Report to the State of Michigan

Mitigating potential vessel anchor strike to Line 5 at the Straits of Mackinac

June 30, 2018

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Executive Summary

The Purpose of This Report

On November 27, 2017, the State of Michigan and Enbridge signed a wide-ranging agreement setting out a plan to improve coordination between Enbridge and the State for the operation and maintenance of the Line 5 pipeline located in Michigan, while also providing enhanced transparency to the citizens of Michigan.

In section E of that agreement, Enbridge agreed to complete a report no later than June 30, 2018, on options to mitigate the risk of a vessel's anchor puncturing, dragging or otherwise damaging Enbridge's existing dual Line 5 pipelines across the Straits of Mackinac (the Straits). At a minimum, Enbridge agreed to assess the following two options:

1. Measures to enhance shipping communication and warning technologies.
2. The use of protective barriers to further protect the dual pipelines from any risks posed by a vessel anchor coming in direct contact with the dual pipelines.

Enbridge also agreed to include in its report:

i. An assessment of the costs and engineering considerations associated with each alternative.

ii. The potential environmental impacts that may result from the construction, operation and maintenance of the alternatives.

iii. A proposed timeline for seeking all regulatory approvals.

Enbridge agreed to proceed with detailed design and installation of the most appropriate option(s) within 180 days of receiving all authorizations and approvals necessary for construction of the option.

Summary of Key Conclusions

Shipping Communication and Warning Technologies

To assess and report on measures that could be taken to enhance shipping communication and warning technologies in the Straits, Enbridge formed an internal team consisting of subject-matter experts who worked in collaboration with State representatives (the Team).

Enbridge also engaged a Reliability Consultant to assess the impact that the preferred communication and warning technology would have to reduce the probability of an anchor coming into contact with Line 5 and causing a product release into the Straits.

Highlights

- The Team identified several communication measures that could potentially reduce the risk on an anchor hitting the dual pipelines. The ideas can be divided into two categories:
  - holistic opportunities to enhance the safety of all the existing pipelines and cables located within the Straits' lakebed utilities corridor, including Line 5; and
  - those that are focused specifically on enhancing the safety of Line 5.
- Potential communication measures identified during brainstorming sessions that could enhance the safety of all the existing pipelines and cables located within the Straits' utilities corridor included:
  - A coordinated Public Awareness Campaign to educate the public—and specifically mariners—about the location of all utilities crossing the Straits.
  - Signage on the Mackinac Bridge to warn vessels.
  - Floating marker buoys with 'No Anchor' warnings in the shipping channel.
  - Dedicated patrol vessels or drones deployed in the Straits.
  - Mandatory checkpoints and anchor inspection before vessels cross the Straits.
  - Collaborate with the U.S. Coast Guard (USCG) to investigate opportunities to enhance current policies and procedures that vessels are required to follow before proceeding to cross the Straits.

  Enbridge would actively support any of these holistic safety initiatives.
- Focusing specifically on the Line 5 pipelines, Enbridge evaluated shipping communication technologies and identified Vesper Marine's web-based *Guardian:protect* system as a potential tool to actively monitor and communicate with vessels in the Straits when they are in close proximity to the dual Line 5 pipelines.
- The *Guardian:protect* system enables a user to:
  - Identify, track, be notified of and communicate with vessels near the user's underwater assets.
  - Intervene proactively when the system detects vessel activity that presents a risk to the underwater assets by setting the system to send early-warning alerts automatically to both the user and the vessel.
- Enbridge has already installed the *Guardian:protect* system hardware at the Enbridge Mackinaw Station on the south shore of the Straits. The system is currently functioning in a test mode.
- In consultation with the USCG, the Federal Communications Commission (FCC) and other key stakeholders, a decision would need to be made on whether the system should communicate with a vessel and the nature of the message—proactive advisory messages such as reminding vessel operators of the pipelines and/or checking that anchors are properly stowed; and/or reactive warning messages sent to vessels that appear to be preparing to anchor.

- Should Enbridge move forward with full implementation of *Guardian:protect*, the company would have to secure licenses from the USCG and the FCC. No other regulatory permits and no environmental permits would be required.
- The estimated capital cost for fully implementing the *Guardian:protect* system is approximately $500,000.
- The Reliability Consultant concluded the following:
  - If *Guardian:protect* is expanded to include sending an advisory message to all vessels approaching the Straits where the message requests vessel operators to confirm that their anchors are properly stowed, the expected result is a 38 percent reduction in an intentional anchor deployment hitting the pipeline and an 89 percent reduction in an unintentional anchor deployment hitting the pipeline and causing a release. (An intentional anchor deployment would most likely be in response to an emergency on a vessel. An unintentional anchor deployment would be an accidental deployment of an anchor, most likely the result of equipment malfunction and/or human error.)

Protective Barrier

Enbridge engaged a prominent engineering company that specializes in offshore pipelines as the Lead Engineering Consultant to (a) assess options for constructing a protective barrier to reduce the risks of an anchor strike to the Line 5 pipelines and (b) recommend the most effective type of barrier.

Then, a team of independent expert Constructibility Reviewers assessed, commented on and verified the Lead Engineering Consultants' conclusions regarding the proposed type of barrier.

Enbridge also engaged a respected environmental consulting firm as the Lead Environmental Consultant to assess and verify the potential environmental impacts and mitigation measures related to the construction of a protective barrier; and carried out an overall analysis of the U.S. regulatory and environmental permits that would be required for the most effective barrier option.

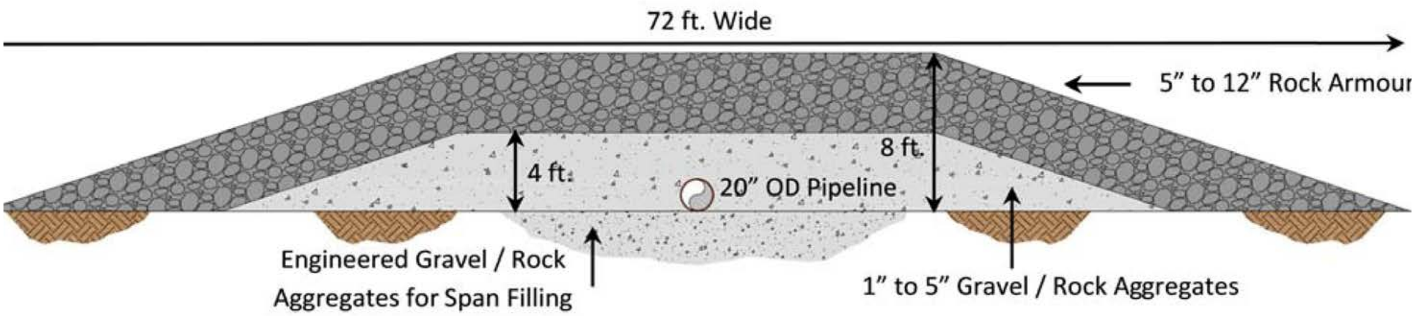
Enbridge also engaged a Reliability Consultant to assess the impact the most effective barrier options would have on the probability of an anchor coming into contact with the Line 5 pipelines and causing a product release into the Straits.

Highlights

- During a brainstorming session with all the subject-matter experts and several State representatives (the Team), 15 types of potential protective barriers were identified.
- In selecting the most effective option, the Team aimed to find the one that: (a) protected the Line 5 pipelines from anchor strike; (b) posed minimum risk to the pipelines during both construction of the barrier and operation and maintenance of the pipelines; and (c) minimized interference to ship traffic, fishing and recreational activities in the Straits during construction.
- Based on the Team's assessment and recommendation, Enbridge has concluded that an engineered gravel/rock protective cover would be the most effective barrier for protecting the Line 5 pipelines against an anchor strike.
- Engineered gravel/rock protective cover has a very strong offshore-industry track record for protecting pipelines from ship anchor strikes in some of the world's busiest harbors. This solution has also been used globally to protect various hydrocarbon pipelines installed in major shipping channels.
- Should the engineered gravel/rock protective cover be constructed to cover the entire length of the dual Line 5 pipelines across the Straits (11,000 feet for the east pipeline and 12,000 feet for the west pipeline), the estimated cost would be approximately $150 million.

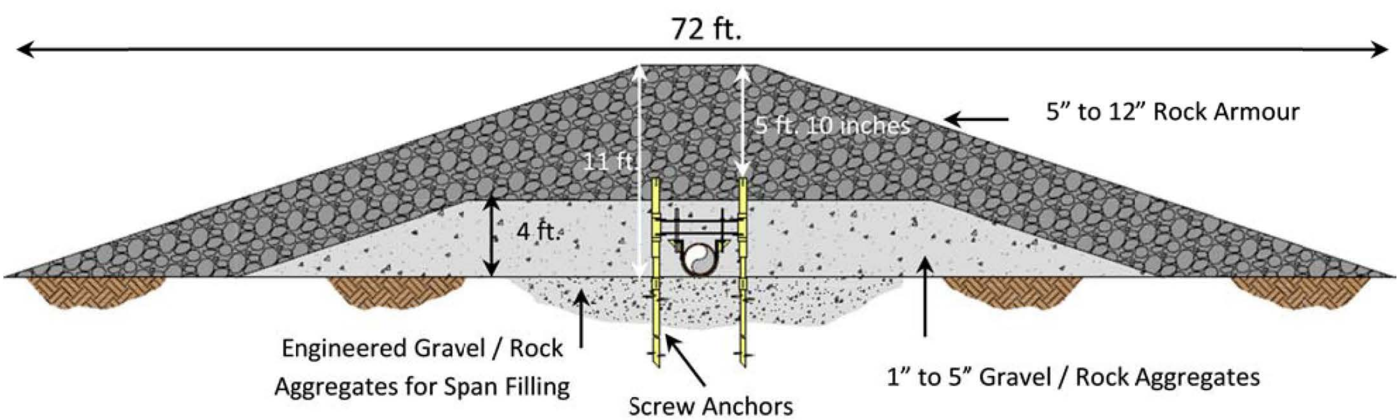
- If the engineered protective cover option moves forward to the implementation phase, another option to consider would be to cover only the sections of the pipelines that are within the shipping channel. Above the Line 5 pipelines, the maximum width of the shipping channel is approximately 700 feet for the east pipeline and 800 feet for the west pipeline. For this option, the Lead Engineering Consultant suggests covering a 2,000-foot section over each pipeline—for a total of 4,000 feet—to allow for a buffer on either side of the shipping channel.
- The engineered gravel/rock protective cover on the pipelines would be approximately 72 feet wide and a minimum of eight feet high from the lakebed. The minimum height of the gravel/rock cover from the top of the existing dual 20-inch pipelines would be over six feet *(Figure 1)*.

Figure 1: The proposed profile and configuration of an engineered gravel/rock protective cover for the 20-inch dual Line 5 pipelines crossing the Straits of Mackinac.



- In locations where screw anchors support sections of the pipelines, the engineered gravel/rock protective cover would be higher—a minimum of 11 feet high from the lakebed and a minimum of approximately nine feet from the top of the pipelines *(Figure 2)*.

Figure 2: The engineered gravel/rock protective cover would have extra cover at screw-anchor locations.



- Installing the engineered protective cover to completely cover both pipelines (~23,000 feet), approximately 360,000 cubic yards of gravel/rock (~610,000 metric tons) would be required.
- Installing the engineered protective cover to cover only the shipping-channel sections of the dual pipelines, approximately 85,000 cubic yards of gravel/rock (~145,000 metric tons) would be required.

- These preliminary profiles and configurations are designed to mitigate the effects of an anchor strike (including a direct drop onto the pipelines or a dragging of an anchor over the pipelines) from the largest vessels moving through the Straits and the expected 10.2-metric-ton weight of the anchors on those ships.
- Approximate timeline to complete the installation of the engineered gravel/rock protective cover over the entire length of the dual pipelines is about two to three years. This includes: engineering and design; procuring the gravel/rock; receiving permits and approvals; and placing the gravel/rock over the pipelines.
- The construction timeline would be extremely sensitive to seasonal windows. Icing of the Straits (December-April) limits the construction season to April-October. It is estimated the gravel/rock placement would take five to six months, so construction could be completed in one construction season, weather permitting.
- The engineered protective cover would require at least 11 state and federal environmental permits and approvals. The primary regulators would be the U.S. Army Corps of Engineers, Michigan Department of Environmental Quality and Michigan Department of Natural Resources. Permitting durations would largely be driven by the time necessary to complete any environmental reviews and consultations that would be required under federal and state law.
- The engineered protective cover would be considered a permanent change to the lake bottom in some areas—from soft sediment to hard—and there would likely be a temporary impact to commercial and recreational marine traffic lasting for the duration of construction activities.
- There would be no shoreline impacts. All onshore construction activities would likely take place at existing facilities—docks and local quarries—so there would be no onshore impacts and no temporary work areas required. There would be no onshore land clearing or grading. After construction, there would be no new impacts related to pipeline operation and maintenance activities.
- While the engineered protective cover would not allow external visual inspection of the Line 5 pipelines, Enbridge would continue to assess the overall integrity of the pipelines through a robust monitoring and inspection program using advanced in-line inspection tools. The pipelines would also continue to be protected by cathodic protection.
- Regular external visual inspections of the engineered protective cover would also take place to ensure an adequate depth of cover of the gravel/rock.
- If the pipelines ever needed external visual inspection at any location, the gravel/rock cover could be removed by subsea construction equipment and divers.
- The Reliability Consultant concluded the engineered protective cover would likely result in a 99 percent reduction in the probability of a pipeline failure from either an intentional or unintentional anchor strike.

How We Prepared This Report

Enbridge used a robust process for assessing each option, as follows:

Communication and Warning Technologies

Enbridge formed an internal team consisting of subject-matter experts who worked in collaboration with State representatives (the Team) to assess and report on measures that could be taken to enhance shipping communication and warning technologies in the Straits to help protect the Line 5 pipelines from an anchor strike.

The Team considered:

- Preventive measures currently in place to protect Line 5 and other utilities in the Straits from anchor strikes.
- Measures already under consideration by Enbridge to further protect Line 5.
- Additional measures that could help to further protect Line 5 in the Straits.

Several ideas were brainstormed during the Team's working sessions. In this Report, we present a summary of the Team's findings.

Protective Barriers

To assess the use of a protective barrier to further protect the Line 5 pipelines, Enbridge engaged a number of consultants who are renowned for their expertise and are recognized leaders in their respective fields:

- **Lead Engineering Consultant—INTECSEA, Inc.:** INTECSEA is a provider of engineering services that has designed subsea production systems, pipelines and floating systems for offshore field development and pipeline projects in the Gulf of Mexico, Arctic Ocean, North Sea, offshore Western Australia, Mediterranean Sea, Black Sea, offshore West Africa and South China Sea. Founded in 1984 and based in Houston, Texas, INTECSEA operates as a subsidiary of WorleyParsons Limited.
- **Constructibility Reviewer—Kokosing Industrial's Durocher Marine Division:** Based in northern Michigan, Durocher Marine provides construction services for activities above or below water and performed some of its first work near the Mackinac Bridge in the 1950s. Kokosing Industrial is one of the largest contractors in the U.S. Midwest, serving the power, oil and gas, industrial, marine, heavy civil, water/wastewater and commercial sectors. Durocher Marine was provided with the Lead Engineering Consultant's work and assessed the constructibility of the proposed protective barrier.
- **Lead Environmental Consultant—Stantec**: Stantec is an international engineering, environmental and technical services firm with five offices in Michigan. Their 2,700 North American environmental services staff and environmental sciences practice works with clients to assess environmental impacts, evaluate project requirements and prepare environmental assessments to meet regulatory standards. Stantec considered the potential environmental impacts of the protective-barrier option.

- **Subject-matter Expert:** Enbridge hired Project Consulting Services, Inc. (PCS) to act as its subject-matter expert for the protective barrier assessment. PCS is a pipeline and pipeline facility engineering and regulatory compliance firm whose scope of expertise includes navigating U.S. Army Corps of Engineers and Bureau of Safety and Environmental Enforcement regulatory processes efficiently and engineering deepwater subsea tie-ins.

To identify the best protective barrier option and to complete this study, three separate sessions were held to do the following:

1. Brainstorming by Enbridge, State-appointed representatives and the consultants to identify the various types of protective barriers that could be used to prevent an anchor from impacting the Line 5 pipelines either from an anchor being dropped directly on the pipelines and/or an anchor being dragged across the pipelines.
2. Categorizing the protective barrier options into two groups: allows external visual inspection; and does not allow external visual inspection.
3. Selecting one option from each category for further study.

In this Report, we present a summary of the consultants' findings. This Report has been reviewed by the respective experts to ensure it accurately represents their findings and opinions.

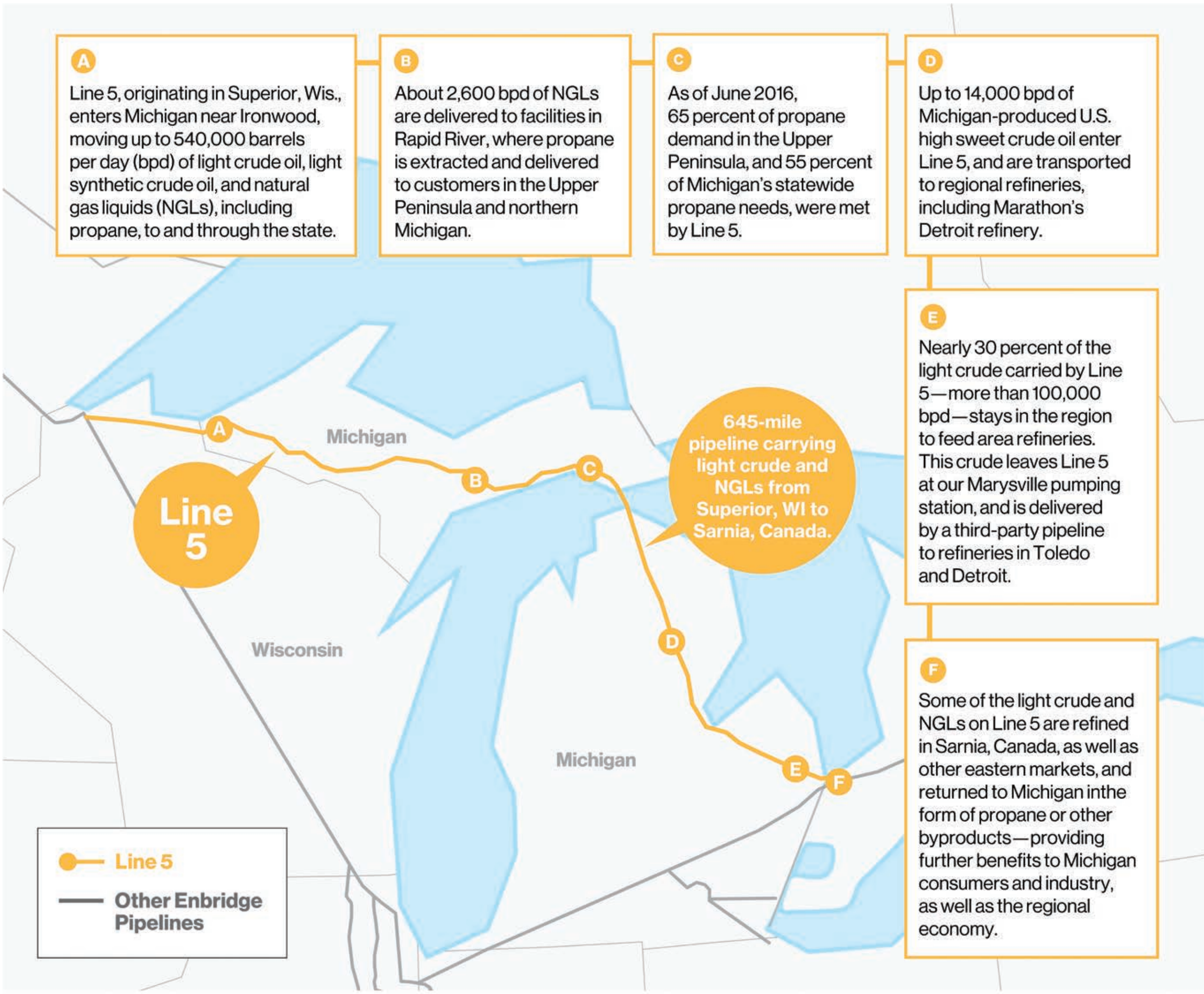
Reliability Consultant

Enbridge also engaged C-FER Technologies as a Reliability Consultant to assess to what degree Vesper Marine's *Guardian:protect* shipping communication technology and the proposed protective barrier would reduce the risk of an anchor striking the Line 5 pipelines and causing a release into the Straits.

C-FER works primarily with the global energy industry—from upstream drilling and production operations, to midstream and downstream pipeline operations—to advance safety, environmental performance and efficiency. C-FER also provides global assistance in dealing with challenging applications, including deepwater operations and Arctic energy developments. C-FER's unique testing systems have also been used by such industries as aerospace, marine and construction.

Enbridge's Line 5 in Michigan

Enbridge's Line 5 is a 645-mile, 30-inch-diameter pipeline that travels through Michigan's Upper and Lower Peninsulas. As it travels under the Straits of Mackinac for a distance of 4.5 miles, Line 5 splits into two 20-inch-diameter, parallel pipelines. Built in 1953, the Line 5 Straits crossing has never experienced a leak in more than 60 years of operation.



Quick facts on Line 5

- Enbridge's Line 5 and Line 78 are critical conduits for refineries in the region, supplying the PBF Energy (Toledo), BP (Toledo) and Marathon (Detroit) refineries with crude oil. This essential feedstock is turned into gas, diesel, jet fuel, and other refined products
- Line 5 helps to ensure a stable, secure supply of North American light crude, keeping prices down at the pump
- To date, Line 5 has carried about 80 million barrels of Michigan based light crude to market
- Line 5 does not carry, and has never carried, heavy crude

For more information on today's Line 5, please see the Enbridge brochure *The Straits of Mackinac crossing and Line 5*. (https://www.enbridge.com/~/media/Enb/Documents/Brochures/Brochure_Line5.pdf) available at enbridge.com

The Shipping Channel in the Straits

There is an existing shipping channel in the Straits. As the channel approaches the Mackinac Bridge, it narrows so that vessels travel between the four central piers of the bridge *(Figures 3 and 4)*. This part of the channel is marked by four navigation buoys—two on each side of the channel. The central portion of the bridge provides the maximum vertical clearance between the lake surface and the underside of the bridge deck.

Enbridge's dual Line 5 pipelines are located within a lakebed utilities corridor west of Mackinac Bridge. This utilities corridor also includes power cables and dual gas lines owned and operated by other companies.

Above the Line 5 pipelines, the maximum width of the shipping channel is approximately 700 feet for the east pipeline and 800 feet for the west pipeline *(Figure 5)*.

Figure 3: A U.S. Coast Guard vessel travels in the shipping channel between the central piers and towers of the Mackinac Bridge.

Figure 4: This shipping-traffic-density map shows how the traffic converges as it approaches the Mackinac Bridge and travels along the Straits shipping channel.

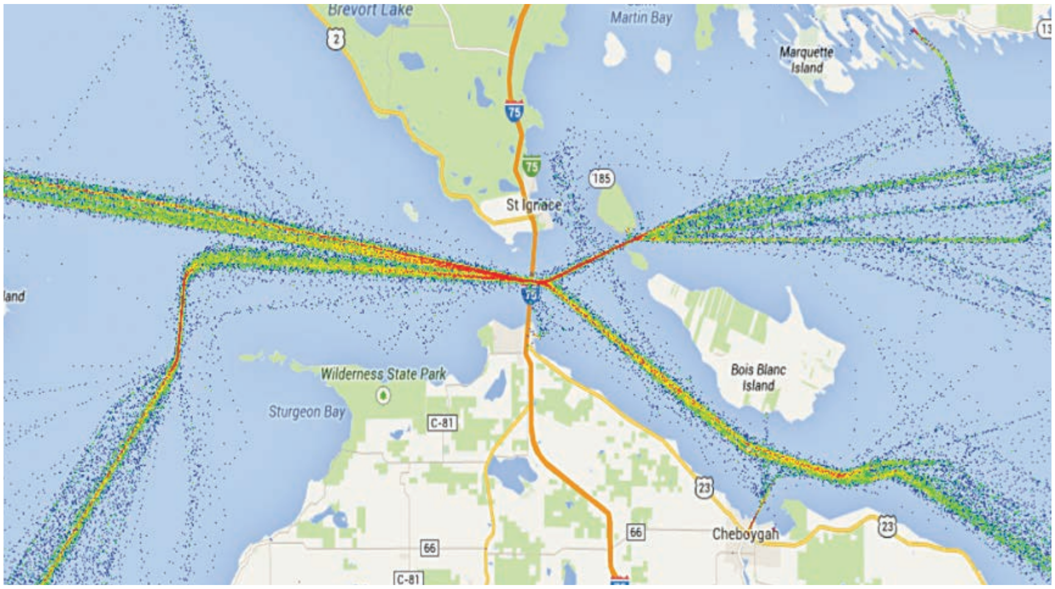
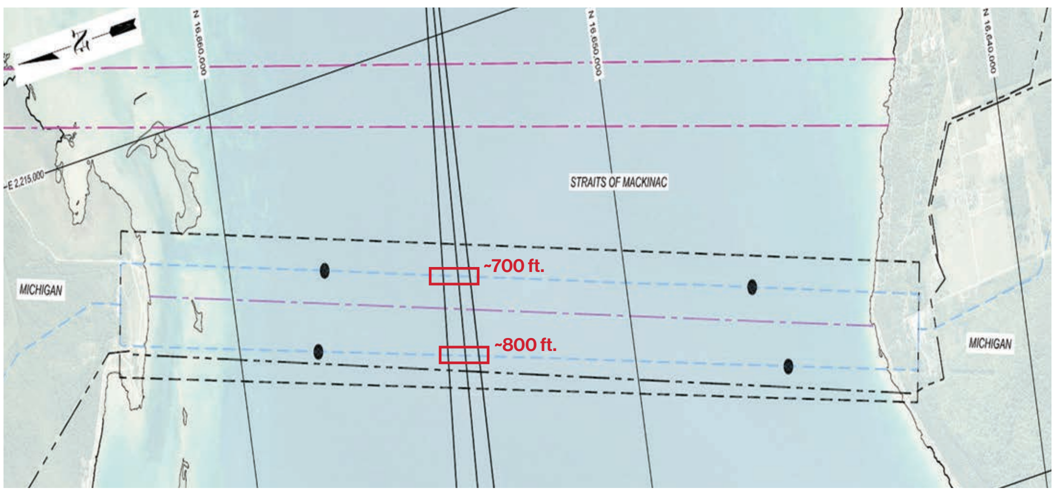


Figure 5: The Straits shipping channel and, in red, the width of the channel over the existing dual Line 5 pipelines.



Measures Currently in Place to Reduce the Threat of Anchor Strikes

There are several measures currently in place to mitigate the threat of anchor strikes on the infrastructure, including Line 5, located within the Straits lakebed utilities corridor. In consultation with State representatives and third-party consultants, Enbridge documented the following measures.

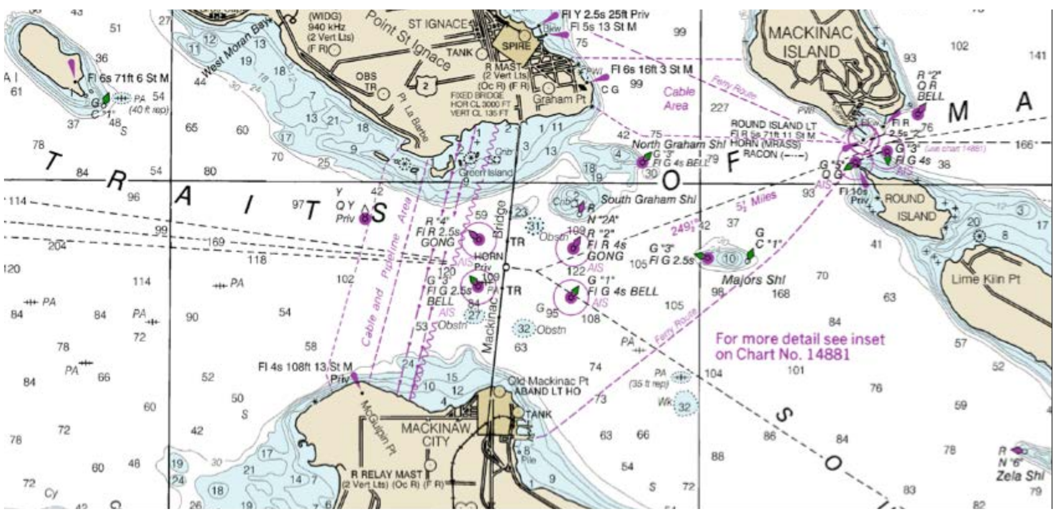
What is a nautical chart?
A nautical chart is one of the most fundamental tools available to the mariner. It is a map that depicts the configuration of the shoreline and seafloor. It provides water depths, locations of dangers to navigation, locations and characteristics of aids to navigation, anchorages and other features.

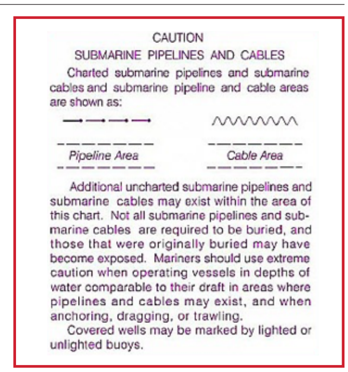
The nautical chart is essential for safe navigation. Mariners use charts to plan voyages and navigate ships safely and economically. Federal regulations require most commercial vessels to carry nautical charts while they transit U.S. waters.
(Source: NOAA)

Nautical charts

The utilities corridor in the Straits is clearly marked on the National Oceanic and Atmospheric Administration (NOAA) nautical chart of the Straits to bring awareness to vessel operators and warn ships against anchoring *(Figure 6)*. Professional mariners are expected to know how to read a standard NOAA chart, including the symbols and cautionary notices on them.

