Top: View of Bad River meander, looking upstream.
Bottom: Same location looking downstream.

Figure 65: Photographs of Bad River Meander on April 16, 2019
Figure 66: Channel Bank Collapse Observed by WWE on April 16, 2019

Figure 67: Recent Bank Failure at Bad River Meander Observed by WWE on May 26, 2021
3.4 Potential Implications of Climate Change on Pipeline Exposure Threats

There have been documented changes to the climate in the Great Lakes region in recent decades, which may have implications for the previously discussed flow frequency analysis and future projections of potential extreme events and associated implications for the Bad River meander. According to Great Lakes Integrated Sciences and Assessments (GLISA, February 14, 2019), a collaboration between the University of Michigan and Michigan State University, supported by the National Oceanic and Atmospheric Administration (NOAA), the following notable changes in climate have been observed in the Great Lakes region.

1. Annual average air temperatures have increased by 2.3°F since 1951.

2. Total annual precipitation has increased by 14%.

3. Lake Superior summer lake surface temperature increased by 4.5°F between 1979 and 2006 (faster temperature increase observed in lake surface temperatures than surrounding air temperatures).

4. For the heaviest 1% of storms, the amount of precipitation that fell increased by 35% from 1951 through 2017. GLISA also notes that broadly, the frequency and intensity of severe storms has increased.

5. Water levels in the Great Lakes have risen at an unprecedented rate since 2014.

GLISA (February 14, 2019) also provides the following projections for future climate in the Great Lakes region.

1. Average air temperatures are projected to increase by 3°F to 6°F by 2050, and 6°F to 11°F by 2100, if trends continue.

2. On average, more precipitation is predicted in the future, although not during all seasons (in general, summer is predicted to be drier) and not in all locations. Different models provide varying predictions.

3. In the near-term, there may be increased lake-effect snowfall, but in the long-term, higher temperatures could cause more winter precipitation to occur as rain instead of snow.

4. Increased frequency and intensity of severe storms is likely to continue.

5. Current evidence suggests that there is likely to be increasing variability in lake level fluctuations.

Observations in recent years of fluctuating water levels, including high water levels and higher average water temperatures have been confirmed by research from USEPA (July 18, 2021).

WWE’s focus in this report has been on observed historic conditions, which inherently does not account for what future conditions may be under climate change. At a high level, and given the
uncertainty of making future projections that will reflect a changing climate, WWE provides the following observations.

1. An increase in the frequency and severity of extreme events means that more erosion-causing events may occur, and thus cause an increased threat of pipeline exposure.

2. When considering possible remediation measures (see Section 7.0 for an evaluation of Enbridge’s proposals), the likelihood of increased frequency and severity of extreme events should also be considered. Appropriate stabilization measures must be able to withstand and function as intended during such extreme events.

3. Changes in the timing of peak flows and increased potential for winter rainfall should be noted for pipeline monitoring and operations considerations. Historically, the Bad River has been frozen for much of December through March with associated low flows and low erosion potential. However, as temperatures increase and winter precipitation events become more frequent, there is greater potential for erosion-causing events in the winter and early spring. Similarly, drier summers mean that erosion-causing events may be less likely during this season.

As has been noted throughout this report, the Bad River is a complex, dynamic system. The uncertainties and potential extremes of climate change add to this complexity and should be taken into consideration as the future security of Line 5 on the Bad River Reservation is evaluated. A significant threat of Line 5 becoming exposed already exists, and there is the potential that the effects of climate change in the coming years could exacerbate this threat.

### 3.5 Conclusion

The analysis described in Section 3.0 addresses the question about whether there exists the potential for the Line 5 pipeline to become exposed at the meander as a result of erosion caused by the Bad River. The analysis yields the following findings:

- The Bad River is an alluvial channel formed on thick accumulations of unconsolidated material. Processes that cause the channel to move are naturally occurring and have been shifting the alignment of the Bad River for many thousands of years.

- Evidence of meander cutoffs are common along the Bad River floodplain, as observed by the presence of multiple oxbow lakes that were formed when the river alignment shifted and meander cutoffs were formed.

- Review of aerial imagery and field measurements indicates that the channel bank at the upstream side of the meander has migrated north toward Line 5, with approximately 310 feet existing between the bank and the pipeline in 1963 to less than 27 feet today based on measurements taken in September 2020 and May 2021.

- During the 2016 flood event, the channel bank movement ranged from approximately two feet to 16 feet, depending on the location.
• Bank erosion is highly spatially variable and does not depend on large flood events. From July 2016 to May 2021 the channel bank migrated as much as 62 feet in one location despite no flow events higher than the ten-year event. The 1-year, 2-year, 5-year, and 10-year events that have occurred in the past five years have cumulatively caused significant bank erosion. Erosion is continually occurring across the entire upstream bank, and the recent relatively static nature of the bank near the M2 monument series is not indicative of overall conditions at the meander.

• An empirical method for analyzing the erosion and movement of meander bends, based on an analysis of over 1,500 meanders on numerous rivers, indicates there is a 5% chance that over 19 feet of lateral bank movement will occur in one year and a 1% chance that over 31 feet of bank movement will occur in one year.

• There were 18 events from 2014 through 2021 that had a flow rate in excess of 6,000 cfs, the approximate flow rate necessary to cause flow in the overflow channels and meander neck overtopping.

The conclusion of the analysis is that the cutoff process at the Bad River meander is underway, and either chute cutoff, neck cutoff, or a combination will expose the pipeline. Although the precise timing and mechanism of Line 5 exposure are difficult to predict, it is clear that the Bad River will continue to erode toward and past the pipeline during the cutoff process.
4.0 IF THE LINE 5 PIPELINE BECOMES EXPOSED, IS IT LIKELY THE PIPELINE WOULD BE DAMAGED AND RELEASE OIL TO THE BAD RIVER?

Opinion: The exposure of the Line 5 pipeline would likely lead to pipeline damage and result in the release of oil.

After determining that a considerable threat of Line 5 exposure at the Bad River meander exists (see Section 3.0), WWE next evaluated whether this exposure would likely lead to pipeline damage and result in the release of oil. We conclude that once the pipeline is exposed at the meander neck, it is likely to be subjected to forces sufficient to cause a rupture and the release of oil. WWE predicts that the pipeline is likely to be subjected to such forces by the time that the unsupported span exceeds approximately 62 feet.

Based on the engineering analysis presented in Section 4.0, once erosion progresses at the meander neck to the point where the pipeline becomes exposed, the supporting soils around the pipeline will continue to erode at an unpredictable and potentially rapid pace. This erosion will result in an increasing span of exposed and unsupported pipeline at the meander neck. As the length of the unsupported span increases, the forces acting upon the exposed portion of the pipeline will increase proportionally. These forces will likely lead to pipeline failure and the release of oil.

The existing Bad River channel is approximately 150 to 200 feet wide on the upstream side of the meander. With time, a cutoff channel is anticipated to grow to comparable width. But, as shown on Figure 28, even before the Bad River meander neck is completely cut off, the riverbank will likely erode horizontally and remove soil surrounding Line 5 over an extended distance. In this way the length of pipeline exposure will continue to grow, and the pipeline will be subjected to various forces that it likely cannot withstand.

An exposed pipeline at the meander will, when the water level is higher than the pipeline, be submerged within the Bad River (a "submerged" pipeline) and subjected to forces caused by river currents. More frequently, when the water level is lower, the exposed pipeline will be suspended in the air above the river channel (a "hanging" or "emergent" pipeline), and will be subject to the force of gravity acting on the unsupported weight of the pipeline and the product within it. Both the submerged pipe and hanging pipe scenarios are evaluated in this section.

Section 4.1 discusses the forces that may impact an exposed pipeline, while Section 4.2 describes the impact that these forces could exert on the pipeline and identifies the maximum span lengths that could be exposed under the various force scenarios before pipeline failure and oil release are likely to occur. Forces described in this section were calculated by Professor Rollin Hotchkiss, P.E., D.WRE, F.ASCE of Brigham Young University. The effects of these forces on the structural integrity of Line 5 were calculated by Mark Weesner, P.E., Consulting Engineer.
4.1 Forces on an Exposed Line 5

An exposed Line 5 will act as a free span, either in the air (referred to as emergent or “hanging”) or submerged in water (referred to as submerged). In both conditions, various forces will act on the pipeline, as shown on Figure 68. The following section describes the forces that will act upon the pipeline in either an emergent or submerged condition.

![Diagram of Forces Potentially Acting on the Exposed Line 5 – Submerged and Emergent Conditions](https://example.com/diagram.png)

**Figure 68: Forces Potentially Acting on the Exposed Line 5 – Submerged and Emergent Conditions**

The following description of forces assumes that either a partial or full channel cutoff has occurred.

4.1.1 Weight

The Line 5 pipeline was not designed to support its own weight, and the weight of the product in it, in either an emergent or submerged state. The pipeline was designed to remain buried in the ground, and to rely on surrounding soils to support the weight of the pipe and of the pipeline products that it transports. If an exposed section of pipeline is unsupported for a sufficient length,
the stress from this weight alone will damage the pipeline, potentially causing a rupture or a release.

**Pipeline weight**

The Line 5 pipeline is a 30-inch light crude oil and natural gas liquids (NGLs) pipeline with a wall thickness that varies between 0.281 and 0.500 inches. ENB00177622. Wall thickness in the section that will be exposed is nominally 0.312 inches. ENB00417450. Line 5 is constructed of a carbon steel material, with a density of 490 lbs/ft\(^3\), as calculated by WWE based on design specifications provided by Enbridge. See ENB00177622. For 30-inch pipe with 0.312-inch nominal wall thickness the weight of the pipe is 99 lbs/ft excluding any exterior coating.

**Liquid weight**

The Line 5 pipeline carries light crude oil or natural gas liquids. Inside a 30-inch-diameter pipe, light crude weighs 250 lbs/ft of pipeline and NGLs weigh approximately 132 lbs/ft (Enbridge, 2020a Crude Characteristics Booklet).

### 4.1.2 Buoyancy

Buoyant force is defined as the weight of fluid that is displaced by an object. Although air produces a buoyant force, the unit weight of air is so small as to make any buoyant force due to air on an emergent pipe negligible, and accordingly is not considered in this analysis. The buoyant force considered here is that of water or woody debris acting on a submerged pipeline. Buoyant forces acting on the pipeline are directed upward, and therefore oppose the forces of gravity pressing downward against the pipe.

**Buoyancy due to water**

The upward buoyant force due to water is equal to the volume of the exposed pipeline times the unit weight of water. Because water density is nearly constant for the observed range of water temperature in the Bad River, the buoyant force of water acting against the pipeline is calculated to be 300 lbs/ft, with no adjustment based on the temperature of the water.
Buoyancy due to woody debris

The Bad River flows through a forested floodplain. There is clear evidence that at the Bad River meander there have been and continue to be fallen trees and woody debris near or against the right bank. An exposed pipeline will act as a debris collector and trapped woody debris beneath the pipeline can exert an upward force. Because the exact configuration of any trapped woody debris is unknown, this upward buoyant force is not calculated for this report.

4.1.3 Hydrodynamic Drag

Hydrodynamic drag is caused by either water or air flowing past the exposed pipeline and is calculated as a function of the fluid velocity approaching the pipeline, the area perpendicular to the fluid velocity (the exposed length times the pipeline diameter), and the fluid properties of density and viscosity. Drag can be thought of as the force that pushes the object that the fluid strikes in the same direction as the fluid is flowing.

For purposes of this analysis, we have calculated the anticipated hydrodynamic drag forces acting against the pipeline for a low- and high-velocity scenario. The low-velocity scenario assumes a velocity of 6 ft/sec. The high-velocity scenario assumes a velocity of 8.13 ft/sec. Both values have been used by Enbridge in its submittals to the Band for river stabilization projects (Enbridge, August 4, 2021; Enbridge, October 29, 2021), and WWE believes that these values represent a reasonable range of design water velocities acting upon an exposed pipeline within the Bad River.

To properly calculate drag forces, a drag coefficient, based on experiments performed on the shape being analyzed, is also necessary. This analysis relies on drag coefficients presented in Gerhart et al 2016 that were determined for cylinders (pipes). Drag coefficients are also a function of fluid velocity and fluid density and viscosity.

The estimated range of hydrodynamic drag due to water is summarized in Table 4 for water temperatures from 32 degrees F to about 70 degrees F. Although there are hydrodynamic forces from wind on an emergent pipeline, values are small due to the low density of air. More important than the hydrodynamic forces due to wind are the transverse forces due to vortices of air shed from the pipeline. This will be discussed in Section 4.1.6.

4.1.4 Ice

Ice forms on the surface of the Bad River during winter months. Upon breakup, this ice flows downstream and can become caught on riverbanks, fallen woody debris, and a pipeline if exposed near the surface of the water. The force due to the ice accumulation acts perpendicularly to the pipeline in the same direction as hydrodynamic drag. During ice accumulation, drag forces acting directly on the pipeline will be reduced due to the lower contact water velocities. Forces due to ice can accumulate as ice continues to flow toward the cutoff channel from upstream, creating an ever-increasing ice dam as greater and greater volumes of ice collect against the exposed pipe.
Due to the uncertain configuration of ice accumulation within a river channel, the forces that accumulated ice would exert on an exposed pipeline are not estimated for this report. While difficult to quantify, these forces can nevertheless be substantial and would serve to decrease the maximum critical span length for an exposed pipe subject to ice buildup.

### 4.1.5 Woody Debris

As noted above in Section 4.1.2, the Bad River accumulates large volumes of fallen trees and woody debris. As banks erode upstream of the meander site, trees and other plant matter growing on the riverbanks become dislodged, fall into the water, and are carried downstream by the river’s currents. Similar to ice flows, this woody debris can accumulate against the pipeline, creating a tree raft that provides more surface area for the river’s currents to act against.

Forces due to the accumulation of woody debris on a pipeline are difficult to quantify due to the chaotic nature of log jams. Instead of expressing the loading of woody debris accumulation as a force, the impacts of woody debris loading can be expressed as a reduction in the maximum allowable free span length of the pipe. For example, Dooley et al. (2014) states that pipeline vulnerability can be reduced by a factor of 1.5, meaning that the calculated maximum span length can be reduced by one-third to accommodate the impacts of woody debris loading.

Another methodology can be used to approximate the forces that would act upon a submerged pipeline due to debris loading. To approximate the effects of accumulated debris piled up against the pipeline, a larger measurement for the outside diameter of the pipeline can be input into the formula used for calculating the applicable forces. Enbridge has applied this methodology to calculate the maximum allowable free span length for a pipeline exposure at the Bad River meander, increasing the outside diameter of the pipeline by a factor of two or three to account for the additional forces imposed on the pipeline due to possible debris loading. An application of Enbridge’s method is provided in Section 4.2.2.

### 4.1.6 Vortex-Induced Vibrations

Vortex-induced vibrations (VIV) occur when air or fluid flows past blunt bodies and “sheds” from the body surface to create complex flow patterns in the wake region (downstream). These vibrations create forces that alternate vertically upward and downward on the pipeline, whether in an emergent or submerged condition. Ferris et al. (2015) documents several cases of submerged pipeline failures due to VIV. Shedding frequency is a function of pipeline diameter, approach velocity, and fluid viscosity and is experimentally determined. Results are remarkably constant for a wide range of factors (van Hinsberg et al. 2014). As calculated in Section 4.2.2 below, a pipeline exposure would likely exceed the maximum permissible emergent or submerged span length as a result of pipeline and liquid weight in an emergent condition and hydrodynamic drag in a submerged condition. Accordingly, this report does not quantify the additional forces induced by VIV. Nevertheless, if pipeline exposure were to go unaddressed by Enbridge, VIV could induce forces that would further threaten pipeline integrity.
4.1.7 Summary of Forces Acting Upon Line 5

Table 4 summarizes the information presented above. Note that some of these forces will be acting concurrently. For example, when the pipeline is submerged, there will be a downward force due to gravity (the weight of the pipe) with an upward force due to buoyancy of the water or woody debris lodged beneath the pipe.

Table 4: Summary of Forces Acting on Line 5
(See Sections 4.1.1 through 4.1.3 for descriptions of force elements)

<table>
<thead>
<tr>
<th>Force Element</th>
<th>Force (lbs/ft¹)</th>
<th>Force (lbs/in)</th>
<th>Direction of Force</th>
<th>Suspended in Air or Submerged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline weight²</td>
<td>99</td>
<td>8.3</td>
<td>Down</td>
<td>Both</td>
</tr>
<tr>
<td>Liquid weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Light Crude³</td>
<td>250</td>
<td>20.8</td>
<td>Down</td>
<td>Both</td>
</tr>
<tr>
<td>- Nat Gas Liquid (NGLs)⁴</td>
<td>132</td>
<td>11.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buoyancy of water on pipe⁵</td>
<td>~300</td>
<td>25.0</td>
<td>Up</td>
<td>Submerged</td>
</tr>
<tr>
<td>Pipeline &amp; Liquid Weight in air</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Light Crude</td>
<td>349</td>
<td>29.1</td>
<td>Down</td>
<td>Suspended in Air</td>
</tr>
<tr>
<td>- NGLs</td>
<td>231</td>
<td>19.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipeline &amp; Liquid Weight in water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Light Crude</td>
<td>49</td>
<td>4.1</td>
<td>Down</td>
<td>Submerged</td>
</tr>
<tr>
<td>Drag (water only)⁶</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- low flow</td>
<td>28</td>
<td>2.3</td>
<td>Downstream</td>
<td>Submerged</td>
</tr>
<tr>
<td>- high flow</td>
<td>106</td>
<td>8.8</td>
<td>Horizontal</td>
<td></td>
</tr>
<tr>
<td>Drag + Net weight (Crude)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- low flow</td>
<td>55</td>
<td>4.6</td>
<td>Downstream</td>
<td>Submerged</td>
</tr>
<tr>
<td>- high flow</td>
<td>116</td>
<td>9.7</td>
<td>Horizontal and down</td>
<td></td>
</tr>
<tr>
<td>Drag + Net Weight (NGLs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- low flow</td>
<td>74</td>
<td>6.2</td>
<td>Downstream</td>
<td>Submerged</td>
</tr>
<tr>
<td>- high flow</td>
<td>127</td>
<td>10.6</td>
<td>Horizontal And up</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
Other forces are addressed qualitatively in the text.
1. Forces are expressed in units of pounds per foot (lbs/ft) of exposed pipeline.
2. The pipe grade, yield strength, diameter, wall thickness, weight per foot, and density (calculated) are taken from Enbridge documents Moody (August 27, 1953) and Enbridge Station Drawing (October 29, 2021).
3. Light crude properties provided by (Enbridge 2020a) Crude Characteristics Booklet.
4. NGL density and specific gravity are highly variable due to differences in composition of individual batches. An estimate of typical properties was made using LNG properties obtained from an internet source (www.kosancrisplant.com), an average between 430 kg/m³ and 470 kg/m³ converted to lbs/ft³ and specific gravity for the analysis. The density of water at 4°C of 62.426 lbs/ft³ was taken from Mark’s Standard Handbook of Mechanical Engineers (Avalone and Baumeister, 1979), General Properties of Materials, Page 6-8.
5. The buoyancy force of water was calculated by Dr. R.H. Hotchkiss, PhD, P.E., D.WRE, F.ASCE (see Section 4.1.2).
6. Water velocity drag forces were calculated by, Dr. R.H. Hotchkiss, PhD, P.E., D.WRE, F.ASCE (see Section 4.1.3).

Not all of the forces acting on the exposed pipeline can simply be added: this depends upon the direction of the force and the interaction between forces. For example, gravitational forces are mitigated by water and/or woody debris buoyant forces. This means that gravitational forces will be highest for the emergent pipeline, which is not buoyed by a non-negligible source of buoyant
force, as opposed to the submerged condition, where the weight of the pipeline is partially countered by the buoyant force of water and/or woody debris.

Additionally, the forces calculated above represent only some of the forces that could be imposed upon an exposed pipeline in an emergent or submerged condition. Other forces that have not been explicitly quantified in this section could additionally impact the pipeline such as ice and/or woody debris loading. Additionally, massive or dense objects, including large masses of ice, tree trunks or large rafts consisting of multiple trees and other debris, or manmade objects such as boats or docks carried away by flood waters, could impact the pipeline at high velocities, potentially causing structural damage or pipeline failures.

