Appendix C

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THE WORST-CASE SCENARIO FOR A RUPTURE OF ENBRIDGE LINE 5 AT THE STRAITS OF MACKINAC

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Scope

The report that follows develops what the author believes to be the Worst-Case Scenario (WCS) for a rupture of Enbridge Line 5 at the Straits of Mackinac. It is not intended that the WCS defined here applies to any other portion of Line 5, either upstream or downstream from the Straits. Development of the WCS for segments outside the Straits is a separate topic.

Table 1 – A Summary of the Several Possible Spill Scenarios

Scenario	Brief Description		Volume of Spill (barrels)	Worst-Case Scenario (Yes/No)
Enbridge	**Source of Spill Scenario size - unknown**		**4,500**	**No**
1	**Spill confined to oil in Line at the Straits**		**20,351**	**No**
2	**Spill includes 2 hours to manually shut valves**		**65,025**	**No**
3	**Spill greatly increase due to NGLs in the line**		**136,478**	**Yes**
4	**Spill results from a Small Undetected Leak**[1]		**16,750**	**No – but must be considered**

Background

In a closely related document, Rick Kane, a colleague of the author, explains the difference between a true Worst-Case Scenario (WCS) and an Alternative Release Scenario[2]. For a more complete discussion of these important two, but very different Scenarios, the reader is referred to work done by Rick Kane. The following text, ending on page 4 and in italics, is extracted from the paper by Rick Kane, with his permission.

"In general, a WCS is a concept in risk management wherein the planner, in planning for potential disasters considers the most severe possible outcome that can reasonably be projected to occur in a given situation. For hazardous materials operations and transportation the definition is more refined.

[1] It is assumed the undetected spill would go on for 5 days. It could be shorter, or much longer.
[2] Private Communication from Rick Kane, Flow for Water, July 2017

Worst-Case Scenario WCS – also called a "credible worst-case scenario" is the potential release volume based on system capacity with consideration of mechanical, control system, operational and human factors failures. Credits for mitigation of a potential release volume are only allowed for **passive controls** that are permanently in place.

> **Passive controls** are equipment, devices, or technologies that function without human, mechanical, or other energy input. Passive mitigation systems include dikes, containment walls and natural barriers such as valleys and berms.
>
> **Active controls** are measures such as remote shutdown valves, computer control and material balancing systems, alarms, operating procedures and training. Active controls require mechanical, energy or human input to function.

The scope of the "system" must also be correctly and consistently defined as changing simple assumptions can drastically change release quantities. A recognized definition is provided by the Occupational Health & Safety Administration (OSHA) Process Safety Management (PSM) Program and used by other regulatory agencies...

> **Process and Interconnected System -** Any activity involving a regulated substance, including any use, storage, manufacturing, handling, or on-site movement of such substances, or combination of these activities. For the purposes of this definition, any group of vessels that are interconnected, or separate vessels that are located such that a regulated substance could be involved in a potential release, shall be considered a single process."

Thus, to calculate a WCS – the system would be defined as connected tanks and pipes, connected storage tanks and credit given for the presence of passive control measures – in the case of crude oil pipelines and facilities, passive control measures are typically permanent secondary containment structures.

Common cause failures and cascading events are also important considerations in identifying the WCS. A "common cause" failure example would be a severe weather event causes power failures affecting equipment and delays response by operating personnel.

Alternative Scenarios are also calculated in addition to the WCS based on assumptions required in regulations or defined by the owner/operator. For example, company management or insurers may define an alternative or "most probably accident scenario" or an "emergency response-planning scenario" required for regulatory or insurance purposes. Such planning scenarios typically have much lower release and consequence levels than the WCS.

The Enbridge / PHMSA Scenario

The key point that must be understood is that the WCS ……..as defined by Enbridge and PHMSA **is not a worst-case scenario as would be defined by other regulatory agencies or risk management professionals in related industries, such as the chemical industry.**

It is a scenario that defines the largest event or spill the submitted emergency response plan is theoretically designed to manage. It is not necessarily the Worst-Case Scenario.

In other words, in other regulatory regimes, the Enbridge / PHMSA scenario would be labeled an "alternative release scenario" and used as a guideline for emergency response planning.