Figure 6: Below, a detail of NOAA's nautical chart of the Straits of Mackinac, showing the Mackinac Bridge (black line, centre right) and the lakebed utilities corridor (purple lines, centre left), including Enbridge's Line 5, as well as power cables and a dual gas line operated by other companies. Below right, the chart includes this cautionary note about the utilities corridor.





CAUTION
SUBMARINE PIPELINES AND CABLES

Charted submarine pipelines and submarine cables and submarine pipeline and cable areas are shown as:

Pipeline Area

Cable Area

Additional uncharted submarine pipelines and submarine cables may exist within the area of this chart. Not all submarine pipelines and submarine cables are required to be buried, and those that were originally buried may have become exposed. Mariners should use extreme caution when operating vessels in depths of water comparable to their draft in areas where pipelines and cables may exist, and when anchoring, dragging, or trawling.

Covered wells may be marked by lighted or unlighted buoys.

Great Lakes Endorsement

In order to operate the type of large vessel that would be traveling through the Straits, professional mariners—masters (the officer in command of a vessel), deck officers and mates—are required, through training and examinations, to obtain a Great Lakes Endorsement from the U.S. Coast Guard's National Maritime Center.

These credentials confirm the individuals have the necessary knowledge and experience to safely operate and work on large vessels operating anywhere on the Great Lakes. The United States Code of Federal Regulations (CFR) outlines the specific requirements in *Title 46—Shipping* and in *Title 46—Chapter I—Subchapter B—Part 11—Subpart D—Sections 11.430-11.456 (Endorsement in the Great Lakes).*

Great Lakes pilots

On the Great Lakes, any foreign vessel on a registered international voyage must travel with a federally registered pilot from the Great Lakes Pilot Association. The pilot boards the vessel before it enters the Great Lakes and acts as pilot for the vessel's entire Great Lakes voyage.

Masters and mates of U.S. and Canadian Lake freighters, which are the largest bulk carriers on the Great Lakes, who have obtained their Great Lakes Endorsement are permitted to navigate the Great Lakes without a federally registered pilot.

U.S. Coast Guard oversight

The district branch of the USCG Sector Sault Sainte Marie is active in the area, monitoring vessels and patrolling in the Straits. While they are not dedicated 100 percent of the time to the pipeline and utilities crossing area, the USCG's visible presence and management of the area acts as a reminder to vessels to be diligent and operate responsibly.

No-Anchor Advisory Zone

Until recently, the Straits of Mackinac was officially categorized as a No-Anchor Advisory Zone, which meant vessels were expected to drop anchor only under the strict supervision of the USCG, or in case of a force-majeure event such as failure of a ship's thrust power, or extreme weather events such as winds greater than 70 miles per hour or tidal- or wind-driven waves.

On May 24, 2018, Michigan Governor Rick Snyder approved the Department of Natural Resources issuing an emergency rule prohibiting anchoring in the Straits. Issued under the Marine Safety sections of the Natural Resources and Environmental Protection Act, the emergency rule will remain in place for six months, with the option of an additional six-month renewal. The eastern boundary of the no-anchor zone is defined by the Mackinac Bridge, and the western boundary is defined by a line beginning at the western edge of McGulpin Point in the Lower Peninsula to the western edge of an unnamed island immediately southwest of Point La Barbe in the Upper Peninsula. Exceptions to the rule include:

- Emergency situations.
- Vessels operating under tribal authorities.
- Written requests documenting the location of the proposed anchorage and the reason for the request. These requests will be reviewed and granted at the discretion of the director of the Department of Natural Resources.

The emergency rule formalizes the previously informal anchor restriction in the Straits by prohibiting anchoring under Michigan state law. A news release announcing the emergency rule also stated that "productive discussions are underway with the U.S. Coast Guard on permanent measures that would complement the state's temporary emergency rule."

Shoreline signage

American Transmission Company (ATC) currently has large signs on each side of the Straits warning vessels not to anchor in the area *(Figure 7)*. Enbridge does not currently have its own signage on the shores because the ATC submarine cable crossing is in close proximity to Line 5. Installing additional signage is noted as a potential communication measure in the section below.

Figure 7: Shoreline signage located next to the Straits utilities corridor.

Shipping Communication and Warning Technologies

Enbridge has identified several communication measures that have the potential to reduce the risk of an anchor strike to all cable and pipeline infrastructure in the Straits of Mackinac lakebed utilities corridor. Enbridge also has identified a potential marine notification system that could actively monitor and communicate with vessels in the Straits when they are in close proximity to the Line 5 pipelines.

Enbridge working in collaboration with State representatives (the Team) assessed a range of technologies and measures for mitigating the risk of a vessel's anchor puncturing, dragging or otherwise damaging the existing Line 5 pipelines across the Straits.

This section of the Anchor Strike Report summarizes that work, including:

1. Potential holistic communication measures to reduce the risk of an anchor strike to the Line 5 pipelines and all other pipelines and cables located within the Straits utilities corridor.
2. Technologies that were considered for reducing the likelihood of an anchor strike to the Line 5 pipelines.
3. Enbridge's progress in testing a shipping communication and warning system for the dual pipelines.

Potential Holistic Communication Initiatives to Reduce Anchor Risk to All Utilities Located in the Straits

While identifying communication technologies and barriers that could reduce the risk of an anchor strike damaging Line 5, a number of ideas were raised that have the potential to reduce the risk to all utilities located within the Straits.

If they are deemed to be feasible, Enbridge would actively support any of the following potential joint initiatives.

Ideas generated included:

- **Enhanced Public Awareness Campaign:** A coordinated Public Awareness Campaign could be initiated in partnership with the State, the U.S. Coast Guard and other utility operators with infrastructure in the Straits to educate people about the location of pipelines and other utilities crossing the Straits. The campaign could target the widest possible audience—vessel operators, landowners, business owners, tenants, communities, Native American groups, visitors and emergency responders—by reaching out on an ongoing basis, similar to the pipeline industry's current '811 Call Before You Dig' collaboration.

  Examples of how this could be executed include:

  - Print, web, radio and/or television campaign.
  - Collaboration with the Great Lakes Maritime Academy to ensure course content covers the utilities corridor located in the Straits.
  - Annual safety kick-off meetings and educational events.

- **Additional signage and physical marker buoys:** Several signage and marker options were considered and, although 'DO NOT ANCHOR' signage is already in place on the north and south shore of the Straits in the utilities corridor area, the Team considered whether additional signage could help further raise awareness.

  The following were identified as being the most practical; however, all require further evaluation to determine if there would be added benefit:

  - **Signage on the Mackinac Bridge:** Add signage to warn vessels, possibly in partnership with the State and/or the Mackinac Bridge Authority.
  - **Additional signage on shorelines:** Additional 'DO NOT ANCHOR' signage on the north and south shore; this would need to be further evaluated to determine if more signage would be beneficial.
  - **Floating marker buoys with 'No Anchor' warnings:** Buoys in the shipping channel could help raise awareness of operators of small vessels

- **Enhanced patrols and increased enforcement:** The Team had two concepts that could reduce the risk of both intentional and unintentional anchor drops in the Straits, as follows:

  - **Dedicated patrol vessels or drones deployed:** Proactively observe in real time the behavior of vessels and the position of the anchors.
  - **Mandatory checkpoints and anchor inspection:** Collaborate with the U.S. Coast Guard to investigate opportunities to enhance current policies and procedures that vessels are required to follow before proceeding to cross the Straits. For example, consider the practicality of requiring larger vessels (Seawaymax-size and Lake freighters) to contact the USCG prior to crossing the Straits.

  Both of these concepts would require USCG consultation, support and approval.

Enbridge's costs associated with all of the communication measures described above would be considered separately should it be decided to implement any of these potential additional communication measures.

Line-5-specific Shipping Communication and Warning Technologies Considered

Working collaboratively with stakeholders, including State of Michigan representatives and third-party consultants and engineering firms, Enbridge assessed the potential for different technologies that could prevent an anchor strike, as follows:

Video and thermal cameras

Enbridge assessed the potential of installing forward-looking infrared (FLIR) 602cz cameras with pan, tilt and zoom functionality to monitor vessels that may be slowing or remaining stationary above the Line 5 pipelines that could indicate the intention to anchor.

FLIR cameras would provide recorded visual and thermal imagery of the Straits crossing. They also could be upgraded so that real-time video could be viewed from a remote desktop platform.

An evaluation of the bandwidth capacity at the north shore of the Straits revealed that the current network had insufficient capacity to broadcast real-time video. To work around this, a satellite broadcasting station would have to be added to the system so that the video could be sent to a desktop application to be recorded. However, such a configuration was deemed to be vulnerable to potential interruptions in power.

The cameras would also have to be installed on a tower to allow sufficient sight lines. Enbridge performed a structural analysis of the existing 160-foot tower at Enbridge's Mackinaw Station on the south shore to determine whether it would be rigid enough to keep a FLIR camera stable. However, to keep the camera stable enough to capture quality video, it would need to be mounted at approximately 32 feet. At 32 feet the camera would be mounted too low to have a line of sight to the Straits crossing.

Given these limitations, Enbridge determined that FLIR technology is not suitable at the Straits at this time. Further, this technology would not prevent anchor strikes on its own as it provides no ability to communicate with the vessels slowing near the pipelines.

Acoustic technologies

Acoustic technologies were also considered for their potential to notify Enbridge in the event of an anchor strike. An impact on the pipe would create a transient acoustic wave that travels upstream and downstream on the pipeline. High-sensitivity hydrophone monitoring systems—that can be installed at valve sites—could measure and validate the type of impact event and determine its location and severity based on the sound characteristics of the acoustic wave. Because this technology would only detect an anchor strike after it occurred, Enbridge determined that this technology is not applicable to protect against anchor strikes.

Automatic Identification System technologies

The Automatic Identification System (AIS) is a critical part of ship-board navigation used around the world. Formed by a network of shipboard transmitters and land-based and satellite-based receivers, AIS broadcasts vessel information—identity, type, position, course, speed, navigational status, etc.—as often as every two seconds to AIS-equipped shore stations, other ships and aircraft. Shore-based AIS-enabled equipment can also be used to send messages to vessels.

The USCG uses AIS to monitor and regulate vessel activity. U.S. federal regulations require any ship over 65 feet long to be equipped with AIS hardware *(Figure 8)*.

Figure 8: An AIS monitor mounted on a vessel.

Enbridge evaluated two marine AIS technologies to determine whether they could be used to actively monitor vessels in the Straits that come in close proximity to the dual Line 5 pipelines.

Enbridge determined that such a system could be useful in mitigating the risk of anchor strikes.

While both systems offered the ability to identify, track and notify Enbridge personnel of vessels near the crossing of the dual pipelines, Enbridge ultimately determined that the functionality of Vesper Marine's *Guardian:protect* system potentially provided the most benefit to Enbridge in mitigating anchor strike risk.*

* Founded in 2007, Vesper Marine is focused on developing AIS solutions for the marine sector. With an ISO 9001:2008 accredited manufacturing facility located in New Zealand, Vesper Marine maintains strict control over quality, and all its products are fully certified by the world's independent authorization bureaus, including: CE/EU; Germany BSH; USA USCG & FCC; Canada IC; Australia; and New Zealand. www.vespermarine.com

A comparison of the features offered by both systems is described in the following table.

Feature	*Guardian:protect*	Other System Considered
Real-time monitoring of AIS-equipped vessels	✓	✓
Automated event alerts to Enbridge personnel based on rule/zone definitions (email and text alerts)	✓	✓
Replay historical events	✓	✓
Web-based service	✓	✓
Transmit cautionary messages to AIS-equipped vessels	✓	
Transmit virtual AIS navigational markers to vessel navigation systems	✓	

Enbridge selected *Guardian:protect* as the system that could meet Enbridge's needs because it provides the ability to send early-warning messages directly to vessels that pose an anchoring risk. Therefore, the remainder of this section of the Report focuses on the *Guardian:protect* system.

Current Status of Enbridge's Evaluation of the *Guardian:protect* System

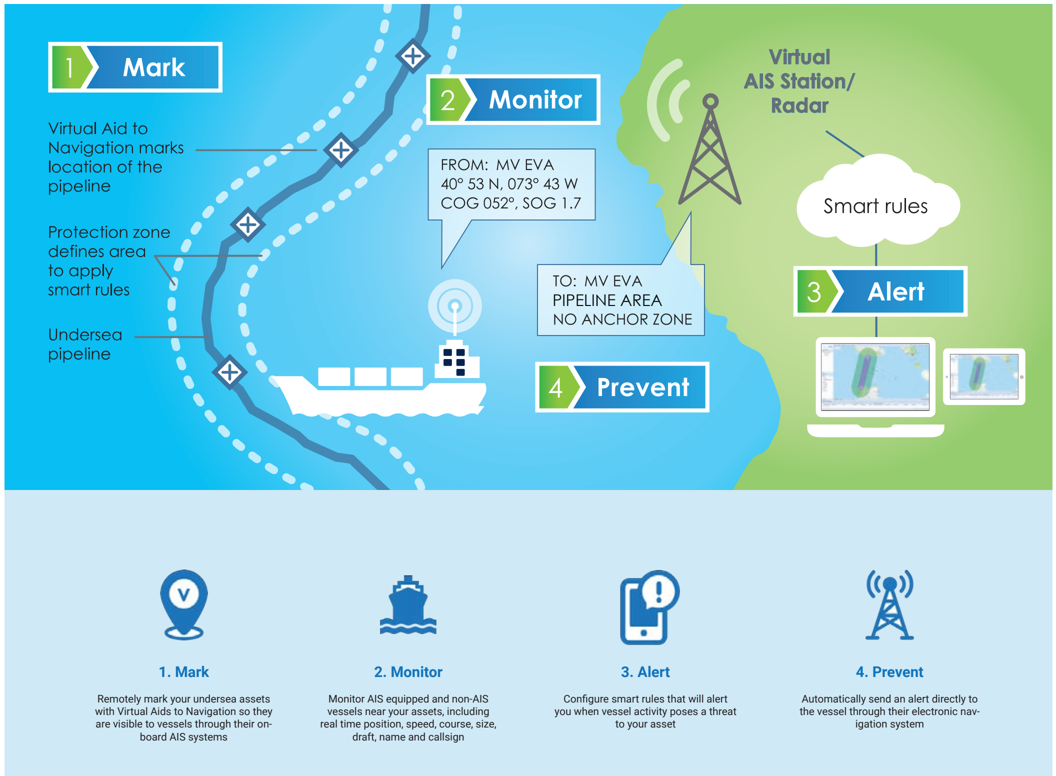
Guardian:protect is a web-based system that enables an owner of underwater assets (like the dual Line 5 pipelines) to identify, track, be notified of and communicate with vessels that are near those assets. It can also be used to intervene proactively when the system detects vessel activity that presents a risk to underwater assets.

It does so by constantly monitoring all vessels equipped with AIS for breaches of 'smart rules and zones' that are customized by the user of the *Guardian:protect* system. When a breach occurs, the system automatically sends early-warning alerts to both the system user and the vessel concerned.

The four main features of the *Guardian:protect* system are *(Figure 9)*:

1. **Mark:** An asset owner can mark its underwater assets with virtual 'buoys' known as Virtual Aids to Navigation (ATON) so the assets are visible to vessels on their on-board AIS screens.
2. **Monitor:** An asset owner can monitor both AIS-equipped and non-AIS vessels near its assets, including vessels' real-time position, speed, course, size, draft, name and call sign.
3. **Alert:** An asset owner can configure smart rules into the system that will alert the asset owner of vessel activity that could pose a threat to the underwater assets.
4. **Prevent:** The system can be configured to automatically send a safety message directly to a vessel's electronic navigation system to alert the crew to the location of the underwater assets and avoid anchoring in the area.

Figure 9: This infographic summarizes the full functionality of Vesper Marine's Guardian:protect system.



Enbridge installed the *Guardian:protect* hardware at the Enbridge Mackinaw Station on the south shore of the Straits in December 2017. The system is currently functioning in a test mode.

Before this system can be considered fully operational, there are two critical functions that Enbridge would need to activate to benefit from the full 'Mark-Monitor-Alert-Prevent' potential of the system.

1. **Mark:** Enbridge would need to enable the system's virtual ATON functionality in the location where the dual Line 5 pipelines cross the Straits. These virtual buoys would be visible on vessels' AIS navigation monitors.
2. **Prevent:** Secondly, Enbridge would have to consult with the USCG, the State and other maritime experts to develop the best strategy for sending out alerts to vessels to prevent potential unsafe anchor activity.

To activate both the Mark and Prevent functionality, the following consultation would have to be completed and approvals and licenses secured:

- **Consultation with the USCG to determine (a) the appropriate level of notification for marine traffic and (b) the appropriate ATONs to use in the Straits:** Any alerts generated by the *Guardian:protect* system must be aligned with the USCG's procedures and expectations.
- **USCG and Federal Communications Commission (FCC) approvals:** Broadcasting AIS messages and using virtual ATONs within U.S. waters requires approval from the USCG and a license from the FCC.

Estimated capital cost:
$500,000

Implementation Cost Estimate

The estimated capital cost for fully implementing the *Guardian:protect* system is approximately $500,000.

Implementation Timeline

The critical path activity is consulting with the USCG, the State and other key stakeholders to determine when the system would communicate with a vessel and the nature of the message—proactive advisory messages such as reminding vessel operators of the pipelines and/or checking that anchors are properly stowed; and/or reactive warning messages sent to vessels that appear to be preparing to anchor. The implementation timeline would largely be driven by the time necessary to complete these consultations and the corresponding approvals. If this option moves forward, Enbridge is committed to implementing the system within 180 days of receiving the licenses.

Permits and Approvals

Three applications would be required before the *Guardian:protect* system could be permitted to transmit messages to vessels and post virtual ATONs:

1. Apply to the district branch of the USCG to approve the initial Private Aids to Navigation (PATON).
2. Apply to the USCG headquarters to approve the PATON application.
3. Apply to the FCC for a Special Temporary Authority (STA)*.

Environmental Impacts of a Communication and Warning System

There are no potential environmental impacts resulting from the installation, operation and maintenance of the *Guardian:protect* system.

* A STA is a Station License to transmit messages and data. This application process would be mediated by the USCG.

Protective Barrier

Enbridge has concluded that an engineered gravel/rock protective cover would be the most effective method to cover and protect the dual Line 5 pipelines against ship anchor strike. Enbridge would continue to assess the overall integrity of the pipelines through a robust monitoring and inspection program. If the pipeline ever needed external visual inspection at any location, the gravel/rock cover could be removed by subsea construction equipment and divers.

- **Estimated cost:** Approximately $150 million
- **Estimated timeline:** 2 to 3 years

This section of the Anchor Strike Report summarizes Enbridge's assessment of the use of a protective barrier to mitigate the risk of a ship anchor puncturing, dragging or otherwise damaging the dual Line 5 pipelines.

Anchor Weights and Types

In calculating the potential impact of an anchor strike on the Line 5 pipelines and to determine the most effective protective barrier, Lead Engineering Consultant INTECSEA used the anchor weights and types that would be on the largest cargo vessels traveling through the Straits, as follows:

- The largest are bulk carriers called Lake freighters that were constructed in the region and are too large to move through the locks of the St. Lawrence Seaway. Data available from the public domain have shown that the largest of these vessels has a capacity of approximately 92,000 deadweight tonnage (DWT) and the longest vessel is approximately 1,000 feet. These freighters would carry the largest anchors of any vessel traveling through the Straits.
- The second largest vessels on the Great Lakes are classed as 'Seawaymax', which can move through the St. Lawrence Seaway locks. The maximum size of a Seawaymax vessel is 740 feet long, 78 feet wide, 116 feet in height with a 26-foot draft. A standard Seawaymax-class vessel has a capacity of 28,500 DWT, while a Seawaymax-class oil tanker has a maximum capacity of 60,000 DWT.

What is deadweight tonnage?
Deadweight tonnage is a measure of the total amount of weight a ship can carry. In other words, DWT is the sum of the weights of cargo, fuel, fresh water, ballast water, provisions, passengers and crew.

What is a fluke?
A fluke is the pointed projection on an anchor that digs into the lakebed.

For its anchor drop and drag assessment, INTECSEA based its calculations for the design of the engineered protective cover on the anchor type, weight and fluke length used by the largest Lake freighters, as per the table below:

Vessel and anchor data

Parameter	Value
Vessel length	1,013 feet (308.8 meters)
Vessel width	105 feet (32 meters)
Vessel depth	56 feet (17.1 meters)
Estimated anchor weight[1]	22.5 kips[2] (10.205 metric tons)
Projected anchor fluke length	4.3 to 5.0 feet (1.3 to 1.4 meters)

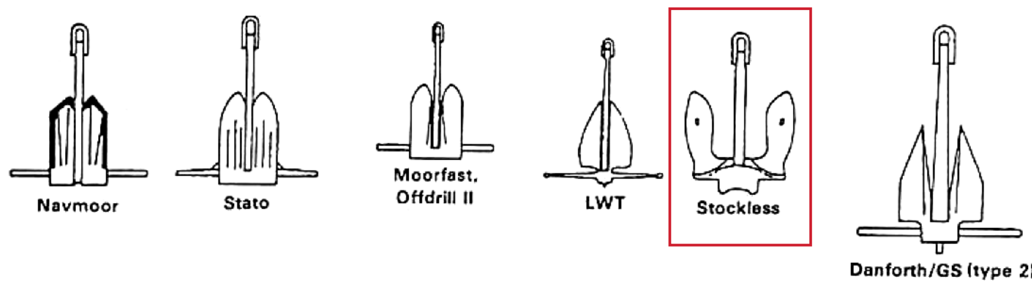
1 Anchor weight estimate is based on "Rules for Building and Classing; Bulk Carriers for Service on the Great Lakes 2017", American Bureau of Shipping, updated March 2018.

2 A kip is a U.S. customary unit of force. One kip equals 1,000 pounds-force.

What is a drag-embedment anchor?
A drag-embedment anchor is pulled—in other words, dragged—into a lakebed or seabed. It is the most common type of anchor used in the Great Lakes.

There are a wide variety of drag-embedment anchors used by ships in the Great Lakes. The majority of these anchors are shown in *Figure 10* below. The U.S. Navy Stockless anchor (second from right) is the most common type and INTECSEA used it as the basis for its feasibility study.

Figure 10: Typical ship drag-embedment anchors.



Potential Impacts of Anchor Drops and Drags

Anchor drop

A dropped anchor will enter the lake at a velocity dependent on the height from which it was dropped. It will then speed up or slow down to reach a terminal velocity after sinking, depending on the anchor's mass and shape. At terminal velocity, the object falls with a constant velocity.

Anchor drag

Dragging of an anchor across an unburied pipeline may result in impact, pull-over or, less frequently, a hooking interaction with the pipeline. A large-diameter pipeline could safely resist the pull-over anchor loads of small vessels, but anchor loads of larger vessels could potentially pull the pipeline beyond its bending capacity. If an anchor is dragging along the lakebed and is not pulled over the pipeline, it could be hooked under the pipeline.

Our Process for Selecting a Proposed Protective Barrier for Line 5

Enbridge's Line 5 protective barrier study was conducted in three separate sessions *(Figure 11)* in which Enbridge aimed to identify the most suitable barrier option, which was defined as one that protects the existing pipelines from anchor drop and drag, poses minimum risk to the dual pipelines during both construction of the barrier and operation of the pipeline, and also minimizes interference to ship traffic, fishing and recreational activities in the Straits during construction.

Figure 11: The process followed to identify the most effective type of barrier for protecting the Line 5 pipelines from anchor strike.

Brainstorming Session

- Pre-Tensioned Cables
- Rirap rock
- Concrete Mattresses
- Fiber Reinforced Plastic (FRP)
- Metal Framework with Concrete Mats
- A-Jacks
- Concrete Cover
- Gravel/Rock Berms
- Engineered Gravel/Rock Protective Cover
- Urethane Ducting System
- HDPE Pipes
- Foam/Polymers
- Metal Cage
- Concrete Barriers
- Concrete Barriers with Steel Covers

Narrowing-Down Session

All options from brainstorming session were categorized into two separate groups— "allows external visual inspection" and "does not allow external visual inspection". If the protective barrier fully covers the pipeline, external visual inspection may not be possible.

Allows External Visual Inspection	Does Not Allow External Visual Inspection
• Gravel/Rock Berms • Concrete Barriers with Steel Covers • Concrete Barriers • HDPE Pipes • Pre-Tensioned Cables	• Engineered Gravel/Rock Protective Cover • Concrete Mats • Concrete Covers • Fiber Reinforced Plastic (FRP) Covers

Selecting Suitable Options

One option from each category was chosen for further feasibility study, including preliminary "Cost and Schedule".

Allows External Visual Inspection	Does Not Allow External Visual Inspection
• Gravel/Rock Berms	• Engineered Gravel/Rock Protective Cover

First, through a brainstorming session involving INTECSEA and other subject-matter experts, as well as representatives of Enbridge and the State (collectively referred to as the Project Team), 15 types of protective barriers were identified that could be used to either impede the impact from an anchor drop/drag or eliminate the risk of damage from a direct anchor strike to the dual Line 5 pipelines.

A weighted-criteria matrix was used to help the Project Team determine the most suitable protective barrier option. Each barrier option was evaluated on specific evaluation criteria, weighted by importance. The evaluation criteria for determining the most suitable protective barrier solution was made up of the following 10 criteria in order of importance:

1. Ability to protect the existing pipelines from anchor drop.
2. Ability to protect the existing pipelines from anchor drag.
3. Potential for damage to the existing pipelines during construction.
4. Potential for damage to the existing pipelines during operation.
5. Constructibility of the proposed protective barrier.
6. Industry experience.
7. Impact to the existing shipping traffic during construction.
8. Cathodic protection shielding.
9. Regulatory and environmental permits and approvals.
10. Cost and schedule.

Second, the Project Team narrowed down the 15 potential protective barriers to a short list of nine and separated those into two categories:

1. Solutions that allow external visual inspection of the pipelines.
2. Solutions that do not allow external visual inspection.

Third, the project team selected the best option from each category for further feasibility study, as follows:

- **Allows external visual inspection:** gravel/rock berms.
- **Does not allow external visual inspection:** engineered gravel/rock protective cover.

Based on further assessment of the two short-listed options, Enbridge and the Project Team concluded that engineered gravel/rock protective cover would be the safest and most effective option to protect the existing Line 5 pipelines from damage due to ship anchor strike.

The Project Team dismissed the visually inspectable gravel/rock berm option because it would only cover the pipeline on the sides and would provide only partial protection against anchor drag and no protection in the event of a direct anchor drop over the pipeline. Further, over time, the pipeline would become partially covered with lake sediment, which would limit external visual inspection.

The other short-listed protective barriers the Project Team considered but dismissed were: concrete barriers; concrete barriers with steel covers; high-density polyethylene (HDPE) pipes; pre-tensioned cables; concrete mats/mattresses; concrete covers; and fiber-reinforced plastic (FRP) covers. For more details about these seven dismissed options, please see *Appendix 2*.

Most Effective Protective Barrier: Engineered Gravel/Rock Cover

Engineered gravel/rock cover has a strong track record in the offshore industry for protecting pipelines from ship anchor drop and drag. The solution has been used globally to protect hydrocarbon pipelines installed in many major shipping channels, including in the North West Shelf area of Australia, the Sakhalin area of Russia, the Norwegian sector of the North Sea, Singapore and Hong Kong.

The engineered gravel/rock cover could be designed either to:

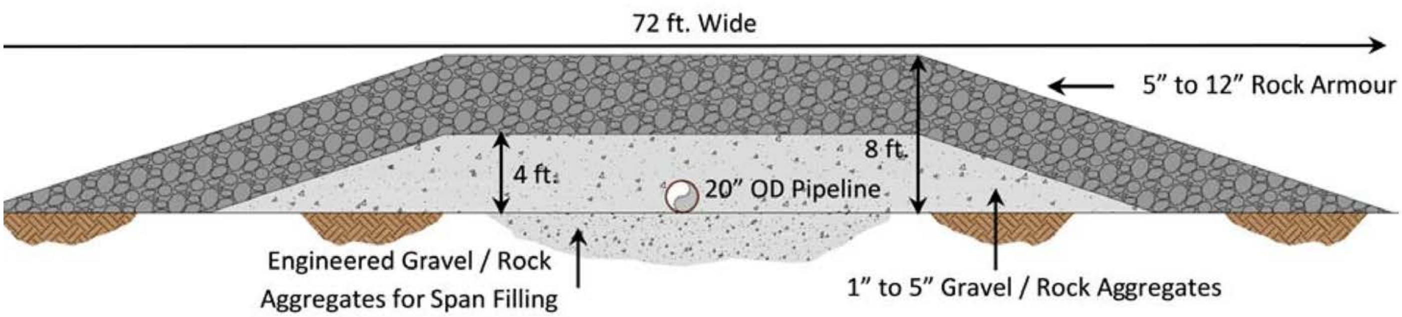
- cover the entire exposed length of the dual pipelines—approximately 11,000 feet for the east pipeline and 12,000 feet for the west pipeline; or
- cover only the sections of pipeline within the shipping channel. Above the Line 5 pipelines, the maximum width of the shipping channel is approximately 700 feet for the east pipeline and 800 feet for the west pipeline *(Figure 5)*. For this option, INTECSEA suggests covering a 2,000-foot section over each pipeline—for a total of 4,000 feet—to allow for a buffer on either side of the shipping channel. The optimal length of the buffer would be determined at the next phase of design.

To cover the entire exposed length of the Line 5 pipelines (~23,000 feet), INTECSEA estimates that approximately 360,000 cubic yards of gravel/rock would be required. To cover only the shipping-channel sections of the Line 5 pipelines, approximately 85,000 cubic yards of gravel/rock would be required.

