Lands Transportation Institute, and the West Region Transportation Workforce Center.

About the Small Urban, Rural and Tribal Center on Mobility

The mission of the Small Urban, Rural and Tribal Center on Mobility (SURTCOM) is to conduct research and provide leadership, education, workforce development and technology transfer in all transportation-related aspects of mobility for people and goods, focusing specifically on small urban, rural and tribal areas. Member institutions include the Western Transportation Institute at Montana State University, the Upper Great Plains Transportation Institute at North Dakota State University, and the Urban and Regional Planning program at Eastern Washington University.

Disclaimer

Alternative Format Statement

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STANDARD CONVERSION TABLE – ENGLISH TO METRIC				
Symbol	To convert from	Multiply by	To determine	Symbol
		LENGTH		
IN	inch	25.4	millimeters	mm
FT	feet	0.3048	meters	m
YD	yards	0.9144	meters	m
MI	miles	1.609344	kilometers	km
		AREA		
SI	square inches	645.16	square millimeters	mm^2
SF	square feet	0.09290304	square meters	m^2
SY	square yards	0.83612736	square meters	m^2
A	acres	0.4046856	hectares	ha
MI^2	square miles	2.59	square kilometers	km^2
		VOLUME		
CI	cubic inches	16.387064	cubic centimeters	cm^3
CF	cubic feet	0.0283168	cubic meters cubic	m^3
CY	cubic yards	0.764555	meters liters	m^3
GAL	gallons fluid	3.78541	liters	L
OZ	ounces	0.0295735	cubic meters	L
MBM	thousand feet board	2.35974		m^3
		MASS		
LB	pounds	0.4535924	kilograms	kg
TON	short tons (2000 lbs)	0.9071848	metric tons	t
		PRESSURE AND STRESS		
PSF	pounds per square foot	47.8803	pascals	Pa
PSI	pounds per square inch	6.89476	kilopascals	kPa
PSI	pounds per square inch	0.00689476	megapascals	Mpa
		DISCHARGE		
CFS	cubic feet per second	0.02831	cubic meters per second	$m^3/_s$
		VELOCITY		
FT/SEC	feet per second	0.3048	meters per second	m/s
		INTENSITY		
IN/HR	inch per hour	25.4	millimeters per hour	mm/hr
		FORCE		
LB	pound (force)	4.448222	newtons	N
		POWER		
HP	horsepower	746.0	watts	W
		TEMPERATURE		
˚F	degrees Fahrenheit	5 X (˚F – 32)/9	degrees Celsius	˚C
		DENSITY		
lb/ft^3	pounds per cubic foot	16.01846	kilograms per cubic meter	kg/m^3
		ACCELERATION		
g	freefall, standard	9.807	meters per second squared	m/s^2

TO CONVERT FROM METRIC TO ENGLISH, DIVIDE BY THE ABOVE CONVERSION FACTORS.

1 Introduction

1.1 Background

Most wildlife mitigation measures along highways are aimed at improving human safety, reducing direct wildlife mortality, and providing safe crossing opportunities for wildlife (e.g., Ford et al. 2009, van der Grift et al. 2017). Fences in combination with wildlife crossing structures are the most effective combination of mitigation measures to achieve these objectives (Clevenger & Waltho 2000, Rytwinski et al. 2016, Huijser et al. 2021). For fences to be reliably reducing collisions with large wild mammals by 80% or more, at least 5 kilometers (3 miles) of road length needs to be fenced, including a buffer zone that extends well beyond the known hotspots for wildlife-vehicle collisions (Huijser et al. 2015, Huijser et al. 2016a). Collisions that still occur within the fenced road sections tend to be concentrated near the fence-ends (Huijser et al. 2016b, 2022, Plante et al. 2019). In addition, gaps in fences, including at access roads, can result in concentrations of collisions inside fenced road sections (Sawyer et al. 2012, Cserkész et al. 2013, Yamashita et al. 2021).

Gates are commonly used at gaps in the fence at low traffic volume access roads, but they are often left open allowing wildlife to access the road corridor (VerCauteren et al. 2009, Sawyer et al. 2012). While single wide cattle guards or wildlife guards (2.1-3.0 m) can be effective for some ungulate species (Huijser et al. 2015), double wide cattle or wildlife guards (4.6-6.6 m (15-22 ft)) consisting of round bars or bridge grate material, situated above a pit, are generally recommended for ungulates (Cramer & Flower 2017, Gagnon et al. 2020). However, such guards are not a substantial barrier for species with paws, including many carnivore species (Allen et al. 2013, Clevenger & Barrueto 2014, Huijser et al. 2015, 2016, Honda et al. 2020). Electrified mats or electrified guards can be a barrier for both ungulates and species with paws, but to prevent animals from jumping across the mat, they need to be 4.6-6.6 m (15-22 ft) wide. Combinations of electrified barriers and non-electrified guards are also possible (Gagnon et al. 2020).

1.2 Goals and objectives

For this project we investigated the effectiveness of two different types of electrified barriers on top of two existing wildlife guards at relatively low volume access roads.

The goals of this project are:

- To reduce the likelihood of large mammals, including both large ungulates (e.g., white-tailed deer or mule deer) and species with paws (e.g., black bears and grizzly bears), entering fenced road corridors at low volume access roads and thereby further improve human safety.
- To gain knowledge of how to keep an endangered species, i.e., grizzly bear, out of fenced road corridors at low volume access roads and to reduce direct road mortality.

The objectives of this project are:

- To install two different electrified mats on top of existing wildlife guards.
- To evaluate the barrier effect of the combination of wildlife guards and electrified mats in keeping ungulate species and bear species out of a fenced road corridor.
- To compare the barrier effect of the combination of wildlife guards and electrified mats to the barrier effect of wildlife guards alone.