Due to the significant uncertainty surrounding the types of forces and magnitude of forces that the pipeline could reasonably be subjected to under a variety of different conditions, it is not feasible to fully account for all of the forces that could be applied to the pipeline in a variety of scenarios.

### 4.1.8 Length of Exposed Pipe

As described in Section 3.0, once a portion of the pipeline becomes exposed, the length of exposure will continue to expand, unpredictably and potentially quite rapidly, whenever the exposed section of pipe is submerged and subjected to the river’s flow. Rapid expansion of the pipeline’s exposed span might occur due to preferential local scour created by the water redirected after impact with the pipeline. As water impacts the pipeline at the juncture where the pipeline intersects with intact soil, some of the water’s force will be redirected toward the soil, producing rapid erosion. As the silty-sandy floodplain deposits are exposed to the erosive impacts of the Bad River, the cross section for water flow will become larger.

While the precise rate of the progression of the pipeline exposure cannot be accurately predicted, it is foreseeable that a substantial length of pipeline could be exposed in a single high flow event, or over the course of several high flow events occurring within a short period of time. Eventually, an equilibrium channel shape will develop, similar to the channel shape immediately upstream from the meander bend. Yet until an equilibrium is achieved, each high flow event could continue to increase the size of the exposure at an unpredictable rate.

### 4.2 Calculation of River Force on Exposed Pipeline and Potential Pipeline Failure

Section 4.2 summarizes the maximum free span calculations associated with the horizontal and vertical forces described in Section 4.1. The maximum free span pipe values calculated below correspond with probable pipe failure.

The force values in Table 5 are expressed in units of lbs/ft of length exposed of pipeline. Therefore, the total force is calculated by multiplying the length of the exposed pipeline by the values in Table 5. For example, if 100 feet of Line 5 is exposed, the downward force due to the weight of the pipeline and the light crude oil in the pipeline is (100 ft) x (99 lbs/ft + 250 lbs/ft), or about 34,900 lbs. In Section 4.2, the ability of Line 5 to withstand this and other forces is determined.
4.2.1 Elastic versus Non-Elastic Deformation

Figure 69 is shown with two zones: elastic and non-elastic. In the elastic zone, steel can stretch, expand, or bend as force is applied. Once the force is removed, the steel returns to its original shape. If more force is applied, the steel can move into the non-elastic zone and begin to deform and lose strength. If the force is now removed, the steel does not return to its original shape. If enough force is applied to the steel, it will fail. Line 5 is made of X-52\textsuperscript{17} grade steel which means the yield point stress (or point at which the material begins to deform non-elastically) occurs at approximately 52,000 lbs/in\(^2\) (pounds per square inch).

4.2.2 Calculation of Maximum Free Span Lengths for Various Forces

WWE has calculated the range of forces that an exposed Line 5 pipeline at the Bad River meander site would be exposed to using a variety of inputs that reflect a range of reasonably foreseeable conditions at the site. Evaluating these various scenarios allows WWE to attribute a “maximum free span length” for an exposed pipeline, which is the maximum length that an exposed and undermined pipeline can maintain before forces acting upon the pipeline could cause damage to the pipeline, including damage resulting in a pipeline rupture and release.

\textsuperscript{17} See Table 6, Note 2 for reference information.
Table 5, below, identifies certain additional key inputs used in these calculations, including the material strength of the Line 5 pipeline and the weight and volume of pipeline products. Table 5 additionally identifies the design factor used in the analysis. The design factor is a margin of safety applied to the length calculations as an allowance for variables such as differences in wall thickness or imperfections in the pipe. WWE utilized a design factor of 0.54 for purposes of this analysis. The design factor, 0.54, is the product of the internal and external pressure stress limit of 0.72 of SMYS and the additive longitudinal stress limit of 0.75 of SMYS specified in ASME B31.4-2016, Table 403.3.1-1 (March 31, 2016).

For unrestrained pipe, that is, pipe that is free to displace laterally and strain axially like a fully exposed pipe hanging in the air across a meander, a design factor of 0.8 or less can be used. The 0.54 design factor selected by WWE is suitable for conservative approaches to pipeline designs and operations. ASME B31.4-2016, Table 403.1-1 (March 31, 2016) allows for a design factor of 0.8 to be used to calculate pipeline maximum free span lengths. WWE has concluded

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18 The stress-strain diagram was drawn by M.D. Weesner, P.E., (Section 4.2 author) as a general representation of a typical stress-strain curve.
that 0.54 is the more appropriate design factor to be applied to an exposure at the Bad River meander, because it reflects a more conservative approach and yields lower allowable free span lengths than the higher design factor of 0.8. Given the environmental resources at risk from a failure of Line 5 (including the Kakagon–Bad River Sloughs and Lake Superior, among others), use of the more conservative design factor is reasonable and appropriate. This determination was made by Mark Weesner, P.E., whose perspective is based on over 40 years of work in the oil and gas industry, including 37 years with ExxonMobil. His responsibilities at ExxonMobil included (among others), pipeline operations, including the application of its Integrity Management System and experience with pipeline crossings of streams and rivers.

Regardless of which design factor is used, 0.54 or 0.8, both sets of calculations show that Line 5 suspended or hanging in the air has a maximum allowable free span length range of 62 feet (design factor of 0.54) to 97 feet (design factor of 0.8) which is smaller than the likely width of the new meander neck channel. Even under a partial cutoff scenario, 62 to 97 feet of pipeline exposure could foreseeably develop rapidly, because once the Bad River channel reaches Line 5, the silty sandy soil beneath the pipeline is likely to readily erode given the hydraulic forces and lateral flows that will be in effect.

The results of these calculations are presented in Table 6.

### Table 5: Key Inputs Used in the Analysis

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Material Grade</td>
<td>X-52</td>
<td>-</td>
</tr>
<tr>
<td>Pipe Yield Stress (SMYS)</td>
<td>52,000</td>
<td>lbs/in²</td>
</tr>
<tr>
<td>Pipe Diameter</td>
<td>30</td>
<td>in</td>
</tr>
<tr>
<td>Pipe Wall Thickness at Meander Neck</td>
<td>0.312</td>
<td>in</td>
</tr>
<tr>
<td>Design Factor Used in the Analysis</td>
<td>0.54</td>
<td>-</td>
</tr>
<tr>
<td>Internal Pressure</td>
<td>779</td>
<td>lbs/in²</td>
</tr>
<tr>
<td>Product Specific Gravity (Light Crude)</td>
<td>0.85</td>
<td>-</td>
</tr>
<tr>
<td>Weight of Light Crude</td>
<td>52</td>
<td>lbs/ft³</td>
</tr>
<tr>
<td>Product Specific Gravity (NGL)</td>
<td>0.45</td>
<td>-</td>
</tr>
<tr>
<td>Weight of NGL</td>
<td>28</td>
<td>lbs/ft³</td>
</tr>
<tr>
<td>Weight of Carbon Steel</td>
<td>490</td>
<td>lbs/ft³</td>
</tr>
</tbody>
</table>

Notes:
1. The pipe grade, yield strength, diameter, wall thickness, weight per foot, and density (calculated) are taken from Enbridge documents Moody (August 27, 1953) and Enbridge Station Drawing (October 29, 2021). Light crude properties provided by Enbridge 2020a Crude Characteristics Booklet.
2. Average wall thickness at meander neck obtained from Enbridge drawing #05_PR_IR_056 dated May 28, 2021.
3. Design factor information taken from the American Society of Mechanical Engineers (ASME) B31.4 -2016, Table 403.3.1-1, Pipeline Transportation Systems for Liquids and Slurries (March 31, 2016).
4. Line 5 internal pressure reference was Enbridge Drag Force Calculator (No Date).
5. NGL density and specific gravity are highly variable due to differences in composition of individual batches. An estimate of typical properties was made using LNG properties obtained from an internet source (Kosan Crisplant, January 18, 2022), an average between 430 kg/m³ and 470 kg/m³ converted to lbs/ft³ and specific gravity for the analysis. The density of water at 4°C of 62.426 lbs/ft³ was taken from Mark’s Standard Handbook of Mechanical Engineers (Avallone and Baumeister, 1979) General Properties of Materials, Page 6-8.
Table 6: Summary of Forces and Free Span Lengths Using 0.54 Design Factor
(See discussion for other design factors)

<table>
<thead>
<tr>
<th>Force Element</th>
<th>Force (lbs/ft)</th>
<th>Force (lbs/in)</th>
<th>Direction of Force</th>
<th>Suspended in Air or Submerged</th>
<th>Maximum Free Span Length (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline weight</td>
<td>99.1</td>
<td>8.3</td>
<td>Down</td>
<td>Both</td>
<td>-</td>
</tr>
<tr>
<td>Liquid weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Light Crude</td>
<td>250</td>
<td>20.8</td>
<td>Down</td>
<td>Both</td>
<td>-</td>
</tr>
<tr>
<td>- Nat Gas Liquid (NGL)</td>
<td>132</td>
<td>11.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buoyancy of water on pipe</td>
<td>~300</td>
<td>25.0</td>
<td>Up</td>
<td>Submerged</td>
<td>-</td>
</tr>
<tr>
<td>P/L &amp; Liquid Weight in air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Light Crude</td>
<td>349</td>
<td>29.1</td>
<td>Down</td>
<td>Suspended in Air</td>
<td>62</td>
</tr>
<tr>
<td>- NGL</td>
<td>231</td>
<td>19.3</td>
<td></td>
<td></td>
<td>76</td>
</tr>
<tr>
<td>P/L &amp; Liquid Weight in water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Light Crude</td>
<td>49</td>
<td>4.1</td>
<td>Down</td>
<td>Submerged</td>
<td>165</td>
</tr>
<tr>
<td>Drag (water only)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- low flow</td>
<td>28</td>
<td>2.3</td>
<td>Downstream/ horizontal</td>
<td>Both Negligible in air</td>
<td>218</td>
</tr>
<tr>
<td>- high flow</td>
<td>106</td>
<td>8.8</td>
<td></td>
<td></td>
<td>112</td>
</tr>
<tr>
<td>Drag + Net weight (Crude)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- low flow</td>
<td>55</td>
<td>4.6</td>
<td>Downstream/ horizontal and down</td>
<td>Submerged</td>
<td>155</td>
</tr>
<tr>
<td>- high flow</td>
<td>116</td>
<td>9.7</td>
<td></td>
<td></td>
<td>106</td>
</tr>
<tr>
<td>Drag + Net Weight (NGL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- low flow</td>
<td>74</td>
<td>6.2</td>
<td>Downstream/ horizontal And up</td>
<td>Submerged</td>
<td>134</td>
</tr>
<tr>
<td>- high flow</td>
<td>127</td>
<td>10.6</td>
<td></td>
<td></td>
<td>102</td>
</tr>
</tbody>
</table>

Notes:
1. Forces are expressed in units of pounds per foot (lbs/ft) of exposed pipeline.
2. The pipe grade, yield strength, diameter, wall thickness, weight per foot, and density (calculated) are taken from Enbridge documents Moody (August 27, 1953) and Enbridge Station Drawing (October 29, 2021). Flows at the USGS gage are multiplied by 1.03 to obtain flows at Line 5 because of the larger watershed area at the location where Line 5 crosses the Bad River. DigitalGlobe imagery is commercial satellite imagery from July 28, 2016.
3. Light crude properties provided by Enbridge 2020a Crude Characteristics Booklet.
4. NGL density and specific gravity are highly variable due to differences in composition of individual batches. An estimate of typical properties was made using LNG properties obtained from an internet source (Kosan Crisplant, January 18, 2022), an average between 430 kg/m³ and 470 kg/m³ converted to lbs/ft³ and specific gravity for the analysis. The density of water at 4C of 62.426 lbs/ft³ was taken from Mark’s Standard Handbook of Mechanical Engineers (Avallone and Baumeister, 1979) General Properties of Materials. Page 6-8.
5. The buoyancy force of water was calculated by Dr. R.H. Hotchkiss, PhD, P.E., D.WRE, F.ASCE (see Section 4.1.2).
6. Water velocity drag forces were calculated by Dr. R.H. Hotchkiss, PhD, P.E., D.WRE, F.ASCE (see Section 4.1.3).
7. “Maximum free span length” refers to the maximum length that an exposed and undermined pipeline can maintain before forces acting on the pipeline could cause damage to the pipeline, including damage resulting in pipeline rupture and release, for the specified design factor.

Table 6 shows that the shortest maximum span length for Line 5 (again, the pipeline length at which pipeline failure would be likely) is 62 feet within a design factor of 0.54. This scenario is based on Line 5 being suspended in the air while filled with light crude oil (the hanging pipe scenario).
Although 62 feet represents the maximum free span length that can reasonably be calculated with the inputs available, as noted previously, this calculation does not guarantee safe pipeline operations at span lengths of less than 62 feet. Rather, 62 feet represents the length at which the forces that WWE is able to calculate a foreseeable risk of pipeline damage, including potential rupture and release. Because of the substantial uncertainty inherent in the identification and calculation of the forces to which an exposed pipe could be subjected, the actual point at which forces acting upon an exposed section of pipe at the meander site could cause a serious pipeline integrity problem could be somewhere below 62 feet. Moreover, as discussed in Section 4.1.8 above, while the precise rate of the progression of the pipeline exposure cannot be accurately predicted, it is foreseeable that a substantial length of pipeline could be exposed in a single high flow event, or over the course of several high flow events occurring within a short period of time.

As noted in Section 4.1.5 of this document, Enbridge has estimated the impact of accumulated debris loading by calculating drag forces on Line 5 by increasing the diameter two and three times. WWE calculated allowable span lengths using this methodology, with resulting maximum allowable free spans of 65 to 126 feet for the 3-times (3x) scenario (based on Enbridge’s factors [ENB00333762-ENB00333766]).

The equation for calculating the maximum allowable free span under internal pressure with external forces acting upon it is taken from ASME B31.4-2016, Section 402.6.2 (March 31, 2016).

4.3 Conclusion

The exposure of the Line 5 pipeline would likely lead to pipeline damage and result in the release of oil. Once an exposure of Line 5 at the meander neck emerges, the length of exposed pipe could expand rapidly and unpredictably, leading to a significant span of unsupported pipe exposed to forces that it was not designed to withstand.

This section has summarized the forces that would be exerted on the pipeline in the event of exposure, and the point at which the pipeline, when subjected to those forces, is likely to fail. The operational implications of these conclusions are addressed in Section 6.0.
5.0 IF THE LINE 5 PIPELINE IS DAMAGED AND RELEASES OIL, WHAT ARE THE ANTICIPATED ENVIRONMENTAL IMPACTS?

**Opinion:** Damage to the Line 5 pipeline resulting in an oil release would have severe environmental impacts under a variety of scenarios.

Analyses provided in the two previous sections established both the considerable potential of Line 5 exposure at the meander and the probability of pipeline damage and oil release following exposure. Given these conclusions, WWE next addressed the third question: If the Line 5 pipeline is damaged and releases oil, what are the anticipated environmental impacts? The basis of this analysis is a series of calculations that were used to evaluate the transport and fate of oil released from Line 5 into the Bad River (see Section 5.1, prepared by WWE). A review of the scientific literature regarding oil spill effects on various species, in combination with the results of these oil release calculations and case studies of past oil spills into inland water bodies, were used to evaluate the ecological consequences of Line 5 releasing oil into the Bad River (see Section 5.2, prepared by Professor Edwin Herricks). Based on this analysis, WWE found that damage to the Line 5 pipeline resulting in oil release would have severe environmental impacts to the Bad River and downstream aquatic resources under a variety of scenarios.

5.1 Implications of Pipeline Failure and Discharge of Oil into the Bad River – Oil Spill Calculations

The focus of this section is on technical aspects of the environmental effects of a release of light crude oil from Line 5 into the Bad River. Topics addressed include a summary of the factors that influence the behavior of oil released into the environment, a description of the methodology used to calculate the predicted fate and transport of oil after it is released, and the results of the analysis.

5.1.1 Factors Influencing the Behavior of an Oil Release into the Environment

Multiple factors influence the behavior of oil released to the environment and the associated impacts to receiving waters. A summary of these factors is provided below.

5.1.1.1 Type of Petroleum Product Released

Light crude oil is the main product transported in Line 5 and is the focus of the analysis described in this report. Crude oils are complex and variable mixtures of hundreds of different organic compounds that originate from naturally occurring geological formations. These compounds are mostly hydrocarbons, with small amounts of other organic compounds and some heavy metals. The physical and chemical characteristics of light crude oil affect its movement in the environment. A general description of the different components of light crude is provided in Appendix D.

Natural gas liquids (NGLs) are also intermittently transported in batches in Line 5. While not evaluated using the calculations described in this section, it is important to be aware that the lightest NGLs such as ethane, propane, and butane, rapidly volatilize into the air. These gases
are highly flammable and, when suddenly released, can produce conditions that are susceptible to explosions and fires. Heavier NGLs are as flammable but less volatile than ethane, propane, and butane. When released in open spaces, they volatilize as heavier-than-air gases and as more persistent, but still relatively short-lived, liquids. These heavier NGLs may collect in low areas where they pose risks related to displacement of oxygen, plant and animal toxicity, and explosions and fire, prior to evaporating and dissipating.

5.1.1.2 Volume and Rate of Oil Release

The volume and rate of an oil release are key factors in assessing its potential environmental impacts. Oil release scenarios range from a full-bore rupture of the pipeline to a “pinhole” release. A large and fast uncontrolled release of oil, such as would occur with a full-bore rupture, is generally presumed to have worse environmental effects compared with a relatively small and slow rate of release. It is also commonly presumed that large releases are often easier to detect than small releases. Pinhole releases are characterized by a slow rate of release through a small leak in the system. Although the volume of leaked oil from a pinhole release may be relatively small for a given period, the environmental risk is that its slow release rate makes it difficult to detect, with the result that the pinhole release may continue undetected for an extended period.

5.1.1.3 Environmental Processes

Multiple environmental processes affect the transport and fate of oil released into a riverine environment and are summarized briefly below:

- Evaporation begins immediately after an oil release enters the environment outside of the pipeline. The rate of evaporation increases as the oil initially spreads, due to the increased surface area of the slick. Turbulent water, high wind speeds, and high temperatures promote the breakup of an oil slick into droplets, increasing its surface area, which generally increases the rate and proportion of oil lost to the atmosphere by evaporation.

- Spreading and adhesion of the oil to the channel banks, to both soil and vegetation, is an important process controlling the fate of oil released into a river and is influenced by factors such as soil type, the amount of vegetation, and bank slopes.

- Dispersion dissipates the initial volume of the spill by breaking it into smaller fragments and droplets, which become mixed in the upper levels of the water column. Some of the smaller droplets will remain suspended in the water while the larger ones will tend to rise back to the surface.

- Other processes also play a less substantial role in the fate of light crude oil released into a river, particularly during the acute phase of transport immediately following the release. These processes include dissolution of oil into the water, sedimentation and sinking, emulsification via weathering, photo-oxidation, and biodegradation.
5.1.1.4 Receiving Water Conditions and Seasonal Factors

The flow rate of the receiving water (e.g., a stream or river), is an important factor in terms of the transport and fate of the oil released to the environment. Higher flows have increased velocity, which reduces the time needed for an oil release to travel downstream. Seasonal effects also have a bearing on the river conditions, with spring and early summer typically having the highest stream flows on the Reservation due to the combination of significant rainfall, snowmelt, and saturated soils from winter conditions that promote runoff. Flow rates are typically lower in the Bad River in late summer and fall, although past high flow events when the Bad River overtops the meander banks have occurred during the fall season. Winter ice and snow cover on the Bad River alter the dominance of processes, with all dissipative and degradative activities, such as evaporation, spreading, and dispersion, also being reduced by the lower winter temperatures.

5.1.2 Projected Effects of a Release of Oil from Line 5 into the Bad River

5.1.2.1 Calculation Methodology

WWE prepared calculations to approximate the fate of oil in the Bad River for different scenarios involving oil releases from Line 5. The analysis uses a mass balance approach to estimate the quantity and fate of oil that will be transported in the environment following a release.