Profile and Configuration of a Line 5 Engineered Gravel/Rock Protective Cover

The proposed profile and configuration of the engineered gravel/rock protective cover option is shown in *Figure 12*. The protective cover over each pipeline would be approximately 72 feet wide and a minimum of eight feet high from the lakebed. The minimum height of gravel/rock cover from the top of the existing dual 20-inch pipelines would be 6.33 feet (76 inches).

Figure 12: The proposed profile and configuration of the engineered gravel/rock protective cover on the 20-inch dual Line 5 pipelines crossing the Straits of Mackinac.



This proposed profile and configuration is designed to mitigate the effects of an anchor drop and drag from the largest cargo vessels that sail through the Straits and the expected 10.2-metric-ton weight and fluke length (4-5 feet) of the anchors on those ships.

Conservative Design Criteria

INTECSEA carried out its feasibility study using the following conservative design criteria for the engineered protective cover:

a. The protective cover is able to absorb all the energy from the direct impact of a dropped anchor such that no dents would occur on the pipeline.

b. No contact is allowed between the anchor and the pipeline as a result of an anchor dropping and dragging over the pipeline.

c. A minimum of 6.33 feet (76 inches) of gravel/rock cover on top of the pipeline is maintained.

d. Regular monitoring of the height of the engineered protective cover would be performed to ensure the integrity of the system.

Anchor Drop and Drag Scenarios

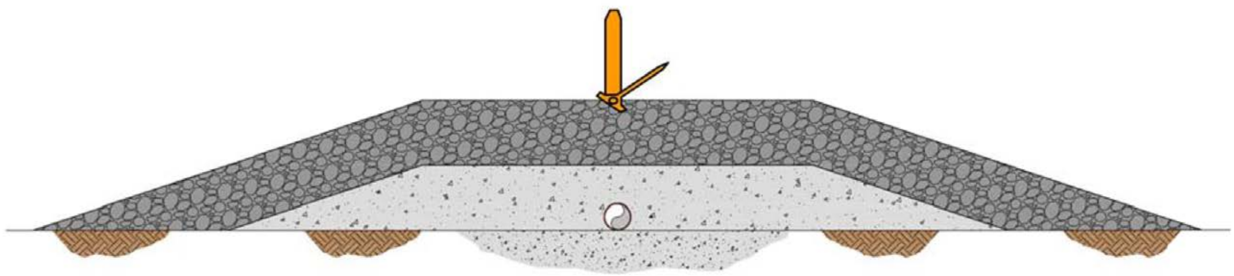
INTECSEA considered three scenarios to estimate the effects of an anchor strike to the Line 5 pipelines if they were covered with an engineered gravel/rock protective cover that has a minimum cover height of 6.33 feet (76 inches) from the top of the pipelines.

All three scenarios illustrate the impact of the type, weight and fluke length (4-5 feet) of an anchor used by the largest cargo vessels traveling through the Straits.

Scenario 1: The anchor drops right over the pipeline and drags away from the pipeline

INTECSEA estimates that in this scenario *(Figure 13)*, the impact energy from the dropped anchor will be absorbed by the engineered protective cover—keeping the pipeline from being damaged. After the drop, the anchor is dragged away from the pipeline, causing no harm to the pipeline.

Figure 13: This illustration of Scenario 1 shows what would happen if an anchor from one of the largest vessels traveling through the Straits dropped directly over the Line 5 pipeline and dragged away from the pipeline—the impact energy is absorbed by the engineered gravel/rock protective cover and there is no harm to the pipeline.

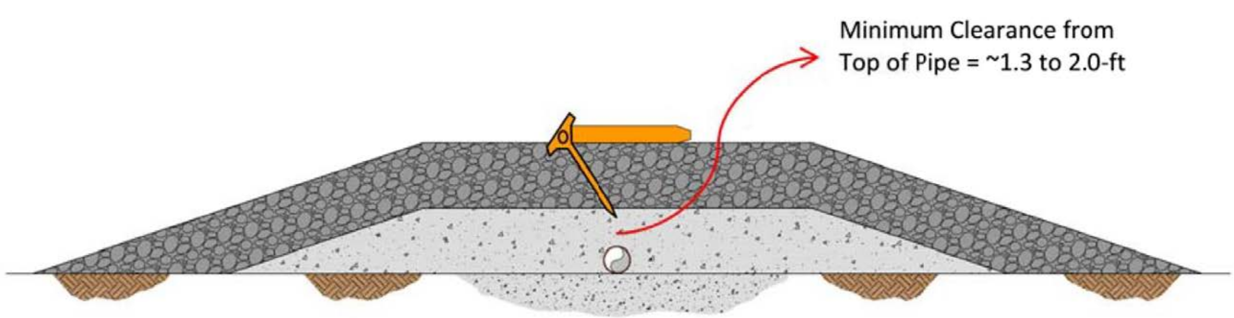


Scenario 2: The anchor drops to the side—but on top of the gravel/rock protective cover—and drags through the protective cover

In this scenario *(Figure 14)*, INTECSEA estimates that, following the drop, the anchor will drag over the engineered protective cover, and the fluke will be unable to penetrate the cover more than the fluke's projected length because the gravel/rock cover is too loose to enable the anchor to set and hold. INTECSEA estimates the clearance range of the anchor to the pipeline would be between 1.3 to 2.0 feet.

If with further study the anchor data suggests deeper projected fluke lengths, then the gravel/rock cover configuration would be modified to prevent anchor contact with the pipeline.

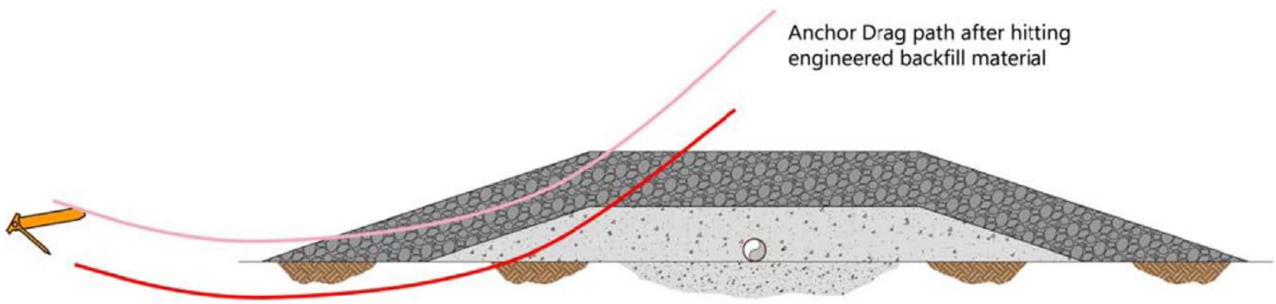
Figure 14: This illustration of Scenario 2 shows what would happen if an anchor from one of the largest vessels traveling through the Straits dropped onto the engineered gravel/rock protective cover but to the side of the pipeline and then drags through the engineered protective cover and over the pipeline—the anchor's fluke would clear the pipeline by 1.3 to 2.0 feet.



Scenario 3: The anchor drops away from the engineered gravel/rock protective cover and then drags toward the pipeline

In this scenario *(Figure 15)*, the anchor drops some distance away from the edge of the protective cover, then drags toward the edge of the cover, approaching the pipeline, and then finally contacts the engineered protective cover and breaks free. The protective cover would be designed so that while the anchor is dragging on the lakebed, the loose gravel and rock of the protective cover prevents the anchor from setting and holding; and instead helps the anchor break free of the gravel/rock. The protective cover profile would be further modified based on the actual soil condition so that any physical contact between the anchor and the pipeline is prevented.

Figure 15: This illustration of Scenario 3 shows what would happen if an anchor from one of the largest vessels traveling through the Straits dropped some distance away from the edge of the protective cover—the anchor first drags towards the edge of the cover (left) and then approaches the pipeline before it breaks out of the gravel/rock (center, top).



Constructing the Engineered Gravel/Rock Protective Cover

Many harbors around the world rely on engineered gravel/rock cover to protect pipelines and power cables from anchor damage.

Gravel/rock placement vessel

For the Straits project, an Enbridge contractor would use a proven and well-tested technique for accurately placing the gravel/rock cover onto the existing Line 5 pipelines without causing damage—using a vessel outfitted with a side-fall pipe *(Figure 16)* that can be directed and monitored by either onboard cameras or a remotely operated vehicle (ROV). This would ensure the gravel/rock cover is placed safely and accurately over the pipelines.

Existing vessels, such as hopper barges or flat top barges, can be outfitted with a side-fall-pipe system that includes a loading conveyor and portable crane or small bulldozer for loading the side-fall pipe with gravel/rock.

Figure 16: This purpose-built gravel/rock placement vessel deploys the stone through a side-fall pipe at a controlled rate, while the vessel moves along the pipeline route forming a stone berm to cover the pipeline. The end of the side-fall pipe is controlled from the surface. To provide precision rock placement, the operator uses visual and sonar confirmation of the side-fall pipe location relative to the pipeline to be covered.

Span filling

For the engineered protective cover to be feasible and effective, it would first be necessary to fill any pre-existing spans—irregular lakebed surface areas—along the pipeline route with gravel/aggregates, which would provide support for both the pipeline and the protective cover.

In addition to this ‘span filling’, it would also be necessary to level the lakebed adjacent to the pipelines using gravel/aggregates to ensure a stable foundation is achieved for the protective cover.

The span filling process would be carried out with precision and accuracy to ensure the existing pipelines are not damaged. This would be achieved by focusing on three key factors:

1. **Size of the gravel/aggregates:** To prevent damage to the pipeline and its coating, the gravel/aggregates are smaller pieces of rock.

2. **A slow, controlled and precise placement process:** Span filling would be done by controlled placement of gravel/aggregates using the same type of vessel equipped with a side-fall pipe as shown in *Figure 16*. This vessel has the tools and equipment to carefully and precisely place the gravel/aggregates under the pipe until all the gaps are filled.
3. **Continuous monitoring:** The operator of the side-fall pipe would use onboard cameras and/or an ROV to constantly monitor the placement of the gravel/aggregates.

At each span location, the side-fall-pipe operator would slowly place gravel/aggregates in the gap between the lakebed and the bottom of the pipe. Once the span is filled, if needed more gravel/aggregates could be added on the sides to achieve a leveled area where the engineered gravel/rock protective cover would be placed.

During the span-filling process, some settling of the gravel/aggregates would occur, so the process would not be deemed complete until adequate gravel/aggregates cover is confirmed by ROV surveys.

The span filling process would not be impeded by the presence of Line 5's screw-anchor supports. The side-fall-pipe vessel would place the gravel/aggregates underneath the pipe and its supporting screw anchor.

Installing the protective cover

Once the spans are filled, the pipeline would be covered with gravel/aggregate approximately four feet from the bottom of the pipe. After confirmation by ROV survey that the pipelines are fully covered, the engineered rock would be placed over the gravel/aggregate to complete the protective cover. This construction process would prevent damage to the coatings of the dual pipelines.

Once covered, the pipelines would continue to be protected by an impressed current system (cathodic protection). As part of designing and optimizing the engineered protective cover, a cathodic protection specialist would also be part of the design team and, if necessary, the cathodic protection system would be augmented to account for the engineered protective cover.

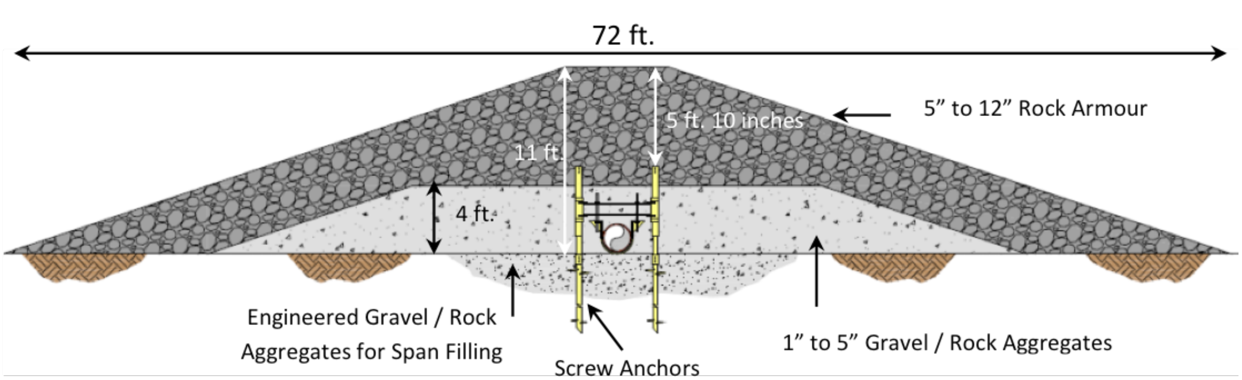
Screw anchor locations

There are several screw anchors supporting the Line 5 pipelines across the Straits.

The top post of these screw anchors is estimated to be approximately three feet from the top of the pipeline.

Since the projected length of the anchor flukes can vary from four to five feet, the height of the engineered protective cover at the screw-anchor locations would be increased by three feet *(Figure 17)* to allow a margin so that an anchor fluke would not come in contact with the screw anchors.

Figure 17: The engineered gravel/rock protective cover would have extra cover at screw-anchor locations.



Geotechnical Considerations

For the purposes of their feasibility study, INTECSEA used the data reported in *Geology of Mackinac Straits in Relation to Mackinac Bridge* by Wilton N. Melhorn (1959), which shows the surficial geology of the area includes lacustrine silt and clay, glacial till, outwash deposits (sand and boulders) and sandy clay (possibly till).

Additionally, 'Report of Clay Overburden Borings on Line A for Mackinac Straits Bridge, Michigan State Highway Department, 1939', shows that the grading analysis of the soil is a varied mix of "sand", "silt" and "clay".

However, there were no detailed site-specific geotechnical data available for the project location when INTECSEA was conducting its feasibility study.

Since lakebed geotechnical data would be critical to planning the protective barrier and the dropped/dragged anchor analyses, collection of project- and site-specific geotechnical data at the crossing location would be imperative.

Design and Planning Phase

A detailed protective-cover profile would be developed to ensure the stability and effectiveness of the proposed gravel/rock cover. Design would be optimized based on geotechnical data and model tests, supplemented by numerical models.

The potential sizes of the largest anchors that could be dropped in the Straits would be investigated further to ensure that the proposed profile and configuration is robust enough to protect the Line 5 pipelines from any anchor strike.

Identifying a suitable rock-placement contractor, local quarries, rock-placement vessels and early engagement of the construction/rock contractor would be crucial to managing the overall duration of construction.

The approach to rock placement on the pipelines, including side-fall pipe arrangement and placement accuracy, would be crucial to the integrity of the pipelines. The highest possible precision of gravel/rock placement and rigging arrangement of the side-fall pipe would be addressed at an early stage of the project. A risk assessment of a vessel modified to carry a side-fall pipe would be carried out to ensure the safety of the equipment and placement operation.

Environment and permitting issues would be addressed at a very early stage of the project. Any impact on the construction duration due to local environmental concerns or fish spawning/breeding season would be considered in the project planning.

Construction Phase

Prior to the work starting, an underwater survey would be carried out to identify locations that require span filling.

Once the span filling is complete, a second survey would be done to ensure the dual pipelines are adequately supported for placement of the gravel/rock protective cover.

Following installation of the protective cover, a third survey would be conducted to ensure the pipelines are properly protected at all locations.

A rigorous monitoring and inspection plan would be developed to ensure that the gravel/rock cover is maintained to ensure the protection of the dual pipelines.

Impact of the Engineered Cover on the Current External Inspection Program

Currently, the Line 5 Straits crossing is the most inspected segment of pipe in Enbridge's entire North American network. Enbridge carries out inspections using in-line inspection (ILI) tools, expert divers and ROVs. Enbridge also uses an Automated Underwater Vehicle to examine and report on the condition of the pipelines and the screw-anchor support system, which is in place to address spans and secure the pipeline.

Installing the engineered protective cover would require filling all spans prior to placing the engineered gravel/rock. (For more details on span filling, please see pages 27-28.) Once the spans are filled and the engineered cover is in place, the pipelines would be fully supported, eliminating the need to visually examine the underwater screw-anchor supports.

While Enbridge would continue to inspect the Line 5 crossing, the focus would shift to ensuring an adequate thickness of engineered cover is maintained and monitoring the immediate environment. If the pipelines needed to be accessed at any location, the gravel/rock protective cover would be removed by divers using pneumatic and/or manual methods.

Further, if the engineered-cover option was to move forward, Enbridge would also continue to implement annual ILI programs that inspect the condition of the steel from inside the pipeline.

Line 5's existing cathodic protection system—a low-voltage electric current used to protect pipe from external corrosion—would also continue to function and be monitored after an engineered cover is installed.

What are in-line inspection tools?
To evaluate the interior and exterior of our pipelines, most of which are underground, Enbridge uses sophisticated ILI tools that incorporate leading imaging and sensor technology to provide us with a level of detail similar to that of MRIs, ultrasound and X-ray technology in the medical industry. By examining the interior walls of our pipes inch by inch, ILI tools alert us to potential problems and help us determine whether or not further investigation, or preventive maintenance work, is required.

Constructibility Reviewer's Opinion

The Constructibility Reviewer of INTECSEA's feasibility study—Kokosing Industrial's Durocher Marine Division, which provides construction services for activities above or below water and performed some of its first work near the Mackinac Bridge in the 1950s—reviewed the two final options for a protective barrier for the Line 5 pipelines, i.e. engineered gravel/rock cover; and gravel/rock berms. In their report, Durocher Marine stated the following:

> *"The INTECSEA proposed design methods are feasible to construct using labor, equipment, and materials currently available on the Great Lakes. Both designs can be completed within one working season, providing stone production begins the year before and the environmental restrictions, such as the fish spawning windows, allow for rock placement within the project limits from April to December."*

Regarding the recommended engineered gravel/rock protective cover option, Durocher Marine said:

> *"The non-visually inspectable option can be exposed in the future using conventional means, such as an airlift, to expose a limited section of pipeline for visual inspection as needed. A similar project was completed in 1993 on the (dual) Trans-Canada (gas) pipelines (in the Straits). The installation method may be similar to the 1993 project, but the technology advancements of the equipment should allow for the same positive end result in a safer and more effective manner."*

Construction Cost Estimate

Estimated capital cost:
Approximately $150 million

The estimated capital cost for constructing an engineered gravel/rock protective cover for the entire length of the dual Line 5 pipelines across the Straits is approximately $150 million. This total installed cost includes all labor, equipment, material (rock) procurement, transportation of material to site, rock placement and internal costs.

Project Timeline

The estimated time to secure all approvals (a description of the permits required can be found in the Permits and Approvals section below), procure materials and construct the gravel/rock protective cover is two to three years. This includes completing all environmental surveys, preparing applications and completing detailed design. On-site construction activities occupy slightly less than one year. The schedule would be sensitive to seasonality. Please see *Appendix 1* for details.

Estimated project timeline: 2 to 3 years

The critical path activity is receiving the environmental permits and approvals; permitting durations would largely be driven by the time necessary to complete any environmental reviews and consultations that would be required under federal and state law. The preliminary schedule allows one year for agency reviews and decisions.

Permits and Approvals

The proposed engineered protective cover falls within Enbridge's existing easement, so no new permanent right-of-way would be required.

While it is anticipated that the placement of the engineered gravel/rock protective cover would not require any approval from the Michigan Public Service Commission (MPSC), it is more likely that Enbridge would be required to submit a Notification Letter. The letter would include information on project scope, location, overview drawings, proposed construction activities and the tentative construction start and completion dates (as known at the time of submittal). Receiving concurrence back from the MPSC typically takes about three months.

Since all materials and construction-related equipment would be stored on barges and there is no need for additional workspace on either shore, no local building or zoning permits would be required.

Permitting durations would largely be driven by the time necessary to complete any environmental reviews and consultations that would be required under federal and state law. The timing for completing these tasks would be under the control of the permitting agencies.

The following table describes the most likely environmental permits that would be required.

Agency, Authority	Jurisdiction	Permit, Authorization, Survey or Consultation
Environmental Permits		
U.S. Army Corps of Engineers (USACE)	Federal	Individual Permit or Nationwide Permit 12—Section 404 Clean Water Act
USACE	Federal	Individual Permit—Section 10 of the Rivers and Harbors Act, and Section 404 of the Clean Water Act
Michigan Department of Environmental Quality (MDEQ)	State	State Individual Permit—Natural Resources and Environmental Protection Act (NREPA), Part 303 Wetlands Protection
MDEQ	State	Permits required for impacts to Great Lakes bottomlands—NREPA Part 325
MDEQ	State	State Individual Permit—NREPA Part 323 Shorelands Protection and Management
MDEQ	State	NREPA Part 761—if certain cultural resources are impacted in the open water
U.S. Fish and Wildlife Service (USFWS)	Federal	Coordination and Report—Section 7 Endangered Species
Michigan Department of Natural Resources (MDNR)	State	Coordination and Report—Part 365 Endangered Species Protection—if State-protected species impacted
USACE in coordination with State Historic Preservation Office (SHPO) and Tribal Historic Preservation Offices (THPO)	Federal	Consultation and Report—Section 106 National Historic Preservation Act—if cultural resources impacted in open water
MDEQ	State	Hydrostatic Discharge of Water—Certificate of Coverage
U.S. Coast Guard	Federal	Individual Authorization—Section 10 Regulated Navigation Area or Safety Zone and Notification for Marine Traffic

Environmental Impacts of the Protective Barrier Option

Simultaneous to the Lead Engineering Consultant conducting their feasibility study on the use of an engineered gravel/rock protective cover to further protect the Line 5 pipelines, Stantec, the Lead Environmental Consultant, conducted a detailed environmental impact analysis of this option. Please see *Appendix 3* for an image of the areas of interest (AOI) that Stantec took into consideration for its analysis.

In considering the potential environmental impacts of the engineered gravel/rock cover, it is helpful to understand some of the proposed construction logistics, as follows:

- It is likely that existing docking facilities could be used to load barges or other marine vessels with gravel/rock, so no onshore land clearing or grading would be needed. Nor would there be any need for additional temporary workspace on either shore. Existing roads would be used to move gravel to the docking facilities; road widening may be necessary, but no new roads are anticipated.
- There should be no effect on the lake shoreline as construction disturbances would occur away from the shoreline.
- There are several existing quarries nearby to provide the gravel/rock, so no significant impacts to onshore land use or cover type are anticipated.
- The total rock depth from the lakebed to the top of the engineered cover would be approximately eight feet. The average width of the barrier on the lake bottom would be approximately 72 feet. This equates to approximately 18 acres of lakebed covered in rock for the east pipeline and approximately 20 acres for the west pipeline.
- Expect to require approximately 3,000 tons/day of 1-inch to 12-inch gravel/rock and a total of approximately 610,000 metric tons of gravel/rock for the combined protective covers.
- Impact to the marine traffic in the Straits—commercial and recreational—would be temporary, lasting the duration of construction.
- The installation of the engineered gravel/rock cover on the lakebed would be considered a permanent land-use change—from soft sediment to hard sediment, in some areas.
- Operation and maintenance of the pipelines would not result in new impact compared to those activities already associated with the existing pipelines.

Based on these proposed construction logistics, the potential environmental impacts and mitigation measures identified by Stantec are described in the tables below.

Potential Environmental Impacts of Engineered Protective Cover

Potentially Affected Environment	Potential Construction, Operation/ Maintenance Impact	Potential Mitigation Measures
Aquatic Organisms and Their Habitats	**Construction** Disturbance of spawning and rearing habitat of fish and other aquatic species	• Span mitigation surveys conducted prior to construction could be used to determine if potential spawning habitat exists within the proposed work areas. • Confirm with local fisheries biologists, MDNR, and other parties of interest to identify potential habitat. • Utilize a gravel/rock placement plan to time installation outside spawning periods. • Use a method such as silt curtains to contain high turbidity, or avoid or reduce work during high currents in the Straits.
	Construction Disturbance of the lake bottom while depositing the engineered gravel/rock cover over the pipelines that creates: • Underwater noise • Habitat disturbance of fish and benthic organisms (those that live in and on the bottom of the lake floor) from open-water light • Impact to diel vertical migrations—the synchronized movement of zooplankton and fish up and down in the water column over a daily cycle	• Light sources that do not penetrate water as deep as white light could be used to reduce the effects of light pollution in open water or use lighting fixtures that focus light on working areas while reducing scatter. • Restrict work to daylight hours.
	Construction Placing the engineered cobble cover on the pipelines would likely result in increased turbidity that would impact fish and other aquatic lifeforms An increase in turbidity would reduce water clarity and could have a short-term effect on algae and aquatic vegetation growth due to reduced sunlight Would change the lake bottom (benthic) habitat from soft sediment to hard sediment	• Use washed gravel/rock, proper placement and use least amount of gravel/rock to complete the task to reduce turbidity during installation. • Use sediment containment measures, for example silt curtains and other best management practices (BMPs), during open-water construction to help contain turbidity. • Turbidity-causing activities could be timed to occur during periods of low current and could be the only option for deepwater disturbance. Equipment designed to minimize turbidity could be used. • Tremie-line type methods, which would reduce the velocity/energy of material placement and associated turbidity, could be used.
	Construction Increases habitat for zebra mussels and/or introduces invasive species	• An Aquatic Invasive Species (AIS) Prevention Plan could be implemented to reduce the risk of AIS introduction. • The U.S. Coast Guard (USCG) and U.S. Environmental Protection Agency (USEPA) have established ballast-water-management regulations and the State of Michigan requires ocean-going vessels discharging ballast in Michigan to have a ballast-water-treatment system to reduce AIS introductions. Visual inspection of all gear and rigs entering the Great Lakes to look for attached AIS, as well as sanitization of smaller crafts, would also help reduce potential introductions. • Use least amount of gravel/rock needed to complete task; use diver or ROV to direct placement; implement an AIS Prevention Plan.
	Construction Exposure to toxins resulting from accidental construction site spills	• Use best management practices, including restricting fueling locations, secondary containment, spill prevention control and countermeasure plan.

Potentially Affected Environment	Potential Construction, Operation/ Maintenance Impact	Potential Mitigation Measures
Aquatic Organisms and Their Habitats	**Construction—water withdrawal for hydrostatic testing** Impingement or incidental take through the water pump* * Generally, hydrotesting is not required after engineered protective cover placement, but some local regulations may require a hydrotest following the installation of a protective cover. This would be determined in consultation with regulators if this option were to be pursued.	• Water withdrawal intake hoses could be located in deep water away from near-shore shallow areas where aquatic organisms are more abundant. • The intake could be screened, and flow velocities reduced at/near the intake to reduce impacts to aquatic organisms.
Open Water of the Straits	**Construction** Temporary disruption to recreational boaters, sport fishermen and, potentially, commercial shipping, resulting in temporary change in use of the open water from vessel/barge traffic installing the engineered protective cover	• If feasible, limit work or reduce the number of vessels to minimize impacts on recreation, fishing, shipping and tourism. Could exclude or reduce work on holiday weekends when recreational boating and fishing activities are high.
	Construction Contamination from worksite spills. Potential pollutants include fuel, grease, hydraulic fluid and sediment. These could cause short- and long-term effects, depending on the material, amount spilled, containment and response	• Use BMPs, including restricting fueling locations, multiple forms of containment for contaminants, monitoring rain events, and having a Spill Prevention Control and Countermeasure (SPCC) Plan and/or a Pollution Incident Prevention Plan (PIPP) in place, as required.
	Construction Construction may disrupt/divert marine traffic	• Prepare and implement a public information plan in consultation with the USCG. Coordinate navigation with the USCG regarding marine traffic in the Straits to implement an effective regulated navigation area or safety zone.
Land Use Change	**Construction**—Transporting gravel and rock for the engineered cover to site Permanent and temporary land-use and cover-type change, including conversion of land-cover type for docking station	• Use off-site staging areas at previously disturbed upland sites (such as industrial parks); could use existing docking stations with sufficient roads to provide truck access.
Archaeological Resources	**Construction** Disturbance of archaeological sites	• Conduct Phase I surveys on areas with proposed lakebed disturbance and develop mitigation plans for any identified potentially eligible sites. • Data recovery of impacted sites. Cultural resources impacts may be minimized through workspace/construction-area siting.
Cultural Resources	**Construction** Disturbance of Traditional Cultural Property (TCP)	• Conduct early coordination with Native American tribes recognized by the State of Michigan to identify potential resources and evaluate measures to minimize or mitigate potential effects on TCPs.

Potentially Affected Environment	Potential Construction, Operation/ Maintenance Impact	Potential Mitigation Measures
Hazardous Materials/ Waste—Open Water and Docking Station	**Construction** Accidental releases of hazardous materials or contaminants	• Employ industry-standard BMPs to prevent release of hazardous materials and contaminants through the use of secondary containments and other spill prevention measures.
	Construction Waste disposal	• Existing waste management infrastructure at the docking stations should be designed to handle site-generated waste. Wastes originating from activities within the open water would be disposed of according to federal and state regulations and those established by the county in which the vessel comes ashore.
	Construction Waste generation	• Employ industry and society standard BMPs to reduce the impact of site waste generation by using recycling and waste segregation techniques.
	Construction Chemicals of concerns in the sediments	• Conduct sampling and chemical analysis of sediments within the open water prior to construction.
Air Quality—Open Water and Docking Station	**Construction** Air emissions from all equipment, including diesel engines (PM10, PM2.5 and SO_2 emissions)	• Where feasible and practical, use ultra-low-sulfur diesel for diesel engines. Proper maintenance of construction equipment and use of ultra-low-sulfur diesel fuel would minimize engine emissions during construction. • Specify that on-site vehicle idle time while in the construction area be restricted for all equipment and vehicles that are not using their engines to operate a loading, unloading or processing device.
	Construction Air emissions of criteria pollutants from new engines, including PM, CO, NO_x and hydrocarbons	• Specify that where feasible and practical, all diesel-powered non-road construction equipment with a power rating of 50 hp or greater should meet at least the Tier 3 emissions standard (i.e. the use of 2010 and newer haul trucks). All diesel-powered engines used in the construction rated less than 50 hp should meet at least the Tier 2 emissions standard as Tier 3 emissions standards do not apply to these engines. Give preference when possible to newer (post-2010) diesel engine-powered marine vessels.
	Construction Air emissions and dust	• Develop a Fugitive Dust Control Plan to be implemented during construction activities. • Select a docking station that minimizes air-quality impacts on neighboring populations.