Assumptions & Basis for the Enbridge Scenario

At a conference sponsored by the Tip of the Mitt Watershed Center in Petoskey Michigan on August 27, 2015 an Enbridge representative presented basic information on the scenario listed below from notes taken by the author {Rick Kane} who attended the conference.

1. Size of the crude oil release 4,500 barrels
2. Failure is a guillotine cut to one of the 20-inch pipelines
3. Supervisory control and data acquisition (SCADA) control and material balancing systems alert control center personnel
4. Personnel act within the 10-minute decision time
5. Operator uses remote control to close block valves
6. The valves close in 3 minutes, slow to prevent hydraulic hammer
7. Total operating flow time from discovery to shutdown is 13 minutes
8. Amount of crude oil drain-down after shutdown per owner/operator judgment – by calculation method, the pipeline was divided into segments that would or would not leak based on the specific gravity of the crude oil being less than water and that the water pressure at depth in the Straits would prevent the crude oil from leaking from the ruptured pipeline.

   {See The Fallacy of Hydraulic Pressure Curtailing a Pipeline Leak

   for a more compete discussion of this issue.}
9. Then, emergency response crews would insert a tube from shore and pump the crude oil out of the underwater pipeline in the segments where it is held back by water pressure.

Shutdown time in a Worst-Case Scenario

Consider the following written exchange[3] between the State and Enbridge that took place in February 2015 ----

SOM: Assuming a leak takes place in the Straits pipelines, and any automatic or remote shut-off systems fail, approximately how long would it take Enbridge workers or contractors to manually close the pipeline on both ends of the Straits?

Enbridge Response: "…In addition, our practice is to dispatch staff to {the} site to control any manual valves in the area, which would include closing the valves at the Straits. Such actions would take **15 minutes to 2 hours** depending on the time of the day and the location of existing personnel" (emphasis added).

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[3] See Exhibit 1, Correspondence from Enbridge (Brad Shamla) to Attorney General Bill Schuette and DEQ Director Dan Wyant, February 27, 2015. Item 14.

Enbridge Reduces Spill Size by over 50%
It is interesting to note that Enbridge, over the course of roughly 15 months, reduced their estimate of a Spill Size at the Straits by nearly 50%, from 8,583 barrels to 4,500 barrels. See **Table 2.**

One can only speculate as to the rationale that was used to reach 4,500 barrels. Here is a possibility of their reasoning: The distance across the Straits per Enbridge[4] is roughly 4.5 miles. The volume in this 4.5-mile segment of the two 20 inch pipelines is 7,793 barrels. This number is reasonably close to the spill volume reported by Enbridge on June 27, 2014, of 8,583 barrels.

Exactly how Enbridge arrived at 8,583 barrels is known only to them.

Having arrived at a spill volume of nearly 8,600 barrels for both lines, the next step may have been to simply assume that only one line ruptures, and "round off" the resulting spill scenario to 4,500 barrels, as reported on September 24, 2015.

This amount – 4,500 barrels – remains as the estimated spill size by Enbridge.

It is important to recognize that 4,500 barrels is merely an Estimated Spill Size – it is not a worst-case scenario.

[4] ***https://www.enbridge.com/projects-and-infrastructure/public-awareness/line-5-michigan/about-line-5***

Table 2 -- A Brief History of the "Spill Size" as Defined by Enbridge

Enbridge Downplaying the Potential Spill Size of a Catastrophic "Line 5" Straits Rupture			
Date	**Estimated Size of a Spill at the Straits of Mackinac (by Enbridge)**		**Source**
	Barrels	**Gallons**	
June 27, 2014	8,583	360,000	Enbridge
June 27, 2014	5,793	243,000	Enbridge
Feb 27, 2015	4,950	208,000	Enbridge
Sep 24, 2015	**4,500**	**189,000**	**Enbridge**

Dynamic Risk States their Spill Scenarios are not Worst-Case Scenarios
In the recent draft of the Dynamic Risk report for the State[5], section 1.6.4 entitled Role of Risk Analysis, states:

"The risk analyses conducted within this study are regarded as objective assessments of credible threats to existing or new infrastructure. They are not intended to represent a worst-case spill. They are intended to provide a consistent means for looking into and comparing risks of different operation." (Emphasis added).