The knowledge gained on the effectiveness of the mitigation measures associated with wildlife fences and modifications to these mitigation measures, is expected to have wide application for highways for which wildlife fences are considered. It may also prove to be particularly useful to US Hwy 93N for the adaptive management of the already mitigated road sections, and to help guide the design and future road reconstruction through the Ninepipe area (e.g., Adams et al. 2023). The objectives of this project are also consistent with the Memorandum of Agreement between the Federal Highway Administration, the Montana Department of Transportation, and CSKT (FHWA, MDT & CSKT 2000).

2 Methods

2.1 Study locations

Two locations were selected for the installation of electrified barriers on top of existing wildlife guards (Figure 1). These two locations meet the following criteria:

- They have an existing wildlife guard without additional barriers such as gates or fences across the wildlife guard.
- They are connected to a wildlife fence on both sides.
- They have very low traffic volume (estimated at less than 10 vehicles per day).
- They have very low vehicle speeds (estimated speed is less than 10 miles per hour).
- They have a known presence of large wild mammals in the surrounding area, both of ungulates (i.e., white-tailed deer and mule deer) and carnivore species (especially black bear) (Allen et al. 2013, Huijser et al. 2016b).
- Adjacent tribal land without houses. Access is restricted to tribal members or, people who graze their livestock on the adjacent lands, and people who purchase conservation permits.

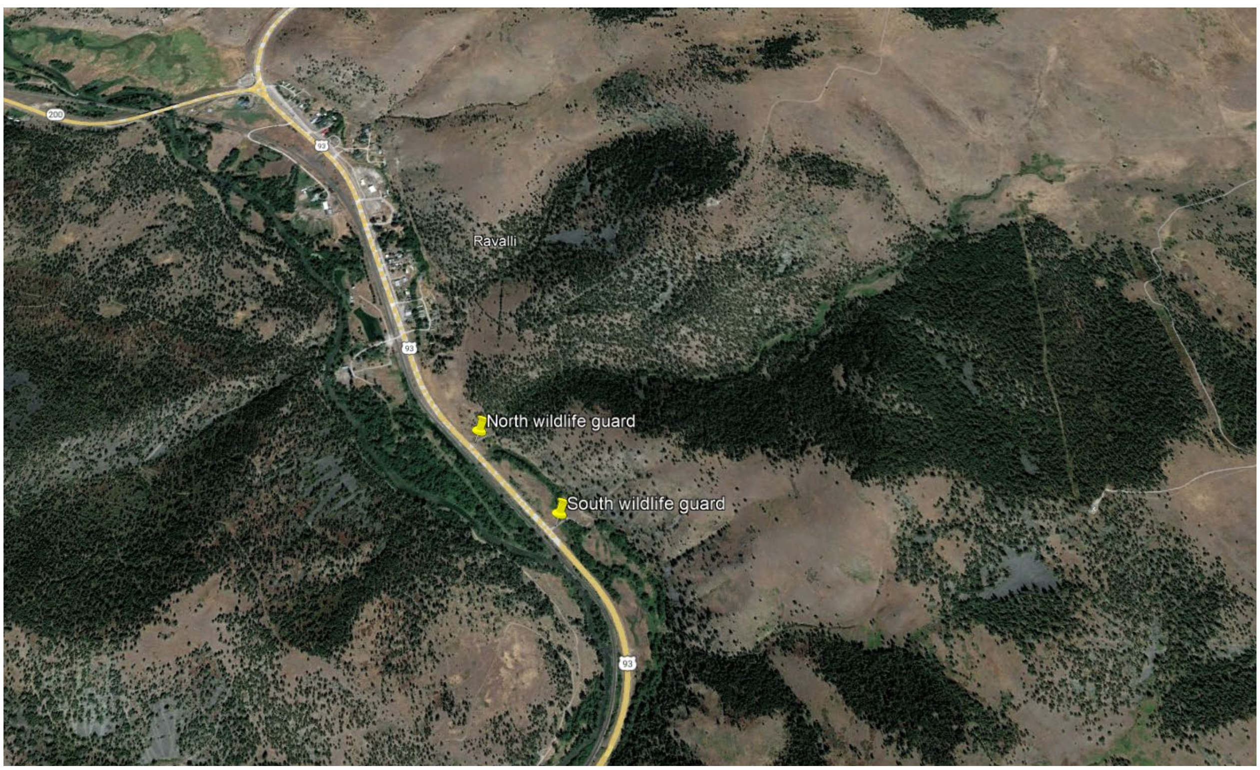

Figure 1: The two locations selected for the installation of an electrified mat on top of an existing wildlife guard, just south of Ravalli, Montana. Note that these are the same two sites that were part of the study by Allen et al. (2013).

2.2 Electrified mats

The following requirements applied to the electrified mats for the installation on top of the wildlife guards.

- They must be suited for very low traffic volume, e.g., perhaps a dozen vehicles per day at a maximum. The mats do not have to be suited for high traffic volume.
- They must be suited for very low traffic speeds, e.g., perhaps 5-20 MPH at a maximum. The mats do not have to be suited for high traffic speeds.
- They must be able to be combined with existing wildlife guards.
- They must be relatively low costs, e.g., thousands of US$ per location, not tens of thousands or hundreds of thousands.
- They must have a push button that temporarily turns off the electricity to allow people to pass with e.g., horses or dogs.
- They must be solar powered with a solar panel and a battery.

