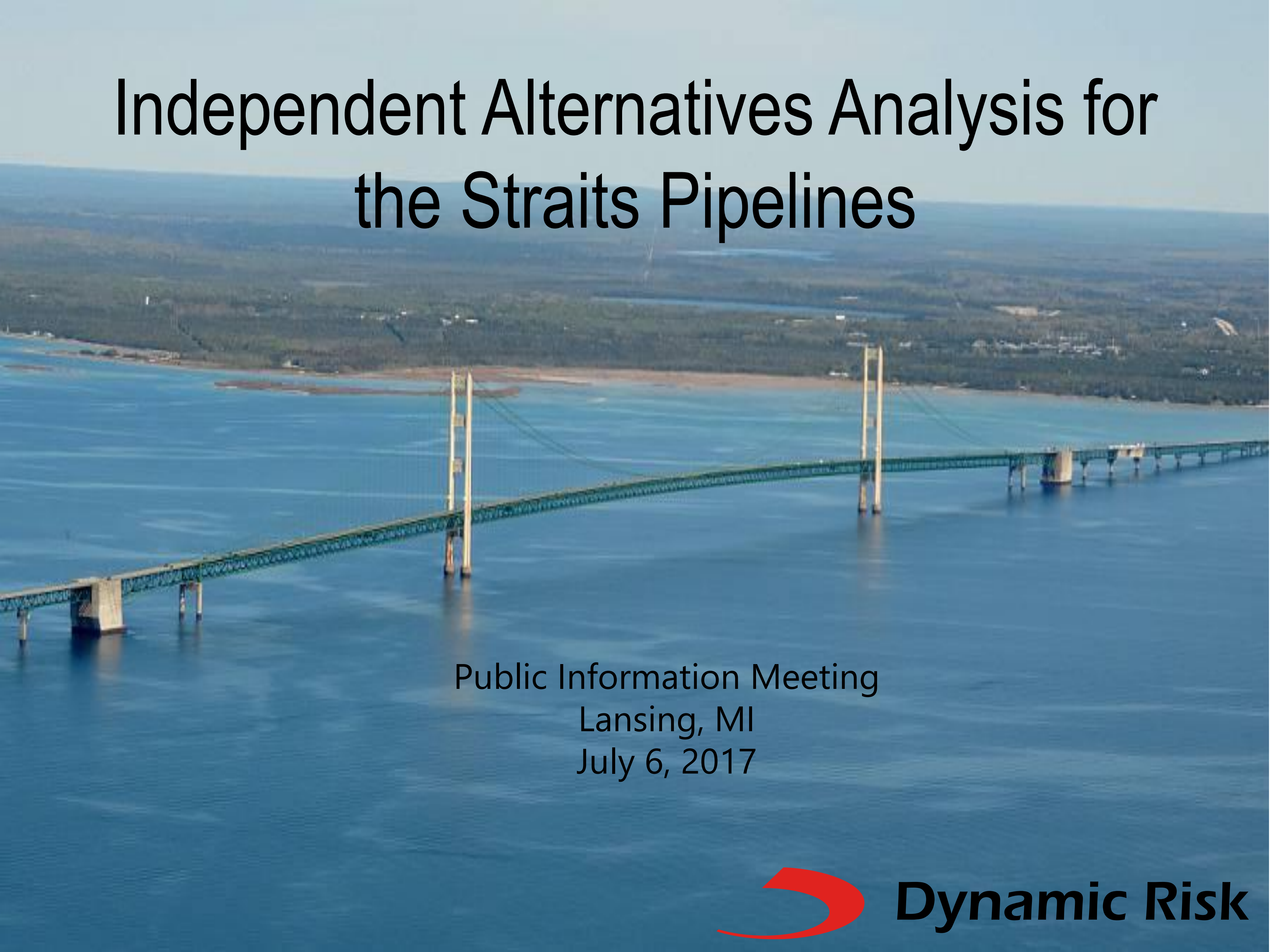
Independent Alternatives Analysis for the Straits Pipelines



Public Information Meeting
Lansing, MI
July 6, 2017

Dynamic Risk

Introductions

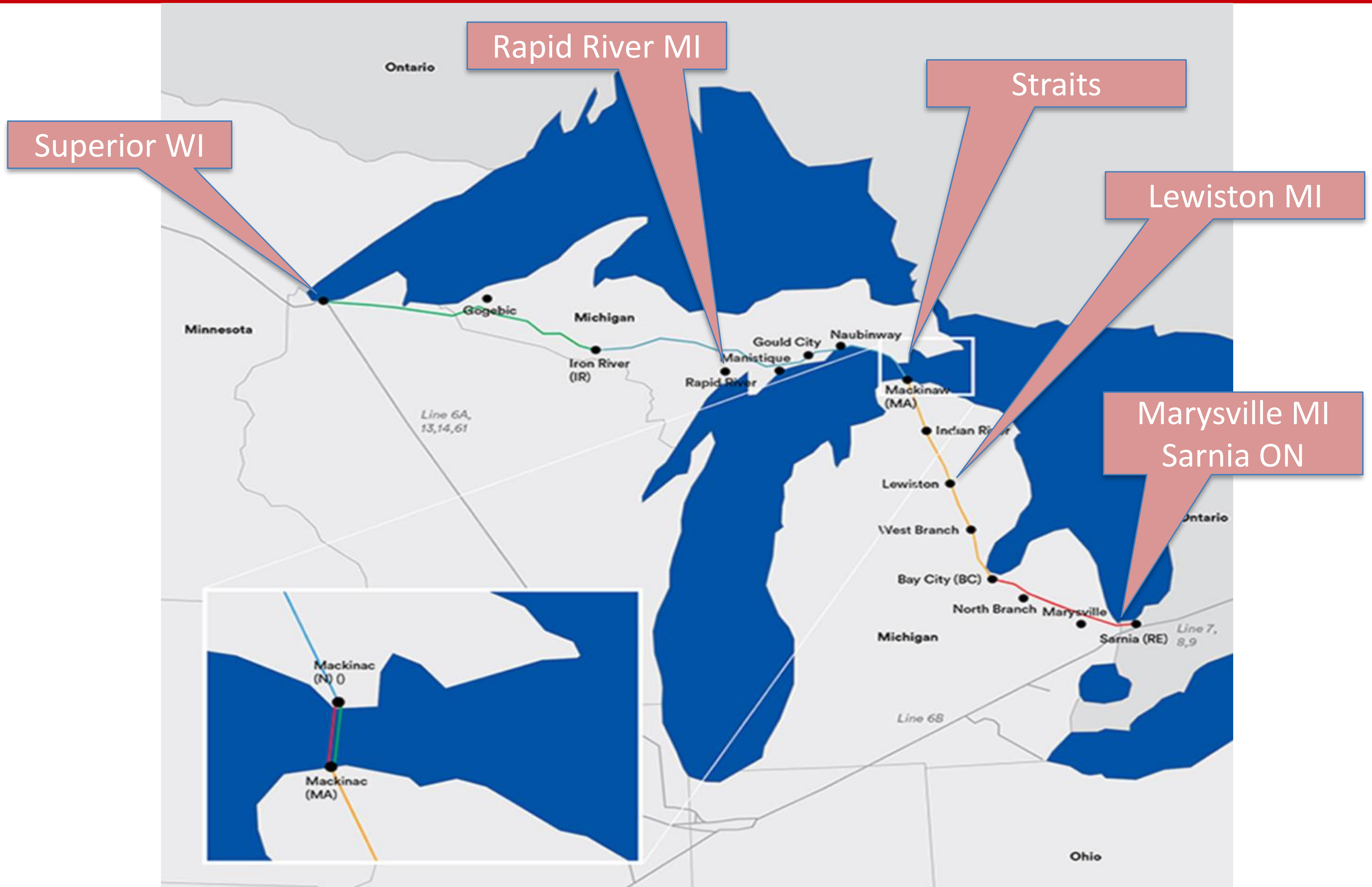
- Project Team
  - Patrick Vieth (Dynamic Risk)
  - Jim Mihell (Dynamic Risk)
  - Nasim Tehrany (Dynamic Risk)
  - Bill Ho (Dynamic Risk)
  - Jack Ruitenbeek (Ruitenbeek Resource Consulting)
  - Dale Kerper (DHI Water & Environment)
  - Jim Kenny (Stantec)
  - Shane Kelly (Kelly Geotechnical)

Project Overview

Objective

> …to provide the State of Michigan and other interested parties with an ***independent, comprehensive analysis of alternatives to the existing Straits Pipelines***, and the extent to which each alternative promotes the public ***health, safety and welfare*** and protects the public trust resources of the ***Great Lakes***. The work <u>does not include a recommendation</u> by the contractor of a preferred alternative. Rather, the work includes the development of information that can be used by the ***State and other interested parties in making decisions about the future of the Straits Pipelines***.

Location of Line 5



Project Overview - Components of Analysis

- Feasibility Analysis
- Design-based cost estimates
- Economic feasibility
- Socio-economic Impacts
  - Jobs, income, government revenue
  - Social impacts
- Spill risk analysis
  - Compare risk of infrastructure required to replace existing Straits Segments
  - Existing Straits Segments considered as Base Case for comparison purposes
    - Threat assessment
    - Spill Probability assessment
    - Safe and reliable operating life
    - Spill release modeling
    - Oil spill behavior and impact modeling
    - NGL release modeling
    - Spill consequence analysis (Safety, Environment, Economic Impact)
- Market Impacts

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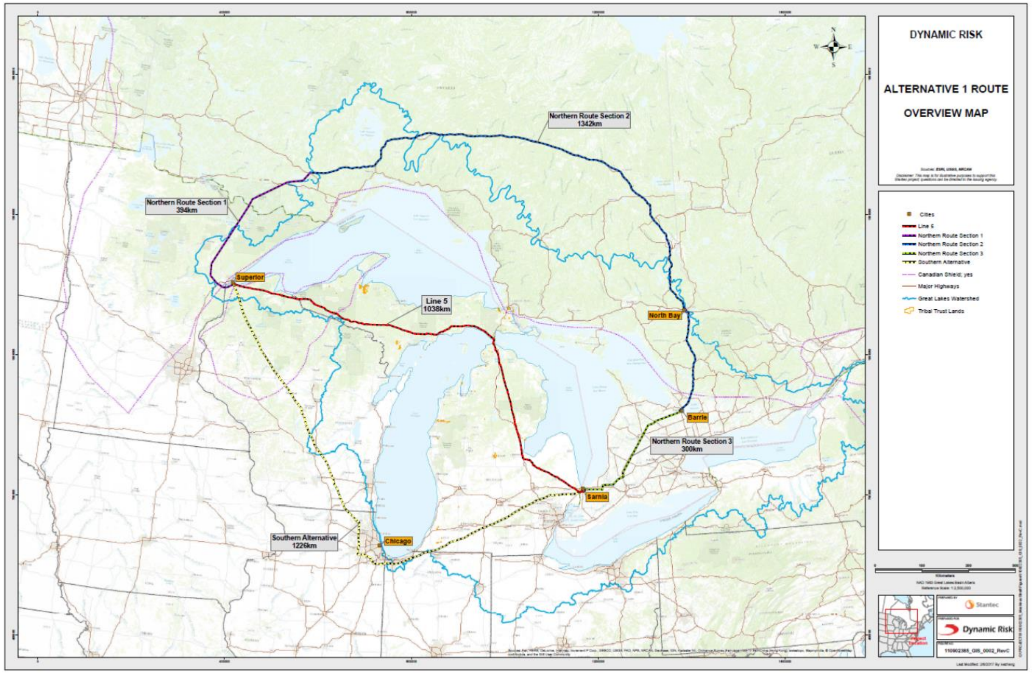
Alternative 1 – New Pipeline Route

Three Routes Investigated:

1. <u>North Route</u>
   - New route from Duluth to Thunder Bay (Ont.)
   - Existing route to Barrie (Ont.)
   - New route to Sarnia (Ont.)
2. <u>Central Route</u>
   - Follow Line 5 to St. Ignace
   - New route across St Mary's River near Sault St Marie into Ontario and on to North Bay (Ont.)
   - Similar to North Route from there on
   - Eliminated as it creates new crossing of Great Lakes
3. <u>Southern Route</u>
   - Follows Enbridge system through Chicago and on to Marysville



Pipeline to be 30" diameter with an MOP of 1440 psi, in accordance with contemporary design practices

Alternative 2 – Utilize Existing Infrastructure

Existing Enbridge System

- Little spare capacity to Line 5 volumes through Chicago
- Require new pipeline parallel to existing, with little cost savings

Third Party Capacity

- No existing system connects Superior to Sarnia directly
  - Cochin Pipeline
  - Guardian Pipeline
  - Enterprise/Sunoco System
  - TransCanada Pipelines
  - Great Lakes Gas Transmission
- In all cases, new facilities required – similar to Alternative 1

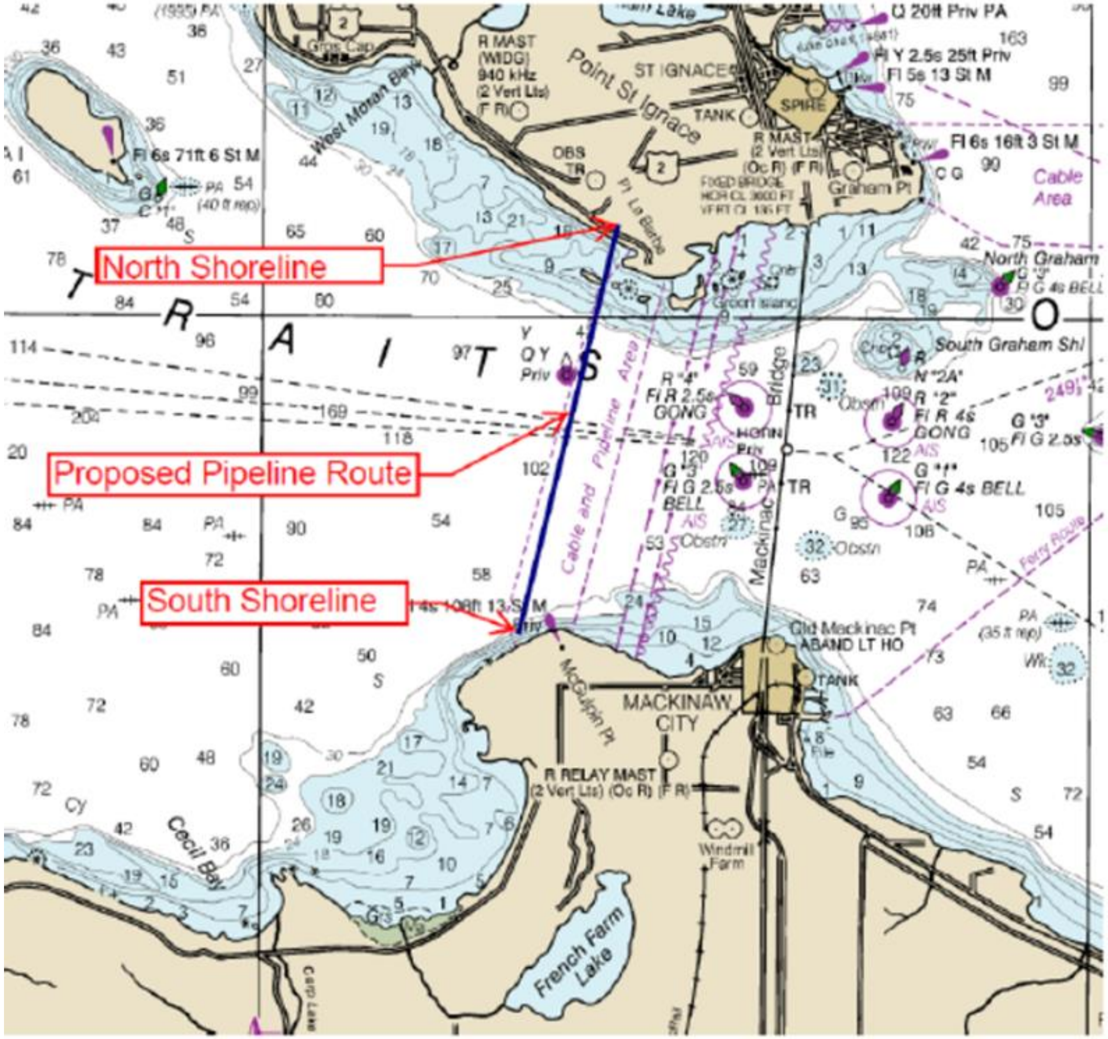
Alternative 3 – Other Transportation Methods

- Ship/Barge from Superior to Sarnia
  - No year-round traffic through Soo Locks
- Road Trucking from Superior to Sarnia
  - Fleet of 3,200 trucks req'd
  - Strain on hwy infrastructure

