

Dynamic Risk

Attachment 1: Pipeline Rupture Analysis Report

Attachment 01 Interglobe Final Report.pdf

Pipeline Rupture Analysis Report
Client: Dynamic Risk, Canada

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ENBDNR0002011

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1. Introduction

Dynamic Risk has contracted Interglobe Ltd. to conduct a number of simulations using the pipeline rupture CFD computer programme, PipeTech to determine the outflow for a number of hypothetical failure scenarios for a long distance high pressure LPG (Liquefied Petroleum Gas) transmission pipeline. This report presents PipeTech's background theory and its validation against available field data, the scope of work followed by presentation and discussion of the simulation results obtained using PipeTech.

2. PipeTech's Background Theory

PipeTech is a rigorous CFD computer programme for predicting the transient fluid flow dynamics following the failure of pressurised pipelines. Its background theory, based on the numerical solution of conservation equations using the Method of Characteristics (Zucrow and Hoffman, 1976) is presented in a number of peer reviewed publications (Mahgerefteh et al., 1999, 2000, 2003, 2006a-d, 2007 to 2009).

Briefly, PipeTech accounts for real fluid behaviour through the use of a suitable Equation of State in conjunction with a rigorous thermodynamic package. Fluid/wall phase and flow dependent heat transfer and friction effects are modelled using established correlations. PipeTech accounts for inclined pipelines, puncture orientation, handles single or multi-component mixtures of up to 70 different components, supercritical pure components and simulates forward and reverse flows. Both isolated and un-isolated flows where pumping at the high pressure end continues despite pipeline failure are modelled. In the case of full bore pipeline rupture, outflow is simulated from both intact sections of the severed pipeline.

In the case of unsteady generalised 1-D flow, the mass, momentum and energy conservation equations for an element of a fluid within the pipeline are respectively given by (Mahgerefteh et al., 2009):

$$\frac{d\rho}{dt} + \rho\frac{\partial u}{\partial x} = 0 \qquad (1)$$

$$\rho\frac{\partial u}{\partial t} + \rho u\frac{\partial u}{\partial x} + \frac{\partial P}{\partial x} = \alpha \qquad (2)$$

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$$\rho\frac{dh}{dt}-\frac{dP}{dt}-\left(q_h-u\beta_y\right)=0 \qquad (3)$$

where ρ, u, P and h are the density, velocity, pressure and specific enthalpy of the homogeneous pseudo fluid as a function of time, t and distance, x along the pipeline respectively. q_h is heat transfer across the pipe wall to the fluid, while β_y, is the friction force term given by:

$$\beta_y=-2\frac{f_w}{D}\rho u|u| \qquad (4)$$

where, f_w is the Fanning friction factor and D, the pipeline diameter.

Also,

$$\alpha=-\left(\frac{2f_w\rho u|u|}{D}+\rho g\sin\theta\right) \qquad (5)$$

Where θ, is the angle of inclination of the pipeline to the horizontal plane.

The solution of the above equations leads to a set of quasi-linear hyperbolic partial differential equations which can only be solved numerically. The Method of Characteristics (MOC) (Mahgerefteh et al., 2000) is used as the preferred numerical solution method (Mahgerefteh et al., 2003, 2006a,b) as opposed to other numerical techniques such as finite difference (Chen et al., 1993; Bendiksen et al., 1991) and finite element methods (Lang, 1991; Bisgaard et al., 1987) as both have difficulty in handling the choking condition at the rupture plane. The MOC handles choked flow intrinsically via the Mach line characteristics. Moreover, MOC is considered to be more accurate than the finite difference method as it is based on the characteristics of wave propagation. Hence, numerical diffusion associated with a finite difference approximation of partial derivatives is avoided (Bisgaard et al., 1987). The pertinent fluid properties and phase equilibrium data are determined using a suitable equation of state.

In essence MOC involves replacing the three conservation equations by the following characteristic and compatibility equations:

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$$\left(\frac{dt}{dx}\right)_p = \frac{1}{u} \qquad \text{(Path line characteristic)} \qquad (6)$$

$$\left(\frac{dt}{dx}\right)_{\pm} = \frac{1}{u \pm a} \qquad \text{(Mach line characteristics)} \qquad (7)$$

The characteristic equations 6 and 7 stipulate the way in which information is propagated through a flow field.

The Path line compatibility is:

$$dP - a^2 d\rho = \frac{\psi}{u} dx = \psi dt \qquad (8)$$

The positive and negative compatibility equations can be written as:

$$d_{\pm} P \pm \rho a d_{\pm} u = [\Psi \pm a\beta] dt \qquad (9)$$

The values of P, ρ, u, and a as a function of time and distance along the pipeline may be obtained by the inverse marching method of characteristics. This involves spatial and temporal discretisation of the pipeline, expressing the compatibility equations in finite difference form, and solving them at the intersection of the characteristics curves with the spatial axis. The previous time line properties are calculated directly from the solution of quadratic interpolation formulas for spatial discretisation.

3. Validation

3.1 Isle of Grain Pipeline Rupture Tests (Richardson and Saville, 1996a)

During the Isle of Grain depressurisation tests conducted by BP and Shell (Richardson and Saville, 1996a), two 100 m instrumented parallel carbon steel pipelines operating at different starting pressures were used. Both pipelines were 154 mm i.d. with a wall thickness of 7.3 mm. Pressure transducers and thermocouples were attached along each line. Inventory and hold-up were measured using load cells and neutron back scattering. The pipelines contained Liquefied Petroleum Gas (LPG). The exact fluid composition is not given, but Chen (1993) assumes a typical LPG mixture comprising 95-mole % propane and 5-mole % butane. The same mixture composition is adopted in this investigation.

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The Full Bore Rupture (FBR) tests were initiated by the rupture of a disc at the downstream end of the un-insulated pipelines exposed to still air. Table 3.1 presents detailed PipeTech input data used to simulate the test conditions for the two FBR tests; namely Test P40 (starting pressure 21.6 bara) and Test P42 (starting pressure 11.3 bara). For heat transfer calculations, respective values of 7854 kg/m^3, 434 J/kgK, and 53.653 W/m^2K for carbon steel are assumed for the wall density, specific heat capacity and thermal conductivity (Perry and Green, 1997). Unless otherwise stated, the Peng-Robinson (PR) Equation of State (Peng and Robinson, 1976) in conjunction with Twu-Coon-Cunningham (TCC) (Twu et al., 1991) mixing rule are used throughout these investigations to generate the relevant thermodynamics and phase equilibrium properties. The above equations have been found to produce accurate predictions for hydrocarbon mixtures at extensive ranges of pressures and temperatures (Walas, 1987). Chen's (1979) flow and phase dependent correlation for hydrocarbons is used to determine the friction factors.

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Table 1. PipeTech input data for the simulations of Isle of Grain P40 and P42 pipeline rupture tests.

Input		Test P40	Test P42
Inlet Parameters	Number of components	2	2
	Feed composition (mole %)	Propane - 95	Propane - 95
		n-Butane - 5	n-Butane - 5
	Feed inlet temperature (K)	293.15	293.15
	Feed inlet pressure (bara)	21.6	11.3
	Ambient temperature (K)	292.25	291.75
	Ambient pressure (bara)	1.01	1.01
Pipeline Characteristics	Length (m)	100	100
	External diameter (mm)	168.6	168.6
	Wall thickness (mm)	7.3	7.3
	Roughness (mm)	0.05	0.05
	Orientation to the horizontal plane (deg)	0	0
Rupture Conditions	Failure mode	FBR	FBR
	Failure location relative to the high pressure end (m)	100	100
	Rupture diameter (mm)	154	154
	Discharge coefficient	1	1
Other Parameters	Feed flow rate prior to rupture (m^3/sec)	0	0
	Pumping cessation time following pipeline failure (s)	0	0
	Pump shut-off head (bara)	110	110
	Grid system used	Simple	Simple
	Number of grid points specified	50	50
	Equation of State	PR	PR
		TCC Alpha parameter	TCC Alpha parameter
	Mixing rule	TCC	TCC
	Friction factor correlation	Chen	Chen
	Heat transfer coefficient (W/m^2K)	Automatically determined (Un-insulated pipeline exposed to still air)	Automatically determined (Un-insulated pipeline exposed to still air)
	Total depressurisation time (s)	25	25

3.1.1 Test P40

Figure 1 shows open end pressure-time histories for the LPG mixture for the P40 FBR Test. Curves A and B show the measured and the predicted data using PipeTech respectively. The transition of the compressed liquid to saturation conditions upon

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rupture is marked by a rapid, almost instantaneous drop in the discharge pressure to ca. 6 bara. The slight undershoot in the open end pressure measurement (curve A) at the early stage of depressurisation is most probably attributed to non-equilibrium effects such as delayed bubble nucleation. This trend is then followed by a relatively slow pressure transient corresponding to the evaporation of the two-phase mixture to pure vapour at about 20 s following rupture. It is interesting to note that the measured open end pressure falls below 1 bara towards the end of the blowdown. This is however within the quoted pressure measurement uncertainty range of ±0.5 bara.

Figure 2 shows the corresponding closed end pressure vs time data for Test P40. Curve A represents measured data, while curve B presents the predicted data. As with the open end data, a rapid drop in pressure to saturated liquid conditions occurs upon FBR. Following this rapid transient, the pressure at the closed end remains approximately at the saturation pressure for a further 7 s, gradually dropping to ambient pressure. Theory and experiment are in good accord.

Figure 3 shows the measured (curve A) and predicted (curve B) temperature vs time profiles at the rupture plane for Test P40. The rapid expansion of the inventory at the rupture plane results in a significant and almost monotonous decrease in its temperature to ca. 236 K at 20 s following rupture. The subsequent rapid recovery in the fluid temperature is due to the warming of the gaseous inventory as a result of heat transfer from the pipe wall. This effect is however not predicted by other workers (see Chen, 1993; Fairuzov, 1998) using a constant heat transfer coefficient. Again, the simulated data are in good agreement with measurements.

Figure 4 shows the closed end fluid transient temperature data for Test P40 based on measurement (curve A) and simulation (curve B). Reasonably good agreement between both sets of data may be observed.

Figure 5 presents the measured discharge rate vs time profile for Test P40 (curve A) in comparison to the model predictions (curve B). In general, a good degree of agreement between PipeTech simulation results as compared to the measured data may be observed. The finite differences in the data fall within the reported (Richardson and Saville, 1996a) ±5% uncertainty in the load cell measurements.

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Interestingly, the measured data (curve A) post 18 s indicates negative mass discharged (i.e. pipeline inventory increases with time). This is clearly physically unrealistic and may be attributed to measurement errors.

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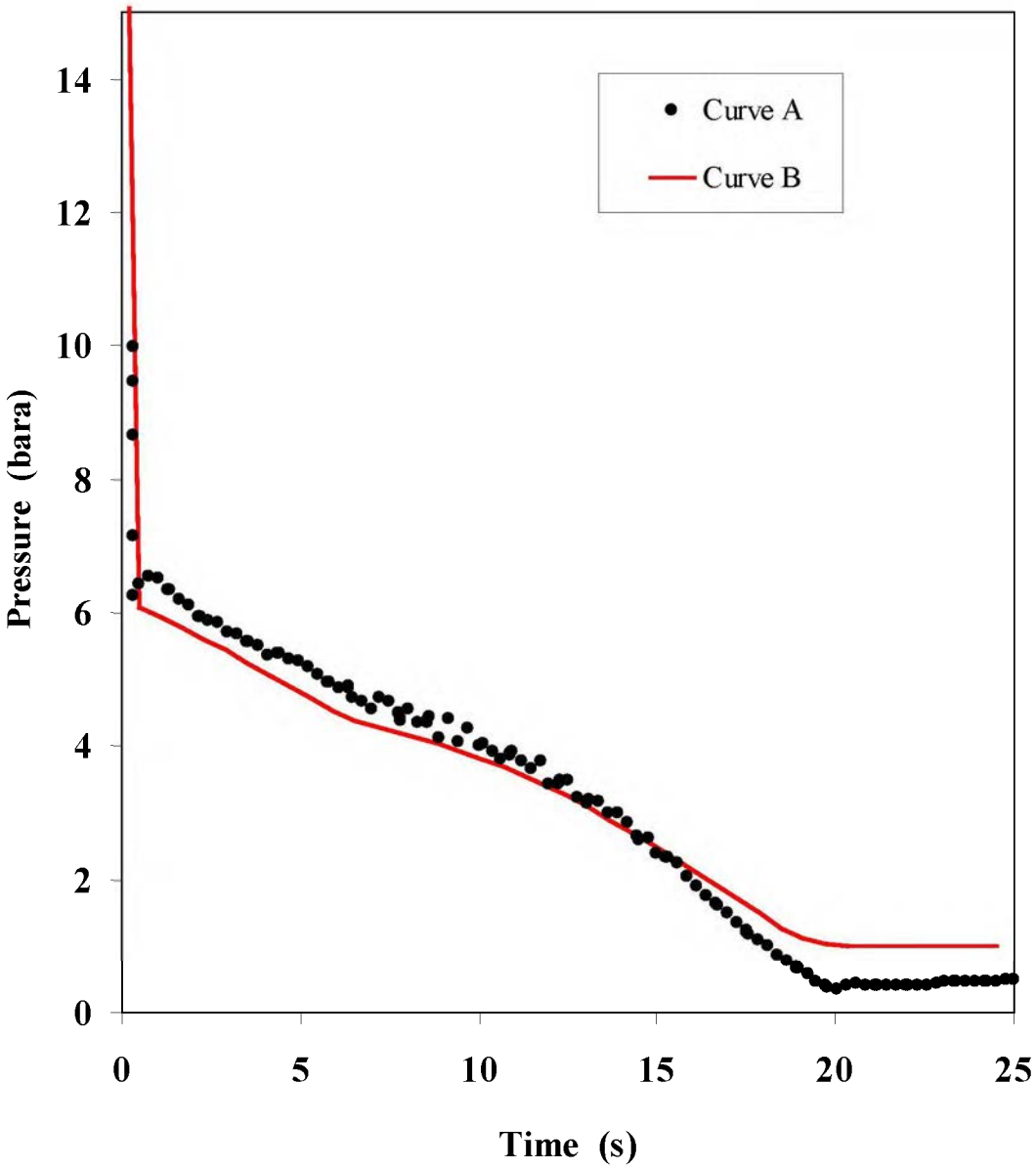


Figure 1. Open end pressure-time profiles for Test P40 following FBR of the LPG pipeline.

Curve A: Measurement (Richardson and Saville, 1996a,b)

Curve B: PipeTech

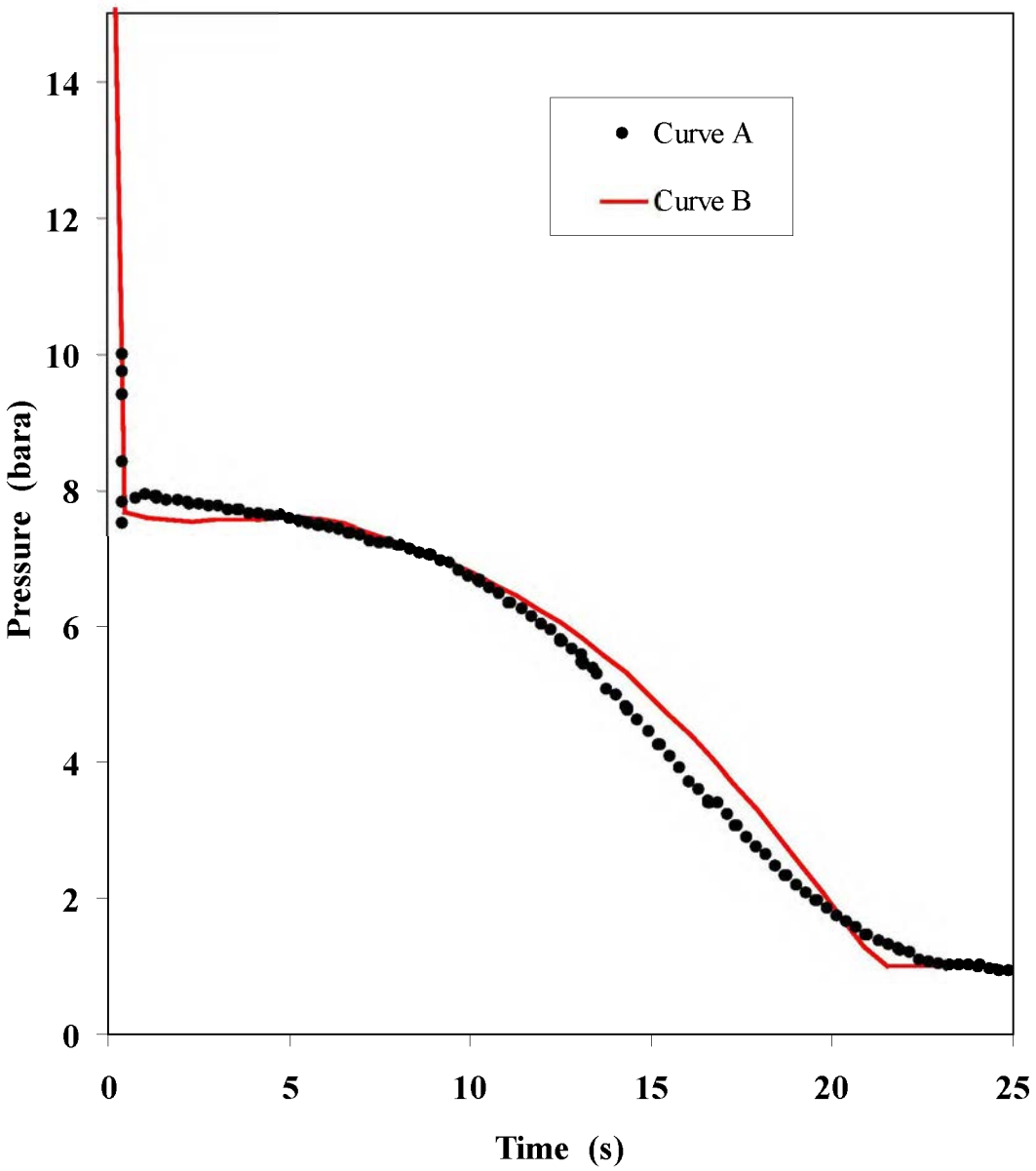


Figure 2. Closed end pressure-time profiles for Test P40 following FBR of the LPG pipeline.

Curve A: Measurement (Richardson and Saville, 1996a,b)

Curve B: PipeTech

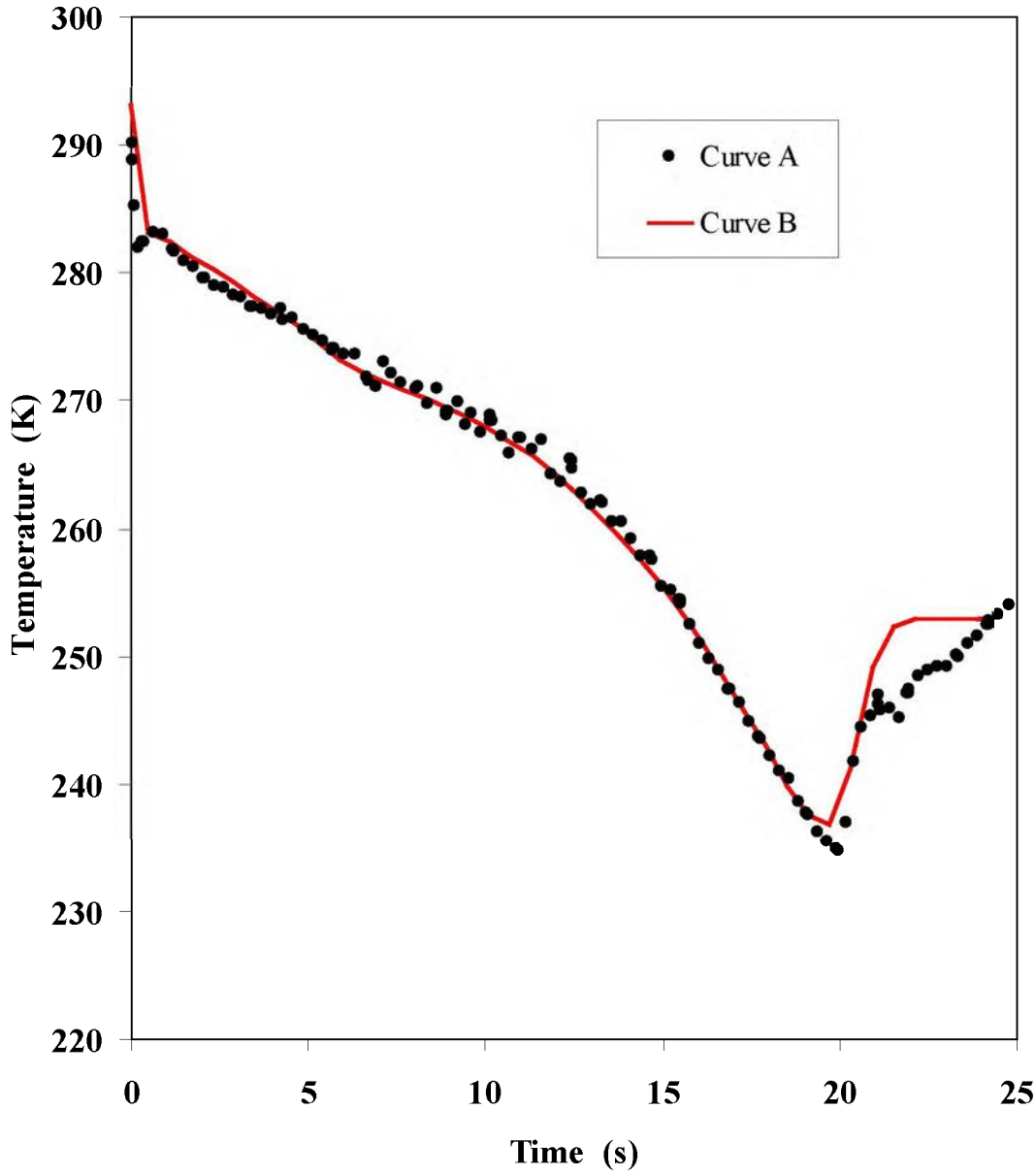


Figure 3. Open end temperature-time profiles for Test P40 following FBR of the LPG pipeline.

Curve A: Measurement (Richardson and Saville, 1996a,b)

Curve B: PipeTech

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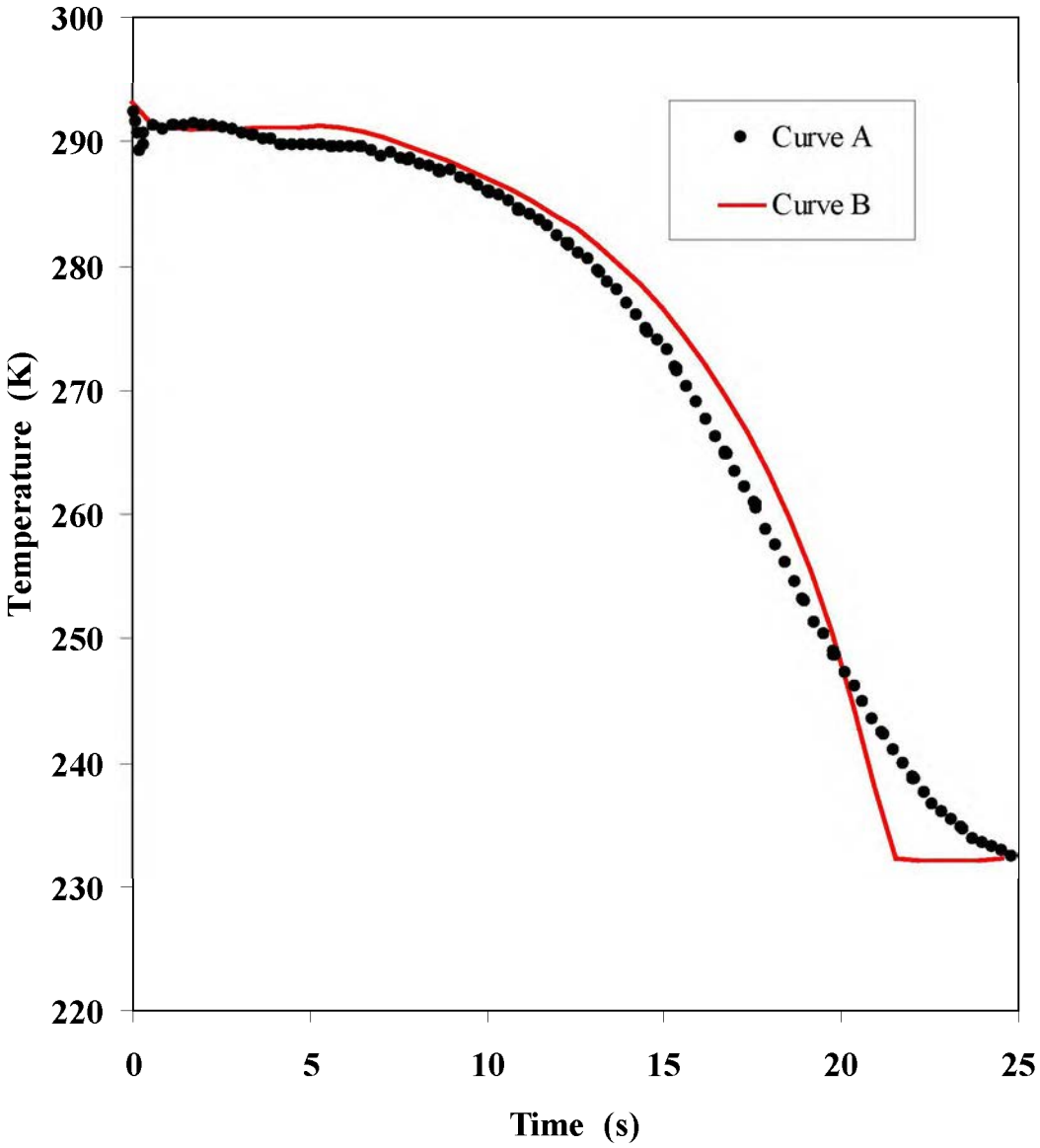


Figure 4. Closed end temperature-time profiles for Test P40 following FBR of the LPG pipeline.

Curve A: Measurement (Richardson and Saville, 1996a,b)

Curve B: PipeTech

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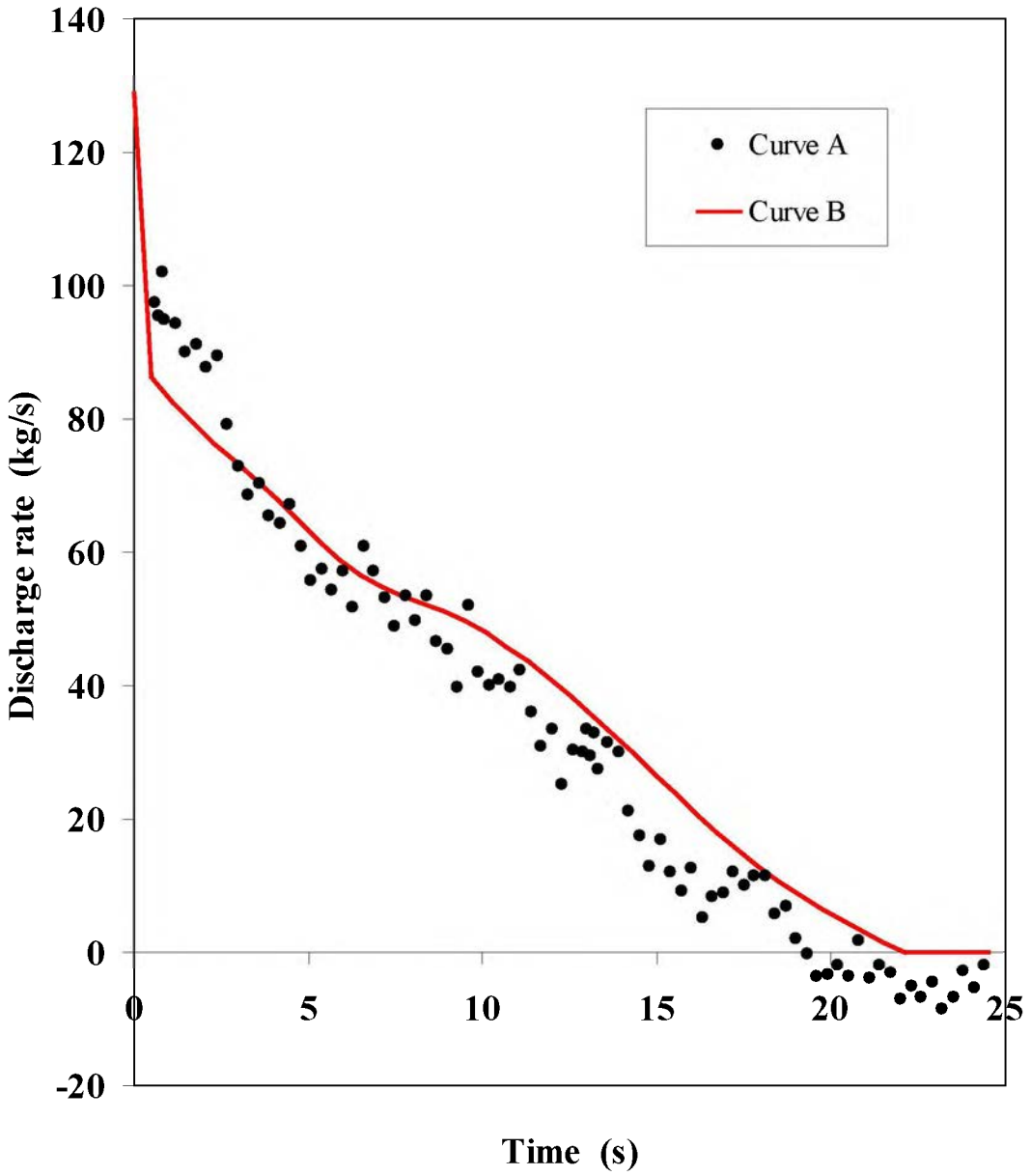


Figure 5. Variation of discharge rate with time for Test P40 following FBR of the LPG pipeline.

Curve A: Measurement (Richardson and Saville, 1996a,b)

Curve B: PipeTech

3.2.2 Test P42

The prevailing conditions and the pipeline overall dimensions for Test P42 (see Table 1) are the same as those for Test P40 with the exception of the starting pressure being 11.3 bara. Figures 6 to 9 show the corresponding measured data (curves A) as compared to PipeTech's predictions (curves B).

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As it may be observed, similar trends but smaller magnitude changes in the fluid transients as compared to Test P40 may be observed due to the lower starting pressure. In all cases, PipeTech's predictions are in good agreement with the measured data.

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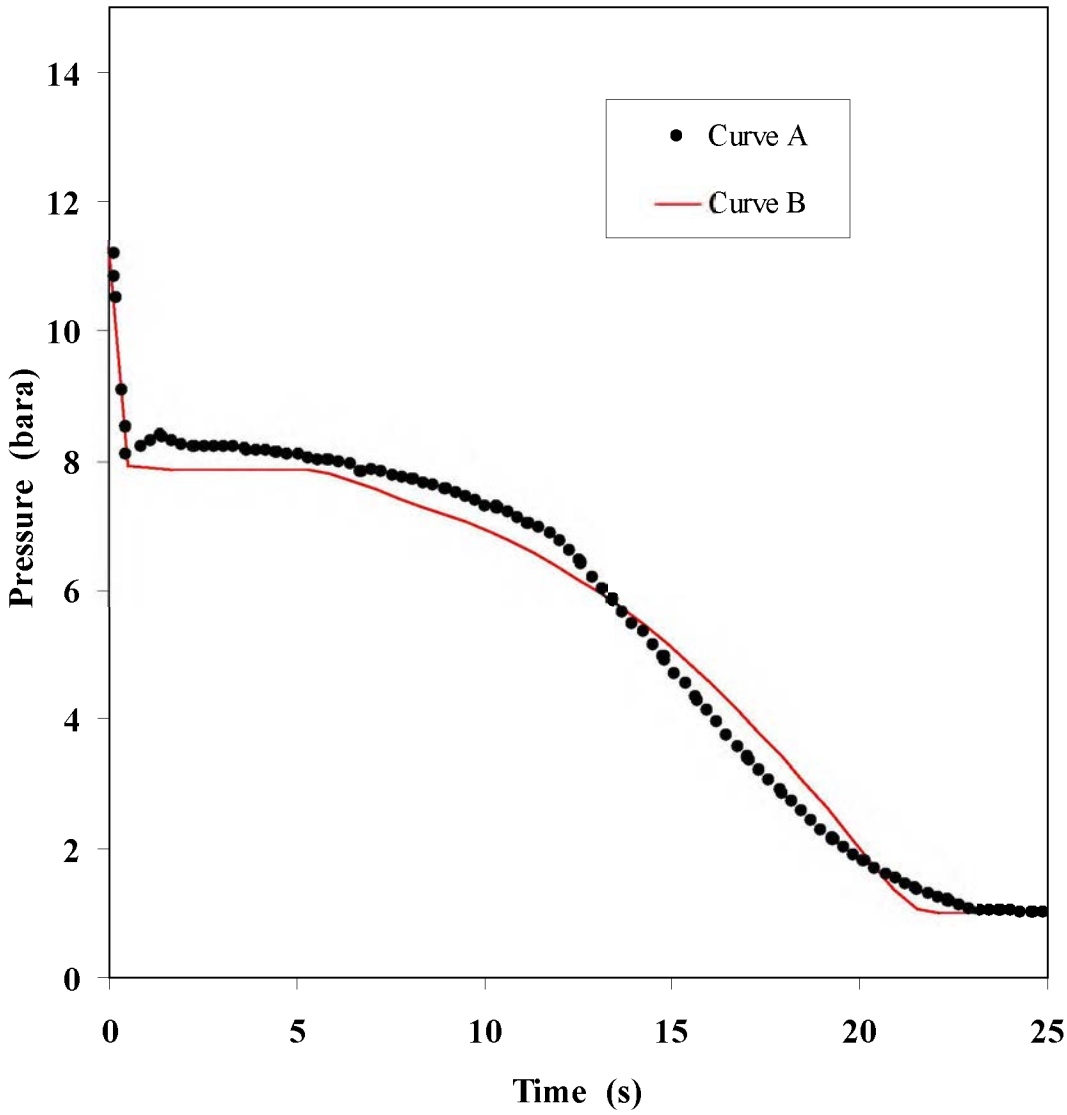


Figure 6. Open end pressure-time profiles for Test P42 following FBR of the LPG pipeline.

Curve A: Measurement (Richardson and Saville, 1996a,b)

Curve B: PipeTech

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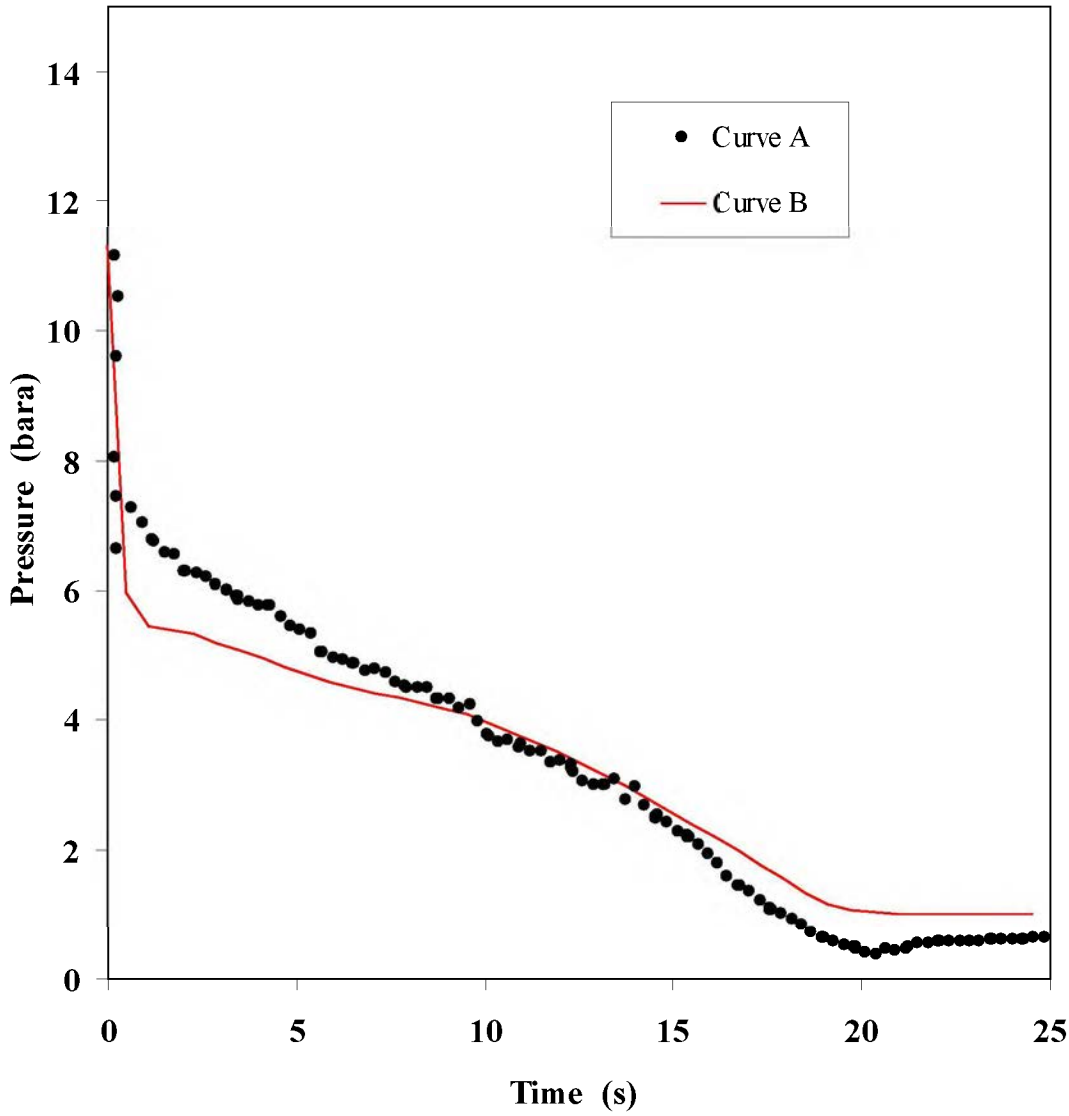


Figure 7. Closed end pressure-time profiles for Test P42 following FBR of the LPG pipeline.

Curve A: Measurement (Richardson and Saville, 1996a,b)

Curve B: PipeTech

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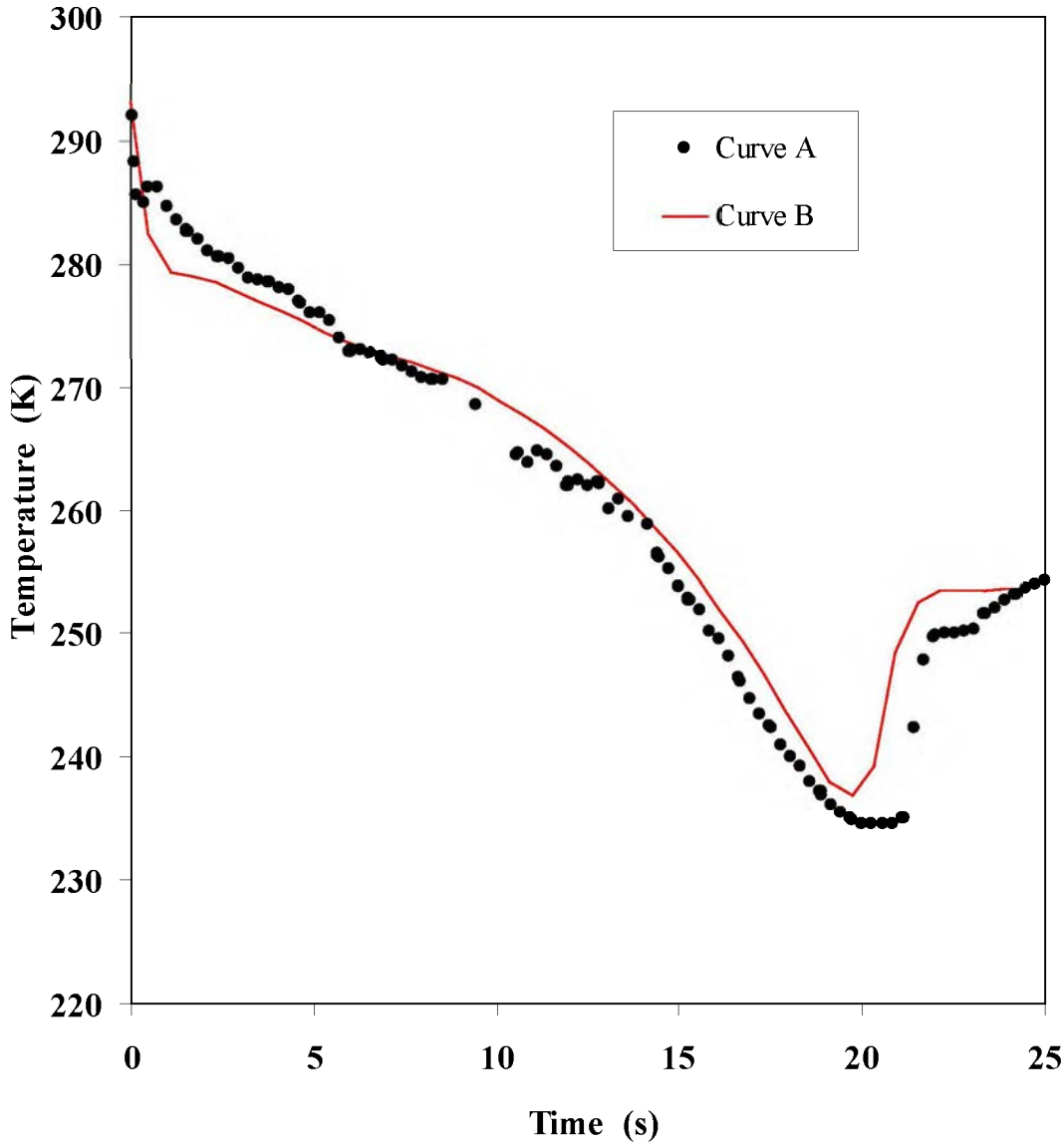


Figure 8. Open end temperature-time profiles for Test P42 following FBR of the LPG pipeline.