Based on these criteria, two designs for electrified mats were selected from two manufacturers (see Appendix A for dimensions):

- North wildlife guard: Crosstek, installed 20-23 May 2022 (Figure 2, 3). This barrier was 8 ft wide and consisted of 2 pairs of alternating positive and negative plates. Costs, including installation: US$ 11,250.
- South wildlife guard: BS Fabrications, installed 6 November 2021 (Figure 4, 5). This barrier was 4 ft wide and consisted of one positive plate in two parts. Costs, including installation: US$ 11,260.

Both mats had 2-3 ft of exposed bridge grate material on the habitat side of the wildlife guard before the start of the electrified barriers. This allowed wildlife that approached the wildlife guards and electrified mats to experience the grate before attempting to cross the electrified barrier.

Both mats had the exact same signs informing the public and road maintenance crews about the mat and they also had a push button that temporarily deactivated the mat (i.e., electricity turned off after pushing the button) (Figure 6, 7, 8). After about 1 minute the electricity came back on again. The signs and push buttons were on both the habitat and roadside of the wildlife barriers.

Figure 2: The installation of the electrified mat by Crosstek at the north wildlife guard, US Hwy 93, south of Ravalli, Montana.

Figure 3: The electrified mat by Crosstek covers the concrete edge around the pit, at the north wildlife guard, US Hwy 93, south of Ravalli, Montana.

Figure 4: The electrified mat installed by BS Fabrications at the south wildlife guard, US Hwy 93, south of Ravalli, Montana.

Figure 5: The electrified mat by BS Fabrications covers the concrete edge around the pit, at the north wildlife guard, US Hwy 93, south of Ravalli, Montana.

Figure 6: Push button for pedestrians to temporarily (about 1 minute) turn off the power.

Figure 7: Warning signs at the electrified mats for pets, horses, and snowplows.

Figure 8: The signs associated with an electrified mat on top of a wildlife guard. There is a set of signs on both the habitat side and the roadside.

2.3 Human safety

In general, the electrical characteristics (Voltage, Amperage, pulsing nature) of the electrified mats are similar to that of electric fences for livestock. These electrical features have been widely used for a long time, and they are generally considered safe for people and livestock. Depending on the type of electrified barrier, the peak voltage is between 5kV and 10kV under optimal conditions. The electrical current on electric fences and associated components is not constant. Fence energizers send electricity in pulses, with a frequency of about one pulse every second and pulse duration of approximately 3/10,000th of a second. The low pulse duration in combination with the one second "off time" between pulses make electric fences and associated components “safe”. This means that there is a very low potential for permanent injuries or deaths for large mammals and healthy people. However, an electric fence and associated components, including electrified mats, do have these considerations:

- While generally considered “safe” for large mammals and people, getting shocked is unpleasant and painful. The unpleasant experience leads to a “deterrent effect”.
- In very rare occasions, people or animals may get injured or die. The probability is extremely low, but not zero.
- People should not touch electric fences or associated components when the electricity is “on”. This is especially true for people with existing health problems, especially people with a heart condition, including implants that operate on a battery such as a pacemaker.
- Wearing shoes with thick rubber soles will reduce or eliminate the shock compared to being barefoot or wearing shoes with thin soles. In practice, wearing dry light hiking boots did not result in a shock from either electrified barrier at the study locations.
- Touching electrified components with your head should be especially avoided.
- Entrapment of people or animals should be avoided; people should be able to detach themselves from the electrified components. Entrapment leads to prolonged exposure to electric shocks. The design of electrified barriers should minimize the probability of entrapment.
- Vehicles (cars) can drive over electrified barriers without an issue as the tires insulate the vehicle and the people inside a vehicle. The same holds true for motorcyclists and bicyclists depending on how thick the tires are and as long as they stay upright on their bike. However, given that wearing light hiking boots did not result in a shock from either electrified barrier, getting shocked on a bicycle or motorcycle is very unlikely.
- Pets (e.g., dogs) and livestock, including horses, would receive the full shock. Pets and livestock, especially horses with a rider, should not be exposed to the electric current.

2.4 Effectiveness of the mats

In the winter of 2021-2022 the northern wildlife guard did not have an electrified mat installed yet. However, between 2 December 2021 and 19 May 2022 a wildlife camera (Reconyx PC 900) was installed on the habitat side. This camera recorded large wild mammals that approached the wildlife guard (without an electrified barrier) and that were potentially interested in crossing into the fenced road corridor. These data are a recent “reference” for the effectiveness of the electrified mats that were added later to the two wildlife guards.

After both electrified mats were installed, there were two cameras operational at each electrified mat; one on the habitat side and one on the roadside. In 2023 there were three cameras installed at each mat to better evaluate wildlife approaching and potentially interacting with the two electrified barriers and the wildlife guards. The effectiveness of the two electrified mats was investigated for a total of 282 days during the following periods:

- 23 May 2022 – 30 November 2022 (192 days)
- 14 April 2023 – 12 July 2023 (90 days)

We restricted the evaluation of the effectiveness of the electrified mats to these periods because:

- The electrified mats were specifically targeted at bears as wildlife guards without electrified mats are not a substantial barrier to bear species and other species with paws (see Allen et al. 2013). Bears are predominantly active during the summer (April - November) and they are rarely active during the winter (December - March).
- The solar panels and associated battery were not designed to be functional throughout the winter (low sunlight, reduced battery performance), and there was no snow removal from the electrified mats.
- Both electrified mats were installed and switched “on” during the periods described above, exposing the two barriers to similar environmental conditions during their evaluation.

The effectiveness of the barriers was expressed as a percentage:

$$Barrier\ effect\ (\%) = \left[\frac{N\_crossed\_barrier}{N\_approached\_barrier}\right]100$$

Animals that came within 2 meters of the edge of the wildlife guard were observed carefully as they may have been more motivated to cross the wildlife guard than animals that were observed at greater distance.