- Rail from Superior to Sarnia/Marysville
  - 9 – 100 car trains required per day
  - ~200 million bbls/yr (~2/3 typical annual oil-by-rail volumes & ~50x more than historical values)
  - Three routes evaluated: North (Winnipeg), Central (Sault Ste. Marie), South (Chicago)
  - Central eliminated due to load restrictions on St Marys River bridge
  - N & S options require tanks, track loading/unloading systems, & short pipelines at both ends.
  - Terminating at Marysville involves more facilities but eliminates Sarnia rail tunnel bottleneck
  - Storage required for product to recover from scheduled or unscheduled rail outages

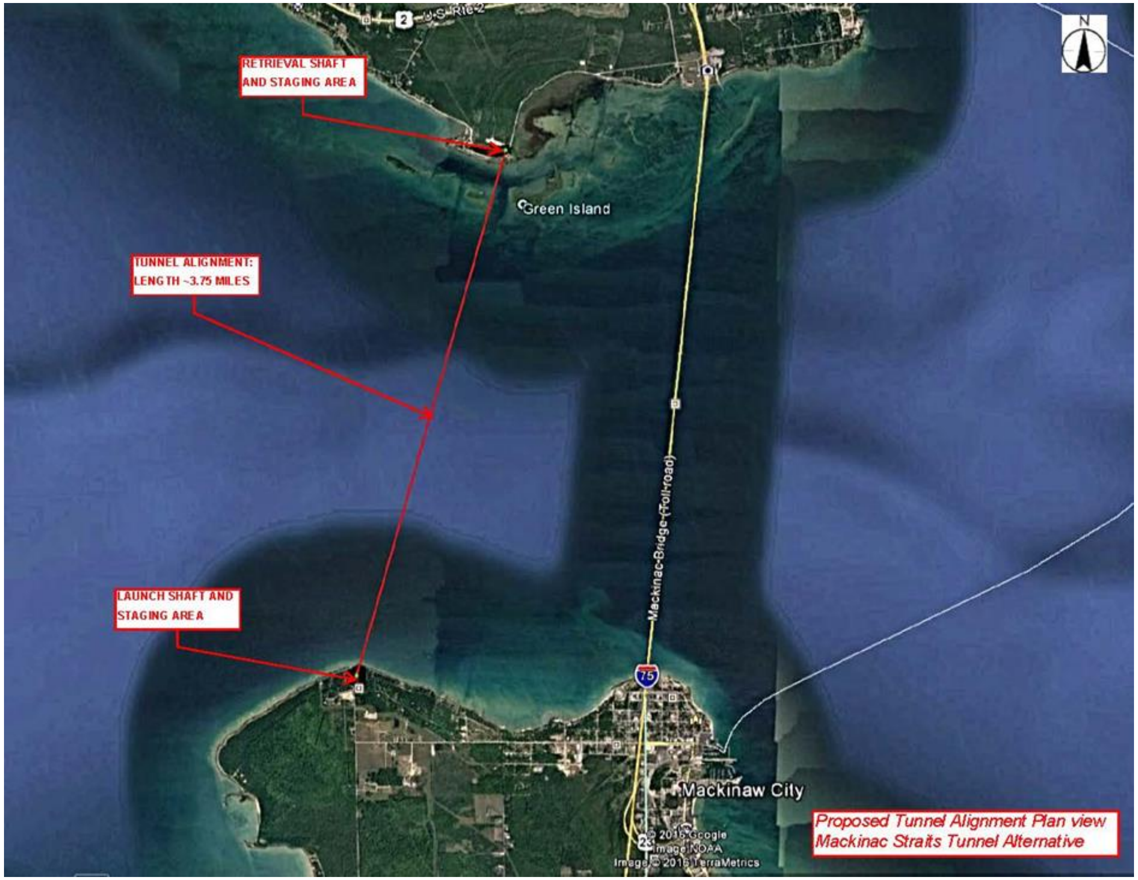
Alternative 4a – Straits Replacement: Trench

- Length: 4.1 miles
- Max. depth: 230 feet
- Pipe Spec: 30" OD x 0.812" X65, 20% SMYS
- Coating: 3LCC with 2" concrete
- Cover: 9' near shore, 3' elsewhere



Alternative 4b – Straits Replacement: Tunnel

- Tunnel via TBM
- Segmented concreted liner following TBM
- Formation drilled & sealed with grout ahead of TBM
- 350' below water level
- Pipe Spec: 30" OD x 0.812" X65, 20% SMYS
- Coating: 3LCC
- Pipe assembled & advanced through tunnel from entry to exit shaft
- Sealed with high strength low-permeability grout



Alternative 6 – Decommission & Abandon Straits

Limitations of using existing Line 5:

- Propane supply to Rapid River:
  - Using segment of Line 5 not operationally practicable
  - Design volume of 3600 bbl/d would require 4" pipeline
- Crude Delivery – Lewiston to Marysville
  - Using segment of Line 5 not operationally practicable
  - Design volume of 12,000 bbl/d would require 8" pipeline

Decommissioning Strategy (per CFR & Industry Recommended Practices):

- Cultivated, forested, urban, wetland, river crossings:
  - Abandon in place (527 mi)
- Road/trail crossings:
  - Abandon in place / concrete fill (13 mi)
- Water crossings:
  - Abandon in place / water fill (5 mi)

Process:

- Clean pipe and purge of hydrocarbons
- Transitions to above-ground to be cut at depth and sealed
- Pump station equipment removed, sites reclaimed

Feasibility of Alternatives

- Alternative 1: New Pipeline Route ✓
- Alternative 2: Utilize Pre-existing Alternative Pipeline Infrastructure ✗
  - Partial capacity exists on short segments – not significantly different from Alt 1
- Alternative 3: Alternative Transportation Methods
  - Water Transport – Tankers / Barges ✗
    - $4.3 billion investment required in tank farms and fleet of vessels
  - Truck Transport ✗
    - 1 truck loaded/unloaded every 40s, 24 hrs/day, 7 days/week.
    - Dedicated fleet of 3,200 trucks required
    - Public costs, strain & congestion on highway infrastructure + public risk
  - Rail ✓
- Alternative 4: Replace Straits Crossing
  - New Trenched Crossing ✓
  - New Tunnel Crossing ✓
- Alternative 5: Maintain Existing Straits Crossing ✓
- Alternative 6: Decommission and Abandon Straits Crossing ✓

Components of Analysis

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Cost-Effectiveness Analysis

- Levelized Cost normalizes capital and operating costs to a single value
- Permits comparison of alternatives across common volume of 540,000 bbl/d
- Common assumption of 6%/y discount rate (real: before inflation)
- Current Tariff Superior – Sarnia Area ~ Oil: $1.50/bbl ; NGL: $1.32/bbl

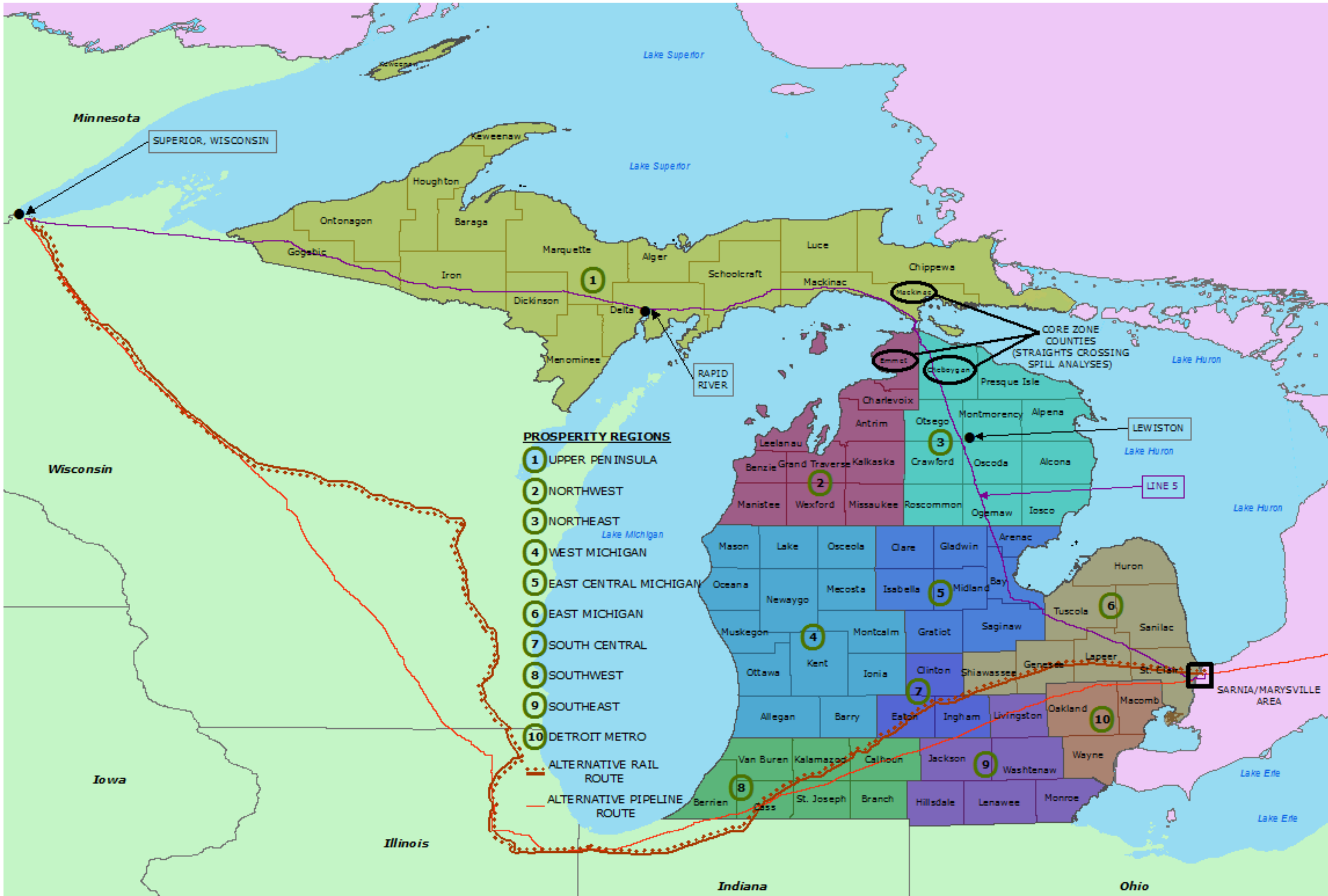
Alternative	Cost Estimates & Levelized Cost Equivalent		
	Capital Cost (million $) [% in Michigan]	Operating Cost (million $/y)	Levelized Cost ($/bbl)
Alternative 3 (Rail Transport)	908 [0%]	1,220 [15%]	$ 6.492 /bbl
Alternative 1 (New Pipeline)	2,025 [29%]	225->165 Year 0->10+ [30%]	$ 1.628 /bbl
Alternative 4a (New Trenched Straits Crossing)	27.3 [100%]	95 [87%]	$ 0.009 /bbl
Alternative 4b (New Tunnel Crossing of the Straits)	152.9 [100%]	95 [87%]	$ 0.046 /bbl
Alternative 6b (Abandonment of Line 5 and Straits Crossing)	212.1 [86%]	n.e.	$ 0.067 /bbl

Socioeconomic Impacts – Areas of Interest

"Michigan"
"Prosperity Region Corridor"
"County Corridor"

<u>Line 5 Counties</u>

Gogebic [Region 1]
Iron [Region 1]
Dickinson [Region 1]
Marquette [Region 1]
Delta [Region 1]
Schoolcraft [Region 1]
Mackinac [Region 1]
Emmet [Region 2]
Cheboygan [Region 3]
Otsego [Region 3]
Crawford [Region 3]
Oscoda [Region 3]
Ogemaw [Region 3]
Arenac [Region 5]
Bay [Region 5]
Saginaw [Region 5]
Tuscola [Region 6]
Lapeer [Region 6]
St. Clair [Region 6]



Socioeconomic Impacts – RIMS II

- US Bureau of Economic Analysis Multipliers (2015)
- Three levels of impacts are tracked
  - Direct: Initial round of expenditures in Michigan
  - Indirect: Suppliers to the direct expenditures in Michigan
  - Induced: Spending by households within Michigan
- Jobs, Earnings, & Output Estimated for Operating or Capital Expenditures
- Distinguish between ‘contribution analysis’ of existing expenditures and ‘impact analysis’ of new expenditures
- Government Revenue based on Dynamic Risk estimates relying on:
  - Labor income estimates from RIMS II
    - Income tax rates
    - Sales taxes and fuel taxes
  - Pipeline and Rail Taxes
- Estimates are most robust for:
  - Larger regions (Michigan): [county level less robust]
  - Operational contribution impacts are most robust because they are currently embedded in economy

Caveat from Appendix O: “RIMS II multipliers provided by the US Bureau of Economic Analysis (BEA) were used to estimate the potential impacts on regional economies of construction and operation expenditures associated with the alternatives investigated in this report.
To note, the BEA does not endorse any of the results or any of the conclusions about the economic impacts of the regional expenditures analyzed.”

Socioeconomic Impacts – SIA Screening

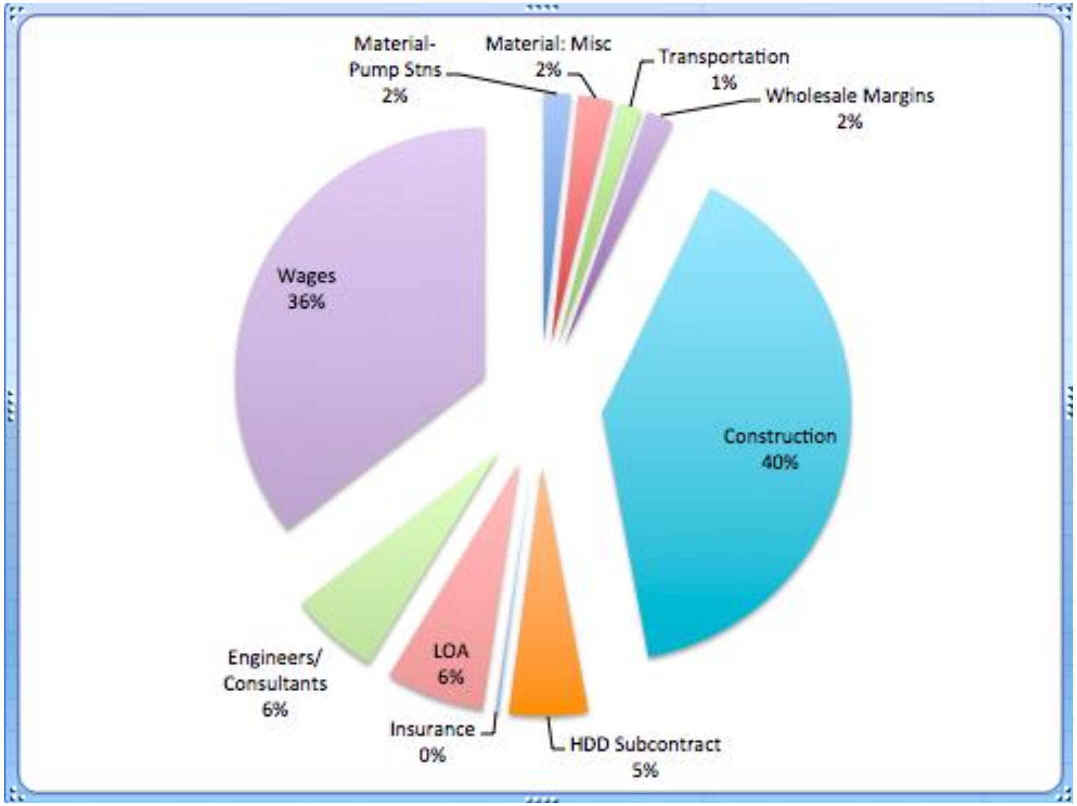
- Social Impact Assessment
- Preliminary Screening before Public Consultations close to Final Design
- Selected Impacts
  - Congestion impacts of construction
  - Housing shortages from Straits construction projects
  - Dust
  - Noise from Rail Operations
- Other Information in Report
  - Baseline Data by County in Report
  - High Consequence Area Land Use
  - Tribal Use in Lake Michigan and Lake Huron