Curve A: Measurement (Richardson and Saville, 1996a,b)

Curve B: PipeTech

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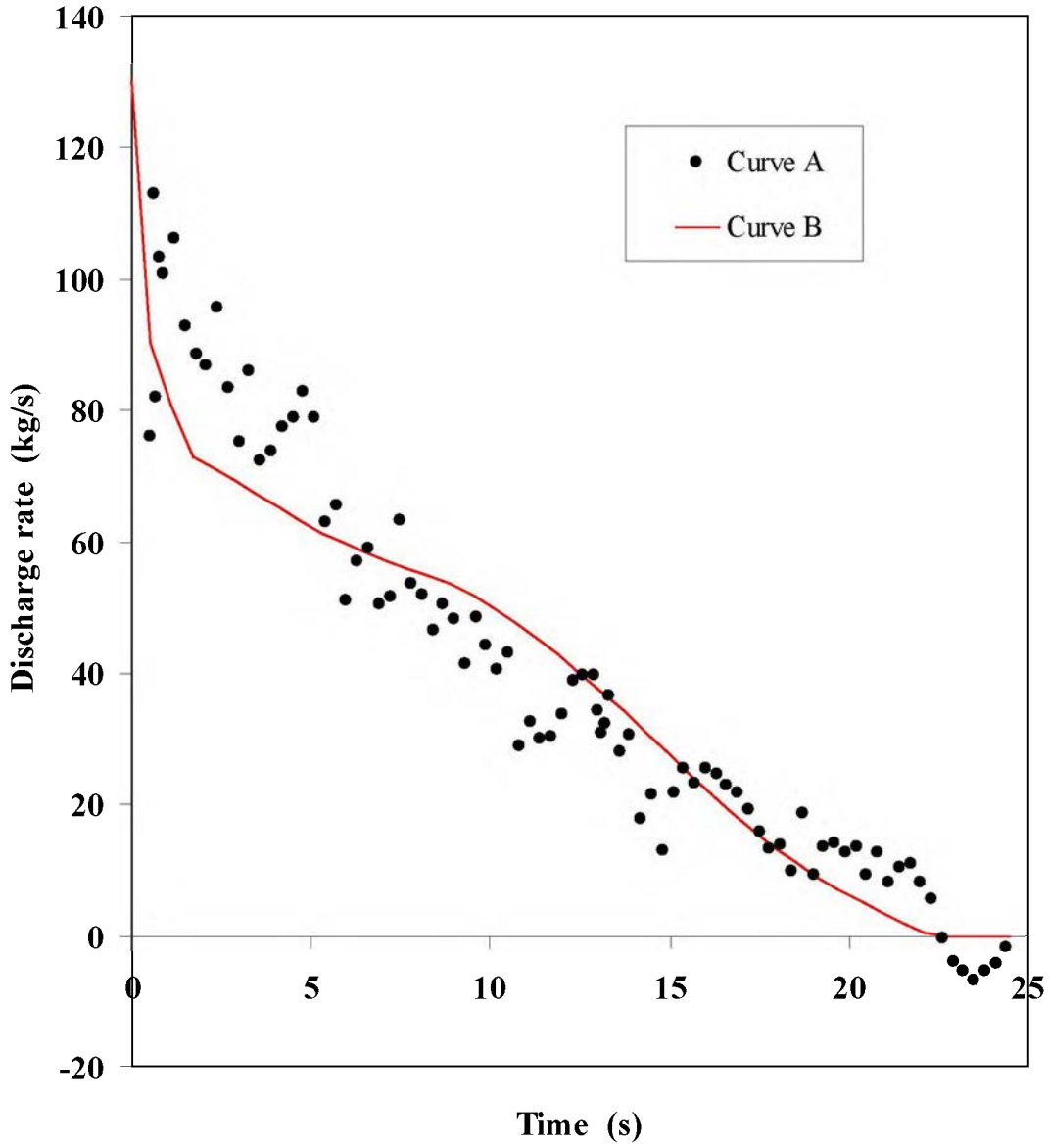


Figure 9. Variation of discharge rate with time for Test P42 following FBR of the LPG pipeline.

Curve A: Measurement (Richardson and Saville, 1996a,b)

Curve B: PipeTech

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3.2 TransCanada and Piper Alpha Pipelines

The TransCanada pipeline test (Atti, 2006) involved the FBR of a 76 km, 894.4 mm i.d. pipeline containing 100% methane at 61 bara. The rupture location was 38 km along the isolated pipeline length. The Piper Alpha investigation on the other hand is based on the pressure-time data recorded (Cullen, 1990) during the night of the Piper Alpha tragedy involving the full bore rupture of the main 54 km natural gas riser connecting the Piper Alpha to the MCP01 platform. Table 2 shows the prevailing conditions used to simulate both pipeline ruptures.

Figure 10 shows the comparison of the total mass release rate with time between PipeTech predictions and measured data following the rupture of the TransCanada pipeline. As no data were recorded during the first 10 s following pipeline rupture, it is impossible to assess PipeTech's performance in this highly transient region. However, the simulated data subsequent to this period show a reasonably good degree of agreement with the measurements corresponding to a maximum discrepancy of about 15%. A possible explanation for the finite discrepancy could be due to the assumption of the pipeline inventory being 100% methane in the simulations. In practice heavier molecular weight hydrocarbons may be present.

The Piper Alpha depressurisation data presented in Figure 11 show very good agreement between simulation and actual data.

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Table 2. PipeTech input data for the simulations of the Piper Alpha and TransCanada pipeline ruptures.

Input		Piper Alpha	TransCanada
Inlet Parameters	Number of components	9	1
	Feed composition (mole %)	Methane - 73.6	Methane - 100
		Ethane - 13.4	
		Propane - 7.4	
		i-Butane - 0.4	
		n-Butane - 1.0	
		i-Pentane - 0.08	
		n-Pentane -0.07	
		Hexane - 0.02	
		Nitrogen - 4.03	
	Feed inlet temperature (K)	283	283
	Feed inlet pressure (bara)	117	61
	Ambient temperature (K)	283	283
	Ambient pressure (bara)	1.01	1.01
Pipeline Characteristics	Length (m)	54000	76000
	External diameter (mm)	457	914.4
	Wall thickness (mm)	19	10
	Roughness (mm)	0.026	0.05
	Orientation to the horizontal plane (deg)	0	0
Rupture Conditions	Failure mode	FBR	FBR
	Failure location relative to high pressure end (m)	54000	38000
	Rupture diameter (mm)	419	894.4
	Discharge coefficient	1	1
Other Parameters	Feed flow rate prior to rupture (m^3/s)	0	0
	Pumping cessation time following pipeline failure (s)	0	0
	Pump shut-off head (bara)	110	110
	Grid system used	Simple	Simple
	Number of grid points specified	50	50
	Equation of State	PR	PR
		TCC alpha parameter	TCC alpha parameter
	Mixing rule	TCC	TCC
	Friction factor correlation	Chen	Chen
	Heat transfer coefficient (W/m^2K)	1.136	5
	Total depressurisation time (s)	20000	60

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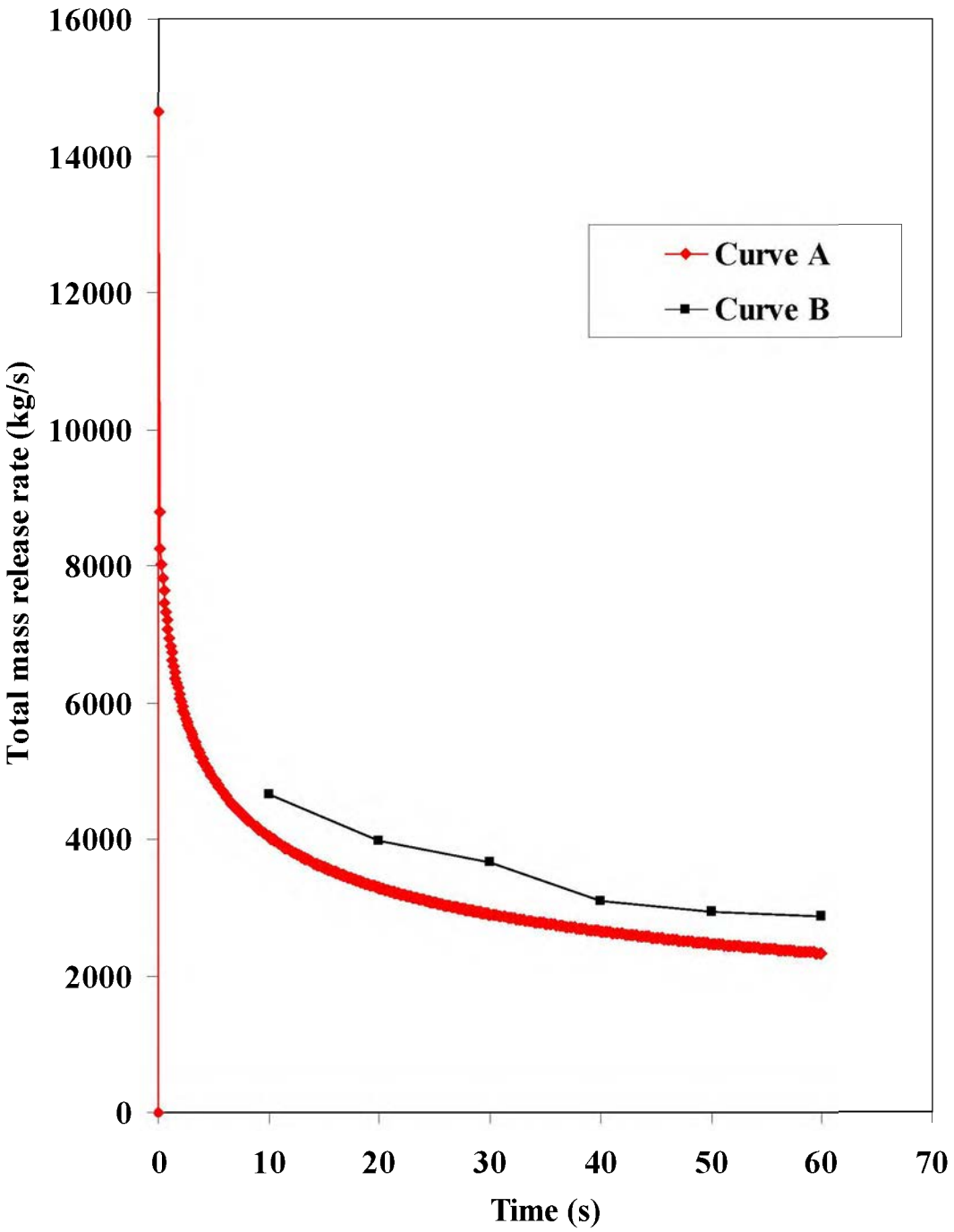


Figure 10. Comparison of variation of release rate with time following the FBR TransCanada pipeline.

Curve A: PipeTech

Curve B: Measurement (Atti, 2006)

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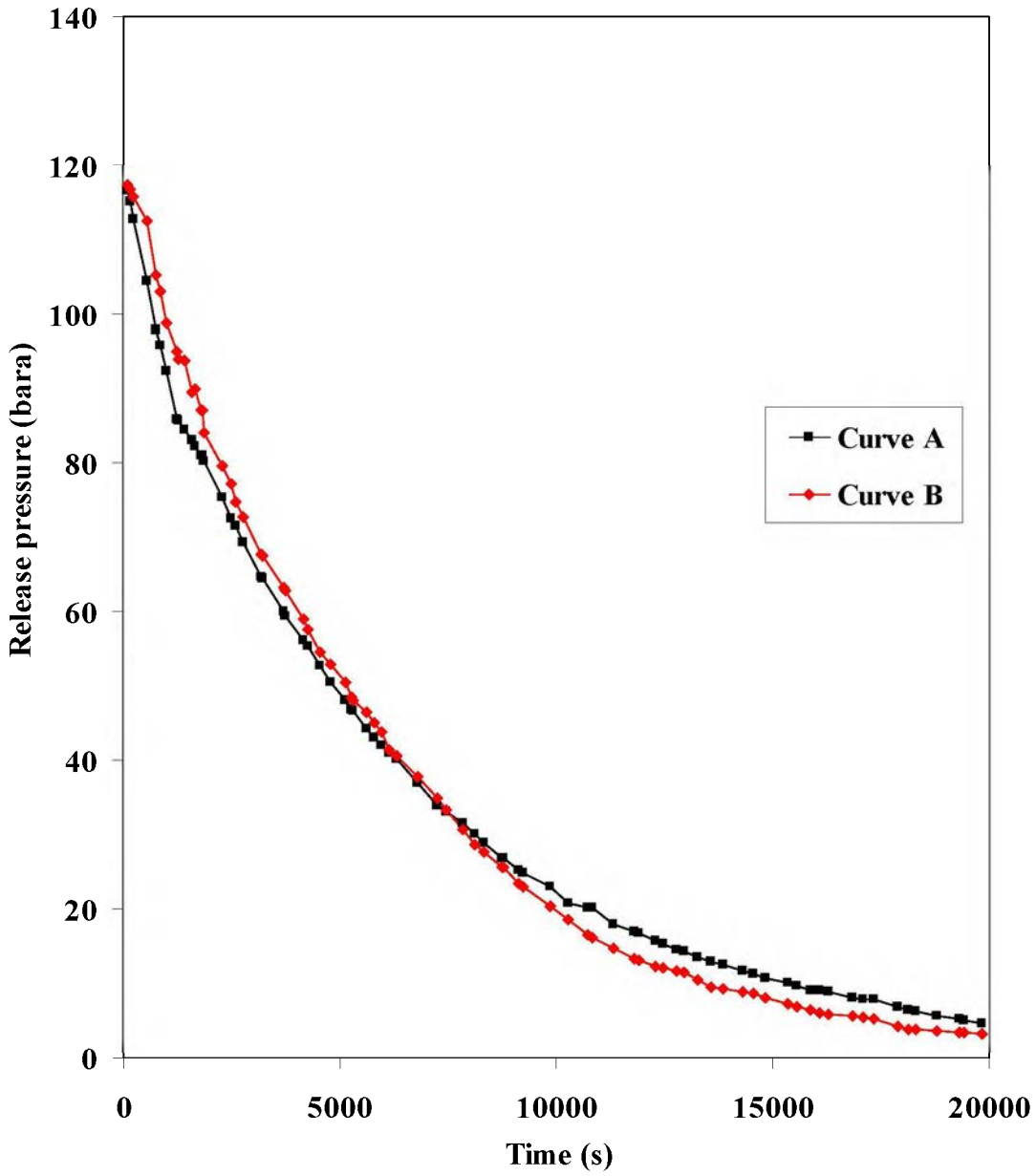


Figure 11. Comparison of the variation of open end pressure with time data following the FBR of the Piper Alpha pipeline.

Curve A: PipeTech

Curve B: Measurement (Cullen, 1990)

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4. Scope of Work

The scenarios described below are simulated using the pipeline rupture CFD computer programme, PipeTech to determine the outflow over the duration of interest as indicated for each scenario. General information on the pipeline elevation profile and valve locations is provided in the attached figures 12 and 13. Figures 14 – 20 are representations of the same profiles as those in figures 12 and 13 where the pipeline gradients have been approximated with segmented straight lines, along with the main input parameters for the outflow simulations. Table 1 shows the pipeline feed composition.

The simulation input conditions are taken as those corresponding to point A shown in the above figures where the mass flow rate is assumed to remain unchanged (worst case scenario) for the duration of the discharge process given the significant amount of upstream inventory.

Scenario 1. Breach of a 20" OD underwater pipeline:

- Orifice size: 466.74 mm (18.37") (single opening – i.e., not 2 open ends)
- Depth of water at the location of leak: 35 m (115 ft.)
- Pump Shutdown time: 10 minutes
- Valve closure time following the pump shutdown: 3 minutes
- Pump flow rate: Based on average operating flow rates
- Pressure at point A: Based on average operating pressure of the line
- Duration of interest: 20 minutes

Scenario 2. Breach of a 30" OD underwater pipeline:

- Orifice size: 720.76 mm (28.38") (single opening – i.e., not 2 open ends)
- Depth of water at the location of leak: 35 m (115 ft.)
- Pump Shutdown time: 10 minutes
- Valve closure time following the pump shutdown: 3 minutes
- Pump flow rate: Based on average operating flow rates

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- Pressure at point A: Based on average operating pressure of the line
- Duration of interest: 20 minutes

Scenario 3. Breach of a 30" OD underwater pipeline:

- Orifice size: 75 mm (3") leak
- Depth of water at the location of leak: 10 m (33 ft.)
- Pump Shutdown time: 30 minutes
- Valve closure time following the pump shutdown: 3 minutes
- Pump flow rate: Based on average operating flow rates
- Pressure at point A: Based on average operating pressure of the line
- Duration of interest: 30 minutes

Scenario 4. Breach of a 20" OD underwater pipeline:

- Orifice size: 466.76 mm (18.38") (single opening – i.e., not 2 open ends)
- Depth of water at the location of leak: 75 m (246 ft.)
- Pump Shutdown time: 10 minutes
- Valve closure time following the pump shutdown: 3 minutes
- Pump flow rate: Based on average operating flow rates
- Pressure at point A: Based on average operating pressure of the line
- Duration of interest: 20 minutes

Scenario 5. Breach of a 30" OD underwater pipeline:

- Orifice size: 720.76 mm (28.38") (single opening – i.e., not 2 open ends)
- Depth of water at the location of leak: 69 m (226 ft.)
- Pump Shutdown time: 10 minutes
- Valve closure time following the pump shutdown: 3 minutes
- Pump flow rate: Based on average operating flow rates

- Pressure at point A: Based on average operating pressure of the line
- Duration of interest: 20 minutes

Scenario 6. Breach of a 30" OD underwater pipeline:

- Orifice size: 75 mm (3") leak
- Depth of water at the location of leak: 35 m (115 ft.)
- Pump Shutdown time: 30 minutes
- Valve closure time following the pump shutdown: 3 minutes
- Pump flow rate: Based on average operating flow rates
- Pressure at point A: Based on average operating pressure of the line
- Duration of interest: 30 minutes

Scenario 7. Breach of a 30" OD underwater pipeline:

- Orifice size: 75 mm (3") leak
- Depth of water at the location of leak: 69 m (226 ft.)
- Pump Shutdown time: 30 minutes
- Valve closure time following the pump shutdown: 3 minutes
- Pump flow rate: Based on average operating flow rates
- Pressure at point A: Based on average operating pressure of the line
- Duration of interest: 30 minutes

4.1 Feed Properties and Composition

The NGL properties and composition are provided below.

- Product Density: As per business confidential information provided by the operator
- RVP: As per business confidential information provided by the operator

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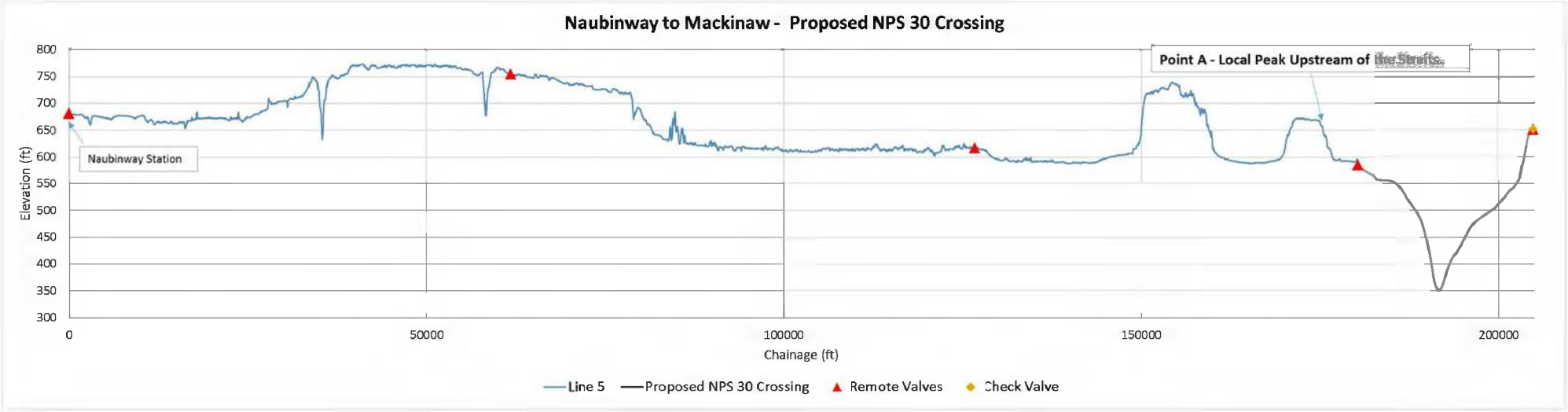


Figure 12. 30" OD Pipeline Crossing Schematic

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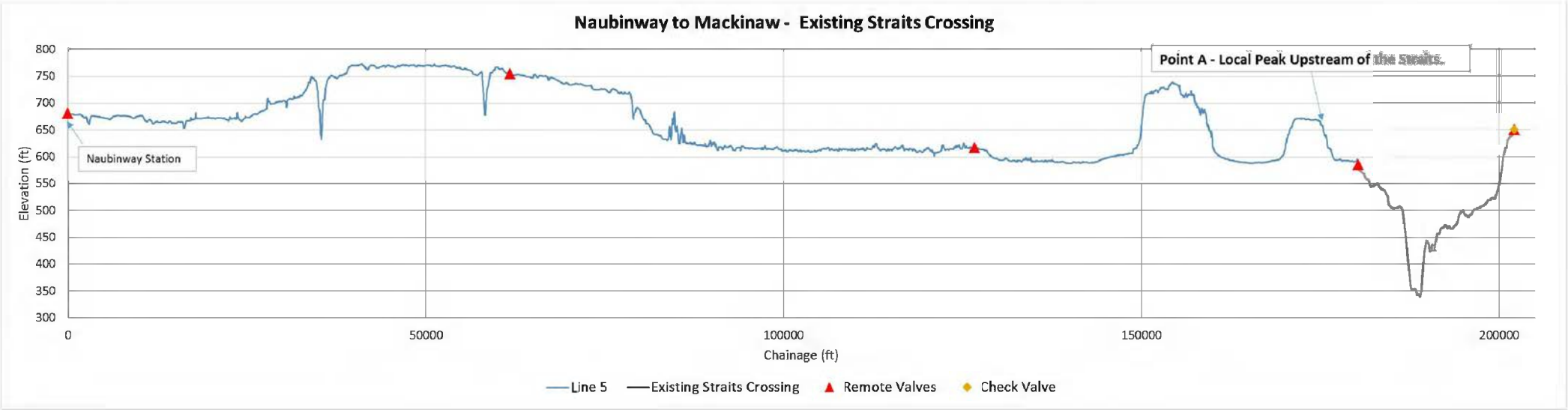


Figure 13. 20" OD Pipeline Crossing Schematic

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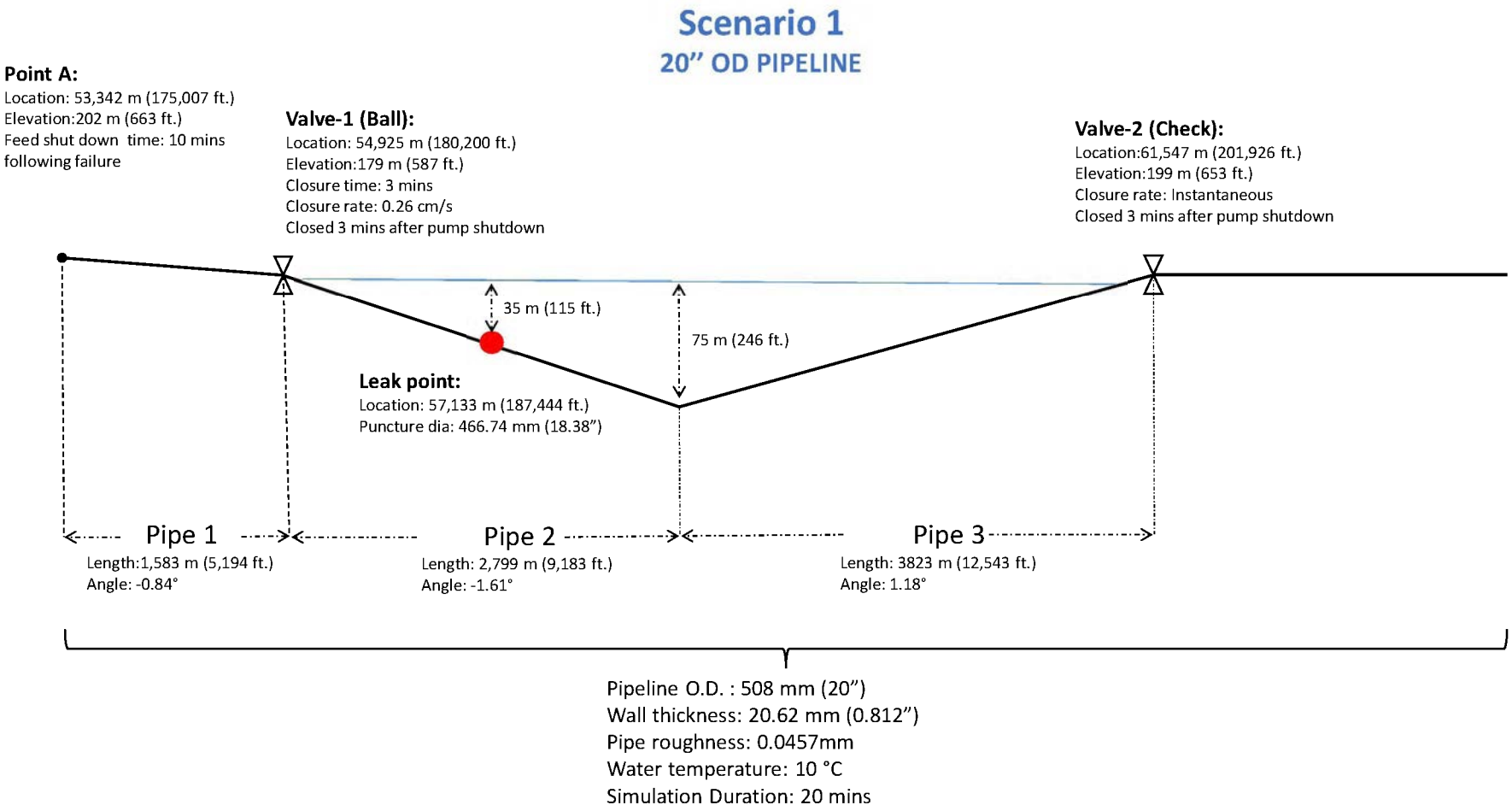


Figure 14. Scenario 1

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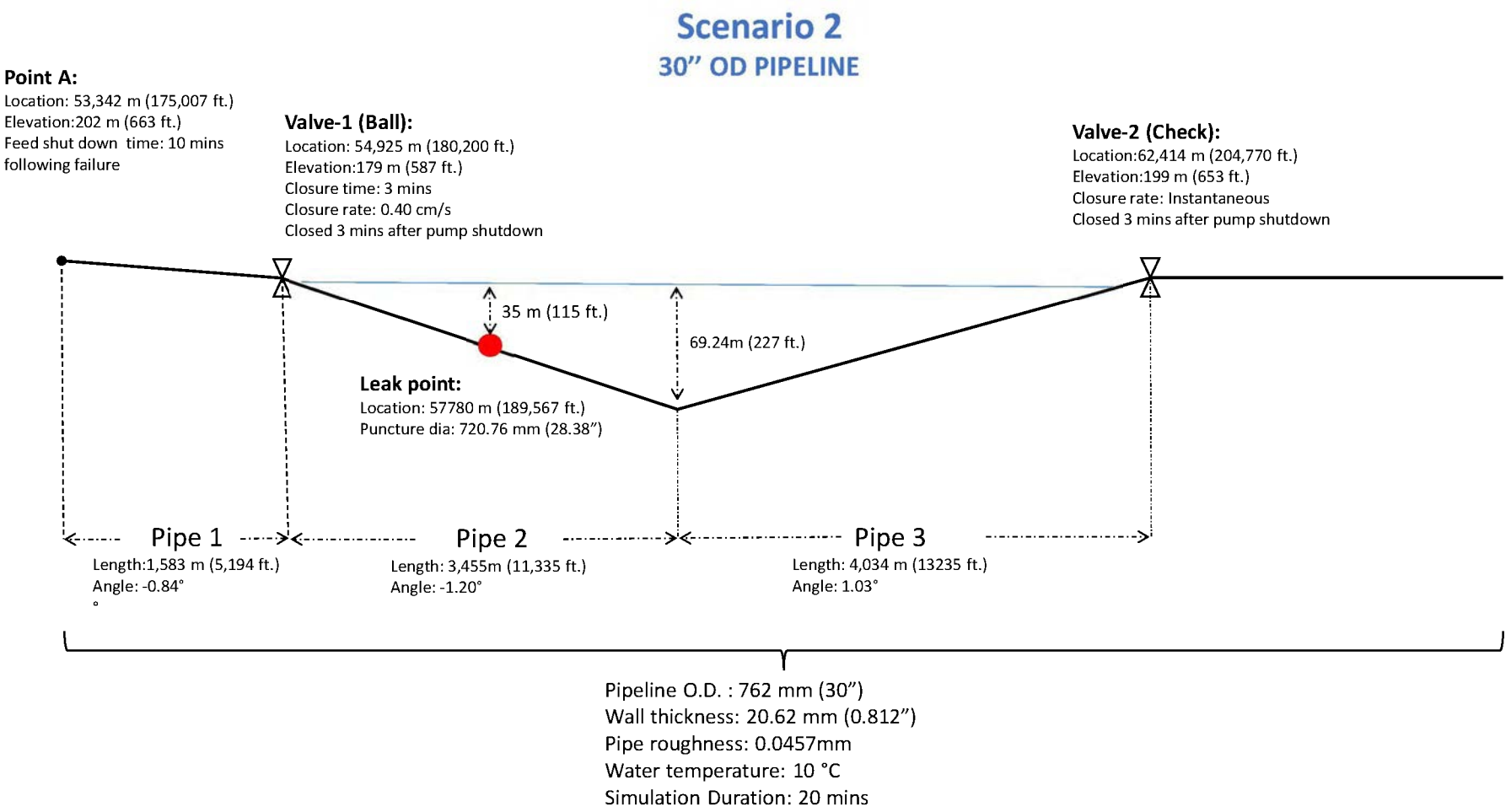


Figure 15. Scenario 2

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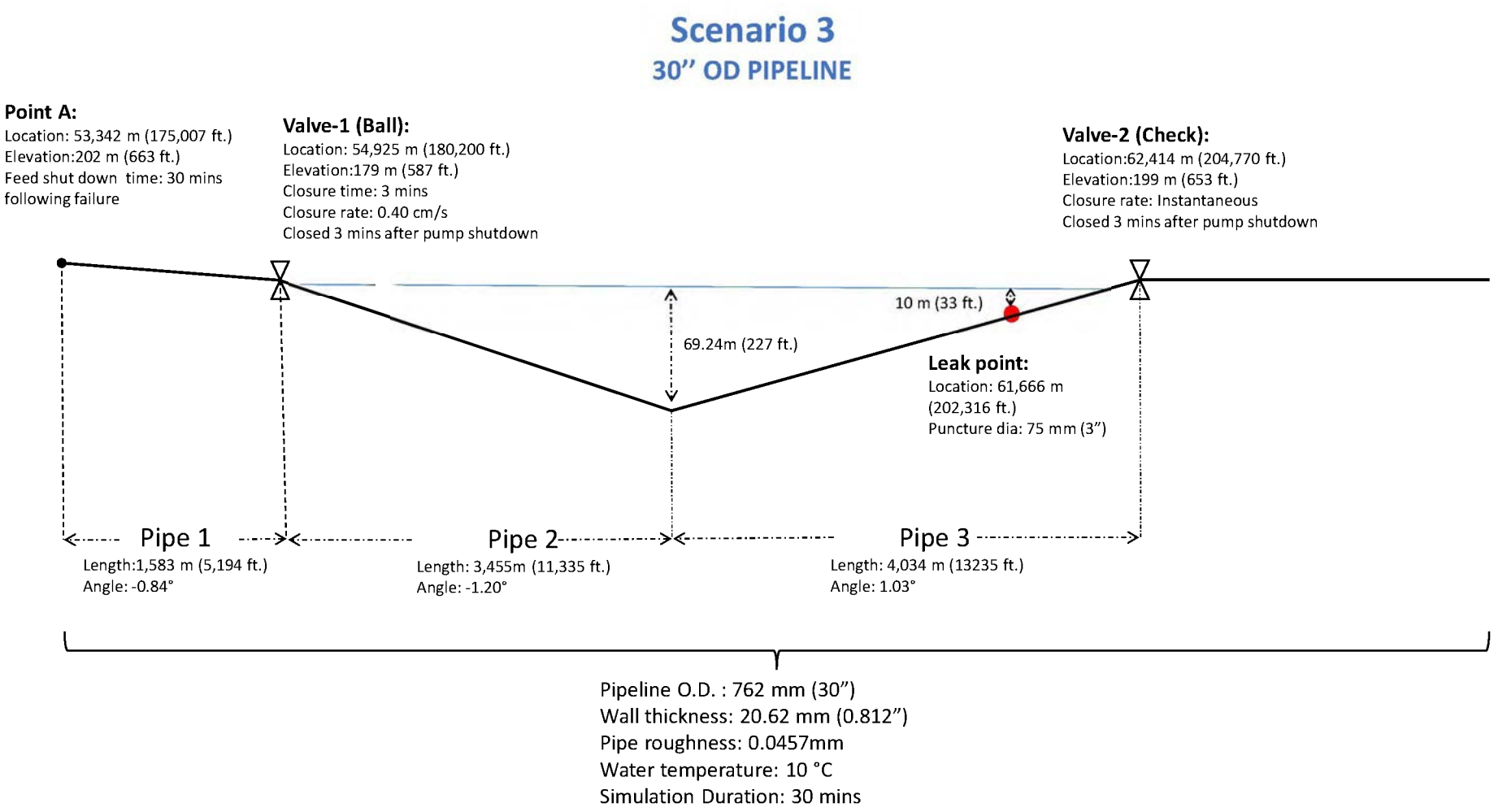


Figure 16. Scenario 3

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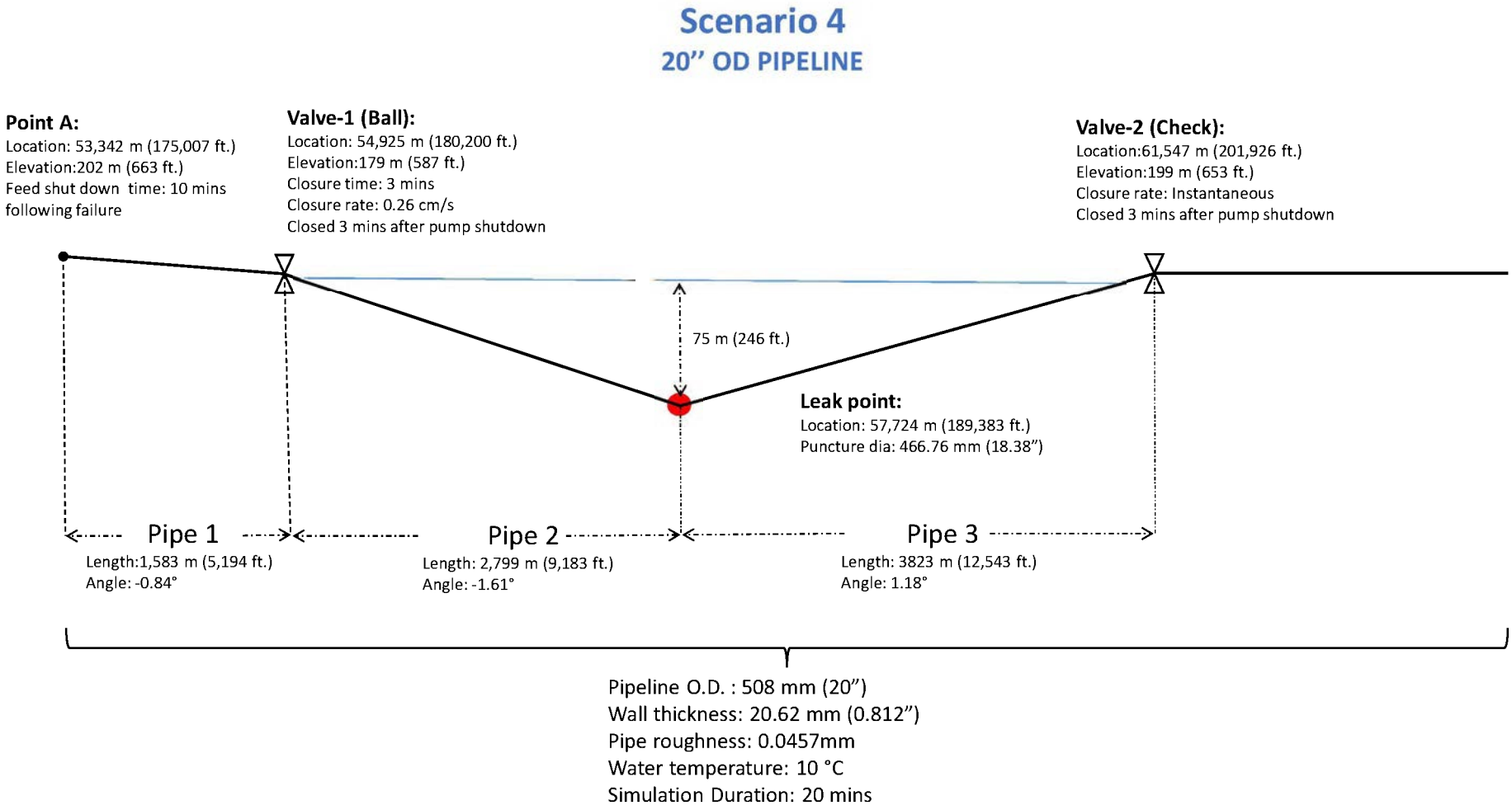


Figure 17. Scenario 4

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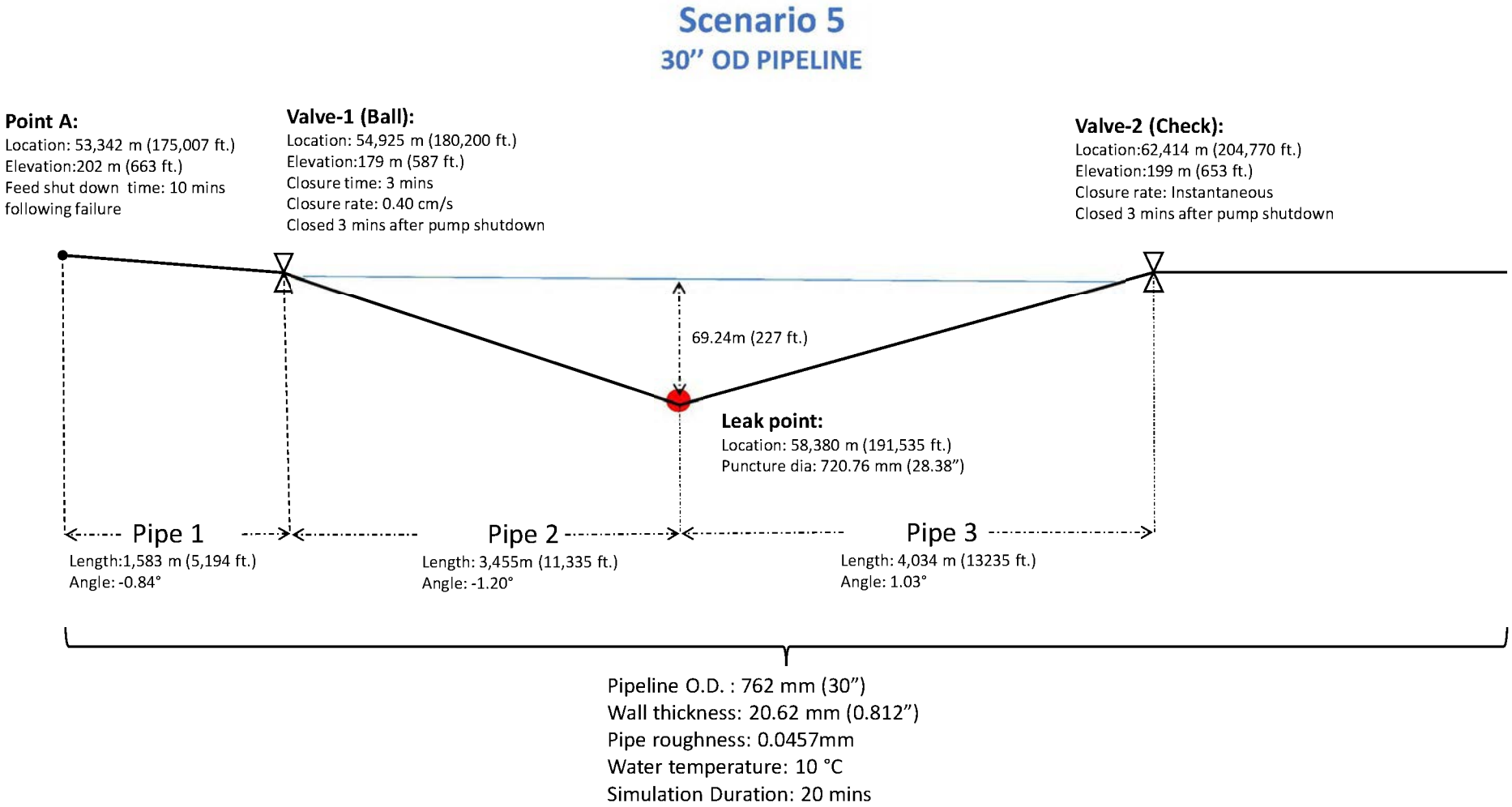