Later in the same report, Dynamic Risk[6], at section 2.4.2.2.1.1 entitled Study Limitations, states:
"The objective of the study has been to establish realistic consequences of possible oil spill scenarios, and does not represent the worst-case scenarios." (Emphasis added).

Clearly, Dynamic Risk did not include Worst-Case Scenario evaluations in their work product.

How Does EPA Define Worst-Case?
EPA has stated the following regarding Modeling for Toxic Substances[7]:

> EPA has defined (§68.3) a worst-case release as the release of the largest quantity of a regulated substance from a vessel or process line (pipe) failure that results in the greatest distance to a specified endpoint. For substances in vessels, you must assume release of the largest amount in a single vessel; for substances in pipes, you must assume release of the largest amount in a pipe. The largest quantity should be determined taking into account administrative controls. Administrative controls are written procedures that limit the quantity of a substance that can be stored or processed in a vessel or pipe at

[5] Dynamic Risk, Alternatives Analysis for the Straits Pipeline, Draft Final Report, Revision 1, June 27, 2017, Calgary, Alberta, Section 1.6.4.
[6] Dynamic Risk, Alternatives Analysis for the Straits Pipeline, Draft Final Report, Revision 1, June 27, 2017, Calgary, Alberta, Section 2.4.2.2.1.1.
[7] ***https://www.epa.gov/sites/production/files/2013-11/documents/chap-04-final.pdf***

any one time, or, alternatively, occasionally allow a vessel or pipe to store larger than usual quantities (e.g., during turnaround). You do not need to consider the possible causes of the worst-case release or the probability that such a release might occur; the release is simply assumed to take place.

The Fallacy of Hydraulic Pressure Curtailing a Pipeline Leak

On several occasions Enbridge has claimed that hydrostatic pressure, from the water column outside of a rupture will prevent crude oil from leaving the pipeline. An examination of this claim shows that it is based on many untested assumptions.

We have found no data in the literature that supports the assumption that water pressure will have a significant deterrent impact on the rate of leakage from a rupture. While conceptually, a leak from a tiny hole may be "slowed down" due to external water pressure, it is inconceivable that a rupture of the pipeline as what occurred in Line 6B at Marshall in 2010, or a "Full Rupture" as acknowledged by Dynamic Risk[8] would be impeded by the external water pressure.

Making the hypothesis even more tenuous, factors such as the location of the leak on the circumference of the pipeline, and the depth at which the rupture occurs come into the discussion. In the past Enbridge has assumed the depth to be roughly 250 feet[9]. This is the maximum depth of the pipelines at the Straits. Obviously, there is no way that assumption can be universally valid, even it was true that external water pressure would play a significant role in curtailing a massive leak – which we have no evidence that it will.

For example, if the leak were to occur on the top of the pipeline, or on the side, gravity would take over and the lighter oil phase would more readily escape. And, the leak/rupture could occur at a depth of 50 feet rather than 250 feet. At 50 feet, the external water pressure is 21.7 psi; at 250 feet it is 108.7 psi.

If the disaster is the result of a complete severance of the pipeline (as may occur with an anchor drag from a lake freighter), it is inconceivable that external water pressure would play any role in curtailing the leak.

In short, the hypothesis is untested, and relies on several assumptions that are not realistic and/or unproven.

What is a Credible Worst-Case Scenario?

Based on the preceding discussion, we have looked at several components that contribute to a Worst-Case Scenario.

Two very different possibilities have emerged:

1. A "Full Bore" rupture referred to by Dynamic Risk.
2. A "Small Leak" that can go on for several hours or even days before being detected.

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[8] Dynamic Risk, Alternatives Analysis for the Straits Pipeline, Draft Final Report, Revision 1, June 27, 2017, Calgary, Alberta, Table 2-11.

[9] Dynamic Risk, Alternatives Analysis for the Straits Pipeline, Draft Final Report, Revision 1, June 27, 2017, Calgary, Alberta, page 2-92.

Each of the above poses a severe environmental risk to the Straits. Since the circumstances leading to the rupture are quite different, each will be dealt with separately.