The concept underlying the mass balance is that the total mass of oil must remain the same through time, but that the mass will be divided into different environmental fates or endpoints as time passes. For this analysis, four major endpoints of oil released into the Bad River were considered, including: 1) evaporative losses, 2) adhesion to the channel bank and vegetation, 3) dispersion within the water column and settling into the river channel sediments, and 4) remaining oil that floats on the water surface. While it is recognized that other environmental processes occur, these four are included in the calculations because they are of greatest overall importance.

At the beginning of the spill calculations, or hour “zero,” it is assumed that all the oil has spilled and is on the water’s surface. During the one-hour time step that follows, the portion of the released oil that evaporates, adheres, and settles or disperses in the water column is calculated. The calculations are based on standard methodologies using inputs from peer-reviewed engineering literature. Any oil that does not end up in one of these environmental endpoints after one hour has passed remains on the water’s surface. For each subsequent one-hour timestep, calculations are made to determine whether the oil that is initially on the water surface is transferred to a different environmental fate by the end of the hour. The process is repeated for multiple one-hour time steps for the time needed for the oil to travel to Lake Superior (the travel time is calculated separately). A graphic representation of the mass balance calculation for a single one-hour time step is shown on Figure 70.
Since the precise conditions under which an oil release might occur are impossible to predict, mass balance calculations were developed for different scenarios to expand the understanding for a range of different conditions. Mass balance calculations involved analyzing the effects from two different volumes of oil released and with two different flow rates of water in the Bad River, as summarized below.

- **Oil Release Volume:** Two oil release volumes were analyzed to occur over the course of one hour: 1) a full-bore release of 20,000 barrels of light crude oil (equivalent to 840,000 gallons); and 2) 10% of a full-bore release, which is 2,000 barrels (84,000 gallons) (see Appendix D for detail on the basis of these release volumes). While even smaller oil releases, such as pinhole releases, are possible, WWE’s analysis focused on the fate of spills of a relatively larger magnitude.

- **Bad River Flow Rate:** Two different flow rates in the Bad River, 2,000 cfs and 5,000 cfs, were analyzed to evaluate the effects that river flow conditions have on the transport and fate of oil released into the river. A flow of 2,000 cfs is the approximate mean monthly discharge flow rate in April (the month with the highest average flows), based on measurements from the USGS Gage 04027000, Bad River near Odanah. A flow of 5,000 cfs is between a 1-year and a 2-year event but is still contained within the banks of the Bad River.
Note that both flow rates analyzed present scenarios where flows are contained within the banks of the Bad River and do not evaluate a situation with flow carrying oil through the floodplain. Once flows exceed the capacity of the channel and spill over the banks and spread through the floodplain, the travel time, path, and implications for fate of the oil will be changed. In a bank overflow condition along the Bad River, the total travel distance is decreased significantly because the flow does not follow the circuitous path along the many meanders, but instead flows in a straighter path downstream following the broader Bad River floodplain. With such a condition, flow in the overbank portion of the floodplain interacts with more vegetation and the increased surface roughness can decrease average velocity.

The combination of two oil release volume scenarios combined with two Bad River flow rate scenarios results in four oil release scenarios being evaluated, as summarized in Table 7.

**Table 7: Bad River Oil Release Simulation Scenarios Evaluated**

<table>
<thead>
<tr>
<th>Oil Release Scenario (1)</th>
<th>Oil Release Volume (bbl)(1)</th>
<th>Bad River Flow Rate (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-Bore Release</td>
<td>20,000</td>
<td>5,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2,000</td>
</tr>
<tr>
<td>10% Full-Bore Release</td>
<td>2,000</td>
<td>5,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2,000</td>
</tr>
</tbody>
</table>

Note:
1. Oil release scenarios are based on the existing valve configuration for Line 5.

Calculations were also made to estimate the velocity of the flow in the river, which was used to determine the time required for the oil to travel downstream starting from the Line 5 crossing of the Bad River (referred to as mile 0) to the Bad River’s outlet into Lake Superior (referred to as mile 16). The channel velocity estimates are based on several parameters including the channel slope, channel cross section geometry (top width and channel side slopes), and channel roughness. Channel velocity estimates were also checked with measurements collected in the field at different locations along the Bad River.

Numerous oil release scenarios involving Line 5 can potentially occur at the Bad River meander. As described in Section 5.1.1, multiple variables exist that have a bearing on the fate and transport of the oil after it has entered the river. These variables include, for example, the volume of oil released, flow conditions in the river at the time of the release, environmental conditions such as air temperature, and the capability for implementing effective emergency response measures to reduce the movement of the spilled oil in the environment.

Detailed descriptions of the input values used for the oil mass balance and channel velocity calculations, and the basis for the values used, are summarized in Appendix D, Table D-2.
5.1.2.2 Calculation results

Under all four oil release scenarios evaluated, oil was transported all the way to Lake Superior and the Bad River Sloughs (at approximately river mile 16). Under the full-bore release scenario (20,000 barrels of oil released), the amount of oil remaining on the water surface appeared as the continuous true oil color (see Appendix D) for the entire length of the river, for both of the two Bad River flow rate scenarios analyzed (i.e., either 2,000 cfs or 5,000 cfs).

Under the smaller oil volume release scenario (2,000 barrels of oil released), the oil appeared as the continuous true oil color for at least the first seven miles along the Bad River, and then as a discontinuous true color through approximately mile 15, and then as a metallic sheen the remainder of the way to Lake Superior.

Oil was estimated to take just over eight hours to reach Highway 2 (approximately 11 miles downstream from Line 5) and just over 22 hours to reach Lake Superior (approximately 16 miles downstream from Line 5) under the 5,000 cfs Bad River flow rate scenario. With the 2,000 cfs Bad River flow rate scenario, the travel times of the released oil were slightly longer, requiring approximately 10 hours to reach Highway 2 and just over 25 hours to reach Lake Superior.

Evaporation accounted for the largest loss of oil from the surface in all four scenarios, although in the 2,000-barrel release scenario the amount of oil adhered was only slightly less than the amount evaporated. Because adhesion is a set amount per river mile, the total amount of oil adhered to the channel bank and vegetation was the same for both the 2,000- and 20,000-barrel spill scenarios, but the relative percentage adhered was higher for the smaller volume release scenario.

Over 25% of the oil released remained on the surface in all scenarios by the time the oil reached Lake Superior. The percentage of oil dispersed to the water column and attached to sediment is relatively low. The oil used as a basis for the calculations is a light crude, which is less likely to sink or stay submerged in the water column, and the modeled wave size (which contributes to dispersion) is relatively small due to the Bad River’s lack of major rapids or turbulence between the meander and Lake Superior, other than the turbulence created by downed timber in the river. In short, for an oil release of either 2,000 barrels or 20,000 barrels, and for either of the Bad River flow rate scenarios evaluated, oil is likely to end up adhered to the banks and vegetation, dispersed in the water column and sediment, and floating on the water surface as it reaches Lake Superior and the Bad River Sloughs. The oil will have corresponding environmental consequences associated with these different fates, as described in Section 5.2. Tables with detailed results of the calculations are presented in Appendix D. The estimated percentage of oil in each environmental endpoint for each of the four scenarios is shown graphically on Figure 71 (20,000-barrel oil release with a 2,000 cfs flow rate in the Bad River), Figure 72 (2,000-barrel oil release with a 2,000 cfs flow rate in the Bad River), Figure 73 (20,000-barrel oil release with a 5,000 cfs flow rate in the Bad River), and Figure 74 (2,000-barrel oil release with a 5,000 cfs flow rate in the Bad River).

Based on WWE’s experience with projects in remote locations with difficult access, such as dams, canals, and mines, and many site visits to the Bad River meander and other locations along the
Bad River, if river erosion resulted in damage to Line 5, an emergency response to a damaged pipeline at the meander neck would be very difficult. No roads lead to the neck of the meander, and access is further impeded by the Bad River’s oxbow lakes, wetlands, stream channels, and steep topography. If the pipeline is compromised during flood conditions, which is when damage would be most probable, there is a high potential that the meander neck area and much of the Bad River floodplain would be inundated by flows from the Bad River, causing the meander neck to be isolated from overland access. Deployment of equipment by helicopter during flood conditions would also be difficult because the meander neck and Line 5 are submerged during high flow conditions. Snow and ice present additional challenges during the winter. Access to the Bad River downstream from the Line 5 crossing is also highly limited. Consequently, a rapid and successful response to a damaged pipeline would be challenging, which increases the probability of difficulties and delayed implementation of spill containment and pipeline repairs. For the purposes of evaluating a severe spill scenario, WWE has not incorporated into the calculations the effects from response measures being executed within the first day of an oil release.

WWE acknowledges that if Enbridge were able to deploy emergency response and containment measures promptly and successfully, such measures would be expected to reduce the amount of oil distributed in each of the four environmental endpoints evaluated. There is significant uncertainty in predicting the response time, location, and effectiveness of any such measures. Upon the receipt of additional information regarding any proposed measures, the speed with which they could realistically be deployed, and their potential effectiveness, WWE (in consultation with subject matter experts) reserves the ability to evaluate that information and, if warranted, to modify our calculations as appropriate.

WWE’s calculations do not evaluate how the oil would travel and transform when it reaches the Bad River Slough and Lake Superior.
Figure 71: Percentage of Oil in Each Environmental Fate Following a Spill at the Bad River Meander for a 20,000-Barrel Oil Spill with a 2,000-cfs Bad River Flow Rate
Figure 72: Percentage of Oil in Each Environmental Fate Following a Spill at the Bad River Meander for a 2,000-Barrel Oil Spill with a 2,000-cfs Bad River Flow Rate
Figure 73: Percentage of Oil in Each Environmental Fate Following a Spill at the Bad River Meander for a 20,000-Barrel Oil Spill with a 5,000-cfs Bad River Flow Rate
Figure 74: Percentage of Oil in Each Environmental Fate Following a Spill at the Bad River Meander for a 2,000-Barrel Oil Spill with a 5,000-cfs Bad River Flow Rate
5.1.2.3 Comparison to Oil Spill Case Studies

Multiple case studies of oil releases from pipelines into rivers were compiled and reviewed by WWE to provide an understanding, based on real-world examples, of how river erosion has been shown to damage pipelines and cause oil releases. Furthermore, the case studies provide an understanding of the distance that oil has been observed to travel in a river, given similar volumes of oil released and with comparable river flow conditions to the scenarios evaluated for this study of the Bad River. A full listing of the case studies described is provided in Appendix I and further discussion of specific case studies is provided in Appendix D, Section D.4.1.4.

The primary finding from the review of case studies is that oil releases with flow conditions similar to those commonly observed on the Bad River (i.e., flow conditions were similar in three of the four case studies) are observed to have been transported distances greater than the distance from Line 5 to Lake Superior along the Bad River. This supports WWE’s calculations that an oil release from Line 5 could reasonably be expected to travel the entire length of the Bad River and reach the Bad River Sloughs and Lake Superior. Uncertainties in WWE’s calculations, which are discussed in Appendix D, Section D.4.1.5, indicate that the exact percentages of calculated oil directed to different fate endpoints may differ slightly from real-world conditions if an oil release occurs. However, the case studies of pipeline oil releases reinforce the overall conclusion that oil sheens extending for multiple miles along rivers and their channel banks have been observed numerous times before.

5.2 Projected Impacts of an Oil Spill on the Bad River

To facilitate an assessment of the potential adverse effects of released oil into the Bad River, Dr. Edwin Herricks of the University of Illinois at Urbana-Champaign and staff from WWE conducted a literature review of oil spill impacts to the environment focusing on the general effects of oil spills on ecosystems, taxonomic groups, and species found in the Bad River watershed. Dr. Herricks then projected impacts to the Bad River watershed based on this literature review, case studies, and an analysis of likely habitat exposure to an oil spill for key Bad River species. This section is organized into two subsections:

Oil Spill Impacts by Taxonomic Group and in Case Studies (Section 5.2.1)

This section illustrates the different ways in which oil affects different taxonomic groups. The habitat, life history, behavior, population dynamics, and sensitivity to toxicants of a given taxonomic group are examples of the many factors that govern injury and damage. Additionally, oil spills affect different taxa through different habitat-based exposure mechanisms (e.g., irritation to eyes and membranes from and inhalation of volatile compounds, coating, smothering, and ingestion resulting in acute and chronic toxicity). Many effects are species and life-stage specific. Taking a taxonomic approach supports an impact assessment using field-based and laboratory studies. The case studies of past spills, often supported by Natural Resource Damage Assessments (NRDA), provide documented examples that support impact projection in the Bad River.
Oil Spill Impacts on Bad River Species (Section 5.2.2)

The previous section is generic in that it draws from research and assessments conducted around the world and across different types of inland environments. This section focuses on the projected oil spill impacts to ecologically, culturally, and economically important species in the Bad River watershed and Lake Superior, such as walleye, lake sturgeon, lake trout, waterfowl, eagles, otters, beavers, deer, and wild rice. Connecting the ecology of key species with their habitat’s exposure to spilled oil provides the basis for projecting damage to the cultural and natural resources of the Bad River Reservation.

5.2.1 Oil Spill Impacts by Taxonomic Group

An oil spill has variable impacts to different groups of organisms. NOAA provides a helpful summary of typical oil effects on biota in its fact sheet, The Toxicity of Oil: What's the Big Deal? (NOAA, July 25, 2019).

We call something toxic if it harms living things. The amount of harm caused depends on how an organism is exposed and to how much oil. For example, crude oil is considered toxic and causes two main kinds of injury: physical and biochemical.

The physical effects of freshly spilled crude oil are all too obvious. You've likely seen the disturbing images of birds and other animals coated in crude oil, struggling to survive. When oil washes ashore, it can completely cover and smother the plants and animals living there.

Crude oil not only destroys the insulating properties of animal fur and bird feathers, which can lead to hypothermia, but it also impairs animals' abilities to fly and swim, sometimes causing oiled animals to drown…

Spilled oil also can harm life because its chemical constituents are poisonous. As we previously learned, petroleum-derived oil is a complex mixture of thousands of chemical compounds. Given oil’s chemical complexity, we need to consider how these different components—and their very different effects on living things—cause harm…

Let’s look at two important components of crude oil: volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs). In terms of how long they remain in the environment, they represent two ends of a spectrum.

All crude oil contains VOCs, which readily evaporate into the air, giving crude oil a distinctive odor. Some VOCs are acutely toxic when inhaled, in addition to being potentially cancer-causing. At the site of a fresh oil spill, these VOCs can threaten nearby residents, responders working on the spill, air-breathing marine mammals, and sea turtles at the water surface. However, VOCs are generally a response
concern only right after oil is spilled, because oil floating on the sea surface quickly loses its VOCs.

In contrast, PAHs can persist in the environment for many years, in some cases continuing to harm organisms long after the oil first spills. How PAHs in oil do that is an active area of research.

Another NOAA Factsheet addresses the question, How Toxic is Oil? (NOAA, August 27, 2012).

Assessing the toxicity of oil is a tricky business. The main difficulty is that "oil" is a mixture of many different chemicals, and no two oils are the same. Proportions of chemicals vary even within a single category of oil, like crude oil or diesel oil.

For example, Arabian crude oil, Louisiana crude oil, and Alaska North Slope crude oil represent very different mixtures that will behave differently in the environment and have different toxic effects to exposed organisms….It was Alaska North Slope crude oil that spilled from the Exxon Valdez into Prince William Sound. Alaska North Slope crude oil contains many chemicals that can kill a plant or animal outright, or cause injury to the extent that it has less chance of surviving in the wild. For example:

- Oil, in high enough concentrations, can poison animals by internal and external routes of exposure.
- Birds and mammals often die because oil fouls fur and feathers so that they no longer insulate.
- Smaller organisms can be smothered by a thick layer of oil washing ashore.
- Recent research studies by NOAA scientists have shown that even small amounts of petroleum hydrocarbons can impair the successful development of fish eggs and embryos.

Taking a taxa-by-taxa approach facilitates a more detailed understanding of adverse oil spill impacts. The following subsections consider field and laboratory reporting of oil spill effects. Oil poses both lethal (acute) and sub-lethal (chronic) effects and affects organisms through a variety of mechanisms. This taxonomic group organization provides summary information, not a comprehensive review of oil spill effects, with more detailed information provided for Bad River species in Section 5.2.2.

5.2.1.1 Bacteria/Microbial Communities

Microbes, as the primary element of the decomposition cycle in ecosystems, degrade oils. During the decomposition process, microbes exhibit varied responses to oil, as some populations experience toxicity and others display no effect or even experience growth stimulation (Mikolasch et al., 2016; Nyman, 1999). Research stemming from the 2010 Deepwater Horizon spill indicates a similar mixed response and ecosystem-wide consequences of the microbial community's
ability to break down oil products (Engel et al., 2017; Overholt et al., 2016). Regardless of the specific response to oil, changes in microbial communities may resonate through freshwater food chains, producing indirect effects with long-term alteration to ecosystems (Haines et al., 2002; Overholt et al., 2016).

5.2.1.2 Algae

Algae are aquatic photosynthetic organisms that are mainly microscopic in size. In the Bad River, algae are predominantly periphyton, a mixture of algal species that adhere to the submerged surfaces illuminated by sunlight, including sediment and woody debris. Phytoplankton, algae that live in the water column, proliferate in open bodies of water such as the Kakagon–Bad River Sloughs. Much of the literature on oil spill impacts to algae comes from studies of phytoplankton. However, due to similarities in structure and function between periphyton and phytoplankton (i.e., both mixtures contain green algae, diatoms, and blue-green algae), it is reasonable to use literature on phytoplankton response to oil spills to assess the likely effects of oil spills on periphyton populations. Thus, in the following analysis, “algae” is used as a general, transferrable term.

Oil spills can affect algae directly through toxicity or indirectly through altered environmental conditions (e.g., oil slicks limit gas exchange and reduce light penetration) (Ozhan et al., 2014). Toxicity is influenced by temperature and seasonality. The reported effects of oil spills on algae are variable, with algal community resilience, in addition to environmental factors, modulating the response (Ozhan et al., 2014; Selala et al., 2014). To this end, studies have documented a wide range of toxic effects in algae populations (Brussaard et al., 2016; Kauss and Hutchinson, 1975).

Cleanup activities may also be harmful to algae, as the use of dispersants in remediation tends to increase water column concentration of toxic components of oil (Hook and Osborn, 2012).

The following examples of algal response to oil draw from varied ecosystems and geographic locations (e.g., Alaska, the Gulf of Mexico, saltwater, and freshwater). Despite these differences, there are discernable common trends of initial effects, toxicity, growth, and recovery time. Initial oil exposure may cause growth inhibition, low-level membrane damage, and changes in gene expression (Hook and Osborn, 2012). This initial depression may be due to the presence of volatiles in oil. As these constituents volatilize following an environmental release, toxicity and adverse impacts on algal growth are less pronounced (Kauss and Hutchinson, 1975). In general, primary productivity decreases after initial exposure to oil following an environmental release, but a return to higher productivity can occur in as little as two years (Miller et al., 1978). Higher biodiversity, both generally and in the case of algal populations, increases community resilience to disturbance and expedites recovery time (Folke et al., 2004; Selala et al., 2014). To summarize, the available literature suggests that oil spill impacts to algae will be variable with factors such as oil type, season, fate of soluble and insoluble fractions that contribute to exposure, and ecosystem condition.
5.2.1.3 Zooplankton

Zooplankton are the animal component of the plankton, living in still waters, such as lakes and wetlands, and uncommon in rivers. Therefore, this section is germane only to off-channel environments in the Bad River watershed, including oxbow lakes and sloughs. The effects of oil on zooplankton have been well documented for marine ecosystems, but have not been extensively studied in freshwater ecosystems. In general, zooplankton are sensitive to oil, and are particularly sensitive to soluble fractions of crude oil. Insoluble fractions in the form of microdroplets may also affect zooplankton as zooplankton have been observed to mistake microdroplets for food, ingesting and defecating the oil droplets. Oil droplet ingestion may cause long-term impacts by influencing food energy in ingested particles (Almeda et al., 2014; Hansen et al., 2017). Because zooplankton are preyed upon by fish and higher organisms, the effects of oil on zooplankton can affect fish, particularly early life stage individuals that are dependent on these groups as a food resource (Hansen et al., 2017).