Figure 18. Scenario 5

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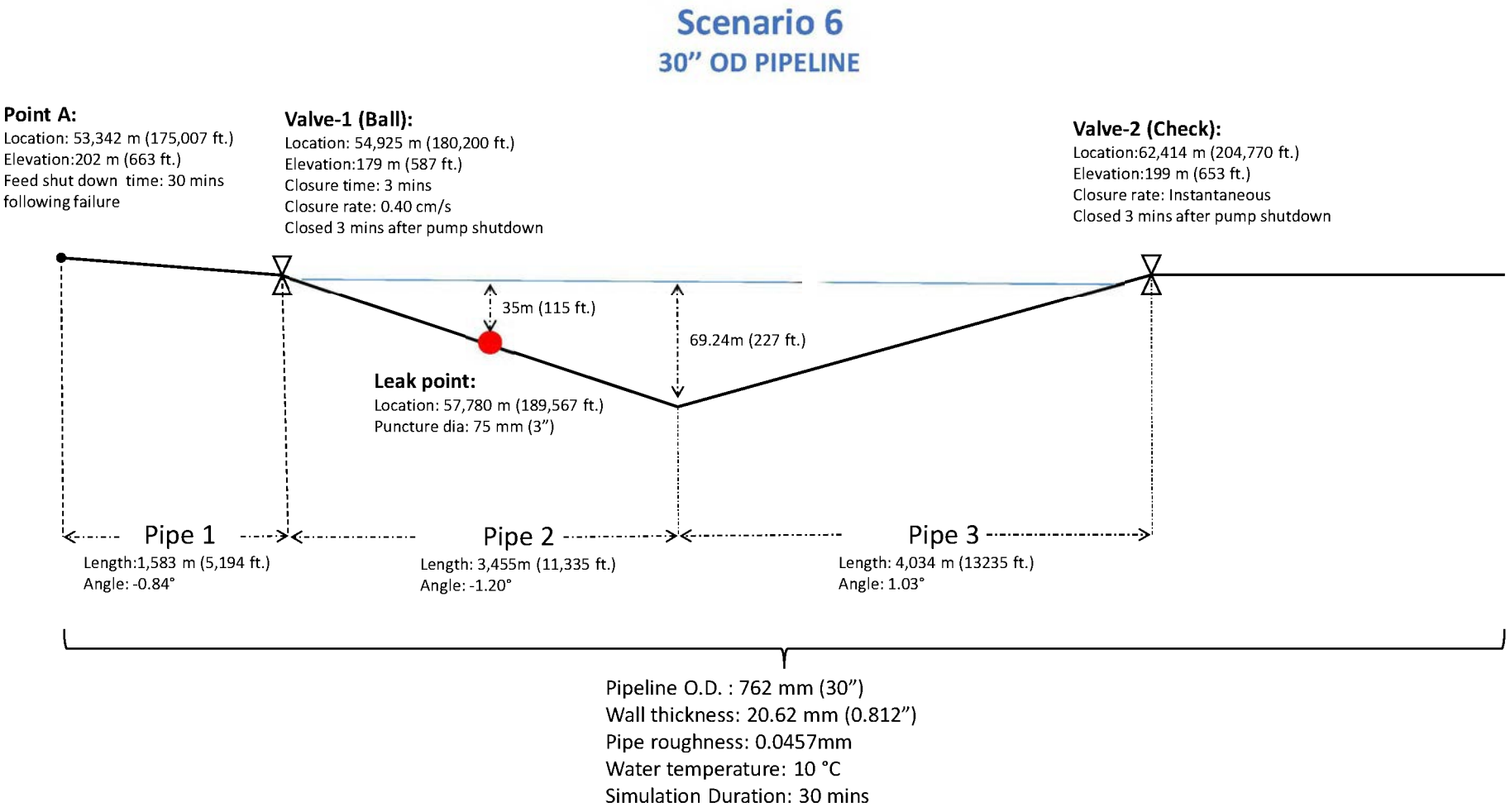


Figure 19. Scenario 6

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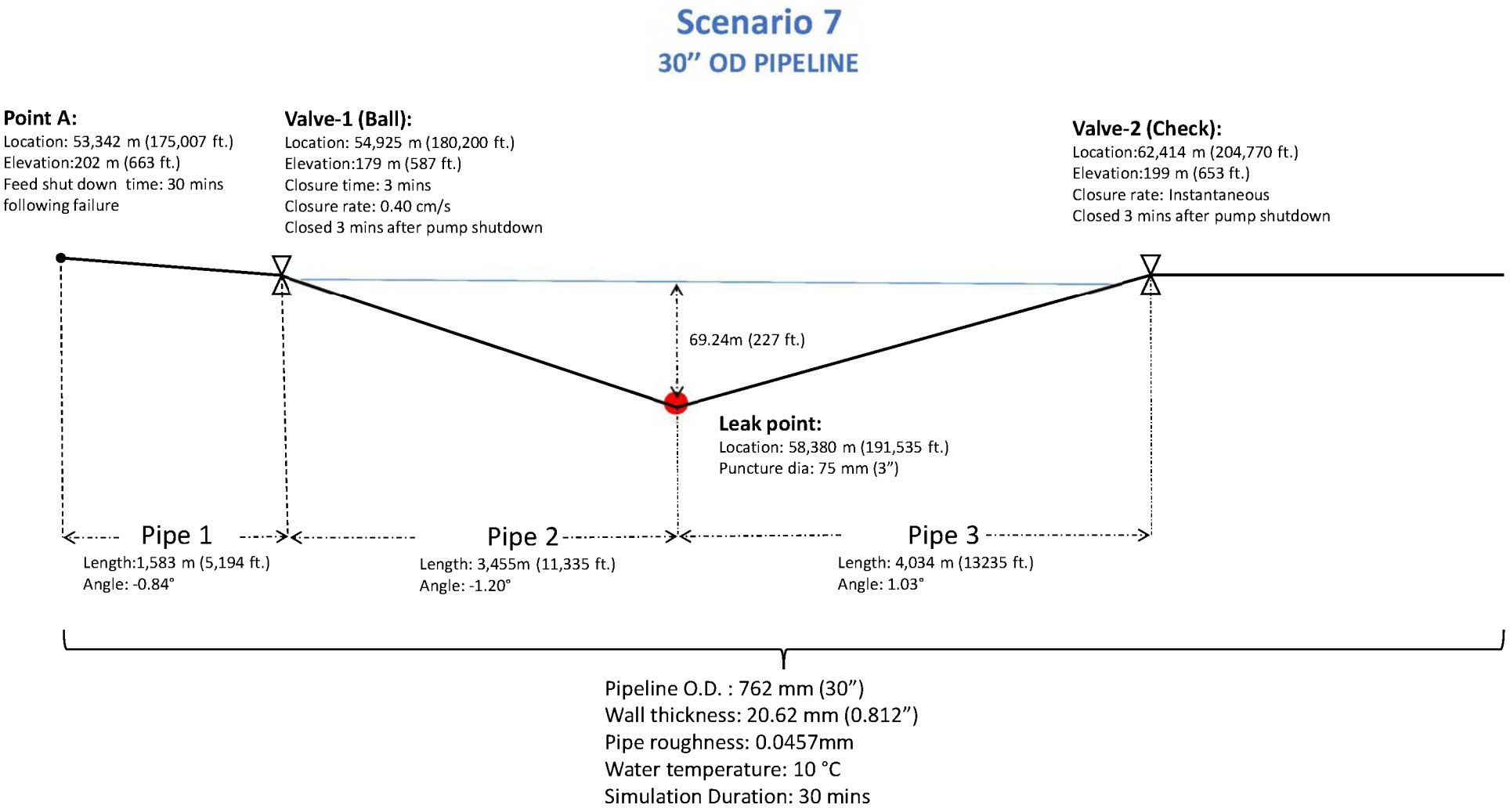


Figure 20. Scenario 7

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5. Results and Discussion

In the following the simulation results for failure Scenarios 1 – 7 are divided, presented and discussed in three groups, namely Groups A, B and C in accordance to their common features as presented in table 3. The corresponding flow regimes during the depressurisation process are also given in the same table.

Table 3. Outflow simulation groupings

Group	Scenarios	Common features	Flow regime
A	1,2	Large puncture diameters with low hydrostatic pressure (puncture situated 35 m below the water level)	Choked, fully-expanded followed by momentum-driven
B	4,5	Large puncture diameters with high hydrostatic pressure (puncture situated ca. 70 m below the water level)	Choked, fully-expanded followed by momentum-driven
C	3, 6, 7	Small puncture diameters	Choked

Depending on the rate of pipeline decompression (puncture size) and surrounding pressure (hydrostatic pressure), the outflow may be 'sonic' (choked), 'fully-expanded' or 'momentum-driven'. Sonic outflow occurs when the pressure upstream of the puncture is significantly higher (e.g > 3bar) than the hydrostatic pressure at the puncture location. Here the outflow is independent of the downstream pressure. As the decompression proceeds, the puncture plane pressure equilibrates with the hydrostatic pressure and the outflow becomes 'fully-expanded'. At the end of pipeline decompression, where the entire pipeline pressure drops to the corresponding hydrostatic pressure, any remaining outflow is 'momentum driven'.

The simulated decompression data presented in the following is discussed with reference to the above three flow regimes.

5.1 Group A

Table 5 shows the corresponding simulation input parameters for Group A.

Table 5. Group A input conditions

Input conditions	Scenario 1	Scenario 2
Overall pipeline length	9,205 m / 30,200 ft.	10,072 m / 33,044 ft.
Pipe roughness	0.0457	0.0457

Input conditions	Scenario 1	Scenario 2
Pipe external diameter	508 mm/ 20"	762 mm / 30"
Pipe wall thickness	20.62 mm / 0.812"	20.62 mm / 0.812"
Orifice size	466.74 mm / 18.38"	720.76 mm / 28.38"
Water depth at leak location	35 m / 115 ft.	35 mm / 115 ft.
Failure location relative to high pressure end	3,791 m / 12,438 ft.	4,438 m / 14,560 ft.
Pump shutdown time (min)	10	10
Remote valve (V-1 & V-2) closure time following pump shutdown (min)	3	3
Check valve (CV-1) closure time following the pump shutdown	instantaneous	instantaneous
Feed temperature	Average operating temperature	Average operating temperature
Ambient temperature	283.15 K / 509.67 R	283.15 K / 509.67 R
Feed pressure	Average operating pressure	Average operating pressure
Ambient pressure	4.44 bara / 64.4 psi	4.44 bara / 64.4 psi
Overall heat transfer coefficient (W/m^2K)	5	5
Maximum depressurisation time (s)	1200	1200

Figure 23 to 27 respectively show variations of release pressure, velocity, total mass release rate, temperature and cumulative mass discharged as a function of time for the first 1200s following pipeline failure. As indicated by the vertical dashed lines in each figure, the remote ball valve V-1 in both scenarios starts to close 600s following failure, fully closing in 3 minutes. Furthermore, for both cases, the check valve CV-1 automatically closes 19s following failure corresponding to the time at which backflow occurs at the valve location. As expected, the larger pipe failure diameter (Scenario 2) results in a faster mass release rate and significantly larger cumulative mass discharged over the release duration of interest.

Upon pipe failure, choked flow (sonic flow) occurs. This is marked by an initial rapid drop in the release pressure (Figure 21) from the compressed liquid pressure to the saturation pressure and temperature of ca 6 bar and ca. 281 K (505.8 R) (Figure 24) respectively. This transition in the fluid state is accompanied by a significant drop in the sonic release velocity (Figure 22) and flow rate (Figure 23; the release flowrate drops from approximately 4,500 kg/s to 1000 kg/s [9,920 lb/s to 2,205 lb/s] for Scenario 1 and from 12000 kg/s to 2200 kg/s [26,455 lb/s to 4,850 lb/s] for Scenario 2).

As the decompression proceeds, liquid flashing-evaporation continues. Given that the outflow is still choked (up to 460s and 700s respectively following failure for Scenarios 1 and 2), the

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release velocity increases as the vapour fraction increases (Figure 22). The almost constant release rate (Figure 23) observed during these time domains is a product of decreasing fluid density and increasing release velocity. The release temperature (Figure 24) follows the fluid saturation value corresponding at the prevailing pressure.

Upon reaching the surrounding hydrostatic pressure of 4.44 bar (ca. 460 s for Scenario 1 and at ca. 700 s for Scenario 2), the transition from choked to fully expanded flow occurs. This is marked by the observed sudden drops in the release velocities for both scenarios (see Figure 22). Both the outflow pressure and temperature remain constant following this point. Once the upstream pressures of the isolated sections of the pipelines reach the downstream pressure (i.e. uniform pressure throughout the isolated sections of the pipeline), the outflow becomes momentum driven (ca. 1000 and 1150 s respectively for Scenarios 1 and 2). This transition is marked by a reduction in the rate of drop in the release velocity (Figure 22) and mass discharge rate (Figure 23).

Valve closure (600s for scenario 1 and 780s for Scenario2) results in the isolation of pipe sections 2 and 3 (see Figures 14 and 15). This is reflected in a delayed modest drop in the rate of cumulative mass discharged for both scenarios as indicated in Figure 25. According to the same figure, the respective cumulative mass discharged for Scenarios 1 and 2 are ca. 190 tonnes and 62 tonnes at 1200s following pipeline failure.

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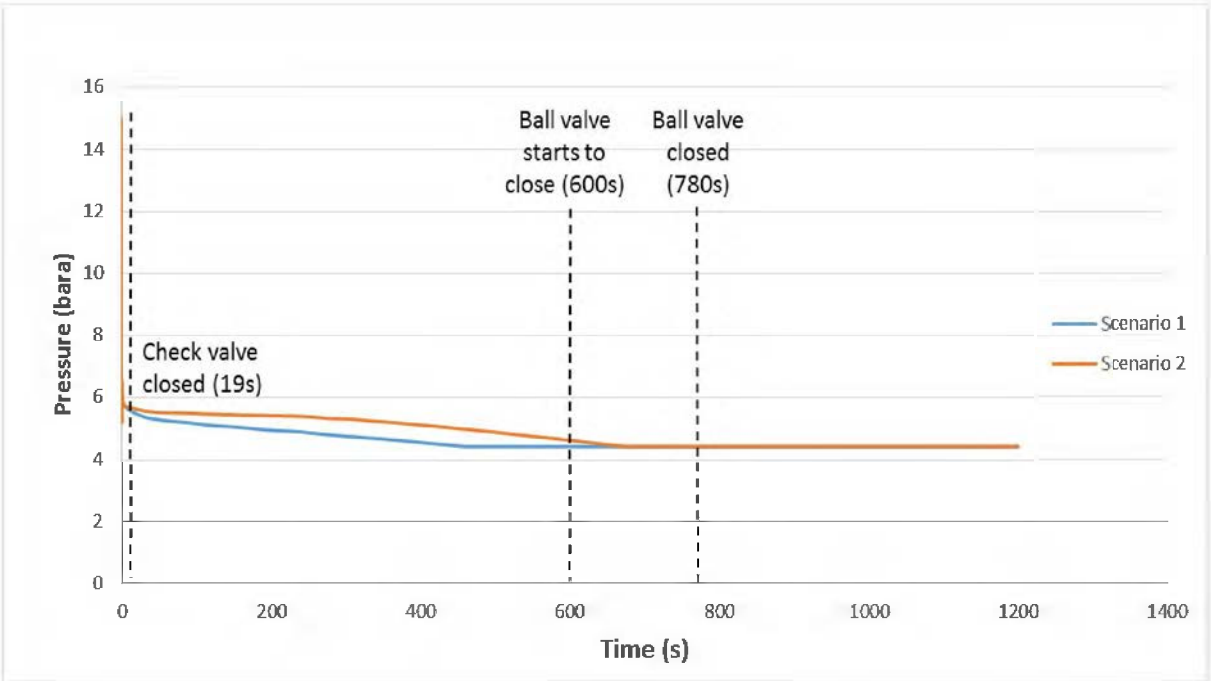


Figure 21. Group A variation of release pressure with time

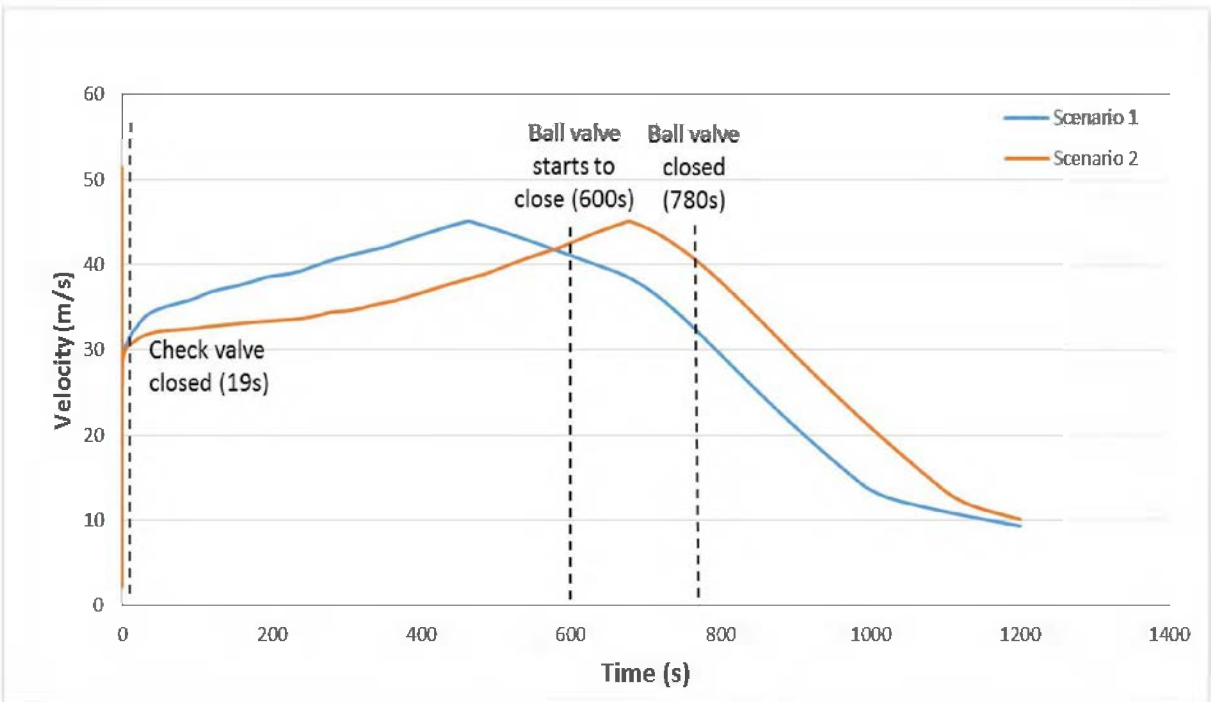


Figure 22. Group A variation of average release velocity with time

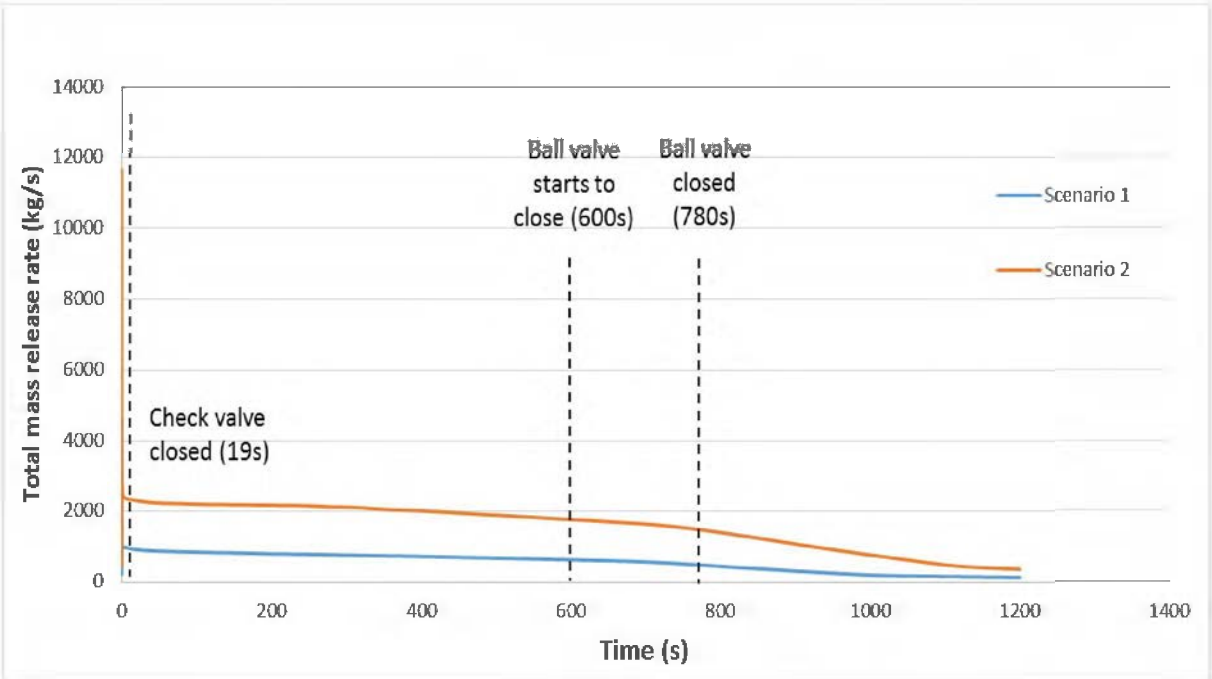


Figure 23. Group A variation of total mass release rate with time

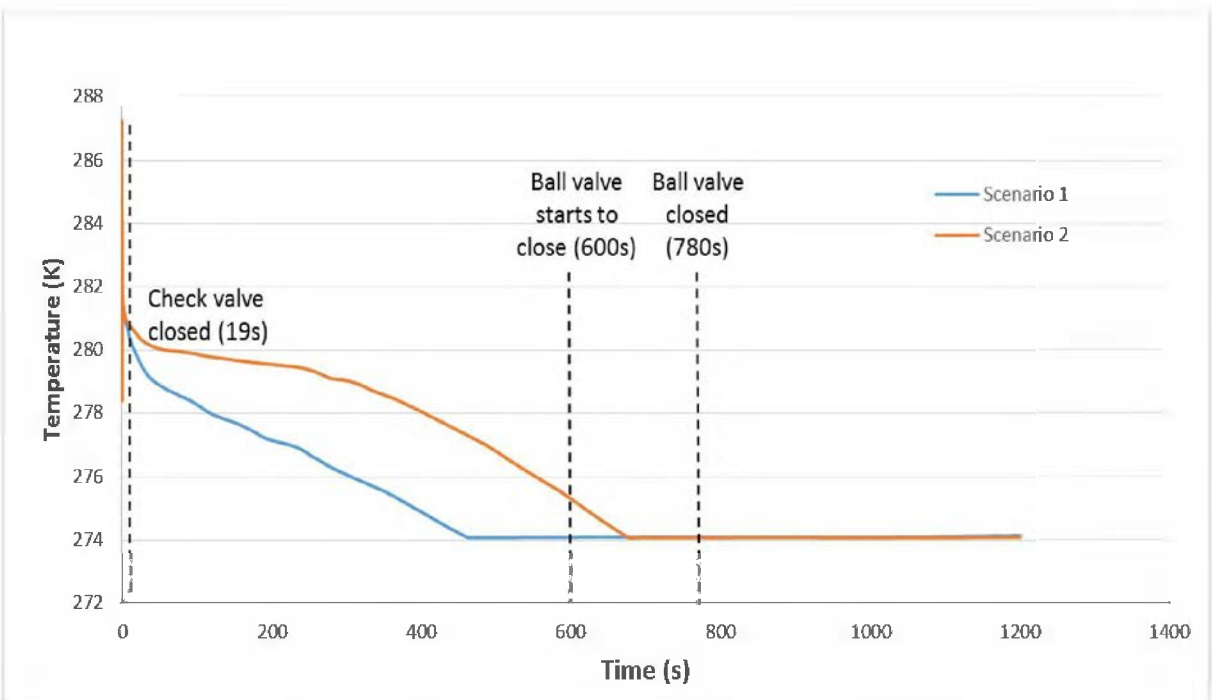


Figure 24. Group A variation of release temperature with time

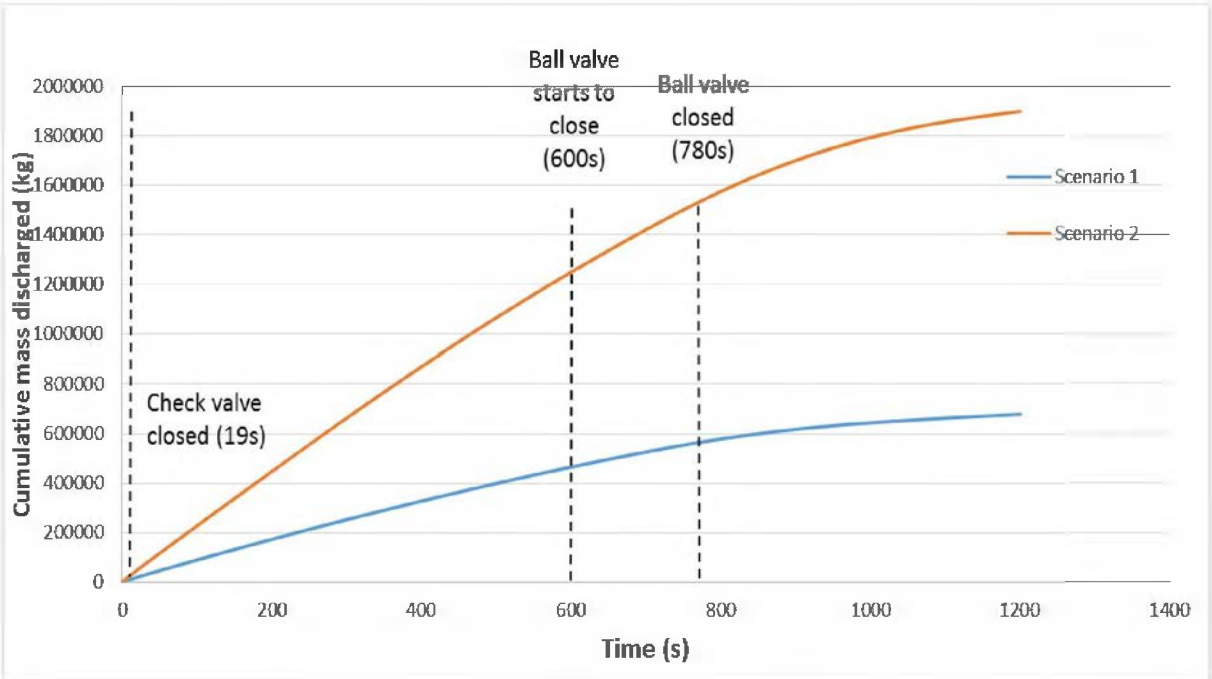


Figure 25. Group A variation of cumulative mass discharged with time

5.2 Group B

Table 6 shows the simulation input parameters for Group B (Scenarios 4 and 5)

Table 6. Group B input conditions

Input conditions	Scenario 4	Scenario 5
Overall pipeline length	9,205 m / 30,200 ft.	10,072 m / 33,044 ft.
Pipe roughness (mm)	0.0457	0.0457
Pipe external diameter	508 mm/ 20"	762 mm / 30"
Pipe wall thickness	20.62 mm / 0.812"	20.62 mm / 0.812"
Orifice size	466.74 mm / 18.38"	720.76 mm / 28.38"
Water depth at leak location	75 m (246 ft.)	69.24 m (227 ft.)
Failure location relative to high pressure end	4,182 m (13,720 ft.)	4438 m (14,560 ft.)
Pump shutdown time (min)	10	10
Remote valve (V-1 & V-2) closure time following pump shutdown (min)	3	3
Check valve (CV-1) closure time following the pump shutdown	instantaneous	instantaneous
Feed temperature	Average operating temperature	Average operating temperature
Ambient temperature	283.15 K / 509.67 R	283.15 K / 509.67 R
Feed pressure	Average operating pressure	Average operating pressure
Ambient pressure	8.36 bara / 121.2 psi	7.77 bara / 112.7 psi
Overall heat transfer coefficient (W/m^2K)	5	5
Maximum depressurisation time (s)	1200	1200

Figure 26 -30 respectively show variations of release pressure, velocity, mass release rate, temperature and cumulative mass discharged as a function of time for the first 1200s following pipeline failure. As indicated by the vertical dashed lines in each figure, the remote ball valve V-1 in both scenarios starts to close 600s following failure, fully closing in 3 minutes. Furthermore, for both cases, the check valve CV-1 automatically closes 6s following failure corresponding to the time at which backflow occurs at the valve location. Much the same as in the case of Group A, the larger pipe failure diameter (Scenario 5) results in a faster mass release rate and significantly larger cumulative mass discharged over the release duration of interest.

Much of the same phenomena referred to for Group A scenarios are also responsible for the observed trends for Group B scenarios.

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However in contrast to Group A, given the much higher water depth, upon rupture the outflow for Scenarios 4 and 5 almost immediately becomes fully-expanded equilibrating with the surrounding hydrostatic pressure (ca. 8.1 bar for Scenario 4 and ca. 8 bar for Scenario 5). The subsequent flow becomes momentum-driven when the pipe upstream and downstream pressures are equal.

The commencement of the ball valve closure (600s following failure) is shortly followed by rapid drops in discharge velocity (Figure 27), the total mass release rate (Figure 28) whence a decrease in the rate of change in the cumulative mass discharge with time (Figure 30).

According to the same figure, the respective cumulative mass discharged for Scenarios 4 and 5 are ca. 63 tonnes and ca. 190 tonnes at 1200s following pipeline failure.

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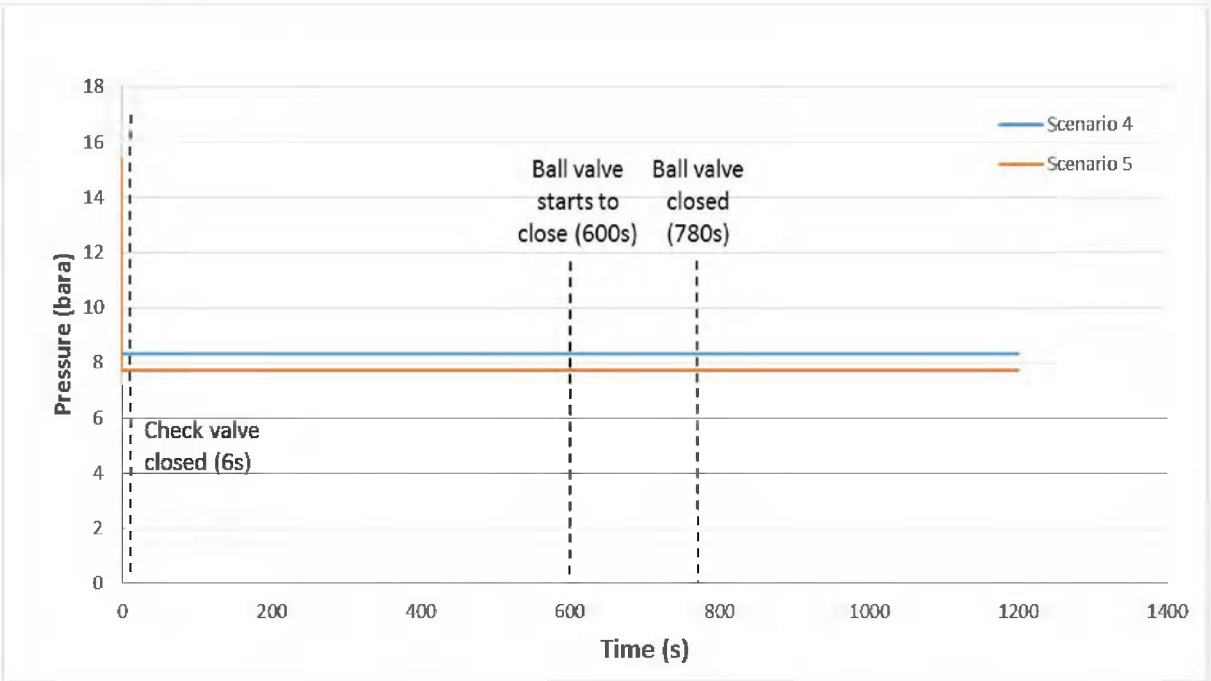


Figure 26. Group B variation of release pressure with time

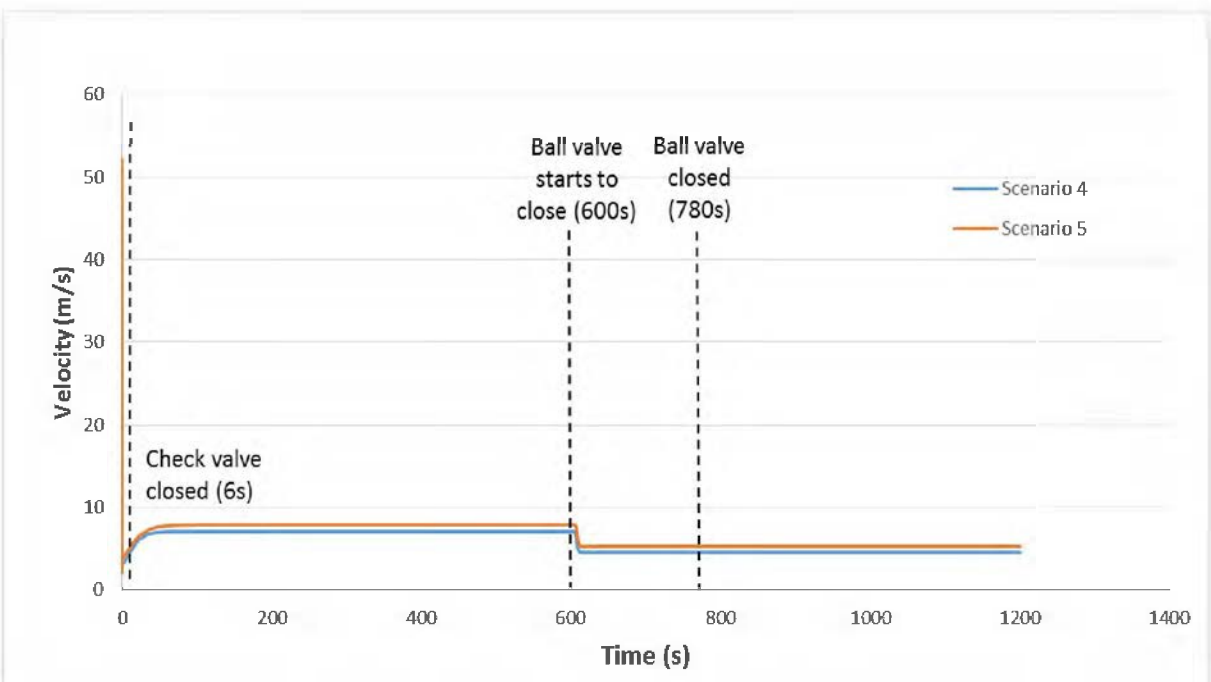


Figure 27. Group B variation of average release velocity with time

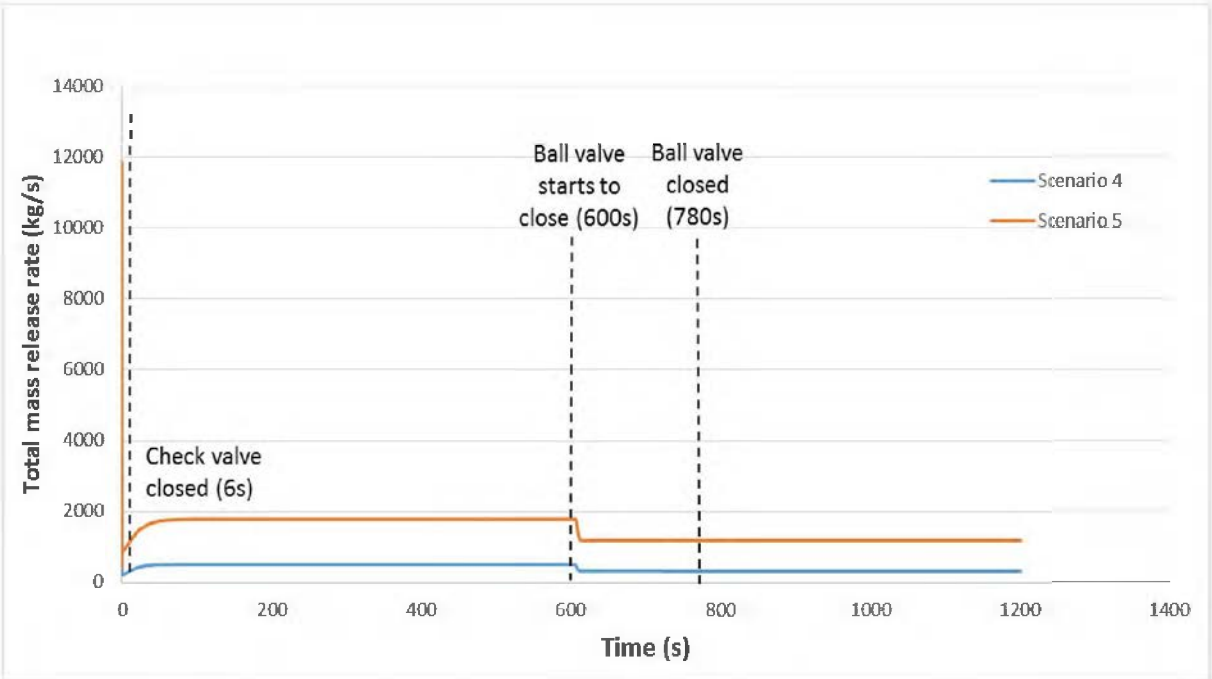


Figure 28. Group B variation of total mass release rate with time

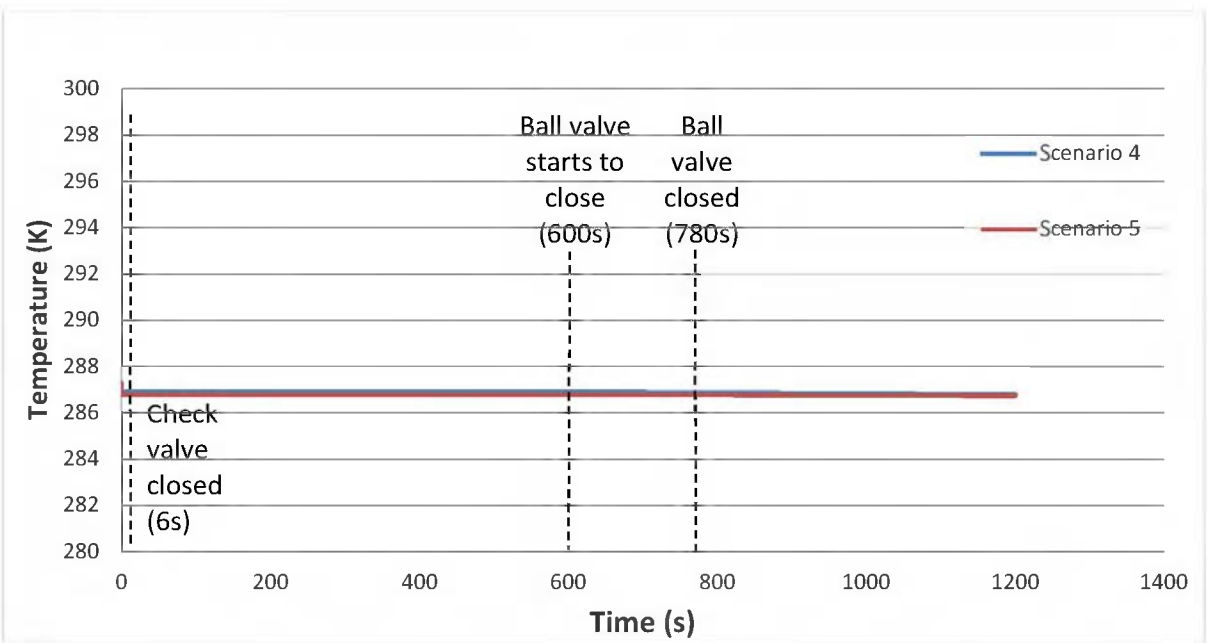


Figure 29. Group B variation of release temperature with time

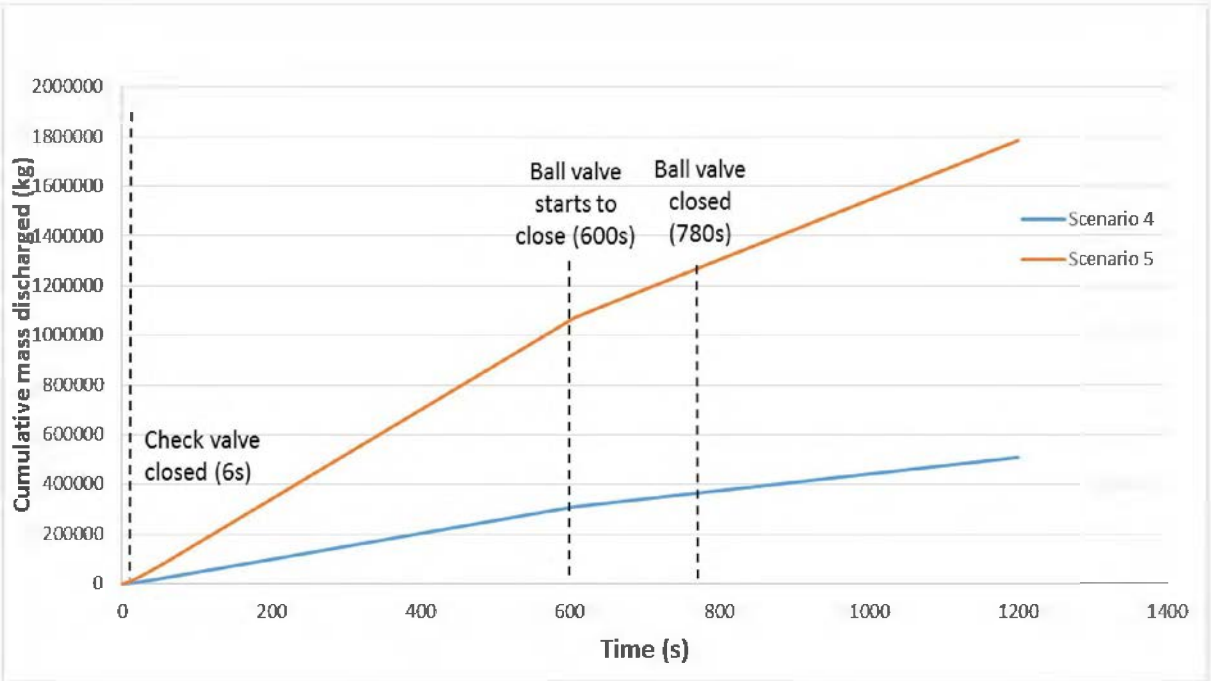


Figure 30. Group B variation of cumulative mass discharged with time

5.3 Group C

Table 7 shows the corresponding simulation input parameters for Group C.