The researchers changed the memory cards in the cameras about once a month and changed the camera batteries about once every three months. Vegetation maintenance was conducted about once per month to reduce the probability of voltage and amperage drainage from the two mats, and to reduce the number of false triggers for the wildlife cameras.

3 Results

3.1 Human use of the wildlife guard and electrified barriers

In the 282 days that the two wildlife guards and electrified barriers were monitored, humans crossed the barriers predominantly by vehicle (Figure 9). The northern barrier (Crosstek, average of 0.91 crossings per day) received higher traffic volume than the southern barrier (BS Fabrications, average of 0.19 crossings per day). Humans not associated with a motorized vehicle were frequently seen using the push buttons that temporarily turned off the power to the electrified mats.

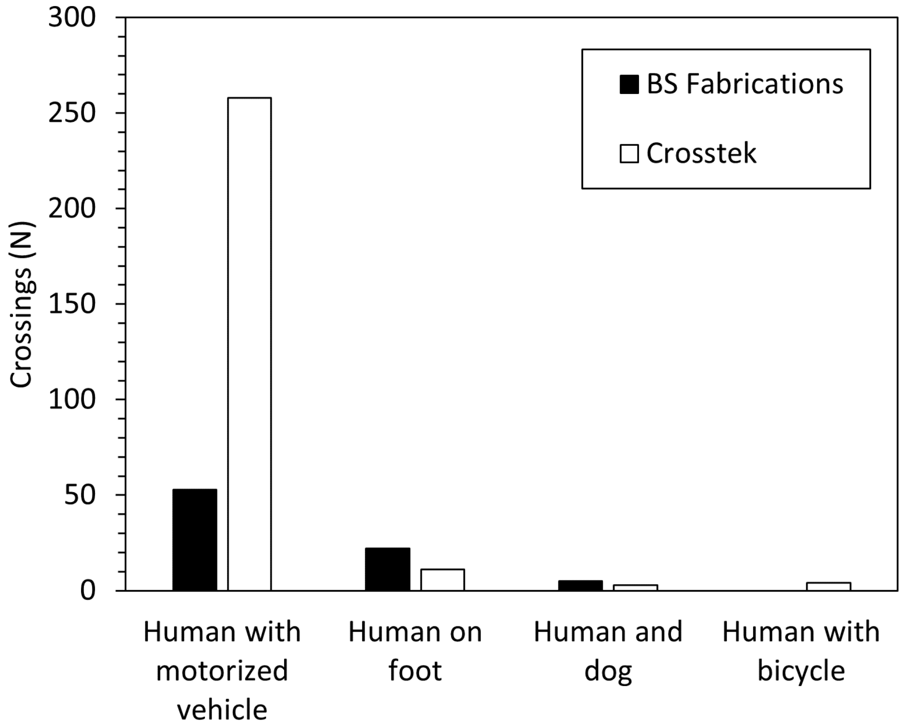

Figure 9: The number of detected barrier crossings by humans (excluding researchers), regardless of whether they left or entered the fenced road corridor.

3.2 Voltage electrified barriers

During the evaluation period, the two electrified barriers were almost always operational and typically had a voltage of about 10kV or higher (Appendix B). Voltage was measured regularly (see Appendix B), and action was taken when voltage was low or absent. However, since voltage was not measured every day, we could not calculate what percentage of the time the electrified barriers were fully operational. Regardless, low voltage or absent voltage did not result in animals breaching the two electrified barriers. There may have been 1 exception where a deer crossed into the fenced road corridor because of low voltage or a delayed delivery of the shock, but that was associated with snow accumulation on the electrified barrier rather than a problem with the equipment itself (see section 3.4).

3.3 Barrier effect wildlife guard without electrified mat

None of the white-tailed deer and mule deer that approached the wildlife guard on the habitat side and that came within 2 m of the wildlife guard crossed into the fenced road corridor (Figure 10). The wildlife guard was also an absolute barrier for coyotes, domesticated cats, and striped skunks. However, 50% of the 6 bobcats that approached the wildlife guard entered the fenced road corridor. All three bobcats that entered the fenced road corridor did so by walking on the exposed concrete edge of the pit (Figure 11).