5.2.1.4 Macroinvertebrates

Macroinvertebrates, such as larval-stage insects, clams, mussels, and crayfish, are commonly found in rivers and are a major food resource for fish and thus are connected to ecosystem-wide responses to oil spills. Macroinvertebrates are useful in impact assessments because the presence of tolerant and intolerant species illuminates a range of pollutant effects (Bertrand and Hare, 2017; Lytle and Peckarsky, 2001; Rosenberg and Wiens, 1976). Additionally, macroinvertebrates are a key food source for fish species. In general, macroinvertebrates subject to oil spills display a consistent response of loss of species diversity and increased dominance of more tolerant groups. Particulate-feeding species usually are most severely impacted whereas shredders (i.e., species that feed on leaves, wood, and plant material) are more tolerant of spills (Crunkilton and Duchrow, 1990; Poulton et al., 1997). The return of macrobenthic communities to more diverse community structure and the presence of more sensitive species are good measures of recovery and can be used to assess the duration of oil spill impacts.

Immediate lethal impacts to macroinvertebrate communities can be severe, with declines to 0.1% of expected population numbers in the month after a spill. Spatially, invertebrate density and taxonomic richness can be affected within five kilometers of a spill (Crunkilton and Duchrow, 1990; Lytle and Peckarsky, 2001; Vinson et al., 2008). Macroinvertebrates are particularly sensitive to spill cleanup efforts. In some reaches, cleanup activities were more detrimental to macroinvertebrate assemblages than the initial oil spill. Humans wading through the creek with cleanup equipment can disrupt benthic macroinvertebrates, especially in small creeks. Additionally, the removal of riparian vegetation for access to the stream increased incoming sunlight and caused algal blooms that reduce habitat area. Recovery times are dependent on environmental conditions and macroinvertebrate community resilience. Deposition and burial of oil can lead to long-term impacts on benthic communities. In the case of a 1950 oil spill in Ontario, contaminated sediment persisted through 2017 (Bertrand and Hare, 2017). Even without significant burial, oil spill effects on macroinvertebrates can last on the order of two to three years (Harrel, 1985; Lytle and Peckarsky, 2001). These findings provide insight into likely recovery times for aquatic ecosystems. As noted in Appendix B, the Band NRD has collected extensive data on macroinvertebrates.
5.2.1.5 Amphibians and Reptiles

Amphibians, such as frogs, salamanders, and newts, are vertebrate animals exploiting both land and water habitat in their life cycles. Eggs and larvae commonly develop in water, while amphibians in later life stages reside in transitional or terrestrial environments. This range of habitats broadens potential exposure to aquatic, airborne, and soil-based pollutants (Wake and Vredenburg, 2008). Relative to other times in an amphibian’s life cycle, the early, aquatic life stage carries a high risk of exposure to the soluble, toxic, or sub-lethal pollutants commonly found in oil. Frogs, specifically, are characterized as sentinel species because of their early stage of life residence in aquatic habitat. Moreover, frogs and salamanders are viewed as “at risk” groups due to drastic global declines in population totals and diversity (Wake and Vredenburg, 2008). This global backdrop is relevant when assessing the impact of oil spills.

Many studies on amphibian exposure to oil use the African clawed frog as a model species. Light crude oil can affect endocrine signaling and metabolism in this species (Eriyamremu et al., 2008; Truter et al., 2016). In green treefrogs, hatching success was not measurably influenced by the presence of oil, but tadpole development and metamorphosis were hindered by high concentrations of oil. These lethal and sub-lethal impacts are wide ranging across species (gray treefrog, American toad, leopard frog, and spotted salamander) and types of oil (engine oil, kerosene, and unleaded gasoline) (Walker, 2014).

Reptiles include snakes, turtles, and lizards. Reptiles, particularly turtles, are subject to oiling because they prefer aquatic and riparian habitats that can be affected by oil spills, but there is a low reported toxicity in adult turtles. As egg-laying organisms, oil contamination of reptilian egg-laying habitat can be toxic to early life stages and have lasting effects. Polycyclic aromatic hydrocarbons (PAHs), a crude oil constituent, have been found to cause musculoskeletal deformities and tumors and lead to declines in hatching success in turtles (Van Meter et al., 2006; Zychowski and Godard-Codd, 2016). These effects are somewhat mixed, however, as the impacts from weathered crude oil are less severe (Rowe et al., 2009). A study from a nature preserve in southwestern Pennsylvania demonstrated the importance of seasonality in assessing spill impact to turtles. This specific spill occurred in the winter with a rapid cleanup, so larval or egg stages were not affected. Oiling of the shell and ingestion were the primary effects to adult turtles (Saba and Spotila, 2003). Finally, oil can have non-toxic, ecosystem-scale ramifications, as reptilian dietary and habitat preferences may shift away from heavily oiled areas of rivers and wetlands (Luiselli et al., 2004)

5.2.1.6 Fish

Fish are an ecologically important component of ecosystems and a key indicator of environmental health. Fish are vertebrates whose entire life cycle takes place in the water. The typical life history of fish includes egg, fry, juvenile, and adult stages. Each life stage has specific food and habitat requirements. Fish have indeterminate growth and continue to grow throughout their lives producing large, old fish. Exposure to pollutants causes deterioration in growth indices and reduced population sustainability. Pollutant effects on fish can be direct or indirect. Common direct effects include fish kills that occur with spills of toxic materials or materials that alter critical environmental parameters in the water, such as dissolved oxygen concentration. Fish species
regularly used in toxicity testing provide an example of possible effects on organisms higher in ecosystem food chains. The aquaculture industry has facilitated extensive sub-lethal and chronic testing; molecular and genetic techniques are regularly used to identify mechanisms of toxicity. In general, adult fish are somewhat more resistant to pollutants than juvenile fish or eggs. Fish eggs may float, thus becoming exposed to floating oil, or may be attached to vegetation, thus becoming exposed to adhered oil. Juvenile fish frequent the water surface when developing swimming abilities (Dupuis and Ucan-Marin, 2015), and, like adults, they are vulnerable to floating and adhered oil. Fish are also affected by ingestion of contaminated food such as zooplankton and macroinvertebrates, which may impact growth and long-term survival.

Oil spill effects on fish have been widely studied, with more research focused on marine systems than in freshwater. However, studies from a variety of ecosystems are generally informative of fish sensitivity to oil spills. In general, fish vulnerability to oil spills is related to the mechanism of exposure. Injury can be short-term or long-term. Immediate effects may be produced by both insoluble and soluble forms of oil, whereas residues can cause long-term responses to habitat contamination. Oil in aquatic habitats poses a sublethal to lethal risk to fish depending on environmental conditions (such as river velocity, temperature, and wind speed) and the composition of the oil. Complete fish kill, with respect to abundance and diversity, has occurred from severe oil spills (Kubach et al., 2011). However, fish kills, reflecting short-term toxicity, are seldom fully documented due to access delays that limit the sampling needed to document a kill. Longer-term consequences of a spill include sublethal effects, such as skin lesions and fin damage, and chronic effects, such as accumulation of contaminants in tissues, DNA damage, impacts to immune functioning, and cardiac dysfunction (Chang et al., 2014). Impacts from persistent oil or less extensive spills also include cancer, reproductive impairment, skeletal deformities, and organ (gill, skin, kidney) alterations (deBruyn et al., 2007; Giari et al., 2012; Jung et al., 2017). The creation of oil-sediment emulsions is also hazardous to fish, as these particles can coat gills and impair respiratory function (Dupuis and Ucan-Marin, 2015). Moreover, oil and sediment in the water column reduces visibility such that hunting becomes more difficult. Actual injury varies by species due to different sensitivity to contaminants and different behaviors that influence exposure.

Oil spill effects on fish are spatially and temporally far-ranging. For example, certain PAHs in oils bioaccumulate in goldeye, pike, and walleye. While the concentration of PAHs in this study was found to be within an “acceptable” range of risk for human consumption, this phenomenon illustrates the ability of oil contamination to magnify beyond fish and the system into which oil is spilled (deBruyn et al., 2007).

Case studies indicate it takes fish and aquatic ecosystems on the order of five to ten years to recover from an oil spill (Incardona et al., 2015; Kubach et al., 2011). In addition to causing immediate fish mortality, an oil spill may pose a latent hazard. The persistence of oil residues in habitats can injure fish communities through reduced reproduction and slower growth, which, in turn, influences population size and genetic diversity for years following a spill. In the case of the 1989 Exxon Valdez spill, the herring fishery in the Prince William Sound collapsed completely four years after the event. Low-level exposure to PAHs by embryos caused cardiototoxicity at a
later developmental stage with effects that radiated throughout the ecosystem (Incardona et al., 2015).

All life stages of fish are vulnerable to spilled oil with early tumors, physiological and biochemical disorders, and abnormalities in development. Both early life stages and adults are at risk from oil ingested from food items. Overall, fish exhibit varied responses to oil spills depending on the species, oil composition, and environmental conditions. In general, oil can cause lethal effects producing fish kills, and sublethal effects impair sustainability after a spill. Moreover, these adverse effects can radiate throughout an ecosystem due to the reliance of other organisms upon fish as a food source.

5.2.1.7 Mammals

Mammals are vulnerable to oil spills due to preferred habitat, their life history, and individual behavior. Mammals are a major element of inland wildlife with species found in both aquatic and terrestrial habitat. They are warm blooded vertebrate organisms that commonly have hair or fur and feed their young with milk. River channels, floodplains, and wetlands will have small species such as semi-aquatic rodents (mice, shrews, and voles) with other species ranging up in size through beaver and otter, coyotes, wolves and deer, with moose being the largest species expected. Mechanistically, flooding will clear floodplain habitats of terrestrial residents with inundation. Individuals move to higher ground and then recolonize abandoned areas after floodwaters recede. Oil spill effects on refugee individuals will begin with injury from VOCs and then, short-term and long-term effects will occur due to contact with adhered or floating oil. When floodwaters recede, spilled oil will contaminate floodplain soils and habitat. With entry into these contaminated habitats to recolonize the previously inundated areas, individuals are again exposed to oil, and now its weathering products, producing long-term effects on individuals and populations. Among the most vulnerable mammalian species are the fur bearers—beaver, muskrat, and otters—that live in banks and lodges in quiet waters. These fur bearers spend much of their lives in water, in the direct path of spilled oil. Their habitat is expected to be oiled by the spill and their primary food resources will be contaminated. Burns et al. (2014) have provided a comprehensive review of the effects of oil on wildlife. They note that compounds in spilled oil, including PAHs, enter the individual through inhalation, ingestion, or absorption. Effects include toxicity, developmental effects, and changes in behavior. The USEPA (1999) provides the following list of effects of oil spills on wildlife:

The primary effects of oil contamination include loss of the insulative capability of feathers and fur which can lead to hypothermia; dehydration resulting from lack of uncontaminated water; stomach and intestinal disorders and destruction of red blood cells resulting from ingestion of oil; pneumonia resulting from inhalation of oil vapors; skin and eye irritation from direct contact with oil; and impaired reproduction. Animals can also suffer during capture and rehabilitation operations; potential ailments include infectious diseases, skin problems, joint swellings, and lesions.
In addition to these direct effects of spilled oil, indirect effects have been identified, Ober (2019). These indirect effects involve species mobility in behavior responses. Oil spills may cause relocation of home ranges as the search for new sources of food is required after the spill. With this search is an increase in the time spent foraging and disruptions to natural life cycles. The result is an energetic challenge to an individual at the same time they are dealing with toxic responses from exposure to oil. In addition, the difficulty maintaining temperature balance with oiled fur or feathers, individuals may not be able to fight off disease with newly compromised immune systems).

5.2.1.8 Birds

Oil spills have harmful effects on birds including physical fouling of plumage, toxicity of ingested petroleum, and embryotoxicity. Damage may be caused by a few drops of oil on feathers or eggshells. Two excellent reviews of oil spill effect on birds (Leighton, 1993; King, et al. 2021) are available and provide an up-to-date compilation of effects.

Birds are commonly impacted by oil spills in riparian and wetland habitat. Waterfowl such as ducks, geese, swans, loons, cranes, and herons that depend on water habitat, as well as birds of prey and songbirds that occupy habitat near water are commonly oiled (King, et al., 2021). Oil coating has been better studied in seabird species than freshwater birds. However, literature from this area provides insight into the susceptibility of bird species in freshwater environments. Oil acts both chemically and physically, as it contaminates water and food sources and damages feathers. Oil coating of feathers reduces insulation, waterproofing, buoyancy, and flight abilities (NOAA, 2021). This can lead to death from exposure and may even cause drowning due to lack of buoyancy. Ingestion of oil may also be lethal. Preening to remove oil from feathers or feeding on oiled food items causes irritation in the digestive tract, which may cause death from starvation or infection. Likewise, oil-related compounds can be absorbed into tissues, causing death. Birds such as ravens, gulls, and eagles that scavenge on the carcasses of oiled birds may be especially susceptible to damage from a spill. Even at low levels of ingestion, reproductive success and development of young are retarded. Oil carried to the nest on the feet or body of nesting birds may also damage or kill eggs and young. Studies on murres, a Pacific seabird, have confirmed these effects. Szaro (1977). In addition to damaging feathers, oil can be ingested in large quantities as birds attempt to preen their coated feathers. Once its feathers are coated, a bird expends more energy on heating and movement. This is especially detrimental during nesting periods, when significant energy needs to be devoted to egg laying and care of young (Hartung, 1967).

5.2.1.9 Woody and Emergent Vegetation

The impact of spilled oil on floodplain and riparian habitat is generally assessed in terms of damage to woody vegetation (trees and shrubs) and emergent vegetation (herbaceous plants that extend above the water surface). The effects of oil on vegetation can be short term or long term (Gheorgh, et al., 2020). Short-term effects are associated with coating limbs and stems, which interferes with respiration and blocks the sunlight needed for photosynthesis. Coating, along with toxic chemicals in the oil, may disrupt plant function, cause leaf loss, and may cause death. Long-term effects are related to retarded seed germination and reductions in plant height,
stem density, photosynthetic rate, and biomass, all of which lead to ecosystem degradation. Long-term effects are also associated with post-spill conditions with weathered oil residuals and soil contamination (Baker, 1970).

Woody vegetation is found primarily in riparian zones and on floodplains. Plant forms vary from shrubs in the understory to trees. The response of woody vegetation to a spill may last weeks to years with initial effects such as leaf loss and growth impairment occurring in a few weeks, followed by long-term plant community change produced by spill residuals and the differential response of the species present to the chemicals in the oil type spilled (Chima and Cure, 2013).

The impact of oil spills on marshes, where emergent plants dominate the habitat, has been reviewed in a report jointly authored by the USEPA and the American Petroleum Institute (API) (Michel and Rutherford, 2013). Marshes and wetlands, which have standing water and little water movement, can be severely affected by an oil spill, and marsh habitats may take years to restore. This report makes the following key points:

- Oil type is one of the major factors determining the degree and type of impacts on marshes.
- Lighter oils are more acutely toxic than heavier oils.
- Heavy refined oils and most crude oils affect marshes through physical smothering of both leaves and soils.
- The extent of oiling on the vegetation is a key factor in the severity or longevity of effects. If only parts of the leaves are oiled, marshes can recover within one growing season.

Exposure to waves and currents that speed oil removal is another key factor. Other factors include degree of contamination of the soils, time of year, and different sensitivities among plant species.

In summary, the impact of spilled oil on vegetation may not be immediately evident, but long-term effects should be expected.

5.2.1.10 Case Studies of Oil Spills in Riverine Ecosystems and Their Effects on Species

In addition to the literature review above, projecting impact of an oil spill in the Bad River can benefit from a review of documentation of the damage caused by past spills. Two recent oil spills have been comprehensively assessed for damage following a structured process defined in the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund). In a Natural Resources Damage Assessment (NRDA), injury is identified and damage assessed. This process develops a comprehensive picture of impact. As a result of NRDA development, there now exists considerable documentation regarding the damage caused by oil releases into the Kalamazoo River in Michigan in 2010 and the Yellowstone River in Montana in 2011. The NRDA for both the Kalamazoo River and Yellowstone River report on biological sampling that initially focused on immediate spill impact and then used post-spill...
sampling to identify long-term injury. The value of these NRDAs is further enhanced by the fact that the species present in the Bad River are those typically found in Midwestern watershed ecosystems and are similar to the species reported on in the Kalamazoo River assessment.

Kalamazoo River (Marshall, Michigan)

In July 2010, Enbridge’s Line 6B in Michigan ruptured and spilled oil, which entered Talmadge Creek and flowed into the Kalamazoo River, a tributary to Lake Michigan. Diluted bitumen, a heavier product than the light crude oil and natural gas liquids transported in Line 5, was spilled during a flood-level river flow, and floodplains were inundated for six days. The Kalamazoo River is designated as a warmwater stream. It is bordered by wetland, forest, residential properties, farmland, and commercial properties. The Kalamazoo River is impounded by dams in many locations. The channel substrate is primarily gravel and rock with deep pools, backwaters, impoundments and other depositional areas with sand and silt substrate. The spill continued unchecked for approximately 17 hours, discharging an estimated 843,000 gallons of oil and traveling approximately 38 miles downriver. The magnitude of the spill produced local, state, tribal, and federal response. Response to the spill was rapid when the spill was finally noticed, but the initiation of cleanup activities was further delayed several days due to continuing high flows. The cleanup continued for more than two years.

The documentation of injury to the Kalamazoo River ecosystem was comprehensive. Environmental damage was reported in the Final Damage Assessment and Restoration Plan published by the USFWS with the Nottawaseppi Huron Band of the Potawatomi Tribe and the Match-E-Be-Nash-She-Wish Band of the Pottawatomi Indians in 2015. The primary difference in projecting oil spill impact between this case study and a potential oil spill in the Bad River is that Enbridge’s Line 6B released heavy crude oil in the Kalamazoo River, whereas Enbridge’s Line 5 carries light crude oil.

In-stream habitats were injured with damage varying based on habitat type, degree of oiling, and the actions taken to respond to the spill. Floodplain and riverine habitats were injured by a type of oil that rapidly sank, with recovery expected to vary from weeks to many years. Upland habitats were injured by response actions, including construction of roads and staging areas. Damage to wildlife was documented. Bird feathers were saturated in thick crude, making it impossible for coated birds to fly. The primary bird species affected were Canada goose (75%), mallard (9%), and great blue heron (5%). Muskrats and beavers, their fur soaked in oil, lost protection from the cold and ingested oil. The primary mammal species impacted were muskrat (45%), raccoon (13%), and beaver (13%). Turtles, frogs, and other reptiles and amphibians were oiled with high survival after cleaning. Nearly 3,000 turtles were captured, cleaned in a wildlife rehabilitation center, and released. Over 500 turtles were recaptured, cleaned again, and released. A few turtles were recaptured five separate times for cleaning after they had previously been cleaned. This reflects fidelity to preferred habitat that must be considered in spill response. The primary turtle species affected were common map turtles (77%), snapping turtles (11%), painted turtles (6%), and eastern spiny softshell turtles (3%). Only forty-two dead fish were found during initial response actions, but a fish health assessment reported in the NRDA indicated long-term effects. A year or more after the spill, injuries such as dermal lesions, fin damage, ventral, and ocular
hemorrhages continued to be documented. Mild-to-moderate congestion was observed in liver and kidney sampling months after the spill, suggesting the continuing presence, and ingestion, of contaminants. A USGS study assessed pathologies along with general fish health. This study confirmed that fish collected from oiled sites had significant adverse changes in bioindicators. (Papoulias et al., 2014).

The NRDA also identified injury to organisms and damage to habitat associated with the cleanup activities, including injuries from intense boat traffic, vehicles driving in the channel, and cleanup personnel walking in river channels. Injury level was quantified in terms of the percentage of the resource that was lost due to the spill. Initial overall injury levels from cleanup activities ranged from 50% in the areas with less oiling and less active remediation to 90% in areas where heavy oiling and intense and intrusive remediation activities, such as dredging, occurred. A summary of direct damage from cleanup was summarized in the NRDA:

…Excavation causes significant physical disturbance to the habitat by removing all habitat structure and function. Soil scraping, high pressure flushing, and agitation of submerged sediment to release oil remove significant [habitat] structure and function. Removal of woody debris and live vegetation has a lesser but still significant impact. Other actions such as placement of absorbent materials, vacuuming oil, and flushing with low pressure hoses all cause some impacts, such as soil compaction. Also, the presence of responders and the noise created by the response actions acted as deterrents to wildlife use of the areas. If multiple response activities took place in the same location, the Trustees assigned the higher injury level. Initial injury levels ranged from 70% to 100%.