Table 7. Group C Input conditions

Input conditions	Scenario 3	Scenario 6	Scenario 7
Overall pipeline length	10,072 m / 33,044 ft.	10,072 m / 33,044 ft.	10,072 m / 33,044 ft.
Pipe roughness (mm)	0.0457	0.0457	0.0457
Pipe external diameter	762 mm / 30"	762 mm / 30"	762 mm / 30"
Pipe wall thickness	20.62 mm / 0.812"	20.62 mm / 0.812"	20.62 mm / 0.812"
Orifice size	75 mm / 3"	75 mm / 3"	75 mm / 3"
Water depth at leak location	10 m / 33 ft.	35 m / 115 ft.	69.24 m / 227 ft.
Failure location relative to high pressure end	8,324 m / 27,310 ft.	4,438 m / 14,560 ft.	4838 m / 15,873 ft.
Pump shutdown time (min)	30	30	30
Remote valve (V-1 & V-2) closure time following pump shutdown (min)	3	3	3
Check valve (CV-1) closure time following the pump shutdown	instantaneous	instantaneous	instantaneous
Feed temperature	Average operating temperature	Average operating temperature	Average operating temperature
Ambient temperature	283.15 K / 509.67 R	283.15 K / 509.67 R	283.15 K / 509.67 R
Feed pressure	Average operating pressure	Average operating pressure	Average operating pressure
Ambient pressure	1.99 bara / 28.9 psi	4.44 bara / 64.4 psi	7.77 bara / 112.7 psi
Overall heat transfer coefficient (W/m^2K)	5	5	5
Maximum depressurisation time (s)	1800	1800	1800

Figures 31-35 respectively show the corresponding simulated variations of release pressure, velocity, mass release rate, temperature and cumulative mass discharged as a function of time for the first 1800s following pipeline failure. For all three failure scenarios, there is no emergency valve closure in the period under consideration. All involve a relatively small puncture diameter of 75 mm (3") resulting in an instantaneous drop to choked flow upon rupture leading to a very slow decompression rate (Figure 31) and almost constant discharge velocity (Figure 32) and mass discharge rate (Figure 33). In essence, given the very large amount of upstream inventory, the pipeline behaves much the same as an infinite reservoir. As expected at any given time during failure, the discharge velocity, discharge temperature

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and mass flow rate drop with increase in water depth, albeit in a nonlinear manner. Additionally, at any given time, the mass release rate (figure 33) is smaller for scenario 3 as compared to those for scenarios 6 and 7 given the larger distance between the upstream feed (point A) and the puncture location in the case of the former (8,324 m / 27,310 ft.) as compared to the latter (Scenario 6 and Scenario 7).

The observed almost linear decrease in the discharge temperature with time (Figure 36) in all three cases is due to the transient cooling of the fluid and the heat exchange with surrounding ambient. According to Figure 35, the respective cumulative mass discharged for Scenarios 3, 6 and 7 are ca. 19.2, 19 and 13 tonnes at 1200s following pipeline failure.

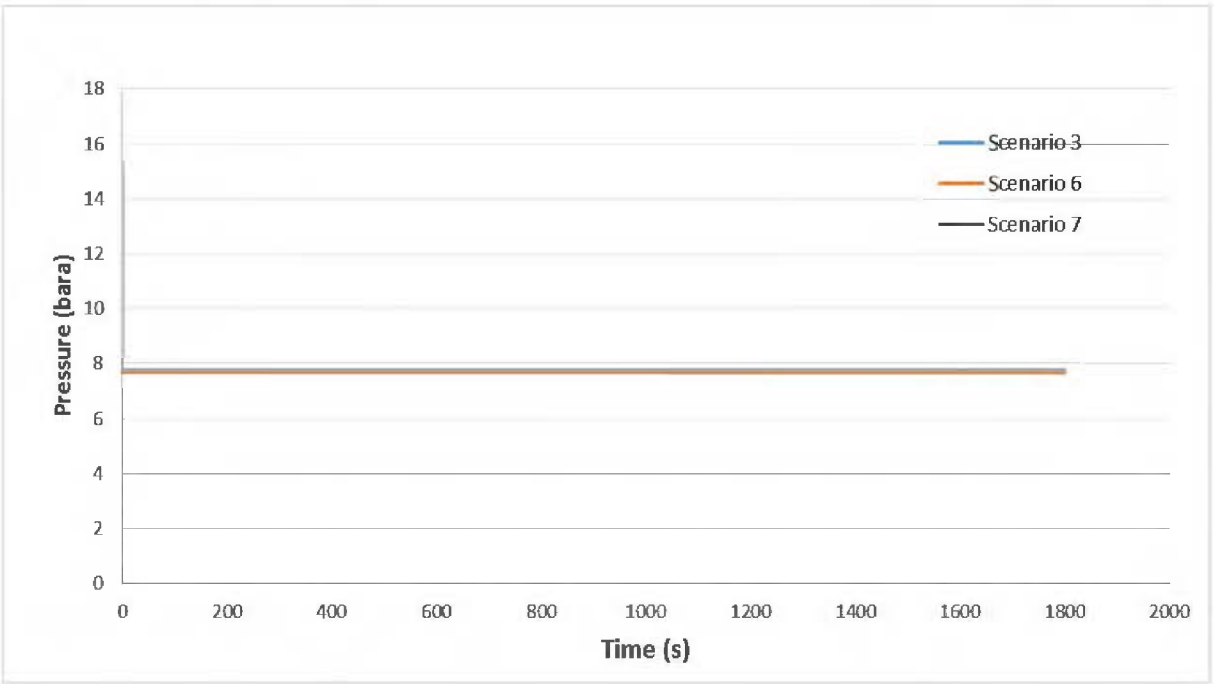


Figure 31. Group C variation of release pressure with time

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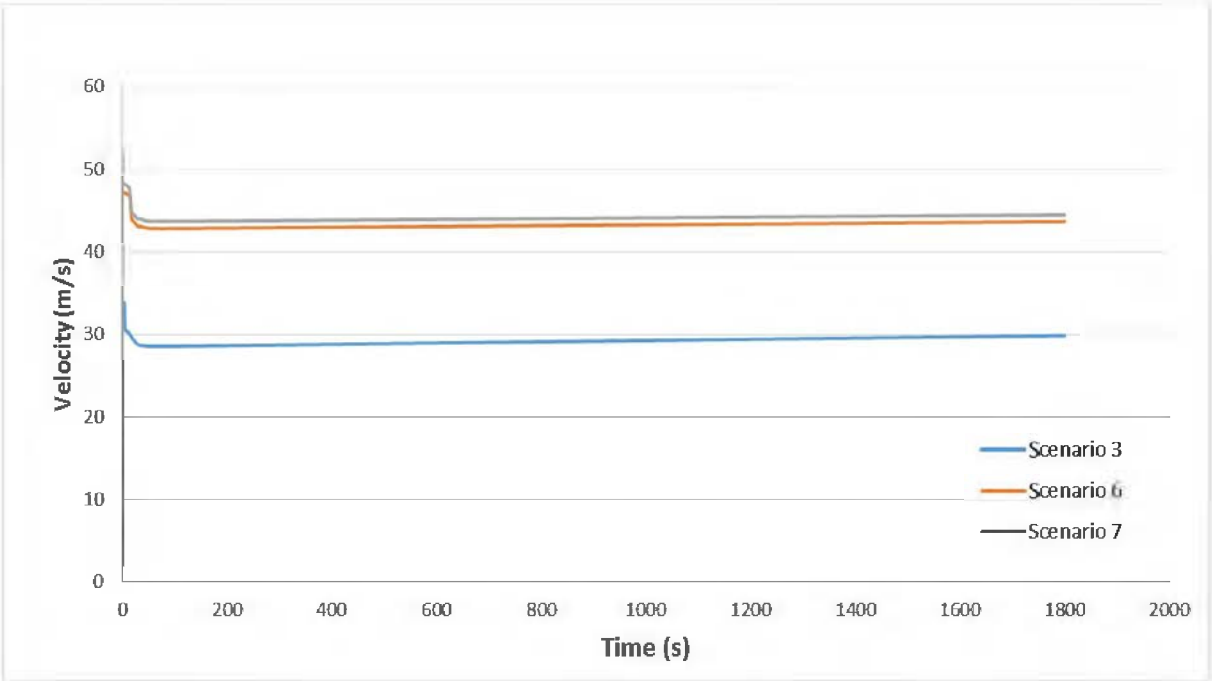


Figure 32. Group C variation of average release velocity with time

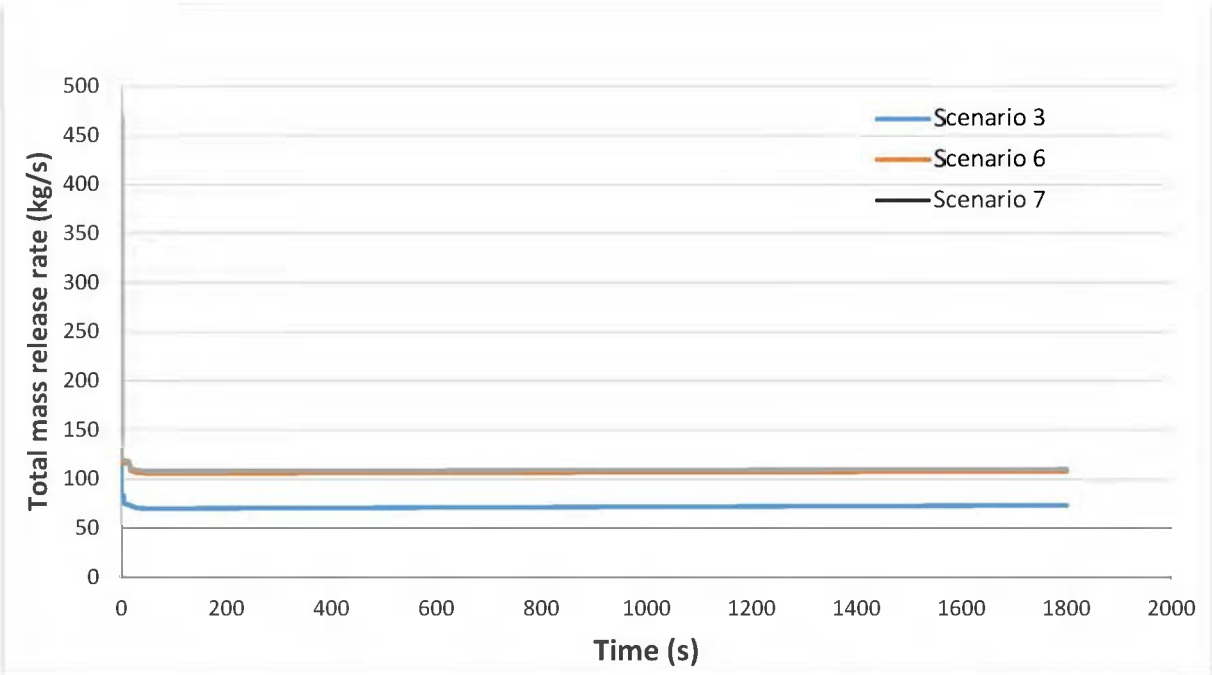


Figure 33. Group C variation of total mass release rate with time

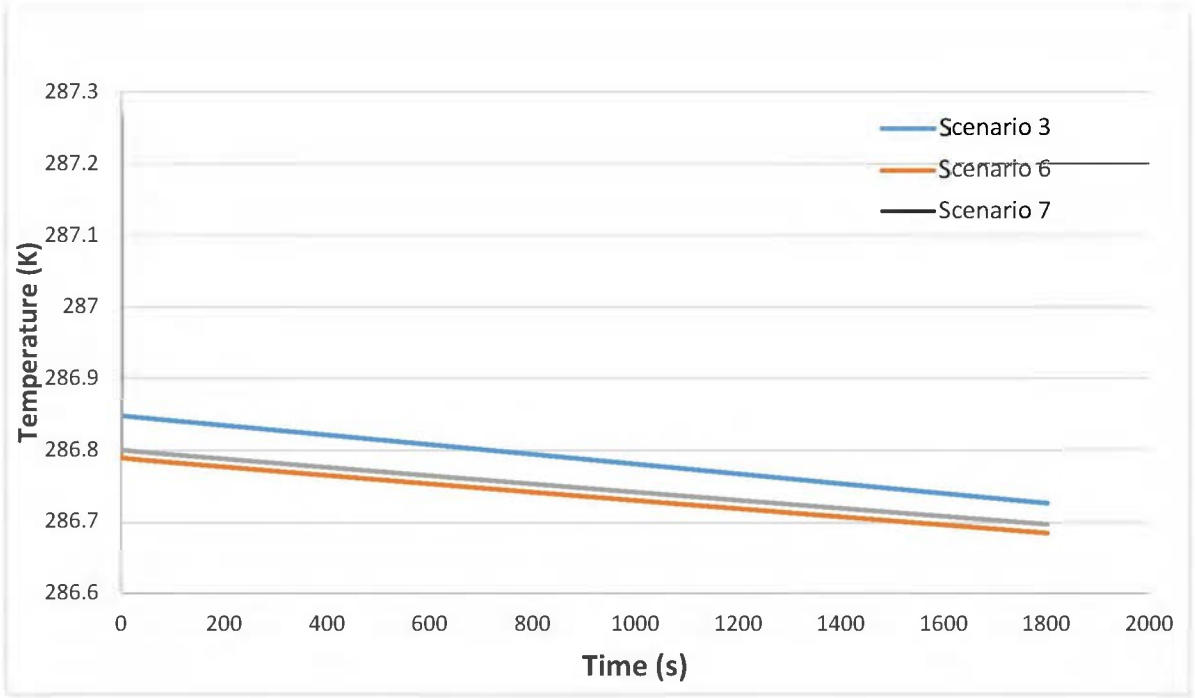


Figure 34. Group C variation of release temperature with time

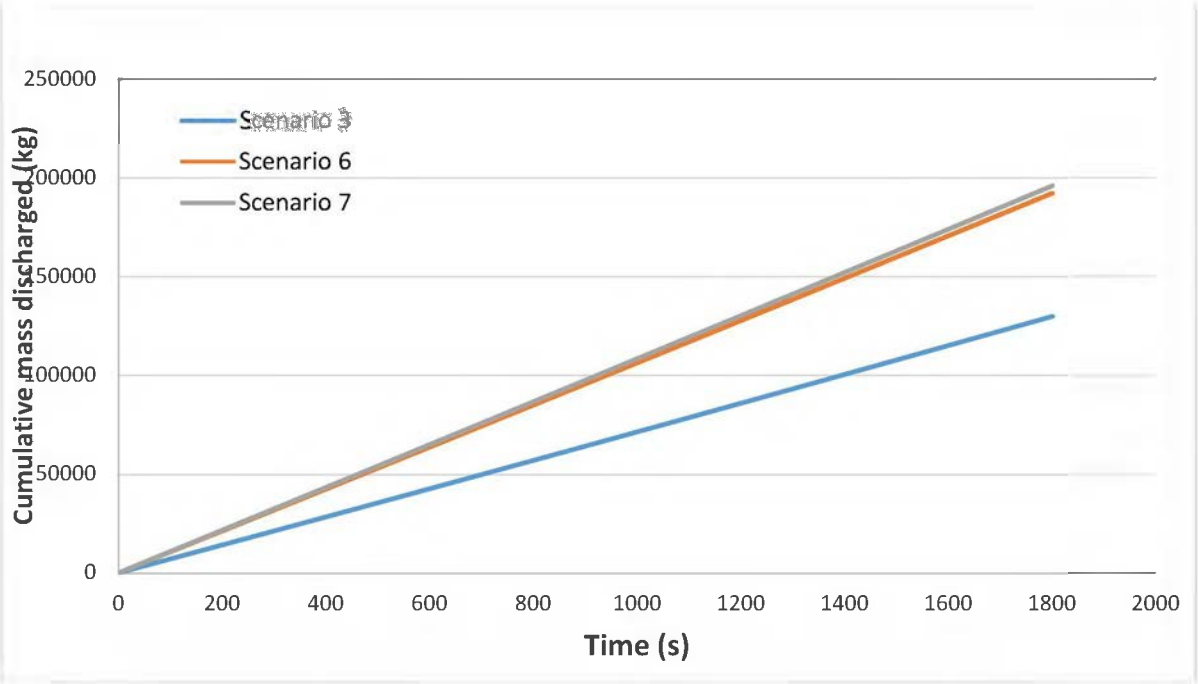


Figure 35. Group C variation of cumulative mass discharged with time

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6. References

Atti, O., "Modelling outflow and low temperature induced crack propagation in pressurised pipelines", PhD Thesis, University College London (2006).

Bendiksen, K.H., Malnes, D., Moe, R., Nuland, S., "The dynamic two-fluid model OLGA: theory and applications", *SPE Production Eng.* **6**,171 (1991).

Bisgaard, C., Sorensen, H.H. and Spangenberg, S., "A finite element method for transient compressible flow in pipelines", *International Journal for Numerical Methods in Fluids*, **7**, 291 (1987).

Chen, N. H., "An explicit equation for friction factor in pipes", *Ind. Eng. Chem. Fundam.*, **18**(3), 296 (1979).

Chen, J. R., "Modelling of transient flow in pipeline blowdown problems", *PhD Thesis*, University of London (1993).

Chen, J.R., Richardson, S.M., Saville, G., "A simplified numerical method for transient two-phase pipe flow", *Trans IChemE.* **71A**, 304 (1993).

Cullen, W. D., "The public inquiry into the Piper Alpha disaster", Dept. of Energy, HMSO (1990).

Fairuzov, Y. V., "Blowdown of pipelines carrying flashing liquids", *AIChE J.*, **44**(5), 245 (1998).

Lang, E., "Gas flow in pipelines following a rupture computed by a spectral method," *J. Appl Math and Physics (ZAMP)*, **42**, 183 (1991).

ENBDNR0002061

Mahgerefteh, H., Rykov,Y. Denton, G., "Courant, Friedrichs and Lewy (CFL) impact on numerical convergence of highly transient flows", *Chem Eng Science,* **64**(23), 14969-4975 (2009).

Mahgerefteh, H., Denton, G. and Rykov, Y., "A hybrid multiphase flow model", *AIChE Journal*, **54**(9), 2261-2268 (2008).

Mahgerefteh, H. and Abbasi, M., "Modeling blowdown of pipelines under fire attack", *AIChE Journal*, **53**(9), 2443-2450 (2007).

Mahgerefteh, H. and Oke, A., "An efficient numerical simulation for highly transient flows", *Chem.Eng.Sci.,* **61**(15), 5049-5056 (2006a).

Mahgerefteh, H. and Atti, O., "Modeling low-temperature-induced failure of pressurized pipelines", *AIChE Journal*, **52**(3), 1248-1256 (2006b).

Mahgerefteh, H., Oke, A. and Atti, O., "Modelling outflow following rupture in pipeline networks", *Chem.Eng.Sci.,* **61**(6) , 1811-1818 (2006c).

Mahgerefteh, H., Atti, O. and Denton, G., "An interpolation technique for Rapid CFD simulation of highly transient flows", *Trans.IChemE., Part B, Process Safety & Environmental Protection*, **84**(B6), 1- 6 (2006d).

Mahgerefteh, H., Oke, A., Economou, I. and Rykov, Y., "A transient outflow model for pipeline puncture", *Chem. Eng. Sci.,* **58**(20), 4591- 4604 (2003).

Mahgerefteh, H., Saha, P. and Economou I.G., "Modelling fluid phase transition effects on the dynamic behaviour of ESDV", *AIChE Journal*, **46**(5), 997 – 1006 (2000).

Mahgerefteh, H., Saha, P. and Economou I.G., "Fast numerical simulation for full bore rupture of pressurised pipelines", *AIChE Journal*, **45**(6), 1191 – 1201 (1999).

Perry, R. H., and Green, D. W., "Perry's chemical engineers' handbook", *7th Ed., McGraw Hill*, London (1997).

ENBDNR0002062

Peng, D. Y., and Robinson, D. B., "A new two-constant equation of state", Ind. Eng. Chem. Fund., 15, 59 (1976).

Richardson, S. M. and Saville, G., "Isle of Grain pipeline depressurisation tests", HSE OTH 94441, HSE Books, HSE, Bootle, U.K. (1996a).

Richardson, S. M. and Saville, G., "Blowdown of LPG pipelines," Trans. IChemE, 74B, 236 (1996b).

Twu, C.H., Bluck D., Cunningham J.R. and Coon J.E., "A Cubic Equation of State with a New Alpha Function and a New Mixing Rule", Fluid Phase Equilibria, 69, 33 – 50 (1991).

Walas, S. M., "Phase equilibrium in chemical engineering", Butterworth Publisher, Boston (1987).

Zucrow, M. J., and J. D. Hoffman, "Gas dynamics" Volumes I and II, Wiley, New York, 297 (1976).

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Dynamic Risk

Attachment 2: Oil Spill Modeling for Straits of Mackinac, Michigan

Spill Modeling Report.pdf

Oil Spill Modeling for Straits of Mackinac, Michigan

Oil Spill Modeling

Final Report



Oil Spill Modeling for Straits of Mackinac, Michigan

Oil Spill Modeling

Final Report

Prepared for Dynamic Risk



Straits of Mackinac

Project Manager	Dale Kerper, Senior Coastal & Marine Engineer, DHI US

Project number	41803539
Approval date	September 29, 2017
Revision	Final Draft 1.0
Classification	Open

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Executive Summary

The MIKE Powered by DHI Oil Spill (OS) model was used to simulate potential spills of oil from the rupture or leakage of both the existing Line 5 pipeline and a proposed new pipeline crossing through the Straits of Mackinac. The MIKE OS model was used in stochastic mode to determine the range of possible water surface and shoreline oiling over 1 year as well as over four (4) quarters, which represent the four seasons. To describe the seasonal variations, hindcast data was obtained for a period of more than one calendar year. This report describes the models used to predict the fate of spilled oil and also presents the model results.

Hypothetical spill scenarios were defined on the basis of an earlier risk assessment outlining the possible causes and volumes for the worst case scenario along the pipeline. All spill scenarios were simulated without application of any interventions (or countermeasures). The scenarios included:

- Spill of oil from the proposed 30" trenched pipeline with full rupture at the shipping channel. The duration is 6 hours to allow for spill during detection and troubleshooting time plus the drainage of gravity spill;
- Spill of oil from the proposed 30" trenched pipeline with 75 mm leak scenario at north shore. The duration is 1 hour to allow for spill during detection and troubleshooting time plus the drainage of gravity spill;
- Spill of oil from the proposed 30" trenched pipeline with 75 mm leak scenario at south shore. The duration is 3.5 hour to allow for spill during detection and troubleshooting time plus the drainage of gravity spill; and
- Spill of oil from the 20" existing eastern pipeline with full rupture in the shipping channel. The duration is 12.5 hours to allow for spill during detection and troubleshooting time plus the drainage of gravity spill;

- Spill of oil from the 20" existing eastern pipeline with 75 mm leak scenario at north shore. The duration is 1.3 hours to allow for spill during detection and troubleshooting time plus the drainage of gravity spill

- Spill of oil from the 20" existing eastern pipeline with 75 mm leak scenario at south shore. The duration is 1.3 hours to allow for spill during detection and troubleshooting time plus the drainage of gravity spill

To provide an accurate description of the hydrodynamic conditions at the site and around Lake Huron and Lake Michigan, detailed hindcast modeling was carried out using DHI's deterministic high resolution models for currents, waves and water level. Meteorological hindcast data such as wind data was obtained from National Centre for Environmental Prediction (NCEP). A detailed description of the hydrodynamic and wave model setups is given in the Attachment 5 "Hydrodynamic and Wave Modeling".

MIKE OS was used to carry out 30 simulations per hypothetical spill scenario per season to assess the probability of oiling the water surface, zone and minimum time of shoreline oiling considering the following two exposure thresholds:

- Surface oil load greater than 0.01 g/m^2 (resulting in a visible sheen with low environmental impacts). 0.01 g/m^2 is analogous to 0.01 µm surface thickness.
- Shoreline oil load greater than 1 g/m^2 (resulting in an oil coat with low environmental impacts)

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LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
CFSR	Climate Forecast System Reanalysis
DHI	DHI Water & Environment (M) Sdn Bhd
FIPS	Federal Information Processing Standards
HD	Hydrodynamic
HYCOM	Hybrid Coordinate Ocean Model
MSL	Mean Sea Level

LIST OF DEFINITIONS

Drift	Transport of oil in the water under the effects of current, wind and bed drag.
Spreading	Physical spreading of the oil on the water surface depending on inertia, viscosity and surface tension.
Water depth	Depth relative to mean sea level (unless other datum specified).
Weathering	The change of physicochemical properties of the spilled oil in the ambient environment.
Wind direction	Direction from where the wind is blowing from at a level of 10 meter above mean sea level or ground (unless other level specified).
Wind speed	Speed of the wind at a level of 10 meter above mean sea level or ground (unless other level specified).

1 Introduction

DHI as member of the Dynamic Risk consortium was contracted by the State of Michigan for the assessment of the possible fate of oil spilled due to failure of pipelines crossing the Straits of Mackinac.

The fate of spilled oil depends much on the environmental conditions which includes wind, ice cover, solar radiation, sea surface temperature, waves, currents, water level at the time of the spill and the properties of the spilled oil.

Whereas the properties of oil that is transported in the pipelines and may be spilled can be specified with some certainty, the environmental conditions that affect the drift, spreading and weathering of the spilled oil are uncertain, since a spill can occur at any time and the environmental conditions vary significantly over time. To accommodate this environmental variability, multiple oil spill simulations have been carried out over a one year period with temporal and spatial varying environmental conditions.

The temporal and spatial variations in the environmental conditions have been described using the best public available meteorological hindcast data from NCEP and hydrodynamic and wave data generated by validated high resolution models developed by DHI.

Six (6) hypothetical spill scenarios were selected for the spill assessment based on failure probabilities. For each scenario, 120 spill simulations have been carried out at random times over a calendar year and a statistical analysis of the many predicted spill trajectories maps have been generated to depict the:

- Probability of spilled oil to reach a given area;
- Category of exposure at the shoreline as high, moderate, low or no exposure;
- Minimum arrival time to the shore and the extent of exposure

In addition to the maps, key statistical results such as the extent of shoreline oiled have been tabulated for each of the modeled oil spill scenarios.

1.1 Study limitations

When referring to the results of the oil spill modeling, the following is to be noted:

- The oil spill modeling has only included the 2D sea surface trajectories and not any subsea oil and gas plumes. Given the water depth at the spill locations, the rise of the oil plume is not considered critical for the assessment of the environmental risk as an oil plume will rise from the seabed to the sea surface within 5-15 minutes (not considering the effect of the jet) and will, depending on the current at the time of the spill, surface within a distance of 1 km from the spill location.
- The modeling results are presented as statistical maps combining the trajectories of many oil spill simulations. Therefore, the maps do not reflect the risk of oil exposure to a single spill.
- For response planning, the results provide the most probable trajectory, minimum time to respond and areas to be affected by an oil spill. In an actual response situation, the oil spill trajectory should be forecasted based on the incident report and best available forecasted environmental data.

1.2 Report outline

The study report is structured as follows:

Section 2: Provides a brief description of the environmental conditions governing the spreading, drift and weathering of spilled oil.

Section 3: Includes a description of the oil spill model used, hypothetical spill scenarios modeled and properties of spilled oil.

Section 4: Interpretation of the oil spill modeling results.

Section 5: Brief discussion of DHI modeling compared to University of Michigan modeling

Section 6: References

Section 7: Statistical maps generated on the basis of the oil spill simulations are presented at the end of the report.

2 Environmental Data as Model Inputs

The spreading, drift and weathering for a given type of oil depends on the environmental conditions. For the present oil spill modeling, the environmental conditions considered include:

- Meteorological conditions
  - Wind
  - Ice
- Lake water conditions
  - Currents
  - Waves
  - Density
  - Surface temperature

Historical meteorological conditions and lake surface temperature have been retrieved from public sources, whereas the marine conditions, currents and waves have been generated using DHI's models as discussed in the report ' Hydrodynamic and Spectral Wave Numerical Modeling'.

2.1 Wind data

Mesoscale weather data has been sourced from the National Centre for Environmental Prediction, USA (NCEP). The data covers a period of 37 years from 1979 to 2016 and is based on the Climate Forecast System Reanalysis (CFSR) project using an assimilated global, high resolution, coupled atmosphere-ocean-land surface-sea ice modeling system.

Period: 1970 onwards.
Temporal resolution: Hourly.
Spatial resolution: 0.30° × 0.30° (through 2010) and 0.20° × 0.20° (from 2011 onwards).

Wind velocity components 10m above the ground and atmospheric pressure at Mean Sea Level were downloaded from the forecast system at a 1-hour time interval, post-processed into MIKEZero compatible format and stored for later use in the numerical modeling analyses.

2.2 Ice

Gridded ice concentration data at a spatial resolution of 1800m were downloaded from NOAA Great Lakes Environmental Research Laboratory, GRERL (http://www.glerl.noaa.gov/data/pgs/glice/glice.html). Except for a few missing datasets, daily maps of ice concentration for all the Great Lakes were available. In addition, other important ice parameters such as ice thickness and ice velocity were also used in the spill modeling. However, there was no measured data or satellite data available at the study area from GRERL. Hence, these additional data were requested from Great Lakes Coastal Forecasting System, GLCFS. It is noted that the ice thickness and ice velocity were simulated results and were not validated against observations. Nevertheless, this is the best available ice data to be applied to the spill model.

All ice data were post-processed into MIKEZero compatible format and stored for later use as input for the spill model.

2.3 Surface temperature

Surface temperatures at Lake Huron and Lake Michigan have been extracted from the Great Lakes CoastWatch Node located at the webpage https://coastwatch.glerl.noaa.gov/. The data are derived from NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery obtained through the CoastWatch program.

Average surface water temperature from the Great Lakes Surface Environmental Analysis (GLSEA) was extracted and is presented in Table 2.1 and Table 2.2. Temperature data was post-processed into MIKEZero compatible format for use in the spill modeling.

Table 2.1 Monthly average of sea surface temperature at Lake Huron and Lake Michigan in 2014.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature –Lake Huron [°C]	1.3	0.3	0.2	0.9	4.1	10.2	15.8	18.1	16.7	12.3	7.7	4.1
Average Temperature –Lake Michigan [°C]	1.9	0.5	0.3	1.3	4.4	10.0	15.7	18.8	17.6	12.7	7.1	4.4

Table 2.2 Monthly average of sea surface temperature at Lake Huron and Lake Michigan in 2015.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature –Lake Huron [°C]	1.5	0.3	0.2	0.9	4.1	10.2	15.8	18.1	16.7	12.3	7.7	4.1
Average Temperature –Lake Michigan [°C]	2.3	1.0	0.8	2.5	5.7	10.5	17.5	20.4	19.0	13.9	9.7	6.8

3 Oil Spill Modeling

DHI's MIKE 21/3 Oil Spill model has been used to predict the spreading, drift and weathering of spilled oil under varying met-ocean conditions (see description in Section 2). The model is implemented in the highly flexible open equation solver being part of DHI's ECOLab software.

Oil in the model is represented as Lagrangian particles drifting (being advected) with the surrounding water body's velocity and exposed to weathering processes. The drift of the individual particles is determined by the combined effects of current, wind and lake bed drag. The variation of current speed over the water depth is emulated by application of a drift profile, being a combination of a simulated current profile or traditional assumed bed shear profile (logarithmic) and wind acceleration of particles directly exposed to the wind.

Weathering processes cause the oil properties of each particle to change over time and with the ambient conditions. Of particular interest for response planning is the evaporation and emulsification that may rapidly change the physical oil properties and affect spreading and dictate clean-up methods.

3.1 Oil spill processes

MIKE 21/3 OS model simulates the spreading and transformation of hydrocarbons in the aquatic environment under the influence of fluid transports and associated dispersion processes. The oil itself is defined according to its distillation properties and chemical structure. The model provides information on oil slick locations, the amount of oil left on the sea surface, the slick mobility and the evolution of the physiochemical properties of the oil (weathering). The following weathering processes are included in the model (see Figure 3.1):

- Spreading
- Evaporation
- Emulsification
- Vertical dispersion (entrainment)
- Dissolution
- Photo-oxidation
- Biodegradation
- Sedimentation

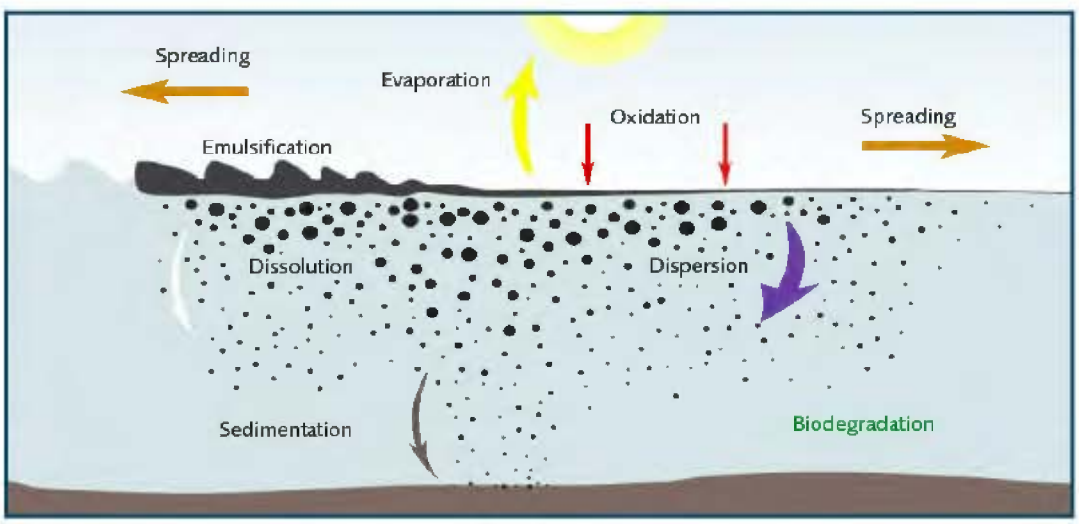


Figure 3.1 Oil weathering processes /1/.

A schematic presentation of time scales for different weathering processes is shown in Figure 3.2 and it is noted that spreading, evaporation, dispersion and dissolution can be defined as short-term weathering processes, whereas emulsification, biodegradation, sedimentation and photochemical oxidation are recognized as long term weathering processes (i.e. weeks to months or years). The different chemical components in the oil are described by, among other things, the molecular weight which is an indication of how volatile the component is and how it is affected by the weathering process.

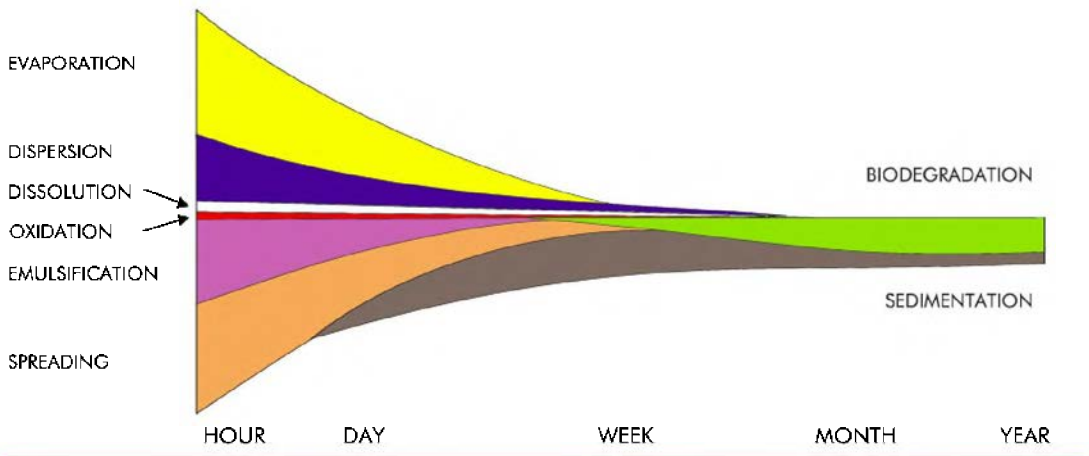


Figure 3.2 A schematic representation of the fate of a crude oil showing changes in the relative importance of weathering processes with time – the width of each band indicates the importance of the process /1/.

In addition to this, the weathering of spilled oil in the presence of ice is also included in the model. The oil spill weathering pattern is greatly affected by the presence of ice, as ice can shelter the oil from wind and wave action, slowing down its spreading and weathering.

3.1.1 Spreading

Oil begins to spread as soon as the spilled oil reaches the sea surface. Spreading is the most important process in the study of oil spill fate because the rate at which the oil spreads on the open water can affect the weathering processes, for example: evaporation, dispersion and emulsification. The spreading of oil in this model is based on the Fay spreading equations. Based on Fay's study, the spreading processes of oil are divided into three separate phases, the inertial spread, viscous phase and surface tension phase.

3.1.2 Evaporation

In the first hours and days following the spill, evaporation at the surface of the slick is the dominant weathering processes. The rate at which the oil evaporates depends on the oil properties, amount of spill exposed to surface water, wind speed and water temperature /2, 3/. In general, if the spill consists of a high fraction of volatile compounds, evaporation happens faster than for heavier products. Whereas for medium-weight crudes, the removal is less complete, but substantial nevertheless. Typically, 10-30% of the material from the spill of medium-weight crudes can be removed through evaporation /3/. In short, most volatile hydrocarbons evaporate most rapidly and, as the oil emulsifies, the rate of evaporation will be significantly reduced.

3.1.3 Emulsification

Emulsification is the formation of a mixture of two distinct liquids. Fine oil droplets are suspended within (but not dissolved into) the water and the emulsification formed occupies a

volume that can be up to four times that of what the oil would form if it created a thick slick. This water-in-oil emulsion is also called "mousse" due to its appearance. The mousse formation can slow and delay the other weathering processes as emulsification increases the viscosity, which reduces the spreading rate and then affects the evaporation processes. The present model describes the emulsification as an equilibrium process between the two stages: oil+water and water in oil. Stability of emulsions is an important factor determining the ability of emulsions to demulsify, as unstable and mesostable emulsions will release water /2/.

3.1.4 Interaction between oil and ice

In the presence of ice, the fate and behavior of spilled oil can be greatly affected. Interaction between oil and ice can cause some fraction of oil to be moving with the ice. Moreover, the presence of ice acts as a shelter to the oil from wind and wave action. This, in turn, slows down the spreading, evaporation and emulsification of the oil. The MIKE 21/3 Oil Spill model used in this study applies the effect of ice for the calculation of advection, surface oil spreading and vertical dispersion, which subsequently affects the evaporation and emulsification. Table 3.1 summarizes how the model deals with oil in the presence of different oil concentrations.

Table 3.1 Summary of oil-ice interaction accounted for in MIKE 21/3 Oil Spill.

Ice Cover/ Concentration [Percent]	Advection	Evaporation	Vertical Dispersion
0 - 30	Oil moves with current	Ice has no effect	Ice has no effect
>30	Oil moves with ice	Evaporation impeded	Dispersion impeded

3.2 Stochastic oil spill modeling

An oil spill simulation using MIKE 21/3 OS describes the spreading, drift and weathering of a single spill taking place over a given period and for a number of days after the spill has stopped. The spilled oil during this period is subjected to environmental conditions at the time of the spill and through the simulation period, and a single simulation will thus only describe the spreading, drift and weathering under these specific conditions.