The Full-Bore rupture --

The basis for this Worst-Case Scenario is:

1. The total volume of crude in Line 5 between St. Ignace and Mackinaw City.
2. The amount of crude that will be discharged to this line segment in the time it takes to manually shut block valves at St. Ignace. Brad Shamla of Enbridge has stated that it may take up to 2 hours to close the valves manually. See Appendix 1.
3. The amount of crude that would be discharged if –
    a. The block valve at St. Ignace cannot be manually shut and it is necessary to isolate the discharge by manually shutting the block valve(s) at Naubinway.
    b. And, since Line 5 is used 20% of the time for NGLs, a portion of the line downstream from Naubinway contains NGLs.

Item 3.b. is particularly interesting. If there are NGLs in some portion of the pipeline between Naubinway and St. Ignace, and a rupture occurs, the line pressure will rapidly drop. When this happens, the NGLs will vaporize, acting as a "driving force" to purge the pipeline of its contents, both crude oil and NGLs. The driving force that is created would cause crude oil (and NGLs) to spill from the rupture at a far greater rate than if the rate of the spill were only a function of gravity[10].

The Full-Bore release involves a massive rupture, like what happened on Enbridge Line 6B (now renamed[11] to Line 78) at Marshall, MI, in 2010. Dynamic Risk defined a "massive rupture" (the author's term) as a "full-bore opening".

The "Small Undetected Leak" ---- The amount of leakage that could go undetected due to inherent Material Balance Error

From correspondence (in italics) between the State of Michigan (SOM) and Enbridge[12]:

State of Michigan (SOM):

For each method, procedure or device used by Enbridge to detect potential leaks or releases, please identify and document its sensitivity or limits, i.e., the smallest quantity or rate of loss that it can detect. Given the limits of Enbridge's leak detection methods, what quantity of oil or other substances could be released from the pipelines without detection each day if the pipelines were operating at (a) full capacity, and (b) the average rate of operation over the last year?

Response by Brad Shamla of Enbridge:

Enbridge employs overlapping leak detection methods to identify leaks and alert the controller. Our CPM system and our line balance calculations are the two methods with defined sensitivity limits.

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[10] To picture this scenario, think of what happens when a bottle of Champagne is opened. Even when carefully opened, the dissolved gas (carbon dioxide) rapidly expands, and causes the bottle to overflow. This rapid expansion of the dissolved gas is analogous to what happens to NGLs in a pipeline when the pressure is suddenly reduced.

[11] https://www.epa.gov/sites/production/files/2017-06/documents/public_copy_lakehead_system_map.pdf

[12] Correspondence from Enbridge (Brad Shamla) to Attorney General Bill Schuette and DEQ Director Dan Wyant, June 27,2014, entitled: Enbridge Lakehead Systems Line 5 Pipelines at the Straits of Mackinac, p. 16. http://www.michigan.gov/documents/deq/Appendix_B.2_493988_7.pdf

Leaks that fall below the thresholds for these two systems will rely on other methods of detection, including: surveillance, inline and facility inspections, aerial patrols, and third party/employee reports.

The quantity of oil that could be released without being detected by the CPM system of the line balance calculations is approximately 400m^3/day (~3350 bbls/day). This unlikely scenario assumes that the other overlapping leak detection do not alert the operator of the release. {For a Worst-Case Scenario, we cannot assume other “overlapping” methods alert the operator, especially when we don’t know what they are.}

Using an undetected leak of 3,350 barrels per day, it then becomes a matter of how many hours could elapse before the leak is detected, most likely visually from a boat, plane or observers on shore. Considering severe weather, possible ice in the Straits, nighttime conditions, and high winds leading to dispersion and large waves, it seems conceivable that the leak could go on for several hours, maybe a few days, or longer.

A Summary of Possible “Worst-Case Scenarios”

Based on the above discussion, three different Release Scenarios have been developed for a massive rupture in one or both pipelines at the Straits. In addition, one other scenario was developed to cover the case of a small, undetected leak, one that could go on for several hours or even days.

Scenario 1: One or both pipelines suffer a “Full Bore” or “guillotine” release. For Example, both lines are ruptured by an anchor drag.

In this scenario, Enbridge claims it would take 10 minutes to ascertain the problem and an additional 3 minutes to close the valves at St. Ignace and Mackinaw City.