(Papoulias et al., 2014)

The financial consequence of the spill was significant. The final damage assessment reported in the NRDA for loss of use and the survey, and assessment costs was over $1.7 billion. Enbridge has listed cleanup costs to the company at $1.2 billion.

**Yellowstone River (Montana)**

On or about July 1, 2011, oil spilled from a section of pipeline crossing under the Yellowstone River. The Yellowstone is the longest free-flowing river in the United States, sustaining exceptional natural resources. Sixty-three thousand gallons of crude oil were spilled during flood conditions, and the floodplain was inundated for approximately three weeks. Response was hampered by this extended period of high flows, delaying initial assessment of damage to fisheries until July 18 and the start of cleanup for several weeks. The spilled oil damaged the floodplain and river channel, spreading 85 miles downstream. The cleanup lasted for more than a year.

The NRDA found injuries from both spilled oil and the response activities undertaken in the cleanup. Injuries were found in terrestrial and riparian habitat and associated biota. One aquatic habitat type important in the Yellowstone River is debris piles. These piles occur throughout the Yellowstone and play an important role as a source of shelter and food for fish, invertebrates,
small mammals (e.g., mink), birds, reptiles, and amphibians, while providing surface area for the growth of aquatic invertebrates, which are an important food source for fish. Unfortunately, this important habitat, when contaminated by oil, harmed the wide range of biota that came into contact with the coated surfaces of the piles. Additional damage occurred as contaminated piles were removed in the spill response, producing a loss of critical habitat along with the disturbance from removal. The NRDA reported that oiled aquatic habitat caused injury to fish. Birds were also injured, particularly cavity nesting species and the American white pelican. Human service losses included recreational angling and park use (State and Federal Trustees, January 2017).

Active cleanup responses continued for four months following the spill. The NRDA estimates that it will take from three to twenty years to return the Yellowstone River ecosystem to baseline conditions depending on the level of oiling, type of habitat, and type of response activity conducted at the cleanup location. Cleanup activities damaged habitats through trampling and crushing vegetation with mechanized equipment, cutting and removal of grasses and woody vegetation, and the physical disturbances caused by the presence of crews and machinery. The NRDA divided injuries from the spill into categories that included terrestrial/riparian habitat and biota (including cavity nesting birds), large woody debris piles, riverine aquatic habitat and biota, American white pelican, and human recreational uses.

5.2.2 Oil Release Impacts in the Bad River Watershed

Section 5.2.1 summarizes scientific literature and reporting on past oil spills, documenting oil spill effects that can be expected across taxonomic groups and habitats common to all freshwater ecosystems. This section (Section 5.2.2) focuses on projecting the impact of oil spilled from Line 5 on taxa found in the Bad River watershed, considering the expected spatial and temporal location of species during an oil spill. This analysis uses the likely habitat exposure of key species based on the projected spread of oil through Bad River habitats, considering spill scenarios in which the oil reaches the Kakagon–Bad River Sloughs or reaches the Bad River floodplain under flood conditions. The literature review and case studies of other oil spills from Section 5.2.1, along with local data and the discussion of oil spill scenarios in the Bad River in Section 5.1, provide the foundation for projecting oil release impacts in the Bad River watershed.

5.2.2.1 Factors Affecting the Severity of Impact Based on Habitat Exposure in the Bad River

A wide range of possible environmental impacts is possible depending on the specific circumstances of an oil spill, from relatively minor impacts caused by a quickly detected pinhole leak to much greater—and even catastrophic—impacts from a full-bore rupture in flow conditions that either remain in the river channel or inundate the floodplain. Factors affecting spill impact include the composition of the oil released, the nature of release (e.g., small leak to full bore discharge), spill volume, spill duration, and the effectiveness and possible damage of any emergency cleanup measures. Factors related to fate and effect, which also influence the spill’s impact, include river flow rate (discharge), the composition of oil released, oil mixing, oil transport, the in-channel habitat exposed to oil, and the extent of oil contamination outside of the channel banks and in the floodplain. Seasonal factors include temperature (which has a bearing on the presence of ice cover and spill mixing effects), changes in spilled oil composition and weathering over time and distance, and ecological conditions, such as the physical presence of migratory
animals and early life stages of resident species. Beyond consideration of the factors above, some sense of overall impacts likely in a full-bore scenario during flood conditions can be learned by reviewing the descriptions of the spills on the Kalamazoo River and the Yellowstone River (Section 5.2.1.10 and Appendix D, Section D.4.1.4), including how spill response is influenced by flood duration.

In the Section 5.1 spill calculations, it is projected that the spilled oil will rapidly lose volatile compounds to the environment with as much as 37% of the spill mass evaporating by the time the spill reaches the Kakagon–Bad River Sloughs, depending on the scenario. Also depending on the scenario, up to 35% of the oil by mass will adhere to the vegetation and channel banks, and a small percentage (roughly 1%) will disperse in the water column. The remainder, ranging from 25% to 60% of the spill mass, depending on the scenario, will float on the water surface. This floating oil is expected to move downstream with the velocity of the river.

Another critical factor in assessing the projected impact of an oil spill is the Bad River flow rate, or discharge, at the time of the spill. Flow rate and local channel configuration combine to determine the depth and velocity of flow, which, in turn, are related to the speed at which spilled oil moves downstream. Flow-related depth is referred to as river stage. Flood stage occurs when floodplains are inundated, which has a bearing on which habitats would be affected by the spilled oil.

At lower flow rates, with corresponding lower channel depths, the exposure of habitat to oiling occurs along the river and its immediate channel banks. For example, spill effects would be limited by channel boundaries with the lower parts of the bank being the primary location for adhesion, while oil dispersion may be reduced by lower flow-related turbulence. At lower flow rates, floating oil and sheens will move more slowly downstream reflecting lower channel velocities. Under both spill volume scenarios evaluated in Section 5.1, oil floating on the surface would reach the sloughs, with associated impacts to local vegetation and wildlife.

At higher river flow rates that are still contained within the channel banks, oil would be transported more quickly downstream. In addition to the more rapid downstream movement of the oil, this condition results in less time for evaporation to occur before the oil reaches the sloughs and Lake Superior. Adhesion of the oil to the channel banks would still occur from Line 5 down the river and to the sloughs.

If the banks are overtapped at the time of or during an oil spill, the habitat exposed to the oil increases as floodplains are inundated. In the floodplain, vegetation is oiled and wetlands and oxbow lakes are exposed to oil. Exceeding bankfull discharges has a recurrence frequency of approximately two years in the Bad River, so floodplain inundation is not a rare occurrence. If the discharge continues to increase, more floodplain area will be inundated and there will be increasing connectivity with floodplain lakes and marginal wetlands with attendant oiling.

Unlike the heavy crude oil spilled in the Kalamazoo River, which tended to sink, the light crude oil and natural gas products transported in Line 5 would behave differently after the spill. In the Bad River, the mass of floating oil will change over time and distance primarily as a result of evaporative losses and adhesion coating channel banks, debris, and vegetation. This floating
fraction is expected to spread over the water surface and travel downstream with the velocity of the river. The floating oil fraction has the highest potential for immediately damaging the Kakagon–Bad River Slough complex.

Mass loss of oil to evaporation and adhesion will reduce the oil mass over time as the oil moves downstream. Initially, there will be increased evaporative losses producing odor and irritants from VOCs. Under all spill scenarios considered in Section 5.1, however, oil will adhere to banks downstream of the spill site for the entire reach of the river from Line 5 to the sloughs, and a floating fraction will reach the Kakagon–Bad River Slough complex, with associated impacts to local vegetation and wildlife.

The case studies in Section 5.2.1.10 and Appendix D, Section D.4.1.4 describe effects that can be expected from oil spills occurring during flood conditions. Following flooding, floodwaters will recede, thereby leaving oil residuals on vegetation, debris, and soils. These residuals, if not removed, will weather and have the potential for ecosystem injury for extended periods. NRDA damage assessments estimated that it would take two to twenty years for the Kalamazoo and Yellowstone ecosystems to return to baseline.

Other issues in spill dynamics are delays in spill response caused by remoteness or flood conditions that limit access to locations exposed to the spilled oil, as well as damage caused by containment and cleanup activities beyond injuries from the spilled oil. The remote location, lack of access roads, and difficulty of boat operation at both high-flow and low-flow conditions of the river will create challenges for cleanup activities.

5.2.2.2 Assessment of Habitat Exposure and Oil Spill Impacts on Key Species in the Bad River Watershed

As indicated by Section 5.2.1, oil spills are a common environmental problem with extensive literature documenting the biological/ecological consequence of oiling. In its Fact Sheet, How Oil Harms Animals and Plants in Marine Environments, NOAA has succinctly summarized the consequence of oil spills and response and cleanup operations for biota, as well as the ultimate factors that affect the severity of an oil spill on local plants and animals:

In general, oil spills can affect animals and plants in two ways: from the oil itself and from the response or cleanup operations...Spilled oil can harm living things because its chemical constituents are poisonous. This can affect organisms both from internal exposure to oil through ingestion or inhalation and from external exposure through skin and eye irritation. Oil can also smother some small species of fish or invertebrates and coat feathers and fur, reducing birds’ and mammals’ ability to maintain their body temperatures. (NOAA, 2021)

Ultimately, the effects of any oil depend on where it is spilled, where it goes, and what animals and plants, or people, it affects. (NOAA, 2021)

A habitat exposure analysis that connects the likely location of spilled oil with the likely presence of organisms is therefore an appropriate method to project the possible severity of effects of an
oil spill from Line 5 at the Bad River meander under various scenarios. The calculations regarding the fate of oil in the Bad River in this report (Section 5.1) indicate that the habitat exposure approach must include oil spill impacts in-channel and downstream of Line 5 at the meander, including impacts to the Kakagon–Bad River Slough complex, which is the largest undeveloped wetland complex in the Great Lakes and an exceptional natural resource of international importance. Moreover, while under many scenarios an oil spill would be contained within the banks of the Bad River, at least until it reaches the slough complex and Lake Superior, the relative frequency with which the Bad River overtops its banks (see Section 3.3) necessitates an assessment of potential environmental impacts from an oil spill during flood conditions, which would extend habitat exposure and effects well beyond the river channel. This analysis therefore accounts for this range of scenarios, including a worst-case oil spill scenario involving a full-bore release of oil into the Bad River during spring flood conditions when the riverbanks are overtopped.

The adhesion of oil to surfaces is expected to coat banks, debris, and vegetation within the channel downstream of the spill, and across inundated portions of the floodplain, or both. Longer-term effects may develop from oil adhering to surfaces as adhered oil and weathering products enter soils. In addition, spill fractions that have adhered to sediment may accumulate in depositional habitats in the river channel. These accumulations of contaminated sediment can be remobilized by higher flows. This remobilization would expose aquatic organisms to oil, oil residues, and oil weathering byproducts as the organisms move or resettle. Sediment-attached oil can produce chronic impacts that extend the effect of a spill for years.

In the channel, oil adhering to banks, sediment, and in-channel debris also has a complex, time-related ecological impact on fish and other aquatic organisms. Debris accumulations are a source of shelter and food for fish, invertebrates, small mammals, birds, reptiles (particularly turtles in the Bad River), and amphibians. The debris accumulations provide surface area for the growth of periphyton and aquatic invertebrates, a major food resource for fish, but the debris also provides abundant surface area for oil coating. An interaction with the coated debris surfaces results in coated animals such as aquatic invertebrates, a foundation for the aquatic food chain. As described in the literature review at Section 5.2.1.4, damage mechanisms for invertebrates includes smothering and toxicity. As also discussed in Section 5.2.1.6, if fish ingest contaminated invertebrates, they may suffer a range of sublethal effects that include changes in heart and respiratory rate, enlarged livers, reduced growth, fin erosion, cancer, reproductive impairment, skeletal deformities, and organ (gill, skin, kidney) alterations. Fry and juvenile fish are particularly susceptible to contamination of invertebrates because this group is the primary food source. Because fish spawn only once a year, injury to early life stages produce population declines in future years.

Some portion of any oil spill will end up floating on the water surface. As demonstrated in the Kalamazoo and Yellowstone River spills, oil on the water surface will spread across the floodplain in flood conditions and will be deposited as the water recedes. For a spill in the Bad River, contained within the river channel, the calculations in Section 5.1 predict that about a quarter of the spilled oil, by mass, will end up floating on the water surface under the 2,000 barrel spill scenario and almost two thirds under the 20,000 barrel spill scenario by the time the oil first
reaches Lake Superior. Floating oil will reach Lake Superior, presenting a major threat to marsh grasses, including wild rice, in the Kakagon–Bad River Slough complex. Floating oil and oil sheens rapidly spread over large areas, particularly in the calm waters of sloughs, marshes, and wetlands.

Floating oil will come into contact with plants at the water surface, causing damage to emergent vegetation. Oil will coat vegetation and seal stems, stalks, and leaves, preventing or interfering with respiration (gas exchange) and growth. In addition to smothering a plant, the oil can also result in toxicity. Stalked plants, including wild rice, are particularly vulnerable in the growth stage. Further, as flood waters recede, more plant stalk area is exposed to oil. When flooded areas dry out, the floating oil will contaminate soils, exposed shallow bars in sloughs and wetlands, channel banks, and previously inundated floodplains.

A Bad River watershed feature particularly vulnerable to an oil spill is the Kakagon–Bad River Slough complex 16 miles downstream from the Line 5 crossing. This 16,000-acre wetland complex has been designated a Ramsar Wetland of International Importance and is an important spawning and nursery area for fish, a critical stopover habitat for migratory birds, and has the largest natural wild rice beds in the Great Lakes basin. Floating oil can cause the oiling of feathers and fur of animals that occupy this important habitat. Oiling bird feathers changes tolerance to cold and can prevent birds from flying. Oiling mammals reduces their fur's ability keep them warm. These types of injury may be short-lived and mitigated through rapid cleanup, but the relative isolation of the slough complex will complicate access and increase response time, producing oiling mortality. The complex is particularly vulnerable in the spring when early growth stages of the rice are present. This is also the time when eggs and fry of walleye, which are particularly susceptible to oil contamination, are present in the slough. In Section 5.1, oil spill calculations for a spill during a 5,000 cfs flow event indicate floating oil would reach the sloughs complex in less than 23 hours.

Dropping water levels after the flood peak produce additional oiled surfaces and will leave residuals and contaminate soils. Soil contamination can have long-term consequence because soil microbial communities, insects, and vegetation will be exposed to oil residuals until cleanup or natural processes remove contaminants.

The remainder of this section addresses the ecology and physiology of selected species/groups in the Bad River watershed and relates factors such as development, reproduction, feeding, and habitat to potential oil spill impacts. This approach facilitates a more detailed understanding of potential vulnerabilities and impacts to organisms of ecological and cultural importance to the Band. The selection of species evaluated is based on the list of the Band’s protected species (provided in Appendix B) and the Assessing Potential Non-Economic Loss and Damage from Climate Change (NELD) (Dooper et al., 2018) report. Species evaluated include fish (both game and non-game species as well as impacts to subsistence and commercial fisheries), mussels, birds, mammals, and wild rice. An oil spill will have direct impacts as well as indirect, radiating impacts throughout the food chain. For example, walleye and wild rice are a food source for the Band as well as for animals in the watershed. Under many scenarios, a spill from Line 5 would thus be damaging on an ecosystem scale.
5.2.2.2.1 Fish

Forty-eight fish species are reported in the Bad River downstream from the confluence with the Marengo River, including migratory species (lake sturgeon, walleye, white and longnose sucker, and silver and shorthead redhorse). Resident fish species include northern pike, muskellunge, yellow perch, smallmouth bass, rock bass, and a variety of forage and minnow species. The Kakagon–Bad River Sloughs are an especially important fishery, providing critical spawning and nursery areas for walleye and lake sturgeon and habitat for cool water species, including northern pike, yellow perch, smallmouth bass, rock bass, bluegill, pumpkinseed, black crappie, black bullhead, white and longnose sucker, and silver and shorthead redhorse. Forage fish and minnow species are also present, but the sampling to develop a comprehensive species inventory has not been conducted (Elias, 2001). The Bad River is regionally important habitat for the lake sturgeon, supporting one of only two self-sustaining spawning populations remaining in the U.S. waters of Lake Superior (Chowlek et al., 2005).

Walleye, sturgeon, and perch are fish species of central ecological and cultural importance to the Band. For example, nighttime spearfishing of walleye is a highly valued traditional practice. Fish species at risk of an oil spill are not restricted to within the Reservation boundary. As described in Appendix B, the Band operates a commercial fishery that predominantly takes lake trout and whitefish from Lake Superior. As described in Section 5.1.2, under all oil spill scenarios modeled, oil would reach Lake Superior. Consequently, valuable resources both on- and off-Reservation would be impacted by a spill.

Section 5.2.1.6 describes oil spill impacts to fish based on various case studies and experiments. To summarize, a large die-off of fish can occur immediately following a spill. Oil-sediment emulsions can also be hazardous through the impairment of gill function. Chronic sub-lethal effects are possible, depending on the degree to which oil persists in aquatic environments. Sublethal toxicity can affect growth, reproduction, and development for years following a spill. In short, if there is an oil spill in the Bad River, it would be expected to cause both immediate injury to fish, potentially including fish die-offs, and long-term sublethal effects to individual species and, in turn, population sustainability. The effects of a spill from Line 5 would be expected to produce similar impact to walleye and lake sturgeon (Section 5.2.2.2.1.2 and Section 5.2.2.2.1.3) and to the 46 other fish species in the Bad River. Fish kills and sublethal effects would vary by species, but it is certain that fish community structure and function will be altered immediately, and the effects of those alterations will extend well into the future.

The Band’s commercial fishery and subsistence fisheries, which are more fully described in Appendix B, are valuable resources that would be at risk in the event of an oil spill. Appendix B provides annual catch statistics that help contextualize the value at risk. Any spill from Line 5 would affect a range of game and non-game fish species in the immediate vicinity of the pipeline. With respect to subsistence fishing on the Reservation, an oil spill could cause immediate fish die-off in addition to chronic impacts to development, growth, and reproduction. Moreover, bioaccumulation of PAHs could temporarily remove fish as a viable food source for humans due to bioaccumulation in subsistence and commercial species. In sum, the subsistence and commercial fisheries, including walleye, lake trout and white fish, are valuable ecological,
cultural, and economic resources. An oil spill at Line 5 would have direct impacts to these fisheries, which would be immediate and could persist for years depending on the form and degree to which oil persists in the environment and affects fish populations.

5.2.2.1.1 Effects on Lake Trout and Whitefish

Both lake trout and whitefish spawn in late autumn or early winter on shoals and reefs with depths of four feet or greater. Eggs develop and hatch in the spring. Lake trout juveniles then move to deeper waters to feed and grow while lake whitefish juveniles move to shorelines before moving to deeper waters to feed and grow (Minnesota Department of Natural Resources [MDNR] No Date; Michigan Sea Grant, No Date; Bob Izumi, No Date; Callaghan, et.al. 2016). Both species are long lived (Michigan Sea Grant, No Date; Bob Izumi, No Date; Callaghan, et.al. 2016). The shorelines of the Reservation and reefs near the Apostle Islands serve as key spawning habitat for both lake trout and whitefish, as shown on Figure 75 and Figure 76, University of Wisconsin GIS Map. Fish eggs and juvenile fish are particularly susceptible to oil spills (Dupuis and Ucan-Marin, 2015). Given the Apostle Islands' regional significance as a fish nursery (discussed in Appendix B), oil reaching Lake Superior could have spatially and temporally far-ranging effects in these near-short habitats.
Figure 75: Lake Superior Spawning Sites for Lake Trout (UW-Madison, No Date)

Figure 76: Lake Superior Spawning Sites for Lake Whitefish (UW-Madison, No Date)
Each of the oil spills modeled in Section 5.1 indicates oil would reach Lake Superior. While the dynamics of oil reaching the lake has not been modeled for this report, any scenario where spilled oil reaches Lake Superior is germane to the Band’s commercial fishery. Aerial imagery is one informative source on transport dynamics in Lake Superior, as the path of sediment-laden discharge from Bad River flooding is generally transferrable to how a pollutant plume would move (see Figure 77). Locations with high sediment concentrations (e.g., most of the coastline of the Bad River Reservation) would be likely places for oil accumulation. NOAA provides monthly depth-averaged current maps, as shown on Figure 78. Seasonal differences in current velocity are an important factor in determining the spatial extent of an oil slick and the accumulation of oil at certain shoreline locations. The exact fate of oil entering Lake Superior from the Bad River is not predicted in this report but based on known effects of oil in aquatic ecosystems and the presence of critical habitat for the highly valued lake trout and lake whitefish, there is a clear concern that persistent oil contamination can damage these valued species. That damage is most likely caused by contamination of food resources, particularly for forage species that inhabit the lake shoreline vegetation habitat.