By performing a large number of simulations of the same hypothetical spill scenario at different times over a historical period of one or more years, it is statistically possible to cover all normally occurring environmental conditions (i.e. combinations of wind, currents, waves, sea surface temperature and solar radiation) under which a spill may occur. At spill locations where the environmental conditions tend to be harmonic due to currents being governed by the tide or winds being affected by land-sea breeze systems, it is important that simulations are started at random times to avoid any bias in the drift.

For response planning purposes, a statistical analysis is carried out to provide maps for each spill scenario showing:

- Probability of a given area being exposed to spilled oil for 1 year, Q1, Q2, Q3 and Q4;
- Time from the occurrence of the spill until the spilled oil reaches a given area for 1 year, Q1, Q2, Q3 and Q4;
- Maximum length of shoreline exposed to oil concentration above a given threshold for 1 year, Q1, Q2, Q3 and Q4.

For areas where oil will reach the shoreline, the statistical results below will be tabulated:

- Maximum amount of oil per township over 1 year;
- Total maximum length of shoreline exposed to oil per county over 1 year.

3.3 Sea surface and shoreline thresholds

The model results in this study are reported for different thresholds based on the amount of oil on the water surface or at the shoreline, and the resources potentially at risk. Impact thresholds have been defined on basis of /4, 5/ and presented in Table 3.2 and Table 3.3.

Table 3.2 Threshold classification to assess zones of sea surface contact.

Hydrocarbon Concentration [g/m^2]	Impact Level	Description of Impact
>0.01 (~0.01 µm slick thickness)	Low	- Barely visible sheen - Likely results in closure of fisheries - Fishing is prohibited - Socio-economic impact
10-25	Moderate	- Mortally impact sea birds and other wildlife associated with water surface - Ecological impact
>25	High	- Harmful to all birds in contact with the slick - This is used to define the zone of potential high exposure

Table 3.3 Threshold classification to assess zones of shoreline contact.

Hydrocarbon Concentration [g/m^2]	Impact Level	Description of Impact
>1	Low	- Socio-economic impact on land - Need for shoreline cleanup on amenity beaches and coastal recreational zones - Less likely to have effect on animals
100-1000	Moderate	- Also called hydrocarbon 'coat' - Likely to have impact on animal survival and reproductive capacity - Lethal threshold for invertebrates living in intertidal habitats
>1000	High	- Impact marsh plants and mangroves significantly during the growing season. - Higher level of ecological impacts

3.4 Oil properties

The selected oil to be assessed in this study was Canadian Sweet Blend and oil properties used for the modeling were based on data taken from the CrudeMonitor.CA database (http://www.crudemonitor.ca/home.php). The characteristics of the oils used are summarized in Table 3.4.

Table 3.4 Oil properties for Canadian Sweet Blend.

Parameters	Unit	Canadian Sweet Blend
Density @ 15°C	[kg/m^3]	824.6
API gravity @ 60°F	[°]	39.9
Pour point	[°C]	-11
Kinematic viscosity @ 40°C	[cSt]	2.5

3.5 Hypothetical spill scenarios

Six (6) hypothetical spill scenarios have been selected for the spill assessment based on pipeline failure probability. The hypothetical spill scenarios considered in the present study include spills from the pipeline due to full rupture and due to pipe leakage (75 mm hole size).

3.5.1 Spill from pipeline rupture

If pipelines are in operation the spill is driven initially by the excess of internal pressure over the external hydrostatic pressure of the sea. On detecting the leak, the operator will shut down the pipeline by stopping pumps and closing isolation valves. Residual pressure will then drive out a further quantity of oil (the pipeline contracts and the oil expands as the residual pressure dissipates). At some stage the internal pressure at the leak orifice equilibrates with the external hydrostatic pressure and oil will continue to flow out due to the density difference between seawater and oil. The heavier water intrudes into the pipeline via the lower part of the leak orifice, with an equal amount of the lighter oil being displaced from the pipeline via the upper part of the leak orifice. The intruding water will flow along the bottom of the pipeline until the moving waterfront encounters the end of the pipeline or a trap (location where the pipeline elevation has increased sufficiently to prevent further water intrusion).

The first phase of a pipeline spill involves high rates of discharge due to the excess pressure, but usually only for a short duration (i.e. until pipeline shutdown and dissipation of residual pressure). For the second phase of a pipeline spill the rate of discharge is lower, but typically of much longer duration with a potential larger spill volume. The spill rate for the second phase very much depends on the size of the leak, pipeline elevation, oil density and viscosity.

3.5.2 Summary of spill scenarios

Six (6) hypothetical spill scenarios representing pipeline failure have been considered in this study for the newly trenched 30" pipeline and the existing pipeline. Oil type is the same for all release scenarios. The scenarios are summarized and listed in Table 3.5 and Table 3.6

Table 3.5 Spill scenarios for newly trenched pipeline.

Spill Scenario	Release Point (coordinates)	Total Outflow Volume	Spill Sequence	Total Spill Duration	Simulation Duration
Full rupture at shipping channel	Lat: 45.8185, Long: -84.7707	931.5 m^3 (5,859 bbl.)	10 minutes detection/troubleshooting time + 30 seconds pump shutdown + 3 minutes valve closure + 5.6 hours drainage time	5.83 hr	30 days
75 mm leak at northern shore	Lat: 45.8332, Long: -84.7653	925.3 m^3 (5,820 bbl.)	30 minutes detection/troubleshooting time + 30 seconds pump shutdown + 3 minutes valve closure + 0.4 hour drainage time	1.0 hr	30 days
75 mm leak at southern shore	Lat: 45.7899, Long: -84.7811	1558.2 m^3 (9801 bbl.)	30 minutes detection/troubleshooting time + 30 seconds pump shutdown + 3 minutes valve closure + 2.9 hours drainage time	3.5 hr	30 days

Table 3.6 Spill scenarios for existing pipeline.

Spill Scenario	Release Point (coordinates)	Total Outflow Volume	Spill Sequence	Total Spill Duration	Simulation Duration
Full rupture at shipping channel	Lat: 45.8200, Long: -84.7600	417.9 m^3 (2629 bbl.)	10 minutes detection/troubleshooting time + 30 seconds pump shutdown + 3 minutes valve closure + 12.4 hours drainage time	12.67	30 days
75 mm leak at northern shore	Lat: 45.8331, Long: -84.7547	461.4 m^3 (2902 bbl.)	30 minutes detection/troubleshooting time + 30 seconds pump shutdown + 3 minutes valve closure + 0.8 hour drainage time	1.33	30 days
75 mm leak at southern shore	Lat: 45.7900, Long: -84.7711	719.7 m^3 (4527 bbl.)	30 minutes detection/troubleshooting time + 30 seconds pump shutdown + 3 minutes valve closure + 0.8 hours drainage time	1.33	30 days

4 Interpretation of Modeling Results

The fate of spilled oil depends much on the environmental conditions at the time of the spill and the properties of the spilled oil. Whereas the properties of oil that may be spilled at a location can be given with some certainty, the environmental conditions that affect the drift, spreading and weathering of the spilled oil are dependent on the environmental conditions occurring at the time of the spill, and vary significantly over time.

It is not practical to make future response decisions or conclusions from the result of a single model simulation, but instead to use the combination of multiple model simulations. Combining the results of many spill simulations provides the basis for a statistical analysis carried out on simulation results on a scenario basis. The statistical analysis provides the following:

- Probability of exposure/occurrence (in percentage). The probability that oil at a concentration equal to or above the critical surface threshold arrives at a given location, calculated as the number of simulations that cause oiling at a given location divided by the total number of simulations
- Minimum arrival time (hours). The minimum time before oil at a concentration equal to or above the critical shoreline impact threshold arrives at a given location;
- Zone of potential exposure. The zone is classified based on the maximum oil loading on shoreline above a critical threshold. Defined zones are high, moderate, low and no exposure, with no exposure representing either no oil exposure or oil exposure lower than a threshold.

When analyzing the simulation results, the probability, the concentration and the exposure time are calculated at each model mesh element considering all simulations for a given scenario. Hence, maps and tables do not represent the results of a single simulation but rather statistics considering all simulations for a hypothetical spill scenario.

Key statistics are given in summary tables in the forthcoming sections and include:
- Maximum amount of oil per township over 1 year;
- Total maximum length of shoreline exposed to oil per county over 1 year.

Statistical maps enclosed at the end of the report include:

- Risk (probability) of sea surface exposure to oil concentration of 0.01 g/m^2 or higher in case of pipeline failure (analogous to surface slick thickness >0.01 µm);
- Potential level of shoreline exposure by impact zones (defined by thresholds for accumulated oiling);
- Minimum arrival time to shoreline for oil concentration of 1 g/m^2 or higher.

4.1 Statistical results

When a spill occurs in the lake environment, shorelines are exposed to the effects of oil, since this is where oil naturally tends to accumulate. Hence, it is essential to look at how the shorelines are affected. In this study, the impacts on shoreline are studied through:

- Total maximum amount of oil per township over 1 year;
- Total maximum length of shoreline exposed to oil per county over 1 year for each simulation.

The results are analyzed and presented in the tables below.

4.1.1 Total maximum amount of oil per township over 1 year

For each coastal township in Michigan the total amount of oil reaching the shoreline has been calculated over one year (or in other words 120 simulations). The townships are identified by name and their unique Federal Information Processing Standards (FIPS) code. Besides the amount of kg oil reaching the township's shoreline the number of spills out of the 120 simulations over the year that reach the shoreline of the township in question are recorded. For example out of the 120 spill trajectories, two simulations result in a spill detected at Alpena's shoreline.

Table 4.1 Total maximum amount of oil in kilogram per township over 120 simulations for Scenario 30" Trenched Pipeline – Full rupture.

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Alpena	01760	507	2
Bear Creek	06380	1535	1
Bearinger	06400	11256	14
Beaugrand	06500	1000261	47
Benton	07420	503544	20
Bliss	08980	3816119	52
Bois Blanc	09500	2410778	59
Charlevoix	14800	77534	6
Cheboygan	15000	193790	17
Clark	16060	87661	14
Cross Village	18900	158596	24
Detour	21770	7684	2
Drummond	23080	18558	3
Friendship	30860	26277	8
Garfield	31620	1534	3
Harbor Springs	36560	763	2
Hayes	37320	35264	5
Hendricks	37660	300955	8
Hudson	39760	181807	5
Krakow	43900	3138	5
Little Traverse	48080	577	1
Mackinac Island	50280	3618556	60
Mackinaw	50300	6682648	66
Marquette	51880	36950	10
Moran	55480	16118508	78
Norwood	59340	6010	3
Ocqueoc	60160	4022	10
Peaine	63140	270	2
Petoskey	63820	2603	2
Presque Isle	66340	1015	3

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Pulawski	66460	15262	6
Readmond	67540	103983	20
Rogers	69240	26718	11
Rogers City	69260	12179	5
St Ignace	70840	422483	53
St Ignace	70860	132252	11
St James	70920	140683	2
Sanborn	71240	24	1
Wawatam	84840	5882085	78
West Traverse	86300	2474	3
Ontario	-	71543	7

Table 4.2 Total maximum amount of oil in kilogram per township over 120 simulations for Scenario 30" Trenched Pipeline – 75 mm Leak at Northern Shore.

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Alpena	01760	192	1
Banks	05240	240	1
Bear Creek	06380	1605	1
Bearinger	06400	11707	9
Beaugrand	06500	1103407	38
Benton	07420	196622	20
Bliss	08980	2474531	48
Bois Blanc	09500	2263454	53
Charlevoix	14800	121589	4
Cheboygan	15000	246008	13
Clark	16060	61982	12
Cross Village	18900	105210	17
Detour	21770	12647	2
Drummond	23080	10938	3
Friendship	30860	25718	3
Garfield	31620	890	2
Harbor Springs	36560	423	2
Hayes	37320	68135	4
Hendricks	37660	237326	10
Hudson	39760	190930	5
Krakow	43900	2108	3
Little Traverse	48080	345	1
Mackinac Island	50280	3936899	53

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Mackinaw	50300	5130165	63
Marquette	51880	123362	8
Moran	55480	20918036	93
Norwood	59340	11955	2
Ocqueoc	60160	5931	5
Peninsula	63340	292	1
Petoskey	63820	2905	2
Presque Isle	66340	1616	2
Pulawski	66460	4744	5
Readmond	67540	141906	15
Rogers	69240	18265	9
Rogers City	69260	5133	7
St Ignace	70840	699351	57
St Ignace	70860	281768	13
St James	70920	178735	2
Wawatam	84840	4628207	66
West Traverse	86300	2427	2
Ontario	-	22326	7

Table 4.3 Total maximum amount of oil in kilogram per township over 120 simulations for Scenario 30" Trenched Pipeline – 75 mm Leak at Southern Shore.

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Alpena	01760	1667	1
Bear Creek	06380	2829	1
Bearinger	06400	34358	11
Beaugrand	06500	622618	45
Benton	07420	1420722	21
Bliss	08980	6202443	53
Bois Blanc	09500	3305492	52
Charlevoix	14800	3208	2
Cheboygan	15000	36721	18
Clark	16060	80698	11
Cross Village	18900	146139	22
Detour	21770	3586	1
Drummond	23080	21539	4
Friendship	30860	35836	6
Garfield	31620	1311	2
Harbor Springs	36560	215	1
Hayes	37320	3521	4

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Hendricks	37660	538318	8
Hudson	39760	75147	5
Krakow	43900	10156	2
Little Traverse	48080	282	1
Mackinac Island	50280	3286004	61
Mackinaw	50300	5726342	93
Marquette	51880	56081	9
Moran	55480	16143091	73
Norwood	59340	93	1
Ocqueoc	60160	13811	11
Petoskey	63820	1947	1
Presque Isle	66340	891	3
Pulawski	66460	53476	5
Readmond	67540	111560	19
Rogers	69240	69352	13
Rogers City	69260	45673	5
St Ignace	70840	307422	46
St Ignace	70860	86645	12
St James	70920	177776	2
Torch Lake	80100	271	1
Wawatam	84840	83773305	120
West Traverse	86300	2926	1
Ontario	-	94617	8

Table 4.4 Total maximum amount of oil in kilogram per township over 120 simulations for Scenario Existing Pipeline – Full rupture.

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Alpena	01760	499	2
Bear Creek	06380	405	1
Bearinger	06400	6769	12
Beaugrand	06500	563040	46
Benton	07420	183464	28
Bliss	08980	1717425	51
Bois Blanc	09500	1174218	63
Charlevoix	14800	24166	6
Cheboygan	15000	120662	16
Clark	16060	93205	14
Cross Village	18900	77135	24
Detour	21770	5109	3
Drummond	23080	11899	4

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Friendship	30860	6394	4
Garfield	31620	562	2
Harbor Springs	36560	59	2
Hayes	37320	12041	4
Hendricks	37660	111150	9
Hudson	39760	81628	4
Krakow	43900	2908	4
Mackinac Island	50280	1806557	60
Mackinaw	50300	3317500	72
Marquette	51880	32869	12
Moran	55480	7359420	84
Norwood	59340	1915	3
Ocqueoc	60160	1439	9
Petoskey	63820	520	2
Presque Isle	66340	337	2
Pulawski	66460	9348	5
Readmond	67540	33512	18
Rogers	69240	15915	10
Rogers City	69260	8329	6
St Ignace	70840	229051	59
St Ignace	70860	85326	16
St James	70920	36959	4
Wawatam	84840	2435913	76
West Traverse	86300	354	1
Ontario	-	42863	8

Table 4.5 Total maximum amount of oil in kilogram per township over 120 simulations for Scenario Existing Pipeline – 75 mm Leak at Northern Shore.

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Alpena	1760	353.3686161	2
Bear Creek	6380	1366.432312	1
Bearinger	6400	14717.65824	8
Beaugrand	6500	741274.9464	39
Benton	7420	112211.9049	19
Bliss	8980	1265067.883	48
Bois Blanc	9500	1277032.537	49
Charlevoix	14800	61598.46268	3
Cheboygan	15000	125954.0823	10
Clark	16060	60100.30317	10
Cross Village	18900	64546.73412	15

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Detour	21770	10225.39688	3
Drummond	23080	7659.62149	4
Friendship	30860	9912.216389	2
Garfield	31620	463.2454147	2
Harbor Springs	36560	140.6384354	1
Hayes	37320	32504.2734	2
Hendricks	37660	112057.1293	9
Hudson	39760	109241.8299	5
Krakow	43900	2399.683399	4
Little Traverse	48080	212.3605957	1
Mackinac Island	50280	2384548.257	57
Mackinaw	50300	2201493.983	60
Marquette	51880	78267.58356	11
Moran	55480	10316147.76	94
Norwood	59340	4880.201435	3
Ocqueoc	60160	3689.63599	8
Peaine	63140	392.4962997	1
Petoskey	63820	1152.878845	2
Presque Isle	66340	1721.398959	3
Pulawski	66460	5398.281555	7
Readmond	67540	70841.65355	10
Rogers	69240	15861.81956	9
Rogers City	69260	4613.657043	6
St Ignace	70840	445441.1761	55
St Ignace	70860	184240.8302	14
St James	70920	120442.4626	2
Sanborn	71240	53.24469376	1
Wawatam	84840	2117870.342	67
West Traverse	86300	1148.955418	2
Ontario	-	13127.68863	7

Table 4.6 Total maximum amount of oil in kilogram per township over 120 simulations for Scenario Existing Pipeline – 75 mm Leak at Southern Shore.

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Alpena	01760	481	1
Bearinger	06400	17719	10
Beaugrand	06500	220100	35
Benton	07420	685646	19
Bliss	08980	1941302	40
Bois Blanc	09500	1493713	47

Township	FIPS Code	Total Oil Reached Shoreline [kg]	Number of Spills
Charlevoix	14780	113	1
Charlevoix	14800	763	2
Cheboygan	15000	13763	14
Clark	16060	35862	8
Cross Village	18900	33560	18
Detour	21770	445	1
Drummond	23080	13487	2
Friendship	30860	669	2
Garfield	31620	351	1
Hayes	37320	321	2
Hendricks	37660	237441	7
Hudson	39760	18067	5
Krakow	43900	3858	2
Mackinac Island	50280	1442775	44
Mackinaw	50300	2416654	92
Marquette	51880	28545	7
Moran	55480	5972539	58
Norwood	59340	293	2
Ocqueoc	60160	4774	10
Presque Isle	66340	147	1
Pulawski	66460	25955	6
Readmond	67540	3361	9
Rogers	69240	25946	12
Rogers City	69260	21231	5
St Ignace	70840	122457	40
St Ignace	70860	30615	12
St James	70920	571	1
Wawatam	84840	48787892	120
Ontario	-	51328	5

4.1.2 Total maximum length of shoreline exposed to oil per county over 1 year

Table 4.7 Total maximum length of shoreline exposed to oil per county over 120 simulations for Scenario 30" Trenched Pipeline – Full rupture.

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
1	5/7/2014 15:06	5754	0	8203	0	0	31769	56510	33836
2	7/7/2014 0:48	0	0	29633	0	16759	12117	0	0
3	9/7/2014 6:59	1348	0	24623	14588	4359	58678	38922	0
4	15/7/2014 4:28	0	0	1278	0	14754	4062	0	0
5	20/7/2014 12:51	0	0	17935	0	0	52289	22796	0
6	20/7/2014 13:37	0	0	17152	0	0	50007	26533	0
7	26/7/2014 3:47	0	0	13036	0	19037	28749	0	0
8	27/7/2014 0:45	0	0	5265	0	24788	0	0	0
9	27/7/2014 3:01	0	0	2045	0	28723	0	0	0
10	28/7/2014 17:47	0	0	22588	0	361	0	0	0
11	31/7/2014 12:21	0	779	15922	0	35188	47308	0	0
12	3/8/2014 9:48	0	0	16398	0	368	10089	0	0
13	9/8/2014 20:44	0	0	0	0	16798	37316	0	0
14	10/8/2014 3:56	0	0	0	0	16386	35251	0	0
15	10/8/2014 13:40	0	0	0	0	20728	28205	0	0
16	18/8/2014 21:36	0	0	0	0	0	58554	0	0
17	20/8/2014 2:06	0	0	14344	0	0	108715	0	0
18	26/8/2014 23:55	0	0	694	0	16330	14894	0	0
19	29/8/2014 10:00	0	0	0	0	0	9770	0	0
20	31/8/2014 11:47	0	0	3979	25891	0	77669	2229	17019
21	4/9/2014 2:15	0	0	1074	0	0	31313	0	0
22	7/9/2014 6:09	0	0	0	0	0	65091	0	0
23	8/9/2014 0:14	0	0	0	0	2577	46223	0	0

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Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
24	11/9/2014 10:32	0	0	14194	0	2944	0	0	0
25	11/9/2014 12:19	0	0	12274	0	2303	0	0	0
26	14/9/2014 22:12	0	0	45696	0	3204	35982	3075	0
27	21/9/2014 9:55	0	0	0	0	21620	415	0	0
28	28/9/2014 10:39	0	0	13433	0	9649	36229	0	0
29	30/9/2014 1:42	0	0	0	0	13227	43159	0	0
30	30/9/2014 8:16	0	0	0	0	11059	44932	0	0
31	4/10/2014 21:30	0	0	3869	4063	4622	30161	33379	0
32	8/10/2014 20:49	0	0	25953	0	0	7384	0	0
33	12/10/2014 7:41	0	0	1610	0	18520	42505	0	0
34	13/10/2014 18:35	0	0	1548	0	47419	17360	0	0
35	14/10/2014 7:26	0	0	0	0	47486	4422	0	0
36	15/10/2014 3:24	0	0	27141	0	27692	24838	0	0
37	16/10/2014 2:40	0	0	29215	0	0	53145	0	0
38	18/10/2014 13:16	0	0	8632	0	14076	21637	0	0
39	24/10/2014 18:21	0	0	8422	0	0	61037	10918	0
40	28/10/2014 1:36	0	0	22941	0	0	33560	1339	0
41	5/11/2014 3:42	0	0	10657	0	34286	46057	0	0
42	9/11/2014 0:32	0	5148	9672	0	40965	40846	0	0
43	9/11/2014 19:41	0	46070	79	0	86646	0	0	0
44	13/11/2014 5:32	0	0	22187	0	12009	5119	0	828
45	17/11/2014 11:10	0	0	28552	0	0	39566	427	133722
46	25/11/2014 10:27	0	0	35050	0	20768	35917	0	0
47	25/11/2014 15:26	0	0	30506	0	23582	39431	0	0
48	29/11/2014 3:55	0	0	0	0	0	15829	0	0
49	1/12/2014 16:40	0	0	9306	0	2014	32949	0	0
50	4/12/2014 7:01	0	0	4044	0	37843	44016	0	0

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Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
51	5/12/2014 13:45	0	0	16063	0	28985	42857	0	0
52	5/12/2014 14:46	0	0	15521	0	32090	44225	0	0
53	9/12/2014 19:32	0	0	0	0	20590	0	0	0
54	15/12/2014 7:05	0	0	0	0	6879	17111	0	0
55	17/12/2014 4:42	0	0	15922	0	0	0	0	0
56	21/12/2014 12:30	0	0	0	0	0	7864	0	0
57	22/12/2014 11:50	0	0	0	0	0	45962	0	0
58	22/12/2014 11:52	0	0	0	0	0	43860	0	0
59	23/12/2014 3:02	0	0	22711	0	3748	105296	51248	11462
60	25/12/2014 19:53	0	0	46836	0	0	62347	31784	15002
61	2/1/2015 10:04	0	0	0	0	1285	0	0	0
62	7/1/2015 15:45	0	0	0	0	0	0	0	0
63	12/1/2015 20:48	0	0	0	0	2338	0	0	0
64	18/1/2015 3:01	0	0	0	0	0	0	0	0
65	20/1/2015 6:54	0	0	0	0	0	0	0	0
66	24/1/2015 21:42	0	0	0	0	0	0	0	0
67	25/1/2015 15:03	0	0	0	0	0	0	0	0
68	26/1/2015 14:18	0	0	0	0	0	0	0	0
69	30/1/2015 10:47	0	0	0	0	0	0	0	0
70	3/2/2015 1:57	0	0	0	0	0	0	0	0
71	9/2/2015 8:54	0	0	0	0	0	0	0	0
72	10/2/2015 21:19	0	0	0	0	0	0	0	0
73	14/2/2015 20:05	0	0	0	0	0	0	0	0
74	16/2/2015 1:45	0	0	0	0	0	0	0	0
75	16/2/2015 11:10	0	0	0	0	0	0	0	0
76	17/2/2015 3:41	0	0	0	0	0	0	0	0
77	21/2/2015 13:39	0	0	0	0	0	0	0	0

ENBDNR0002092

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
78	21/2/2015 22:49	0	0	0	0	0	0	0	0
79	9/3/2015 23:00	0	0	0	0	0	0	0	0
80	12/3/2015 22:24	0	0	0	0	673	0	0	0
81	16/3/2015 22:27	0	0	0	0	3041	1298	0	0
82	21/3/2015 16:41	0	0	0	0	2882	20539	0	0
83	22/3/2015 0:40	0	0	0	0	3582	26003	0	0
84	23/3/2015 8:42	0	0	0	0	3482	41805	0	0
85	26/3/2015 8:59	0	0	15179	0	42039	38601	0	0
86	26/3/2015 23:24	0	0	16326	0	47324	43918	0	0
87	27/3/2015 1:10	0	0	17203	0	38252	37246	953	0
88	28/3/2015 20:07	0	0	19397	0	45641	39795	0	0
89	28/3/2015 23:16	0	0	21293	0	46953	42137	0	0
90	31/3/2015 3:14	0	0	17293	0	54525	42829	3364	0
91	8/4/2015 1:15	0	0	19734	0	51261	39146	0	0
92	9/4/2015 9:02	0	6777	14840	0	50920	46695	825	0
93	12/4/2015 6:37	0	0	16622	0	37981	31466	0	0
94	16/4/2015 19:02	0	24220	20872	0	47013	62825	13091	0
95	18/4/2015 1:45	0	2642	17638	0	50890	43155	1647	0
96	24/4/2015 2:34	0	29463	0	0	64012	0	0	0
97	25/4/2015 8:31	0	17789	0	0	42960	5866	0	0
98	26/4/2015 19:50	0	0	6418	0	2699	0	0	0
99	28/4/2015 13:52	0	0	15104	0	8899	0	0	0
100	29/4/2015 13:02	0	0	6418	0	5042	0	0	0
101	30/4/2015 15:33	0	0	2394	0	15133	59984	0	0
102	6/5/2015 0:06	0	0	0	0	0	30484	0	0
103	6/5/2015 10:33	0	0	0	0	0	25813	0	0
104	8/5/2015 20:47	0	0	5576	0	34256	21893	0	0

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Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
105	13/5/2015 13:55	0	0	15536	0	27218	70501	0	0
106	16/5/2015 19:08	0	0	0	0	0	37910	0	0
107	19/5/2015 6:40	0	0	20613	0	389	7596	846	0
108	23/5/2015 22:54	0	0	0	0	2559	114330	0	0
109	24/5/2015 2:41	0	0	1106	0	4591	87103	0	0
110	26/5/2015 4:48	0	0	3232	0	777	124864	0	0
111	1/6/2015 0:52	0	0	2939	0	17254	68236	0	0
112	9/6/2015 0:46	0	0	43132	0	10148	61655	0	0
113	10/6/2015 15:16	0	0	19864	0	18890	48694	0	0
114	12/6/2015 21:53	0	0	16331	0	27304	58211	0	0
115	15/6/2015 15:27	0	0	12274	0	16874	11620	0	0
116	19/6/2015 23:51	0	0	0	0	0	20688	0	0
117	20/6/2015 12:55	0	0	48725	0	4359	66944	17419	735
118	29/6/2015 9:49	0	0	17748	0	18783	9148	0	0
119	29/6/2015 10:05	0	0	16398	0	18409	13416	0	0
120	30/6/2015 3:18	0	0	15521	0	11387	6148	0	0

Table 4.8 Total maximum length of shoreline exposed to oil per county over 120 simulations for Scenario 30" Trenched Pipeline – 75 mm Leak at Northern Shore.

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]									
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Grand Traverse	Mackinac	Presque Isle	Ontario
1	5/7/2014 15:06	0	0	0	1639	0	0	0	15262	36279	14043
2	7/7/2014 0:48	0	0	0	35555	0	9920	0	21106	0	0
3	9/7/2014 6:59	7333	0	0	20022	13479	0	0	39868	43045	0
4	15/7/2014 4:28	0	0	0	421	0	12098	0	941	0	0
5	20/7/2014 12:51	0	0	0	7154	0	0	0	32259	12363	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]									
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Grand Traverse	Mackinac	Presque Isle	Ontario
6	20/7/2014 13:37	0	0	0	13399	0	0	0	38946	9887	0
7	26/7/2014 3:47	0	0	0	13433	0	6890	0	40337	0	0
8	27/7/2014 0:45	0	0	0	4854	0	24833	0	3033	0	0
9	27/7/2014 3:01	0	0	0	1185	0	25404	0	1241	0	0
10	28/7/2014 17:47	0	0	0	41931	0	0	0	15707	0	0
11	31/7/2014 12:21	0	0	1718	15517	0	29277	0	52140	0	0
12	3/8/2014 9:48	0	0	0	13653	0	416	0	9489	0	0
13	9/8/2014 20:44	0	0	0	0	0	11055	0	34638	0	0
14	10/8/2014 3:56	0	0	0	0	0	9229	0	32242	0	0
15	10/8/2014 13:40	0	0	0	0	0	14772	0	29630	0	0
16	18/8/2014 21:36	0	0	0	0	0	0	0	46408	0	0
17	20/8/2014 2:06	0	0	0	3941	0	0	0	79114	0	0
18	26/8/2014 23:55	0	0	0	2520	0	14754	0	17031	0	0
19	29/8/2014 10:00	0	0	0	0	0	0	0	5260	0	0
20	31/8/2014 11:47	0	0	0	3535	24366	0	0	63665	2976	37973
21	4/9/2014 2:15	0	0	0	0	0	0	0	8488	0	0
22	7/9/2014 6:09	0	0	0	0	0	0	0	46577	0	0
23	8/9/2014 0:14	0	0	0	5148	0	6035	0	55183	0	0
24	11/9/2014 10:32	0	0	0	22286	0	27320	0	40739	0	0
25	11/9/2014 12:19	0	0	0	13028	0	22227	0	7366	0	0
26	14/9/2014 22:12	0	0	0	30217	0	0	0	37850	0	0
27	21/9/2014 9:55	0	0	0	0	0	22541	0	2783	0	0
28	28/9/2014 10:39	0	0	0	9471	0	10896	0	37548	0	0
29	30/9/2014 1:42	0	0	0	0	0	12588	0	41951	1560	0
30	30/9/2014 8:16	0	0	0	0	0	1757	0	35519	0	0
31	4/10/2014 21:30	0	0	0	1476	3303	4082	0	40210	53079	850
32	8/10/2014 20:49	0	0	0	20504	0	0	0	23168	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]									
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Grand Traverse	Mackinac	Presque Isle	Ontario
33	12/10/2014 7:41	0	0	0	0	0	10517	0	38690	0	0
34	13/10/2014 18:35	0	0	0	0	0	1752	0	11151	0	0
35	14/10/2014 7:26	0	0	0	0	0	12130	0	3797	0	0
36	15/10/2014 3:24	0	0	0	23898	0	27320	0	8895	0	0
37	16/10/2014 2:40	0	0	0	28067	0	0	0	62372	0	0
38	18/10/2014 13:16	0	0	0	8177	0	13979	0	14631	0	0
39	24/10/2014 18:21	0	0	0	10916	0	0	0	51256	24404	0
40	28/10/2014 1:36	0	0	0	841	0	0	0	18611	0	0
41	5/11/2014 3:42	0	0	0	9540	0	33178	0	41471	0	0
42	9/11/2014 0:32	0	0	0	0	0	16561	0	51092	0	0
43	9/11/2014 19:41	0	0	36728	0	0	68871	0	1233	0	0
44	13/11/2014 5:32	0	0	0	21716	0	8881	0	9412	0	20881
45	17/11/2014 11:10	0	0	0	13805	0	0	0	57563	1339	89367
46	25/11/2014 10:27	0	0	0	37172	0	18409	0	27395	0	0
47	25/11/2014 15:26	0	0	0	36394	0	21170	0	54315	0	0
48	29/11/2014 3:55	0	0	0	0	0	0	0	5865	0	0
49	1/12/2014 16:40	0	0	0	2256	0	0	0	29444	0	0
50	4/12/2014 7:01	0	0	0	3428	0	44635	0	40637	0	0
51	5/12/2014 13:45	0	0	0	9659	0	20929	0	27971	0	0
52	5/12/2014 14:46	0	0	0	12938	0	24747	0	43229	0	0
53	9/12/2014 19:32	0	0	0	0	0	20555	0	0	0	0
54	15/12/2014 7:05	0	0	0	3654	0	5508	0	16580	0	0
55	17/12/2014 4:42	0	0	0	17748	0	10890	0	5706	0	0
56	21/12/2014 12:30	0	0	0	0	0	0	0	4643	0	0
57	22/12/2014 11:50	0	0	0	0	0	0	0	9288	0	0
58	22/12/2014 11:52	0	0	0	0	0	0	0	14170	0	0
59	23/12/2014 3:02	0	0	0	11856	0	0	0	91800	27311	3852

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Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]									
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Grand Traverse	Mackinac	Presque Isle	Ontario
60	25/12/2014 19:53	0	0	0	42840	0	0	0	70405	33627	16566
61	2/1/2015 10:04	0	0	0	0	0	0	0	0	0	0
62	7/1/2015 15:45	0	0	0	0	0	0	0	0	0	0
63	12/1/2015 20:48	0	0	0	0	0	0	0	0	0	0
64	18/1/2015 3:01	0	0	0	0	0	0	0	0	0	0
65	20/1/2015 6:54	0	0	0	0	0	0	0	0	0	0
66	24/1/2015 21:42	0	0	0	0	0	0	0	0	0	0
67	25/1/2015 15:03	0	0	0	0	0	0	0	0	0	0
68	26/1/2015 14:18	0	0	0	0	0	0	0	0	0	0
69	30/1/2015 10:47	0	0	0	0	0	0	0	0	0	0
70	3/2/2015 1:57	0	0	0	0	0	0	0	0	0	0
71	9/2/2015 8:54	0	0	0	0	0	0	0	0	0	0
72	10/2/2015 21:19	0	0	0	0	0	0	0	0	0	0
73	14/2/2015 20:05	0	0	0	0	0	0	0	0	0	0
74	16/2/2015 1:45	0	0	0	0	0	0	0	0	0	0
75	16/2/2015 11:10	0	0	0	0	0	0	0	0	0	0
76	17/2/2015 3:41	0	0	0	0	0	0	0	0	0	0
77	21/2/2015 13:39	0	0	0	0	0	0	0	0	0	0
78	21/2/2015 22:49	0	0	0	0	0	0	0	0	0	0
79	9/3/2015 23:00	0	0	0	326	0	1492	0	820	0	0
80	12/3/2015 22:24	0	0	0	194	0	2996	0	620	0	0
81	16/3/2015 22:27	0	0	0	0	0	3923	0	2381	0	0
82	21/3/2015 16:41	0	0	0	0	0	2691	0	24525	0	0
83	22/3/2015 0:40	0	0	0	0	0	2766	0	29254	0	0
84	23/3/2015 8:42	0	0	0	0	0	3672	0	32461	0	0
85	26/3/2015 8:59	0	0	0	11882	0	34739	0	32440	0	0
86	26/3/2015 23:24	0	0	0	13657	0	42263	0	39508	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]									
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Grand Traverse	Mackinac	Presque Isle	Ontario
87	27/3/2015 1:10	0	0	0	13139	0	38214	0	32613	0	0
88	28/3/2015 20:07	0	0	0	19815	0	40361	0	35004	0	0
89	28/3/2015 23:16	0	0	0	16187	0	40666	0	38416	784	0
90	31/3/2015 3:14	0	0	0	17638	0	45586	0	36565	0	0
91	8/4/2015 1:15	0	0	0	15314	0	34014	3599	34302	0	0
92	9/4/2015 9:02	0	0	4169	12679	0	30050	0	34678	0	0
93	12/4/2015 6:37	0	0	0	14682	0	30598	0	31248	0	0
94	16/4/2015 19:02	0	0	9081	17829	0	41341	0	31252	0	0
95	18/4/2015 1:45	0	0	0	15556	0	42065	0	29534	0	0
96	24/4/2015 2:34	0	3204	31497	0	0	71149	0	2152	0	0
97	25/4/2015 8:31	0	0	0	10298	0	25747	0	9458	0	0
98	26/4/2015 19:50	0	0	0	7298	0	2120	0	0	0	0
99	28/4/2015 13:52	0	0	0	18309	0	1354	0	3446	0	0
100	29/4/2015 13:02	0	0	0	8276	0	2526	0	224	0	0
101	30/4/2015 15:33	0	0	0	1476	0	12592	0	72013	0	0
102	6/5/2015 0:06	0	0	0	0	0	0	0	27043	0	0
103	6/5/2015 10:33	0	0	0	0	0	0	0	25999	0	0
104	8/5/2015 20:47	0	0	0	3820	0	31686	0	31596	0	0
105	13/5/2015 13:55	0	0	0	3205	0	9020	0	65570	0	0
106	16/5/2015 19:08	0	0	0	0	0	0	0	44338	0	0
107	19/5/2015 6:40	0	0	0	34879	2328	0	0	14374	13438	0
108	23/5/2015 22:54	0	0	0	0	0	0	0	72884	0	0
109	24/5/2015 2:41	0	0	0	0	0	2051	0	61874	0	0
110	26/5/2015 4:48	0	0	0	2504	0	5338	0	121485	0	0
111	1/6/2015 0:52	0	0	0	3254	0	12741	0	67828	0	0
112	9/6/2015 0:46	0	0	0	44005	0	10757	0	61164	0	0
113	10/6/2015 15:16	0	0	0	23338	0	15949	0	64320	0	0

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Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]									
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Grand Traverse	Mackinac	Presque Isle	Ontario
114	12/6/2015 21:53	0	0	0	10352	0	29447	0	61590	0	0
115	15/6/2015 15:27	0	0	0	11846	0	12079	0	3781	0	0
116	19/6/2015 23:51	0	0	0	0	0	0	0	10097	0	0
117	20/6/2015 12:55	0	0	0	8574	0	0	0	52569	0	0
118	29/6/2015 9:49	0	0	0	17904	0	18067	0	8716	0	0
119	29/6/2015 10:05	0	0	0	17235	0	18067	0	8716	0	0
120	30/6/2015 3:18	0	0	0	18309	0	2850	0	6587	0	0

Table 4.9 Total maximum length of shoreline exposed to oil per county over 120 simulations for Scenario 30" Trenched Pipeline – 75 mm Leak at Southern Shore.