Potentially Affected Environment	Potential Construction, Operation/ Maintenance Impact	Potential Mitigation Measures
Noise—Open Water and Docking Station	**Construction** Proximity noise from construction activities and/or excessive noise generated during construction is disruptive to nearby residents and businesses and/or noise sensitive areas (NSAs) Night-time noise	• Perform construction activities that generate the most noise during daytime hours (7 a.m. to 10 p.m.) when there is less sensitivity to sound, if practical. Mitigate nighttime-work noise by limiting construction equipment and implementing noise-abatement devices. • Where possible, the docking station for offloading of material from land to water could be located to increase the setback from NSAs. • A noise control plan could be developed and implemented during construction activities. The noise-control measures would be selected based on the specific equipment used, activity conducted in specific locations and proximity to NSAs. The plan would outline the layout of the construction activities and look at reducing noise from back-up alarms (alarms that signal vehicle travel in reverse) by providing a layout of the construction site that minimizes the need for back-up alarms and use flagmen to minimize the time needed to back up vehicles. When possible, construction equipment specifically designed for low noise emissions (e.g. equipment such as generators with noise enclosures) could be used. Where practical, locate stationary equipment away from sensitive receptors, position equipment so noise propagates away from the nearest NSAs, and position non-noise generating equipment between the barrier installation operation and the nearby NSAs to provide shielding. Work could be done to limit heavy-equipment activity adjacent to residences or other sensitive receptors to the shortest possible period required to complete the work activity. • Temporarily install and maintain an absorptive noise-control barrier in the perimeter of construction sites, around stationary equipment of interest, and/or between construction equipment and NSAs when located in close proximity of noise-intensive equipment operating during overnight periods. • Consideration can be made to utilize electrically powered equipment, where possible, instead of operating generators and other engine-powered equipment, such as light stands or compressors.
	Unnecessary equipment noise	• The project plan could specify that on-site equipment idle time while in the construction area would be restricted for all equipment that are not using their engines to operate a loading, unloading or processing device, or are otherwise required for the proper operation of the engine. All contractors could be required to utilize sound-control devices no less effective than those provided by the manufacturer and maintain equipment in accordance with manufacturer's recommendations. No equipment should have unmuffled exhausts.
Avian Species	**Construction** Increased activity during construction disrupts bird migration	• Construction activities could be designed to limit potential unavoidable impact to migratory bird species during spring and fall migration periods by limiting activities during this time.

Potentially Affected Environment	Potential Construction, Operation/ Maintenance Impact	Potential Mitigation Measures
Use, Access and Impacts to Roads—Docking Station and Vicinity	**Construction** Heavy truck traffic on roadways; congestion from construction workers arriving and departing during AM and PM peak hours Increased air and noise impacts from heavy truck traffic	• Where practical and feasible, consider the implementation of a Truck-routing Plan, which would route trucks to access routes that do not impact residential and institutional uses. • Restrict truck traffic to weekday daylight, non-peak hours, if possible. Restricting truck hours mitigates additional congestion caused by slow, heavy trucks during peak travel times. Restricting to weekday daylight hours eliminates noise impacts from truck traffic at times most people would typically be indoors. • Similar to a truck routing plan, educate construction workers as to the preferred access routes to and from the docking station(s). By keeping construction-worker traffic off busy access routes, possible peak-hour congestion impacts to those routes could be minimized. Restrict construction traffic during peak tourism events. Prepare and implement a public information plan in advance of scheduled work that would allow commercial and recreational mariners to be aware of the upcoming work and what to expect. • If the number of construction workers is particularly large, investigate opportunities for remote parking in areas away from the docking station(s) that would not affect residential or institutional uses, and shuttle workers to and from the remote parking site to the work area(s). The use of shuttles to and from the remote parking area could significantly reduce the AM and PM peak-hour-traffic volume resulting from construction-worker traffic.
	Damage to roads	• Conduct pre- and post-construction roadway surveys along truck routes to assess changes to the road surface. If warranted, consider repairs to the roads.
Tourism Use of Roads—Docking Station and Vicinity	**Construction** Potential impacts to tourist traffic	• Restrict construction traffic during peak tourism events to help reduce impact. Some of these events are: Memorial Weekend Pageant; Troop Mackinaw (multiple occurrences June through September); Antiques on the Bay Auto Show; the annual St. Ignace Car Show; Mackinaw City Fourth of July (Conkling Heritage Park); and Labor Day Bridge Walk. • Select a docking station that would have minimal traffic-related impacts on the neighboring population.
Visual Impacts—Near Shore and Open-water Areas	**Construction** Lighting associated with nighttime construction could spill outside the project site, affecting surrounding areas, particularly the Headlands International Dark Sky Park Visual impacts from the barges and support vessels Docking station impacts on the local viewshed	• Where practical and feasible, lighting required to facilitate nighttime construction activities could, to the extent that it is consistent with worker safety codes and requirements, be directed toward the center of the construction and shielded to prevent light from straying, or spilling, offsite. Hooded, task-specific lighting could be used to the extent practical to reduce light trespass beyond the site during operation. • If practicable and feasible, limiting the size of the barges and support equipment and minimizing the duration of installation activities would limit the visual impacts. Avoiding recreation and tourism events (such as holiday weekends) would also limit the visual impacts, as would limiting or eliminating construction activities during specific times of the day or year. • Coordination with the Dark Sky Park could be initiated if nighttime use of watercraft is required for construction. Specifically, limits could be placed on open-water-construction lighting during times of day (e.g., twilight and early evening) and year when attendance is high at the Dark Sky Park, or when special events are planned. Coordination with the Dark Sky Park could provide advanced notice of events sensitive to light. • Select a docking station that would minimize potential visual-related impacts on the neighboring population.

Evaluation of the Anchor Strike Prevention and Protection Measures

The wide-ranging agreement regarding Line 5 that the State of Michigan and Enbridge signed on November 27, 2017, acknowledges the importance of the Straits of Mackinac to the people of Michigan and our mutual commitment to ensuring that everything possible is being done to reduce the risk of operating Line 5.

To assess the possible benefits of enhanced ship communication technologies, such as Vesper Marine's *Guardian:protect* system, and/or gravel/rock barriers, Enbridge engaged C-FER Technologies, which works with the global energy industry to advance safety, environmental performance and efficiency, to estimate the potential of a product release into the Straits from an anchor striking or hooking the pipeline(s) if these protective measures were implemented.

C-FER evaluated the following:

- Annual probability of a failure (POF) of the existing dual Line 5 pipelines.
- Effect on the POF if enhanced ship-communication technology (*Guardian:protect*) is implemented.
- Effect on the POF if a rock barrier is installed—either an engineered gravel/rock protective cover on top of the pipelines; or a rock berm that is next to each pipeline.
- Effect on the POF if both a rock barrier is installed and an enhanced communication technology is implemented.

All calculations and more details on how C-FER conducted its analysis are included in *Appendix 4*.

For consistency, the approach used to estimate POF in the event of anchor hooking was similar to that described in a report prepared by a company called Dynamic Risk for the State of Michigan titled *Alternatives Analysis for the Straits Pipelines, 2017* (the Dynamic Risk Report). C-FER did make a notable adjustment to the Dynamic Risk Report estimate of the existing crossing annual failure rate.

Probability of a Failure of the Existing Dual Pipelines

C-FER estimates the annual failure rate of the existing crossing to be approximately 7×10^{-4} per year. This is two to three times higher than the values provided in the Dynamic Risk Report. The higher failure rate estimate arrived at in C-FER's evaluation is largely attributable to a difference in the assumption made regarding the time required to detect an unintentionally deployed anchor. C-FER took a more conservative approach; the difference between this evaluation and the evaluation described in the Dynamic Risk Report is as follows:

- The Dynamic Risk Report assumes that unintentional anchor deployments would go undetected for one hour and the drag distance would be about 20 miles.
- C-FER assumes that an unintended anchor deployment could go undetected for a significantly longer period of time. The average time to detect a deployment was assessed to be three and a half hours and the associated drag distance was estimated to be about 53 miles.

The longer detection time assumed in C-FER's evaluation is considered to be a more prudent choice given the uncertainty associated with the detection time.

Intentional and Unintentional Anchor Deployment

Before estimating the probability of a product release into the Straits, C-FER first had to determine the different ways that an anchor could interact with the pipeline and cause it to fail. C-FER determined there are two distinct anchor deployment scenarios that would result in an anchor causing the pipeline to fail and release product into the Straits:

1. **Intentional anchor deployment:** This would most likely be in response to an emergency on a vessel.
2. **Unintentional anchor deployment:** This would be an accidental deployment of an anchor, most likely the result of equipment malfunction and/or human error.

By taking into consideration both the intentional and the unintentional anchor deployment scenarios, C-FER estimated a combined probability of a release into the Straits caused by an anchor for the existing lines, per year, as follows:

- Failure rate of the pipelines caused by an intentional anchor deployment = 1.27×10^{-6}
- Failure rate of the pipelines caused by an unintentional anchor deployment = 7.35×10^{-4}
- Failure rate of the pipelines caused by combined (intentional and unintentional) anchor deployments = 7.36×10^{-4}

Based on the results, it becomes apparent that the combined probability of a release into the Straits caused by an anchor is dominated by the threat of an unintentional anchor deployment. This is because the anchor drag distances for unintentional deployments are typically much longer than for deployments from vessels intending to anchor; and longer anchor-drag distances increase the likelihood of an anchor hitting or hooking the pipelines.

Guardian:protect Vessel Notification Options

As described on pages 17-18 of this Report, *Guardian:protect* is a web-based system that can communicate with vessels. C-FER considered two vessel communication options:

Option 1—A hazard-awareness message that would notify vessels of the pipelines if the vessel is behaving in a manner that indicates an intention to deploy an anchor.

- This could prevent an intentional anchor drop, but it would have no impact on preventing an unintentional anchor deployment.
- Also, a vessel operator may choose to deploy an anchor if the operator believes the risk of not deploying the anchor is greater than the risk of pipeline damage. This was considered unlikely but still a possibility in an emergency situation.

Option 2—Includes the Option 1 hazard-awareness message to vessels intending to anchor, plus an advisory message to vessels approaching the Straits requesting that they check anchors to ensure they are properly stowed.

- In addition to managing the intentional anchor deployment threat, the additional message could prevent an unintentionally deployed anchor from contacting the pipeline.
- Consideration would have to be given as to whether this additional message would be perceived as a nuisance and if all vessels or just vessels of a certain size receive the message.

Protective Barrier Options

Enbridge evaluated two protective barrier options to prevent vessel anchors from coming into contact with the dual Line 5 pipelines. These are described on page 23 of this Report. Both options use forms of gravel and rock berms. Specific to the results of this evaluation, the options considered to determine the probability of failure are as follows:

Option 1—Engineered protective cover made of gravel and rock.

Option 2—Placement of two rock berms next to each pipeline; allowing visual inspection of the dual pipelines.

Enbridge determined that Option 2 would be the least effective method because it would provide only partial protection against anchor drag and no protection in the event of a direct anchor drop over the pipelines. C-FER's estimate of POF supports Enbridge's conclusion that Option 2 provides little to no value in protecting the existing lines from contact with an anchor.

Effect of Preventive and Protective Measures

The Line 5 probabilities of a release from both intentional and unintentional anchor deployment—with and without relevant combinations of the potential damage prevention and protection measures—are summarized in the table below. The probabilities of a release from an anchor striking or hooking the existing Line 5 pipelines are highlighted in light yellow; and the combination of protective and preventive measures that create the most significant reduction in the estimate of the probability of a product release is highlighted in dark yellow—*Guardian:protect* option 2; and barrier option 1.

The Line 5 probabilities of a release from both intentional and unintentional anchor deployment

Table Legend

- ***Guardian:protect* option 1:** Hazard awareness message to vessels that appear to have an intention to deploy an anchor.
- ***Guardian:protect* option 2:** Option 1 message, plus advisory message to vessels to check that anchors are stowed.
- **Barrier option 1:** Engineered gravel/rock protective cover over top of the pipelines.
- **Barrier option 2:** Placing rock berms on either side of the pipelines (not covered).

Analysis Case	**Failure Rate due to Intentional Anchor Deployment** *(per year)*	**Rate Reduction** *(% of existing)*	**Failure Rate due to Unintentional Anchor Deployment** *(per year)*	**Rate Reduction** *(% of existing)*	**Failure Rate due to Combined Anchor Deployments** *(per year)*	**Rate Reduction** *(% of existing)*
Existing Line	1.27×10^{-6}	N/A*	7.35×10^{-4}	N/A*	7.36×10^{-4}	N/A*
Guardian:protect option 1 only	7.82×10^{-7}	38.4%	7.35×10^{-4}	0	7.36×10^{-4}	0.1%
Guardian:protect option 2 only	7.82×10^{-7}	38.4%	8.45×10^{-5}	88.5%	8.53×10^{-5}	88.4%
Barrier option 1 only	1.01×10^{-8}	99.2%	7.83×10^{-6}	98.9%	7.84×10^{-6}	98.9%
Barrier option 2 only	1.27×10^{-6}	0	7.35×10^{-4}	0	7.36×10^{-4}	0
Guardian:protect option 1 and Barrier option 1	6.22×10^{-9}	99.5%	7.83×10^{-6}	98.9%	7.84×10^{-6}	98.9%
Guardian:protect option 1 and Barrier option 2	7.82×10^{-7}	38.4%	7.35×10^{-4}	0	7.36×10^{-4}	0.1%
Guardian:protect option 2 and Barrier option 1	6.22×10^{-9}	99.5%	9.01×10^{-7}	99.9%	9.01×10^{-7}	99.9%
Guardian:protect option 2 and Barrier option 2	7.82×10^{-7}	38.4%	8.45×10^{-5}	88.5%	8.53×10^{-5}	88.4%

* N/A = not applicable

Key Findings—Shipping Communication Technologies

Option 1—*Guardian:protect*: If the *Guardian:protect* vessel tracking and communication system is implemented with a focus on issuing a warning message only to vessels demonstrating movement suggesting an intent to anchor, it is expected to result in a 38 percent reduction in the probability that an intentional anchoring would cause a release of product into the Straits. However, it will have no effect on the probability of a release caused by an unintentional anchoring because vessels unintentionally dragging an anchor will not exhibit movement that triggers an advisory.

- The overall effect on the probability of a release in the Straits would, therefore, be negligible because the combined probability of a release is driven by unintentional anchor deployment.

Option 2—*Guardian:protect*: If the *Guardian:protect* system implementation is expanded to include sending an advisory message to all vessels (or selectively to all significant vessels) approaching the Straits where the message requests vessel operators to confirm that their anchors are properly stowed, the expected result is a 38 percent reduction in an intentional anchoring hitting the pipeline and causing a release and an 89 percent reduction in an unintentional anchoring hitting the pipeline and causing a release.

- The combined probability of an anchor hitting the pipeline and causing a release is expected to fall to approximately 9×10^{-5} per year.

Key Findings—Barriers

Barrier Option 1: The engineered gravel/rock protective cover designed, constructed and maintained to prevent contact between the pipeline and the largest anchor likely to be carried by the largest vessel operating in the Great Lakes would result in an extremely low likelihood of an anchor penetrating the engineered cover and hitting or hooking the pipeline.

- The engineered protective cover is expected to result in a 99 percent reduction in the combined probability of an anchor hitting or hooking the pipeline to approximately 8×10^{-6} per year.

Barrier Option 2: The barrier option of creating a rock berm next to each pipeline—intended to allow visual inspection of the pipelines—would not result in any meaningful reduction in the combined probability of an anchor hitting or hooking the pipeline and causing a release because of the lack of protective cover over the pipeline.

- Option 2 would not provide any measurable benefits in preventing an anchor from hitting or hooking the pipeline from that of the existing dual pipelines.

Key Findings—Combined Shipping Communication and Warning Technologies and Barrier Option 1

By implementing one of the *Guardian:protect* options with Barrier Option 1, the resulting combined probabilities of an anchor hitting the pipeline and causing a release are estimated to be approximately:

- 8×10^{-6} per year for *Guardian:protect* Option 1 and Barrier Option 1—amounting to a 99 percent reduction in the expected annual probability of an anchor causing a leak into the Straits.
- 9×10^{-7} per year for *Guardian:protect* Option 2 and Barrier Option 1—amounting to a 99.9 percent reduction in the expected annual probability of an anchor-caused leak into the Straits.

Enbridge's Conclusions

Enbridge used a robust process for assessing many options for mitigating the risk of an anchor strike to the existing Line 5 pipelines crossing the Straits. The risk reductions options focused on two distinct areas:

- **Technology and communication solutions:** Enhancing shipping communication and warning systems.
- **Protective barriers:** Constructing some type of physical barrier over or next to the Line 5 pipelines to prevent an anchor from contacting the pipelines.

A team of subject-matter experts—representing Enbridge and the State and including a Lead Engineering Consultant, a Constructibility Reviewer, a protective-cover subject-matter expert representing Enbridge, a Lead Environmental Consultant, and a Reliability Consultant—evaluated the options and then determined the most effective ones.

In determining the most effective option in each category—technology and communication solutions and protective barriers—the experts considered the engineering requirements, costs, potential environmental impacts, and what permits and approvals would be required.

Summary of the Most Effective Communication and Technology Solutions

Out of that process, Enbridge has concluded the following:

Enhancing the safety of all the existing pipelines and cables located within the Straits	
Potential holistic communication measures identified during brainstorming sessions	• A coordinated Enhanced Public Awareness Campaign to educate the public, and specifically mariners, about the location of all utilities crossing the Straits. • Signage on the Mackinac Bridge to warn vessels. • Floating marker buoys with 'No Anchor' warnings in the shipping channel. • Dedicated patrol vessels or drones deployed in the Straits. • Mandatory checkpoints and anchor inspection before vessels cross the Straits. • Collaborate with the U.S. Coast Guard to investigate opportunities to enhance current policies and procedures that vessels are required to follow before proceeding to cross the Straits.
Implementation considerations, costs, timelines, permits and approvals	Determining the implementation strategies for these ideas was not part of the scope of this Report. Enbridge would actively support any of these holistic opportunities.

The ***Guardian:protect*** system	
Implementation considerations	Enbridge would need to consult and secure licenses from the U.S. Coast Guard and Federal Communications Commission. In consultation with these agencies and other key stakeholders, a decision would need to be made on when the system communicated with a vessel and the nature of the message—proactive advisory messages such as reminding vessel operators of the pipelines and/or checking that anchors are properly stowed; and/or reactive warning messages sent to vessels that appear to be preparing to anchor.
Estimated cost	Approximately $500,000
Project timeline—consultation with USCG and mariners, licenses and implementation	The critical path activity is consulting with the USCG, the State and other key stakeholders to determine when the system would communicate with a vessel and the nature of the message—proactive advisory messages; and/or reactive warning messages. The implementation timeline would largely be driven by the time necessary to complete these consultations. If this option moves forward, Enbridge is committed to implementing the system within 180 days of receiving the licenses.
Permitting and approvals	Three applications would be required: 1. Apply to the district branch of the USCG to approve the initial Private Aids to Navigation (PATON). 2. Apply to the USCG headquarters to approve the PATON application. 3. Apply to the FCC for a Special Temporary Authority (STA).
Potential environmental impacts	None
Risk of product release into the Straits *Guardian:protect* issuing *a warning message* only to vessels demonstrating movement suggesting an intent to anchor	**7×10^{-4}** Expected to result in a 38 percent reduction in the probability that an intentional anchoring would cause a release of product into the Straits; no effect on the probability of a release caused by an unintentional anchoring. Overall effect compared to the probability of release caused by an anchor strike for the Line 5 pipelines as they are today would be negligible.
Guardian:protect expanded to include sending *an advisory message* to all vessels approaching the Straits and *a warning message* only to vessels demonstrating movement suggesting an intent to anchor	**9×10^{-5}** Expected to result in a 38 percent reduction in an intentional anchoring hitting the pipeline and an 89 percent reduction in an unintentional anchoring hitting the pipeline and causing a release.

Summary of the Most Effective Protective Barrier

After considering and evaluating 15 protective barrier options, it was concluded that the most effective barrier would be an engineered gravel/rock protective cover. This opinion is shared by the Lead Engineering Consultant, the Constructibility Reviewer and all Enbridge subject-matter experts involved in creating this Report.

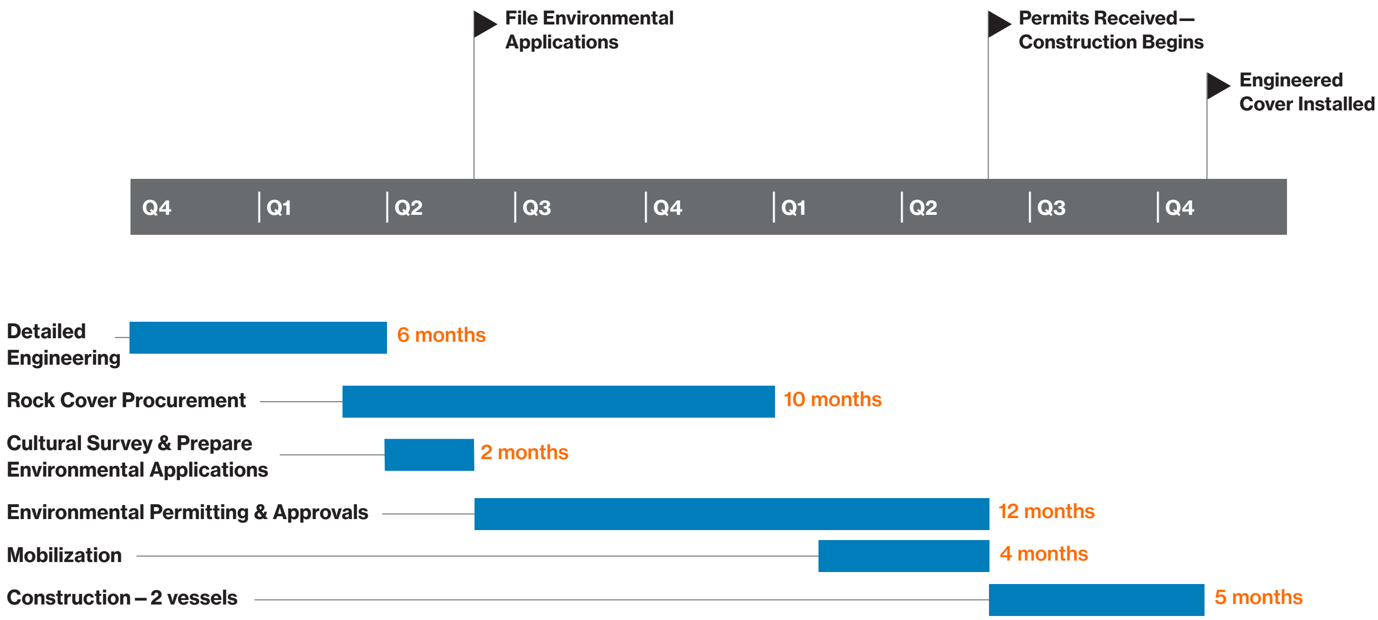
Engineered gravel/rock protective cover	
The three most significant reasons why the engineered protective cover is the most effective option	1. The loosely compacted mass of the gravel/rock cover prevents an anchor from being able to set and hold if it drags over the pipelines. 2. The minimum 6-foot depth of gravel/rock cover would also prevent an anchor on the largest Lake freighters from being able to penetrate the engineered protective cover in the unlikely event of a direct drop on top of the pipeline. 3. The engineered protective cover is expected to result in a 99-percent reduction in the combined probability of an intentional or unintentional anchor hitting or hooking the pipelines and causing product to be released into the Straits. None of the other 14 options considered can achieve this level of anchor protection.
Estimated cost	**Approximately $150 million**
Project timeline—engineering and design, permitting and construction	**2 to 3 years** • The critical-path activity is receiving environmental permits/approvals; permitting durations would largely be driven by time to complete environmental reviews and consultations; preliminary schedule allows one year for agency reviews and approvals. • Schedule would be sensitive to seasonality.
Permitting and approvals	The engineered protective cover would require at least 11 state and federal environmental permits and approval. The primary regulators would be the U.S. Army Corps of Engineers, the Michigan Department of Environmental Quality and the Michigan Department of Natural Resources.
Potential environmental impacts	**Construction:** • Placement of the engineered protective cover would be considered a permanent change to the lake bottom in some areas—from soft sediment to hard. • There would likely be a temporary impact to marine traffic that would last for the duration of construction activities. • No onshore or shoreline impacts; all onshore construction activities would likely take place at existing facilities—docks and local quarries—so there would be no onshore impacts, no temporary work areas required, and no onshore land clearing or grading needed. • **Operations and Maintenance:** No new impact.
Risk of product release into the Straits	**8×10^{-6}** Expected to result in a 99-percent reduction in the combined probability (intentional and unintentional) of an anchor hitting the pipeline; an extremely low likelihood of an anchor penetrating the engineered cover. **9×10^{-7}** If both *Guardian:protect* (issuing both advisory and warning messages) and the engineered protective cover are advanced—this would amount to a 99.9 percent reduction in the expected probability of an anchor causing a leak into the Straits.

Enbridge will continue to work with the State in the spirit of openness and transparency to determine the optimal path forward for Line 5—one that respects both the importance of the Great Lakes to the people of Michigan and recognizes the vital energy that is being delivered by Line 5 to those same Michigan residents.

Appendices

Appendix 1:
Project Timeline for the Engineered Protective Cover

Engineered Protective Cover Timeline = 2 to 3 years



Schedule Considerations:

- This schedule is extremely sensitive to seasonal windows. Icing of the Straits (Dec – Apr) limits construction windows to Apr – Oct; cultural surveys, if required, can only be collected when there is no ice on the Straits.

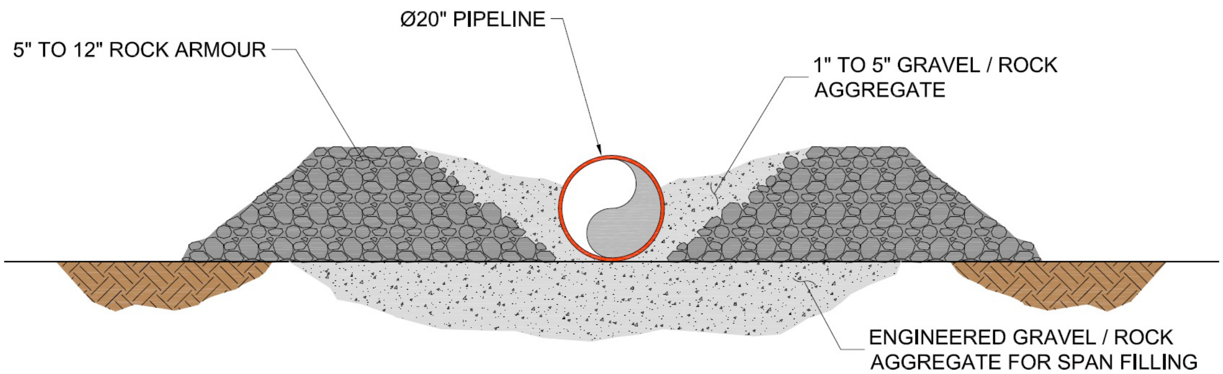
Appendix 2:
Protective Barrier Options Considered but Dismissed

Options That Allow External Visual Inspection

Gravel/rock berms

A protective berm with gravel/rock on either side of a pipeline may be used as a protection from anchor drag *(Figure 18)*. This allows the pipeline to be visually inspected externally as it is not covered by rock. However, this system would not be very effective in protecting the dual Line 5 pipelines from direct anchor drop. The protection from anchor drag also would not be fully realized.

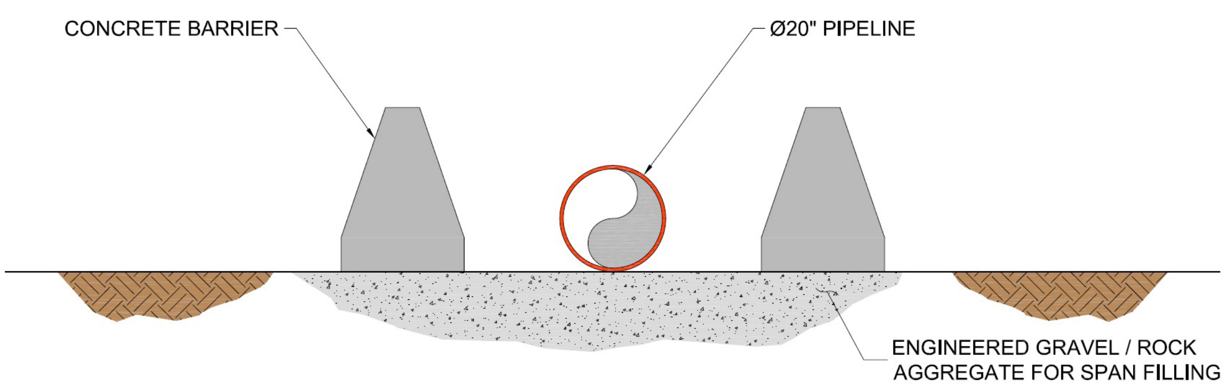
Figure 18: Gravel/rock berm.