Figure 77: Sediment in Lake Superior Resulting from June 2012 Precipitation (Myers, 2012)
Figure 78: Depth-Averaged Currents in Lake Superior (NOAA/GLERL, 2019)

5.2.2.2.1.2 Effects on Walleye

Walleye is a well-studied game fish that is also a primary component of the Bad River Band subsistence fishery. Walleye are an adaptable species found throughout rivers and lakes in the Great Lakes region. Overfishing, pollution, and dam building have greatly reduced walleye populations, however. The Kakagon and Bad rivers have both been identified as areas in need of walleye population rehabilitation (Hoff, 2001).

While lake and river populations tend to remain in their respective systems, migration is not uncommon, especially in the early lifecycles and near river outlets (Bozek et al., 2011). Walleye generally prefer waters with moderate to high turbidity (up to 125 NTU), summer temperatures of 70 to 72 degrees Fahrenheit, and slow-moving currents (Regier et al., 1969; Suedel et al., 2012). Highly eutrophicated waters, with summer temperatures above 75 degrees Fahrenheit and total nitrogen above 0.4 ppm, are considered detrimental to walleye growth and survival. Walleye eyes are adapted to low light conditions and walleye thrive at catching prey during dusk and nighttime and in moderately turbid waters.

Depending on the season, walleye utilize different habitats in a watershed, preferring transitional channel morphology (i.e., rapids and riffles) and deep pools in the summer months and shallower waters during the winter and fall months. Given this, walleye would be expected to migrate between different portions of the Bad River watershed and reside in the Bad River’s main channel, oxbow lakes formed by cutoff meanders, the Kakagon–Bad River Slough complex, and Lake Superior. Walleye tend to spawn in coarse gravel and cobble environments and overturn finer material to wedge and secure eggs (Paragamian, 1989). However, high rates of channel-bottom sedimentation and concentrations of suspended sediment (>500 mg/L) may be detrimental to larval hatching success (Suedel et al., 2012).

Exposure to oil can have detrimental effects on walleye. If fertilized eggs encounter oil and walleye are exposed at an embryonic stage, the embryos can experience developmental abnormalities. If juveniles are exposed through contact or ingestion, effects can include mortality,
cardiovascular abnormalities, and spinal curvature. If adults are exposed through contact or ingestion, expectations are for poor health with greater numbers and severity of skin lesions, fin damage, and hemorrhages. These effects are commonly found in low level exposures of walleye to polycyclic aromatic hydrocarbons (PAHs), which are common in oil.

Habitats particularly vulnerable to spilled oil are slack water locations where suspended sediment settles (depositional habitat) and contaminated sediment accumulates. The quiet waters of the Kakagon–Bad River Slough complex are particularly vulnerable to this settling, as well as floating oil and sheens. Walleye spawn in the early spring. When walleye spawn in lakes and sloughs, they typically spawn along shorelines in the same sedges or grasses that are easily coated by oil. In rivers, walleyes usually spawn in rapids and riffles, where there is adequate flow and oxygen for egg development. Eggs are broadcast, fertilized, and settle. The fertilized eggs may be transported by currents to areas where contact with oiled surfaces and contaminated sediments is a risk. Hatching time varies from one to four weeks, depending on temperature, such that the fertilized eggs may be exposed to oil as the spill dynamics play out.

Feeding habits, food size, and food composition change over the life cycle of walleye, presenting varied ingestion risk over time. In the early life stages, walleye feed upon a diverse array of small food items, including rotifers, diatoms, and zooplankton (Regier et al., 1969), which are vulnerable to oil coated surfaces and contaminated sediment. Larval walleye may be prey for yellow perch and white bass. Adult walleye, on the other hand, are top predators in freshwater ecosystems, producing a high risk of contaminant ingestion. Further, as adults, walleye prefer habitats with moderate to high turbidity and slow-moving currents, which is a depositional habitat that accumulates contaminated sediment. In the winter and fall months, adult walleye prefer shallow conditions and the faster flows in rapids and riffles. In the summer months, adult walleye prefer deep pools, another depositional habitat, where exposure to contaminated sediment is possible. Consequently, while the seasonal timing of an oil spill will determine if all life stages of walleye are present in habitats vulnerable to spilled oil, adult walleye can be exposed to spill residuals year-round in preferred habitat. If a worst-case scenario occurred, in which an oil spill occurred during the spring spawning season and oil persisted in preferred walleye habitats within the Bad River and sloughs over the summer months, an oil spill could prove devastating to the population of walleye in the Bad River.

5.2.2.2.1.3 Effects on Lake Sturgeon

Lake sturgeon is the largest fish species (up to eight feet long and 300 pounds) found in the Great Lakes region. They travel through many portions of the Bad River watershed, from fast-moving, rocky headwaters reaches to sloughs and lakeshores with water depths of 20 to 30 feet (Schloesser, 2013). Overfishing, especially for caviar production, and hydroelectric dams pose major threats to sturgeon. Because of declining populations, the sturgeon has been the focus of multiple management plans, including a plan for the Bad River. The Bad River is regionally important habitat for this species, as it “… supports one of only two self-sustaining spawning populations remaining in the U.S. waters of Lake Superior” (Chowlek et al., No Date).
Sturgeon are a benthic species and utilize a filter-like mouth for obtaining food from sediments. During feeding, they intake large quantities of sediment containing leeches, snails, clams, fish, and insect larvae and expel excess sediment (Peterson et al., 2006).

Adult lake sturgeon spawn from late spring to early summer (from mid-April to early June) in the upper part of the Bad River basin near Copper Falls. Sturgeon spawning begins once water temperature is consistently in the 50 to 60 degrees Fahrenheit range (Peterson et al., 2006). During spawning season, adults migrate from Lake Superior upstream to course gravel or cobble stream reaches with higher velocities, spawn, and then immediately return to Lake Superior. In the Bad River, spawning is most frequently observed at the lower falls area (Schloesser, 2013), which is located approximately six miles along the river upstream from the Line 5 crossing. Females only lay eggs every five to nine years but may produce up to 500,000 eggs during a spawning season. Among fish species, sturgeon have exceptional longevity; females may live up to 150 years.

Sturgeon eggs hatch and fry drift downstream, feeding and growing along the way. Early juvenile stages remain in the river mouth and eventually move to Lake Superior as juveniles.

A spill from Line 5 during spawning would mean that the adult sturgeon would need to move through contaminated habitat in the lower part of the Bad River, both on their way upstream to spawn and on their migration back downstream to Lake Superior. Both ways, they would eat bottom dwelling organisms that may be contaminated (Billard and Leconte, 2001). Drifting fry would be exposed to oil residuals and find contaminated food resources. The early juvenile stage that remains in the river mouth would face extended exposure to oil spill components. Since sturgeon are bottom feeders, they would likely ingest coated food in contaminated sediment, but they can also sorb oil related contaminants through their skin. Various studies have documented that exposure to oil for only a few days can result in a significantly increased morality rate, induce lesions, and cause physiological and biochemical disorders, tumors, and abnormalities in development (Jahanbakhshi and Hedayati, 2013a; Jahanbakhshi and Hedayati, 2013b).

Lake sturgeon populations are at risk from an oil spill at all life stages, from the loss of drifting fry and juveniles to injury to adults. Adult sensitivity to oil contamination means that lake surgeon can be injured, even though individual organisms spend only a few days in the Bad River. Since spawning is irregular—only once every two to seven years for some individuals—the loss of a single spawning period due to an oil spill would have a negative long-term impact on the sturgeon population.

5.2.2.1.4 Effects on Yellow Perch

Yellow perch are a widely distributed species that has been widely introduced to provide a forage base for bass and walleye (University of Michigan, Animal Diversity Web; U. S. Fish and Wildlife Service - Walleye). The Bad River Tribal Fish Hatchery can raise up to four million yellow perch eggs for release into the Kakagon–Bad River Sloughs. For example, in 2017, 150,000 perch were released. Although they may be found in waters up to 50 feet, yellow perch prefer sloughs and shorelines of large and small lakes, spawning and living in shoreline vegetation. They may also be found in slow moving rivers (Krieger et al., 1983). Perch spawn in the spring in large
groups, leaving ropes of eggs on shoreline vegetation. The eggs hatch in 11-27 days, they mature in two to four years, and live nine to ten years. Juveniles initially feed on zooplankton and by Year 1 forage on macroinvertebrates. Adults feed on crayfish, shrimp, clams, aquatic grasses, and juvenile and embryonic walleye. Notably, perch are a key food source for walleye.

Perch are extremely vulnerable to an oil spill in the Kakagon–Bad River Sloughs where oiling of shoreline vegetation is expected. Oiling of the primary habitat of yellow perch could impact all life stages of resident perch, particularly the early life stages that may be present for up to two years. The primary food resources of yellow perch are readily oiled, subjecting all life stages to damage caused by oil ingestion. Since perch are a forage fish for walleye, spill effects that cause a decline in perch populations may radiate upward to walleye (Brown et al., 2009).

5.2.2.2 Effects on Freshwater Mussels

In the Great Lakes region, there are numerous native bivalve species in the Unionidae and Sphaeriidae families. The black sandshell, eastern elliptio, eastern floater, fatmucket, and fluted-shell mussels have been reported in the Kakagon–Bad River Sloughs (Wisconsin Aquatic and Terrestrial Resources Inventory and Wisconsin DNR, 2022). Native mussels are an integral component of aquatic ecosystems because they filter particulate matter from water, and in the process may remove pollutants from water (Badra, 2004). Mussels are adaptable to different fluvial habitats, but generally reside in pools and banks as opposed to riffle and run habitats (Neves and Widlak, 1987). Mussels prefer mixtures of gravel and sand, with low silt contents. Mussels are filter feeders, with specialized feeding structures through which to extract sediment and organic matter, such as bacteria and algae, from water. In rivers and lakes, mussels remove sediment and pollutants (i.e., from eutrophication) and redistribute benthic sediments to release organic matter elsewhere in the food chain. As with other bivalves, freshwater mussels have a specialized life stage--glochidia--that attaches to foraging fish and transports larvae to new locations. Larvae may remain attached to fish for weeks before dropping and binding to benthic sediment. Mortality rates are highest during the transition between eggs and larvae (i.e., before the organism latches onto fish).

Mussels are sessile (i.e., unable to move). They are therefore highly vulnerable to oil spills because they cannot move away from their preferred habitat if it becomes coated with crude oil during a spill. Further, as active filter feeders that pump water through their bodies, they are prone to accumulating oil and contaminated sediment (Dupuis and Ucan-Marin, 2015). Oil droplets and oil contaminated suspended solids are primed for uptake by bivalves. The contaminant concentration required to kill half the population, or LC50, for larval mussels has been documented in the 1.14 to 1.83 TPH (total petroleum hydrocarbons)/L range. PAHs can strongly bioaccumulate in mussels. In another study that examined the 48-hour toxicity of PAHs to the glochidia and juveniles and the sub-acute toxicity to adult mussels, no acute effects for any life stage were found, but possible genetic damage in adults was found (Humphreis, 2006). Another mechanism of impact to mussels is fish mortality that hinders larval transport and dispersal. Mussels are also subject to physical damage. In the Kalamazoo River damage assessment, broken mussel shells were found as evidence of damage caused by machine and human transit of mussel beds.
Oil spill damage to mussels, along with other macroinvertebrates, will be related to chemical compounds in the spilled oils, specifically PAH, oil coating, oil ingestion, and physical damage due to cleanup activities. Although laboratory testing found no acute toxicity, bioaccumulation of PAH points to the effects of coating and ingestion. The bioaccumulation found in studies presents a risk of food chain effects to predators, mainly fish. The most immediate effect of an oil spill is physical. Sampling in the Kalamazoo River found mussels were crushed by vehicles and personnel transiting mussel beds as a part of cleanup. Further, because mussels are dependent on fish hosts for successful reproduction, fish population decline after a spill will have a long-term effect on mussels.

For these reasons, considerable mussel mortality should be expected in the wake of an oil release into on- and off-Reservation waterways downstream of the Bad River meander. Finally, mussel mortality from toxin uptake could adversely impact long-term water quality in the Bad River watershed because those individuals will no longer remove pollutants from the water.

5.2.2.2.3 Effects on Amphibians and Reptiles

A review of the literature in Section 5.2.1.5 indicates mixed impact of oil spills on amphibians and reptiles. Based on the assessment of the Kalamazoo oil spill, it is possible to project the effects of an oil spill in the Bad River. There is an abundance of amphibian habitat in the Bad River watershed. The projected effect of an oil spill on amphibians in the Bad River could be severe depending on the timing of the spill. In lab tests, tadpole growth was impaired, and at high test concentrations, no tadpoles metamorphized to adults (Mahaney, 1994). However, oiled amphibians from the Kalamazoo River spill were cleaned and released alive. This indicates critical vulnerability of the early life stages of frogs and limited impact on adults. Reptiles, particularly turtles, showed little impact from spilled oil in a field study in Pennsylvania where Saba and Spotila (2003) found high survival in oiled turtles. In the Kalamazoo River spill, over 3,800 oiled turtles were captured, cleaned, and released with a significant recapture rate, indicating they returned to oiled habitat but suffered relatively little consequence from the oil. However, studies have shown toxicity and lasting effects from PAHs, such as musculoskeletal deformities, tumors, and decreased hatching success, in early life stages of turtles (Van Meter et al., 2006; Zychowski and Godard-Codding, 2016).

An oil spill in the Bad River would have major impact in the spring when amphibian eggs and tadpole stages are present, but potentially lesser effects on adult amphibians. While adult turtles in the Bad River may not suffer severe effects, any oiling of turtle eggs would have a significant impact on unhatched and juvenile turtles.

5.2.2.2.4 Effects on Birds

The Bad River watershed provides excellent riparian and wetland habitat for water birds, such as ducks, geese, swans, loons, cranes, and herons. Additionally, there is a wide variety of birds of prey and songbirds in the area. Duck, swan, owl, and eagle were identified as key culturally important species in the NELD report (Dooper et al., 2018). The sloughs and shorelines along Lake Superior are especially important as a migration corridor and stopover for passerines, raptors, shorebirds, and waterbirds.
Many duck species utilize Great Lakes shoreline ecosystems for year-round residence, winter migration, and summer breeding. Prevalent species in northern Wisconsin include the mallard; green-winged Teal; common, hooded, and red-Breasted Merganser; the ruddy duck; and ring-necked duck. These species are mostly generalists and eat a wide variety of macroinvertebrates, seeds, mollusks, and aquatic and riparian grasses. Red-breasted mergansers rely on a narrower diet of fish and crustaceans (USFWS, January 18, 2018). In addition to having different food preferences, these species utilize different nesting habitats. While most species utilize grasses, sedges, and wetland habitat within a couple hundred yards of water, hooded mergansers build nests in tree cavities (The Cornell Lab of Ornithology, 2018.). These duck species reside along Lake Superior during different times of the year. For example, hooded mergansers breed in northern Wisconsin, mallards are found in this region year-round, and red-breasted merganser migrate through the area and generally are found in large lakes rather than along shorelines.

Other regional and local avian fauna include common loon, great blue heron, Canada goose, snow goose, and trumpeter swan (USFWS, January 10, 2018). These birds occupy different niches in the Bad River watershed over the course of the year. Common loons need large areas of open water to dive for small fish in clear, deep lake waters. Herons, in contrast, utilize habitats ranging from marshes to riverbanks, and generally build nests in trees. They eat a variety of fish, amphibians, insects, and small birds. Seasonal differences in the species present in this habitat also exist; the Canada goose is found year-round in northern Wisconsin, whereas the snow goose migrates through the area to breeding grounds in northern Canada. Trumpeter swans historically ranged more extensively in the Great Lakes but now are only found in isolated patches of the area.

In the Kakagon–Bad River Sloughs, the wetland complex supports a wide diversity of breeding species that include yellow rail, Virginia rail, northern harrier, sedge wren, Le Conte’s sparrow, northern waterthrush, Blackburnian warbler, and golden-winged warbler. The forested river corridors are particularly important for breeding neotropical migrants such as ovenbird, Canada warbler, Nashville warbler, black-throated green warbler, and mourning warbler.

Finally, the bald eagle warrants special consideration in the context of any oil spill scenario (WDNR, 2022b). The bald eagle holds cultural significance to the Band and has 220 miles of potential nesting habitat on the Reservation (see Figure 79). Nesting habitat includes riparian areas along all the Bad River, the Potato River, and the White River, the slough complex, and the Lake Superior coastline (WDNR, 2022a).
The effects of an oil spill on a specific avian species in the Bad River watershed are dependent upon the location of the spill, the season of a spill (as it relates to migratory patterns), as well as the species diet, habitat, and other ecological considerations.

In the Bad River watershed, water birds (e.g., ducks, swans, and herons) would be particularly vulnerable to an oil spill given the amount of time they spend on the water. Each of these species would be affected by coating and associated internal damage. These populations could also face die-off from ingestion of oil from preening and oil contaminated primary food sources. Ducks are omnivorous and because the diets of each of these species vary, effects will vary with ingestion. Ingestion of contaminated food will cause the poisoning of kidneys, liver, lungs, intestines, and other internal organs, causing death. Waterfowl such as ducks and geese nest in marsh grasses and wetland habitat near water bodies and shorelines where oil accumulation on plants can be transferred to birds making nesting habitat dangerous to both birds and eggs. Generalist species such as the great blue heron would likely be more adaptable and not as vulnerable to oiled habitat. Nevertheless, each of the heron’s food sources is susceptible to oil contamination and

Figure 79: Eagle Nesting Habitat on the Bad River Reservation (Band NRD, 2019)
poisoning. Bald eagles would be very vulnerable to a spill. Eagles come into contact with floating oil and sheens while feeding and are likely to feed on oiled organisms. They will coat themselves with oil and ingest oil while feeding. Additional oil can be ingested during preening. Young eagles can be harmed by ingestion of contaminated food and contact with oiled parents.

Regarding timing, an oil spill during the spring breeding season would be more detrimental than one during migration or non-breeding periods, as mating, reproduction, and care of young would be more difficult with the physiological stresses from oil coating feathers and metabolic stresses from contaminated food sources. Moreover, eggs could be damaged chemically and physically from the coating of oil. Eggs are particularly vulnerable to oil; even a few drops transferred from an adult to the egg while incubating can be toxic to the embryo. Preferred nesting habitat would likely be correlated to the severity of oil spill impacts upon a given species. Birds, such as ducks and geese who nest and lay eggs in marsh grasses, would be severely affected by an oiling of their habitat. Even though heron, hooded merganser, and eagle nests are in trees and not likely to be oiled directly, secondary exposure to eggs from even lightly oiled adults would be damaging.

5.2.2.2.5 Effects on Mammals

Mammals are warm-blooded vertebrate organisms that commonly have hair or fur and feed their young with milk. Wolf, muskrat, deer, and rabbit were identified as culturally important mammal species in the NELD report (Dooper et al., 2018). Protected species include bats (big brown bat, little brown bat, northern long-eared bat, and tricolored bat), the American marten, the gray wolf, lynx, and moose. The Wisconsin Wildlife Primer, published by the Wisconsin DNR (1997), lists additional common mammals of Wisconsin, including muskrats, skunks, squirrels, mice, weasel, fox, gopher, beaver, bobcat, raccoon, shrews, porcupine, and otter, among other animals.