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]								
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
1	5/7/2014 15:06	18535	0	0	14326	0	4082	38134	69912	51749
2	7/7/2014 0:48	0	0	0	29655	0	14754	9845	0	0
3	9/7/2014 6:59	0	0	0	11990	0	9425	24377	0	0
4	15/7/2014 4:28	0	0	0	174	0	11531	1750	0	0
5	20/7/2014 12:51	0	0	0	23254	0	4082	57403	39866	0
6	20/7/2014 13:37	0	0	0	24037	0	4082	58888	35087	0
7	26/7/2014 3:47	0	0	0	15521	0	17483	22263	0	0
8	27/7/2014 0:45	0	0	0	4108	0	19021	0	0	0
9	27/7/2014 3:01	0	0	0	500	0	20599	0	0	0
10	28/7/2014 17:47	0	0	0	9661	0	12983	6916	0	0
11	31/7/2014 12:21	0	0	0	17840	0	14353	41720	0	0
12	3/8/2014 9:48	0	0	0	15521	0	4359	0	0	0
13	9/8/2014 20:44	0	0	0	0	0	24711	38029	0	0
14	10/8/2014 3:56	0	0	0	0	0	26170	36225	0	0
15	10/8/2014 13:40	0	0	0	0	0	30093	19286	0	0

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Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]								
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
16	18/8/2014 21:36	0	0	0	8288	0	6099	74377	0	0
17	20/8/2014 2:06	0	0	0	20491	0	4359	117467	0	0
18	26/8/2014 23:55	0	0	0	0	0	14743	10327	0	0
19	29/8/2014 10:00	0	0	0	0	0	2466	13236	0	0
20	31/8/2014 11:47	0	0	0	1923	16695	4622	65565	0	822
21	4/9/2014 2:15	0	0	0	27883	0	3557	94287	0	0
22	7/9/2014 6:09	0	0	0	694	0	4359	84116	0	0
23	8/9/2014 0:14	0	0	0	1308	0	11149	46201	0	0
24	11/9/2014 10:32	0	0	0	6276	0	25534	407	0	0
25	11/9/2014 12:19	0	0	0	1804	0	25765	639	0	0
26	14/9/2014 22:12	0	0	0	48519	0	3833	28776	4029	0
27	21/9/2014 9:55	0	0	0	0	0	13199	0	0	0
28	28/9/2014 10:39	0	0	0	17235	0	4359	18677	0	0
29	30/9/2014 1:42	0	0	0	0	0	18438	18351	0	0
30	30/9/2014 8:16	0	0	0	0	0	17748	38586	0	0
31	4/10/2014 21:30	0	0	0	1476	0	8270	26124	27627	0
32	8/10/2014 20:49	0	0	0	21848	0	8660	438	0	0
33	12/10/2014 7:41	0	0	0	694	0	21770	45341	0	0
34	13/10/2014 18:35	0	0	0	1715	0	56631	10153	0	0
35	14/10/2014 7:26	0	0	0	1797	0	58212	0	0	0
36	15/10/2014 3:24	0	0	0	0	0	23822	0	0	0
37	16/10/2014 2:40	0	0	0	27556	0	4992	16658	0	0
38	18/10/2014 13:16	0	0	0	2522	0	13356	4492	0	0
39	24/10/2014 18:21	0	0	0	12758	0	4082	58693	1622	0
40	28/10/2014 1:36	0	0	0	25399	0	1923	70842	4029	7347
41	5/11/2014 3:42	0	0	0	18309	0	24036	15093	0	1157
42	9/11/2014 0:32	0	0	12880	16518	0	58093	20635	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]								
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
43	9/11/2014 19:41	0	0	32863	0	0	79259	0	0	0
44	13/11/2014 5:32	0	0	0	13192	0	10969	0	0	0
45	17/11/2014 11:10	0	0	0	45113	0	3833	11902	1339	125223
46	25/11/2014 10:27	0	0	0	9629	0	23582	8625	0	0
47	25/11/2014 15:26	0	0	0	6555	0	23582	9943	0	0
48	29/11/2014 3:55	0	0	0	0	0	2394	17391	0	0
49	1/12/2014 16:40	0	0	0	2345	0	6033	52424	0	0
50	4/12/2014 7:01	0	0	0	0	0	41214	46454	0	0
51	5/12/2014 13:45	0	0	0	16759	0	30634	38479	0	0
52	5/12/2014 14:46	0	0	0	14638	0	25148	25815	0	0
53	9/12/2014 19:32	0	0	0	0	0	18332	0	0	0
54	15/12/2014 7:05	0	0	0	9754	0	26542	20570	0	0
55	17/12/2014 4:42	0	0	0	4734	0	15916	0	0	0
56	21/12/2014 12:30	0	0	0	0	0	2056	42582	0	0
57	22/12/2014 11:50	0	0	0	25064	0	3305	73528	0	0
58	22/12/2014 11:52	0	0	0	16976	0	4746	67782	0	0
59	23/12/2014 3:02	0	0	0	14979	0	18067	61000	41669	10834
60	25/12/2014 19:53	0	0	0	51129	0	3833	50676	24864	0
61	2/1/2015 10:04	0	0	0	16776	0	6182	4701	0	0
62	7/1/2015 15:45	0	0	0	2432	0	6191	0	0	0
63	12/1/2015 20:48	0	0	0	500	0	12079	0	0	0
64	18/1/2015 3:01	0	0	0	1140	0	4622	0	0	0
65	20/1/2015 6:54	0	0	0	946	0	6033	0	0	0
66	24/1/2015 21:42	0	0	0	0	0	12079	0	0	0
67	25/1/2015 15:03	0	0	0	0	0	12079	0	0	0
68	26/1/2015 14:18	0	0	0	79	0	5783	0	0	0
69	30/1/2015 10:47	0	0	0	500	0	12079	0	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]								
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
70	3/2/2015 1:57	0	0	0	253	0	4622	0	0	0
71	9/2/2015 8:54	0	0	0	0	0	11342	0	0	0
72	10/2/2015 21:19	0	0	0	0	0	9053	0	0	0
73	14/2/2015 20:05	0	0	0	0	0	12079	0	0	0
74	16/2/2015 1:45	0	0	0	0	0	8182	0	0	0
75	16/2/2015 11:10	0	0	0	253	0	8641	0	0	0
76	17/2/2015 3:41	0	0	0	0	0	5783	0	0	0
77	21/2/2015 13:39	0	0	0	500	0	7486	0	0	0
78	21/2/2015 22:49	0	0	0	500	0	8669	0	0	0
79	9/3/2015 23:00	0	0	0	500	0	5390	0	0	0
80	12/3/2015 22:24	0	0	0	174	0	8242	0	0	0
81	16/3/2015 22:27	0	0	0	500	0	12592	3283	0	0
82	21/3/2015 16:41	0	0	0	694	0	10537	24407	0	0
83	22/3/2015 0:40	0	0	0	500	2334	10548	35186	0	0
84	23/3/2015 8:42	0	0	0	500	0	9425	39091	0	0
85	26/3/2015 8:59	0	0	0	12898	0	36537	35043	1720	0
86	26/3/2015 23:24	0	0	0	15086	0	46886	46525	0	0
87	27/3/2015 1:10	0	0	0	16012	0	43611	45165	2502	0
88	28/3/2015 20:07	0	0	0	17235	0	43327	39977	0	0
89	28/3/2015 23:16	0	0	0	19423	0	41184	38413	0	0
90	31/3/2015 3:14	0	0	0	17748	0	51143	44802	836	0
91	8/4/2015 1:15	0	3043	0	17990	0	48160	46713	0	0
92	9/4/2015 9:02	0	0	14419	16546	0	49545	43080	0	0
93	12/4/2015 6:37	0	0	0	22086	0	46198	44672	2454	0
94	16/4/2015 19:02	0	0	0	15250	0	33733	60837	18662	0
95	18/4/2015 1:45	0	0	0	20777	0	42476	78735	34099	0
96	24/4/2015 2:34	0	0	14899	0	0	38906	0	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]								
		Alpena	Antrim	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
97	25/4/2015 8:31	0	0	0	0	0	23101	0	0	0
98	26/4/2015 19:50	0	0	0	10652	0	14360	0	0	0
99	28/4/2015 13:52	0	0	0	13028	0	11387	0	0	0
100	29/4/2015 13:02	0	0	0	0	0	14048	0	0	0
101	30/4/2015 15:33	0	0	0	1476	0	13302	39476	0	0
102	6/5/2015 0:06	0	0	0	0	0	2729	27195	0	0
103	6/5/2015 10:33	0	0	0	0	0	2882	30858	0	0
104	8/5/2015 20:47	0	0	0	500	0	21539	3865	0	0
105	13/5/2015 13:55	0	0	0	15748	0	21954	59384	0	0
106	16/5/2015 19:08	0	0	0	10896	0	7077	35668	0	0
107	19/5/2015 6:40	0	0	0	12811	0	10168	17745	0	0
108	23/5/2015 22:54	0	0	0	1278	0	4359	133697	0	0
109	24/5/2015 2:41	0	0	0	945	0	6033	92513	0	0
110	26/5/2015 4:48	0	0	0	7287	0	9137	103446	0	0
111	1/6/2015 0:52	0	0	0	1185	0	23009	57391	0	0
112	9/6/2015 0:46	0	0	0	38461	0	14822	54514	0	0
113	10/6/2015 15:16	0	0	0	11453	0	37697	18414	0	0
114	12/6/2015 21:53	0	0	0	14050	0	28062	57356	0	0
115	15/6/2015 15:27	0	0	0	7685	0	16528	4415	0	0
116	19/6/2015 23:51	0	0	0	53197	0	4622	69959	3146	9084
117	20/6/2015 12:55	0	0	0	53197	0	7486	62580	14081	12679
118	29/6/2015 9:49	0	0	0	15104	0	19224	5950	0	0
119	29/6/2015 10:05	0	0	0	15104	0	18783	5656	0	0
120	30/6/2015 3:18	0	0	0	13433	0	10969	0	0	0

Table 4.10 Total maximum length of shoreline exposed to oil per county over 120 simulations for Scenario Existing Pipeline – Full rupture.

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
1	5/7/2014 15:06	6156	0	5827	0	0	33484	51428	32527
2	7/7/2014 0:48	0	0	31716	0	15898	17421	0	0
3	9/7/2014 6:59	10653	0	24842	5681	8962	60190	18144	0
4	15/7/2014 4:28	0	0	13853	0	13975	2104	0	0
5	20/7/2014 12:51	0	0	14362	0	0	55789	20039	0
6	20/7/2014 13:37	0	0	12930	0	0	48612	16638	0
7	26/7/2014 3:47	0	0	13433	0	18040	31336	0	0
8	27/7/2014 0:45	0	0	6104	0	25264	0	0	0
9	27/7/2014 3:01	0	0	3034	0	24122	0	0	0
10	28/7/2014 17:47	0	0	26285	0	0	0	0	0
11	31/7/2014 12:21	0	9901	16803	0	38332	47796	0	0
12	3/8/2014 9:48	0	0	16803	0	1893	11445	0	0
13	9/8/2014 20:44	0	0	0	0	10560	37696	0	0
14	10/8/2014 3:56	0	0	0	0	14002	32422	0	0
15	10/8/2014 13:40	0	0	0	0	19885	28657	0	0
16	18/8/2014 21:36	0	0	247	0	0	58115	0	0
17	20/8/2014 2:06	0	0	7227	0	0	100342	0	0
18	26/8/2014 23:55	0	0	5888	0	14754	14093	0	0
19	29/8/2014 10:00	0	0	0	5681	0	22103	0	822
20	31/8/2014 11:47	0	0	2694	23664	0	72460	0	14535
21	4/9/2014 2:15	0	0	11652	0	0	56867	0	0
22	7/9/2014 6:09	0	0	0	0	0	53597	0	0
23	8/9/2014 0:14	0	0	1708	0	0	43603	0	0
24	11/9/2014 10:32	0	0	16308	0	18639	5783	0	0
25	11/9/2014 12:19	0	0	12615	0	23962	5847	0	0
26	14/9/2014 22:12	0	0	44402	0	5359	34325	4029	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
27	21/9/2014 9:55	0	0	2575	0	23582	6869	0	0
28	28/9/2014 10:39	0	0	14701	0	9972	35308	0	0
29	30/9/2014 1:42	0	0	0	0	16999	54072	0	0
30	30/9/2014 8:16	0	0	500	0	11849	48727	0	0
31	4/10/2014 21:30	0	0	4089	7347	3405	40710	36106	0
32	8/10/2014 20:49	0	0	33600	0	1787	14613	0	0
33	12/10/2014 7:41	0	0	0	0	14187	50969	0	0
34	13/10/2014 18:35	0	0	0	0	36755	14876	0	0
35	14/10/2014 7:26	0	0	0	0	37760	5272	0	0
36	15/10/2014 3:24	0	0	28427	0	27692	42053	0	0
37	16/10/2014 2:40	0	0	28427	0	0	46165	0	0
38	18/10/2014 13:16	0	0	7885	0	12473	23837	0	0
39	24/10/2014 18:21	0	0	10389	0	0	63963	9108	0
40	28/10/2014 1:36	0	0	19158	0	0	39858	4727	1482
41	5/11/2014 3:42	0	0	10245	0	56017	40559	0	0
42	9/11/2014 0:32	0	19157	11190	0	59518	37632	0	0
43	9/11/2014 19:41	0	29019	945	0	72684	4501	0	0
44	13/11/2014 5:32	0	0	30448	0	15167	0	0	7667
45	17/11/2014 11:10	0	0	19701	0	0	48818	427	123261
46	25/11/2014 10:27	0	0	35015	0	23582	31933	0	0
47	25/11/2014 15:26	0	0	32819	0	23582	34440	0	0
48	29/11/2014 3:55	0	0	0	0	0	14794	0	0
49	1/12/2014 16:40	0	0	5904	0	0	32888	0	0
50	4/12/2014 7:01	0	490	694	0	32112	43238	0	0
51	5/12/2014 13:45	0	0	14248	0	24898	36417	0	0
52	5/12/2014 14:46	0	0	15463	0	27635	43362	0	0
53	9/12/2014 19:32	0	0	4138	0	23582	0	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
54	15/12/2014 7:05	0	0	5813	0	17374	17565	0	0
55	17/12/2014 4:42	0	0	15192	0	0	0	0	0
56	21/12/2014 12:30	0	0	0	0	0	6689	0	0
57	22/12/2014 11:50	0	0	405	0	152	57600	2466	0
58	22/12/2014 11:52	0	0	0	0	0	57467	0	0
59	23/12/2014 3:02	0	0	15223	0	3540	100641	34895	18218
60	25/12/2014 19:53	0	0	51005	0	8436	62850	32158	11364
61	2/1/2015 10:04	0	0	0	0	0	0	0	0
62	7/1/2015 15:45	0	0	0	0	0	0	0	0
63	12/1/2015 20:48	0	0	0	0	0	0	0	0
64	18/1/2015 3:01	0	0	0	0	0	0	0	0
65	20/1/2015 6:54	0	0	0	0	0	0	0	0
66	24/1/2015 21:42	0	0	0	0	0	0	0	0
67	25/1/2015 15:03	0	0	0	0	0	0	0	0
68	26/1/2015 14:18	0	0	0	0	0	0	0	0
69	30/1/2015 10:47	0	0	0	0	0	0	0	0
70	3/2/2015 1:57	0	0	0	0	0	0	0	0
71	9/2/2015 8:54	0	0	0	0	0	0	0	0
72	10/2/2015 21:19	0	0	0	0	0	0	0	0
73	14/2/2015 20:05	0	0	0	0	0	0	0	0
74	16/2/2015 1:45	0	0	0	0	0	0	0	0
75	16/2/2015 11:10	0	0	0	0	0	0	0	0
76	17/2/2015 3:41	0	0	0	0	0	0	0	0
77	21/2/2015 13:39	0	0	0	0	0	0	0	0
78	21/2/2015 22:49	0	0	0	0	0	0	0	0
79	9/3/2015 23:00	0	0	0	0	336	0	0	0
80	12/3/2015 22:24	0	0	0	0	0	0	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
81	16/3/2015 22:27	0	0	0	0	2882	1405	0	0
82	21/3/2015 16:41	0	0	0	0	2882	22454	0	0
83	22/3/2015 0:40	0	0	0	0	2946	26181	0	0
84	23/3/2015 8:42	0	0	0	0	2763	38140	0	0
85	26/3/2015 8:59	0	0	15465	0	34576	36725	0	0
86	26/3/2015 23:24	0	0	16657	0	41766	38324	0	0
87	27/3/2015 1:10	0	0	11702	0	38791	34752	0	0
88	28/3/2015 20:07	0	0	15437	0	35053	37287	0	0
89	28/3/2015 23:16	0	0	20539	0	40710	37408	0	0
90	31/3/2015 3:14	0	0	19016	0	40843	43862	3229	0
91	8/4/2015 1:15	0	0	15956	0	38645	44672	0	0
92	9/4/2015 9:02	0	8351	17671	0	39556	50481	0	0
93	12/4/2015 6:37	0	0	16683	0	38851	36908	0	0
94	16/4/2015 19:02	0	876	16080	0	40741	45154	11530	0
95	18/4/2015 1:45	0	2585	23058	0	47848	40743	2968	0
96	24/4/2015 2:34	0	29414	0	0	58506	823	0	0
97	25/4/2015 8:31	0	6584	9007	0	37928	2880	0	0
98	26/4/2015 19:50	0	0	7609	0	5406	0	0	0
99	28/4/2015 13:52	0	0	15521	0	2850	0	0	0
100	29/4/2015 13:02	0	0	8276	0	6142	0	0	0
101	30/4/2015 15:33	0	0	1185	0	14743	58824	0	0
102	6/5/2015 0:06	0	0	0	0	0	30146	0	0
103	6/5/2015 10:33	0	0	0	0	0	25183	0	0
104	8/5/2015 20:47	0	0	6104	0	29274	13165	0	0
105	13/5/2015 13:55	0	0	14658	0	24024	60293	0	0
106	16/5/2015 19:08	0	0	0	0	0	38953	0	0
107	19/5/2015 6:40	0	0	25404	0	0	16963	1791	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
108	23/5/2015 22:54	0	0	0	0	1347	90379	0	0
109	24/5/2015 2:41	0	0	868	0	3831	95798	0	0
110	26/5/2015 4:48	0	0	2494	0	3227	124121	0	0
111	1/6/2015 0:52	0	0	3838	0	6665	58376	0	0
112	9/6/2015 0:46	0	0	40693	0	6168	60739	0	0
113	10/6/2015 15:16	0	0	19469	0	27206	53280	0	0
114	12/6/2015 21:53	0	0	9511	0	31056	61171	0	0
115	15/6/2015 15:27	0	0	13028	0	14461	7741	0	0
116	19/6/2015 23:51	0	0	4677	0	0	55770	0	0
117	20/6/2015 12:55	0	0	48133	0	159	61639	8368	0
118	29/6/2015 9:49	0	0	15950	0	18783	7821	0	0
119	29/6/2015 10:05	0	0	17816	0	18067	8703	0	0
120	30/6/2015 3:18	0	0	18539	0	8737	5255	0	0

Table 4.11 Total maximum length of shoreline exposed to oil per county over 120 simulations for Scenario Existing Pipeline – 75 mm Leak at Northern Shore.

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
1	5/7/2014 15:06	0	0	1029	0	0	15237	42551	33498
2	7/7/2014 0:48	0	0	37159	0	5737	20188	0	0
3	9/7/2014 6:59	13020	0	18694	15406	0	36008	38077	0
4	15/7/2014 4:28	0	0	174	0	11208	1578	0	0
5	20/7/2014 12:51	0	0	5965	0	0	37320	13161	0
6	20/7/2014 13:37	0	0	7915	0	0	38351	3161	0
7	26/7/2014 3:47	0	0	13028	0	4309	39615	0	0
8	27/7/2014 0:45	0	0	5265	0	23518	5471	0	0
9	27/7/2014 3:01	0	0	2575	0	21797	1714	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
10	28/7/2014 17:47	0	0	46026	0	0	39096	0	0
11	31/7/2014 12:21	0	4208	14356	0	24782	46425	0	0
12	3/8/2014 9:48	0	0	15060	0	564	11946	0	0
13	9/8/2014 20:44	0	0	0	0	9104	32919	0	0
14	10/8/2014 3:56	0	0	0	0	4848	21902	0	0
15	10/8/2014 13:40	0	0	0	0	11775	28234	0	0
16	18/8/2014 21:36	0	0	0	0	0	35168	0	0
17	20/8/2014 2:06	0	0	3789	0	0	60791	0	0
18	26/8/2014 23:55	0	0	6935	0	14076	12824	0	0
19	29/8/2014 10:00	0	0	0	0	0	6123	0	0
20	31/8/2014 11:47	0	0	0	27552	0	58385	1803	21994
21	4/9/2014 2:15	0	0	0	0	0	7533	0	0
22	7/9/2014 6:09	0	0	0	0	0	42817	0	0
23	8/9/2014 0:14	0	0	3759	0	3913	60635	0	0
24	11/9/2014 10:32	0	0	26692	0	27304	39617	0	0
25	11/9/2014 12:19	0	0	13589	0	24201	21817	0	0
26	14/9/2014 22:12	0	0	20861	0	0	37985	0	0
27	21/9/2014 9:55	0	0	0	0	18511	0	0	0
28	28/9/2014 10:39	0	0	7685	0	6131	37014	0	0
29	30/9/2014 1:42	0	0	0	0	12973	40867	0	0
30	30/9/2014 8:16	0	0	0	0	1597	33728	0	0
31	4/10/2014 21:30	0	0	1476	5649	4082	38015	44368	957
32	8/10/2014 20:49	0	0	19875	0	0	26422	0	0
33	12/10/2014 7:41	0	0	0	0	9520	44012	0	0
34	13/10/2014 18:35	0	0	0	0	812	12050	0	0
35	14/10/2014 7:26	0	0	0	0	7272	3911	0	0
36	15/10/2014 3:24	0	0	22991	0	26542	8390	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
37	16/10/2014 2:40	0	0	20172	0	0	50781	0	0
38	18/10/2014 13:16	0	0	4848	0	12983	16270	0	0
39	24/10/2014 18:21	0	0	10396	0	0	47511	26873	0
40	28/10/2014 1:36	0	0	0	0	0	15746	0	0
41	5/11/2014 3:42	0	0	3127	0	17221	31210	0	0
42	9/11/2014 0:32	0	928	0	0	10646	48714	0	0
43	9/11/2014 19:41	0	38405	0	0	67235	2466	0	0
44	13/11/2014 5:32	0	0	26269	0	1687	10944	0	16191
45	17/11/2014 11:10	0	0	10875	0	0	56582	427	66137
46	25/11/2014 10:27	1102	0	39613	0	17416	25719	3252	0
47	25/11/2014 15:26	0	0	35555	0	19224	39474	0	0
48	29/11/2014 3:55	0	0	0	0	0	6457	0	0
49	1/12/2014 16:40	0	0	0	0	0	27214	0	0
50	4/12/2014 7:01	0	0	1486	0	30437	42813	0	0
51	5/12/2014 13:45	0	0	10225	0	21944	26265	0	0
52	5/12/2014 14:46	0	0	12623	0	26729	32645	0	0
53	9/12/2014 19:32	0	0	822	0	20821	0	0	0
54	15/12/2014 7:05	0	0	763	0	599	9131	0	0
55	17/12/2014 4:42	0	0	17235	0	21712	28325	0	0
56	21/12/2014 12:30	0	0	0	0	0	4356	0	0
57	22/12/2014 11:50	0	0	0	0	0	8501	0	0
58	22/12/2014 11:52	0	0	0	0	0	8332	0	0
59	23/12/2014 3:02	0	0	12292	0	0	89258	37902	5679
60	25/12/2014 19:53	0	0	40143	0	0	52142	37908	16629
61	2/1/2015 10:04	0	0	0	0	0	0	0	0
62	7/1/2015 15:45	0	0	0	0	0	0	0	0
63	12/1/2015 20:48	0	0	0	0	0	0	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
64	18/1/2015 3:01	0	0	0	0	0	0	0	0
65	20/1/2015 6:54	0	0	0	0	0	0	0	0
66	24/1/2015 21:42	0	0	0	0	0	0	0	0
67	25/1/2015 15:03	0	0	0	0	0	0	0	0
68	26/1/2015 14:18	0	0	0	0	0	0	0	0
69	30/1/2015 10:47	0	0	0	0	0	0	0	0
70	3/2/2015 1:57	0	0	0	0	0	0	0	0
71	9/2/2015 8:54	0	0	0	0	0	0	0	0
72	10/2/2015 21:19	0	0	0	0	0	0	0	0
73	14/2/2015 20:05	0	0	0	0	0	0	0	0
74	16/2/2015 1:45	0	0	0	0	0	0	0	0
75	16/2/2015 11:10	0	0	0	0	0	0	0	0
76	17/2/2015 3:41	0	0	0	0	0	0	0	0
77	21/2/2015 13:39	0	0	0	0	0	0	0	0
78	21/2/2015 22:49	0	0	0	0	0	0	0	0
79	9/3/2015 23:00	0	0	0	0	1038	584	0	0
80	12/3/2015 22:24	0	0	0	0	2421	200	0	0
81	16/3/2015 22:27	0	0	0	0	3195	2078	0	0
82	21/3/2015 16:41	0	0	0	0	3874	21107	0	0
83	22/3/2015 0:40	0	0	0	0	2763	26703	0	0
84	23/3/2015 8:42	0	0	0	0	3660	39941	0	0
85	26/3/2015 8:59	0	0	10901	0	31243	34802	0	0
86	26/3/2015 23:24	0	0	13591	0	41634	35049	0	0
87	27/3/2015 1:10	0	0	12225	0	35902	33729	0	0
88	28/3/2015 20:07	0	0	17748	0	38792	37100	0	0
89	28/3/2015 23:16	0	0	15409	0	41084	35257	0	0
90	31/3/2015 3:14	0	871	13163	0	42798	41469	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
91	8/4/2015 1:15	0	0	4430	0	7910	30077	0	0
92	9/4/2015 9:02	0	0	2749	0	5037	29236	0	0
93	12/4/2015 6:37	0	0	3232	0	5099	29703	0	0
94	16/4/2015 19:02	0	807	16882	0	38848	45979	1549	0
95	18/4/2015 1:45	0	0	16220	0	37596	32812	863	0
96	24/4/2015 2:34	0	27461	667	0	60551	411	0	0
97	25/4/2015 8:31	0	0	8434	0	25374	8747	0	0
98	26/4/2015 19:50	0	0	7685	0	1477	0	0	0
99	28/4/2015 13:52	0	0	19176	0	361	6465	0	0
100	29/4/2015 13:02	0	0	9007	0	1687	0	0	0
101	30/4/2015 15:33	0	0	1476	0	12592	50778	0	0
102	6/5/2015 0:06	0	0	0	0	0	21609	0	0
103	6/5/2015 10:33	0	0	0	0	0	24000	0	0
104	8/5/2015 20:47	0	0	3761	0	33056	25115	0	0
105	13/5/2015 13:55	0	0	5652	0	14579	62540	0	0
106	16/5/2015 19:08	0	0	0	0	0	40630	0	0
107	19/5/2015 6:40	0	0	33730	795	0	20284	13482	0
108	23/5/2015 22:54	0	0	0	0	0	68804	0	0
109	24/5/2015 2:41	0	0	0	0	2377	88561	0	0
110	26/5/2015 4:48	0	0	1754	0	2839	116959	0	0
111	1/6/2015 0:52	0	0	2575	0	9563	69177	0	0
112	9/6/2015 0:46	0	0	42236	0	8095	62799	0	0
113	10/6/2015 15:16	0	0	22151	0	14984	60820	0	0
114	12/6/2015 21:53	0	0	5787	0	31373	66966	0	0
115	15/6/2015 15:27	0	0	11846	0	5788	5063	0	0
116	19/6/2015 23:51	0	0	0	0	0	8733	0	0
117	20/6/2015 12:55	0	0	6522	0	0	46230	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
118	29/6/2015 9:49	0	0	17235	0	18409	13192	0	0
119	29/6/2015 10:05	0	0	16830	0	16330	7841	0	0
120	30/6/2015 3:18	0	0	17365	0	3704	5285	0	0

Table 4.12 Total maximum length of shoreline exposed to oil per county over 120 simulations for Scenario 3 Existing Pipeline – 75 mm Leak at Southern Shore.

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
1	5/7/2014 15:06	8693	0	11472	10449	2850	35995	64812	29165
2	7/7/2014 0:48	0	0	27390	0	13683	8909	0	0
3	9/7/2014 6:59	0	0	9964	0	4359	1078	0	0
4	15/7/2014 4:28	0	0	0	0	10883	0	0	0
5	20/7/2014 12:51	0	0	22486	0	3193	52774	36352	0
6	20/7/2014 13:37	0	0	22367	0	3405	54093	33331	0
7	26/7/2014 3:47	0	0	15130	0	15943	16528	0	0
8	27/7/2014 0:45	0	0	5684	0	13305	0	0	0
9	27/7/2014 3:01	0	0	971	0	15528	0	0	0
10	28/7/2014 17:47	0	0	3340	0	8395	0	0	0
11	31/7/2014 12:21	0	0	18368	0	4194	32360	0	0
12	3/8/2014 9:48	0	0	15130	0	3621	0	0	0
13	9/8/2014 20:44	0	0	0	0	21456	37189	0	0
14	10/8/2014 3:56	0	0	367	0	22404	32086	0	0
15	10/8/2014 13:40	0	0	0	0	26245	21817	0	0
16	18/8/2014 21:36	0	0	2331	0	4658	69294	0	0
17	20/8/2014 2:06	0	0	20541	0	3874	115823	0	0
18	26/8/2014 23:55	0	0	0	0	13208	11477	0	0
19	29/8/2014 10:00	0	0	0	0	2756	12367	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
20	31/8/2014 11:47	0	0	4694	6997	3193	35809	0	0
21	4/9/2014 2:15	0	0	24533	0	2325	80921	0	0
22	7/9/2014 6:09	0	0	247	0	3621	75978	0	0
23	8/9/2014 0:14	0	0	2090	0	15281	55868	0	0
24	11/9/2014 10:32	0	0	4164	0	6233	0	0	0
25	11/9/2014 12:19	0	0	2464	0	9605	0	0	0
26	14/9/2014 22:12	0	0	39021	0	2850	28270	3075	0
27	21/9/2014 9:55	0	0	421	0	14162	2955	0	0
28	28/9/2014 10:39	0	0	14473	0	3193	15751	0	0
29	30/9/2014 1:42	0	0	0	0	18818	30119	0	0
30	30/9/2014 8:16	0	0	0	0	16068	39735	0	0
31	4/10/2014 21:30	0	0	971	0	5407	6547	0	0
32	8/10/2014 20:49	0	0	13944	0	2850	0	0	0
33	12/10/2014 7:41	0	0	1503	0	19788	37945	0	0
34	13/10/2014 18:35	0	0	526	0	52376	7368	0	0
35	14/10/2014 7:26	0	0	839	0	46401	0	0	0
36	15/10/2014 3:24	0	0	0	0	23395	0	0	0
37	16/10/2014 2:40	0	0	27575	0	4359	10301	0	0
38	18/10/2014 13:16	0	0	4978	0	13302	12102	0	0
39	24/10/2014 18:21	0	0	6960	0	3013	59987	5033	0
40	28/10/2014 1:36	0	0	24288	0	2188	53303	4940	5538
41	5/11/2014 3:42	0	0	18335	0	20224	8828	0	0
42	9/11/2014 0:32	0	0	2439	0	22373	11335	0	0
43	9/11/2014 19:41	0	3542	0	0	7451	0	0	0
44	13/11/2014 5:32	0	0	10462	0	2850	0	0	0
45	17/11/2014 11:10	0	0	45072	20757	2850	12409	1339	126421
46	25/11/2014 10:27	0	0	3603	0	3833	0	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
47	25/11/2014 15:26	0	0	7069	0	8164	0	0	0
48	29/11/2014 3:55	0	0	0	0	1928	16140	0	0
49	1/12/2014 16:40	0	0	3778	0	2850	5319	0	0
50	4/12/2014 7:01	0	0	0	0	5204	12573	0	0
51	5/12/2014 13:45	0	0	15965	0	27385	41526	0	0
52	5/12/2014 14:46	0	0	14133	0	24565	33748	0	0
53	9/12/2014 19:32	0	0	0	0	19948	0	0	0
54	15/12/2014 7:05	0	0	8738	0	24987	16838	0	0
55	17/12/2014 4:42	0	0	4301	0	14561	0	0	0
56	21/12/2014 12:30	0	0	0	0	2604	37299	0	0
57	22/12/2014 11:50	0	0	14325	0	2810	58118	0	0
58	22/12/2014 11:52	0	0	9679	0	3702	65705	0	0
59	23/12/2014 3:02	0	0	13865	0	18409	54594	44247	6626
60	25/12/2014 19:53	0	0	41631	0	2699	44989	34957	0
61	2/1/2015 10:04	0	0	4018	0	3013	0	0	0
62	7/1/2015 15:45	0	0	0	0	4082	0	0	0
63	12/1/2015 20:48	0	0	971	0	9900	0	0	0
64	18/1/2015 3:01	0	0	1877	0	4082	0	0	0
65	20/1/2015 6:54	0	0	526	0	4622	0	0	0
66	24/1/2015 21:42	0	0	0	0	3685	0	0	0
67	25/1/2015 15:03	0	0	0	0	10118	0	0	0
68	26/1/2015 14:18	0	0	352	0	4359	0	0	0
69	30/1/2015 10:47	0	0	0	0	4359	0	0	0
70	3/2/2015 1:57	0	0	721	0	2850	0	0	0
71	9/2/2015 8:54	0	0	0	0	4622	0	0	0
72	10/2/2015 21:19	0	0	279	0	7186	0	0	0
73	14/2/2015 20:05	0	0	0	0	6270	0	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
74	16/2/2015 1:45	0	0	279	0	4622	0	0	0
75	16/2/2015 11:10	0	0	279	0	4359	0	0	0
76	17/2/2015 3:41	0	0	106	0	4082	0	0	0
77	21/2/2015 13:39	0	0	352	0	3621	0	0	0
78	21/2/2015 22:49	0	0	0	0	4082	0	0	0
79	9/3/2015 23:00	0	0	526	0	4992	0	0	0
80	12/3/2015 22:24	0	0	526	0	5407	0	0	0
81	16/3/2015 22:27	0	0	526	0	4359	1236	0	0
82	21/3/2015 16:41	0	0	0	0	3445	0	0	0
83	22/3/2015 0:40	0	0	0	0	4463	9085	0	0
84	23/3/2015 8:42	0	0	526	0	8261	39590	0	0
85	26/3/2015 8:59	0	0	3240	0	16696	30712	0	0
86	26/3/2015 23:24	0	0	0	0	12993	15012	0	0
87	27/3/2015 1:10	0	0	377	0	13363	24544	0	0
88	28/3/2015 20:07	0	0	12076	0	26004	32490	0	0
89	28/3/2015 23:16	0	0	17023	0	38139	38426	784	0
90	31/3/2015 3:14	0	0	14857	0	42281	39195	4851	0
91	8/4/2015 1:15	0	0	17310	0	43878	40557	0	0
92	9/4/2015 9:02	0	11800	16782	0	41973	39725	0	0
93	12/4/2015 6:37	0	0	16536	0	36513	37584	0	0
94	16/4/2015 19:02	0	0	11747	0	32668	44086	5580	0
95	18/4/2015 1:45	0	0	17371	0	34333	61478	10453	0
96	24/4/2015 2:34	0	7906	0	0	27722	0	0	0
97	25/4/2015 8:31	0	0	4016	0	26356	0	0	0
98	26/4/2015 19:50	0	0	7325	0	12565	0	0	0
99	28/4/2015 13:52	0	0	13349	0	5410	0	0	0
100	29/4/2015 13:02	0	0	0	0	11090	0	0	0

Simulation	Simulation Start Time	Total Shoreline Length Oiled after 30 Days [m]							
		Alpena	Charlevoix	Cheboygan	Chippewa	Emmet	Mackinac	Presque Isle	Ontario
101	30/4/2015 15:33	0	0	2995	0	12592	25773	0	0
102	6/5/2015 0:06	0	0	0	0	3478	28699	0	0
103	6/5/2015 10:33	0	0	0	0	3770	32973	0	0
104	8/5/2015 20:47	0	0	971	0	8525	0	0	0
105	13/5/2015 13:55	0	0	1138	0	7784	26399	0	0
106	16/5/2015 19:08	0	0	1377	0	4262	31419	0	0
107	19/5/2015 6:40	0	0	4231	0	3013	0	0	0
108	23/5/2015 22:54	0	0	1539	0	2699	121210	0	0
109	24/5/2015 2:41	0	0	1994	0	4992	85874	0	0
110	26/5/2015 4:48	0	0	2680	0	2699	73707	0	0
111	1/6/2015 0:52	0	0	2089	0	12551	44757	0	0
112	9/6/2015 0:46	0	0	36747	0	7486	35585	0	0
113	10/6/2015 15:16	0	0	9921	0	3833	0	0	0
114	12/6/2015 21:53	0	0	7302	0	25374	36332	0	0
115	15/6/2015 15:27	0	0	6444	0	6033	0	0	0
116	19/6/2015 23:51	0	0	52307	0	4359	69240	9081	0
117	20/6/2015 12:55	0	0	45164	0	4359	58542	14950	5742
118	29/6/2015 9:49	0	0	13459	0	18783	6486	0	0
119	29/6/2015 10:05	0	0	13880	0	18409	5949	0	0
120	30/6/2015 3:18	0	0	13129	0	10638	0	0	0

5 Comparison to University of Michigan Oil Spill Modeling

In a similar study, the University of Michigan (UM) modeled oil spill trajectories (Schwab, 2016) using the Lagrangian particle tracking code supplied with the Finite Volume Coastal Ocean Model (FVCOM) model. The FVCOM with particle tracking model is similar to DHI's MIKE 3 HD FM and MIKE 3 FM OS models. The FVCOM model uses a flexible mesh of ~31000 surface elements, with 20 vertical layers, compared to ~53000 surface elements and 20 vertical layers in the DHI model. Element sizes in the UM model are reported to range from about 100m to 2.5km compared to about 150m to 6.6km in the DHI model. Both models rely on a one-year hydrodynamic simulation as the basis for oil spill transport. DHI simulated the period 7/1/2014-7/1/2015, and UM simulated an ice-free period in 2014, or starting from 3/31/2014 to about 10/27/2014.

Though there are many similarities between the two models and two studies, a few differences are noteworthy. The DHI MIKE models include ice on lake surfaces, whereas the FVCOM based model reportedly neglects ice (did not simulate months with ice cover). The MIKE models included the effect of wind-generated waves on the sea surface, which accelerates the process of emulsification. The UM FVCOM based model reportedly does not include waves, but likely parameterizes the process. The DHI MIKE models include wind stress applied directly on the oil; the UM FVCOM model reportedly does not. Wind stress applied directly on the oil provides for an additional transport mechanism besides advection with the surface currents and dispersion. Other differences include the number of particles released (DHI ~6000, UM 10,000), volume of oil released (UM used 5k, 10k and 25k bbl), and locations of release. Table 3.5 and Table 3.6 describe DHI volumes, but are most comparable to the 5k bbl UM case. DHI simulated 120 simulations per release scenario over the entire year, or roughly once every 3 days. The start time is randomized between the 3-day intervals, and each simulation runs for 30 days. UM simulated 840 simulations during the year's ice-free period , with one simulation starting every 6 hours. UM released the oil from one location, with three different release sizes just south of halfway between the two pipelines. DHI used 6 different combinations of release location and size (described in Table 3.5 and Table 3.6).

Given the varying similarities and differences in models and methodologies, the results are quite similar when it comes to extent of shoreline impact (Schwab, 2017).

6 References

/1/ ITOPF (2002), Fate of Marine Oil Spills, Technical Information Paper 2, The International Tanker Owners Pollution Federation Limited.

/2/ MIKE (2016), DHI Oil spill Model – Scientific Description.

/3/ NOAA (2002), Trajectory Analysis Handbook. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Response and Restoration, Hazardous Materials Response Division.

/4/ NOAA (2013), Screening Level Risk Assessment Package – Bunker Hill, Office of National Marine Sanctuaries and Office of Response and Restoration, National Oceanic and Atmospheric Administration.

/5/ French-McCay (2015), Comprehensive Approach to Risk Analysis of Sunken Shipwrecks: The use of trajectory, fate and effects modelling. Presentation slide for Wrecks of the Work III: Shipwreck Risk Assessment. 12-13 October 2015.

/6/ Anderson, E.J., and D.J. Schwab, 2013. Predicting the oscillating bi-directional exchange flow in the Straits of Mackinac. Journal of Great Lakes Research 39(4):9 pp.(DOI:10.1016/j.jglr.2013.09.001).

/7/ Schwab, David, "Statistical analysis of Straits of Mackinac Line 5 Worst Case Spill Scenarios," University of Michigan Water Center, Graham Sustainability Institute, March 2016. http://graham.umich.edu/media/pubs/Mackinac-Line-5-Worst-Case-Spill-Scenarios.pdf

/8/ Schwab, David, Comparison of oil spill release modeling results from Dynamic Risk report: “Alternatives Analysis for the Straits Pipeline Attachment 2: Oil Spill Modeling for Straits of Mackinac,Michigan” (DR17) and University of Michigan Water Center report “Statistical Analysis of Straits of Mackinac Line 5 Worst Case Spill Scenarios” (UM16). Comments provided by David Schwab, July 21, 2017.