Concrete barrier

Concrete barriers can be placed on either side of a pipeline to protect it from anchor drag *(Figure 19)*. However, this does not protect the pipeline from direct anchor drop. In the case of the dual Line 5 pipelines, this option would require a large number of barriers to be placed on either side of the pipeline, which would cause risk during both construction and future operation.

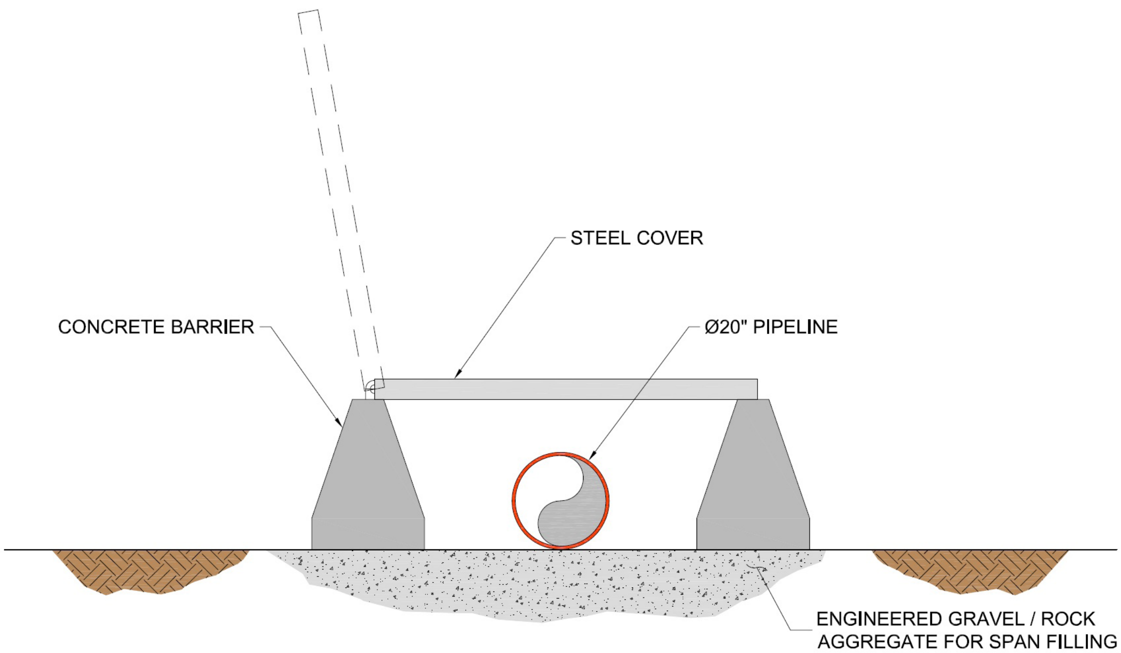
Figure 19: Concrete barrier.



Concrete barrier with steel cover

For this option, concrete barriers are placed on either side of the pipeline and a removable steel cover is attached to the concrete barrier (through a hinge mechanism) to protect the pipeline against anchor drop *(Figure 20)*. The pipeline can be inspected by opening the steel hatches. In theory, this concept addresses the requirements of protecting the dual Line 5 pipelines from both anchor drop and drag. However, this option also adds lots of risk of damage during construction and operation. Further, the ability for the steel cover to work problem-free is questionable as there are good possibilities of hinges getting stuck or jammed in water. Also, since this process would entail opening the steel cover to allow for visual inspections, any differential settlement/movements could cause the system to become unstable, which could impose high overburden load or impact (if steel cover falls) to the pipeline. The risks posed to the integrity of the pipeline by using this option far outweigh the actual benefit of visual inspection that this option allows.

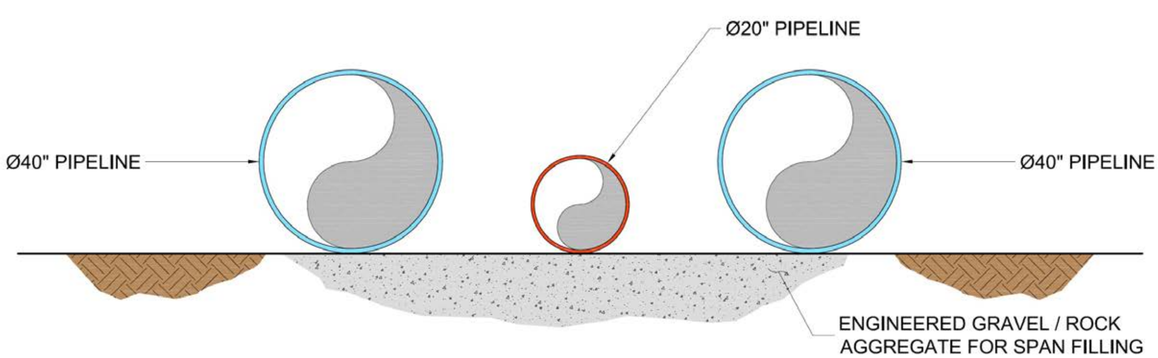
Figure 20: Concrete barrier with steel cover.



High-density polyethylene (HDPE) pipelines

For this concept, HDPE pipe sections filled with cement grout are placed on either side of the pipeline *(Figure 21)*. However, there would be a risk of stability of the HDPE pipes on a lake-bottom. Also, the ability for this option to protect the dual Line 5 pipelines from anchor drag is minimal, and this option does not protect the pipeline from anchor drop.

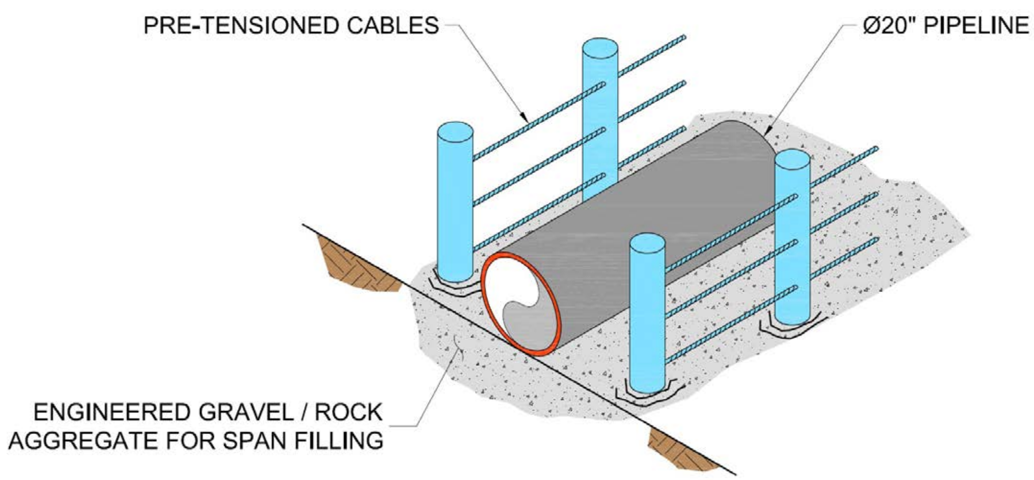
Figure 21: HDPE pipelines.



Pre-tensioned cables

This concept includes a pre-tensioned cable barrier with concrete posts on either side of the pipeline *(Figure 22)*. This option would not protect the dual Line 5 pipelines from anchor drop. In case of an anchor dragging on the lakebed, the anchor could snag on the cables and any subsequent quick release of the anchor could bring the anchor in contact with the pipeline. In some instances, the anchor could pose a high-impact load on the pipeline. Also, the construction of this option is considered to pose significant challenges.

Figure 22: Pre-tensioned cables.

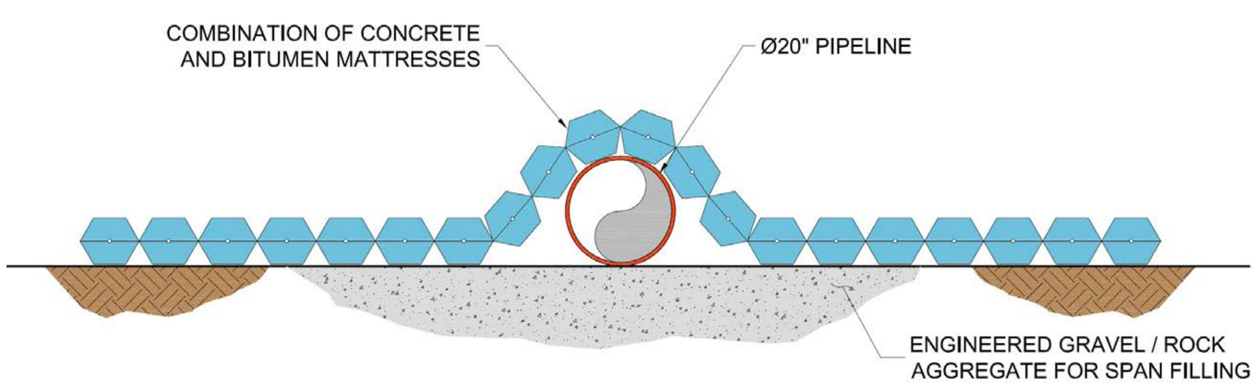


Options That Do Not Allow External Visual Inspection

Concrete and bitumen mattresses

Concrete mats are sometimes installed over pipelines to improve their stability against current and wave forces. They are also used to facilitate the crossing of one pipeline over another so that direct steel-to-steel contact is avoided. Concrete mattresses are used to protect pipelines or other critical structures from the impact of dropped objects. To avoid damage to a pipeline during installation, bitumen mattresses can be draped over the pipeline before placing concrete mats *(Figure 23)*. While an increased number of layers could help protect the dual Line 5 pipelines against anchor impact, concrete mattresses have not been used to protect pipelines from anchor drop/drag.

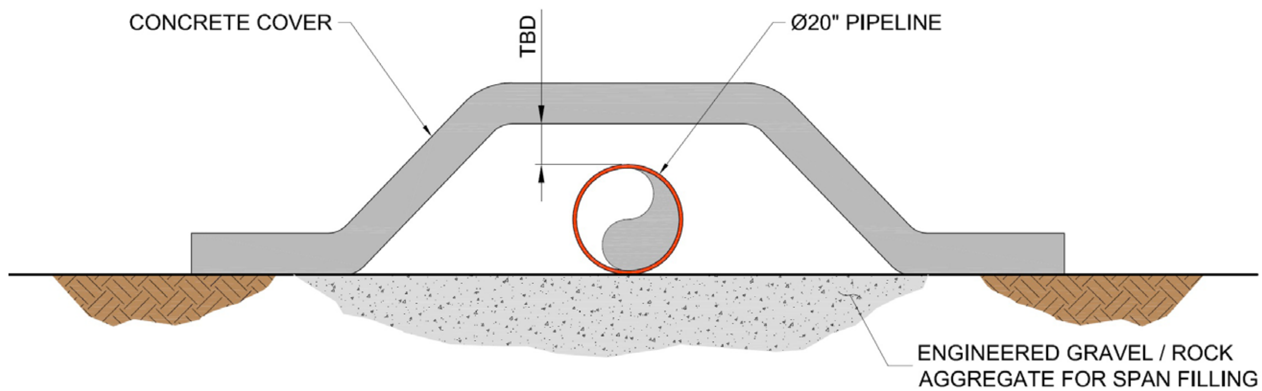
Figure 23: Concrete and bitumen mattresses.



Concrete cover

Concrete covers *(Figure 24)* are generally used to facilitate the crossing of one pipeline over another pipeline by providing the necessary separation. However, this is not a common design in the offshore industry. Due to the large number of concrete covers that would be required for the dual Line 5 pipelines, as well as the risk of overburden load on the pipelines due to later settlement of the concrete covers, this option would pose serious risk both during installation of this type of cover and subsequent operation of the dual Line 5 pipelines.

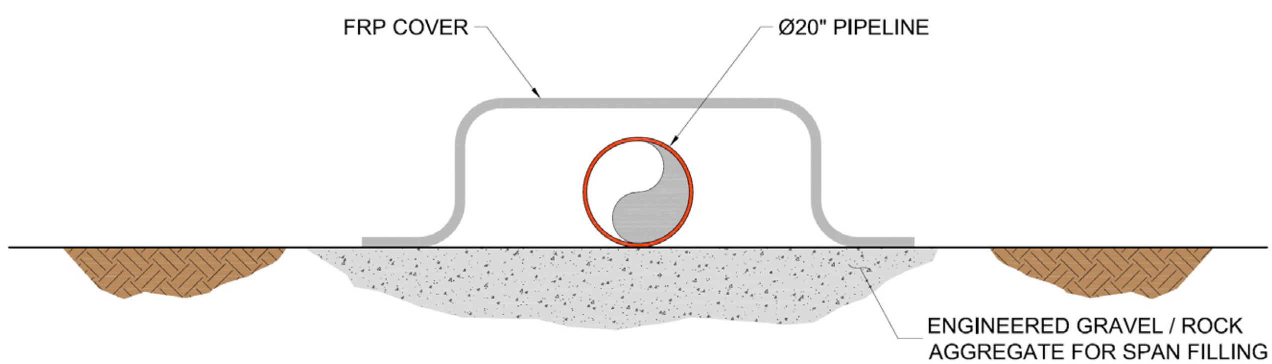
Figure 24: Concrete cover.



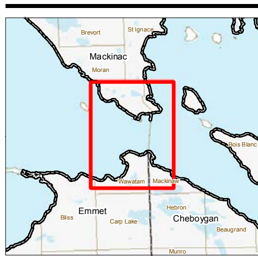
Fiber-reinforced plastic (FRP) covers

FRP covers *(Figure 25)* are designed to protect pipelines from the impact of the trawl boards used by fishing trawlers. FRP covers are not strong enough to protect against anchor drop and drag, but they are used in conjunction with gravel and rock protective cover to reduce the quantity of rock. However, differential settlement of FRP cover would be a concern for the integrity of the Line 5 pipelines during operation.

Figure 25: Fiber-reinforced plastic cover.



Appendix 3:
Environmental Areas of Interest



Legend

Area of Interest

Figure No.
2-2

Title
Project Location and USGS Topography

Client/Project
Enbridge - Line 5 Straits of Mackinac
Environmental Impact Report

Project Location
Emmet Co. &
Mackinac Co., MI

193705885
Prepared by JM on 2018-03-19
Technical Review by MP on 2018-03-19
Independent Review by BJ on 2018-04-06

N

0 2,500 5,000 Feet
1:60,000 (At Original document size of 11x17)

Notes
1. Coordinate System: NAD 1983 StatePlane Michigan North FIPS 2111 Feet
2. Data Sources Include: Stantec, Enbridge, USGS, NADS
3. Background: USGS 7.5' Topographic Quadrangles

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Appendix 4:
Evaluation of the Anchor Strike Prevention and Protection Measures

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Final Report

Evaluation of Anchor Strike Prevention and Protection Measures for the Line 5 Crossing of the Mackinac Straits

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June 2018
M268

C-FER Technologies

PROJECT TEAM

Evaluation of Anchor Strike Prevention and Protection Measures for the Line 5 Crossing of the Mackinac Straits	C-FER Project: M268	
Task/Deliverable	**Contributors**	**Responsible Professional**
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REVISION HISTORY

Evaluation of Anchor Strike Prevention and Protection Measures for the Line 5 Crossing of the Mackinac Straits			C-FER Project: M268		
Revision	**Date**	**Description**	**Prepared**	**Reviewed**	**Approved**
1	May 4, 2018	Internal Draft	MJS	MAN	--
2	May 6, 2018	Draft	MJS	--	MAN
3	May 30, 2018	Revised Draft	MJS	--	MAN
4	June 19, 2018	Final	MJS	MAN	MAN

NOTICE

This Report was prepared as an account of work conducted by C-FER Technologies (1999) Inc. ("C-FER") on behalf of Enbridge Energy, Limited Partnership ("Enbridge"). All reasonable efforts were made to ensure that the work conforms to accepted scientific, engineering and environmental practices, but C-FER makes no other representation and gives no other warranty with respect to the reliability, accuracy, validity or fitness of the information, analysis and conclusions contained in this Report. Any and all implied or statutory warranties of merchantability or fitness for any purpose are expressly excluded. Any use or interpretation of the information, analysis or conclusions contained in this Report is at Enbridge's own risk. Reference herein to any specified commercial product, process or service by trade name, trademark, manufacturer or otherwise does not constitute or imply an endorsement or recommendation by C-FER.

C-FER Technologies

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EXECUTIVE SUMMARY

C-FER Technologies (1999) Inc. was engaged by Enbridge Energy, Limited Partnership to evaluate the implications of the adoption of selected damage prevention and protection options to manage the potential for pipeline failure due to anchor strike for the Line 5 crossing of the Mackinac Straits. To this end, a study was carried out to estimate the annual failure rate for the crossing due to anchor hooking resulting from either intentional anchor deployment by a vessel in response to an emergency situation, or unintentional deployment from a vessel while underway due to equipment failure or human error. The effect of candidate damage prevention and protective measures on these failure rates was also estimated.

The calculated annual crossing failure rates attributable to both intentional and unintentional anchor deployment, with and without consideration of the relevant combinations of candidate damage prevention and protection measures, are summarized in Table 1. The key findings arising from this analysis and the associated results are as follows:

The anchor strike failure rate for the existing crossing and for the crossing with selected preventive and/or protective measures implemented is dominated by the failure potential attributable to unintentional anchor deployment. The contribution from unintentional anchor deployment dominates because anchor drag distances are typically much longer for unintentional deployments from vessels underway than for intentional deployments from vessels intending to anchor. Longer anchor drag distances imply that anchors deployed from vessels approaching the pipeline crossing from further away will have the potential to reach the pipeline, thereby increasing the likelihood of an anchor encounter with the pipelines on a per vessel crossing basis.

For the existing crossing, the annual failure rate is estimated to be approximately 7×10^{-4} per yr. This failure rate estimate is two to three times higher than the values bounding the failure rate range provided in the Alternatives Analysis Report prepared in 2017 by Dynamic Risk for the State of Michigan. The higher rate estimate arrived at in this study is largely attributable to a difference in the assumption made regarding the time required to detect an unintentionally deployed anchor. The longer detection time assumed in this study is considered a more prudent choice given the uncertainty associated with the detection time.

Implementation of the proposed vessel tracking and communication system (i.e. Vesper Marine's Guardian:protect system), if used for identifying and issuing an anchor deployment warning message only to vessels demonstrating movement indicative of an intent to anchor (i.e. Guardian:protect Option 1), is expected to result in a 38% reduction in the intentional anchoring failure rate. This implementation will have no effect on the failure rate due to unintentional anchoring because vessels unintentionally dragging an anchor will not exhibit movement that triggers a Guardian:protect advisory. Because the combined-case failure rate is dominated by the threat posed by unintentional anchor deployment, the overall effect on the crossing failure rate of this Guardian:protect system implementation is negligible.

If the Guardian:protect system implementation is expanded beyond the Option 1 messaging to also include sending an advisory message to all vessels (or selectively to just significant vessels) approaching the Straits (i.e. Guardian:protect Option 2), where the message includes notification of a pipeline crossing ahead and the need for vessel operators to confirm that anchors are

properly stowed, the expected result is a 38% reduction in the intentional anchoring failure rate, and an 89% reduction in the unintentional anchoring failure rate. For this implementation, the resulting combined-cause crossing failure rate is expected to fall to about 9×10^{-5} per yr.

The proposed gravel/rock barrier option involving the placement of an engineered protective cover to fully encase each pipeline (Barrier Option 1) is expected to result in a 99% reduction in the combined-cause failure rate to approximately 8×10^{-6} per yr. Central to this determination is the assumption that the engineered cover design, construction and maintenance program will be aimed at assuring that the largest anchor likely to be carried by a vessel operating in the Great Lakes will have an extremely low likelihood of penetrating the engineered cover to the point where contact between the anchor and the pipeline results in hooking.

The proposed alternative gravel/rock barrier option involving the placement of four berms, one flanking each side of each pipeline (Barrier Option 2), is not expected to result in a meaningful reduction in the combined-cause failure rate. The lack of protective cover over the pipeline and the overall berm geometry (intended to allow direct visual examination of the pipeline) support the finding that the potential for pipeline hooking in the event of an anchor drag encounter is not demonstrably different from that of the existing on-bottom pipelines.

If the candidate failure prevention measures (either Guardian:protect Option 1 or 2) are combined with the one effective protection option (i.e. Barrier Option 1), the resulting combined-cause failure rates are estimated to be:

- 8×10^{-6} per yr for Guardian:protect Option 1 together with Barrier Option 1 (amounting to a 99% reduction in the expected annual crossing failure rate); and
- 9×10^{-7} per yr for Guardian:protect Option 2 together with Barrier Option 1 (amounting to a 99.9% reduction in the expected annual crossing failure rate).

The crossing failure rate reductions attributable to the implementation of candidate damage prevention and protection measures have been determined using deductive analysis methods (i.e. fault trees) wherein some basic event probabilities have been established based on informed judgment. The selective use of judgment-based probability assignments was necessitated by the fact that the type of system performance or human performance data required to characterize these probabilities using statistical analysis, or other more objective methods, could not be found. With specific reference to the evaluation of protective barrier options, to the extent that planning decisions to be made are dependent on the assumed magnitude of barrier effectiveness, it is recommended that the probability assignment developed herein to characterize the effectiveness of full encasement should be revisited to more fully and formally evaluate the uncertainties inherent in the design, construction and expected performance of this option.

Analysis Case	Failure Rate due to Intentional Anchor Deployment (per year)	Rate Reduction (% of existing)	Failure Rate due to Unintentional Anchor Deployment (per year)	Rate Reduction (% of existing)	Failure Rate due to Combined Anchor Deployments (per year)	Rate Reduction (% of existing)
Existing Line	1.27×10^{-6}		7.35×10^{-4}		7.36×10^{-4}	
Guardian: protect Option 1 Only	7.82×10^{-7}	38.4	7.35×10^{-4}	0	7.36×10^{-4}	0.1
Guardian: protect Option 2 Only	7.82×10^{-7}	38.4	8.45×10^{-5}	88.5	8.53×10^{-5}	88.4
Barrier Option 1 Only	1.01×10^{-8}	99.2	7.83×10^{-6}	98.9	7.84×10^{-6}	98.9
Barrier Option 2 Only	1.27×10^{-6}	0	7.35×10^{-4}	0	7.36×10^{-4}	0
Guardian: protect Option 1 and Barrier Option 1	6.22×10^{-9}	99.5	7.83×10^{-6}	98.9	7.84×10^{-6}	98.9
Guardian: protect Option 1 and Barrier Option 2	7.82×10^{-7}	38.4	7.35×10^{-4}	0	7.36×10^{-4}	0.1
Guardian: protect Option 2 and Barrier Option 1	6.22×10^{-9}	99.5	9.01×10^{-7}	99.9	9.07×10^{-7}	99.9
Guardian: protect Option 2 and Barrier Option 2	7.82×10^{-7}	38.4	8.45×10^{-5}	88.5	8.53×10^{-5}	88.4

Table 1 Line 5 Crossing Failure Rates and Effect of Preventative and Protective Measures

1. INTRODUCTION

1.1 Terms of Reference

C-FER Technologies (1999) Inc. ("C-FER") was engaged by Enbridge Energy, Limited Partnership ("Enbridge") to evaluate the implications of the adoption of select damage prevention and protection options to manage the potential for pipeline failure due to anchor strike for the Line 5 crossing of the Mackinac Straits (the "Straits").

1.2 Objectives

The specific objectives of this study were:

1. To determine the annual probability of failure of Enbridge's dual-pipeline crossing of the Straits due to the threat posed by anchor strike;

2. To evaluate the reduction in failure probability expected to result from the deployment of specific measures proposed by Enbridge that use enhanced shipping communication and warning technologies to reduce the likelihood of anchor deployment from vessels crossing the Straits; and

3. To evaluate the reduction in failure probability expected to result from the installation of protective barriers intended to prevent vessel anchors from coming into contact with the pipelines.

1.3 Analysis Approach

The analysis approach adopted in this study to estimate the probability of pipeline failure due to anchor strike involves the use of *fault trees* and quantitative fault tree analysis. A fault tree is a deductive analysis model that identifies the logical combinations of *basic events* leading to the main accidental event being analyzed (referred to as the *top event*). Construction of a fault tree is a top down process in which the top event is identified and related to the events that contribute directly to its occurrence (called *intermediate events*). Each intermediate event is then related to its direct contributors until the basic events are reached at the bottom of the tree. A simple conceptual example of a fault tree is shown in Figure 1.1.

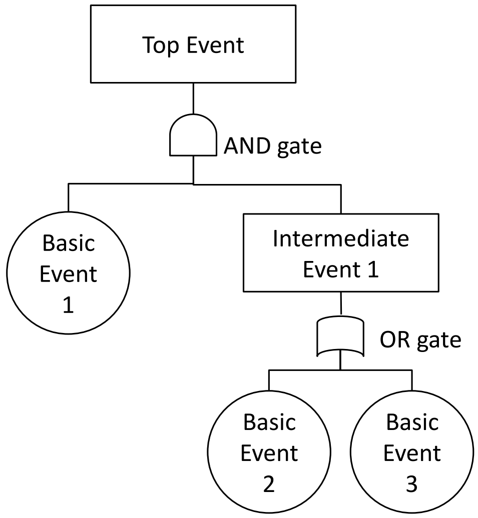

Figure 1.1 Fault Tree Structure and Notation

The two main types of event interactions considered in fault trees are:

- The OR relationship, which means that any one (or more) of a number of events could cause the output event to occur. For example, in Figure 1.1, either Basic Event 2 OR Basic Event 3 must exist for Intermediate Event 1 to occur (and the probability of Intermediate Event 1 is equal to the probability of Basic Event 2 plus the probability of Basic Event 3[1]).
- The AND relationship, which means that a number of events must co-exist for the output event to occur. For example, in Figure 1.1, Basic Event 1 AND Intermediate Event 1 must co-exist for the Top Event to occur (and the probability of the Top Event is given by the probability of Basic Event 1 multiplied by the probability of Intermediate Event 1[2]).

If the set of basic events relevant to the occurrence of the top event can be identified and their relationships established, and if the probability associated with each basic event can be estimated, then the fault tree can be used to calculate the probability of the top event (in this application, the probability of pipeline failure due to anchor strike). It is noted that if one of the top level basic events in the fault tree is linked to the top event via an AND gate (e.g. Basic Event 1 in Figure 1.1) and that event is defined as an annual rate of occurrence (rather than a probability), the top event is similarly quantified in terms of its rate of occurrence (in this case, the frequency of pipeline failure due to anchor strike).

---

[1] This additive relationship is strictly correct only for events that are mutually exclusive.
[2] This multiplicative relationship holds for events that are independent.

In the present application, the events leading to the top event include the deployment of an anchor from a vessel in proximity to the pipeline, the failure of measures to prevent anchor deployment, the conditions under which a deployed anchor will interact with the pipeline, the failure of measures to prevent interaction between the anchor and the pipeline, and the conditions under which interaction between an anchor and the pipeline will lead to pipeline failure.

This study acknowledges that anchor deployment with the potential to cause pipeline failure is the result of two distinct deployment scenarios. The first scenario involves intentional anchor deployment in response to a vessel emergency that warrants anchor deployment. The second scenario involves unintentional (or accidental) anchor deployment from a vessel underway due to equipment malfunction and/or human error.

Separate fault trees were developed for each deployment scenario because: 1) the likelihoods of pipeline interaction with an intentionally or unintentionally deployed anchor are different, 2) the measures to prevent deployment do not necessarily apply to both scenarios, and 3) the conditions under which the interaction between an anchor and the pipeline will lead to failure differ between the two deployment scenarios.

The analysis approach adopted in this study for assessing the potential for pipeline failure due to unintentional anchor deployment closely follows the approach developed by Det Norske Veritas (DNV), as set out in Appendix E of Revision 1 to DNV Report 2009-1115, “Recommended Failure Rates for Pipelines” (2010). The analysis approach adopted for assessing intentional anchor deployment follows a similar approach, but leverages other relevant information sources where appropriate.

1.4 Scope Limitations

The scope of this analysis has been restricted to explicit consideration of the frequency of pipeline failure due to interaction events that have the potential to result in hooking of the pipeline. Anchor hooking is the result of a deployed anchor being dragged along or very close to the lake bottom, which then comes into direct contact with the pipeline. If the anchor is of sufficient size, the pipeline can become caught or hooked between the anchor shank and one or both anchor flukes. If the associated vessel is sufficiently large and moving at sufficient speed, the lateral force exerted on the pipeline by the moving vessel (through the anchor chain) can lead to severe pipeline denting, or sufficient pipe or girth weld strain to cause tensile rupture.

A deployed anchor can also contact the pipeline when it first reaches the lakebed. This interaction, referred to as a drop encounter (distinct from a drag encounter, which leads to hooking), can cause severe denting. However, even severe denting due to impact loading does not necessarily lead to loss of containment. More importantly, it can be shown that the chance of a pipeline being subject to contact from a drop encounter is orders of magnitude less likely than the chance of it being subject to contact from a drag encounter with the same anchor. This stems from the fact that the interaction distance[3] for a dropped anchor encounter is on the order of a few feet (i.e. a function of the size of the anchor and the diameter of the pipeline), whereas the interaction distance for a drag encounter is typically on the order of hundreds or thousands of feet (i.e. a function of the length over which the anchor could be dragged once it is deployed).

The analysis described herein is also focused on the potential for failure of the exposed part of the pipeline crossing since this is the portion of the crossing that intersects the shipping lane. An analysis of the shore approach sections of the crossing was not carried out because the likelihood of significant vessel traffic in these relatively shallow water areas outside the shipping lane is very low and, according to the construction drawings, the pipelines were buried to a depth of 15 ft in these areas (where the water depth is less than 65 ft), thereby significantly reducing the likelihood of an anchor hooking event. Vessel grounding was also not considered because the draft of all significant vessels operating in the Great Lakes is significantly less than the water depth in this part of the Straits, except in very close proximity to the shoreline and in these areas, as noted, the pipelines are buried.