Oil spill impacts to these specific species will vary and depend on factors such as preferred habitat, diet and feeding habits, reproduction, and proximity to water during different life stages. Mammals’ contact with oil causes physiological damage (such as blindness), the loss of protection from fur, or poisoning from ingestion of oil as they groom or feed on contaminated food resources. In an oil spill scenario in which the Bad River overtops its banks, animals already displaced by flood waters may be further displaced to escape irritating effects from VOCs on their eyes and skin membranes and may suffer further injury as they are exposed to oil adhering to leaves and stems of plants, either through simple physical contact or ingestion.

Because of this variability in response, this section does not exhaustively detail potential impacts to individual species. Rather, it uses species that would have different exposures to spilled oil. Beavers, river otters, and muskrat live in or near the water in habitats that would be oiled in a spill. Beaver and muskrat are herbivores while the river otter preys on a wide array of animals, including fish, crayfish, crabs, frogs, birds’ eggs, birds, and reptiles such as turtles. In contrast, deer are also herbivores, but they do not depend on aquatic habitat and would primarily be exposed to spilled oil that has coated vegetation on floodplains. The feeding range of deer is much larger than that of beaver, allowing deer to utilize other food sources and avoid contaminated vegetation. Oiling of deer is likely limited to the legs and underbody, reducing the likelihood of coating to a level that would produce hypothermia. Further, deer could move their
home range in the aftermath of a spill. In contrast, beavers, muskrats, and otters, whose presence and activity is documented in the Bad River watershed, are semi-aquatic and less mobile than deer. Beavers, muskrats, and otters live in dens in riverbanks or lodges, which serve as the center of a limited home range. If a beaver lodge or bank den is oiled, the beavers, muskrats, or otters are likely to continue residence, leading to a continuing exposure to oil. All of these species have fur and are very sensitive to oil due to their fur's role in thermoregulation, as well as inevitable ingestion of oil from preening. Ingestion of oil can be expected in beavers and muskrats as they feed on oiled vegetation, and otters are expected to ingest oil that has coated food resources. Internal damage can be expected to kidneys, liver, lungs, intestines, and other internal organs, leading to death.

In summary, oil spill impacts to semi-aquatic and inland wildlife will vary with spill dynamics (i.e., the magnitude and extent of the spill) and the vulnerability of wildlife species in the area, and the habitat oiled. Furred mammals, including beaver, muskrat, and otters, which live on, or near, the water will be exposed to oil in their habitat and food. Some animals, such as deer, that can selectively graze and move away from contaminated areas are less vulnerable to oil spills. For mammals living in dens or lodges, the effects of an oil spill would be devastating.

### 5.2.2.2.6 Effects on Wild Rice

Wild rice is a valued natural resource and a major element of subsistence gathering for the Bad River Band. The essential physiological functions and ecology of wild rice in the Great Lakes region have been well studied. The predominant species of wild rice are *Z. aquatica* and *Z. palustris*; *Z. palustris* is the edible species harvested by the Band (Meeker, 1993; 1996). The Kakagon–Bad River Sloughs, with slow moving water and large volumes of nutrient-rich sediment, provide ideal wild rice habitat. Optimal growth conditions vary, but water chemistry, water discharge and depth, and sediment chemistry and depth have been identified as important factors (Meeker, 1993; Moyle, 1944). Water level and sulfate concentration, specifically, are thought to be the most important environmental factors that affect wild rice growth. Sustained water level changes must be less than six inches to promote germination and development; tolerable sulfate concentrations may range from 10 mg/L to 250 mg/L (Moyle, 1944). Wild rice germinates annually in the spring from seeds deposited in bottom sediment during the fall and winter months. Cool and wet winter conditions are necessary for spring growth and development (Meeker, 1993; MWH, 2004). After germination, the plants progress through the submerged leaf, floating leaf, emergent leaf, flowering leaf, and seed phases of their life cycle. Figure 80 shows key aspects of the nature of wild rice, including its life cycle. Mortality is highest during the submerged leaf and floating leaf stages because the seedlings are sensitive to detachment from the sediment (Meeker, 1993).
Figure 80: Wild Rice Ecology (Band DNR PowerPoint Presentation, Tillison and Soine, 2013)

The subaerial portion of the wild rice plant photosynthesizes beginning with the floating leaf stage. During the emergent leaf stage, the stalk grows and leaves continue to proliferate. After the emergent leaf stage, tilling and flowering occurs in mid-July. By mid-August, most rice reaches maturity and has fully developed rice grains. The rice falls in mid-August to early September and with no new growth, the rice awaits harvest starting in mid-September (Meeker, 1993).

Wild rice is an annual species with new growth dependent on seeds produced the previous year. Seeds do not decompose rapidly on the bottom, so an accumulation of seeds over several years is termed a seed bank. This seed bank is of prime importance in maintaining wild rice beds over time to account for variable annual success. Wild rice populations have a moderate seed banking ability that allows for adaptation to changing environmental conditions, with 50% of an annual seed population not germinating in the spring and 10% remaining dormant for five years (Caldwell et al., 1978; Meeker, 1996).
Sulfate concentrations in marsh soils are known to impact wild rice. When sulfate penetrates into saturated soils where wild rice grows, bacteria in those anaerobic conditions transforms sulfate into sulfide, which is toxic to wild rice roots and inhibits plant growth (Pollman et al., 2017). As part of a monitoring program, the Band has sampled for sulfate (see Figure 81 and published literature on the subject [MPCA, 2014, UM-Duluth, 2017]). These studies illustrate vulnerabilities of wild rice on the Reservation.

While extensive literature on the effects of oil on wild rice does not exist, it is possible to summarize general oil spill impacts to aquatic vegetation with consideration to the ecology and life cycle of wild rice. As discussed in Appendix D, light crude oil exhibits variable behavior in aquatic environments based on the size of the spill and environmental conditions. Generally, however, light crude oil will likely float on the surface of a wild rice slough and primarily impact wild rice function near the water surface. As a result of standing water in the Kakagon–Bad River Sloughs, light crude oil that does not evaporate would not be easily transported away from this environment. The impacts of an oil spill on aquatic plants depend on the type of oil and the extent of leaf coverage by oil. Light crude oils, the type conveyed in Line 5, are chemically toxic to plant cells, whereas medium to heavy crude oils are more likely to physically coat and smother leaves. The severity of these effects is correlated to the amount of leaf area exposed (Michel and Rutherford, 2014).
The life cycle of wild rice is a key determinant by which to assess oil spill impact severity. With oil exposure, wild rice plants would either die quickly, depending on growth state, or slowly show reductions in growth and development due to stalk surface coating. The submerged leaf through flowering leaf phases are the most susceptible to the impacts of an oil spill. A spring oil spill would directly impact growing plants, and any accumulation in sediments would also impact the seed bank in that oil presence would disrupt seed development. High spring runoff, combined with an oil spill, could disrupt seedling development in the sediment. Floating oil will impact wild rice as soon as stalks break the water surface. A high proportion of leaves could be affected by physical coating and chemical toxicity from oil at the water surface. The wild rice plants would die quickly or slowly lose photosynthetic function, thus preventing further growth and development. After active growth, the impacts would be the least severe, as the leaves and grains have already fallen and oil would only be able to coat or enter the cells of the dormant stalks.

An oil spill would also interfere with wild rice growth through increasing the turbidity, where turbidity above levels of 0.5 to 10.0 Nephelometric Turbidity Units (NTU) will block sunlight and limit photosynthesis. Sunlight reaching wild rice plants may also be reduced by floating oil.

There are also potential long-term impacts depending on the degree to which oil persists in the slough. Wild rice, as a perennial plant, is positioned advantageously for quicker recovery than annuals. Perennials damaged at the leaves and stalks can regrow from the roots, whereas annuals have to re-establish their seeds (Michel and Rutherford, 2013). The seed banking ability of wild rice would mitigate oil spill impacts, to some degree, and expedite the recovery process. The duration of recovery largely depends on whether the oil binds to sediments. Oil emulsions could disturb ideal soil conditions and create a chemically adverse environment for seedling growth.

Oiling renders plants inedible. A spill affecting the harvest period (i.e., in late summer and fall) would produce little reduction in plant growth because the annual growth has been completed, but oil could contaminate grains during harvest, making the grain inedible. After harvesting, the impact on plants would be the least severe, as the leaves and grains have already fallen, and oil would only coat the dormant stalks. Grains in the seed bank would be vulnerable to oiling and a spill in May through August would remove at least one season of harvest due to inedible grain.

5.2.2.7 Effects on Woody and Herbaceous Vegetation.

The Bad River watershed is comprised of upland forest, floodplains, river and stream channels, lakes, wetlands, and the Kakagon–Bad River Sloughs. An oil spill from Line 5 would be expected to affect all of these habitats either due to oil presence or damage from clean-up activities. A spill reaching the Kakagon–Bad River Sloughs where oil on the water surface would damage the herbaceous plants, and wild rice, in this internationally recognized wetland habitat would have the greatest impact. Floodplain vegetation—predominantly woody species—would be impacted as flows overtop channel banks and inundate floodplain areas, but oxbow lakes and connected wetlands would contain herbaceous plants that would also be impacted.

The primary mechanism of initial effect on both woody and herbaceous plants will be coating of limbs, leaves, and stems which occurs at the contact between the water surface and plant
structures. In general, plants respire through stomata, the minute openings on leaves, stems, and other plant organs. Oil blocks these stomata, affecting respiration and harming plant health. The visible responses to coating are not immediate, often observed in leaf loss and slower growth of the oiled plants. Oil coatings also block light, hampering photosynthesis, which also has delayed effects.

In addition to coating, compounds in oil are toxic to plants (Caudle and Maricle 2014). Oil can penetrate into a plant, damaging cells and impairing plant function with the actual effect dependent on the compound (Baker, 1970). It is known that uptake of toxic compounds can occur through plant root systems. As flood waters recede from an oiled floodplain or marsh, floating oil will be left on soil that it comes into contact with, leading to soil contamination. Effects on plants from soil contamination by oil will be long-term.

In summary, an oil spill in the Bad River can be expected to reach marsh vegetation in the Kakagon–Bad River Sloughs and coat stems and leaves, producing immediate degradation of plant function and longer-term chronic effects. Woody vegetation will be impacted if the spill occurs during flood conditions where there will also be an immediate degradation of plant function and long-term consequence from soil contamination.

5.2.2.2.8 Effects from Spill Response and Cleanup

Projecting the impact of an oil spill must include both the direct effects of the spill and the collateral damage produced by the cleanup activities. In the Bad River, cleanup will involve gaining access in a virtually roadless area. This means that it will likely be necessary to build roads and establish work pads for materials storage and equipment operation. Regulation will require installation of stormwater controls with monitoring and maintenance, adding to access-related damage. In Enbridge’s Kalamazoo River spill, intense boat traffic and helicopter overflights caused disturbances throughout the watershed, not just in the immediate area where work was being conducted. The initial injury levels identified in the NRDA damage assessment, determined by assessed state and condition compared with an unoiled state and condition, ranged from a resource loss of 50% in the areas with less oiling and less active remediation to a resource loss of 90% in areas with heavy oiling and intense and intrusive remediation activities. The isolated nature of the Bad River will likely produce more injury than in the more accessible Kalamazoo River.

Deployment of equipment and transport of cleanup supplies and materials will cause ongoing injury concerns due to minor spills, air pollution, and harassment of local wildlife. The Bad River channel has high banks and various locations along the channel have steep slopes that are subject to failure. This alluvial channel will present constant challenges to cleanup operations. Moving equipment, such as wheeled or tracked vehicles, to access oiled channel and floodplain locations will disturb habitat, crush bottom dwelling organisms, and disturb aquatic organism habitat availability leading to altered reproduction and growth and longer-term effects. The Yellowstone NRDA noted that floodplain habitats were damaged by trampling and crushing of vegetation by mechanized equipment, cutting and removing grasses and woody vegetation, and physical disturbance caused by the presence of crews and machinery.
Debris piles are common in both the Bad and Yellowstone rivers and are a habitat that is readily oiled in a spill. Debris piles are an important and unique source of shelter and food for fish, invertebrates, small mammals, birds, reptiles (particularly turtles in the Bad River), and amphibians. The piles provide surface area for the growth of aquatic invertebrates, a major food resource for fish, but also provide abundant surface area for oil coating. Oil spill response will require removal of oiled debris, destroying critical habitat in the channel and along the banks of the Bad River.

The methods used for cleanup will vary. Excavation to remove contaminated soils or sediment causes physical disturbance to the habitat, basically removing habitat structure or altering habitat function. Soil scraping, high pressure flushing, and agitation of submerged sediment tend to release attached oil, which can move to new locations and habitat. Other actions such as placement of absorbent materials, vacuuming oil, and flushing with low pressure hoses all cause some injury from habitat disruption and additional oil release. The presence of responders and the noise created by the response actions acted as deterrents to wildlife use in areas beyond the immediate oiled areas. In the Bad River watershed, use by wolves, deer, and many bird species would be deterred. In the Kalamazoo River spill, the NRDA noted that if multiple response activities took place in the same location, initial injury levels ranged from 70% to 100% of the resource damaged.

The end result is that cleanup practices add further physical impacts to the physical and chemical impacts of the initial spill. Cleanup approach requires careful planning because response actions may result in greater initial injury but a faster recovery time than if the oil were to be left in place.

5.2.2.9 Effects on Humans

Oil spills also have human health consequences. If people come into direct contact with spilled oil and vapors, a wide range of symptoms have been reported including memory loss, dizziness, irritability, headache, nausea and vomiting, chest pain, coughing and lung problems, fatigue, skin injuries, rashes, blisters, eye sores, and mental confusion. Longer term effects from extended exposure to oil, weathered oil, and residuals can include respiratory damage, liver damage, decreased immunity, increased cancer risk, reproductive damage and higher levels of toxic substances in blood tissues. Members of the Bad River Band are at particular risk because the river and river corridor are integral to the past, present, and future life of the Band, providing water travel, subsistence, medicinal, economic, educational, and ceremonial services. The Band’s subsistence hunting, fishing, and gathering not only place members in locations with high risk of immediate exposure to volatile and other oil fractions at high concentrations, but also exposes the entire Band to oil residuals in their environment and contaminants in the food they gather and consume, such as walleye and wild rice.

5.2.3 Summary

The consequences of an oil spill at the Line 5 crossing of the Bad River could range from a local and short-term disturbance to a large-scale ecosystem disaster with long-term and international consequences. Impact will depend on spill volume, the flow of the Bad River, season, and other factors. In addition to the impact from the spill itself, additional impacts can be expected from oil
cleanup and ecosystem remediation. Using calculated estimates of the fate of oil in the Bad River and accounting for the regular recurrence of flooding events that inundate the Bad River floodplain, a habitat exposure approach that connects the likely location of spilled oil with the likely presence of organisms projects severe impacts to the Bad River watershed from an oil spill.

The worst-case scenario consists of a high volume, large full-bore oil spill that reaches the Kakagon–Bad River Slough complex and/or occurs during a flood large enough to overtop the banks and inundate the Bad River floodplain. If such an event occurs in the spring when migratory species, such as waterfowl and the most vulnerable early life stages of aquatic organisms, are present, the injury would be catastrophic. Habitat in the Bad River channel, Kakagon–Bad River Slough complex, and floodplain would be acutely damaged by oil. However, spills occurring during lower flow conditions, where the river flow is contained—and even low—within the Bad River channel banks, can also have major adverse environmental impacts.

The ecosystem response to a spill is complex, and biological effects will vary with habitat and species-specific exposure. Oil adhering to banks, sediment, and in-channel debris has a complex, time-related ecological impact on fish and other aquatic organisms. An interaction with oil-coated surfaces results in coated animals. Aquatic invertebrates, a foundation for the aquatic food chain, are commonly oiled when a release occurs. Damage to these organisms is due to smothering and toxicity. If fish ingest contaminated invertebrates, they may suffer a range of sublethal effects. Eggs and juveniles are particularly susceptible to contamination from oil. A spring spill is particularly damaging because most fish species spawn only once a year, such that the lost juveniles would produce population declines in future years. Oiled birds and mammals are likewise susceptible to oil spills. For example, oiling causes the loss of the protection provided by feathers or fur to deal with low temperatures. They may be poisoned as they ingest oil while grooming or feeding on contaminated food resources.

Oil will also have a direct effect on vegetation. Floating oil and oil sheens rapidly spread over large areas, particularly in the calm waters of sloughs, marshes, and wetlands. Floating oil comes into contact with plants at the water surface, causing damage to emergent vegetation where oiling can result in toxicity as well as interference with respiration and growth. Stalked plants, including wild rice, are particularly vulnerable in the growth stage. Further, as flood waters recede, more stalk area is exposed to oil and contamination as the water level lowers, increasing the overall effect.

When flooded areas dry out, the floating oil will contaminate the soils of shallow bars in sloughs, channel banks, and floodplains. A Bad River watershed feature particularly vulnerable to an oil spill is the Kakagon–Bad River Slough complex 16 miles downstream from the Line 5 crossing. This 16,000-acre wetland complex has been designated a Ramsar Wetland of International Importance and is an important spawning and nursery area for fish, a critical stopover habitat for migratory birds, and has the largest natural wild rice beds in the Great Lakes basin. The complex is particularly vulnerable in the spring when early growth stages of the rice are present. This is also the time when eggs and fry of walleye are present in the slough.
To illustrate the projected impacts, conditions for various fish species (including walleye and lake sturgeon) and plant species (including wild rice) have been reviewed in detail for this report. Walleye are a well-studied game fish that are also a primary component of the Bad River Band subsistence fishery. Walleye occupy a range of habitats in the Bad River, including the main channel, lakes formed by cutoff meanders in the floodplain, and the Kakagon–Bad River Slough complex. The quiet waters of the Kakagon–Bad River Slough complex are particularly vulnerable to floating oil and sheens because walleye spawn along shorelines in lakes and sloughs in the same sedges or grasses that are easily coated by oil. In rivers, walleyes usually spawn in rapids and riffles. In the early life stages, walleye feed upon a diverse array of small food items, including rotifers, diatoms, and zooplankton, which are vulnerable to contamination by oil. Since adult walleye are voracious predators, they can be injured if they accumulate oil from contaminated food. While the seasonal timing of an oil spill will determine what life stages of walleye are present in oiled habitats, adult walleye can be exposed to spill residuals year-round. If the worst-case scenario occurred with a spill during the spring spawning season, the spill could prove devastating to the population of walleye in the Bad River.

Lake sturgeon are the largest fish in the Great Lakes basin. Adult lake sturgeon spawn from late spring to early summer in the upper part of the Bad River basin near Copper Falls. To spawn, these long-lived fish, which can reach seven feet in length and only spawn infrequently, migrate upstream, spawn, and then the adults immediately return to Lake Superior. Eggs hatch and the fry drift downstream feeding and growing. Early juvenile stages remain in the river mouth and eventually move to Lake Superior. A spill from Line 5 during spring spawning would mean that the adult sturgeon would move upriver and downriver through oil-contaminated habitat in the lower part of the Bad River. Drifting fry would also be exposed to oil residuals in the lower part of the river, as well as encounter contaminated food resources. The juveniles that remain in the river mouth would face extended exposure to oil spill components. Since sturgeon are bottom feeders, they would likely ingest contaminated food, but they can also absorb oil contaminants through their skin. Various studies have documented that exposure to oil for only a few days can result in a significantly increased morality rate, induce lesions, and produce physiological and biochemical disorders, tumors, and abnormalities in fish development. Lake Sturgeon are thus at significant risk from an oil spill even though adult sturgeon may spend only a few days in the Bad River.

Wild rice is a highly valued natural resource and a major element of subsistence gathering for the Band. Wild rice is an annual species with new growth from seeds, so the seed bank is of prime importance in maintaining wild rice beds. A spring oil spill would directly impact growing plants and any accumulation in sediments would also impact the seed bank where oiling would disrupt seed development. In the wild rice growth cycle, the submerged leaf through flowering leaf phases are the most susceptible to oiling, and, again, are most vulnerable in the spring. Floating oil would impact wild rice as soon as stalks break the water surface. Wild rice plants would either die quickly, depending on growth state, or slowly show reductions in growth and development due to stalk surface coating. Oilling renders the plants inedible. Any spill in May through August would remove at least one season of harvest because rice would be inedible after coating and chemical impacts.
Projecting the impact of an oil spill must include both the direct effects of the spill and the collateral damage produced by the cleanup activities. Along the Bad River, cleanup would involve gaining access in a virtually roadless area. This means that it potentially would be necessary to build roads with their associated impacts. Deployment of equipment and transport of cleanup supplies and materials would cause ongoing concerns due to small spills, air pollution, and harassment of local wildlife. In some reaches, the river channel has high banks and steep slopes that are subject to failure. Access in these areas would likely cause additional damage. The channel would present constant challenges to cleanup operations. Moving equipment, such as wheeled or tracked vehicles, to access oiled channel and floodplain locations would disturb habitat, crush bottom dwelling organisms, and disturb aquatic organisms with typical injuries including altered reproduction and growth. Remediation would require removal of potentially large quantities of contaminated sediment and debris, destroy critical habitat, and add to the transportation impacts in the watershed. Cleanup practices would, in sum, add physical impacts to the chemical impacts of the initial spill.