Social Assessment Variables	Alt 1: South Pipeline Route – Superior, WI to Sarnia, ON via IL, IN, MI			Alt 3: South Rail Route – Superior, WI to Sarnia, ON via IL, IN, MI			Alt 4a: Straits Crossing pipeline replaced with Trenched Pipeline			Alt 4b: Straits Crossing pipeline replaced with new Tunnel Pipeline			Alt 6: Abandon Line 5
	Planning	Construction	Operation	Planning	Construction	Operation	Planning	Construction	Operation	Planning	Construction	Operation	Construction
Economic Impacts													
Economy: impacts from project expenditures		■	■			■		■			■		■
Community Resources													
Land: cultivation disruption		■				■							■■
Land: disruption on Tribal trust or treaty land		■				■		■			■		■■
Water: disruption of commercial traffic in Straits of								■					■
Water: disruption of recreational boating in Straits of								■					■
Water: disruption on Treaty water & fisheries								■					■
Infrastructure disruption: road traffic congestion		■				■■		■			■		■■
Infrastructure disruptions: access to local business		■						■			■		■
Infrastructure disruption: access to lakefront recreation								■			■		■
Compromised visual aesthetics								■			■		■
Population Impacts													
Housing issues influx of temporary construction		■				■		■			■		■■
Housing issues: disproportionally-affected seasonal								■			■		■
Housing issues: influx of special interest groups –	■			■			■	■		■	■		
Seasonal population: reduced presence of seasonal								■			■		■
Seasonal population: reduced tourist influx								■			■		■
Community Structural Impacts													
Changes to labor force composition		■						■			■		■
Inequity: increased accommodation costs for seasonal								■			■		■
Business: increased cost of seasonal workers								■			■		■
Business: reduced tourism revenue								■			■		■
Property speculation	■						■			■			■
Community and Family Impacts													
Stresses: increased costs – community services		■						■			■		■
Anxiety: perception of increased risk to public health						■■		■	■		■	■	
Anxiety: conflict between project opponents and project	■						■			■			
Health: noise impact		■				■■		■			■		■
Health: air pollution impact – dust						■					■		

Socioeconomic Impacts – Bill of Goods

Alternative 1 – New Pipeline South
(5 year construction period)
Excludes Line 5 Abandonment Costs

Cost: $ 2,025 million (4 States)
Cost: $ 586 million (Michigan)
Source: $ 435 million (Michigan)



Michigan Results:

- Construction Jobs: 8,100
- Earnings: $ 370 million
- Output: $1,300 million
- Value Added: $ 400 million
- Government Revenue: <$ 18 million

Socioeconomic Impacts – Construction

- Non–persistent impacts from construction period expenditures in Michigan

Alternative	Impact in Michigan*			
	Jobs	Earnings ($ million)	Output ($ million)	Government Revenue ($ million)
Alternative 3 (Rail Transport)	0	$ 0	$ 0	$ 0
Alternative 1 (New Pipeline)	8,110	$ 370	$ 1,300	< $ 18
Alternative 4a (New Trenched Straits Crossing)	413	$ 21	$ 71	~ $ 1.0
Alternative 4b(New Tunnel Crossing of the Straits)	1,763	$ 91	$ 328	< $ 4.4
Alternative 6b (Abandonment of Line 5 and Straits Crossing)	2,188	$ 104	$ 362	< $ 5.0

* Based on RIMS II multipliers.

Socioeconomic Impacts – Operations

- Persistent impacts from operating expenditures in Michigan

Alternative	Impact in Michigan*			
	Jobs (/y)	Earnings ($ million/y)	Output ($ million/y)	Government Revenue ($ million/y)
Alternative 3 (Rail Transport)	1,191	$ 84	$ 320	~ $ 12
Alternative 1 (New Pipeline)	399	$ 24	$ 80	$ 6 – 11
Straits Crossing ** (Alternative 5 Status Quo or Alternative 4 Trench or Tunnel)	913	$ 45	$ 136	$ 7 – 9
Alternative 6b (Abandonment of Line 5 and Straits Crossing)	0	$ 0	$ 0	$ 0

* Based on RIMS II multipliers.

** All have approximately same operating cost.

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    - Evaluation of safe and reliable operating life
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Failure Probability – Existing Crossing

Approach: Threat Assessment

- Assessment of vulnerability to each of 12 Threat Categories based on threat attribute review (assessment data, design, materials, installation, operations, environment)
- Classify each Threat Category as:
  - Principal Threat
    - Significant vulnerability
    - Potential to provide most significant contributions to overall failure probability
    - Assign failure mode associated with each threat (leak / rupture)
  - Secondary Threat
    - Vulnerability insignificant relative to Principal Threats
    - Potential to contribute to overall failure probability only at second-order levels
    - Typically orders of magnitude below, and within estimation error of Principal Threats
- Probability Analysis
  - Quantify failure probability for each Principal Threat
    - Reliability methods (statistical methods applied to limit state models)
    - Logical methods (event trees, evaluation of threat environment)
    - Industry incident data

Threat Assessment – Approach

- Threat Categories and attributes based on API – 1160 "Managing System Integrity for Hazardous Liquids Pipelines", augmented by ASME B31.8S Appendix A.
- Threat Categories:
  1. External Corrosion
  2. Internal Corrosion
  3. Selective Seam Corrosion
  4. Stress Corrosion Cracking
  5. Manufacturing Defects
  6. Construction and Fabrication Defects
  7. Equipment Failure
  8. Immediate Failure due to Mechanical Damage
  9. Time-dependent Failure due to Resident Mechanical Damage
  10. Incorrect Operations
  11. Weather and Outside Force
  12. Activation of Resident Damage from Pressure-Cycle-Induced Fatigue

In-line Inspections Since 2008

Type of Inspection	Year	Description
Magnetic Flux Leakage (volumetric wall loss)	2008	GE Pipeline Integrity Services - East Leg
	2008	GE Pipeline Integrity Services - West Leg
	2013	GE Pipeline Integrity Services - East Leg
	2013	GE Pipeline Integrity Services - West Leg
Geometry / Caliper Tool	2008	GE Pipeline Integrity Services - East Leg
	2008	GE Pipeline Integrity Services - West Leg
	2013	Baker Hughes Pipeline Inspection – East Leg
	2013	Baker Hughes Pipeline Inspection – West Leg
	2016	Baker Hughes Pipeline Inspection – East Leg
	2016	Baker Hughes Pipeline Inspection – West Leg
Ultrasonic Circumferential Crack Detection	2014	NDT Global Inspection – East Leg
	2014	NDT Global Inspection – West Leg
Tethered TOFD / PA Girth Weld Inspection	2014	Oceaneering Pipetech Inspection – East Leg
	2014	Oceaneering Pipetech Inspection – West Leg
Cathodic Protetcion Current Mapper Inspection	2016	Baker Hughes Pipeline Inspection – East Leg
	2016	Baker Hughes Pipeline Inspection – West Leg
Acoustic Leak Detection	2016	PureHM SmartBall Inspection – East Leg
	2016	PureHM SmartBall Inspection – West Leg
	2017	PureHM SmartBall Inspection – East Leg
	2017	PureHM SmartBall Inspection – West Leg

Threat Assessment - Results

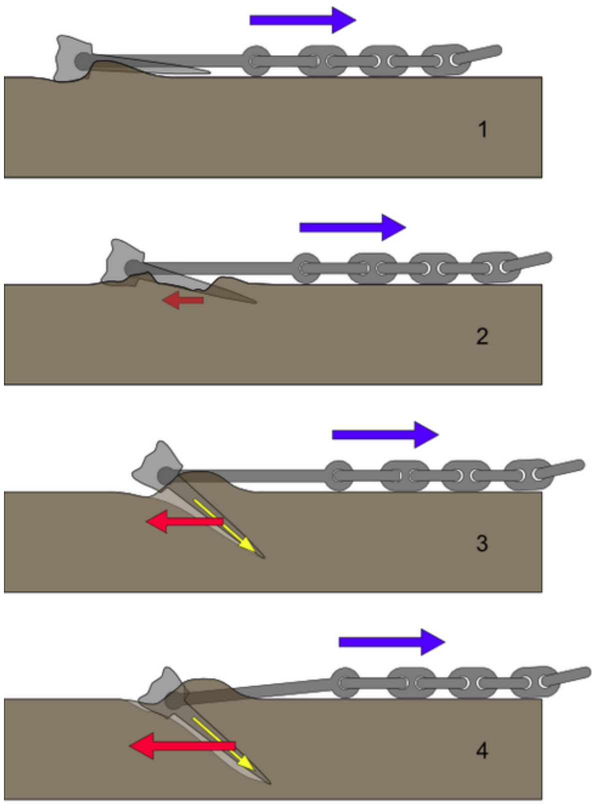
- Principal Threats:
  - Immediate Failure Due to Mechanical Damage (Anchor Interaction)
  - Incorrect Operations
  - Weather and Outside Force (Spanning-Related Threats)
    - Vortex-Induced Vibration
    - Spanning
- Secondary Threats:
  - External Corrosion
  - Internal Corrosion
  - Selective Seam Corrosion
  - Stress Corrosion Cracking
  - Manufacturing Defects
  - Construction and Fabrication Defects
  - Equipment Failure
  - Time-dependent Failure due to Resident Mechanical Damage
  - Activation of Resident Damage from Pressure-Cycle-Induced Fatigue

Corrosion Assessment – Existing Pipeline

- Contribution of corrosion to overall $P_{failure}$ not significant relative to principal threats
  - Anchor Interaction
  - Incorrect Operations
  - Spanning-related threats
- Corrosion Assessments
  - High-res MFL ILI every 5 years since 1998
  - No evidence of corrosion wall loss in Straits Crossing segments
  - Evidence of wall thickness variation consistent with mill anomalies
  - DOT study indicates no measurable variation in wall thickness between ILI runs
- Coating
  - 2016 CPCM inspection - no current anomalies. Concluded coating in excellent condition
  - CTE coatings, although vintage, have good performance record
  - Visual inspection shows evidence that outer-wrap layer has become detached
- Cathodic Protection
  - CPCM tool indicates low current demand
  - CP readings dating back to 1989 reviewed – no sub-criteria readings
- Operating Experience
  - Other than risers, "cases of significant external corrosion extremely rare" in offshore pipeline segments (DOT Study - Pipeline Corrosion)

Failure Probability – Anchor Interaction

- Approach based on Industry Guidelines: "Unintentional Anchor Drops From Ships Under Way"
- Failure Mode: Full-Bore Rupture



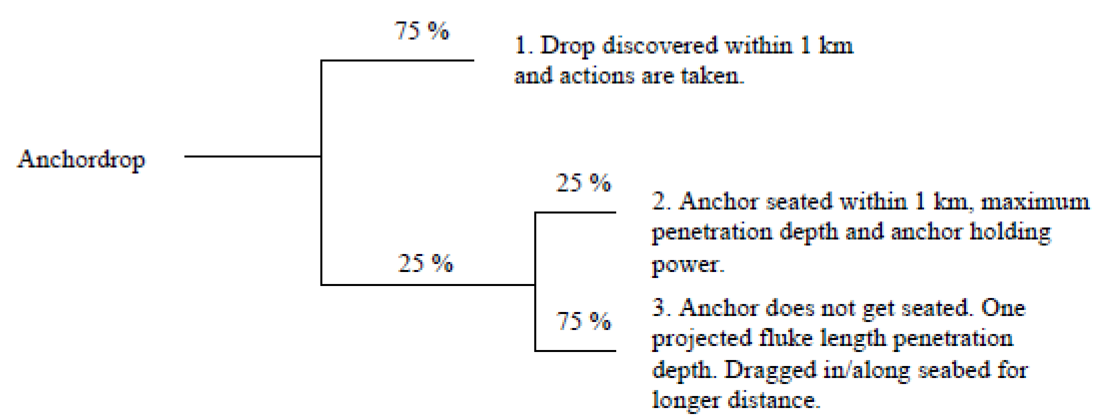


Figure E.2 Event tree for the case uncontrolled anchor drop

Anchor Interaction (Continued)

- Historical Data Feed Request made to US Coast Guard Navigation Center for Nationwide Automatic Identification System data
  - AIS receivers provide coverage through the Straits of Mackinac
  - AIS data for 2014, 2015, 2016
  - Marine Mobile Service Identity information for each transiting vessel cross-referenced to displacement
- Analysis considers two limit states:
  - Strain Overload (Based on Finite-Element Analysis results for 20” pipe)
  - Failure by Critical Dent (Based on empirical model result for 20” pipe)
- Minimum force required to cause failure is deemed ‘Critical Force’
- Critical Force is compared against anchor chain break load for each vessel class
- Failure probability calculated on basis of number of vessel transits in class large enough to have chain break load greater than Critical Force
- Analysis also considers influence of vessel class on:
  - Anchor chain length, relative to water depth
  - Anchor dimensions, relative to pipe size (hooking capability)
  - Anchor penetration depth, relative to burial depth (not a consideration for existing Straits segments)

Failure Probability – Incorrect Operations

- PHMSA Hazardous Liquids Incident Database (Offshore Pipelines)
- Failure Mode: Leak (probability-weighted hole size: 3″ diameter)

	Y	AQ	BA	CL	CN	DJ	DK	DL	DM	DP
1	UNINTENTIONAL_	SHUTDOWN_DUE	ON_OFF_SHORE	SYSTEM_PART_IN	ITEM_INVOLVED	INSTALLATION_YE	MATERIAL_INVOL	MATERIAL_DETAIL	RELEASE_TYPE	LEAK_TYPE
19	0.5	NO	OFFSHORE	OFFSHORE PLATFORI	OTHER	2004	CARBON STEEL		LEAK	CONNECTIO
42	5.7	YES	OFFSHORE	OFFSHORE PIPELINE,	PIPE	1968	CARBON STEEL		LEAK	CRACK
142	0.52	NO	OFFSHORE	OFFSHORE PIPELINE,	VALVE	1995	CARBON STEEL		LEAK	SEAL OR PA
202	0	NO	OFFSHORE	OFFSHORE PLATFORI	VALVE	2000	CARBON STEEL		LEAK	OTHER
343	79	YES	OFFSHORE	OFFSHORE PIPELINE,	PIPE	1953	CARBON STEEL		LEAK	CRACK
470	0.02	YES	OFFSHORE	OFFSHORE PIPELINE,	FLANGE	1997	CARBON STEEL		LEAK	CONNECTIO
556	0.09	YES	OFFSHORE	OFFSHORE PIPELINE,	PIPE	1971	CARBON STEEL		LEAK	OTHER
895	0.02	NO	OFFSHORE	OFFSHORE PIPELINE,	FLANGE	2008	MATERIAL OTHER TH	FLANGE GASKET MAT	LEAK	OTHER
933	0	YES	OFFSHORE	OFFSHORE PIPELINE,	PIPE	1955	CARBON STEEL		MECHANICAL PUNCTURE	
948	0.11		OFFSHORE	OFFSHORE PIPELINE,	PIPE	1972	CARBON STEEL		LEAK	PINHOLE
1227	0.01	YES	OFFSHORE	OFFSHORE PIPELINE,	PIPE	2000	CARBON STEEL		LEAK	PINHOLE
1584	0.1	YES	OFFSHORE	OFFSHORE PIPELINE,	PIPE	1989	CARBON STEEL		LEAK	PINHOLE
1650	1.49	YES	OFFSHORE	OFFSHORE PLATFORI	PIPE	2004	CARBON STEEL		LEAK	PINHOLE
1677	0.1	YES	OFFSHORE	OFFSHORE PIPELINE,	PIPE	1980	CARBON STEEL		LEAK	CRACK
1924	1.4	NO	OFFSHORE	OFFSHORE PLATFORI	TUBING	2008	MATERIAL OTHER TH	STANLESS STEEL BRAI	LEAK	PINHOLE
2145	0.39	NO	OFFSHORE	OFFSHORE PLATFORI	AUXILIARY PIPING (E.G. DRAIN LINES)		CARBON STEEL		LEAK	CONNECTIO
2199	0.02	YES	OFFSHORE	OFFSHORE PIPELINE,	REPAIR SLEEVE OR CL	1971	CARBON STEEL		LEAK	PINHOLE
2221	220	YES	OFFSHORE	OFFSHORE PIPELINE,	PIPE	1967	CARBON STEEL		LEAK	CRACK

Failure Probability – Vortex-Induced Vibration

- Reliability approach based on limit states derived from:
  - DNV-RP-F105 “Free Spanning Pipelines” (Amplitude Response Models):

Function of
D, w.t., L, E

$$S_{IL} = 2 \cdot A_{IL} \cdot \frac{A_y}{D} \cdot \psi_{\alpha,IL} \cdot \gamma_s$$

In-Line VIV Stress Range

Function of
V, f, L

$$S_{CF} = 2 \cdot A_{CF} \cdot \frac{A_z}{D} \cdot R_k \cdot \gamma_s$$

Cross-Flow Induced Stress Range

  - Fatigue Life - API RP – 579 “Fitness For Service” (Fatigue Life Model):

$$N = A \cdot f_t \cdot f_c \left[\left(\frac{2.09 \times 10^5}{E_y} \right) \sigma_r \right]^m$$