[3] In this study, the interaction distance is the distance travelled by a vessel over which anchor deployment can lead to contact with the pipeline.

2. ANALYSIS OF EXISTING CROSSING

2.1 Intentional Anchor Deployment

2.1.1 Fault Tree

As discussed, pipeline failure due to intentional anchor deployment is the potential result of a response to a vessel emergency that is deemed sufficiently serious by the vessel operator to warrant anchor deployment. Such vessel emergency events could include collision, contact, grounding, fires and explosions, and heavy weather.

The fault tree developed to estimate the pipeline failure frequency due to intentional anchor deployment for the existing pipeline crossing is shown in Figure 2.1.

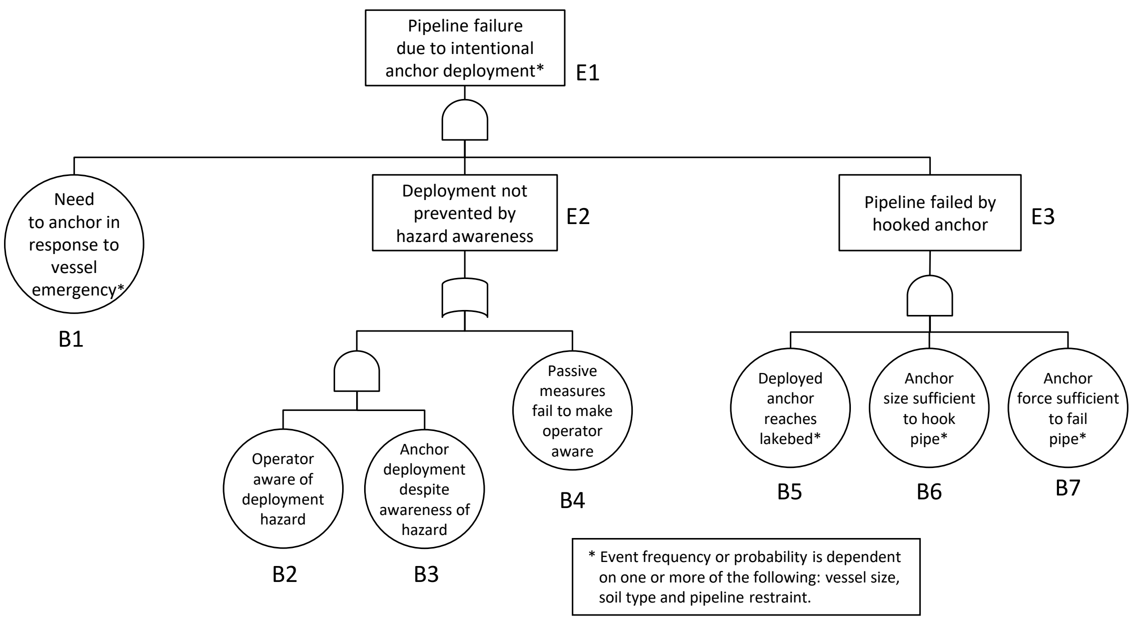

Figure 2.1 Fault Tree for Pipeline Failure Due to Intentional Deployment – Existing Crossing

The fault tree structure indicates that failure is the product of three outcomes: the need to deploy an anchor in response to a vessel emergency within the interaction distance (Event B1); the intent to anchor not being prevented by hazard awareness (Event E2); and pipeline failure by anchor hooking (Event E3). The determination of the probability of occurrence, or rate of occurrence, as appropriate, for each basic event and for the intermediate events, as determined by the fault tree logic, is described in Section 2.1.2.

2.1.2 Fault Tree Event Probabilities

2.1.2.1 Need to Anchor in Response to Vessel Emergency

Based on ship accident data compiled and analysed by the International Maritime Organization (IMO 2007), the combined frequency of collision, contact, and fire and explosion events on bulk carriers[4] is 3.29×10^{-2} per vessel yr[5,6]. Additional data analysed by the IMO (2008) suggests that the proportion of vessel accidents that qualify as serious is approximately 20%. Assuming that only serious accidents warrant emergency vessel anchoring (Environmental Resources Management 2010), the rate of occurrence of vessel accidents warranting anchor deployment is 6.58×10^{-3} per vessel yr.

Based on typical annual travel distances for maritime shipping, as estimated by DNV (see Appendix E in DNV 2009-1115 (2010)), the serious accident occurrence rate per vessel year can be converted into an occurrence rate per vessel mile as follows:

Serious accident rate per mi = Serious accident rate per yr / Distance travelled[7], mi/yr
= 6.58×10^{-3} per yr / (0.7×8760 hr/yr $\times$ 15 nmi/hr $\times$ 1.15 mi/nmi)
= 6.2×10^{-8} per mi

To obtain the rate of occurrence of vessel emergencies warranting anchoring that happen within the interaction distance (Basic Event B1), the above accident rate per vessel mile must be multiplied by the interaction distance. As previously stated, this distance is defined as the approach distance to the pipeline within which vessel anchor deployment could result in anchor interaction with the pipeline. For vessels intending to anchor in response to an emergency, this corresponds to the distance required for the drag force from a deployed and seated anchor to dissipate the kinetic energy associated with the moving vessel. Since the kinetic energy depends on vessel speed and its effective mass, which can be estimated from vessel displacement[8], the

[4] The larger Great Lake vessels with the most significant chance of causing pipeline failure in the event of anchor hooking are predominantly bulk carriers.
[5] Accidents attributable to vessel grounding are not considered because water depths within the shipping channel significantly exceed the maximum draft of vessels that traverse the Strait.
[6] Heavy weather is not considered an emergency that would lead to anchoring in the vicinity of the crossing because the Straits are designated as a ‘narrow channel’. Applicable regulations advise that anchoring in a narrow channel is to be avoided and vessel operators are aware that a relatively sheltered vessel layup area exists nearby to the north-west of Mackinac Island.
[7] Estimate of distance travelled assumes an average annual vessel utilization factor of 0.7.
[8] The effective vessel mass was taken to be equal to the mass equivalent of the vessel displacement multiplied by 1.08 (to account for the effective added mass of the water entrained by the moving vessel (Hvam 1990)).

stopping distance therefore depends on the vessel displacement[9], vessel speed, anchor holding power[10] and the soil type within which the anchor is assumed to seat.

In estimating the interaction distance, consideration was given to the fact that anchoring in response to a vessel emergency might not always occur at the preferred anchor deployment speed. In acknowledgement of this, and consistent with modeling assumptions made by others (Environmental Resources Management 2010), the deployment scenarios considered are as shown in Figure 2.2.

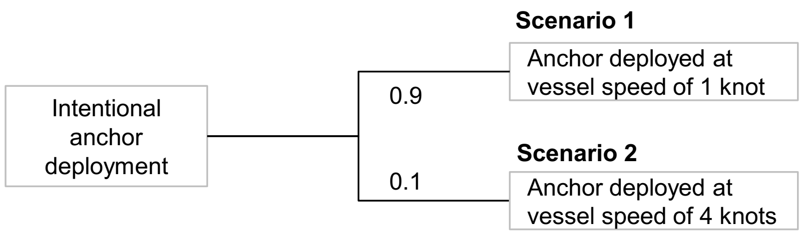

Figure 2.2 Event Tree for Intentional Anchor Deployment in Response to a Vessel Emergency

Scenario 1 is associated with deployment at what can be considered a preferred anchoring speed of 1 knot. This is taken to be the most likely outcome and it is assigned a probability of 0.9. Scenario 2 is associated with anchor deployment at a higher speed (4 knots) in response to conditions that warrant more rapid control of further vessel advance. This outcome is assigned the residual probability of 0.1.

For any vessel traversing the Straits, the intentional anchoring interaction distance, L_{in}, can be calculated for each anchor deployment scenario and soil type. For a representative sample of vessels that are known to have traversed the Straits and have sufficient kinetic energy when traveling at anchoring speeds to fail the pipeline in the event of line hooking, these interaction distances, weighted by the relative likelihood of the two assumed anchor deployment speeds, were found to range from 0.018 to 0.038 mi (96 to 200 ft) for anchor deployment in hard sand and from 0.040 to 0.080 mi (210 to 420 ft) for anchor deployment in soft clay.

For a single pipeline crossing of the Strait, the rate of exposure to anchor strike based on a vessel's need to anchor in response to an emergency, per vessel crossing (Event B1), for a given

[9] For each vessel traversing the Straits, the vessel dead weight tonnage (DWT) can be obtained from the reported vessel identification number by cross-referencing it to vessel specific information obtained from http://marinetraffic.com. Vessel displacement was estimated from the DWT by assuming that vessel displacement is equal to 1.17 times DWT (Man 2011).

[10] For a vessel of a given displacement, the anchor holding power in both soft and hard soil was estimated by interpolating the values provided in Table E.5 of DNV 2009-1115 (2010).

vessel and soil type, would be equal to 6.2 x 10^{-8} x L_{in}, where L_{in} (in miles) is the intentional anchoring drag length for a vessel as a function of vessel displacement, anchoring speed and soil type.

However, the Line 5 crossing of the Straits involves two separate pipelines and there are two 24-inch diameter natural gas transmission pipelines (now owned by TransCanada) crossing the Straits to the east of the Line 5 crossing. According to information provided by Enbridge, the two Line 5 oil pipelines are separated from each other by approximately one-quarter of a mile, as are the two TransCanada gas pipelines. The two dual-line pairs are separated from each other by a distance of approximately one-half of a mile at mid-strait.

Given that the expected drag distance in response to intentional deployment is shown to typically be much less than the separation distance between any of the above lines, consideration of each line in isolation is appropriate. On this basis, the dual-line crossing of Line 5 presents two distinct opportunities for an anchor drag encounter resulting from intentionally deployed anchors.

Therefore, the effective interaction length for the Line 5 crossing is twice the individual vessel drag length calculated as described above, and for this dual-line crossing the combined exposure is given by

$$\text{Event B1} = 2 \times 6.2 \times 10^{-8} \times L_{in} = 1.2 \times 10^{-7} \times L_{in}$$

where L_{in} (in miles) is the intentional anchoring drag length for a vessel as a function of vessel displacement, anchoring speed and soil type.

2.1.2.2 Deployment Not Prevented by Hazard Awareness

Figure 2.1 indicates that anchor deployment will not be prevented by hazard awareness (Event E2) if the current passive measures fail to make the vessel operator aware of the location of the pipeline crossings and the deployment hazard (Basic Event B4), or the vessel operator is aware of the anchor deployment hazard (Basic Event B2) and choses to deploy despite this awareness (Basic Event B3).

The pipeline crossings of the Straits are clearly delineated on all official navigation charts and cautionary notes provided on official charts state that “Not all submarine pipelines and submarine cable are required to be buried, and those that were originally buried may become exposed. Mariners should use extreme caution… when anchoring, dragging or trawling”. The State of Michigan has also recently enacted an emergency rule barring anchor usage within the Straits[11]. In addition, commercial vessels operating on the Great Lakes must be under the control of professional mariners, and part of their training and certification process requires

[11] This rule was enacted in May of 2018 on a temporary basis with the option to renew after six months.

demonstration of the ability to understand and use the appropriate navigation charts and an understanding of the need to be familiar with the navigation hazards along the routes that they travel. Foreign vessels entering the Great Lakes from overseas are required to hire an American or Canadian pilot to assist with navigation. Given the above, it is considered very unlikely that a vessel operator (i.e. vessel captain and/or vessel pilot) would be unaware of the general location of the pipeline crossings and the hazard posed by anchoring in the area. Consistent with guidance provided by the Intergovernmental Panel on Climate Change on the use of calibrated language for characterizing uncertainties (Mastrandea et al. 2011), the probability of occurrence of a very unlikely event is taken to be no higher than 10% and, on that basis, Basic Event B4 is assigned a value of 0.1.

If a vessel operator is aware of the crossing location and the hazard posed by anchor deployment, it is acknowledged that the vessel operator may still choose to deploy the anchor if the vessel operator deems that the risk posed by not deploying an anchor is greater than the risk of pipeline damage posed by deployment. Deployment given awareness can occur because, while the navigation chart notes caution against anchor deployment in the vicinity of submarine pipelines and cables, they do not prohibit deployment[12] and the final decision making authority always resides with the vessel operator, who is assumed to be in the best position to determine the most prudent course of action. In acknowledgement of these factors, it is considered possible but 'very unlikely' that an anchor will be deployed in response to a vessel emergency in the vicinity of the crossing if the operator is aware of the crossing area and further aware of the anchoring hazard. Consistent with the above, Basic Event B3 is assigned a probability of 0.1.

The probability that the operator will be aware of the deployment hazard (Basic Event B2) can be shown to be equal to one minus the probability of Basic Event B4. Given that Basic Event B4 has been assigned a value of 0.1, Basic Event B2 takes a value of 0.9.

Based on the fault tree logic and the assigned basic event probabilities, the probability that deployment will not be prevented by hazard awareness (Event E2) is given by:

$$\begin{aligned}\text{Event E2} &= (\text{B2} \times \text{B3}) + \text{B4} \\ &= (0.9 \times 0.1) + 0.1 \\ &= 0.19\end{aligned}$$

[12] The emergency rule recently enacted by the State of Michigan, which prohibits anchor usage within the Straits, does allow vessels to use their anchors in emergency situations. Given that the intentional anchor deployments under consideration are those precipitated by a vessel emergency, the new regulation is not anticipated to affect a vessel operator's decision to deploy in response to emergency conditions.

2.1.2.3 Pipeline Failed by Hooked Anchor

Figure 2.1 indicates that the pipeline will fail by anchor hooking (Event E3) if the deployed anchor reaches the lakebed (Basic Event B5), the anchor size is sufficient to hook the pipeline (Basic Event B6) and the anchor force applied to the pipe is sufficient to fail the pipeline (Basic Event B7).

Given the water depth at the pipeline crossing location (maximum depth of approximately 235 ft) and guided by generic information on anchor chain lengths for vessels of various displacement classes (Table E.1 in Appendix E of DNV Report 2009-1115 (2010)), it was determined that all vessels having a displacement sufficient to fail the pipeline by hooking will have chain lengths sufficient to enable a deployed anchor to reach the lakebed. Basic Event B5 is therefore assigned a probability of 1.0.

Similarly, given the diameter of the Enbridge pipelines crossing the Straits (i.e. 20 in) and generic information on anchor dimensions for vessels of various displacement classes (Table E.2 in Appendix E of DNV Report 2009-1115 (2010)), it was determined that all vessels having a displacement sufficient to fail the pipeline by hooking will carry anchors large enough to hook the pipeline in the event of a drag encounter. Basic Event B6 is therefore assigned a probability of 1.0.

The probability that the lateral force acting on the pipeline by an anchor hooking event will be sufficient to fail the pipeline (Basic Event B7) is dependent on the magnitude of the force that can be exerted on the pipeline by the anchor and the resistance capacity of the pipeline. The maximum force that can be applied to the pipeline in the event of anchor hooking is a function of the kinetic energy of the vessel, which, as previously discussed, is dependent on vessel displacement and speed. This maximum force is, however, limited by the breaking strength of the anchor chain. The resistance capacity of the pipeline can be shown to be dependent on the size of the pipeline, and the degree of restraint against lateral movement provided by soil embedment and/or other lateral restraint mechanisms, where applicable.

Based on the guidance provide in Appendix E of DNV Report 2009-1115 (2010), pipeline failure due to the lateral force generated by anchor hooking can be assumed to occur if either the resulting dent amplitude exceeds a threshold value (i.e. 10% of the pipe diameter), or the combined bending plus tension-induced strain in the pipe wall exceeds a threshold value (i.e. 5%). Tables E.6 and E.7 in DNV Report 2009-1115 (2010) provide estimates, based on detailed numerical modeling, of the pipe load resistance and the lateral pipe displacement required to reach the load limit. These estimates are developed and presented in the DNV report as a function of pipe diameter, the degree of lateral pipe restraint (i.e. exposed on bottom, embedded or trenched) and the assumed soil type (i.e. hard sand or soft clay). It is noted that, for a 20-inch diameter pipe, the pipe load capacity is effectively controlled by the strain limit for all cases[13]. The pipeline load resistance and corresponding lateral displacement estimates for a 20-inch line subject to hooking, as developed by DNV, are reproduced in Table 2.1.

Soil Type	Parameter	Pipeline Lateral Restraint Condition		
		Exposed Pipe	Embedded Pipe	Pipe in Trench
Hard sand	Load resistance	508 kips (2260 kN)	211 kips (940 kN)	355 kips (1580 kN)
	Lateral displacement	177 ft (54 m)	19 ft (5.8 m)	4.9 ft (1.5 m)
Soft clay	Load resistance	472 kips (2100 kN)	157 kips (700 kN)	283 kips (1260 kN)
	Lateral displacement	203 ft (62 m)	8.5 ft (2.6 m)	5.2 ft (1.6 m)

Table 2.1 Pipeline Load and Displacement Limits for a 20-inch Line as a Function of Soil Type and Restraint Condition

It is noted that the existing line crossings are neither embedded in the lakebed soil nor contained in trenches. However, the presence of screw anchors intended to manage current-induced vibration at intervals along the length of the pipelines will offer some lateral restraint and, for this analysis, it was assumed that the degree of lateral pipeline restraint in close proximity to these devices is similar to that afforded by soil embedment, which is shown by the tabulated results to be the restraint condition which produces the lowest pipeline load capacity.

For a vessel traversing the Straits, there are two limiting conditions that must be exceeded for the anchor to fail the pipeline. The first is that the kinetic energy associated with the moving vessel must be larger than the energy that can be absorbed by the pipeline as it displaces laterally under the anchor chain load[14]. The second is that the anchor chain strength[15] must exceed the lateral load limit for the pipeline. Checks exist to determine if these limits are exceeded for a given vessel and they must be carried out separately for each combination of soil type and pipe restraint condition.

[13] A 20-inch fully exposed pipeline resting on hard soil was found to have a dent capacity 1% lower than the strain capacity. This difference in load capacity is insignificant and this condition can effectively be treated as strain controlled.
[14] For this analysis, it was assumed that, during a hooking event, the lateral load on the pipeline will increase linearly with lateral pipe displacement at a rate of increase given by the ratio between the limit load and limit displacement.
[15] For a vessel of a given displacement, the anchor chain break strength was estimated by interpolating the values provided in Table E.4 of DNV 2009-1115 (2010).

Given the above, on a per vessel crossing basis, the probability that the anchor force is sufficient to fail the pipeline (Basic Event B7) is a binary outcome (i.e. 0 or 1.0), depending on the vessel size, the assumed pipeline restraint and soil type.

Based on the fault tree logic and the assigned basic event probabilities, the probability that the pipeline will fail due to anchor hooking (Event E3) is given by:

Event E3 = B5 x B6 x B7

Since the probabilities of Basic Events B5 and B6 are both 1.0, the probability of Event E3 is equal to the probability of Basic Event B7, which, on a per vessel crossing basis, is given by

Event E3 = 0.0 or 1.0

with the outcome being dependent on vessel displacement, degree of pipeline restraint and assumed soil type.

2.1.3 Failure Due to Intentional Anchor Deployment

Based on the fault tree logic shown in Figure 2.1, the rate of occurrence of the top event (Event 1), is given by:

Event E1 = B1 x E2 x E3

The preceding discussion of the basis for intermediate event probabilities or occurrence rates indicates that some events are best quantified on a per vessel crossing basis. To generate the top event occurrence rate on a per year basis, the approach taken was to first calculate the top event occurrence rate for each significant vessel crossing reported to have occurred within the three year period extending from 2014 to 2016[16]. These top event occurrence rates were then aggregated and the total was divided by three to obtain the top event occurrence rate (i.e. the pipeline failure rate) on an annual basis.

The above calculation process was repeated for each soil type and pipe restraint condition, and the results obtained are summarized in Table 2.2.

[16] Vessel traffic data was obtained from a Nationwide Automatic Identification System (NAIS) Historical Data Feed Request made to the United States Coast Guard Center. This data set is the same as that provided by the Coast Guard to Dynamic Risk for their Alternatives Analysis for the Straits Pipelines, which was prepared in 2017 for the State of Michigan.

Soil Type	Fully Exposed	Partially Restrained
Hard Sand	5.56×10^{-7} per yr	1.01×10^{-6} per yr
Soft Clay	1.19×10^{-6} per yr	2.32×10^{-6} per yr

Table 2.2 Line 5 Crossing Failure Rate due to Intentional Anchor Deployment for the Existing Line as a Function of Soil Type and Pipeline Restraint Condition.

The tabulated results show that, for a given deployment detection case, the failure rates do exhibit some variability with changes in assumed soil type and degree of pipeline restraint. However, given that pipeline restraint and soil conditions will vary along the length of each line crossing, and given further that failure due to anchor hooking could occur at any point over a significant length of line which traverses areas encompassing both soil types and both pipe restraint conditions, a failure rate equal to the average of the values for the four soil type and pipe restraint combinations is considered a representative single measure of expected pipeline performance. The annual pipeline failure rate estimate, averaged over the four soil type and pipe restraint combinations, is 1.27×10^{-6} per yr.

2.2 Unintentional Anchor Deployment

2.2.1 Fault Tree

As discussed earlier, pipeline failure due to unintentional anchor deployment is the potential result of an accident caused by anchor equipment malfunction and/or human error. The fault tree developed to estimate the pipeline failure frequency due to unintentional anchor deployment for the existing pipeline crossing is shown in Figure 2.3.

The fault tree structure indicates that failure is the product of two outcomes: the unintentional deployment of an anchor within the interaction distance (Basic Event B1) and pipeline failure by anchor hooking (Event E2). The probability of occurrence or rate of occurrence, as appropriate, for each basic event and the single intermediate event, as determined by the fault tree logic, is described in Section 2.2.2. It is noted that deployment prevention based on operator awareness of the deployment hazards in the vicinity of submarine pipelines, which was considered for intentional anchoring, is not a relevant consideration for unintentional deployment because unintentional deployments occur independently of vessel operator awareness.

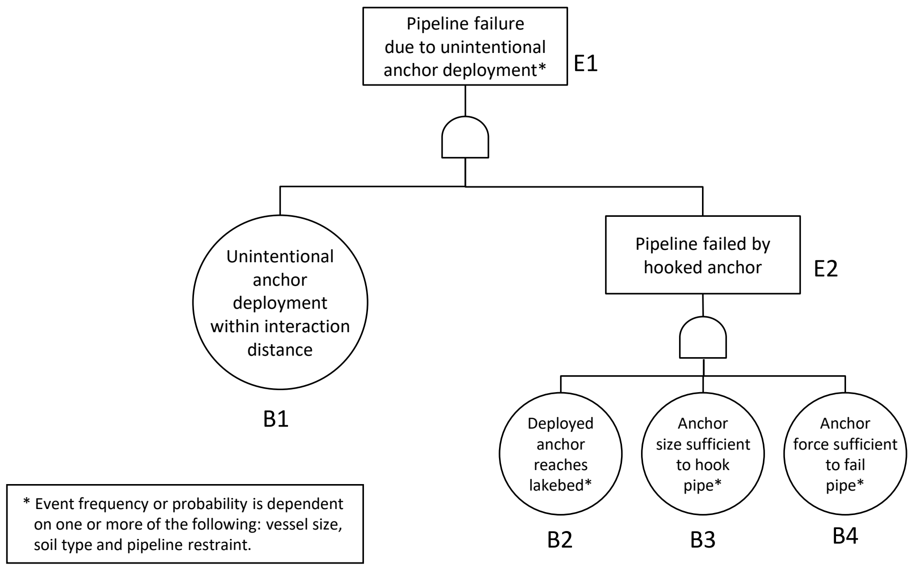

Figure 2.3 Fault Tree for Pipeline Failure Due to Unintentional Deployment – Existing Crossing

2.2.2 Fault Tree Event Probabilities

2.2.2.1 Unintentional Anchor Deployment

In Appendix E of the DNV Report 2009-1115 (2010), a representative anchor loss frequency of 1×10^{-2} per vessel yr is presented, citing insurance records and trend analysis. From this, and introducing assumptions regarding the proportion of lost anchors that are related to unintentional deployment and the fact that not all unintentionally deployed anchors are lost, DNV arrived at an unintentional anchor deployment rate of 4.6×10^{-3} per vessel yr.

Based on typical annual travel distances for maritime shipping, DNV then converted the deployment rate per vessel year into an occurrence rate per vessel mile as follows:

$$\begin{aligned}\text{Deployment rate per mi} &= \text{Deployment rate per yr / Distance travelled}^{17}\text{, mi/yr} \\ &= 4.6 \times 10^{-3} \text{ per yr / } (0.7 \times 8760 \text{ hr/yr} \times 15 \text{ nmi/hr} \times 1.15 \text{ mi/nmi}) \\ &= 4.4 \times 10^{-8} \text{ per mi}\end{aligned}$$

To obtain the rate of occurrence of unintentional deployment within the interaction distance (Basic Event B1), the above deployment rate per vessel mile must be multiplied by the

[17] Estimate of distance travelled assumes an average annual vessel utilization factor of 0.7.

interaction distance. This distance, as previously defined, is the approach distance to the pipeline within which unintentional vessel anchor deployment could result in anchor interaction with the pipeline. For vessels underway when an accidental deployment occurs, this distance is the distance travelled by the vessel between the time at which the anchor is deployed, and the time at which the deployment is detected or the time at which the anchor is lost due to interaction with a submarine obstruction.

According to the DNV analysis approach, the interaction distance is taken as the weighted average of the drag distances associated with three possible unintentional deployment outcomes (see Figure 2.4).

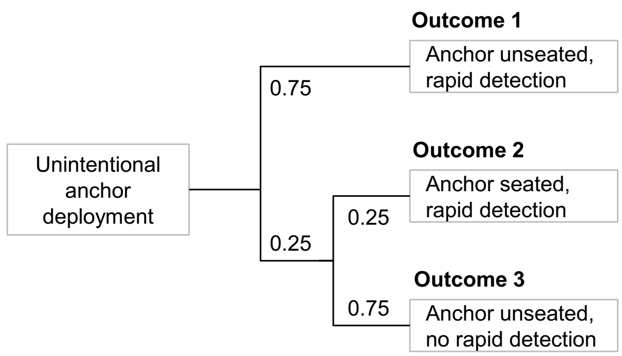

Figure 2.4 Event Tree for Unintentional Anchor Deployment

Outcome 1 is associated with an anchor deployment that is rapidly detected due to the noise and vibration generated when the anchor is deployed. For this rapid detection outcome, the anchor is assumed not to have seated and the drag distance is set to 0.62 mi (1 km). This is considered the likely outcome of an unintentional deployment and it is assigned a probability of 0.75.

Outcome 2 is associated with a deployment wherein the anchor seats and either the anchor chain breaks and the anchor is lost or, due to the anchor holding power, vessel maneuvering is affected to the point where anchor deployment is detected. For this rapid detection outcome, the drag distance is similarly set to 0.62 mi (1 km). This is considered the unlikely outcome of an unintentional deployment that does not result in Outcome 1 and is assigned a probability of 0.25 x 0.25 = 0.0625.

Outcome 3 is associated with a deployment wherein the anchor remains unseated and rapid detection does not occur. The DNV approach assumes that these deployments are not detected and the drag distance is set equal to the average spacing between subsea pipelines in the North Sea, which, according to DNV, is about 20 mi (33 km). This is considered the likely outcome of an unintentional deployment that does not result in Outcome 1 and is assigned a probability of 0.25 x 0.75 = 0.1875.

Analysis of Existing Crossing

The authors of this study consider the DNV approach to estimating the drag distance for Outcome 3 to be appropriate for North Sea application, but not necessarily applicable in other areas where the spacing of significant submarine obstructions is potentially much greater. For an ocean going vessel traveling at a typical speed of 15 knots, the drag distance assumed by DNV for North Sea application (i.e. 20 mi) would be covered in just over one hour. However, when the same approach is applied to shipping in the Great Lakes where significant submarine obstructions could be hundreds of miles apart, the drag distance according to this model would be significantly longer, and a significantly longer drag distance implies that unintended anchor deployments would have to go undetected for significantly longer than one hour.

It is noted that, in the Alternatives Analysis Report prepared by Dynamic Risk for the State of Michigan (2017), the drag distance for Outcome 3 was taken to be the distance traveled by a typical vessel in one hour, which can be interpreted to mean that the authors of the Dynamic Risk report considered detection after about one hour to be a reasonable assumption.

For this study, the one hour time to detection assumed by Dynamic Risk has been adopted as a reference assumption for Outcome 3 to facilitate comparison between the findings of this study and the Alternatives Analysis Report. For Great Lake vessels traveling at a typical open lake speed of 15 mph, the drag distance for Outcome 3, based on a one-hour time to detection, is 15 mi.

An alternative basis for establishing a drag distance for Outcome 3 is as follows: If deployment detection in the course of routine vessel activities is assumed to be a random process, the time to detection can be approximated by an exponential distribution. Given this, the average time to deployment detection is given by the rate parameter of the chosen exponential distribution. If it is further assumed that detection via these activities is 'very likely' within a standard vessel watch-keeping period of eight hours and assigned a probability of 90%, the assumed exponential distribution is fully defined and the associated rate parameter, which is the average time to deployment detection, is 3.5 hours. Under these assumptions, assuming a typical open lake vessel speed of 15 mph, the expected drag distance for Outcome 3 is 53 mi (15 mi/hr x 3.5 hr).