Oil spills also have human health consequences. If people come into direct contact with spilled oil and vapors, a wide range of symptoms have been reported including memory loss, dizziness and irritability, headache, nausea and vomiting, chest pain, coughing and lung problems, fatigue, skin injuries, rashes, blisters, eye sores, and mental confusion. Longer term effects from extended exposure to oil, weathered oil, and residuals can include respiratory damage, liver damage, decreased immunity, increased cancer risk, reproductive damage, and higher levels of toxic substances in blood and tissues. Members of the Bad River Band are at particular risk due to subsistence gathering, which not only places them in locations with high risk of immediate exposure to volatile and other compounds at their highest concentrations, but also exposes them to oil residuals in the environment and the food they gather.

In summary, transport and fate calculations indicate that a range of oil release scenarios would rapidly spread downstream with different fractions of the oil displaying different dynamics and habitat affected. Spill effect would be immediate as the oil is transported downstream. Oil would coat riverbanks, bank and channel debris, and animals living in the channel and cause further damage with floating oil components reaching the Kakagon–Bad River Slough complex in about a day, rapidly contaminating rice beds and wetland habitat in the slough complex. The spill would cause detrimental effects to a wide range of local wildlife and vegetation in the river and slough downstream of the spill, and impacts would be particularly great during a spring spill due to the temporal overlap with spawning and juvenile fish and migratory bird presence. If the spill occurs when the Bad River has overtopped its banks, such detrimental effects would extend to habitat and species across the Bad River’s floodplain.
6.0 DOES ENBRIDGE’S LINE 5 MONITORING AND SHUTDOWN PROTOCOL ENSURE THE PIPELINE WOULD NOT BE EXPOSED, DAMAGED, AND RESULT IN THE RELEASE OF OIL?

Opinion: Enbridge’s Line 5 shutdown protocol would not ensure that the pipeline is protected from damage and a potential oil release.

Previous sections of this report describe the potential for erosion caused by the Bad River to expose Line 5 (Section 3.0), which would likely damage the pipeline and result in the release of oil (Section 4.0) and cause severe environmental impacts (Section 5.0). Based on the possibility for pipeline exposure and damage, if Line 5 is operating, an appropriately stringent pipeline monitoring and shutdown protocol must be adhered to.

Given the necessity to have an appropriately stringent monitoring and shutdown protocol for Line 5, WWE addressed Question 4:

Does the Line 5 monitoring and shutdown protocol proposed by Enbridge ensure the pipeline would not be exposed, damaged, and result in the release of oil?

To address this question, this section provides: 1) a description of the proposed Enbridge monitoring and shutdown protocols for Line 5 and WWE’s evaluation as to the inadequacies of those protocols (Section 6.1), and 2) a description of an alternative monitoring and shutdown protocol developed by WWE (Section 6.2 and Appendix O) that would preemptively shut down the pipeline prior to an acute erosion event occurring that could cause Line 5 to become exposed, damaged, and release oil into the Bad River.

6.1 WWE Comments on the Enbridge Line 5 Monitoring and Shutdown Protocols

Two separate Line 5 monitoring and shutdown protocols that were developed by Enbridge were evaluated by WWE (Enbridge, 2019; Enbridge, June 13, 2021). The primary focus of WWE’s evaluation is on the more recent protocol dated June 13, 2021 (see Section 6.1.1). However, a comparison between the 2019 and 2021 protocols is provided for the purpose of observing changes made by Enbridge as the protocol evolved (see Section 6.1.2).

6.1.1 Review of the 2021 Enbridge Monitoring and Shutdown Protocol

WWE evaluated Enbridge’s 2021 proposed monitoring and shutdown protocol and found it to be, in general, overly reactive and inconsistent with the approach stated in the introduction of the protocol: to make decisions using an “abundance of caution.” A detailed summary of WWE’s comments on Enbridge’s protocol is provided in tabular format in Appendix N.

WWE finds the Enbridge protocol to be insufficiently protective because it fails to provide for the shutting down of Line 5 operations when Bad River erosion will potentially damage the pipeline. The key underpinnings of this finding are summarized below:
1. **The protocol allows the critical unsupported span length of the pipeline to be exceeded before initiating shutdown of Line 5.** Enbridge identifies a critical span length of 100 feet that the pipeline can extend unsupported without failing. The protocol proposed by Enbridge would allow the pipeline to reach 90% or more of its critical span length without support (i.e., hanging suspended in the air) prior to taking any action. The protocol provides no basis or explanation for how the critical span length was calculated (as discussed in detail in Section 4.0, WWE has calculated the maximum allowable span length to be 62 feet) nor why allowing 90% of the critical span to be unsupported provides an adequate safety factor.

   Indeed, the protocol does not require pipeline shutdown until the critical span has been exceeded, meaning that by Enbridge’s own calculations, there is potential for the pipeline to be hanging unsupported for a span length sufficient to cause pipeline damage before any shutdown is initiated. Enbridge cannot claim to be acting with an “abundance of caution” while at the same time providing a protocol that allows what it views to be the critical length of unsupported pipeline to be exceeded before action is taken.

2. **The protocol acknowledges that, under the current configuration, purging Line 5 may not be feasible during conditions that warrant pipeline shutdown.** The Enbridge protocol text states, “Action 2: Execute temporary shutdown, and, if feasible, execute purge.”

   Enbridge’s protocol states that it requires 45 hours to purge the pipeline. Enbridge does not provide information about specifically when a purge would be feasible versus infeasible. This text suggests that Enbridge recognizes, that under its proposal not to initiate action until the critical span length has been exceeded, there is a likelihood that it may be unable to remove oil from the pipeline in time to prevent a spill if pipeline damage occurs, based on the current configuration of the pipeline, potential site conditions, and proposed operations protocol. Enbridge’s willingness to accept the consequences of leaving oil in Line 5 even when damage to the pipeline may occur is not protective of the environment. The protocol should ensure, to the greatest extent feasible, that steps are taken to prevent a release of oil in advance of pipeline damage occurring.

3. **The protocol lacks details in decision criteria and corresponding response actions.** The proposed protocol includes vague criteria such as “triggered by flood events,” “significant erosion,” or “potential for significant bank loss” without defining what the thresholds are. Without clear guidance on when preventive actions must be taken, and by whom, the protocol allows for uncertain operating decisions and the potential for unacceptable levels of threat to occur without an appropriate and defined response action from Enbridge. Where Enbridge does define specific thresholds, such as 4,000 cfs and 10,500 cfs in relation to the frequency of image review, it does not provide a basis for these thresholds.

4. **The protocol does not address and incorporate communications with Band.** The proposed protocol provides no mention of any communication or involvement between
Enbridge and the Band. Considering the threat that an oil release from Line 5 poses to the Reservation and the Band community, and the Band’s governmental authority over and responsibility for the Reservation, it is a glaring oversight to exclude the Band from the monitoring and shutdown protocol and subsequent communications.

A conservative approach that is protective of the environment would include guidelines that incorporate a safety buffer, or “safety cushion,” with respect to implementing measures to shut down the pipeline prior to erosion and subsequent damage to Line 5 resulting in a release of oil.

In summary, the June 2021 monitoring and shutdown protocol proposed by Enbridge has multiple shortcomings in terms of the adequacy of the measures proposed to be undertaken, including principally the fact that Enbridge would only initiate a shutdown and attempted purge of the pipeline after the pipeline is exposed to damaging conditions. While Enbridge emphasizes making decisions out of an “abundance of caution,” a review of the specific criteria and guidance issued by Enbridge indicates that its proposed protocol lacks such caution and does not promote a conservative approach.

6.1.2 Comparison Between the 2019 and 2021 Enbridge Protocols

In addition to reviewing the 2021 monitoring and shutdown protocol, WWE also reviewed Enbridge’s 2019 Line 5 – Bad River Crossing Shutdown Plan [ENB00410202]. There are several instances in which the protocol has become less pro-active regarding shutdown between 2019 and 2021. In other words, a condition that would have prompted shutdown of the pipeline under the 2019 protocol is not cause for shutdown in the 2021 protocol. Since the threats present in 2019 remain in 2021, there is no clear reason why Enbridge would allow more erosion to occur in 2021 before taking precautions than it had planned to take two years prior. Three major differences between the 2019 and 2021 monitoring and shutdown protocols are discussed below.

1. The amount of allowable horizontal bank erosion is larger in the 2021 protocol. Enbridge’s 2021 protocol allows for over 90 feet of pipeline to become exposed before Line 5 is shut down. In contrast, in the 2019 protocol, one of Enbridge’s conditions for shutdown occurs if monuments M2A, M2B, and M2C are all lost (see 2019 monuments labeled on Figure 82). Monument M2C, the closest of the three to the pipeline, is 15 feet from the pipeline. This 2019 protocol safety factor of initiating a shutdown with 15 feet remaining between the bank and the pipeline is significantly different, and more conservative (i.e., protective), than the 2021 protocol that allows the pipeline to become exposed for over 90 feet before it is shutdown. In addition, in the 2019 protocol, Enbridge also includes the condition to shut down Line 5 if any of the monuments within five feet of the pipeline (M1, M2, or M3) are lost. This more conservative approach in the 2019 protocol compared to 2021 again highlights a significant change in Enbridge’s willingness to allow horizontal erosion and pipeline exposure before taking precautionary measures.
Figure 82: Figure 2 from Enbridge’s 2019 Monitoring and Shutdown Protocol Showing Monuments Existing as of 2019 Used to Monitor Horizontal Bank Erosion

2. **Vertical erosion in the overflow channels receives less attention in the 2021 protocol.** Enbridge proposes a significantly different approach to vertical erosion in the overflow channels in the two protocols. In the 2021 protocol, Enbridge’s discussion of the overflow channels is limited to this statement: “There is minimal likelihood of erosion occurring at the location where channelization has occurred that would be significant enough to require shutdown.” Enbridge provides no basis for this statement. LiDAR data reviewed by WWE indicate that significant erosion (i.e., several feet in some locations) occurred in the chute cutoff channels between 2014 and 2019 (see Section 3.2.3).

In contrast, in 2019, Enbridge’s protocol included several conditions in which the pipeline would be shut down or purged based on erosion in the overflow channels. The 2019 Enbridge protocol mapped six overflow channels with the locations of 14 additional monuments marked (see Figure 83). These monuments were never installed. Under the 2019 protocol, shutdown would occur if monuments M4A and M5A, or M6A and M7A, or M8A and M9A, or M10A and M11A were lost. Purging of Line 5 would occur if monuments M4B, M7B, M8B, M9B, M10B or M11B were lost. The horizontal distances from each of these monuments to the pipeline are not provided. Again, there is not an explanation from Enbridge, nor a clear reason to WWE, why the threat from the overflow channels identified in 2019 would not be relevant to monitor and respond to in 2021. Enbridge has provided no adequate explanation for its decreased vigilance with respect to the overflow channels.
Figure 83: Figure 3 from Enbridge’s 2019 Monitoring and Shutdown Protocol Showing Overflow Channels and Locations of Proposed Monitoring Monuments

3. **Clear guidance is not provided for the conditions that warrant the pipeline being shut down.** In its 2021 protocol, Enbridge does not discuss a specific flow rate at which pipeline integrity is “at risk,” as the PHMSA Bulletin ADB-2019-01 recommends. Nowhere in the protocol does Enbridge follow the guidance to present thresholds for river flow rates that threaten the pipeline, nor does the proposed protocol present contingency plans to shut down and isolate the pipeline when those flows occur. In contrast, in its 2019 protocol, Enbridge identified the 500-year flood as the “flow of concern for this crossing” that called for pipeline shutdown due to scour risk. Again, there is no clear reason for the omission of this important criterion from the 2021 protocol.

As a general observation, it is concerning to WWE that the Line 5 monitoring and shutdown protocols proposed by Enbridge have become less conservative (i.e., less cautious) in 2021 compared to 2019. A clear basis for understanding the significant changes in the protocols discussed above has not been provided.

### 6.2 Alternative Line 5 Monitoring and Shutdown Protocol

After reviewing the Line 5 monitoring and shutdown protocols developed by Enbridge, WWE developed a recommended alternative protocol. WWE’s proposed protocol uses a more preemptive approach for shutting down Line 5 operations, as conditions warrant, before conditions necessitate a crisis-driven emergency response to prevent Line 5 from being damaged and releasing oil into the Bad River.

The protocol developed by WWE is more conservative in terms of taking defined actions prior to Line 5 becoming exposed and subject to failure. The protocol proposed by WWE also incorporates more specific criteria compared to the Enbridge protocols to help clarify and facilitate the decision-making process regarding how and when specific actions need to be taken. WWE’s analysis is focused on hazards posed by Bad River erosion, and WWE believes the decision criteria in its protocol are appropriate in light of those hazards. The alternative Line 5 monitoring and shutdown protocol developed by WWE is presented in Appendix O.
Given the potential for a consequential spill to occur, even when a shutdown protocol is in place, this monitoring and shutdown protocol should be considered temporary and only in effect until Line 5 is shut down on the Reservation.

### 6.3 Summary of the Line 5 Monitoring and Shutdown Protocol

In summary, WWE evaluated the Line 5 monitoring and shutdown protocol developed by Enbridge and has determined the protocol is not protective of the Bad River and surrounding environs because: 1) the protocol allows Line 5 to become exposed by erosion and unsupported (i.e., undermined) for a length sufficient to cause it to fail, based on Enbridge’s own calculations, prior to any preventive actions being taken by Enbridge, 2) the protocol does not direct appropriate efforts to be taken to preemptively shut down the pipeline when a threat is recognized, 3) the protocol lacks details in decision criteria and corresponding response actions, and 4) the protocol does not address and incorporate communications with Band.

WWE accordingly determined that an alternative monitoring and shutdown protocol is necessary for Line 5. The proposed protocol is appropriately protective by providing for the shutdown and purge of Line 5 before emergency conditions develop, at which point it could be too late to prevent damage to the pipeline and the release of oil into the Bad River.

Finally, it is emphasized that monitoring and shutdown protocols do not guarantee a spill will be prevented. Past spills into rivers have occurred from pipelines that were being consistently monitored yet still failed (for example, see the Yellowstone River Spill in 2011, described in Appendix I). While providing a robust monitoring and shutdown protocol helps lower the potential for a release to occur, such a protocol cannot entirely prevent the potential for release. Past spills demonstrate the importance of a protocol that accounts for the uncertainties of the erosion processes that threaten Line 5 and conservatively manages the pipeline operations to substantially reduce the risk of an oil release occurring while Line 5 is operating.
7.0 WOULD THE STABILIZATION PROJECTS PROPOSED BY ENBRIDGE ELIMINATE THE RISK OF LINE 5 RELEASING OIL AND ALSO NOT CAUSE LOCAL ADVERSE ENVIRONMENTAL IMPACTS IF IMPLEMENTED?

Opinion: The stabilization projects proposed by Enbridge would not eliminate the risk of Line 5 releasing oil due to erosion and they pose a risk of local adverse environmental impacts to the Reservation.

Sections 3.0 through 6.0 provide an evaluation of the potential for pipeline exposure, failure and oil release, the environmental consequences if a release were to occur, and the monitoring and shutdown protocol proposed by Enbridge. Enbridge has submitted various project proposals to the Band that attempt to address the threat posed by the Bad River meander cutoff. The intent of two proposals is to stabilize the bank on the south side of the meander neck to prevent further erosion and encroachment towards the pipeline, using either: 1) riprap (rock armor placed against the bank) or, 2) trees anchored near the bottom of the channel bank. The intent of two other proposed projects is to stabilize a cutoff channel that runs across the meander neck by using either: 1) turf reinforcement mat (TRM\textsuperscript{19}), or 2) riprap to prevent vertical erosion that could lead to pipeline exposure. Separate from the stabilization projects listed above, Enbridge has also proposed to conduct horizontal directional drilling (HDD\textsuperscript{20}) beneath the Bad River floodplain.

The purpose of Section 7.0 is to determine if the projects proposed by Enbridge (collectively referred to as “stabilization measures”) would eliminate the risk of Line 5 releasing oil due to damage caused by river erosion and also not cause local adverse environmental impacts to the Bad River Reservation. More detailed descriptions of each of these projects are presented in Section 7.2 and feasibility considerations for each are provided in Sections 7.4 through 7.7.

WWE’s evaluation is based on review of the relevant Enbridge documents and engineering literature, engineering calculations, field observations, peer review, discussions with other practitioners in channel stabilization and restoration, and our work experience.

Throughout Section 7.0, the terms “projects”, “stabilization projects”, “Enbridge stabilization projects”, “proposals”, and “submittals” are used synonymously. HDD is not an activity related to bank or overflow channel stabilization; however, because the five projects are linked in Enbridge’s submittals to the Band, they are collectively referred to as “stabilization projects” for purposes of this section.

\textsuperscript{19} TRM is a matrix of synthetic materials placed on the soil surface in which vegetation can establish and grow through the matrix to provide stabilization.

\textsuperscript{20} HDD is a construction technique whereby a tunnel (or “borehole”) is drilled under a waterway or other designated area, and then a pipe is pulled through the tunnel.
7.1 Context for Evaluating Enbridge’s Stabilization Proposals and Key Definitions

7.1.1 Band Perspective on Meander Cutoff

Before commenting on specific engineering considerations for Enbridge’s proposals, it must be recognized that with the exception of HDD, all of the projects seek to “stabilize” the riverbank or overflow channel, or in other words prevent erosion from occurring in the future, which is fundamentally counter to the Band’s desire to allow the Bad River to flow and erode naturally, without human interference. The stabilization methods would require the import of substantial quantities of materials and would restrict the natural evolution of the river. From the outset of WWE’s work for the Band in 2017, Band staff and leadership have expressed to WWE their strong preference not to alter the Bad River’s natural evolution at the meander near Line 5 but instead to allow the river to behave naturally, in an unconstrained manner, including cutting a new channel across the meander neck whenever that would occur via the natural progression of channel morphology processes.

In WWE’s experience with river restoration and stabilization projects, an essential step in the engineering and design process involves gathering feedback from affected property owners, the public, and regulatory agencies. This input often fundamentally influences the nature of the proposed design. A challenge for any engineering design used on the Bad River Reservation is the overriding objective to provide for the management and protection of natural resources, reflecting the Band’s philosophy, which is to strictly sustain ecosystem integrity and avoid adverse environmental impacts from construction activities, especially in areas designated as Conservation Areas or Watershed Protection Areas in the Tribe’s Integrated Resources Management Plan (IRMP) (Elias, 2001), using the best available science and technology. For the purposes of this report, WWE provides comments from an engineering perspective on Enbridge’s stabilization projects, putting aside the fundamental incompatibility between engineering modifications to the riverbanks and overflow channels and the Band’s philosophy regarding natural resources.

Since 2019, the Band has provided many comments to Enbridge on its stabilization submittals. Some of WWE’s concerns in Section 7.0 were previously expressed by the Band to Enbridge. Examples of such concerns are provided in Sections 7.4 through 7.7.
7.1.2 Methodology Used to Evaluate Enbridge’s Proposed Projects

WWE evaluated each of the projects proposed by Enbridge by considering the following two questions:

1. Is there a non-trivial risk that the project would physically fail?

2. Is there a non-trivial risk that the project would cause local adverse environmental impacts to the Bad River Reservation?

If the answer to either or both of these questions is “yes,” this constitutes “project failure” as shown on Figure 84. By contrast, if the answer to both questions is “no,” then there is only a trivial risk of project failure. The terms used on Figure 84, including “project failure” and “Line 5 failure,” are defined in Section 7.1.3.