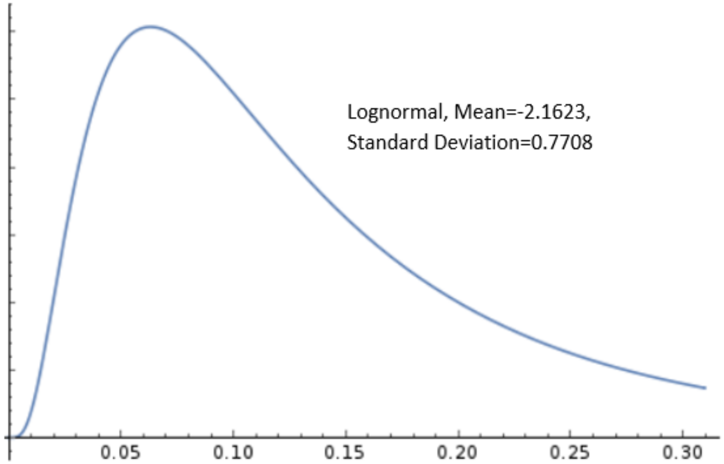
Cycles to Failure

Function of
S_{IL}, S_{CF}

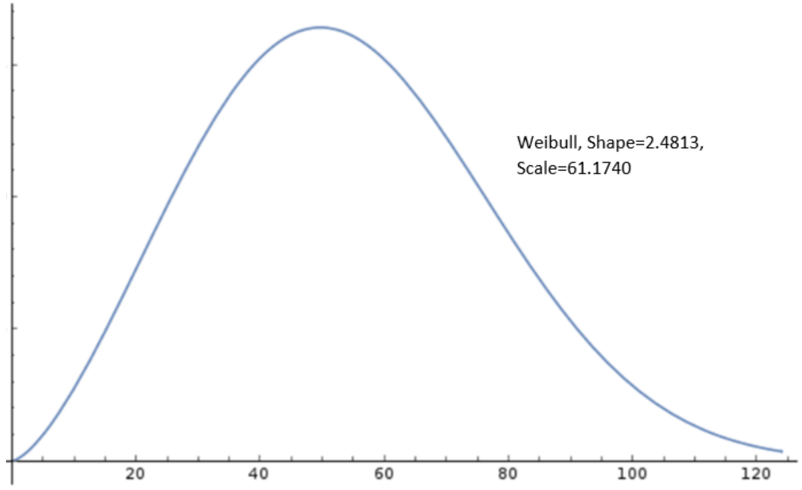
Vortex-Induced Vibration (Continued)

- Extract of Upper-bound bottom-layer water currents (one year of hourly data) for East and West segments (from DHI 3D hydrodynamic model)
- Enbridge Span Inspection Data, 2005 – 2016

Upper-bound Bottom-Layer Current Velocity, West Segment



Span Length Distribution, West Segment



- Used as input to Limit State Equations in Monte Carlo Analysis (100,000,000 simulations)

Failure Probability - Spanning

- Spanning stresses due to gravity, pressure, temperature differential and water current drag forces
- Water current and span length distributions (per VIV Analysis)
- Analysis considers effect of mussel growth (surface roughness, weight, thickness)
- Analysis also considers enhancement of stress amplitude due to dynamic effects of vortex-induced vibration

$$F_D = \frac{1}{2} \cdot C_D \cdot \rho \cdot D \cdot U^2$$

Drag Force Due to Water Current

$$\sigma_{b,g}^{\max} = \frac{M_{\max}}{I} \cdot \frac{D}{2} = \frac{\left(\frac{wl^2}{10}\right)}{\frac{\pi}{64}\left[D^4 - (D-2t)^4\right]} \cdot \frac{D}{2}$$

Maximum Bending Stress Due to Gravity

$$\sigma_{Axial,Poisson} = \frac{P_{Net} \cdot D \cdot \nu}{2 \cdot t}$$

Axial Poisson's Stress Due to Operating Pressure

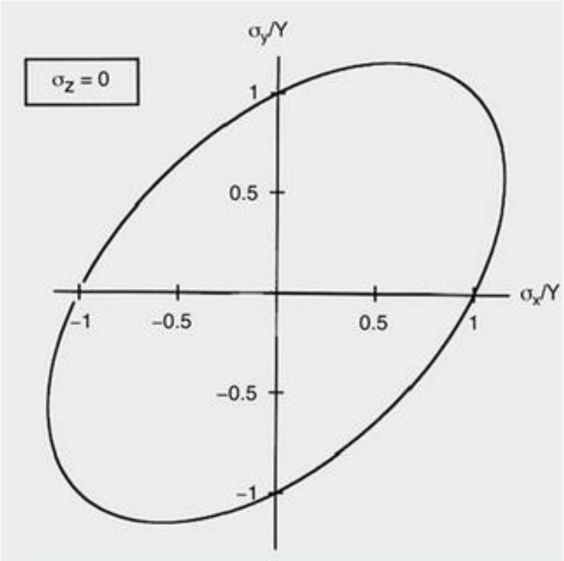
$$\sigma_{\Delta T} = -\alpha \cdot E \cdot (T_o - T_i)$$

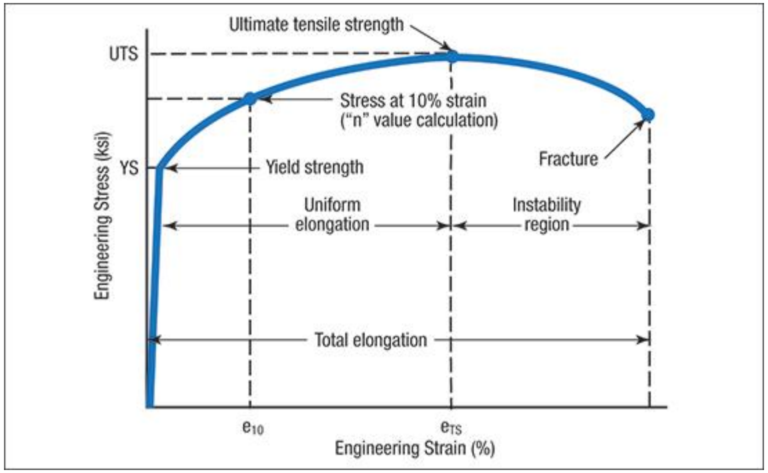
Axial Stress Due to Temperature Differential

- Random sampling of span length and current velocity using Monte Carlo Analysis (100,000,000 simulations)

Spanning (Continued)

- Limit state is exceedance of Von Mises biaxial yield criterion
- Addresses for potential for high-strain fatigue





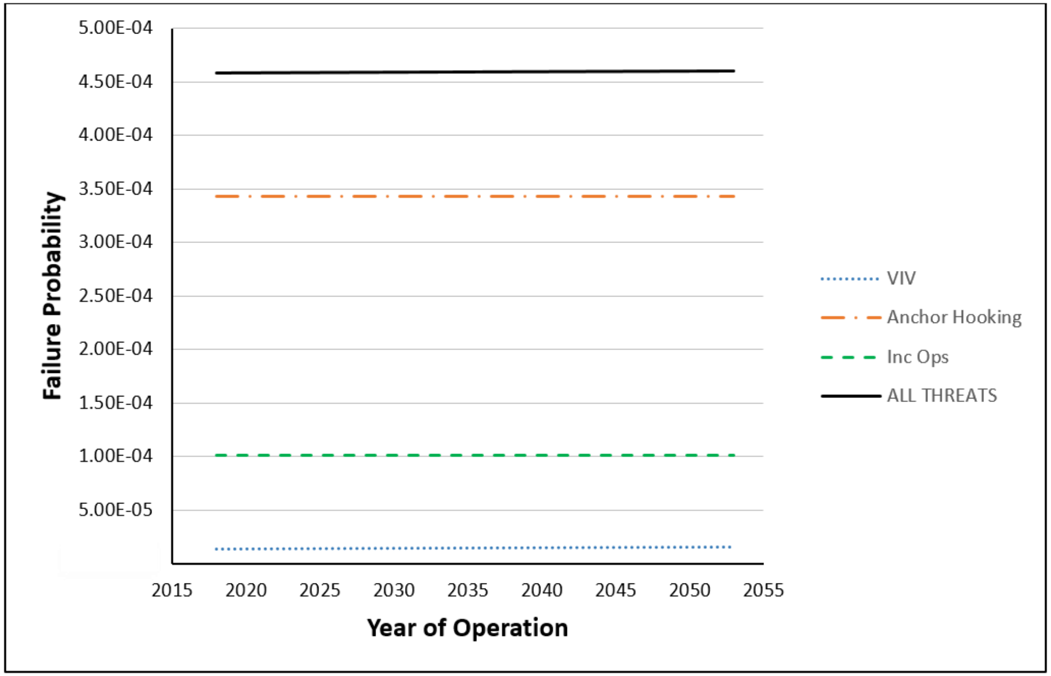
- Most conservative of six combinations of water depth and product density used to address factors affecting biaxial stress state

Spanning – Related Threats Summary

- Two spanning-related threats identified
  - Vortex-induced vibration
  - Over-strain due to unsupported span length (gravity and water current drag force)
- Vortex-induced Vibration Analysis
  - 100,000,000 simulations employing amplitude response model coupled with fatigue life model
  - 1.42x10-05 [3.1% of Total $P_{failure}$ (2018)] – 1.61x10-05 [3.5% of Total $P_{failure}$ (2053)]
- Overstrain Analysis
  - Gravity & Drag forces in conjunction with forces arising from operating temperature and pressure
  - 100,000,000 simulations
  - Probability that Stress > Maximum Combined Effective Stress <10-08 (resolution of analysis)
  - 2016 IMU data reviewed
    - 20 bends > 1.5o on East Segment: 2 in un-trenched portion
    - 23 bends > 1.5o on West Segment: 5 in un-trenched portion
    - Comparison against 2003 IMU data – no movement other than at launcher / receiver sites, where replacements had occurred
    - 2 bends on West Segment within 3 ft. of girth weld (2.8 ft & 2.9 ft).
    - Cross-reference to 2014 tethered weld inspection – no girth weld anomalies

Failure Probability Results Summary

Failure Probability Over Time



- Failure Probability (in order of significance):
  - Anchor Damage: 3.433x10-04 per year (rupture failure mode)
  - Incorrect Operations: 1.007x10-04 per year (leak failure mode)
  - Vortex-Induced Vibration: 1.42x10-05 per year (2018) (rupture failure mode)
  - Overstrain due to Spanning: <1x10-08 (beyond resolution of analysis)
- Vortex-Induced Vibration the only time-dependent threat
  - 1.42x10-05 (2018), increasing to 1.61x10-05 (2053) (0.4% of Combined Threat Probability)
- Poisson Distribution Estimate of Probability of Failure prior to 2053 (100th Anniversary of Pipeline): 1.6%

Evaluation of Operating Life

- Of 12 Threat Categories investigated, Principal Threats are:
  - Anchor Interaction
  - Incorrect Operations
  - Spanning-related threats
    - Vortex-induced Vibration
    - Overstrain due to Spanning
- Only Spanning-related threats are time-dependent
  - 1.42x10-05 [3.1% of Total $P_{failure}$ (2018)] – 1.61x10-05 [3.5% of Total $P_{failure}$ (2053)]
  - ~97% of annual failure probability is not influenced by passage of time, but rather, by random threats related to design
- Metallurgical Considerations
  - While some metallurgical phenomena can influence material properties, they are only relevant at temperatures well above normal pipeline operating temperatures
  - No significant degradation in material properties of pipeline steels occurs as a result of the passage of time

Spill Release Modeling (Existing Segments)

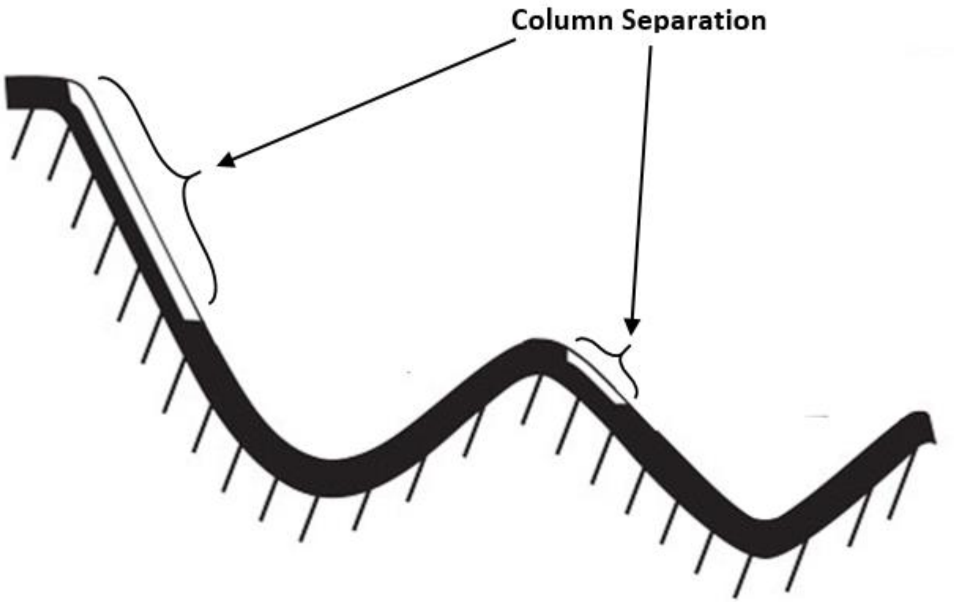
- Leak Detection System
  - SCADA continuous monitoring
  - Computational Pipeline Monitoring systems:
    - real-time transient model
    - line balance calculations
  - Local low-pressure shutdown of Straits Isolation Valves

		Detection & Response	Pump Shut-down	Valve Closure	Total Isolation Time
3” Hole	Equipment Performance Standard	5 min	Immediate	3 min	8 min
	Value Assumed for Calculations	30 min	0.5 min	3 min	33.5 min
FBR	Equipment Performance Standard	Immediate	Immediate	3 min	3 min
	Value Assumed for Calculations	10 min	0.5 min	3 min	13.5 min

- Hole sizes representative of principal threats
- 3 release locations, representing range of positions within bathymetric profile
- Drain-down to fullest extent possible, given elevation profile and valve configuration
- No account taken of any potential response, intervention or attenuation of volumes

Column Separation

- Can confound leak detection equipment, potentially leading to lengthy interpretation, trouble-shooting and diagnosis periods (Marshall)
- Occurs near high points of a pipeline segment
- Straits of Mackinac segment is lowest elevation point of Line 5. Not prone to column Separation



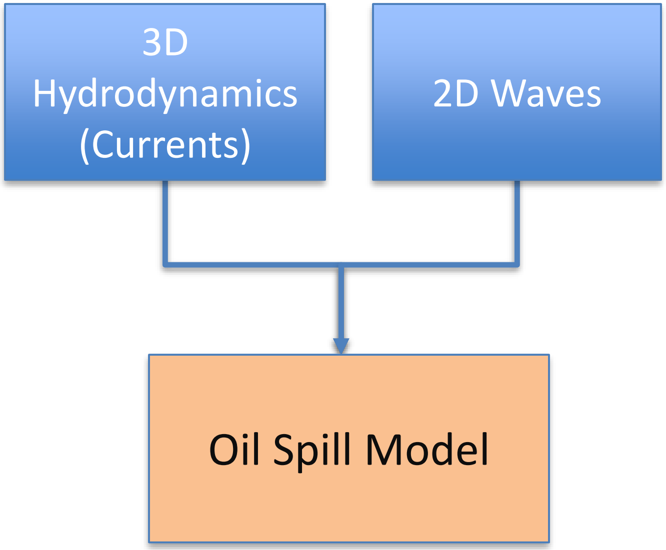
Outflow Results

Release Size	Pipe Segment	Principal Threat	Modeled Release Location	Release Volume (bbl)
FBR	East Segment	Anchor hooking, Spanning-related	Shipping Channel	2,629
FBR	West Segment	Anchor hooking, Spanning-related	Shipping Channel	2,623
3-in. Hole	East Segment	Incorrect Operations	Near North Shore	2,902
3-in. Hole	East Segment	Incorrect Operations	Near South Shore	4,527

Release volume of 4,527 bbls > 99% of all releases in PHMSA Hazardous Liquids Incident Database 2010 - 2016 incl.

Oil Spill Behavior & Impact

- Conceptual Model
  - 3D Hydrodynamic Model – Time varying Currents and water levels
  - 2D Spectral Wave Model – Time varying wind generated wave heights
  - 2D/3D Oil Spill Transport and Processes Model.