As previously discussed, using the DNV approach, the interaction distance to be used in the unintentional deployment failure rate calculation is the weighted average of the drag distance associated with each of the three possible deployment outcomes. Based on the above, the unintentional deployment interaction distance, L_{un}, for the Dynamic Risk assumption of deployment detection in one hour for Outcome 3, is

$$L_{un} = 0.75 \times 0.62 + 0.25 \times (0.25 \times 0.62) + 0.25 \times (0.75 \times 15) = 3.32 \text{ mi.}$$

For the alternative C-FER assumption that there is a 90% probability of deployment detection within eight hours for Outcome 3, the unintentional deployment interaction distance is

$$L_{un} = 0.75 \times 0.62 + 0.25 \times (0.25 \times 0.62) + 0.25 \times (0.75 \times 53) = 10.4 \text{ mi.}$$

Analysis of Existing Crossing

Given the above, for a single pipeline crossing of the Straits, the rate of exposure to anchor strike based on unintentional deployment (Event B1), on a per crossing basis, would be 4.35×10^{-8} per mi $\times$ L_{un}, with L_{in} varying with the assumption made regarding the time to deployment detection.

However, as previously noted, the Line 5 crossing of the Straits involves two separate pipelines and there are two gas transmission pipelines crossing the Straits to the east of the Line 5 crossing. The spacing between each of these four lines ranges from approximately one-quarter to one-half of a mile. Given the interaction lengths (i.e. unintentional deployment drag distances) developed above, which significantly exceed the line spacing, the potential exists for a single anchor drag event to interact with multiple pipelines.

The analysis approach described in the Alternatives Analysis Report (Dynamic Risk 2017) assumed that a vessel approaching the Line 5 crossing from the east will interact with and potentially fail the east-side pipeline, whereas vessels approaching from the west will interact with and potentially fail the west-side pipeline. In addition, no consideration was given to the effect of the adjacent gas pipelines on the failure potential of the Line 5 crossing. This approach is considered both reasonable and conservative for an assessment of the Line 5 crossing, provided that an anchor encounter with one of the two pipelines in the Line 5 crossing cannot be followed by an encounter with the other. The principal argument[18] provided in the Alternatives Analysis Report for assuming that only one line can fail is the claim that the forces acting on the vessel anchor chain in the event of a hooking encounter with one line will affect the speed and maneuverability of the vessel sufficiently to make the operator aware of the situation, thereby enabling emergency measures to be taken to prevent an anchor encounter with a second line.

The authors of this report consider that anchor interaction leading to failure of the first line does not preclude the possibility of an anchor encounter with the second line. For many of the vessels large enough to fail a Line 5 pipeline by anchor hooking, their kinetic energy when traveling at or near the 12 knot maximum speed allowed in the Mackinac Bridge Security Zone (33 CFR 165.928) can be shown to be more than sufficient to fail two pipelines in succession. In addition, at this vessel speed, given the line spacing, the time to anchor encounter with the second pipeline would be approximately one minute. This may not be sufficient time to initiate measures to prevent a second anchor encounter.

An alternative evaluation of the implications of a dual-line crossing on failure potential is as follows: Research under the supervision of the Norwegian University of Science and Technology (Wei 2015) indicates that an encounter between an unseated dragging anchor and an exposed

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[18] The Alternatives Analysis Report also suggests that hooking and failure of the first pipe will prevent the second line from failing because the first line will remain hooked to the anchor, thereby making it impossible to hook the second and to similarly hook between the anchor shank and the flukes. This argument is dismissed on the basis that the first line, if it fails, is sufficiently separated from the second line that it will be pulled clear of the anchor before the second line is encountered.

submarine pipeline will result in hooking approximately 50% of the time[19]. Given this, a simple event tree can be constructed to demonstrate that, for an anchor encounter that would fail the pipeline if hooking occurs, the expected outcome of an encounter with the dual-line crossing is one pipeline failure. It is noted that this finding acknowledges the possibility of three different outcomes: no line failures, one line failure, or two line failures. The expected outcome reflects the relative likelihood of each of the three outcomes[20]. Given that hooking and failure of the first line encountered may in fact precipitate vessel actions that prevent anchor interaction with the second line, which was not considered in the event tree analysis, this result is considered a reasonable but somewhat conservative estimate of the expected outcome of an anchor interaction event involving a vessel and anchor combination with the potential to fail the pipeline if hooking occurs.

The above confirms that it is reasonable to assume that, on average, the outcome of a single drag encounter with the dual-line crossing is the failure of a single pipeline, which is consistent with the assumption made in the Alternatives Analysis Report, albeit based on different arguments.

With regard to the effect of the gas pipeline crossing to the east of the Line 5 crossing, unintentionally deployed anchors approaching the Line 5 crossing from the east may hook and fail one of the gas pipelines, thereby potentially providing an opportunity for the vessel to take measures to avoid a subsequent encounter with the Line 5 crossing. Based on this, the gas pipelines could be assumed to provide some shielding to the oil pipelines at the Line 5 crossing.

Based on the above reasoning and the above estimated probability of pipeline hooking given an anchor encounter, it can be shown via event tree analysis that the probability that an anchor drag associated with a vessel approaching Line 5 from the east will pass the gas pipeline crossing without hooking either line is 0.25. On this basis, 75% of possible drag encounters associated with vessels approaching Line 5 from the east will be intercepted by the gas line crossing. Assuming that overall vessel traffic through the Straits is equal in both directions, it follows that the average east-west drag encounter rate would drop by 38% due to the shielding effect of the gas pipelines[21]. However, the gas pipelines are contained within gravel berms designed to manage current-induced vibration. These gravel berms, while not designed to prevent anchor

[19] The 50% estimate was developed by C-FER through interpolation of the reported hooking ratios for analysis cases involving encounters with large anchors (4 to 10 tons) traveling at 12 knots encountering a pipeline with a height above the seabed ranging from zero (i.e. on-bottom) to three pipe diameters.

[20] Event tree analysis shows that, if the probability of hooking a pipeline is 0.5, the probability of not hooking either line is 0.25, the probability of hooking and failing only one line is 0.5, and the probability of hooking and failing two lines is 0.25. The expected outcome of this anchor-pipeline interaction event, in terms of the number of pipelines failed, is therefore (0.25 x 0) + (0.5 x 1) + (0.25 x 2) = 1.0.

[21] If none of the drag encounters associated with vessels approaching from the west are prevented by gas line hooking, but 75% of the drag encounters associated with vessels approaching from the east are prevented by gas line hooking, and if vessel traffic in each direction is equal, the relative Line 5 encounter rate is (0.5 x 1) + (0.5 x (1-0.75)) = 0.625, which amounts to a 37.5% reduction compared to the encounter rate if the gas line shielding is ignored.

strike, will afford some protection against hooking and, on that basis, the exposed pipeline hooking probability (i.e. 50%) likely over-estimates the hooking rate that would apply to the gas pipelines. To illustrate the implications of this point, if the hooking probability is reduced by half to 25%, it can be shown that the probability that an anchor drag associated with a vessel approaching Line 5 from the east will pass the gas pipeline crossing without hooking either gas pipeline climbs to 0.5625 and, on this basis, it can further be shown that the drag encounter rate reduction due to gas pipeline shielding drops to 22%. If the gravel berms placed for current-induced vibration management are more effective at preventing hooking than assumed, the drag encounter rate reduction associated with gas line shielding will be even less. Given this, combined with the fact that hooking and failure of a gas pipeline will not (with certainty) preclude a subsequent anchor drag encounter with the Line 5 crossing (for the reasons outlined earlier), the likely benefit attributable to gas line shielding is sufficiently small to ignore.

Therefore, the rate of exposure to anchor strike for the dual-line crossing, based on unintentional anchor deployment, as calculated based on the rate of occurrence of unintentional anchor deployments within the interaction distance (Event B1), on a per crossing basis, is given by:

Event B1 = 4.35×10^{-8} per mi $\times L_{un}$
= 1.44×10^{-7} per crossing, for the Dynamic Risk Outcome 3 detection assumption
= 4.52×10^{-7} per crossing, for the C-FER Outcome 3 detection assumption

2.2.2.2 Pipeline Failed by Hooked Anchor

Figure 2.3 indicates that the pipeline will fail by anchor hooking (Event E2) if the deployed anchor reaches the lakebed (Basic Event B2), the anchor size is sufficient to hook the pipeline (Basic Event B3), and the anchor force applied to the pipe is sufficient to fail the pipeline (Basic Event B4).

The process for determining the basic event probabilities is very similar to that described in Section 2.1.2.3 for intentional anchoring[22]. Therefore, on a per vessel crossing basis, the probability that the anchor force is sufficient to fail the pipeline (Basic Event B4) is again a binary outcome (i.e. 0 or 1), depending on the vessel size, the assumed pipeline restraint and soil condition. Since the probabilities of Basic Events B2 and B3 are both 1.0 (see Section 2.1.2.3), the probability that the pipeline will fail by a hooked anchor (Event E2) is given on a per vessel crossing basis by:

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[22] The only difference in the event probability calculation is associated with determination of the probability of pipeline failure by anchor hooking (Event E2); the primary difference for this calculation being that the vessel speed required for the kinetic energy calculation is assumed to be the vessel anchoring speed (either 1 or 4 knots) for intentional anchor deployment and the average open lake vessel speed (15 mph or about 13 knots) for unintentional deployment. In addition, as recommended by DNV, for unintentional anchoring, the vessel thrust while underway is added to the kinetic-energy-induced force assumed to be acting on the anchor chain as the vessel is slowed.

Event E2 = 0.0 or 1.0

with the outcome being dependent on vessel displacement, degree of pipeline restraint and assumed soil type.

2.2.3 Failure Due to Unintentional Anchor Deployment

Based on the fault tree logic shown in Figure 2.3, the rate of occurrence of the top event (Event E1), is given by:

Event E1 = B1 x E2

The preceding discussion of the basis for the intermediate event probabilities associated with Event E2 indicates that this event is best quantified on a per vessel crossing basis. To generate the top event occurrence rate on a per year basis, the approach taken was to first calculate the top event occurrence rate for each significant vessel crossing reported to occur in the three-year period extending from 2014 to 2016[16]. These top event occurrence rates were then aggregated and the total was divided by three to obtain the top event occurrence rate (i.e. the pipeline failure rate) on an annual basis.

The above calculation process was repeated for each soil type and pipe restraint condition, and the results obtained are summarized in Table 2.3 for the two deployment detection scenarios discussed in Section 2.2.2.1.

Soil Type	Dynamic Risk Deployment Detection Assumption		C-FER Deployment Detection Assumption	
	Fully Exposed	Partially Restrained	Fully Exposed	Partially Restrained
Hard Sand	2.00×10^{-4} per yr	2.57×10^{-4} per yr	6.26×10^{-4} per yr	8.04×10^{-4} per yr
Soft Clay	2.24×10^{-4} per yr	2.57×10^{-4} per yr	7.01×10^{-4} per yr	8.04×10^{-4} per yr

Table 2.3 Line 5 Crossing Failure Rate due to Unintentional Anchor Deployment for Existing Line as a Function of Soil Type and Restraint Condition

The tabulated results show that, for a given deployment detection case, the failure rates are largely insensitive to soil type and degree of pipeline restraint. In addition, given that pipeline restraint and soil conditions will vary along the length of each line crossing, and given further that failure due to anchor hooking could occur at any point over a significant length of line which traverses areas encompassing both soil types and both pipe restraint conditions, a failure rate equal to the average of the values for the four soil type and pipe restraint combinations is considered to be a representative single measure of expected pipeline performance. The average annual Line 5 crossing failure rates for each deployment detection scenario are provided in Table 2.4.

Dynamic Risk Deployment Detection Assumption	C-FER Deployment Detection Assumption
2.35×10^{-4} per yr	7.35×10^{-4} per yr

Table 2.4 Line 5 Crossing Failure Rate Due to Unintentional Anchor Deployment for Existing Line

2.3 Combined Failure Frequencies for Existing Line 5 Crossing

The Line 5 crossing failure rates attributable to both intentional and unintentional anchor deployment, for the two deployment detection assumptions considered herein, are provided in Table 2.5.

Damage Mechanism	Dynamic Risk Deployment Detection Assumption	C-FER Deployment Detection Assumption
Intentional Deployment	1.27×10^{-6} per yr	1.27×10^{-6} per yr
Unintentional Deployment	2.35×10^{-4} per yr	7.35×10^{-4} per yr
Total Combined	2.36×10^{-4} per yr	7.36×10^{-4} per yr

Table 2.5 Line 5 Crossing Failure Rate Due to Intentional and Unintentional Anchor Deployment for Existing Line

The tabulated results indicate that the total combined annual failure rate is overwhelmingly dominated by the failure potential attributable to unintentional anchor deployment. The results also show that the unintentional anchor deployment failure rate obtained using the C-FER assumption regarding the time required to detect an unintentionally deployed anchor (i.e. 3.5 hours for the Outcome 3 detection scenario) is approximately three times higher than the failure rate obtained using the Dynamic Risk detection time assumption (i.e. one hour for the Outcome 3 scenario). It is noted that the analysis described herein produces a failure rate estimate for unintentional deployment that is very similar to that obtained by Dynamic Risk, as reported in the Alternatives Analysis Report, if the Dynamic Risk deployment detection assumption is employed[23]. The Alternatives Analysis Report did not address intentional anchor deployment.

The C-FER assumption regarding time to deployment detection is considered a more prudent choice given the uncertainty associated with the time to detection for the Outcome 3 scenario,

[23] The unintentional anchor deployment failure rate reported by Dynamic Risk is given as a range between 2.51×10^{-4} and 3.43×10^{-4} per yr, which compares favorably with the failure rate estimate of 2.35×10^{-4} per yr obtained by C-FER for unintentional anchor deployment if the Dynamic Risk detection time assumption is used.

which applies for unintentionally deployed anchors if rapid detection by the vessel crew does not occur as a result of the noise and vibration associated with anchor deployment or vessel maneuvering changes caused by anchor seating. Further discussion and comparison of failure rates in this study are based on failure rates obtained using the C-FER assumption regarding the time to unintentional deployment detection.

3. EFFECT OF PREVENTATIVE AND PROTECTIVE MEASURES

3.1 Overview

Enbridge is currently testing a system intended to reduce the likelihood of anchor deployment from vessels crossing the Straits. This system (see Figure 3.1), Guardian:protect developed and distributed by Vesper Marine, uses real-time vessel position monitoring[24] in combination with automated analysis of vessel movement to detect behaviour indicative of an intention to anchor. The Guardian:protect system is also capable of automatically generating and transmitting a warning message to these vessels, the intent being to ensure that vessel operators are aware that they are operating in proximity to a submarine pipeline and that anchor deployment in the area is not advised. In effect, the system is intended to compliment the passive awareness system currently in place, which presumes that vessel operators are aware of their location and the hazards of anchor deployment based on information provided on navigation charts, and through their general awareness and familiarity with the hazards associated with the route that they are traveling.

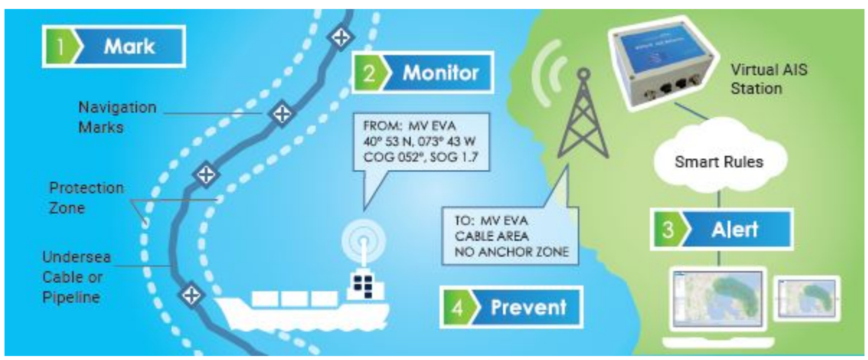


Figure 3.1 Vesper Marine Guardian:protect System (image used with permission)

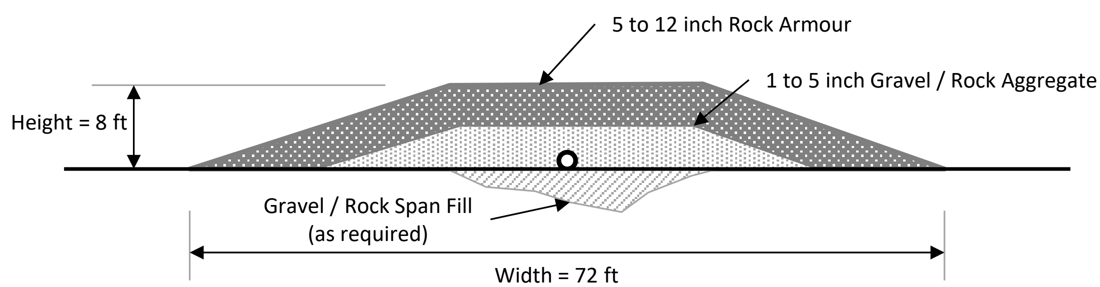
The planned implementation of the Guardian:protect system (Option 1), described above, will serve to mitigate the potential for pipeline failure due to intentional anchor deployment. However, it will not mitigate the potential for pipeline failure due to unintentional anchor deployment because vessels dragging accidentally deployed anchors will not exhibit movement patterns indicative of an intention to anchor and, on that basis, a Guardian:protect advisory message will not be sent. In light of this, consideration was also given to an alternate Guardian:protect system implementation strategy (Option 2) wherein the automatic messaging capability of the Guardian:protect system is further utilized to include the transmission of an

---

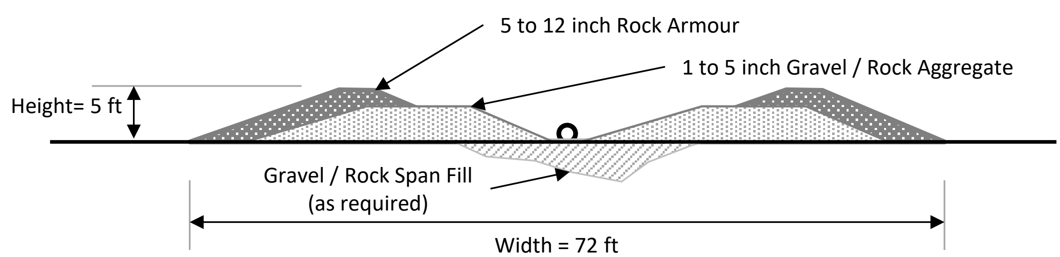
[24] The Guardian:protect system utilizes the Automatic Identification System (AIS), a vessel tracking and communication system that is required on all major vessels.

advisory message to vessels approaching the Straits. This analysis assumes that the message will advise that the vessel is approaching a pipeline crossing and that anchors should be checked to ensure that they are properly stowed.

Enbridge is also evaluating two protective barrier options intended to prevent vessel anchors from coming into contact with the pipelines. The gravel/rock barrier options being considered are described in a feasibility study prepared by IntecSea (2018). The first option (see Figure 3.2a) involves an engineered protective cover to fully encase each pipeline; the second option (see Figure 3.2b) involves the placement of two engineered gravel/rock berms flanking each pipeline.



a) Option 1 – Full encasement



b) Option 2 – Flanking berms

Figure 3.2 Protective Barrier Options

The full encasement option (Option 1) is intended to provide a depth of cover and a cross-sectional width sufficient to prevent dragged anchors from coming into contact with the pipeline. This option also affords protection against direct impact from an anchor drop. The flanking berm option (Option 2) is similarly intended to mitigate the dragged anchor threat. However, this second option is acknowledged by IntecSea to likely be significantly less effective at preventing an encounter between the pipeline and a dragged anchor because the rock armour does not cover the top of pipeline and does not provide protection against direct impact from a dropped anchor. It has been included in this assessment because consideration of a protective barrier option that affords direct visual examination of the pipeline was requested by the State of Michigan.

Effect of Preventative and Protective Measures

It is noted that, as discussed in Section 1.4, this study is focussed on assessment of the probability of pipeline failure due to anchor drag because the likelihood of a drop encounter is orders of magnitude lower than that of a drag encounter. The findings provided here, with respect to the effectiveness of the protective barrier options, therefore pertain to their effectiveness in mitigating the potential for pipeline failure due to anchor drag only.

3.2 Failure Due to Intentional Anchor Deployment

3.2.1 Revised Fault Tree

The fault tree developed to estimate the pipeline failure frequency due to intentional anchor deployment for the pipeline crossing, accounting for the proposed preventative and protective measures, is shown in Figure 3.3.

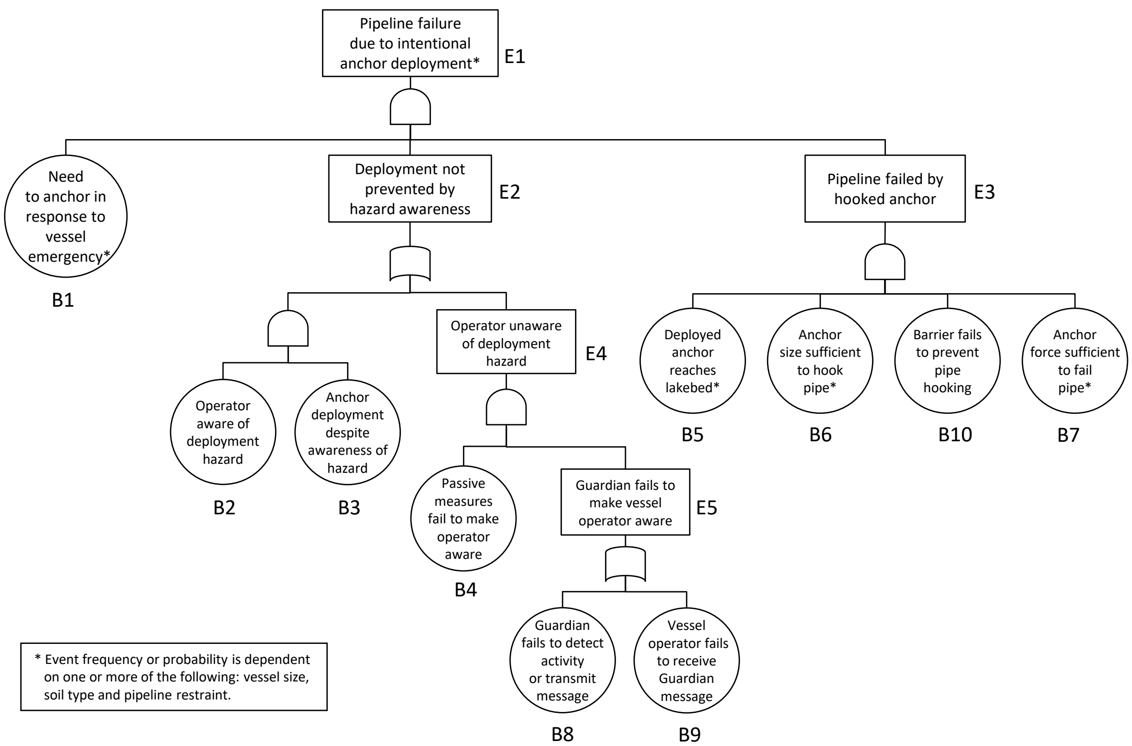


Figure 3.3 Fault Tree for Pipeline Failure Due to Intentional Deployment – Crossing with Enhanced Preventative and/or Protective Measures

The fault tree differs from that developed for the existing crossing (Figure 2.1) by the addition of three basic events. Basic Events B8 and B9 (together with associated Intermediate Events E4 and E5) are intended to address the effect of the Guardian:protect system on the probability that anchor deployment will not be prevented by hazard awareness (Event E2), which in turn affects the probability of pipeline failure due to intentional anchor deployment. Basic Event B10 has been added to address the effect of a protective barrier in preventing deployed vessel anchors from coming into contact with the pipeline.

3.2.2 Effect of Guardian:protect System Alone

The modified fault tree shown in Figure 3.3 indicates that anchor deployment will not be prevented by hazard awareness (Event E2) if the vessel operator is unaware of the deployment hazard (Event E4), or the vessel operator is aware of the anchor deployment hazard (Basic Event B2) and choses to deploy despite this awareness (Basic Event B3).

The modified fault tree further indicates that the vessel operator will be unaware of the deployment hazard (Event E4) if passive measures fail to make the operator aware (Basic Event B4) or the Guardian:protect system, as implemented in accordance with either Option 1 or 2 as described in Section 3.1, fails to make the vessel operator aware (Event E5). (In the fault tree for the existing crossing, Event E4 was solely dependent on the effectiveness of passive awareness measures.) Failure of the Guardian:protect system to make the vessel operator aware of deployment hazards (Event E5) requires the Guardian:protect system to fail to detect and transmit a warning message regarding vessel activity indicative of an intention to anchor (Basic Event B8) or failure of the vessel operator to receive the Guardian:protect message (Basic Event B9).

Guardian:protect system failure to detect and transmit (Basic Event B8) requires failure of the algorithm employed to identify vessel movement indicative of an intention to anchor or failure of the equipment involved in sending and receiving information. However, it has been assumed that equipment failure (either failure of equipment to continue operation or failure of equipment to operate on demand) is sufficiently unlikely in relative terms to not contribute significantly to this event outcome. The probability that the Guardian:protect system detection algorithm fails to identify a vessel intending to anchor is assumed to be very unlikely and is assigned a base case probability of 0.1. In acknowledgement of the fact that the probability of non-detection could be lower than assumed (i.e. that the Guardian:protect detection algorithm could be better than assumed), or that the detection algorithm could be conservatively modified to include vessel movement that otherwise might not trigger a warning, consideration was given to an alternative basic event probability of 0.01.

Vessel operator failure to receive the Guardian:protect system message (Basic Event B9) requires failure of the vessel operator to see the message that is provided to the vessel by the Guardian:protect system or failure of the equipment involved in receiving and displaying the information. However, it has again been assumed that equipment failure is sufficiently unlikely in relative terms to not contribute significantly to the event outcome. The probability that a vessel operator will not see the Guardian:protect system message is assumed to be very unlikely and is assigned a probability of 0.1. It is acknowledged that, under normal circumstances, the likelihood that messages presented to the vessel operator will not be seen is extremely low; however, events that warrant anchor deployment in the Straits are assumed to be restricted to deployments in response to vessel emergencies and it has been further assumed that the vessel operator may be sufficiently distracted by ongoing events during a vessel emergency to fail to see the Guardian:protect message even if it is displayed.

Based on the fault tree logic shown in Figure 3.3 and the assigned basic event probabilities, including the probabilities previously assigned to Basic Events B3 and B4 (see Section 2.1.2.2), the probability that deployment will not be prevented by hazard awareness (Event E2) is given by:

Event E2 = E4 + (B2 x B3) = (B4 x E5) + ((1–E4) x B3)
= (B4 x (B8 + B9 – (B8 x B9))) + ((1 – (B4 x (B8 + B9 – (B8 x B9)))) x B3)
= 0.117 for the base case assumption, Event B8 = 0.1; and
= 0.110 for the alternative assumption, Event B8 = 0.01.

The above demonstrates that the probability that deployment will not be prevented by hazard awareness (Event E2) is not very sensitive to the assumed probability that the Guardian:protect system will fail to detect a pending anchoring event and transmit a warning (Basic Event B8). It can be shown that this stems from the fact that, for the assumed level of passive awareness (Basic Event B4), the probability of Event E2 is controlled by the vessel operator's decision to deploy despite his awareness of the deployment hazards (Basic Event B3) and the potential for a vessel operator to fail to see the Guardian:protect warning message during a vessel emergency (Basic Event B9). Both of these event probabilities are deemed emergency situation dependent and neither are affected by how well the Guardian:protect system performs its intended function.

Since the fault tree logic conveyed in Figure 3.3 shows that the probability of pipeline failure due to intentional anchor deployment is directly proportional to the probability that anchor deployment will not be prevented by hazard awareness (Event E2), it follows that the effectiveness of the Guardian:protect system can be evaluated by comparing the probabilities calculated for Event E2 with and without the Guardian:protect system in place.

The probability of Event E2 without the Guardian:protect system in place is calculated to be 0.19 (see Section 2.1.2.2). The probability of Event E2 with the Guardian:protect system in place is given above and ranges from 0.117 to 0.110, depending on the assumed effectiveness of the vessel detection algorithm. The reduction in the probability of Event E2 with the introduction of the Guardian:protect system is a measure of the amount by which the probability of pipeline failure is expected to be reduced. This reduction in failure probability, expressed as a percentage of the value without the Guardian:protect system in place is

Guardian:protect effectiveness = (0.19 – 0.117) / 0.19
= 38% for base case assumption, B8 = 0.1; and

= (0.19 – 0.110) / 0.19
= 42% for alternative assumption, B8 = 0.01.

Effect of Preventative and Protective Measures

The above indicates that, for the assumed level of effectiveness of passive measures in conveying anchor hazard awareness and the assumed probability that a vessel operator will anchor despite awareness of the deployment hazards, the Guardian:protect system (Option 1 or 2) is expected to achieve about a 40% reduction in the probability of pipeline failure due to intentional anchoring.

With regard to the annual probability of pipeline failure due to intentional anchor deployment resulting from the implementation of the Guardian:protect system (either Option 1 or 2), based on the analysis approach described in Section 2.1.3 and using identical analysis assumptions, except for the value of Event E2, which is reduced from 0.19 to 0.117 for the base case Guardian:protect system performance characterization, the annual Line 5 crossing failure rate, averaged over the four soil type and pipe restraint combinations, is 7.82×10^{-7} per yr.

3.2.3 Effect of Protective Barriers Alone

The modified fault tree shown in Figure 3.3 indicates that the pipeline will fail by anchor hooking (Event E3) if the deployed anchor reaches the lakebed (Basic Event B5), the anchor size is sufficient to hook the pipeline (Basic Event B6), the protective barrier fails to protect the pipeline (Basic Event 10) and the anchor force applied to the pipe is sufficient to fail the pipeline (Basic Event B7).

Basic Events B5 and B6 are unaffected by the introduction of protective barriers and, as described in Section 2.1.2.3, both are assigned a probability of 1.0.

Basic Event B10 is the probability that the protective barrier does not prevent the dragged anchor from hooking the pipeline.