7 Statistical Maps

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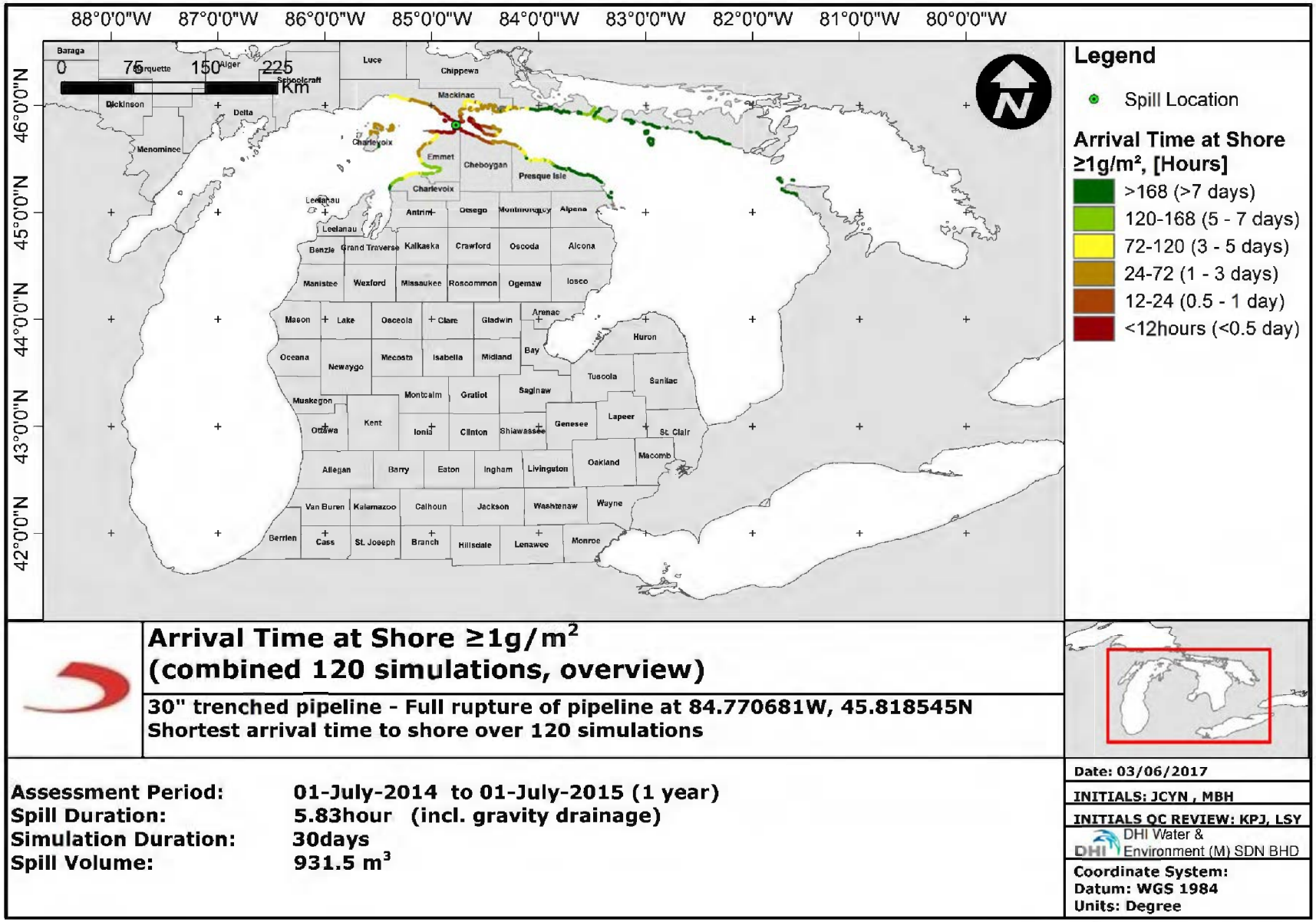
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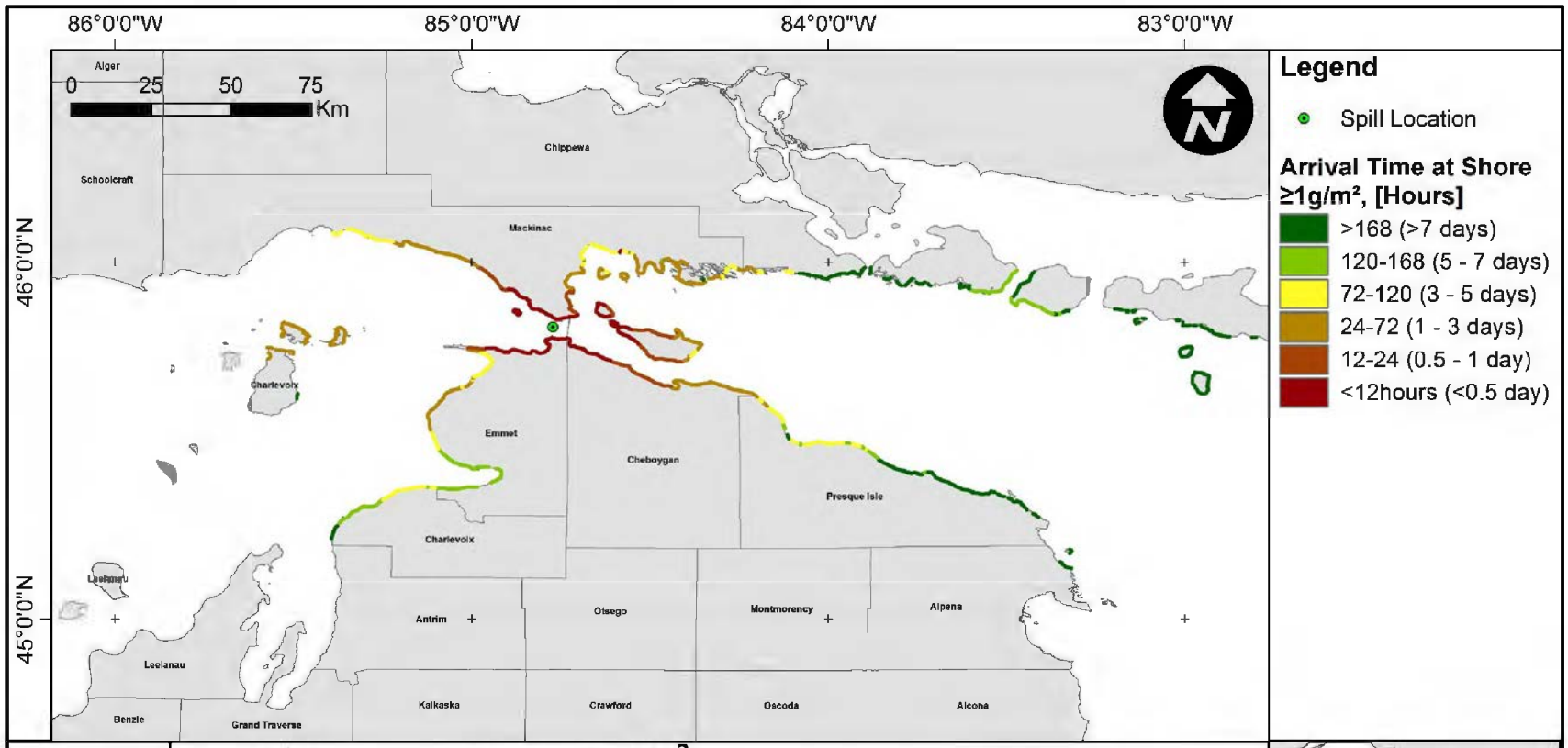
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Set 1
30” Trenched Pipeline – Full rupture

1 year


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 120 simulations, overview)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 120 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

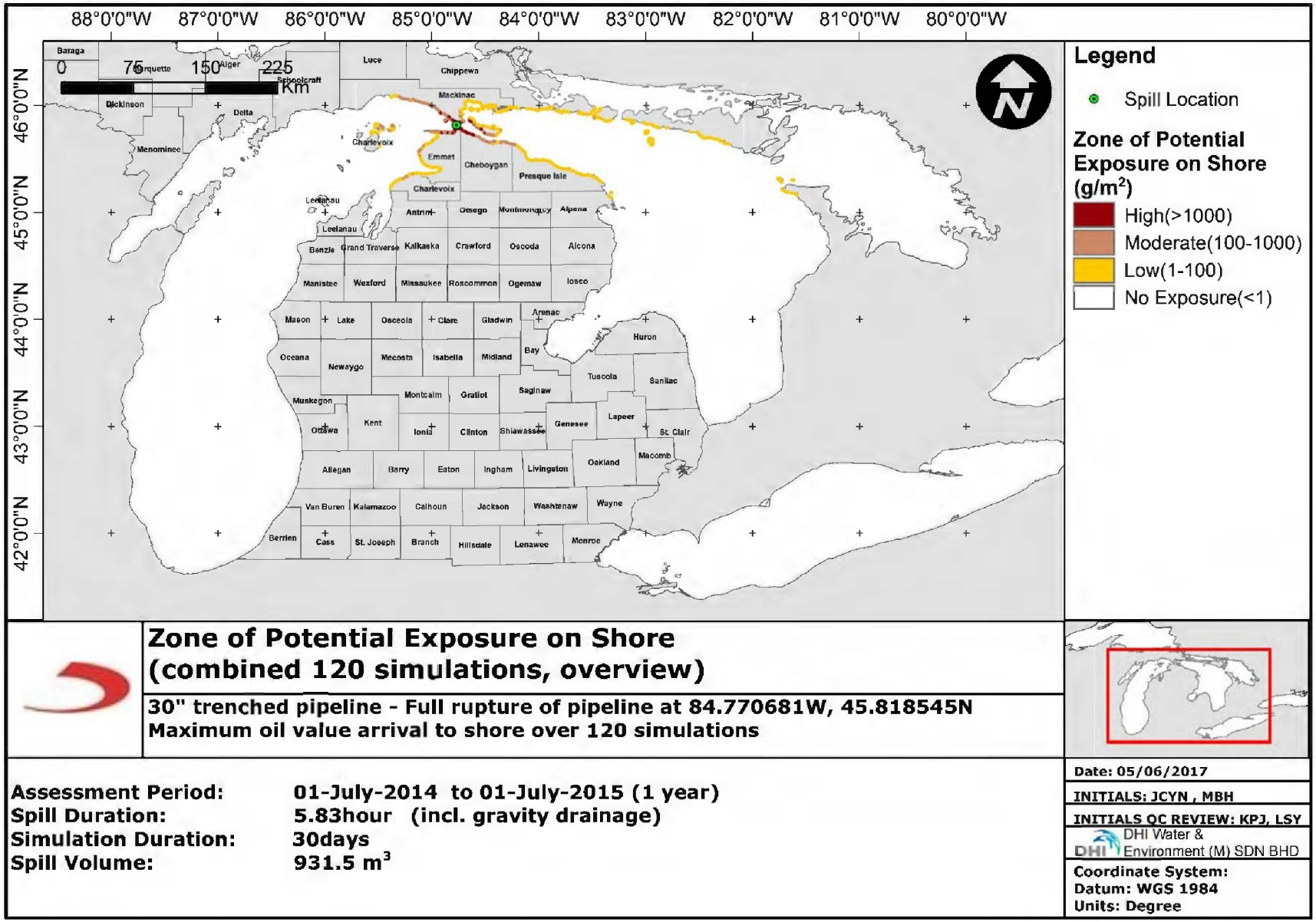


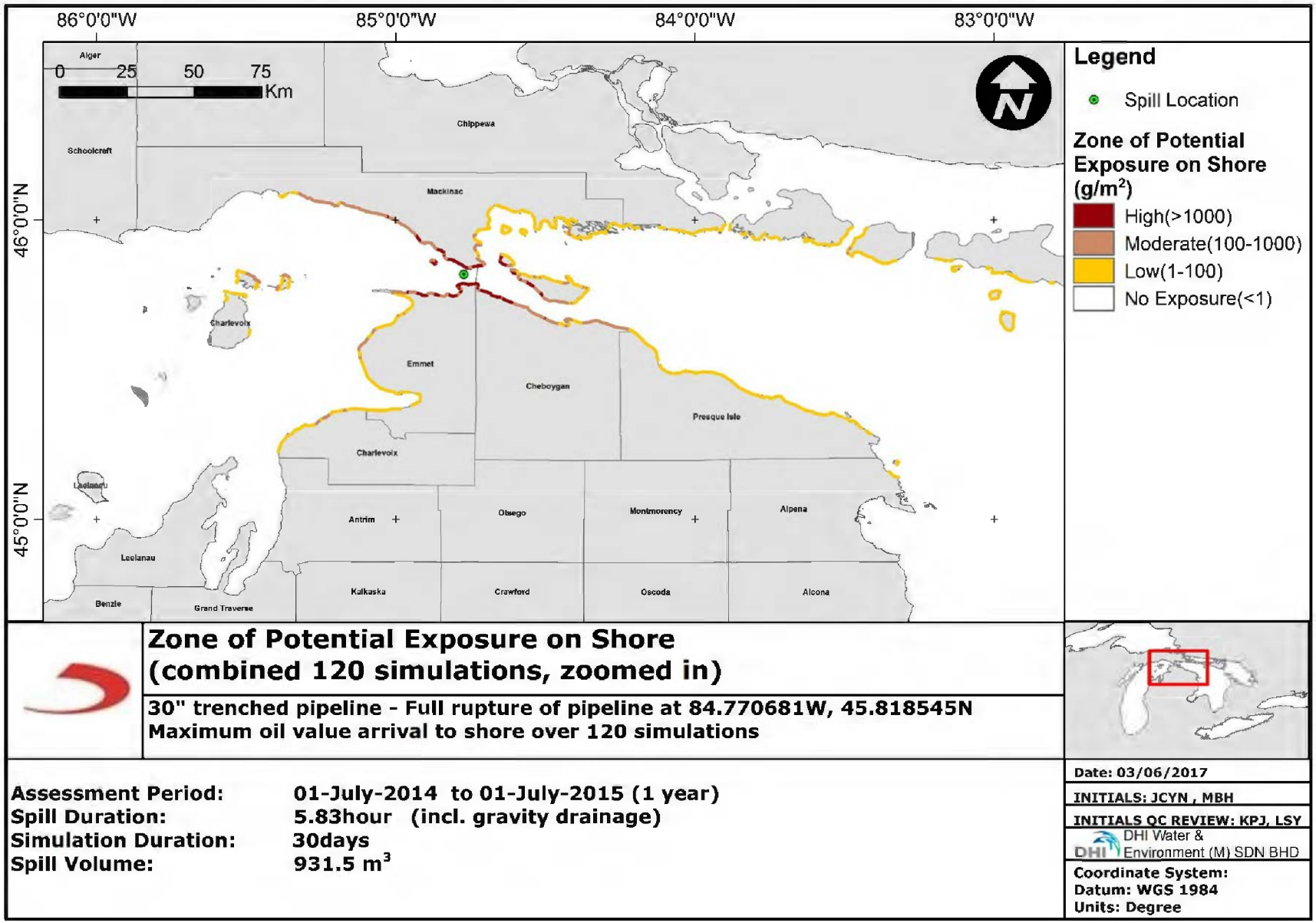
Arrival Time at Shore ≥1g/m²
(combined 120 simulations, zoomed in)

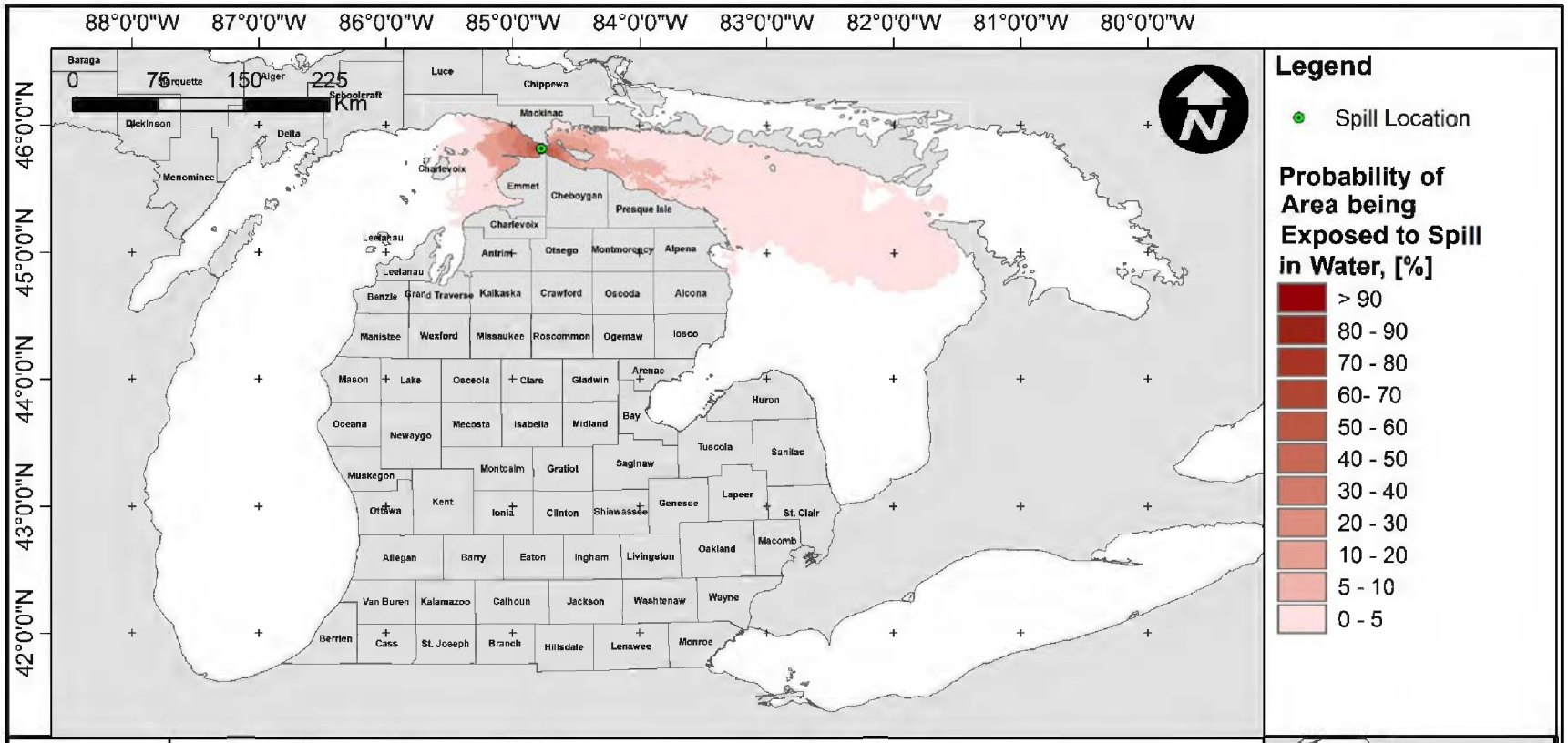
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 120 simulations

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 120 simulations, overview)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 120 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 120 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 120 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

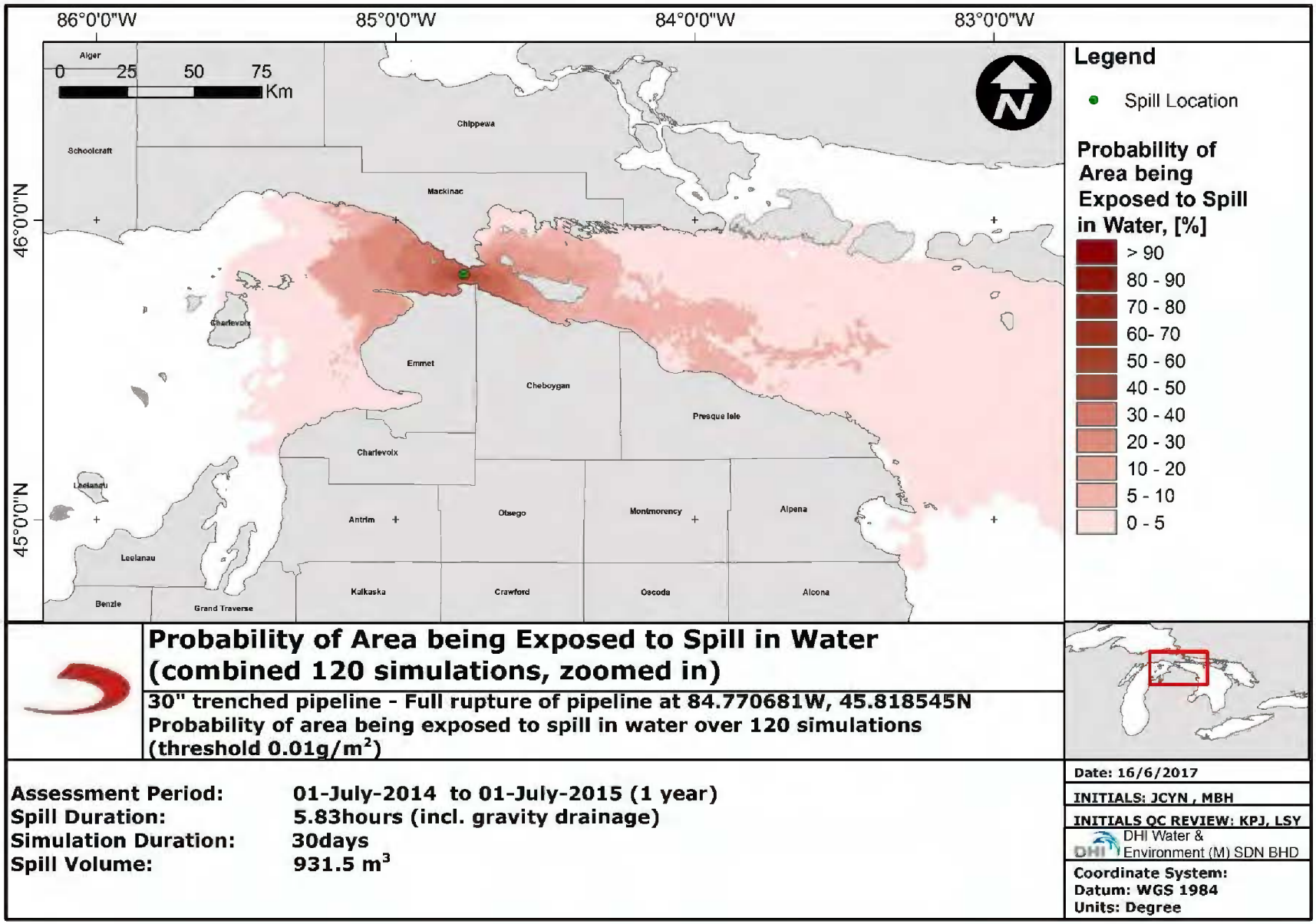


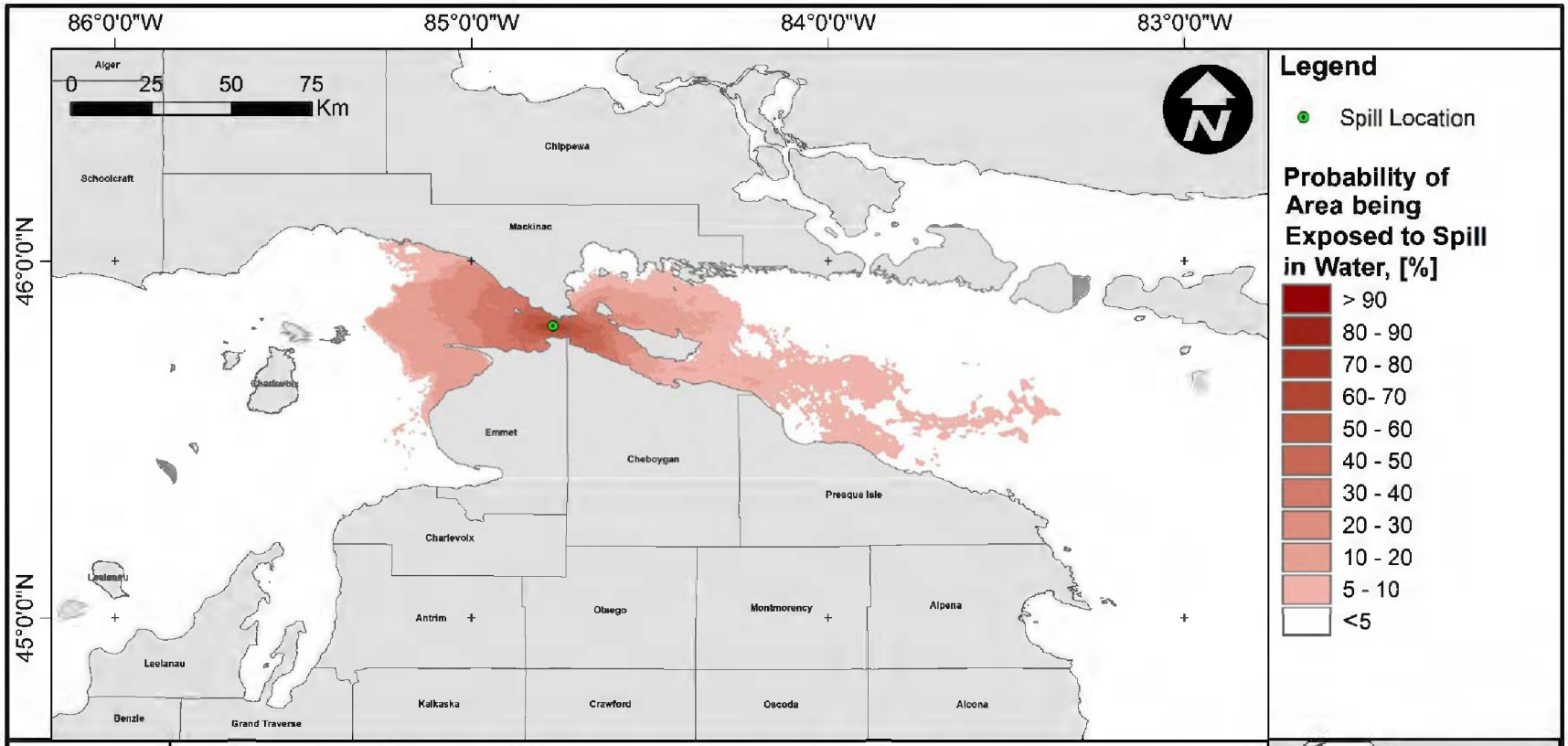
Probability of Area being Exposed to Spill in Water (combined 120 simulations, overview)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
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)**
Spill Duration:	**5.83hours (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 120 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
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: 5.83hours (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree



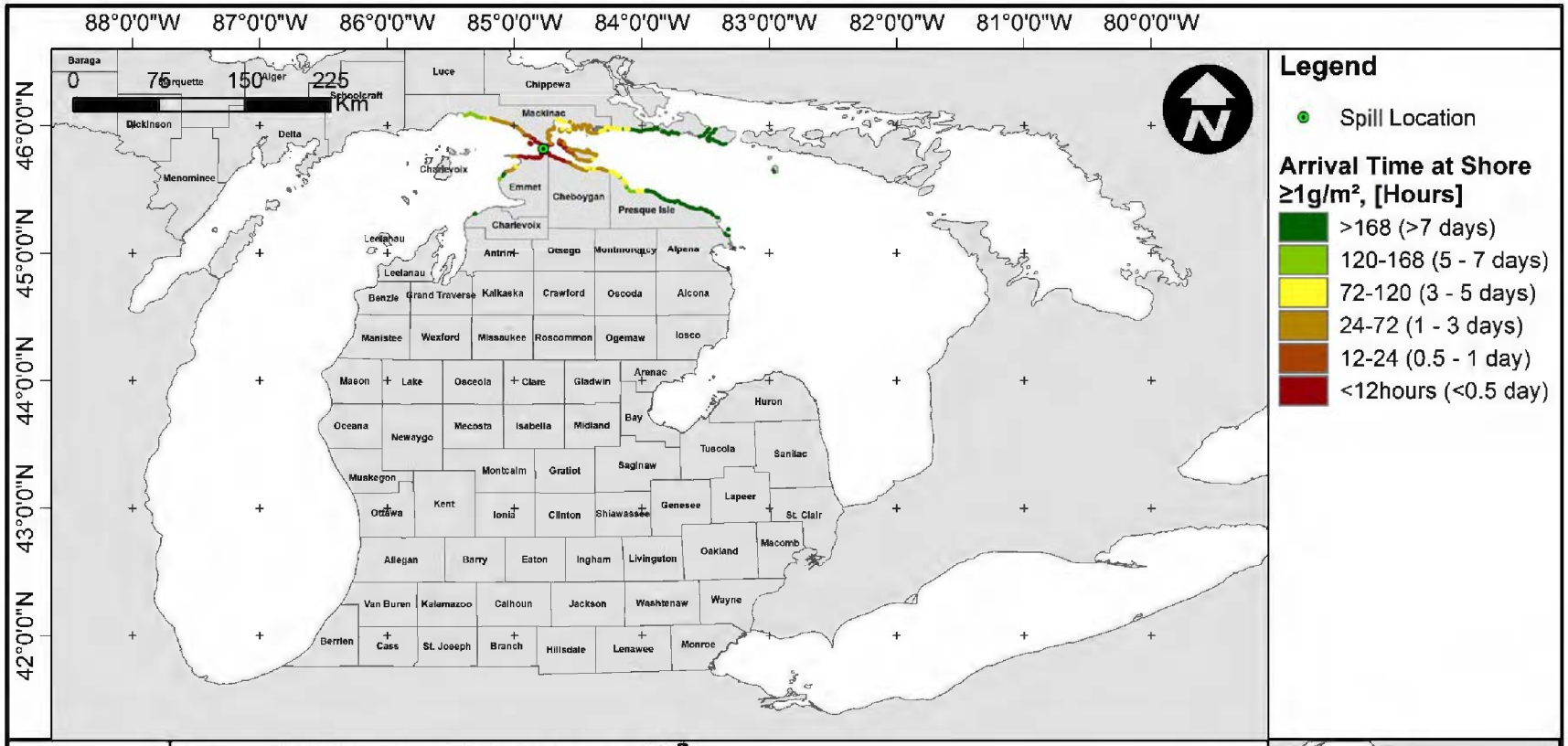
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 120 simulations, zoomed in)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
95th perct. 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)**
Spill Duration:	**5.83hours (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

Q1

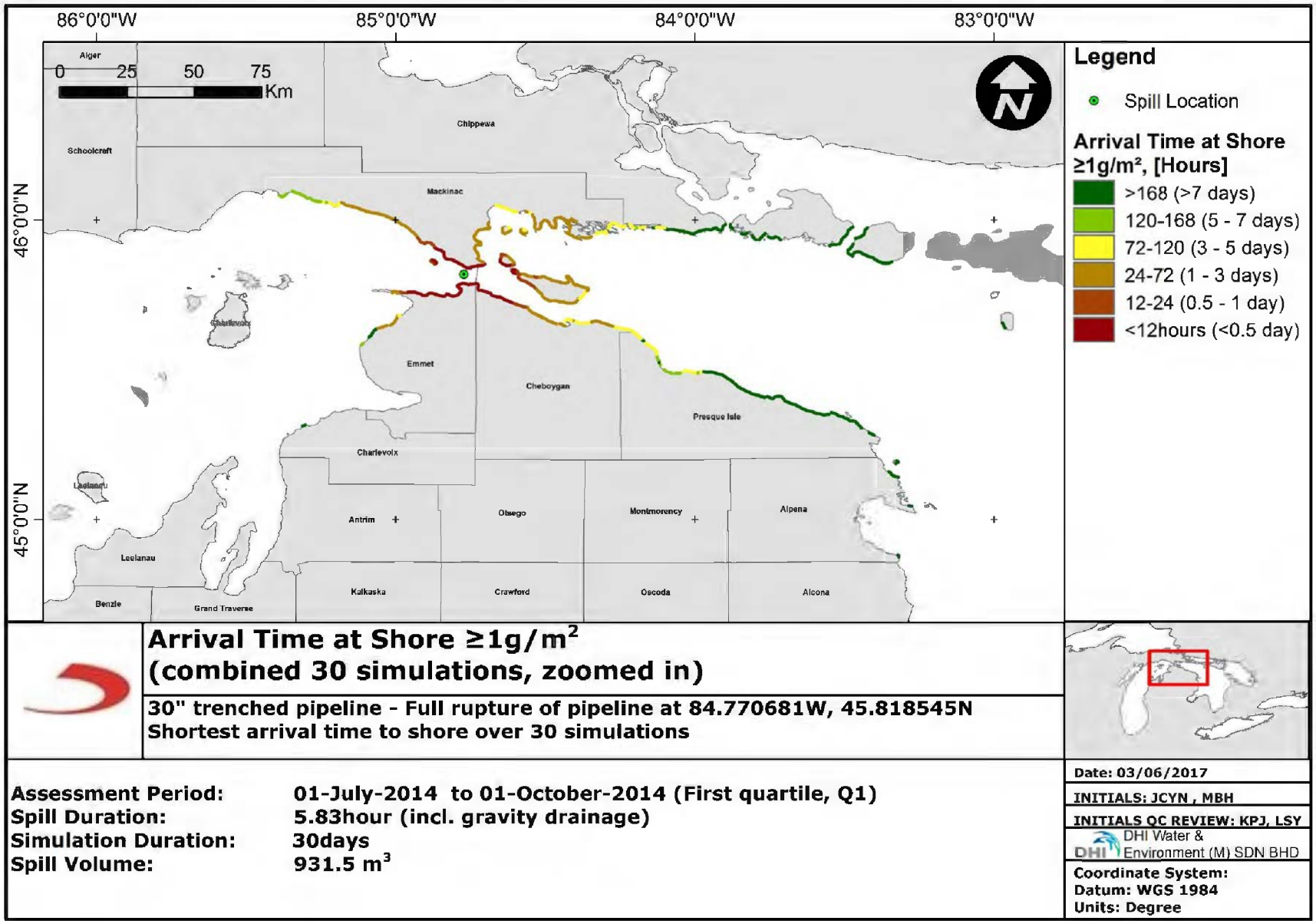


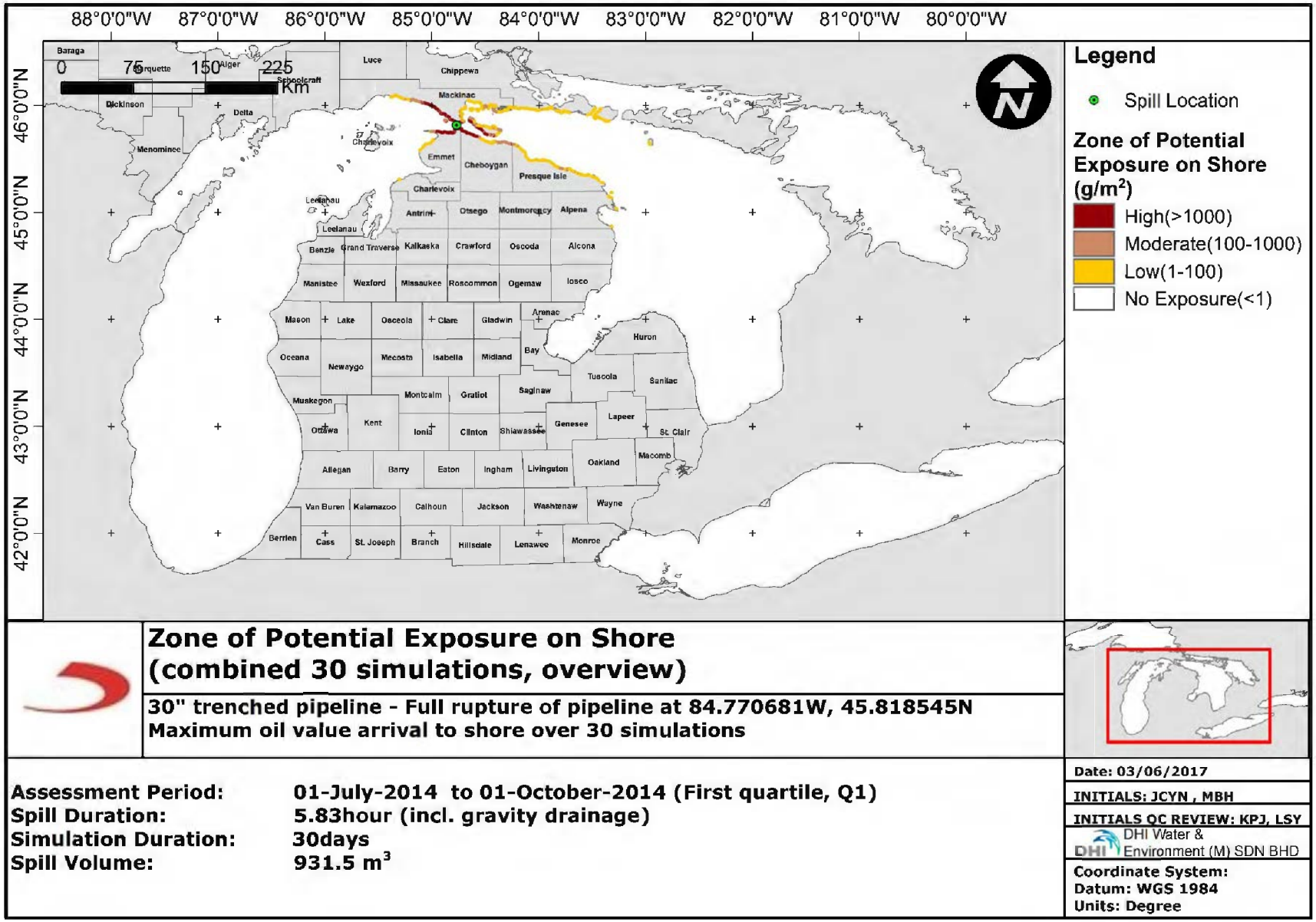
Arrival Time at Shore ≥1g/m² (combined 30 simulations, overview)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Emmet
Cheboygan
Presque Isle
Charlevoix
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

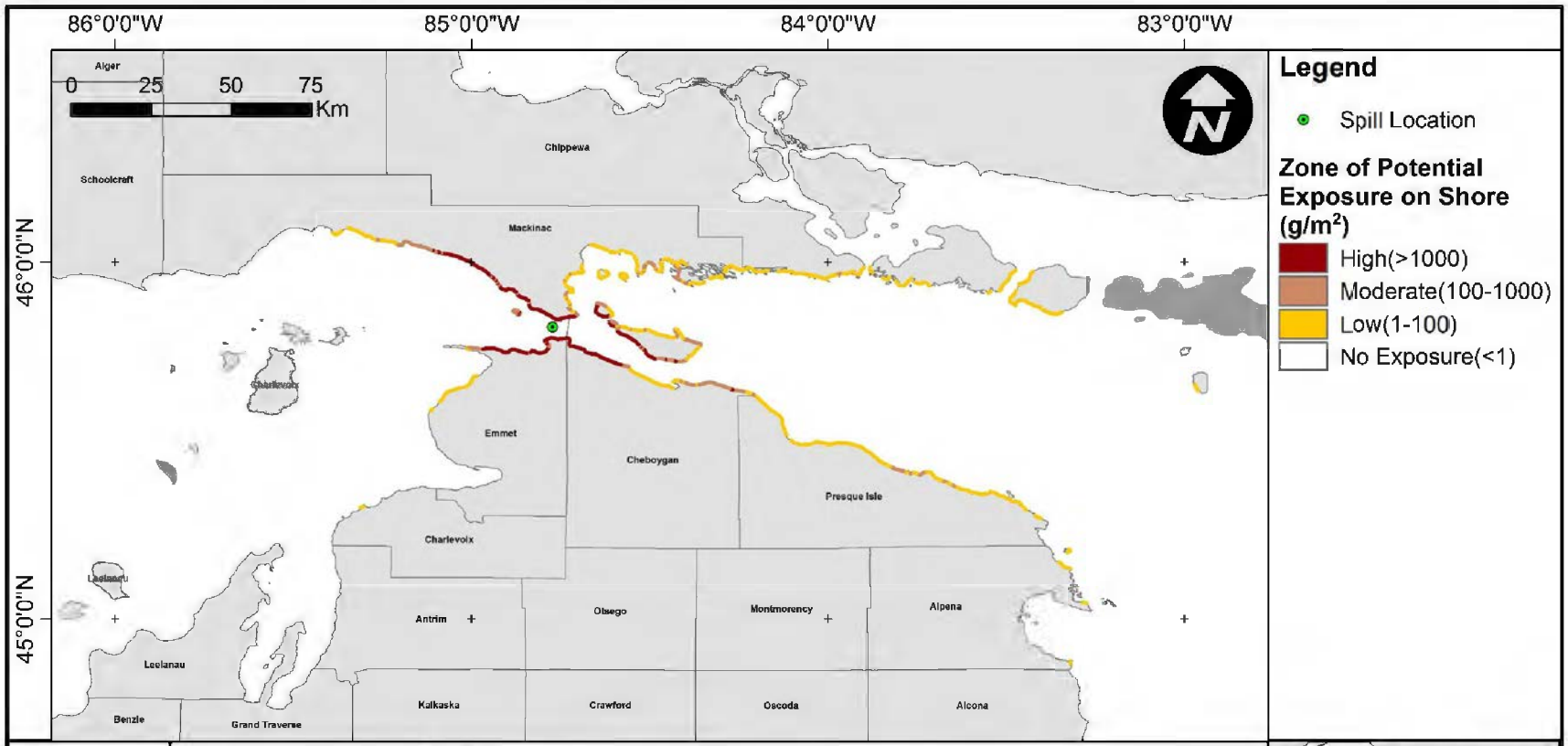


Zone of Potential Exposure on Shore (combined 30 simulations, overview)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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Units: Degree