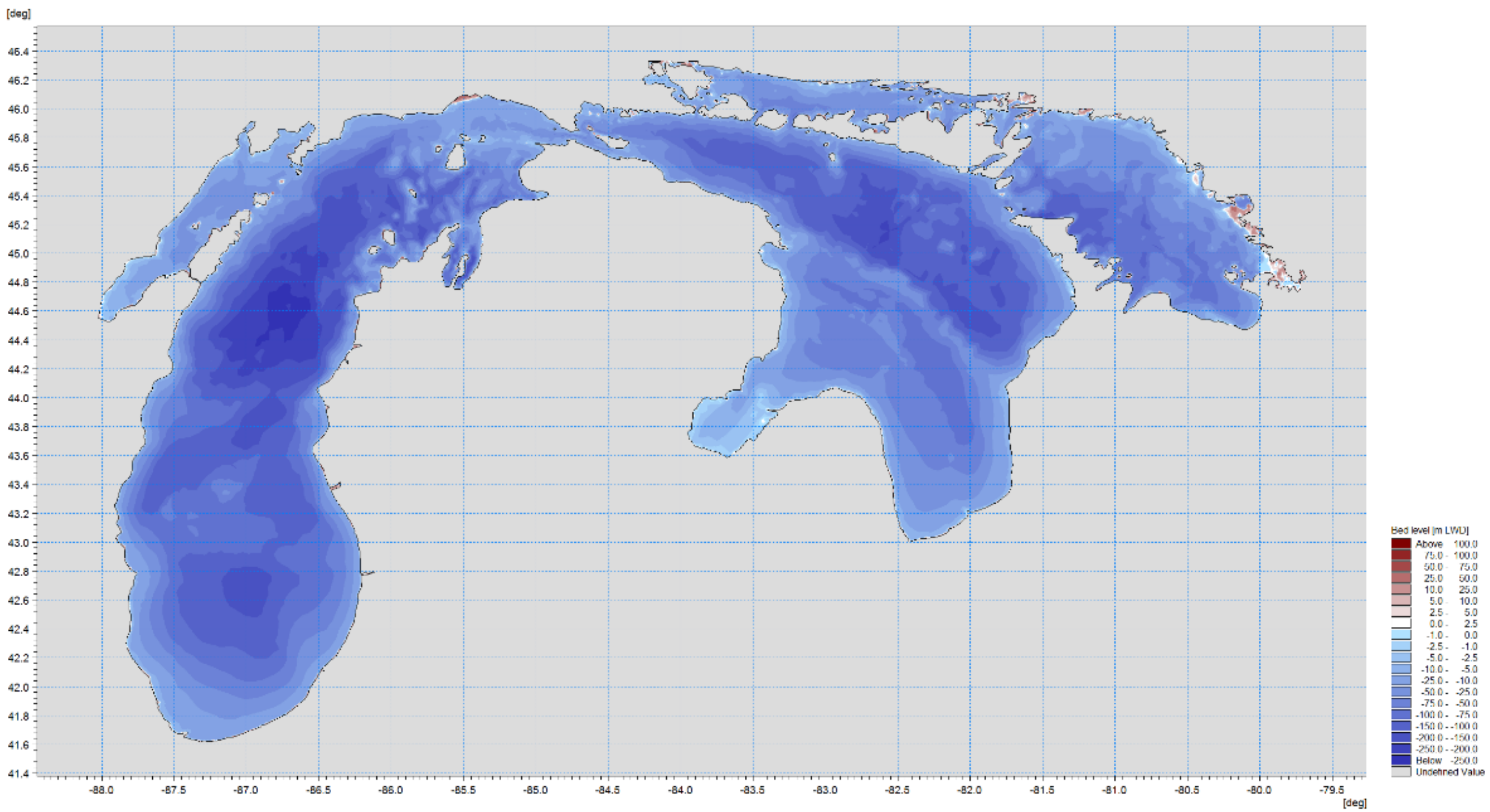
- 3D Hydrodynamic Model – MIKE 3 FM HD
  - Flexible Mesh of bathymetry
  - 2D Winds, Pressure and Ice Fields
  - Calibration and Validation to Measurements
- 2D Spectral Wave Model – MIKE 21 FM SW
  - Flexible Mesh of bathymetry
  - 2D Winds and Ice Fields
  - Calibration and Validation to Measurements
- Oil Spill Transport Model – MIKE 21/3 OS (Oil Spill)
  - Scenario – Location, Pipe, Rupture, Puncture, Oil Type, Rate and Duration of Discharge
  - Flexible Mesh of bathymetry
  - 3D Current and water level fields – from MIKE 3 FM HD
  - 2D Winds Fields
  - 2D Wave fields – from MIKE 21 FM SW
  - 2D Exposure, probability maps

Oil Spill Behavior & Impact

- Oil spill behavior modeled using DHI MIKE 21/3 OS (Oil Spill) module of MIKE 3 Flow Model (3D hydrodynamic model)
  - Predicts spreading, drift and weathering of spilled oil
  - Inputs:
    - Environmental conditions (temperature, wind speed, water currents, water levels, waves, ice)
    - Bathymetric Profile
    - Oil properties
- Data Sources
  - NCEP - National Center for Environmental Prediction (hourly wind hindcast data)
  - NOAA Bathymetry and Global Relief Datasets (DEM of Lakes Huron, Michigan & Straits)
  - NOAA National Data Buoy Center (hourly water levels)
  - ADCP buoys (wave parameters, current speed at various depths)
  - NOAA Great Lakes Environmental Research Laboratory (gridded ice concentration data)
- 30-day simulation length
  - Assumes no response or intervention
  - Allows full development of spill
- 120 separate simulations per spill
  - Varying environmental inputs representative of conditions over 12-month period
    - Probability maps of spill extent
    - Zone of exposure maps (ZOE)

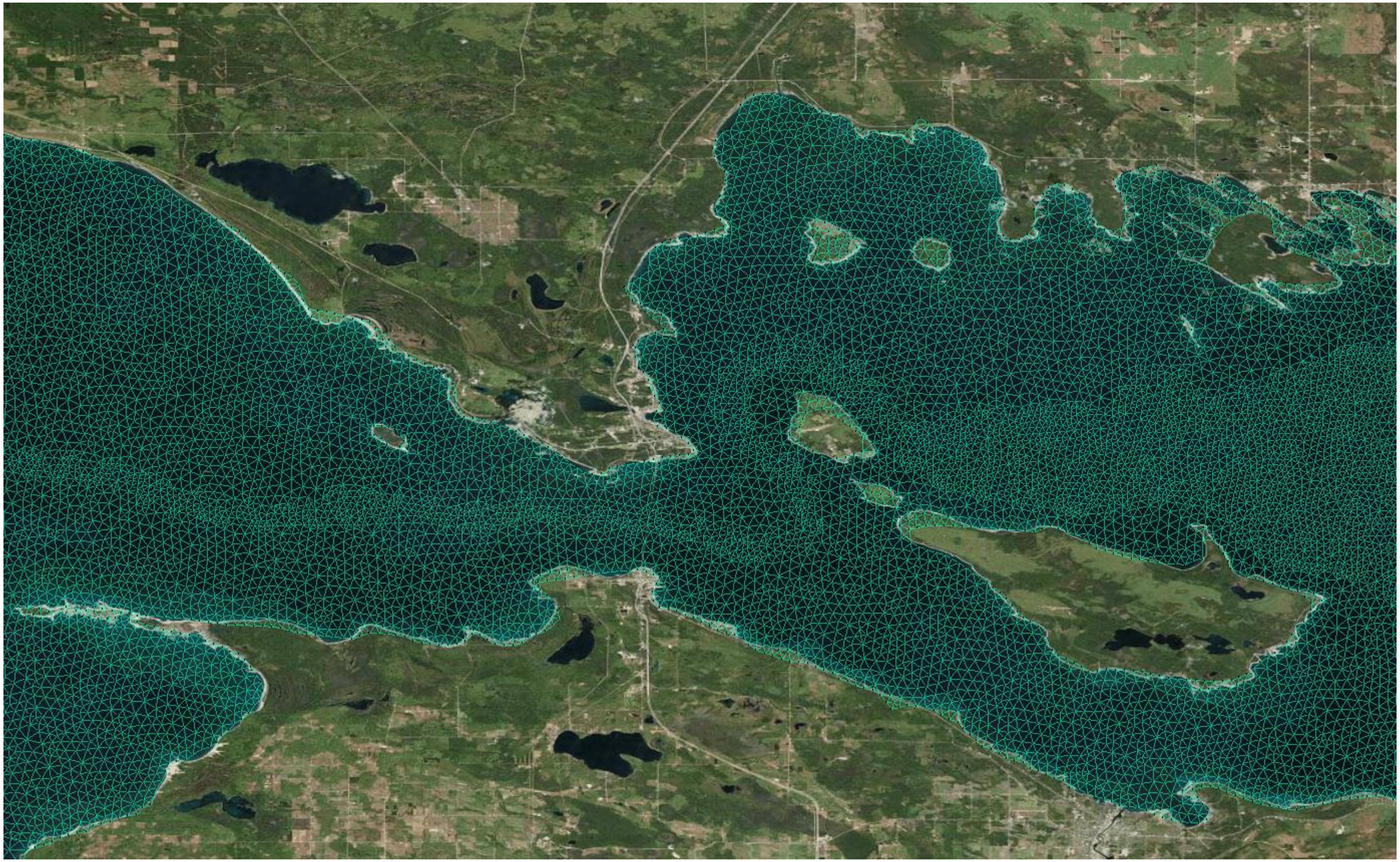
Numerical Model Bathymetry Mesh

- Model Mesh – same used for all three models (HD, Waves and Oil Spill)
  - 52852 Elements
  - 30093 Nodes
  - 20 vertical layers – sigma – equidistant in 3D model
  - Same mesh used for hydrodynamic, wave and oil spill models