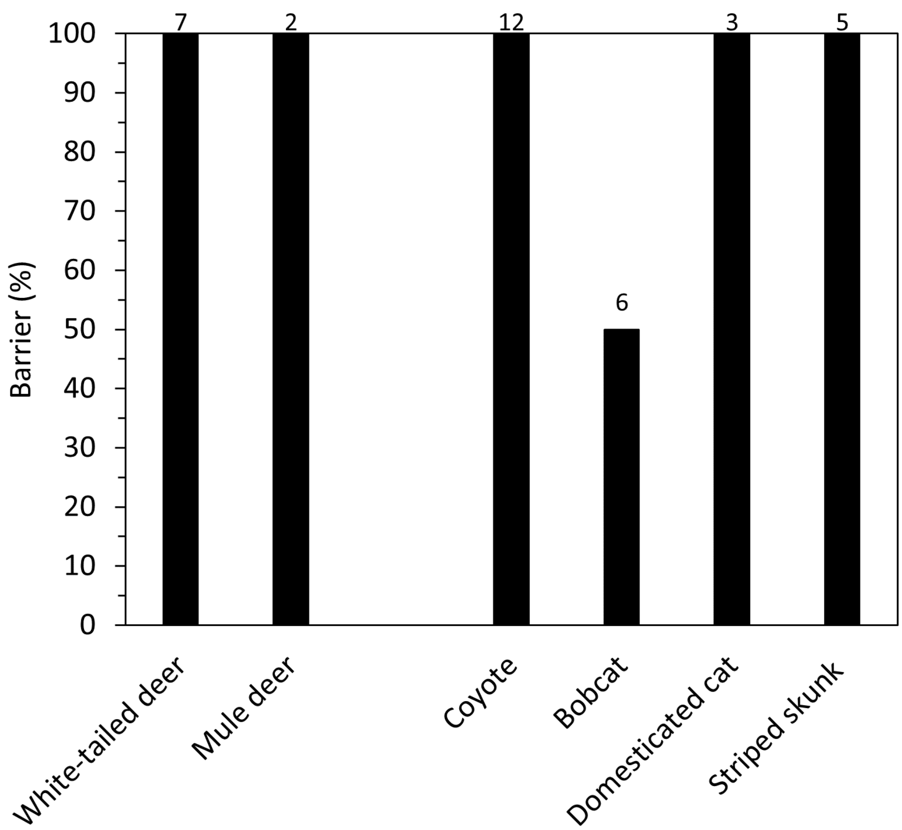

Figure 10: The barrier effect (%) for the different ungulate species (left) and species with paws (right) that approached the wildlife guard (without an electrified barrier) within 2 meters on the habitat side. The numbers on top of the bars are the sample size (i.e., the total number of animals that approached the wildlife guard on the habitat side and that came within 2 m of the wildlife guard).

Figure 11: A bobcat enters the fenced road corridor by walking on the accessible concrete edge of the pit under the grate of the wildlife guard. There is no electrified barrier installed yet at the time of the event.

3.4 Barrier effect wildlife guards with electrified mats

One of the 31 white-tailed deer but none of the 16 mule deer that approached the 2 wildlife guards on the habitat side and that came within 2 m of the electrified wildlife guards crossed into the fenced road corridor (Figure 12) (96.8% barrier for white-tailed deer, 100% barrier for mule deer, 97.9% barrier for the 2 deer species combined). The northern barrier (Crosstek) had 7 white-tailed deer and 2 mule deer approach the wildlife guard on the habitat side within 2 m. None of these animals crossed into the fenced road corridor (100% barrier for both deer species). The southern barrier (BS Fabrications) had 24 white-tailed deer and 14 mule deer approach the wildlife guard on the habitat side within 2 m. One white-tailed deer but none of the mule deer crossed into the fenced road corridor (95.8% barrier for white-tailed deer, 100% barrier for mule deer). Based on the images, the one white-tailed deer that entered the fenced road corridor still got shocked, but there seems to have been a delay because of the snow, likely contributing to the animal jumping forward rather than backing off (Figure 13).

The electrified wildlife guards were an absolute barrier (100%) for domesticated cattle, black bears, grizzly bears, coyotes, bobcats, striped skunks, and eastern fox squirrel. Based on the images, at least 2 of the 4 black bears were shocked (Figure 14), and the one grizzly bear was also shocked (Figure 15). There was one additional black bear on 25 April 2022 (outside of the formal evaluation period) that started crossing the wildlife guard with an electrified mat by BS Fabrications. Based on the images, this black bear was shocked as well and ran back to the habitat side. Thus, if it was not for the electrified barriers, likely at least 3 black bears and 1 grizzly bear would have crossed into the fenced road corridor where they would have been exposed to vehicles.

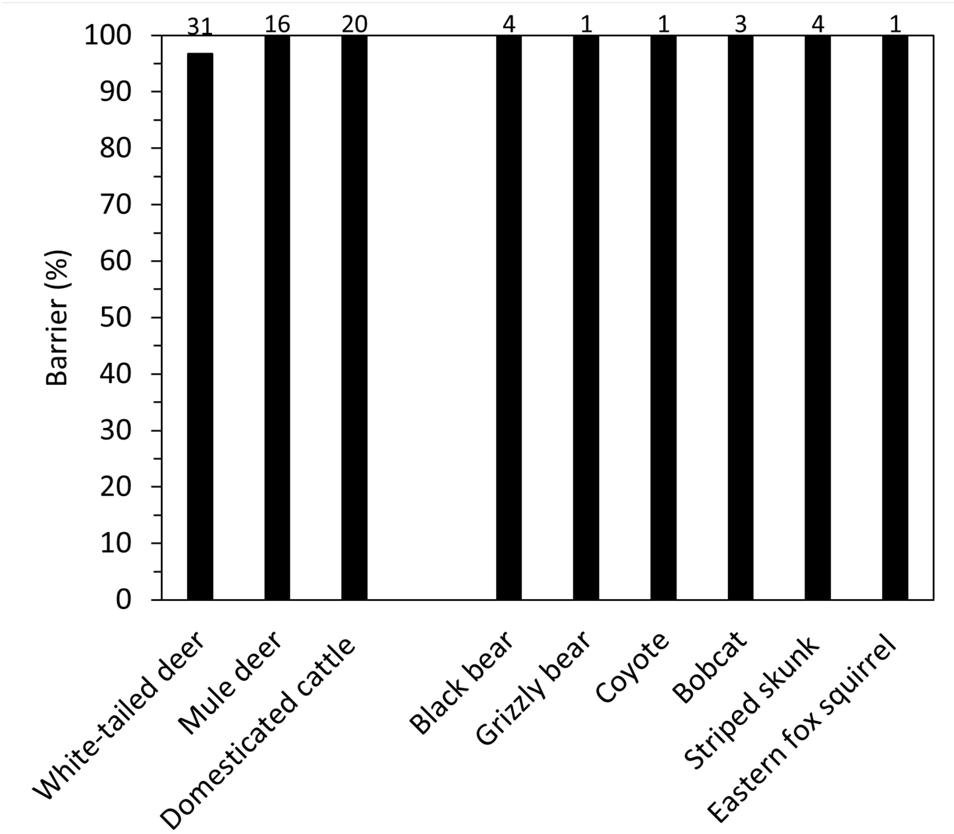

Figure 12: The barrier effect (%) for the different ungulate species (left) and species with paws (right) that approached the two wildlife guards and electrified mats (both Crosstek and BS Fabrications combined) within 2 meters on the habitat side. The numbers on top of the bars are the sample size (i.e., the total number of animals that approached the two wildlife guards and electrified mats on the habitat side and that came within 2 m of the edge of the wildlife guard).