Barrier Option 1 – Encasement

- Based on discussions with IntecSea, it is the authors' understanding that, for Option 1, the design approach is that the height, width and profile of both the gravel/rock core and the outer rock armouring are established based on numerical modeling and experience such that, for the 'design anchor', the likelihood of contact between the anchor flukes and the pipeline during a drag encounter will be extremely low. It is the authors' further understanding that: 1) final barrier design is contingent on scale model tests to confirm intended barrier performance, 2) measures will be taken during barrier installation to confirm that the key dimensions are achieved (including the depth of cover above the pipeline), and 3) periodic underwater inspection will ensure that as-placed dimensions are maintained over time.

- Given the above, it is assumed that an encounter with a large anchor that penetrates the barrier to the point where the flukes contact the pipeline is very unlikely and that sufficient anchor penetration to result in pipe hooking is extremely unlikely. On that basis, Basic Event B10 is assigned a probability of 0.01. It is acknowledged that the low probability assignment adopted for Basic Event B10 is based on judgment; however, this judgment-based assignment was informed by the understanding that the design basis explicitly considers the most extreme interaction scenario, that being engineered cover interaction with the largest anchor that could be expected to be used on a vessel operating on the Great Lakes.

- For context regarding the probability assignment for this basic event, it is noted that a similar determination was arrived at in an anchor strike threat assessment carried out by Environmental Resources Management (2010) as part of a comprehensive risk assessment of, among other facilities, the subsea natural gas pipelines intended to feed the Black Point Power Station in Hong Kong. In that study, the effectiveness of the rock armour protection option was assessed to be on the order of 99% for large anchors approaching the size of the rock armour 'design anchor' and 99.9% for smaller anchors.

Barrier Option 2 – Flanking Berms

- Option 2, while providing access for direct visual inspection, does not, in the authors' opinion, provide an effective barrier against pipeline contact due to an anchor drag encounter. It is noted that the proposed barrier configuration does offer the potential to reduce the likelihood that an anchor is seated when it contacts the pipeline, but no information is available to evaluate the likelihood of hooking when the anchor crosses over the first berm and descends into the space between that and the second berm where the pipeline will be located with no protective cover or significant embedment. In the absence of information to the contrary, it is assumed that this protection option offers no significant protection against pipeline contact and hooking could very well be the result of contact, should it occur. On this basis, Basic Event B10 is assigned a probability of 1.0 for this option.

For Basic Event B7, the probability that the pipeline will fail in the event of anchor hooking can be determined using an approach very similar to that described in Section 2.1.2.3 for assessment of the unprotected pipeline. The one difference for protective barrier Option 1 is that, in the event of the engineered cover failing to prevent pipeline hooking, the limiting force and the lateral pipeline displacement at the limit load were assessed for pipeline restraint conditions equivalent to trenched construction in hard soil[25] (see Table 2.1). For Option 2, no change from the unprotected pipe analysis case was made.

Given the above, on a per vessel crossing basis, the probability that the anchor force is sufficient to fail the pipeline (Basic Event B7) is a binary outcome (i.e. 0 or 1.0), depending on the vessel size, pipeline restraint condition and assumed soil type.

Based on the fault tree logic and the assigned basic event probabilities, the probability that the pipeline will fail due to anchor hooking (Event E3) is given by:

Event E3 = B5 x B6 x B7 x B10

[25] It is acknowledged that the existing line is not trenched into the lakebed, but the gravel/rock amour surrounding the pipeline will have a similar restraining effect.

Effect of Preventative and Protective Measures

Since the probabilities of Basic Events B5 and B6 are both 1.0, and the probability of Basic Event B10 is 0.01 for protective barrier Option 1 and 1.0 for protective barrier Option 2, the probability of Event E3 is equal to the probability of Basic Event B7 multiplied by either 0.01 or 1.0, depending on the protective barrier option, which, on a per vessel crossing basis, is given by:

Event E3= 0.0 or 0.01 for protective barrier Option 1; and
= 0.0 or 1.0 for protective barrier Option 2.

with the outcome being dependent on vessel displacement, pipeline restraint condition and assumed soil type.

The remainder of the basic and intermediate events in the modified fault tree shown in Figure 3.3 have probabilities or occurrence rates identical to those described in Section 2.1, because, for the analysis, the Guardian:protect system is assumed not to be in place.

The annual probability of pipeline failure due to intentional anchor deployment, resulting from the implementation of proposed protective barrier Option 1, was obtained using the analysis approach described in Section 2.1.3, with identical analysis assumptions except for the value of Event E3, which was reduced as described above, to account for the effectiveness of the barrier option in preventing anchor contact with the pipeline and the change in pipeline restraint if anchor hooking does occur. The Line 5 crossing annual failure rate, with protective barrier Option 1 in place, is 1.01×10^{-8} per yr.

The annual probability of pipeline failure due to intentional anchor deployment, resulting from the implementation of the proposed protective barrier Option 2, is identical to that calculated for the existing line without a protective barrier because this option is deemed to be entirely ineffective in preventing anchor hooking and subsequent anchor strike. The Line 5 crossing annual failure rate, with protective barrier Option 2 in place is, therefore, 1.27×10^{-6} per yr.

3.2.4 Combined Effect of Guardian:protect System and Protective Barriers

The annual probability of pipeline failure due to intentional anchor deployment, resulting from the combined implementation of the Guardian:protect system (either Option 1 or 2) and proposed protective barrier Option 1 (full encasement), can be obtained from the calculation process used to determine the failure rate associated with implementation of the protective barrier alone by replacing the Event E2 probability with that resulting from the implementation of the Guardian:protect system. The Line 5 crossing annual failure rate for these two measures in combination is 6.22×10^{-9} per yr.

The annual probability of pipeline failure due to intentional anchor deployment, resulting from the combined implementation of the Guardian:protect system (either Option 1 or 2) and protective barrier Option 2 (flanking berms), is identical to that calculated for the implementation of the Guardian:protect system alone, because protective barrier Option 2 is deemed entirely ineffective in preventing anchor hooking and subsequent anchor strike. The Line 5 crossing annual failure rate for these two measures in combination is 7.82×10^{-7} per yr.

3.3 Failure Due to Unintentional Anchor Deployment

3.3.1 Revised Fault Tree

The fault tree developed to estimate the pipeline failure frequency due to unintentional anchor deployment for the pipeline crossing, accounting for the proposed preventative and protective measures, is shown in Figure 3.4.

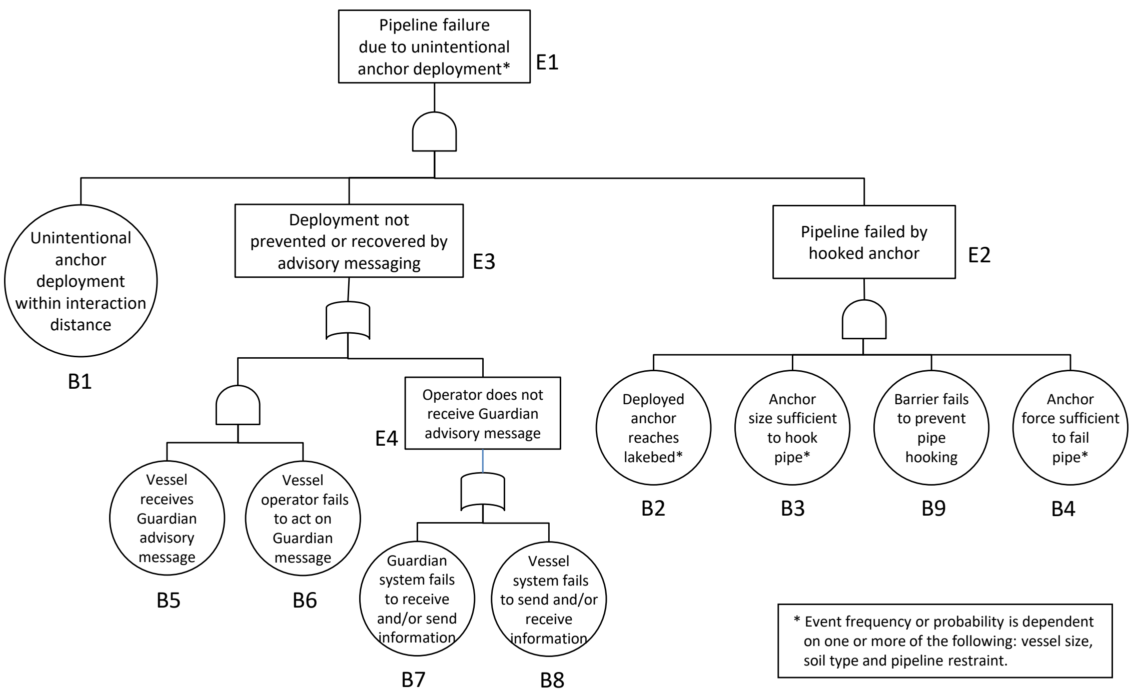


Figure 3.4 Fault Tree for Pipeline Failure Due to Unintentional Deployment – Crossing with Enhanced Preventative and/or Protective Measures

The fault tree differs from that developed for the existing crossing (Figure 2.3) by the addition of an anchor deployment prevention or deployment recovery branch (Event E3) and associated Basic Events B5 through B8, which are intended to account for the preventative effect of the Guardian:protect system (for Option 2 only), and Basic Event B9, which has been added to address the effect of a protective barrier in preventing deployed vessel anchors from coming into contact with the pipeline.

3.3.2 Effect of Guardian:protect System Alone

The modified fault tree shown in Figure 3.4 indicates that unintentional anchor deployment will not be prevented or recovered by Guardian:protect system advisory messaging (Event E3), assuming Guardian:protect implementation in accordance with Option 2, as described in Section 3.1[26], if the vessel operator does not receive a Guardian:protect advisory message (Event E4), or if the vessel operator does receive an advisory message (Basic Event B5) and fails to act (Basic Event B6)[27].

The modified fault tree further indicates that the vessel operator will not receive the Guardian:protect advisory message (Event E4) if the Guardian:protect communication system fails to receive information regarding the approach of a vessel or the system fails to transmit the intended advisory message to the vessel (Basic Event B7), or the vessel communication system fails to transmit vessel information or to receive and display the Guardian:protect advisory message (Basic Event B8).

For this study, failure of either the Guardian:protect system or the vessel system is defined as the likelihood that the system will not be operational (i.e. unavailable) at any point in time. The overall unavailability of a system can be shown to be a function of the mean time between failures (MTBF) and the mean time to repair (MTTR) for each component in the system.

The Guardian:protect system is assumed to consist of an AIS Base Station interfacing with a dedicated computer running proprietary software. The key assumptions made to evaluate overall Guardian:protect system unavailability are:

- *AIS Base Station* – The base station is an off-the-shelf system for which the design MTBF is typically 100,000 hours (e.g. SAAB 2007). A system failure will require unit replacement, and a spare unit is assumed not to be on site, which means that it will need to be sourced, delivered and installed, and, on this basis, a representative MTTR is one week (EventHelix.com 2017).

- *Computer* – The computer is a typical workstation for which a representative MTBF is 3500 hours (Quanterion Solutions 2015). A system failure will require component replacement and

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[26] Guardian:protect system implementation in accordance with Option 1 does not address unintentional anchor deployment because this configuration will only generate a warning message if vessel movement is indicative of an intention to anchor, which would not be the case for vessels traversing the Straits with an unintentionally deployed anchor.

[27] It is assumed that the action required in response to the advisory message is to check that vessel anchors are properly stowed. Implicit in the required check is that an unintentionally deployment anchor will be detected and recovered, and the potential for unintentional deployment between the time of inspection and the vessel reaching the crossing is eliminated because part of the check involves confirming that the physical mechanisms in place on the vessel to prevent accidental anchor deployment are properly configured. On this basis, this study assumes that successful action on the part of the vessel operator in response to the Guardian:protect system advisory message will eliminate the threat of unintentional deployment for that vessel crossing.

spare components are assumed not to be on site, but readily available. Assuming further that the Guardian:protect system is manned, or at least monitored, on a daily basis (including holidays and weekends), a representative MTTR of 36 hours can be assigned based on guidance provided in EventHelix.com (2017).

- *Computer Software* – The combined Guardian:protect software and computer system is assumed to be configured such that a software failure will trigger a system reboot; thus system downtime attributable to software failure is negligible (in comparison to the assumed hardware failure induced downtime).

Consistent with the above, it can be shown that the random point in time unavailability of the Guardian:protect communication system is 1.2×10^{-2}. On this basis, Guardian:protect communication system failure (Basic Event B7) is assigned a probability of 0.012.

The vessel system is assumed to consist of an off-the-shelf AIS Mobile Station for which a representative design MTBF is 40,000 hours (e.g. Kongsberg Seatex 2010). It is further assumed that a spare unit is not carried by the vessel, implying that it will need to be sourced, delivered and installed, and, on this basis, a representative MTTR is one week (EventHelix.com 2017). Consistent with the above, the random point in time unavailability of the vessel communication system is 4.2×10^{-3}. On this basis, vessel communication system failure (Basic Event B8) is assigned a probability of 0.0042.

With regard to a vessel operator failing to act on an advisory message (Basic Event B6), if failure to act constitutes an error in judgment, an estimate of the likelihood of this event can be based on human reliability considerations. Consistent with guidance on estimating failure rates and event data for use in risk assessments (HSE 2012), a human error potential of 0.1 can generally be considered a conservative estimate of the risk of human failure. To the extent that this failure probability level is perceived to be unduly conservative, it is noted that the intended advisory message will require vessel operators to carry out an inspection of a vessel component that is very unlikely to be in a problematic state (i.e. it will be exceptionally unlikely that an anchor will be found to be deployed and it will be very unlikely that the anchor securing system will be set improperly). On this basis, because response to the advisory will rarely lead to the need to take corrective action, vessel operators could become complacent over time, leading to a reduced likelihood of taking action in response to a Guardian:protect advisory message. However, this tendency towards complacency on the part of a vessel operator or the crew member tasked with performing the inspection will likely be tempered by the fact that the Straits have, as of May 2018, been declared a “no anchor zone” by the State of Michigan[28]. This new regulation should encourage diligence in ensuring that anchors are not deployed when passing through the Straits. Given the above, a probability of 0.1 for Basic Event B6 is considered appropriate.

[28] It is noted that the declaration, in the form of an emergency rule, has, at the time of this writing, been implemented on a temporary basis with an option to renew after six months.

Effect of Preventative and Protective Measures

Lastly, the probability that the vessel operator receives the Guardian:protect advisory message (Basic Event B5) can be shown to be equal to one minus the probability of Event E4. On that basis, given the structure of the fault tree shown in Figure 3.4 and the assigned basic event probabilities, the probability that unintentional anchor deployment will not be prevented or recovered by a Guardian:protect system advisory message (Event E3) is given by:

$$
\begin{aligned}
\text{Event E3} &= E4 + (B5 \times B6) = E4 + ((1 - E4) \times B6) \\
&= (B7 + B8 - (B7 \times B8)) + ((1 - (B7 + B8 - (B7 \times B8))) \times B6) \\
&= (0.012 + 0.0042 - (0.012 \times 0.0042)) + \\
&\qquad ((1 - (0.012 + 0.0042 - (0.012 \times 0.0042))) \times 0.1) \\
&= 0.115.
\end{aligned}
$$

Since the fault tree logic conveyed in Figure 3.4 shows that the probability of pipeline failure due to unintentional anchor deployment is directly proportional to the probability that anchor deployment will not be prevented or recovered by advisory messaging (Event E3), it follows that the effectiveness of the Guardian:protect system (for Option 2 only) can be evaluated by comparing the probabilities calculated for Event E3 with and without the Guardian:protect system in place.

The probability of Event E3 without the Guardian:protect system in place is 1.0 and the probability of Event E2 with the Guardian:protect system (Option 2) in place is estimated to be 0.115. The reduction in the probability of Event E2 with the introduction of the Guardian:protect system is a measure of the amount by which the probability of pipeline failure is expected to be reduced. This reduction in failure probability, expressed as a percentage of the value without the Guardian:protect system in place, is

$$\text{Guardian:protect effectiveness} = (1.0 - 0.115) / 1.0 = 0.885 = 89\%.$$

With regard to the annual probability of pipeline failure due to unintentional anchor deployment, based on the fault tree logic shown in Figure 3.4, the rate of occurrence of the top event (Event E1) is given by:

$$\text{Event E1} = B1 \times E3 \times E2$$

Based on the analysis approach described in Section 2.2.3 and using identical analysis assumptions for Basic Event B1 and Event E2, with the introduction of Event E3, the annual Line 5 crossing failure rate, averaged over the four soil type and pipe restraint combinations, for the C-FER deployment detection assumption is 8.45×10^{-5} per yr with the Guardian:protect system (Option 2 only) in place.

3.3.3 Effect of Protective Barriers Alone

The modified fault tree shown in Figure 3.4 indicates that the pipeline will fail by anchor hooking (Event E2) if the deployed anchor reaches the lakebed (Basic Event B2), the anchor size is sufficient to hook the pipeline (Basic Event B3), the protective barrier fails to protect the pipeline (Basic Event B5) and the anchor force applied to the pipe is sufficient to fail the pipeline (Basic Event B4).

Basic Events B2 and B3 are unaffected by the introduction of protective barriers and, as described in Section 2.1.2.3, both are assigned a probability of 1.0.

Basic Event B9 is the probability that the protective barrier does not prevent the dragged anchor from hooking the pipeline. For protective barrier Option 1 involving full pipeline encasement, it is assumed that, in the event of a drag encounter with an unintentionally deployed anchor, anchor penetration into the barrier far enough to result in pipe hooking is extremely unlikely, as was assumed for intentionally deployed anchors. On this basis, Basic Event B9 is assigned a probability of 0.01 (see Section 3.2.3 for further discussion).

For protective barrier Option 2 involving two flanking berms, it is assumed that, in the event of a drag encounter with an unintentionally deployed anchor, this protection option offers no significant protection against pipeline contact and hooking could very well be the result of contact should it occur, as was assumed for intentionally deployed anchors. On this basis, Basic Event B9 is assigned a probability of 1.0 (see Section 3.2.3 for further discussion).

For Basic Event B4, the probability that the pipeline will fail in the event of anchor hooking can be determined using an approach very similar to that described in Section 2.2.2.2 for assessment of the unprotected pipeline. The one difference for protective barrier Option 1 is that, in the event of engineered cover failure leading to pipeline hooking, the limiting force and the lateral pipeline displacement at the limit load were assessed for pipeline restraint conditions equivalent to trenched construction in hard soil[29] (see Table 2.1). For Option 2, no change from the unprotected pipe analysis case was made.

Given the above, on a per vessel crossing basis, the probability that the anchor force is sufficient to fail the pipeline (Basic Event B4) is a binary outcome (i.e. 0 or 1.0), depending on the vessel size, pipeline restraint condition and assumed soil type.

Based on the fault tree logic and the assigned basic event probabilities, the probability that the pipeline will fail due to anchor hooking (Event E2) is given by:

$$\text{Event E2} = B2 \times B3 \times B4 \times B5$$

[29] It is acknowledged that the existing line is not trenched into the lakebed, but the gravel/rock amour surrounding the pipeline will have a similar restraining effect.

Effect of Preventative and Protective Measures

Since the probabilities of Basic Events B2 and B3 are both 1.0, and the probability of Basic Event B5 is 0.01 for protective barrier Option 1 and 1.0 for protective barrier Option 2, the probability of Event E2 is equal to the probability of Basic Event B4 multiplied by either 0.01 or 1.0, depending on the protective barrier option, which, on a per vessel crossing basis, is given by:

Event E2 = 0.0 or 0.01 for protective barrier Option 1; and
= 0.0 or 1.0 for protective barrier Option 2.

with the outcome being dependent on vessel displacement, pipeline restraint condition and assumed soil type.

With regard to the annual probability of pipeline failure due to unintentional anchor deployment, based on the fault tree logic shown in Figure 3.4, the rate of occurrence of the top event (Event E1), is given by:

Event E1 = B1 x E3 x E2

The remaining basic event in the modified fault tree shown in Figure 3.4 (i.e. Event B1) has an occurrence rate identical to that described in Section 2.2.2.1 and Event E3 is set to 1.0 because the Guardian:protect system benefit is not being considered here.

The probability of pipeline failure due to unintentional anchor deployment, resulting from the implementation of proposed protective barrier Option 1 (full encasement), was obtained using the analysis approach described in Section 2.2.3, with identical analysis assumptions except for the value of Event E3, which was reduced, as described above, to account for the effectiveness of the barrier option in preventing anchor contact with the pipeline and the change in pipeline restraint if anchor hooking occurs.

The annual Line 5 crossing failure rate associated with unintentional anchor deployment with protective barrier Option 1 in place is 7.83×10^{-6} per yr.

The annual Line 5 crossing failure rate associated with unintentional anchor deployment with protective barrier Option 2 in place is 7.35×10^{-4} per yr.

3.3.4 Combined Effect of Guardian:protect System and Protective Barriers

The annual probability of pipeline failure due to unintentional anchor deployment, resulting from the combined implementation of the Guardian:protect system (Option 1) and protective barrier Option 1 (full encasement), is identical to that calculated for the implementation of the protective barrier alone, because Guardian:protect Option 1 is not effective in preventing unintentional anchor deployment. The Line 5 crossing annual failure rate for these two measures in combination is 7.83×10^{-6} per yr.

Effect of Preventative and Protective Measures

The annual probability of pipeline failure due to unintentional anchor deployment, resulting from the combined implementation of the Guardian:protect system (Option 1) and protective barrier Option 2 (flanking berms), is identical to that calculated for the existing crossing, because neither measure is effective in mitigating the unintentional anchor strike threat. The Line 5 crossing annual failure rate for these two measures in combination is 7.35×10^{-4} per yr.

The annual probability of pipeline failure due to unintentional anchor deployment, resulting from the combined implementation of the alternate Guardian:protect system (Option 2) and the protective barrier Option 1 (full encasement), can be obtained from the calculation process used to determine the failure rate associated with implementation of the protective barrier alone by replacing the Event E3 probability with that resulting from the implementation of the Guardian:protect system. The Line 5 crossing annual failure rate for these two measures in combination is 9.01×10^{-7} per yr.

The annual probability of pipeline failure due to unintentional anchor deployment, resulting from the combined implementation of the Guardian:protect system (Option 2) and protective barrier Option 2 (flanking berms), is identical to that calculated for the implementation of the Guardian:protect system alone, because protective barrier Option 2 is deemed entirely ineffective in preventing anchor hooking and subsequent anchor strike. The Line 5 crossing annual failure rate for these two measures in combination is 8.45×10^{-5} per yr.

3.4 Combined Failure Frequencies for Scenarios Involving Preventative and Protective Measures

The Line 5 crossing failure rates, attributable to both intentional and unintentional anchor deployment, with and without relevant combinations of the candidate damage prevention and protection measures, as obtained by combining the failure rates developed in Sections 3.2 and 3.3, are summarized in Table 3.1.

Effect of Preventative and Protective Measures

Analysis Case	**Failure Rate due to Intentional Anchor Deployment** (per year)	**Rate Reduction** (% of existing)	**Failure Rate due to Unintentional Anchor Deployment** (per year)	**Rate Reduction** (% of existing)	**Failure Rate due to Combined Anchor Deployments** (per year)	**Rate Reduction** (% of existing)
Existing Line	1.27×10^{-6}		7.35×10^{-4}		7.36×10^{-4}	
Guardian: protect Option 1 Only	7.82×10^{-7}	38.4	7.35×10^{-4}	0	7.36×10^{-4}	0.1
Guardian: protect Option 2 Only	7.82×10^{-7}	38.4	8.45×10^{-5}	88.5	8.53×10^{-5}	88.4
Barrier Option 1 Only	1.01×10^{-8}	99.2	7.83×10^{-6}	98.9	7.84×10^{-6}	98.9
Barrier Option 2 Only	1.27×10^{-6}	0	7.35×10^{-4}	0	7.36×10^{-4}	0
Guardian: protect Option 1 and Barrier Option 1	6.22×10^{-9}	99.5	7.83×10^{-6}	98.9	7.84×10^{-6}	98.9
Guardian: protect Option 1 and Barrier Option 2	7.82×10^{-7}	38.4	7.35×10^{-4}	0	7.36×10^{-4}	0.1
Guardian: protect Option 2 and Barrier Option 1	6.22×10^{-9}	99.5	9.01×10^{-7}	99.9	9.07×10^{-7}	99.9
Guardian: protect Option 2 and Barrier Option 2	7.82×10^{-7}	38.4	8.45×10^{-5}	88.5	8.53×10^{-5}	88.4

Table 3.1 Effect of Preventative and Protective Measures on Line 5 Crossing Failure Rate

4. SUMMARY OF RESULTS AND KEY FINDINGS

For the existing crossing and scenarios involving preventative and protective measures, the anchor strike failure rate is shown to be dominated by the contribution from unintentional anchor deployment. The contribution from unintentional anchor deployment dominates because anchor drag distances are typically much longer for unintentional deployments from vessels underway than for intentional deployments from vessels intending to anchor. Longer anchor drag distances imply that anchors deployed from vessels approaching the pipeline crossing from further away will have the potential to reach the pipelines, thereby increasing the likelihood of an anchor encounter with the pipelines on a per vessel crossing basis.

For the existing crossing, the annual failure rate is estimated to be approximately 7×10^{-4} per yr. This failure rate estimate is two to three times higher than the values bounding the failure rate range provided in the Alternatives Analysis Report prepared by Dynamic Risk for the State of Michigan (2017). The higher failure rate estimate arrived at in this study for the existing crossing is largely attributable to a difference in the assumption made regarding the time required to detect an unintentionally deployed anchor. The longer detection time assumed in this study is considered a more prudent choice given the uncertainty associated with the detection time.

Implementation of the Guardian:protect vessel tracking and communication system, if focused on identifying and issuing an anchor deployment warning message only to vessels demonstrating movement indicative of an intent to anchor (i.e. Guardian:protect Option 1), is expected to result in a 38% reduction in the intentional anchoring failure rate. However, this implementation will have no effect on the failure rate due to unintentional anchoring because vessels unintentionally dragging an anchor will not exhibit movement that triggers a Guardian:protect advisory. Because the combined-case failure rate is dominated by the threat posed by unintentional anchor deployment, the overall effect on the crossing failure rate of this Guardian:protect system implementation is negligible.

If the Guardian:protect system implementation is expanded beyond the Option 1 messaging to also include sending an advisory message to all vessels (or selectively to all significant vessels) approaching the Straits (i.e. Guardian:protect Option 2), where the message includes notification of a pipeline crossing ahead and the need for vessel operators to confirm that their anchors are properly stowed, the expected result is a 38% reduction in the intentional anchoring failure rate, and an 89% reduction in the unintentional anchoring failure rate. For this implementation, the combined-cause crossing failure rate is expected to fall to about 9×10^{-5} per yr.

The proposed gravel/rock barrier option involving full pipeline encasement (Barrier Option 1), is expected to result in a 99% reduction in the combined-cause failure rate to approximately 8×10^{-6} per yr. Central to this determination is the assumption that the barrier design, construction and maintenance program will be aimed at assuring that the largest anchor likely to be carried by a vessel operating in the Great Lakes will have an extremely low likelihood of penetrating the barrier to the point where contact between the anchor and the pipeline results in hooking.

Summary of Results and Key Findings

The proposed alternative gravel/rock barrier option involving the placement of four berms, one flanking each side of each pipeline (Barrier Option 2), is not expected to result in a meaningful reduction in the combined-cause failure rate. The lack of protective cover over the pipeline and the overall berm geometry (intended to facilitate direct visual examination of the pipeline) support the finding that the potential for pipeline hooking in the event of an anchor drag encounter is not demonstrably different from that of the existing on-bottom pipelines.

If the candidate anchor-induced failure prevention measures (either Guardian:protect Option 1 or 2) are combined with the one effective protection option (i.e. Barrier Option 1), the resulting combined-cause failure rates are estimated to be:

- 8×10^{-6} per yr for Guardian:protect Option 1 together with Barrier Option 1 (amounting to a 99% reduction in the expected annual crossing failure rate); and
- 9×10^{-7} per yr for Guardian:protect Option 2 together with Barrier Option 1 (amounting to a 99.9% reduction in the expected annual crossing failure rate).

The crossing failure rate reductions attributable to the implementation of candidate damage prevention and protection measures have been determined using deductive analysis methods (i.e. fault trees), wherein some basic event probabilities have been established based on informed judgment. The selective use of judgment-based probability assignments was necessitated by the fact that the type of system performance or human performance data required to characterize these probabilities using statistical analysis, or other more objective methods, could not be found. With specific reference to the evaluation of protective barrier options, to the extent that planning decisions to be made are dependent on the assumed magnitude of barrier effectiveness, it is recommended that the probability assignment developed herein to characterize the effectiveness of full encasement should be revisited to more fully and formally evaluate the uncertainties inherent in the design, construction and expected performance of this option.

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Appendix 6: Glossary

Abbreviations and acronyms

AIS (environmental)	aquatic invasive species
AIS (technology)	Automatic Identification System
ATON	aids to navigation
BMP	best management practice
CFR	U.S. Code of Federal Regulations
CP	cathodic protection
DWT	deadweight tonnage
FCC	Federal Communications Commission
FLIR	forward-looking infrared
FRP	fiber-reinforced plastic
HDPE	high-density polyethylene
ILI	in-line inspection
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
MPSC	Michigan Public Service Commission
NOAA	National Oceanic and Atmospheric Administration
NREPA	Natural Resources and Environmental Protection Act
NSA	noise sensitive areas
PATON	private aids to navigation
PIPP	Pollution Incident Prevention Plan
POF	probability of a failure
ROV	remotely operated vehicle
SHPO	State Historic Preservation Office
SPCC	spill prevention control and countermeasure
STA	special temporary authority
TCP	traditional cultural property
THPO	Tribal Historic Preservation Office
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service

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