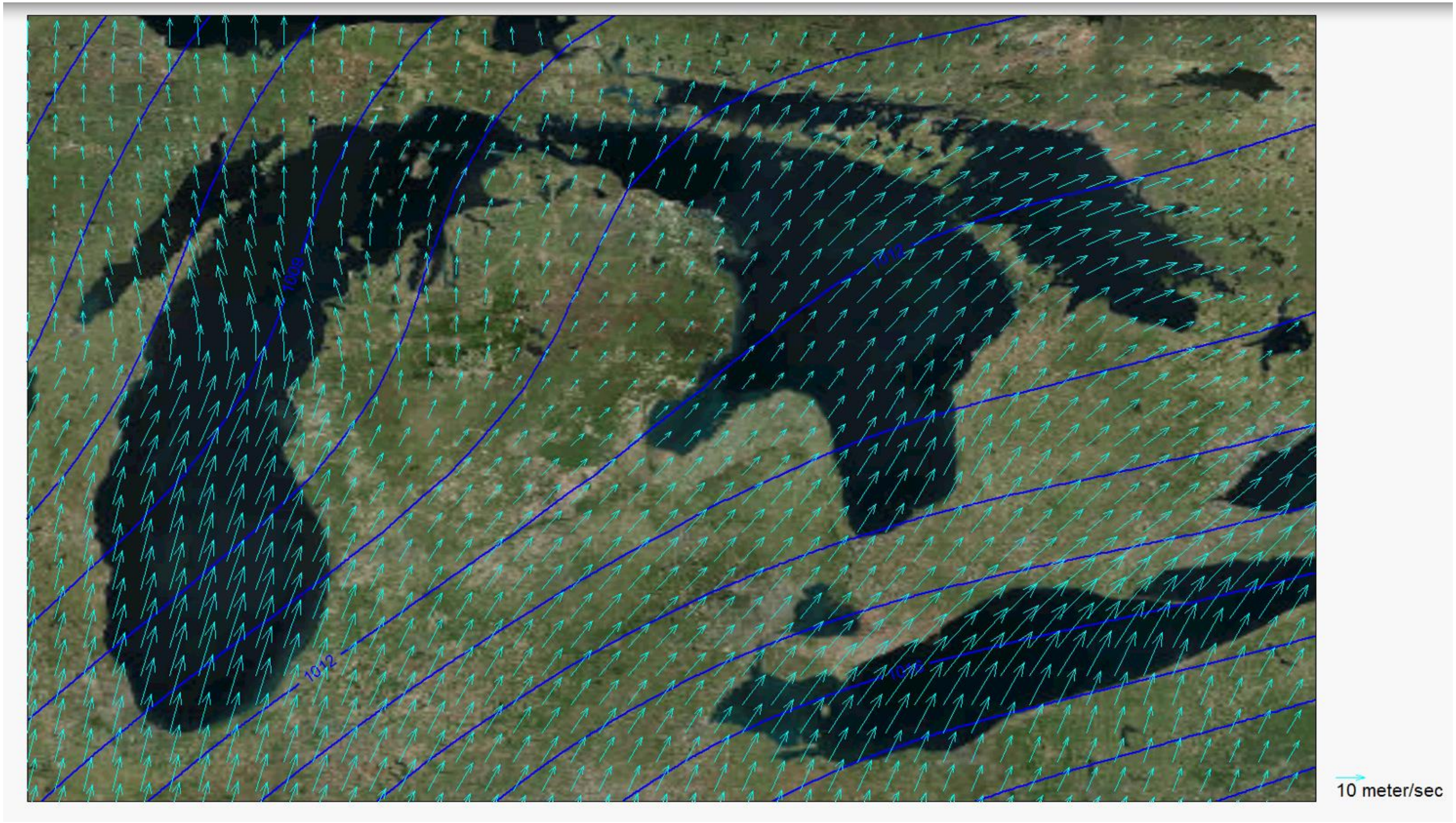
Numerical Model Bathymetry Mesh

- Model Mesh
  - Zoom in around Strait



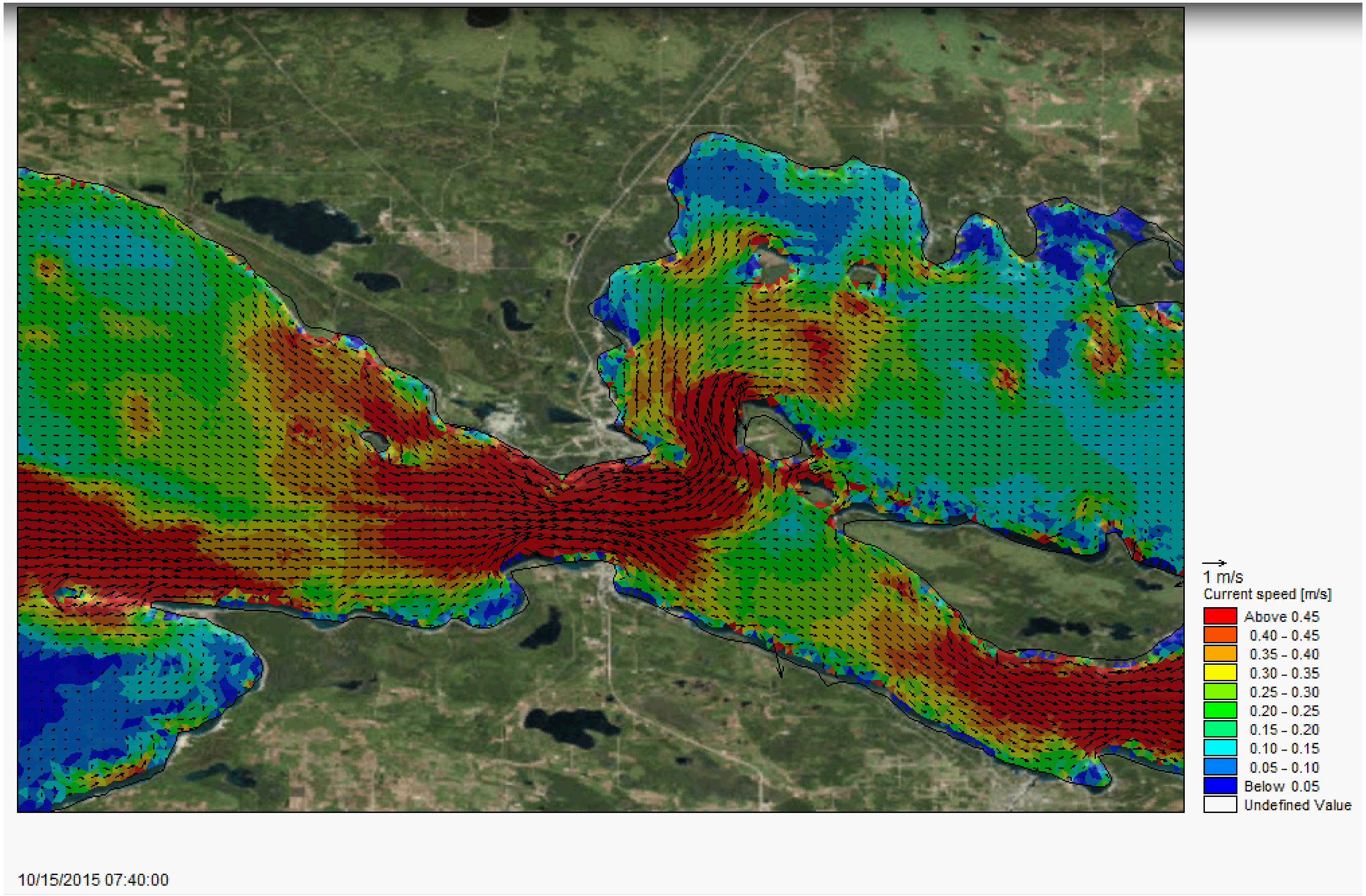
Wind and Pressure Fields

- Wind and Pressure Field - CFSR2 wind data from NCEP/NOAA



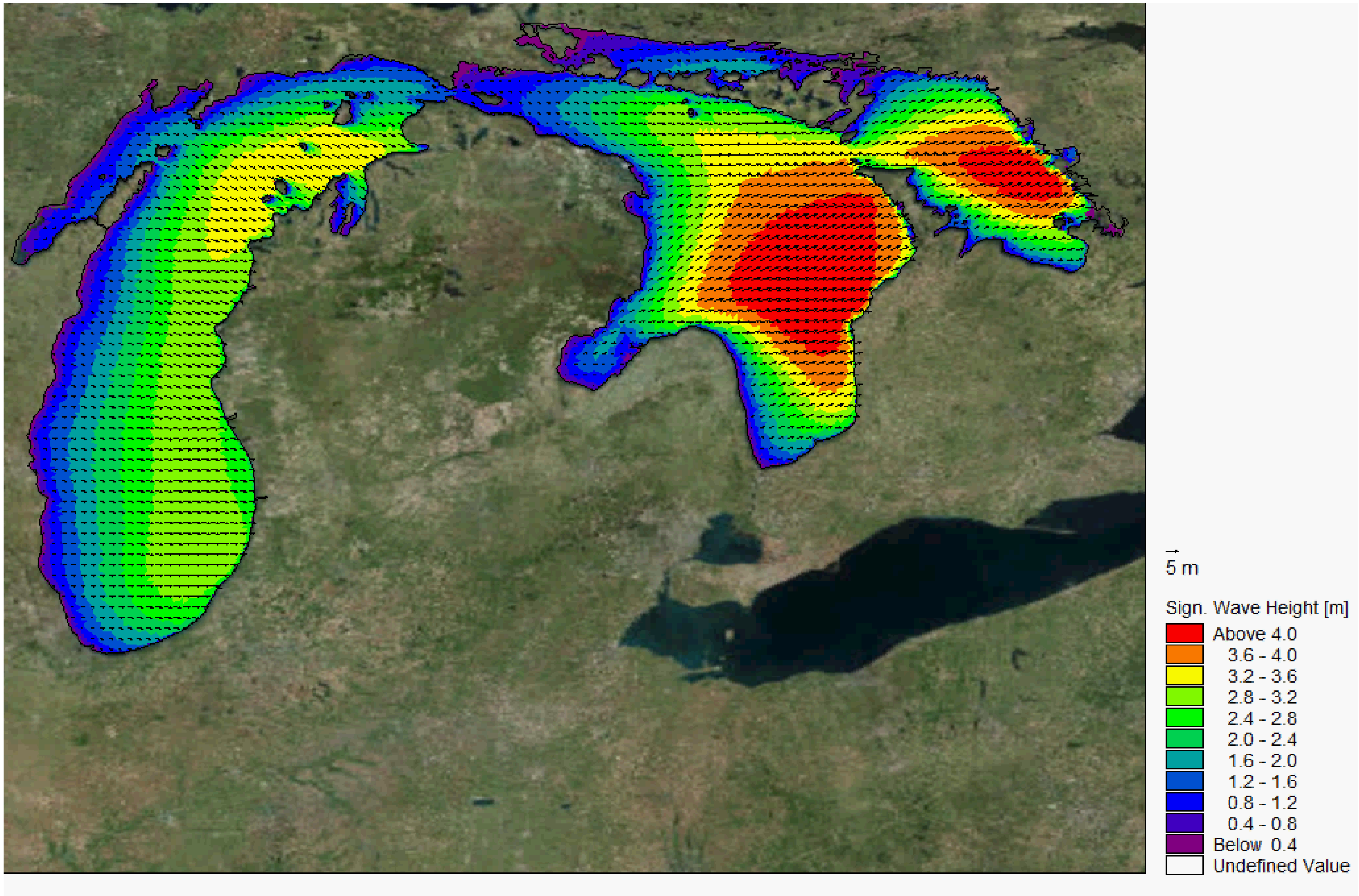
Current Modeling

- MIKE 3 HD Hydrodynamic Model Current Field – Surface Layer



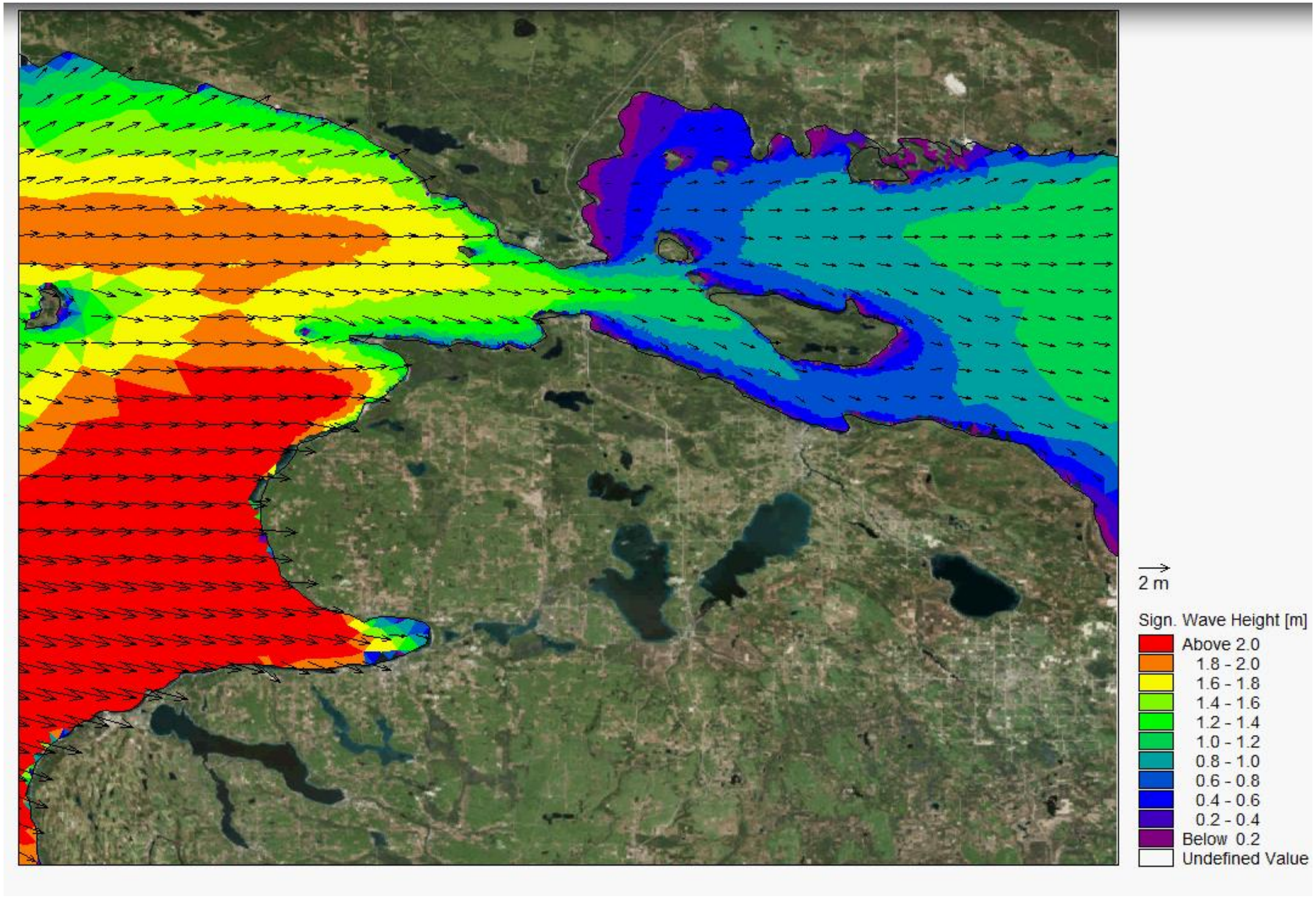
Wave Modeling

- 2D Spectral Wave Model Wave Height Field

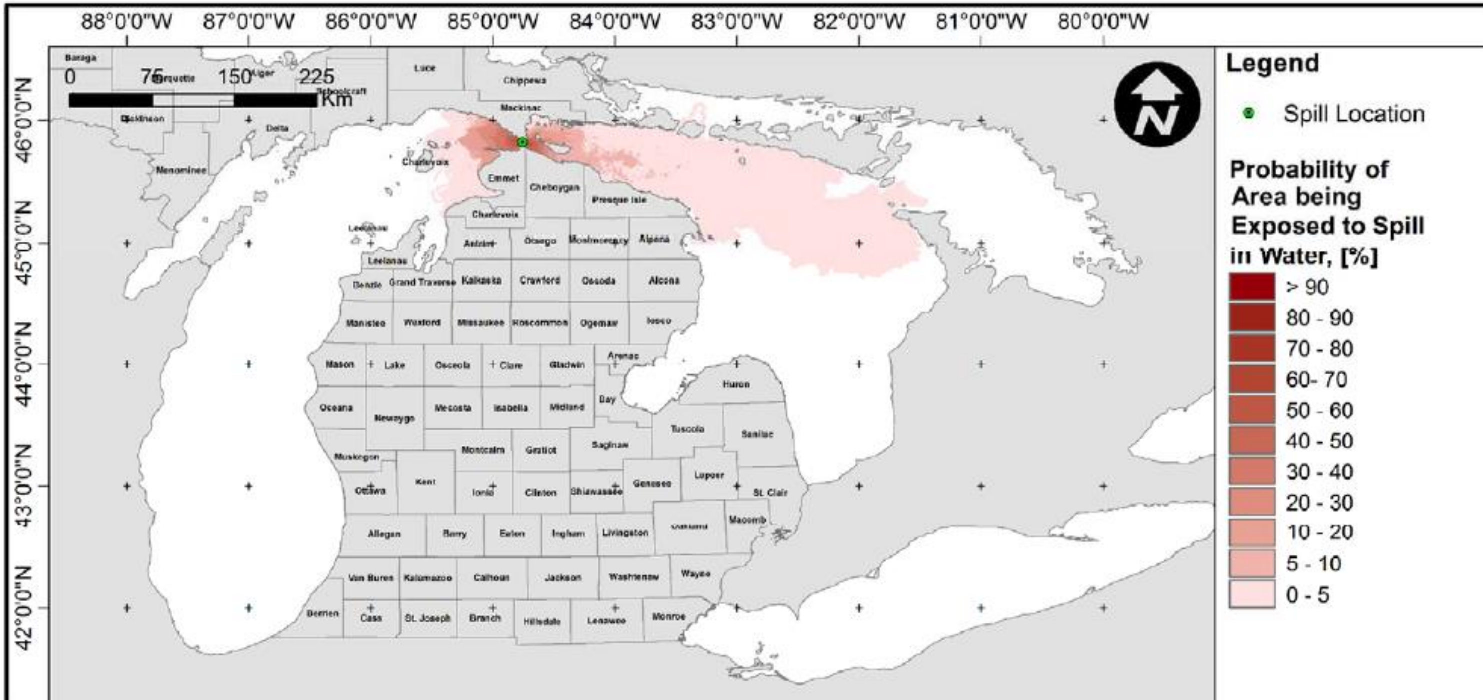


Wave Modeling

- 2D Spectral Wave Model Wave Height Field



Spill Extent Probability Map – Existing (Rupture)



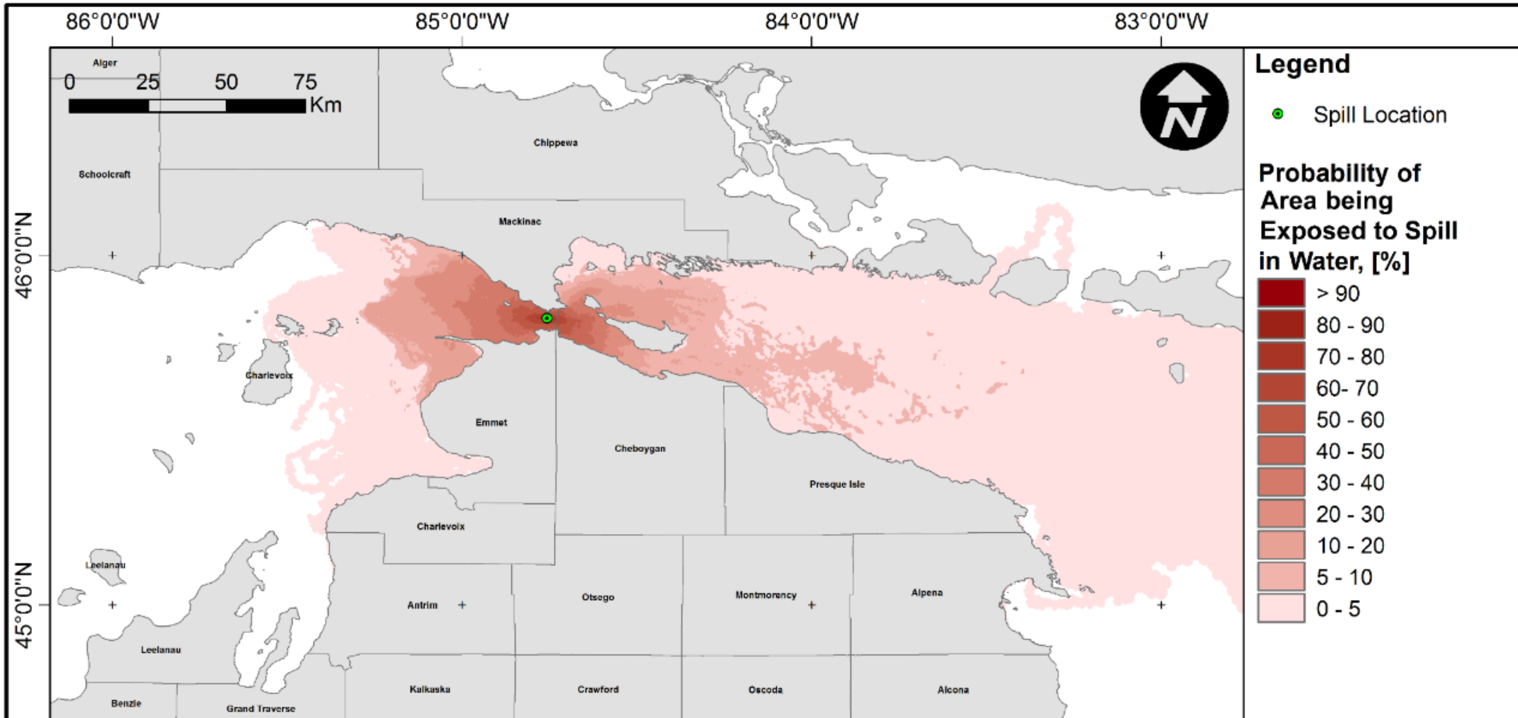
Probability of Area being Exposed to Spill in Water (combined 120 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 120 simulations (threshold 0.01g/m²)

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m³**

Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

Spill Extent Probability Map – Existing (Rupture)