Figure 13: The white-tailed deer that did cross over the wildlife guard and electrified barrier (BS Fabrications) did so on 18 November 2022 at 11:56 pm with several inches of snow present on the mat and at -17˚ C (1˚ F). Based on the images, this animal still appears to have been shocked, but with a bit of a delay after it already had both of its front hoofs on the snow on top of the mat. After the shock the animal jumped forward into the fenced road corridor. Note that this was an exception; only 1 out of 31 white-tailed deer that approached, crossed the combination of the wildlife guards and electrified barriers.

Figure 14: A black bear approached the wildlife guard and electrified barrier (BS Fabrications). Based on the images, this animal was shocked and ran back to the habitat side.

Figure 15: A grizzly bear approached the wildlife guard and electrified barrier (Crosstek). Based on the images, this animal was shocked and ran back to the habitat side.

4 Discussion and conclusion

Both electrified mats (Crosstek and BS Fabrications) installed on top of existing wildlife guards resulted in a near absolute barrier for both ungulates and species with paws. Based on the images, there is evidence that a shock is delivered to the animals that touch the electrified mats and that most of the animals respond by returning to the habitat side of the barrier. Specifically for bears, if it was not for the electrified barriers, it is likely that at least 3 black bears and 1 grizzly bear would have crossed into the fenced road corridor where they would have been exposed to vehicles. Compared to historical data from the exact same two wildlife guards without electrified mats (Allen et al. 2013), the wildlife guards with electrified barriers (96.8% barrier for white-tailed deer, 100% barrier for mule deer, 97.9% barrier for the 2 deer species combined) were more effective in keeping deer, especially white-tailed deer, from accessing the fenced road corridor than wildlife guards without electrified barriers (60.0% barrier for white-tailed deer, 93.8% barrier for mule deer, 89.3% barrier for the 2 deer species combined) (Allen et al. 2013). The wildlife guards with electrified barriers were much more effective (100%) in keeping coyotes and black bears out of the fenced road corridor that wildlife guards alone (54.5% barrier for coyotes and 45.5% barrier for black bears) (Allen et al. 2013). Nonetheless, because of the small sample size, especially for bears, the researchers recommend increasing the length of the project. A higher sample size will result in greater confidence in recommending these types of electrified barriers for low volume access roads elsewhere, especially in places where species with paws are among the target species.

While it is encouraging that wildlife guards combined with electrified mats can keep most large mammal species from entering a fenced road corridor, it is important that fences, wildlife guards and electrified mats are combined with suitable wildlife crossing structures under and over the road for the target species. Crossing structures need to be in the right locations, be of the correct type (underpass vs. overpass), have the correct dimensions (e.g., width, height, potentially also length) and have the correct spacing for the target species that roads and traffic should not be a (substantial) barrier for (e.g., Huijser et al. 2022a, Adams et al. 2023). If appropriate crossing structures are readily available, animals may also be less likely to exploit potential “leaky” locations in a fence such as gaps at access roads and fence-ends.

An unintended negative side effect of electrified barriers is that it can result in mortalities of small species. Small mammals (a mouse), reptiles (an eastern racer), and a striped skunk were found dead on or partially on the electrified barriers (Appendix B). A potential solution is to have lower voltage barriers on either end of the high voltage barrier, but that would require substantial additional equipment and result in higher costs.

The electrified barriers were not designed to be operational in winter as bears, especially black bears, were the primary target species for the research. In winter, there is reduced sunlight on the solar panels and reduced performance of the batteries, making it less likely that the voltage can be maintained, especially towards the end of the night. Nonetheless, at different times there was snow that accumulated on the electrified mats during the period that the effectiveness was evaluated. There was one instance where a white-tailed deer entered the fenced road corridor, and that was when the electrified mat was covered in snow. Based on the images, a shock was delivered to the animal, but potentially later than normal, causing the animal to leap forward rather than turn back. If an electrified barrier is designed for year-round operation, larger solar panels, larger capacity batteries, and snow removal from the electrified mat and wildlife guard would need to be considered. Note that the current design of the electrified mats makes the mats stick out above the grate of the wildlife guard. Therefore, snowplows would likely cause substantial damage to the electrified mats. Low profile electrified mats, or electrified mats that are integrated in the pavement are likely a better design in situations where traffic volume is high and where the electrified barrier needs to be operational throughout the winter. Note that such designs are likely to come at a substantially higher cost, which was important to avoid for the application at the current locations (Huijser & Getty 2022). Longer term deployment at low volume roads, even in summer only would benefit from replacing the wooden "ramps" at the two sides of the Crosstek barrier with composite ramps (Pers. com. Tim Hazlehurst, Crosstek) (see also Appendix A). The electrified barrier by BS Fabrications experienced a problem with the bridging wire between the two plates, and cracked bolts because of differences in expansion and contraction of the metal and isolation material (Pers. com. Brady Stone, BS Fabrications) (Appendix B). The problem associated with expansion and contraction was addressed, but the design of the bridge between the 2 plates would still need to be addressed for higher traffic volumes and snow removal.