During this time, the volume of oil trapped in the two lines is 15,587 barrels. In addition, the 13 minutes of time needed to close the valves results in another 4,944 barrels that would be released. When added together the amount of the release could be **20,531 barrels** or **862,288 gallons.**

- ➔ **This is NOT the Worst-Case Scenario.**

Scenario 2: Same as Scenario 1, except the automatic block valves at St. Ignace and/or Mackinaw City do not close and must be shut manually. Enbridge claims this may take as long as 2 hours. See Appendix 1.

In this scenario[13], the volume of crude trapped in the line (15,587 barrels), the 10 minutes to ascertain the problem (3,803 barrels) and the 2 hours to manually shut the valves (45,635 barrels) adds up to **65,025 barrels** or **2,731, 038 gallons.**

- ➔ **This is NOT the Worst-Case Scenario.**

Scenario 3: In this scenario, it becomes impossible to close the block valve(s) at St. Ignace, and automated closure of a block valve at Naubinway does not work. The only way to stop the flow is to

[13] This calculation ignores the 3-minute block closure time as the valve(s) did not close.

manually close the block valve at Naubinway. Compounding the problem is that Line 5 is being shifted from transporting crude oil to transporting NGLs[14]. We now have a true Worst-Case. Will it ever happen? Maybe not. Could it happen? Yes. And that is why it is the Worst-Case Scenario.

Why is this scenario so significant? If a rupture occurs, the line pressure rapidly decreases. This causes the NGLs that are in a portion of the line to begin vaporizing. Since NGL vapor occupies far more space than NGL liquid, the rapidly expanding vapor acts as a driving force to expel the contents of the line – both vapor and liquid - through the rupture. The resulting release is far more rapid than if liquid crude oil were released only by gravity.

Assume at the time of the incident there are 20% NGLs by volume in Line 5 (80% crude). The line pressure, due to a massive rupture, suddenly drops from 600 psig to 100 psig[15]. When this happens, the entrapped NGLs will expand to 753% of their liquid volume.

This sudden vapor expansion will provide the "driving force" to rapidly evacuate the pipeline, of any both crude and NGLs that are in it.

The volume of the pipeline from Naubinway to St. Ignace is 151,114 barrels. If 80% of the volume in the pipeline is crude, then 120,891 barrels of crude would be expelled from this portion of the line to the waters of the Straits. Add to this the volume of liquid in the pipeline at the time of failure between St. Ignace and Mackinac City – 15,587 barrels. The crude oil spill amount therefore is 120,891 + 15,587 = **136,478 barrels or 5,732,000 gallons.**

➔ **This IS the Worst-Case Scenario.**

Scenario 4: Another Possible Worst-Case Scenario --- the Small Undetected Leak

The Small Undetected Leak Scenario is far less dramatic than a scenario involving a major rupture of the pipeline, perhaps a "full bore" rupture. However, the Small Undetected Leak may be more insidious. Per Enbridge, the spill volume for this scenario could be as great as 3,350 barrels per day per line.

Since it is small, and since it is less than the Enbridge lower limit of detection, it can go on for several hours, perhaps even days before detection.

As a starting point, let us assume the undetected leak goes on for 3 days before it is discovered, and is confined to one of the two 20-inch pipelines. This results in a spill of 10,050 barrels. In 5 days, the spill becomes 16,750 barrels. Obviously, this spill scenario is far less than Scenario 3. But since it has gone on for perhaps several days before being detected, it could also be difficult to clean up.

➔ **While not likely to be the Worst Case, this Scenario is unique and must be considered.**

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[14] Enbridge has stated on several occasions that 20% of the volume of material transported in Line 5 is NGL.

[15] The reduced line pressure of 100 psig is an assumption. It is likely on the high side. The actual line pressure could be much less.

Conclusion (Including a Comparison to the Enbridge Spill Scenario)

The spill scenario used by Enbridge is 4,500 barrels. However, Dynamic Risk has stated this is NOT the Worst-Case Scenario, even though they did not define a Worst-Case Scenario. At this time neither Enbridge nor Dynamic Risk have defined a true Worst-Case Scenario.

Based on practices recommended by EPA, and used by major U.S. chemical companies for the development of a Worst-Case Scenario, the Worst-Case Scenario is far greater than 4,500 barrels. It is 136,578 barrels. This is the spill volume that should be used.