Probability of Area being Exposed to Spill in Water (combined 120 simulations, zoomed in)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 120 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
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Coordinate System:
Datum: WGS 1984
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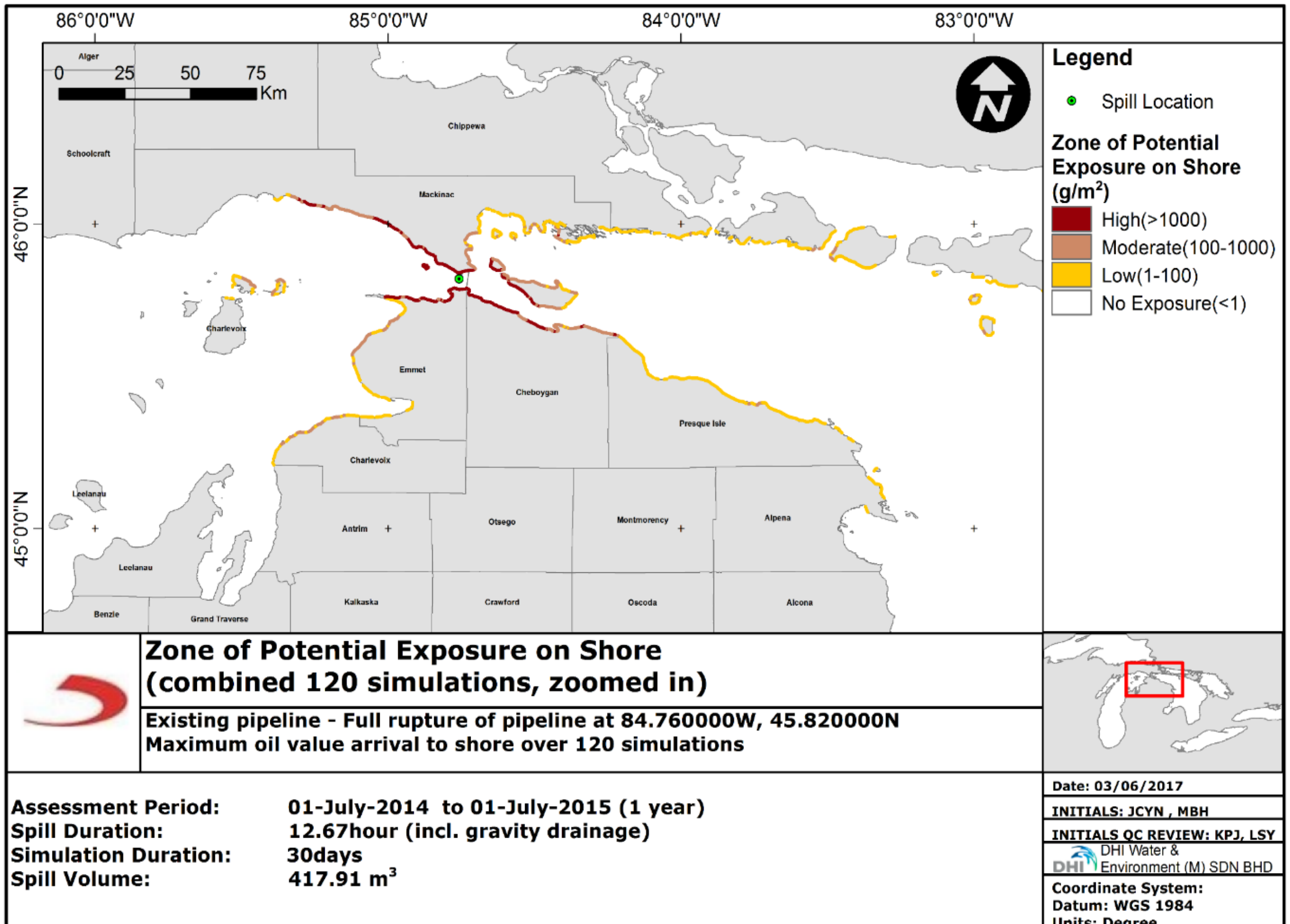
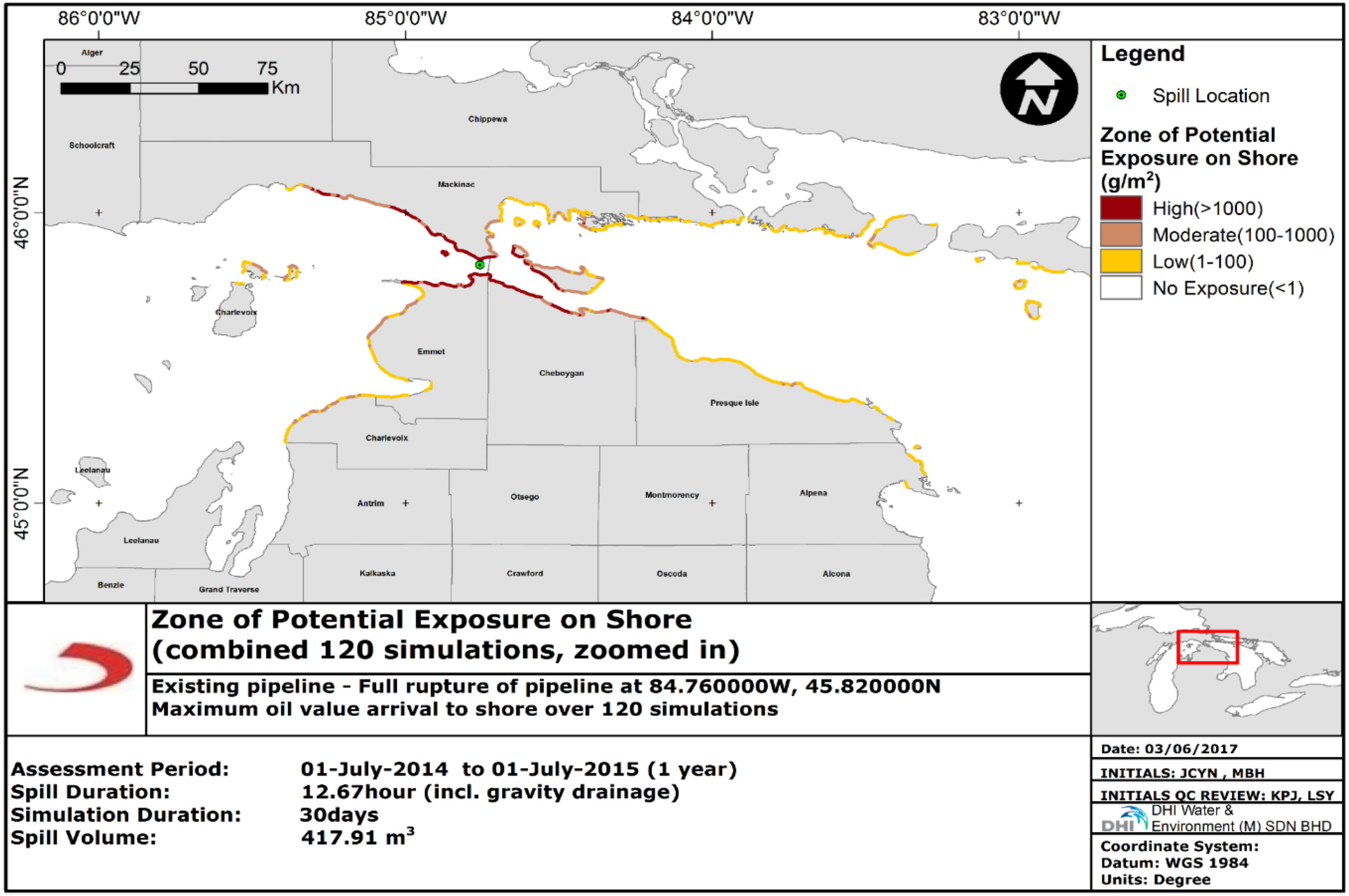
Zone of Exposure Map – Existing (Rupture)

- Maximum value at shoreline from 120 simulations
  - Low (barely visible sheen but with fishing prohibitions)
  - High (harmful to all birds coming into contact with slick)



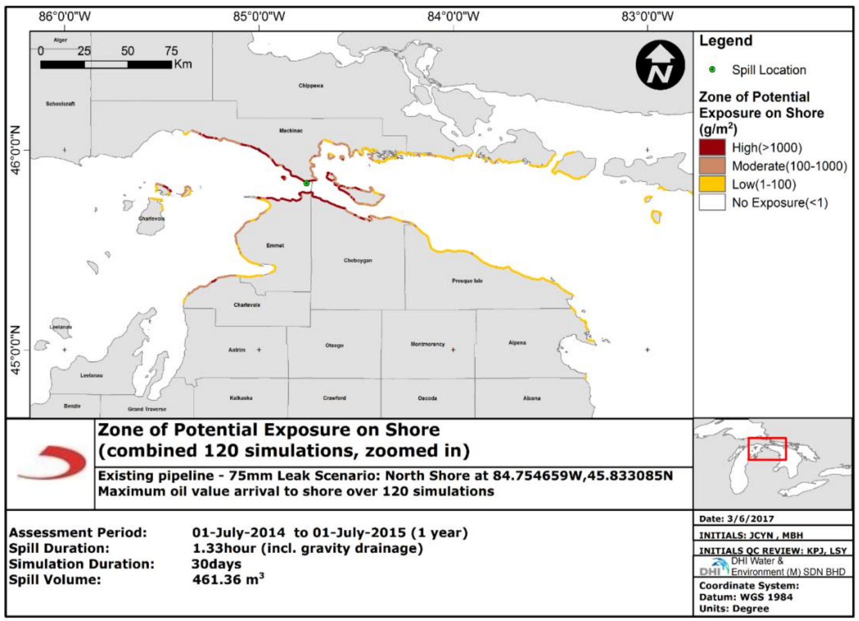
Arrival Time to Shore Map – Existing (Rupture)

- Shortest arrival time from 120 simulations

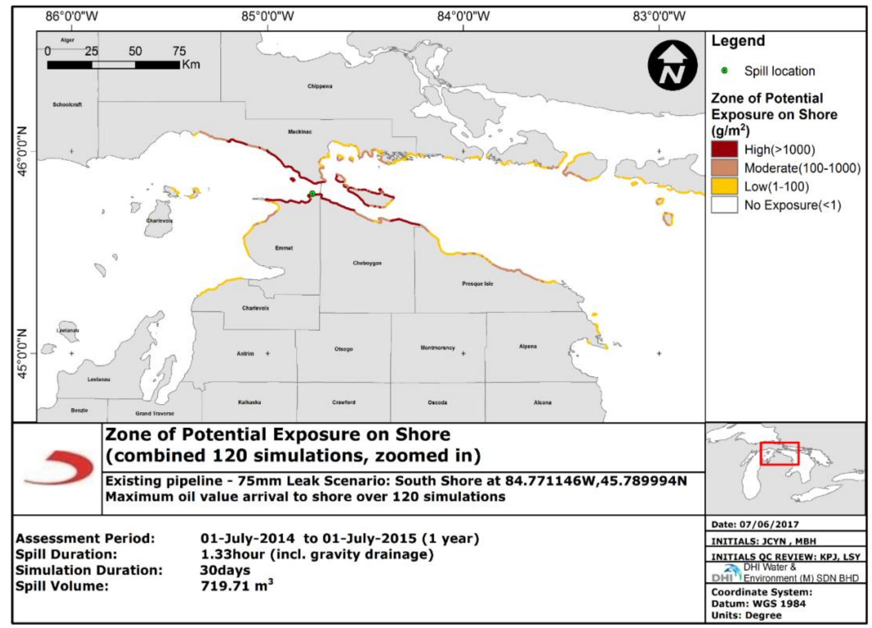


Zone of Exposure Maps – 3-in. Hole

Near-north shore: 2902 bbls



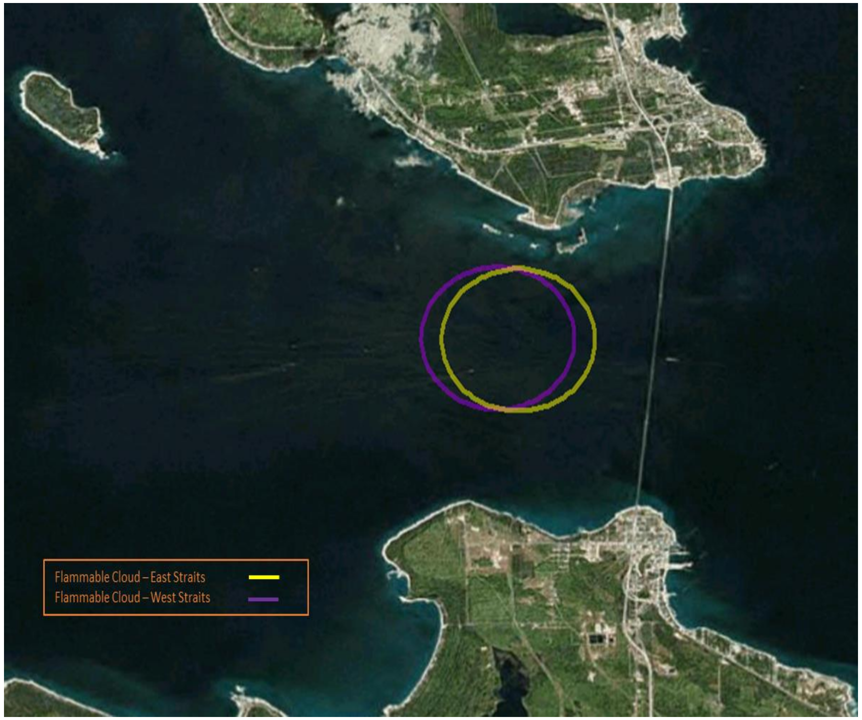
Near-south shore: 4527 bbls



NGL Release Model

- PipeTech CFD Software used to simulate phase change, depressurization and release rates in underwater environments
- 5 scenarios of water depth and hole size modeled
- Flame envelope radii: Rupture: 4729 ft., Leak: 1526 ft.

Rupture



Leak

Spill Costs – Model and Assumptions 1

- Model
  - Incorporates about 4 decades of North American and International spill data
  - Estimates total spill cost as:
    - Total Cost = Cleanup Costs + Damage Costs
  - Damage costs include environmental damage and restoration plus compensation to those impacted by spill and dependent on natural resources
  - Reflects spill volumes, incidence on high consequence areas, cleanup method, season, and other factors
  - Excludes fine and penalties
  - Model is intended for evaluation of hypothetical sets of spills for insurance purposes, comparisons of different conditions, and project planning within context of cost-benefit analysis or comparative cost-effectiveness analysis
  - Model is not intended for damage claim settlement

Spill Costs – Model and Assumptions 2

- Calibrated for Michigan
  - Factors in 1.26 multiple for US Midwest per API cost estimating findings (2017)
  - Replicated Marshall Michigan 2010 spill cost results within -30%/+50% tolerances of model: model estimate was $935 million to be compared to $1,215 million filed by Enbridge in its FERC Form 6 (April 2017)
- Local Land-Use
  - GIS interpreted land-use in entire 9 county zone of exposure at township level within 1500′ coastal strip
  - GIS interpreted land-use in 1500′ strip on either side of rail and pipeline centerline for Alternative 1 and Alternative 3 and use of sensitive areas based on PHMSA populated areas and national wetland inventory of all sensitive ecosystems
  - Recognition of 100% of Lake Michigan as "HCA" in view of environmental significance and cultural significant tribal waters
- Other Assumptions
  - Outflows as described elsewhere in this study
  - Shoreline oiling as described elsewhere in this study

Spill Costs – Model and Assumptions 3

- Models based on predicted outflow and fates
- This table shows mean fate of 120 spills from south shore release
- 95% of all of these spills involved <60 miles of shoreline oiling
- Most oiling was in Cheboygan, Emmet and Mackinac counties

Indicator	Alternative 5 Existing Crossing	Alternative 4a Trenched Crossing
Outflow	4,527 bbl	9,801 bbl
Total Shoreline Oiling (mean 120 spills)	20.8 mi.	24.7 mi.
Total in Core Zone 3 Counties[a]	19.5 mi.	23.2 mi.
Total in Remaining 6 Counties in ZOE[a]	1.3 mi.	1.6 mi.

Notes:

[a]Core Zone counties include Cheboygan, Emmet, and Mackinac. The remaining counties in the Zone of Exposure (ZOE) include three neighboring counties (Charlevoix, Chippewa, and Presque Isle) and three other counties (Alpena, Antrim, and Grand Traverse).

Spill Costs – Results

Alternative 5 (Status Quo) South Shore leak (4,527 bbl)

Max Spill Cost at means = $146 million

Max Spill cost at 95th percentile of South shore spills = $200 million

Alternative 4a (Trenched 30" Pipeline) South Shore leak (9,800 bbl)

Max Spill Cost at means = $237 million

Max Spill cost at 95th percentile of South shore spills = $310 million

This table shows expected values at the means of 120 spill simulations for the spills into Mackinac Straits, with and without ice.

The expected spill cost from a 3,784 bbl rupture into an HCA from the southern pipeline is $112 million.

The median rail spill of 462 barrels into an HCA has an expected cost of about $22 million.