The increase in barrier effect for large mammals, especially for species with paws, came at a cost of US$ 22,510 for the two electrified mats combined. This excludes the costs for the two existing wildlife guards which were estimated at $30,000 each (Huijser et al. 2016b). Without the electrified barriers, it is likely that at least 3 black bears and 1 grizzly bear would have crossed into the fenced road corridor where they would have been exposed to vehicles. Should these animals have been hit by vehicles, this may have resulted in a cost of $57,267 (3*$19,089) for the 3 black bears and an additional $4,249,784 for the grizzly bear (Huijser et al. 2022c). The comparison of the costs and benefits suggests that there is a strong economic argument for the implementation of electrified mats on top of wildlife guards, especially if the objective is to keep bears out of the fenced road corridor. Note that the wildlife guards may not be needed and that the electrified mats on their own may be similarly effective. However, to be similarly effective, the electrified mats would have to be operational year-round, including during the winter months.

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Appendix A: Specifications electrified mats

Specifications electrified mat by Crosstek (Figure 16)

CrossTek Wildlife Solutions
2212 Queen Anne Ave N #519
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USA
email: info@crosstekco.com
website: crosstekco.com

Contact person:
Tim Hazlehurst
Phone: +1.330.414.1995
Email: timh@crosstekco.com

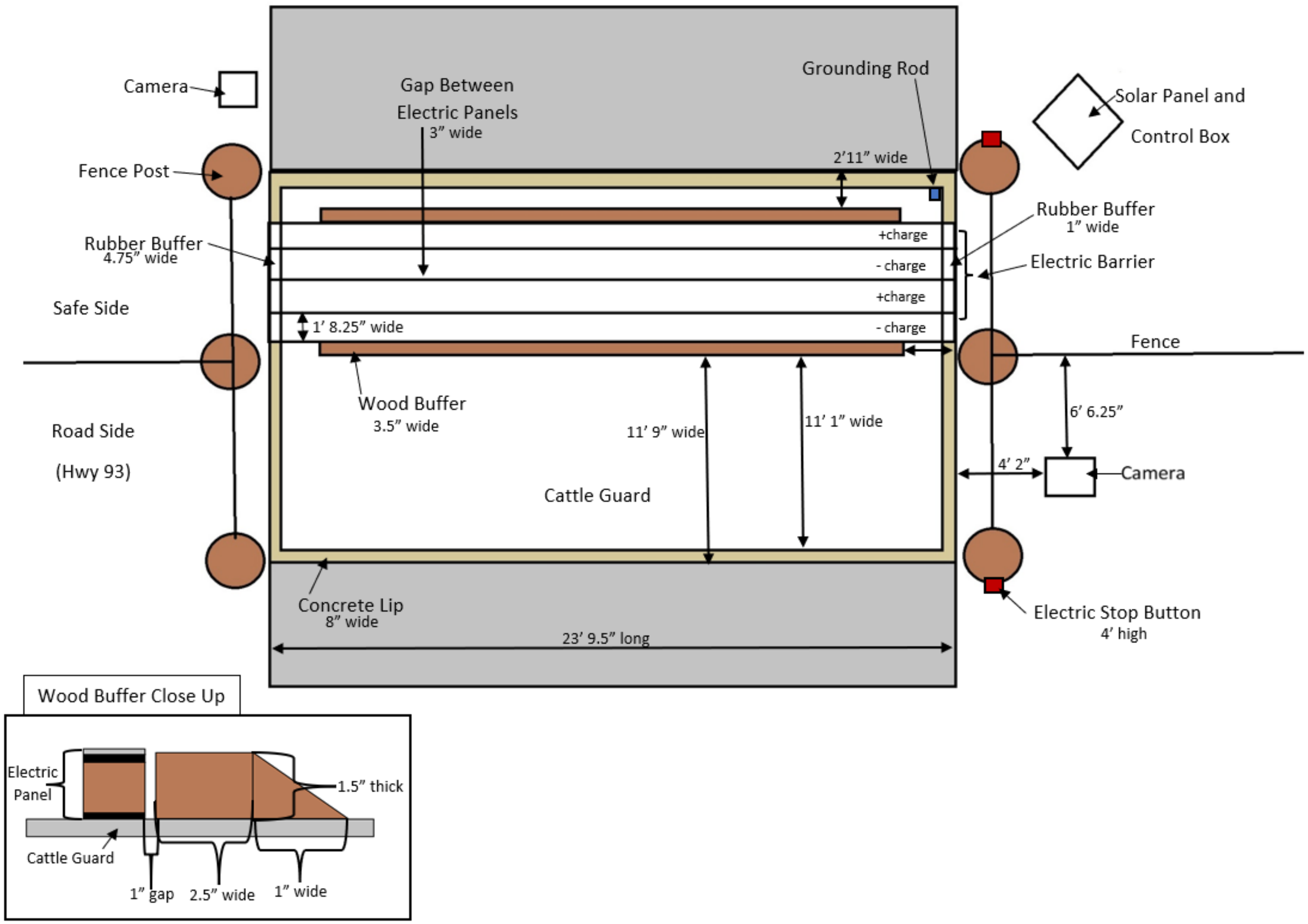

Figure 16: Technical drawing of the Crosstek electrified mat. Note: for "proof of concept" for this project, CrossTek determined inclusion of wood materials was adequate given the expected short study length and low traffic volume. CrossTek uses a variety of very long life and highly durable materials including composites and concrete where necessary, designed for and matched to individual site conditions.