Scenario	Oil Volume bbl		Total Costs million $	Total Costs (million $) Clean up Costs	Damage Costs
Alt 5 Mid-Channel	2629	HCA Shoreline	105.44	42.18	63.26
		HCA Ice	92.10	36.84	55.26
Alt 5 North	2902	HCA Shoreline	111.67	44.67	67.00
		HCA Ice	97.92	39.17	58.75
Alt 5 South	4527	HCA Shoreline	146.71	58.68	88.03
		HCA Ice	128.91	51.56	77.35
Alt 4a Mid-Channel	5859	HCA Shoreline	173.05	69.22	103.83
		HCA Ice	151.20	60.48	90.72
Alt 4a North	5820	HCA Shoreline	171.88	68.75	103.13
		HCA Ice	150.58	60.23	90.35
Alt 4a South	9801	HCA Shoreline	237.29	94.92	142.37
		HCA Ice	207.85	83.14	124.71
Alt 1 Rupture	3784	HCA	112.45	44.98	67.47
		non-HCA	72.66	29.06	43.60
Alt 1 Puncture	300	HCA	15.34	11.13	4.21
		non-HCA	9.91	7.19	2.72
Alt 1 Leak	57	HCA	4.88	4.55	0.33
		non-HCA	3.15	2.94	0.21
Alt 3 S Rail	462	HCA	21.97	13.88	8.09
		non-HCA	14.20	8.97	5.22

Spill Costs – Results

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Operating Risk Results

	Alt 5 Existing Operations (Base Case)	Alt 4a New Trenched Crossing	Alt 4b New Tunnel Crossing	Alt 6 Abandon Line 5 & Crossing	Alt 1 New Pipeline Route	Alt 3 Alt Transport (Rail)
Principal Threats	Anchor Drag, Incorrect Operations, Spanning, Vortex-Induced Vibration	Anchor Drag, Incorrect Operations	Negligible	N/A	Per Incident Statistics	Per Incident Statistics
Zone of Exposure	Core: Mackinac, Emmet, Cheboygan; Other: Chippewa, Charlevoix, Presque Isle, Antrim, Grand Traverse, Alpena		None	N/A	~762 mi. of WI, IL, IN, MI (MI = ~226 mi)	~800 mi. of WI, IL, IN, MI (MI = ~240 mi.)
Oil Spill Outflow – Rupture (bbl)	2,629	5,859	None	N/A	3,784	Median Spill 462 bbl
Oil Spill Outflow – Puncture (bbl)	N/A	N/A	None	N/A	300	
Oil Spill Outflow – Leak (bbl)	North: 2,902; South: 4527	North: 5,820 South: 9,801	None	N/A	57	
Failure Frequency -Rupture (/y)	3.575×10^{-04}	2.430×10^{-06}	Negligible	N/A	1.84×10^{-02}	2.891
Failure Frequency – Puncture (/y)	N/A	N/A	Negligible	N/A	1.67×10^{-03}	
Failure Frequency – Leak (/y)	1.007×10^{-04}	5.040×10^{-05}	Negligible	N/A	0.187	
Safety Risk (fatalities/y)	2.69×10^{-06}	1.68×10^{-07}	Negligible	0.00	3.66×10^{-01}	2.24
Total Economic Risk ($/y)	41,500[a]	8,870[a]	Negligible	0.00	1,920,000[a]	49,700,000[a]
Monetized Environmental Risk ($/y)	24,900[a]	5,320[a]	Negligible	0.00	841,000[a]	18,300,000[a]

Notes:

[a]results may reflect rounding

Risk Summary for Alternatives

Alternative	Risk Multiple, Relative to Base Case (Existing Crossing)		
	Safety Risk	**Monetized Environmental Risk**	**Total Economic Risk**
Alternative 3 (Rail Transport)	830,000 X Base	734 X Base	1,196 X Base
Alternative 1 (New Pipeline)	136,000 X Base	34 X Base	46 X Base
Alternative 4a (New Trenched Straits Crossing)	0.062 X Base	0.214 X Base	0.214 X Base
Alternative 4b (New Tunnel Crossing of the Straits)	Negligible	Negligible	Negligible
Alternative 6 (Abandonment of Line 5 and Straits Crossing)	Zero	Zero	Zero

Components of Analysis

- Feasibility Analysis
- Design-based cost estimates
- Economic feasibility
- Socio-economic Impacts
  - Jobs, income, government revenue
  - Social impacts
- Spill risk analysis
  - Compare risk of infrastructure required to replace existing Straits Segments
  - Existing Straits Segments considered as Base Case for comparison purposes
    - Threat assessment
    - Spill Probability assessment
    - Safe and reliable operating life
    - Spill release modeling
    - Oil spill behavior and impact modeling
    - NGL release modeling
    - Spill consequence analysis (Safety, Environment, Economic Impact)
- Market Impacts

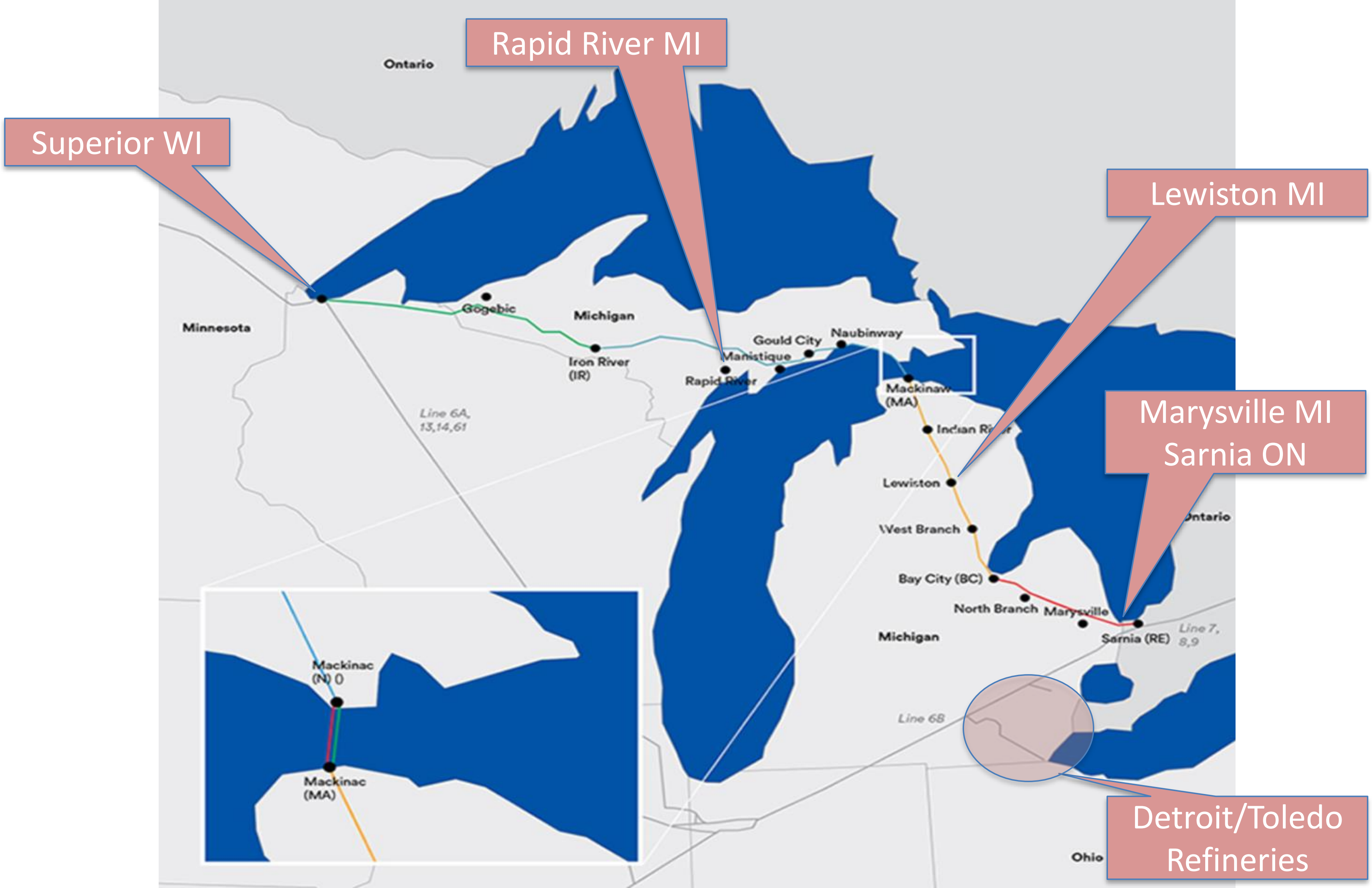
Market Impacts – Approach & Assumptions 1

- Lakehead System
  - Line 5 NGL Deliveries to Rapid River – annually for 2,000 bbl/d propane consumption (peak ~ 3,000 bbl/d)
  - Line 5 Crude Injection at Lewiston – annually 10,000 bbl/d light crude (peak ~ 12,000 bbl/d)
  - Line 5 Throughput – annually 540,000 bbl/d (of which 90,000 bbl/d NGL)
  - Total Lakehead System throughput (FERC regulated) 2,600,000 bbl/d (includes Line 5)
  - Lakehead System Delivery Capacity near Line 5 Terminus 1,110,000 bbl/d (includes Line 5)
- Detroit and Toledo Refineries
  - Detroit Refinery 132,000 bbl/d capacity
  - Toledo Refineries 330,000 bbl/d capacity
- Michigan Consumers
  - Upper Peninsula Propane Consumers (about 30 million gallons a year current supply via Rapid River)
  - Michigan consumers would experience increased costs of transportation fuels (gasoline and other refined petroleum products); current consumption is approximately 5,700 million gallons a year

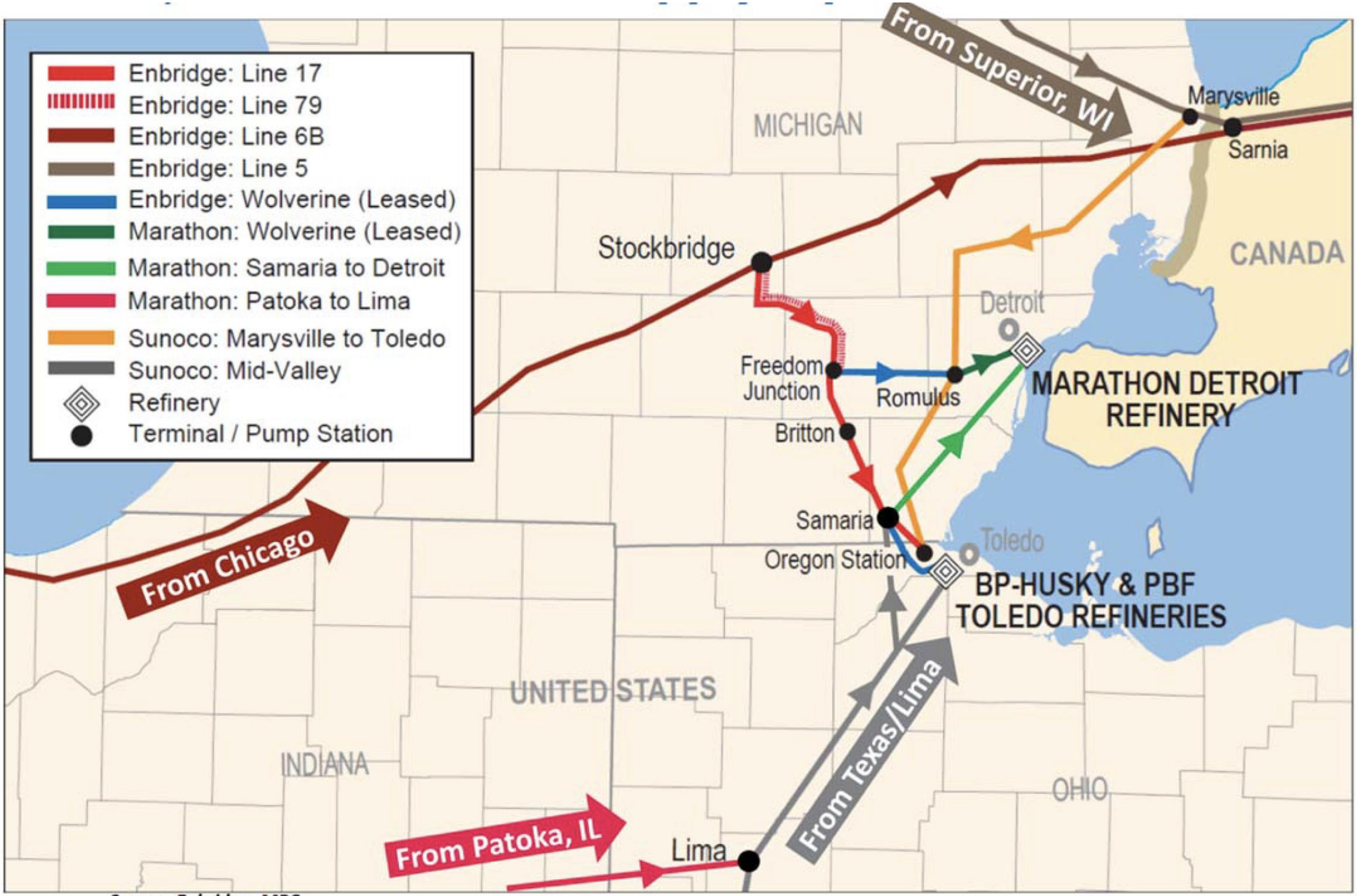
Market Impacts – Approach & Assumptions 2

- Impacts of Costs and/or Shortages on System
  - New construction imposes costs in Lakehead System distributed over system throughput
  - Abandonment implies existing system costs (including Line 5 fixed costs) and abandonment costs are carried by remaining (lower) system throughput (2,060,000 bbl/d)
  - Near-term crude shortages associated with abandonment are handled via system apportionment in Sarnia/Marysville Area and to Detroit/Toledo refineries. Refiners still receive some crude through Lakehead system but revert also to Mid-Valley pipeline for southern crude supply and potentially increased rail or truck deliveries
  - Local loss of pipeline services (Rapid River and Lewiston) met by increased cost of service using truck and rail for propane, and truck at Lewiston
- A Note on Market Impacts
  - Intended to demonstrate hypothetical maximum impacts on consumers, refiners, or producers and are regarded as appropriate for comparison of alternatives

Market Impacts – Line 5 in Lakehead System



Market Impacts – Detroit/Toledo Refineries

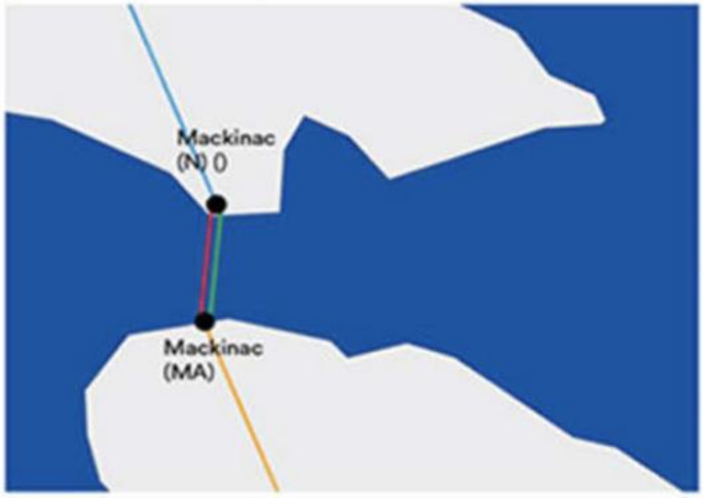


Source: Enbridge, MPC

See Appendix F. Note: Line 6B right of way now pertains to Line 78.

Market Impacts – Results Alternative 4

- Throughput Impacts – No Change
  - NGL Deliveries to Rapid River – no change from Status Quo
  - Crude Injection at Lewiston – no change from Status Quo
  - Total Lakehead System throughput – no change from Status Quo
  - Lakehead System Delivery Capacity near Line 5 Terminus 1,110,000 bbl/d (includes Line 5)
- Cost Impacts – Negligible
  - < $0.01/bbl on Lakehead system tariffs



Market Impacts – Results Alternative 6 1

- General Impacts
  - Deliveries to Rapid River interrupted and propane served by truck and rail via Kincheloe to a Rapid River distribution facility
  - Injections at Lewiston interrupted and crude collected at Lewiston terminal and Markwest pipeline by truck for delivery to Marathon refinery in Detroit
  - Apportionment (rationing) of supplies to Detroit, Toledo, Sarnia refineries, and Eastern Canada and Eastern US refineries
  - Abandonment costs rolled into Lakehead System regulated rate base and increased rates generally due to lowered system throughput

Market Impacts – Results Alternative 6 2

- Local Impacts – Upper Peninsula Propane
  - 10¢/gallon to 35¢/gallon for propane on 2,000 bbl/d average
  - Least cost alternative will cost additional $3.1 million/y to consumers
- Local Impacts – Lower Peninsula Crude Oil Injection
  - $2.40/bbl additional for crude delivery to market on 10,000 bbl/d average
  - Least cost alternative will cost additional $8.7 million/y to producers
    - Note: this may be reduced somewhat through lower payments to the State, but impact still all borne within Michigan
- Impacts on Refiners and Consumers
  - Detroit and Toledo average cost of crude increases by $0.76/bbl
  - Consumer prices of gasoline and refined petroleum products increase by 2.13¢/gallon
  - Impacts equate to additional $121 million/y to Michigan consumers

Questions

Guidance on evaluating the draft Line 5 Alternatives Report in preparation for commenting on report or attending meeting:

1. Clarity: Are any parts of the report confusing and need clarification?
2. Data: Are there any sources of information that should have been included that were not?
3. Completeness: Upon review of the report, did the contractor fail to cover a key topic? If something was left out, was the reason for doing so addressed and is the reasoning sufficient for the exclusion?
4. Methodology: Was the methodology understandable or does more information need to be given? Is it sufficient to accurately address the questions presented? Are there any flaws in the methodology used?
5. Cost: Are all cost components identified, or is there a category of costs that were not considered?
6. Report Assumptions: Are the assumptions in the report realistic? Are they explained well?

Notation

- *This presentation is based upon the Draft Final Report dated June 27 2017 (Rev 1). Thus it is subject to change should information be made available.*
- *Information from these slides should consider information details from the Draft Final Report, and in the event of any potential discrepancy with these slides, the Draft Final Report takes precedence.*