Specifications electrified mat by BS Fabrications (Figure 17)

BS Fabrications
PO Box 148
Ovando, MT 59854-0148

Contact person:
Brady Stone
Phone: +406.210.7600
Email: bradys352@gmail.com

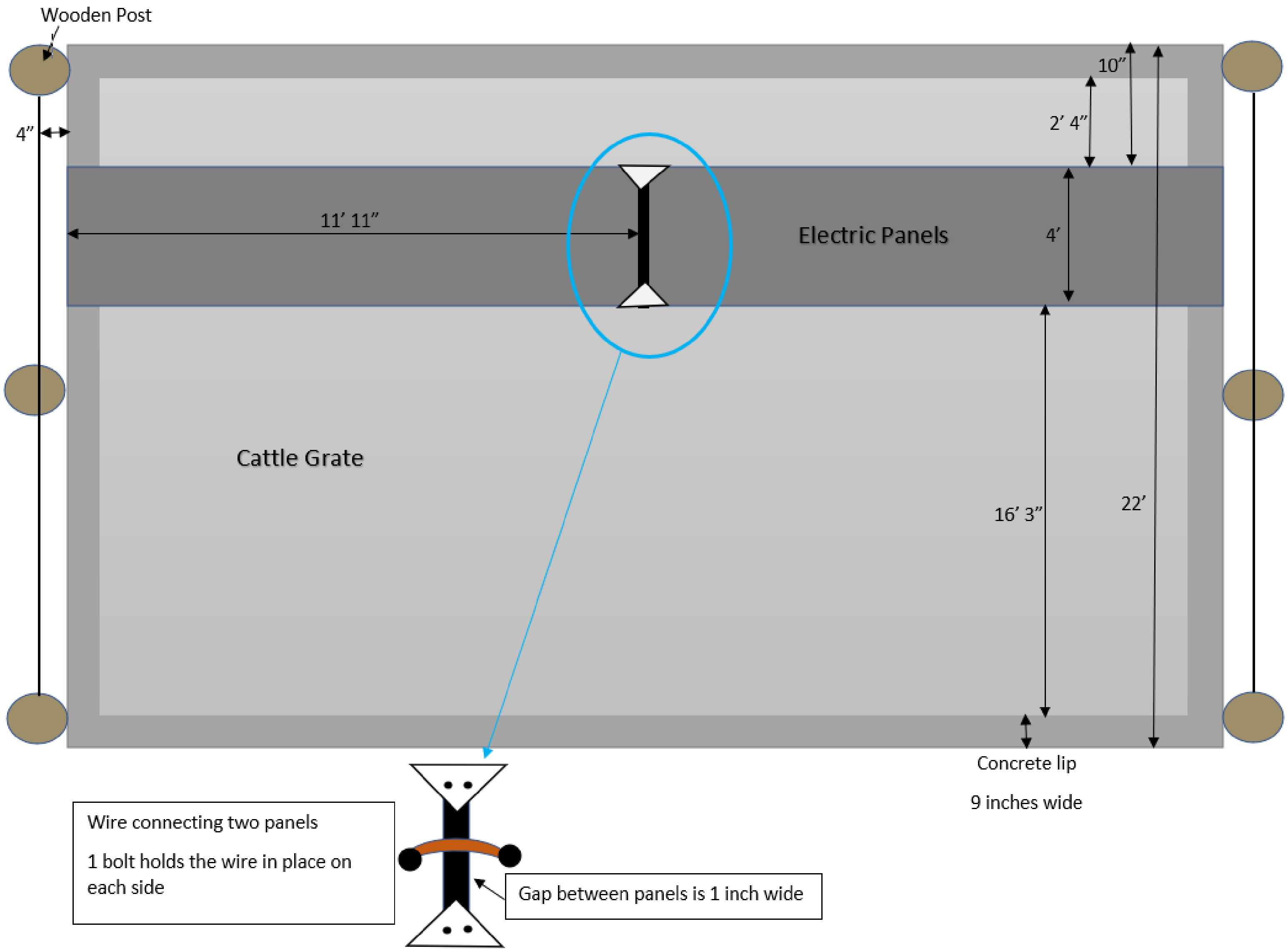

Figure 17: Technical drawing of the BS Fabrications electrified mat.

Appendix B: Voltage readings and field observations (Table 1)

Table 1: Voltage readings (in kV) and other field observations.

Date	Time	Crosstek habitat	Crosstek road	BS Fabrications north	BS Fabrications south	Notes
6-Nov-21						Electrified mat installed, signs installed
± 1 Dec 2022				0.0	0.0	Possibly not enough light, solar panel too small
12-Jan-22						Battery removed, winterized
7-Apr-22				12.0	12.0	Battery installed for the season, larger solar panel (75W) and
24-Apr-22				good	good	Dead mouse on mat
20-23-May-22						Electrified mat installed, signs installed
25-May-22		good	good	good	good	
14-Jul-22				8.6	8.6	
15-Aug-22		good	good	4.6	4.6	Possibly vegetation leaking voltage, mowed
12-Jan-23				12.0	12.0	Battery removed, winterized
14-Apr-23	7:21 AM					Battery installed for the season
27-Apr-23	6:15 PM	9.6	9.6			
27-Apr-23	5:57 PM			10.0	11.0	
14-Jun-23	6:15 AM	9.6	9.5			
14-Jun-23	6:09 PM			9.5	0.0	Bridge wire was loose between the 2 panels
14-Jun-23	6:10 PM			11.0	11.0	Fixed bridge wire between the 2 panels
15-Jun-23	5:42 AM			0.0	0.0	Shrinking/expansion metal and insulator caused shorting (1 night)
15-Jun-23	5:45 AM	9.3	9.5			Very overcast, barely light, light rain, wet mat
16-Jun-23	6:14 AM			12.0	12.0	Brady Stone repaired the mat
12-Jul-23	5:38 AM			4.4	4.9	Dead snake shorting on mat, eastern racer
12-Jul-23	5:39 AM			12.0	12.0	Voltage restored after removing snake
12-Jul-23	5:57 AM	9.5	9.6			
21-Jul-23	7:50 AM			12.0	12.0	
21-Jul-23	7:58 AM	9.6	9.6			