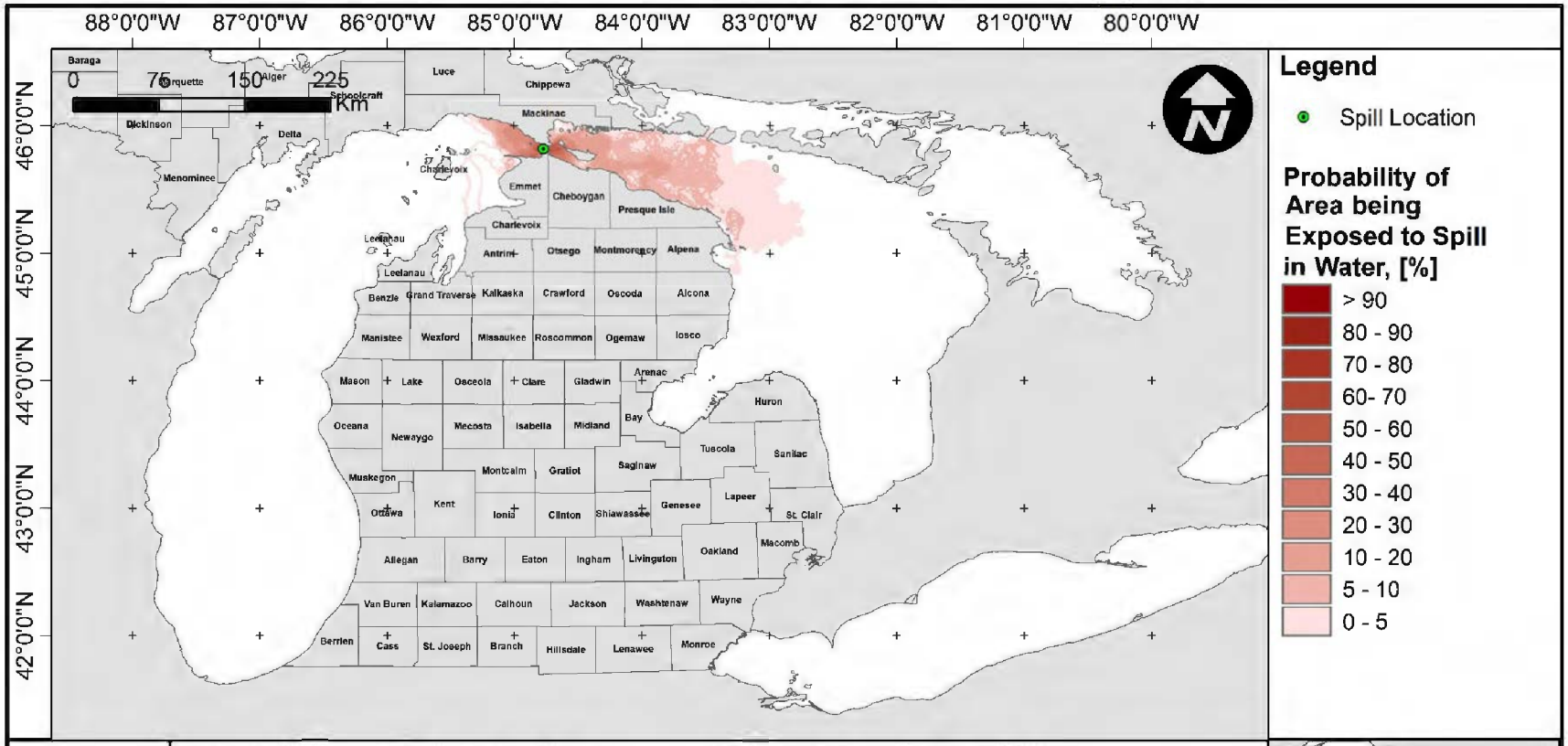


Zone of Potential Exposure on Shore (combined 30 simulations, zoomed in)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
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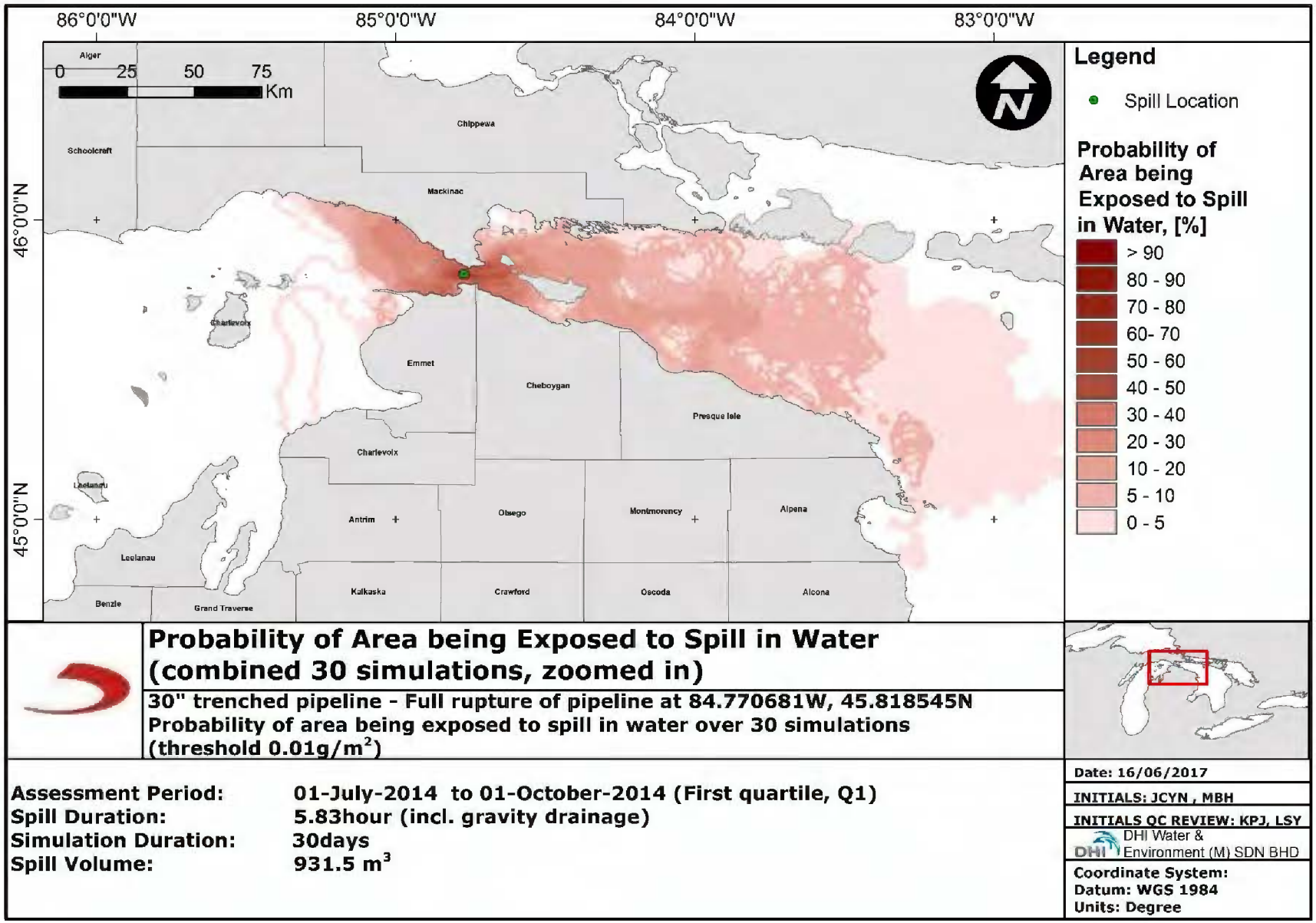


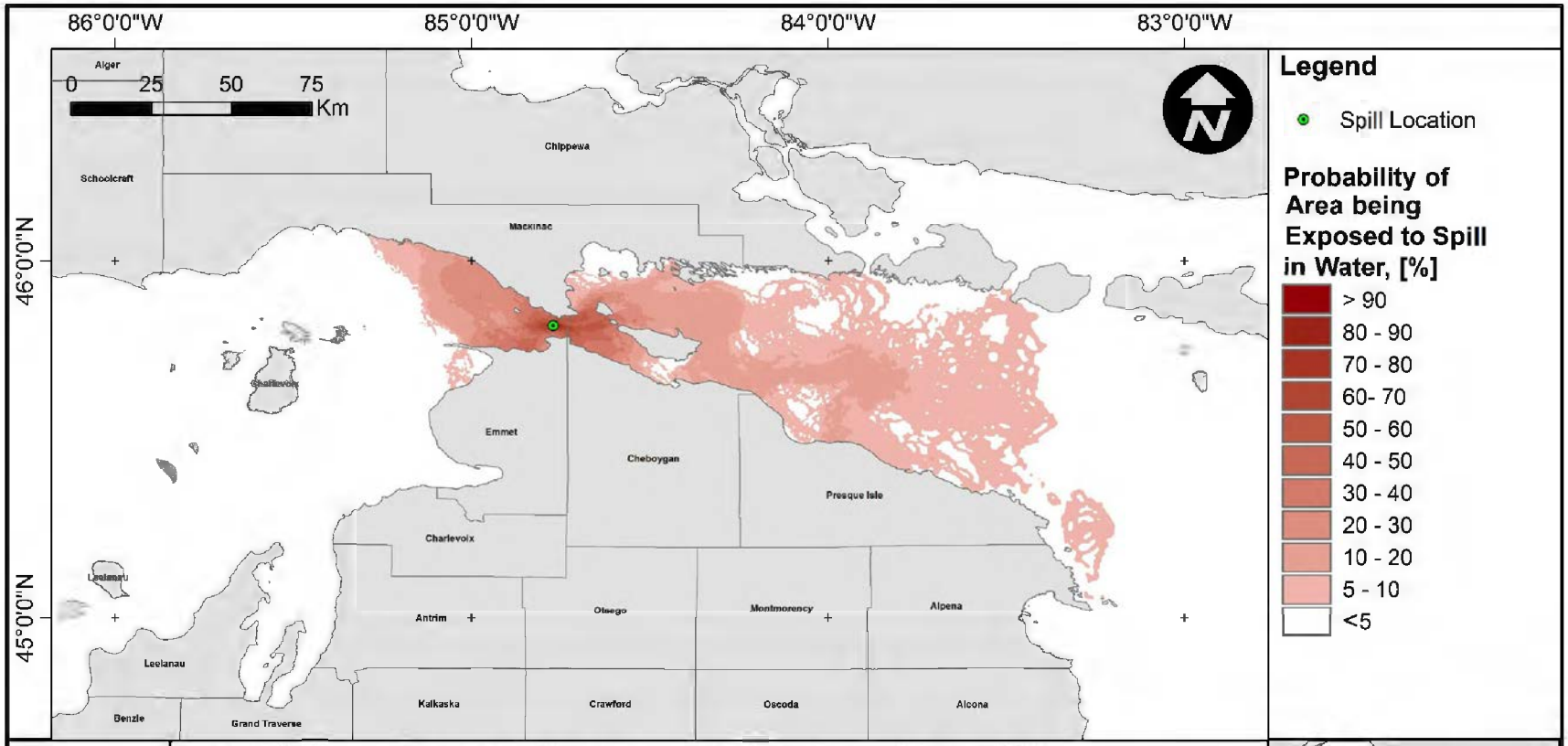
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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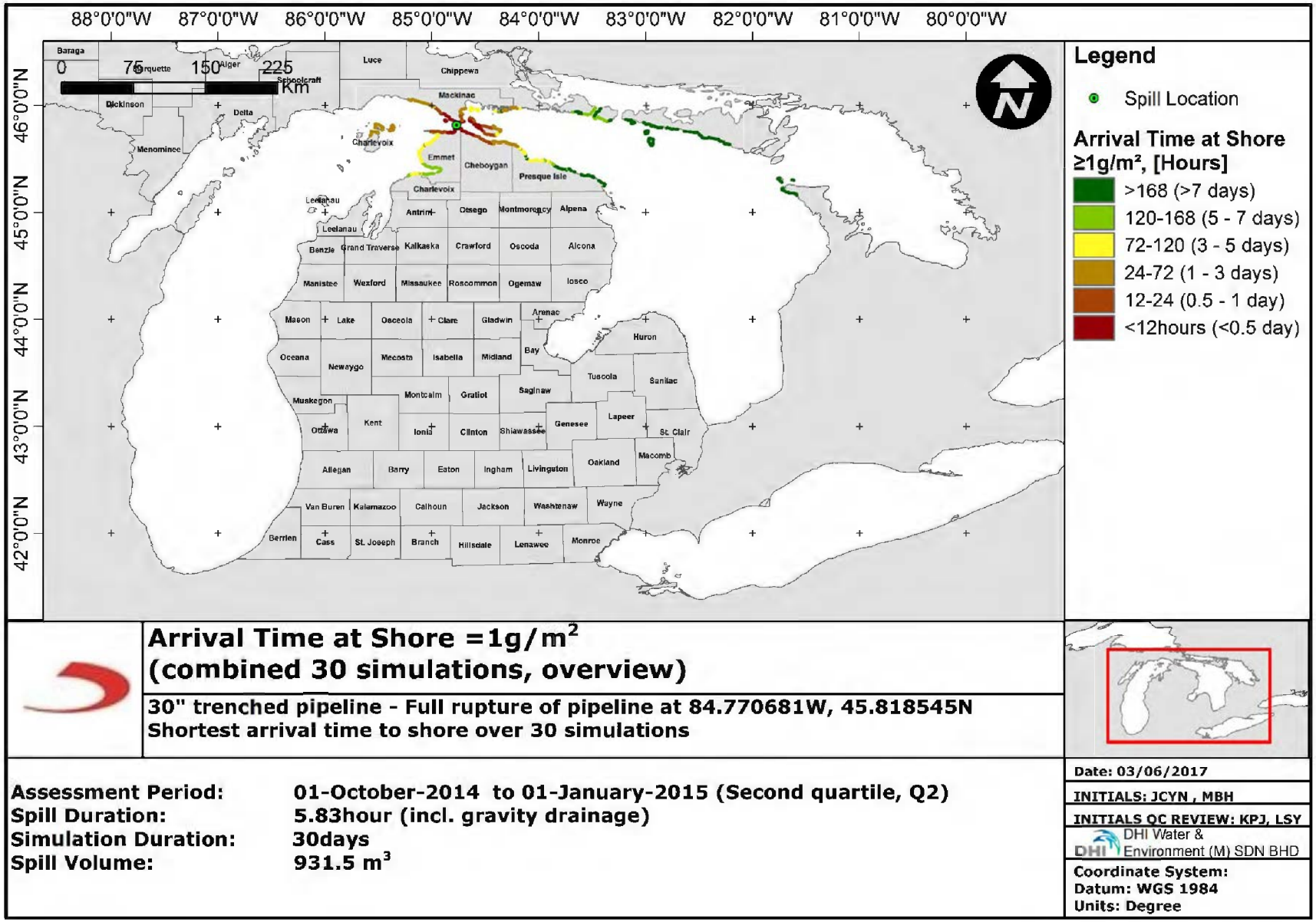
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

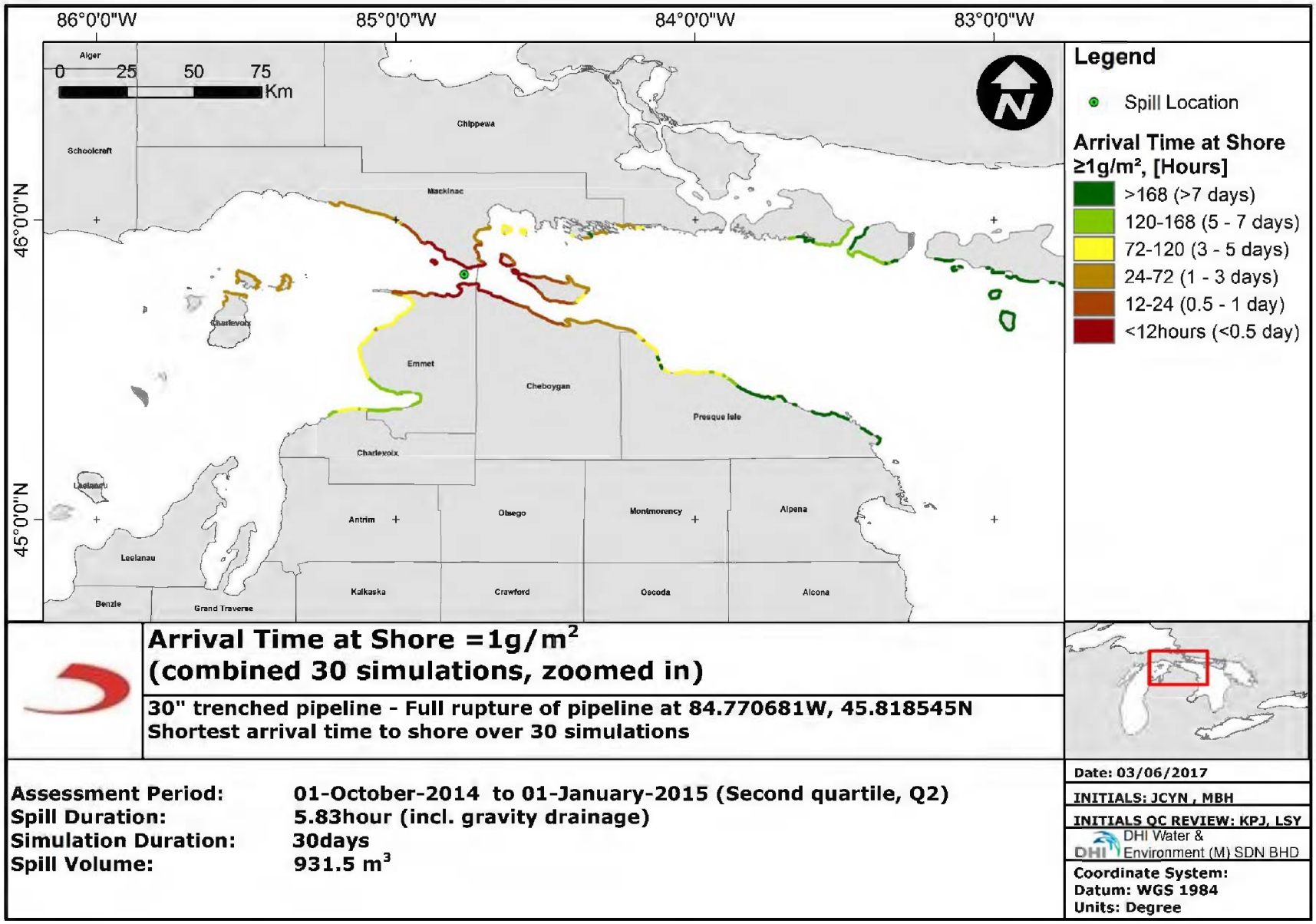
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

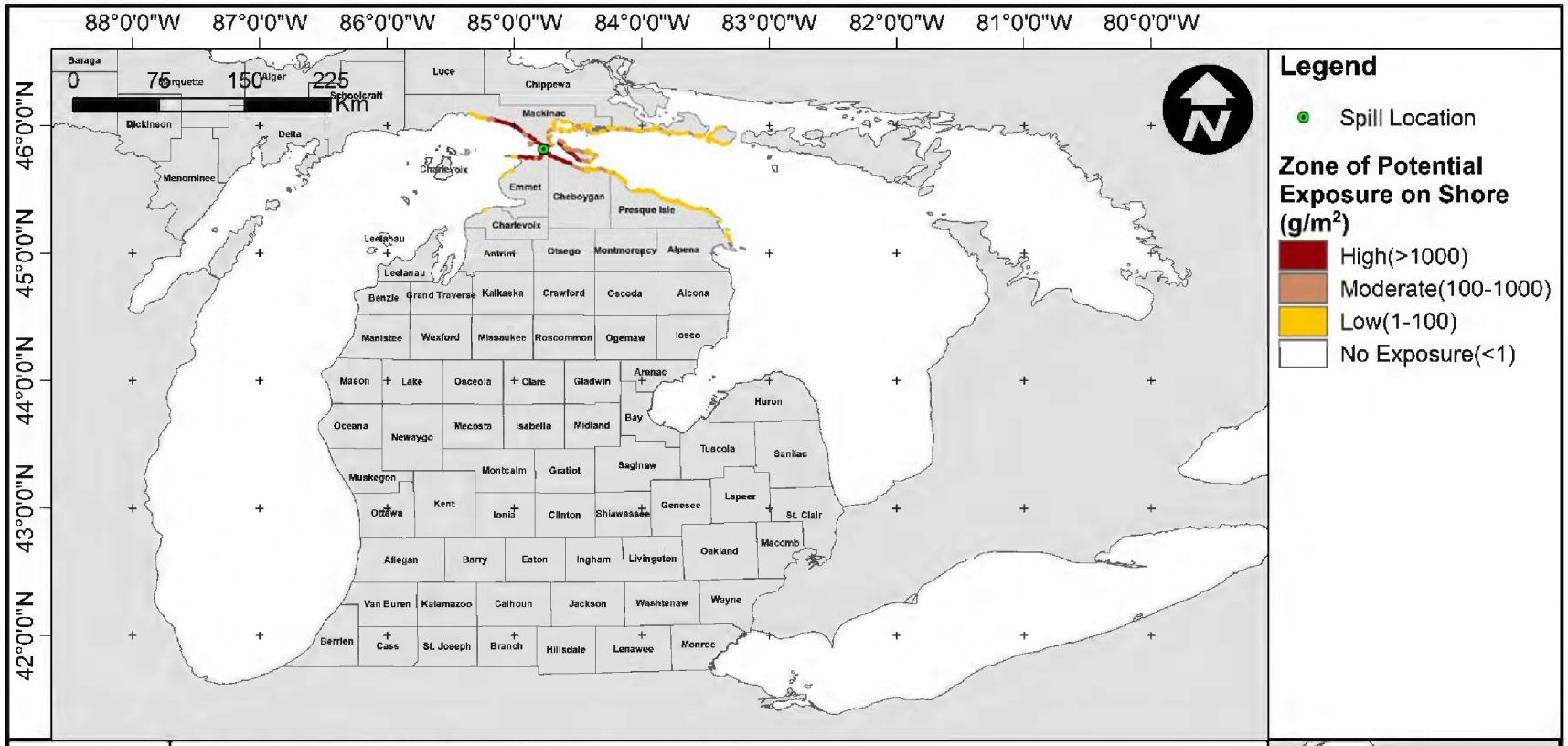
Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

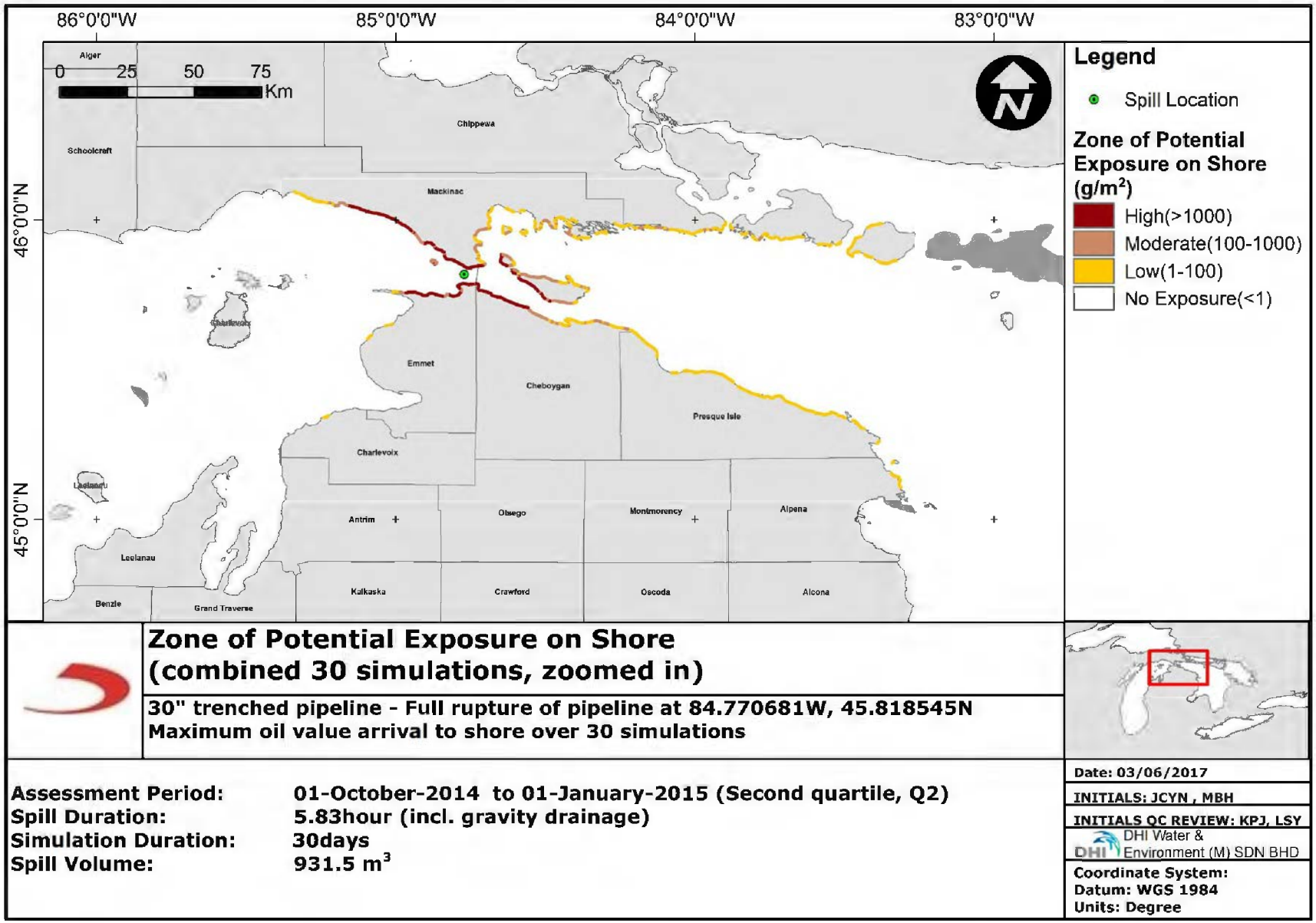
Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

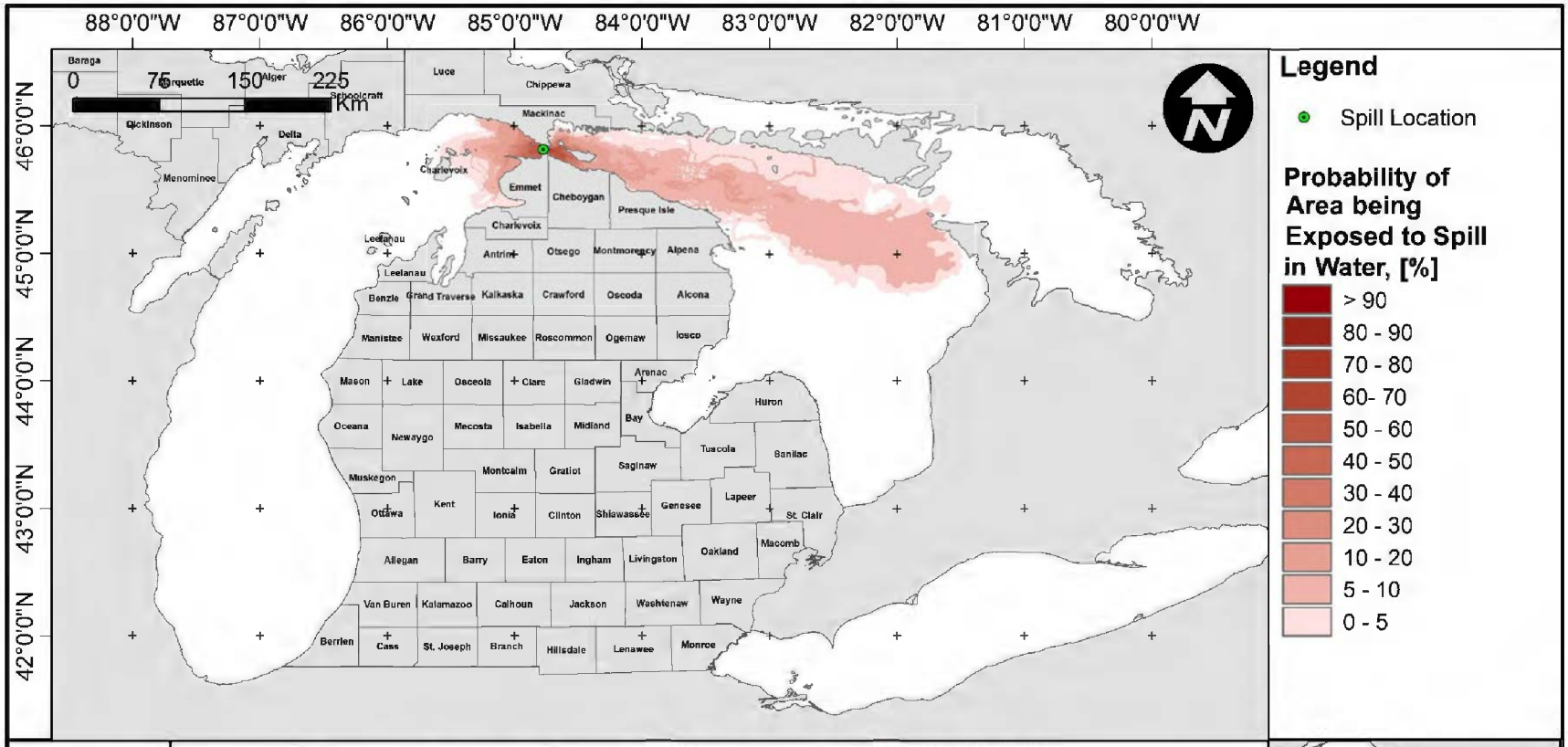
Q2


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, overview)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, overview)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Emmet
Cheboygan
Presque Isle
Charlevoix
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

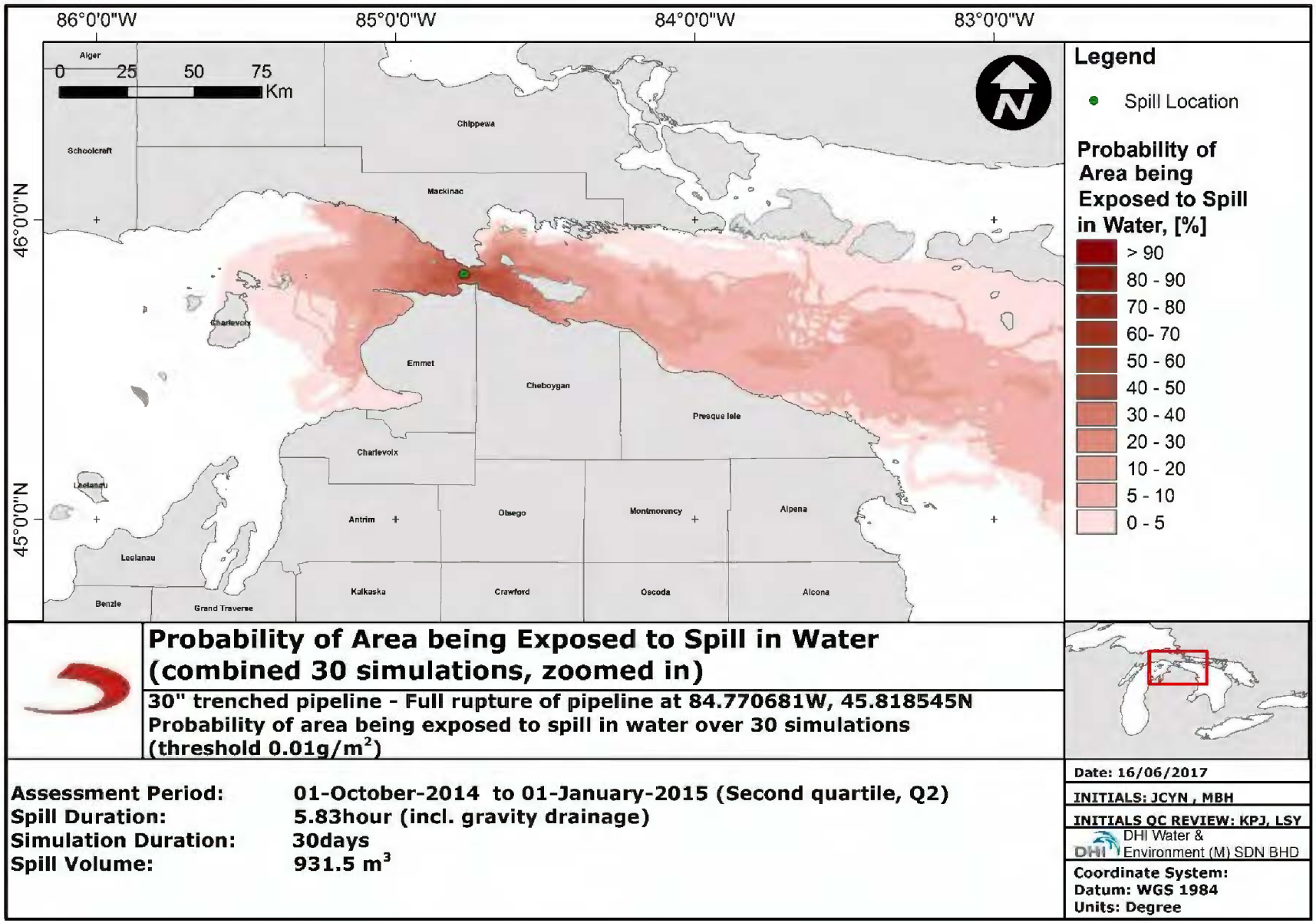


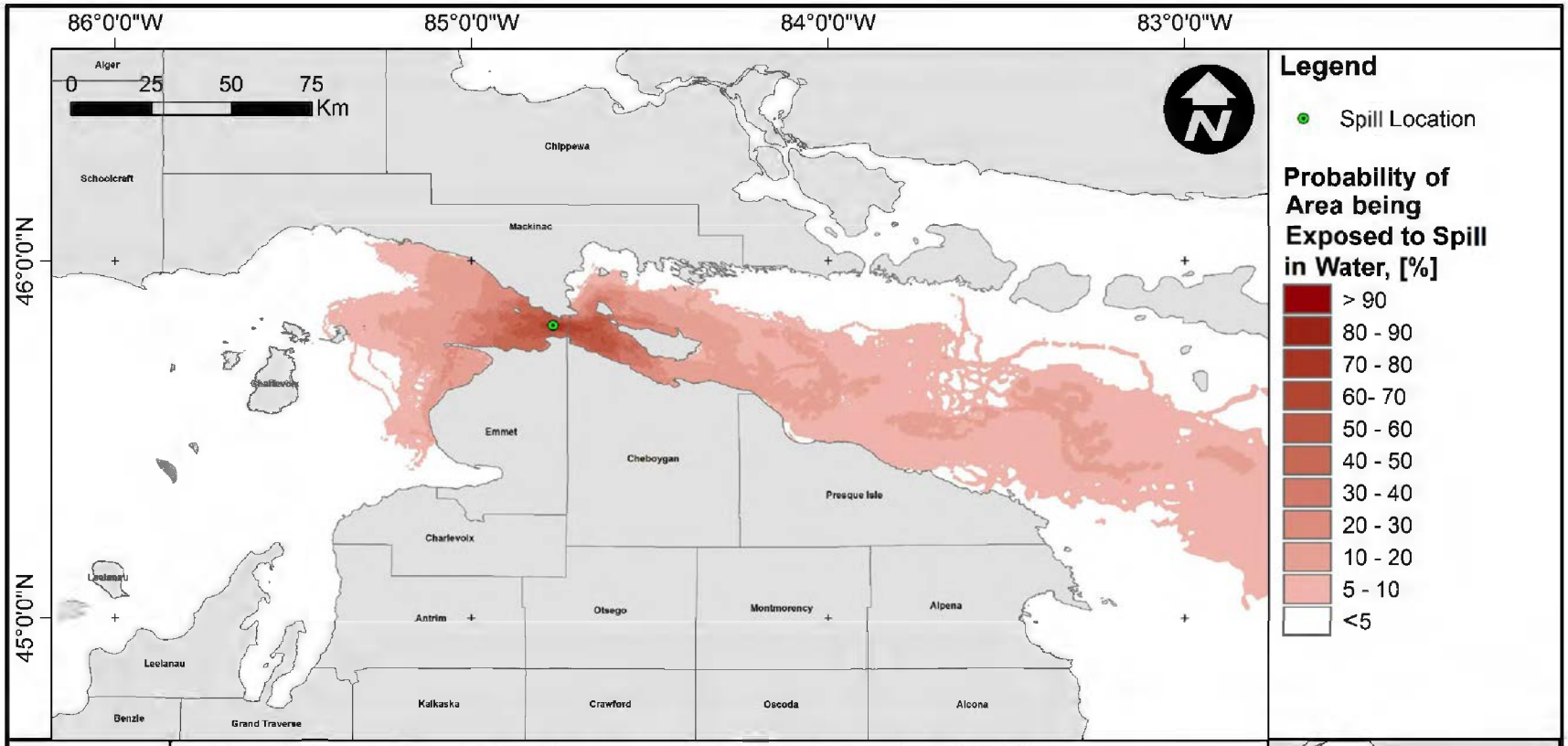
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
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Charlevoix
Leelanau
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Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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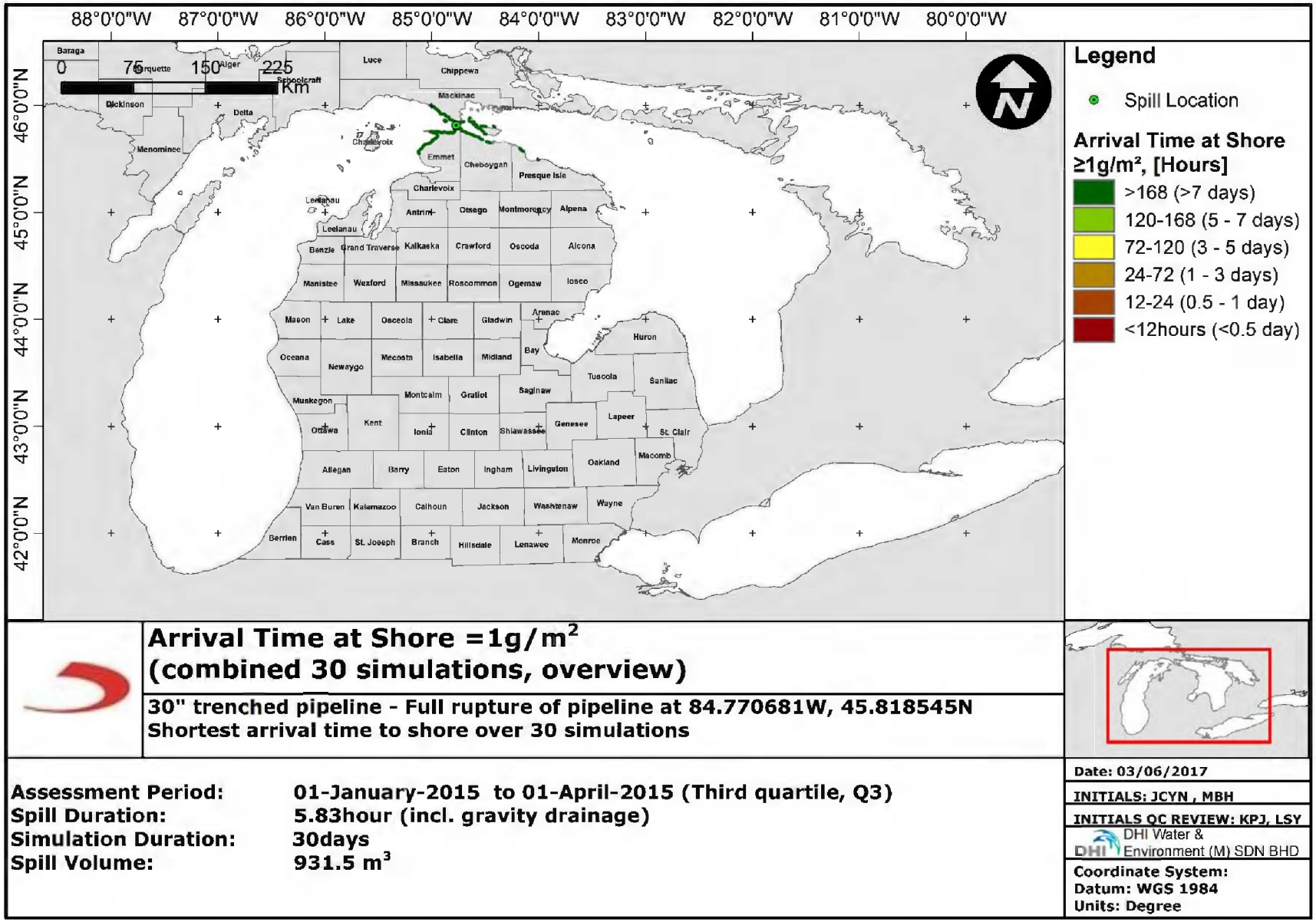
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

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

Q3

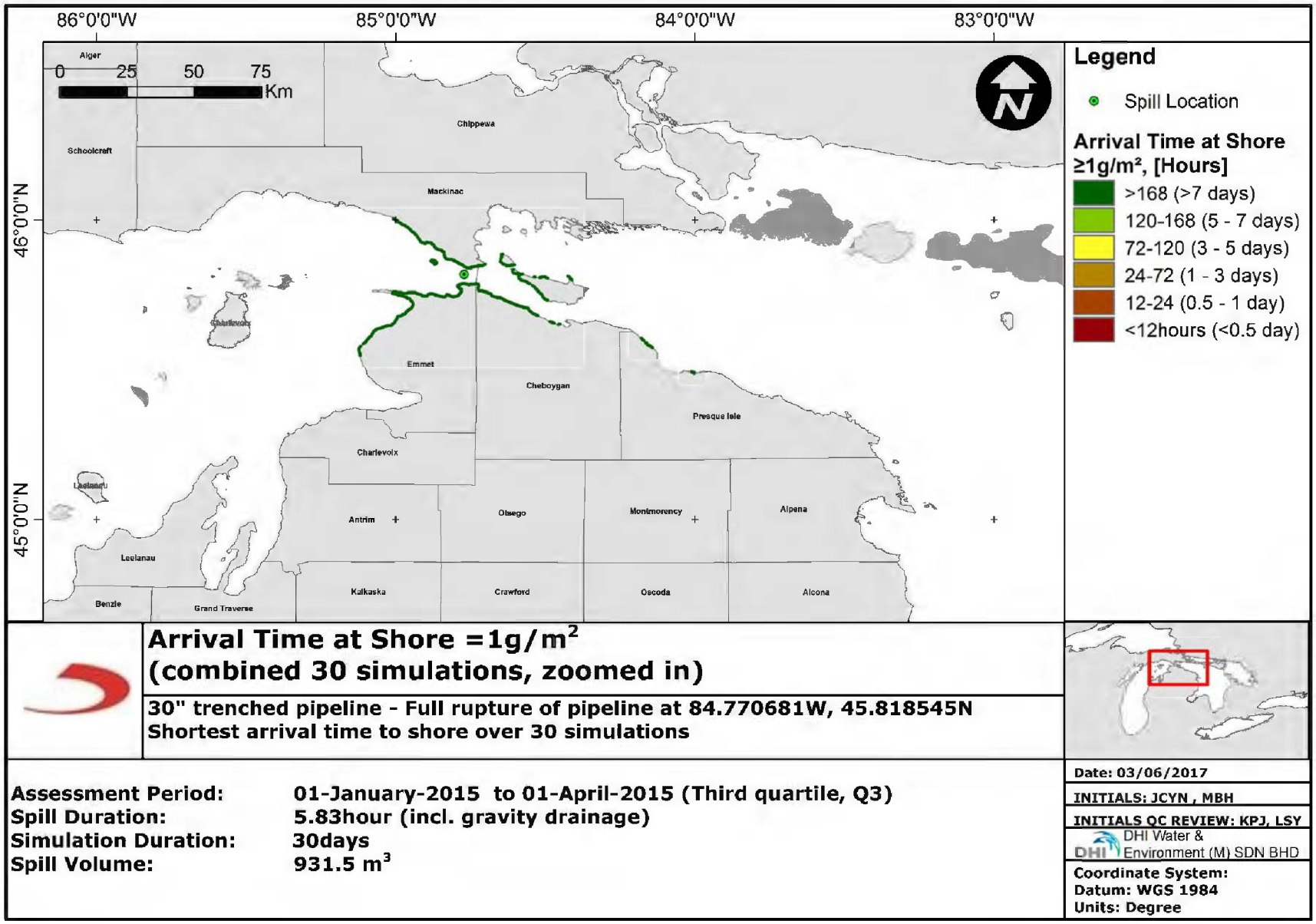


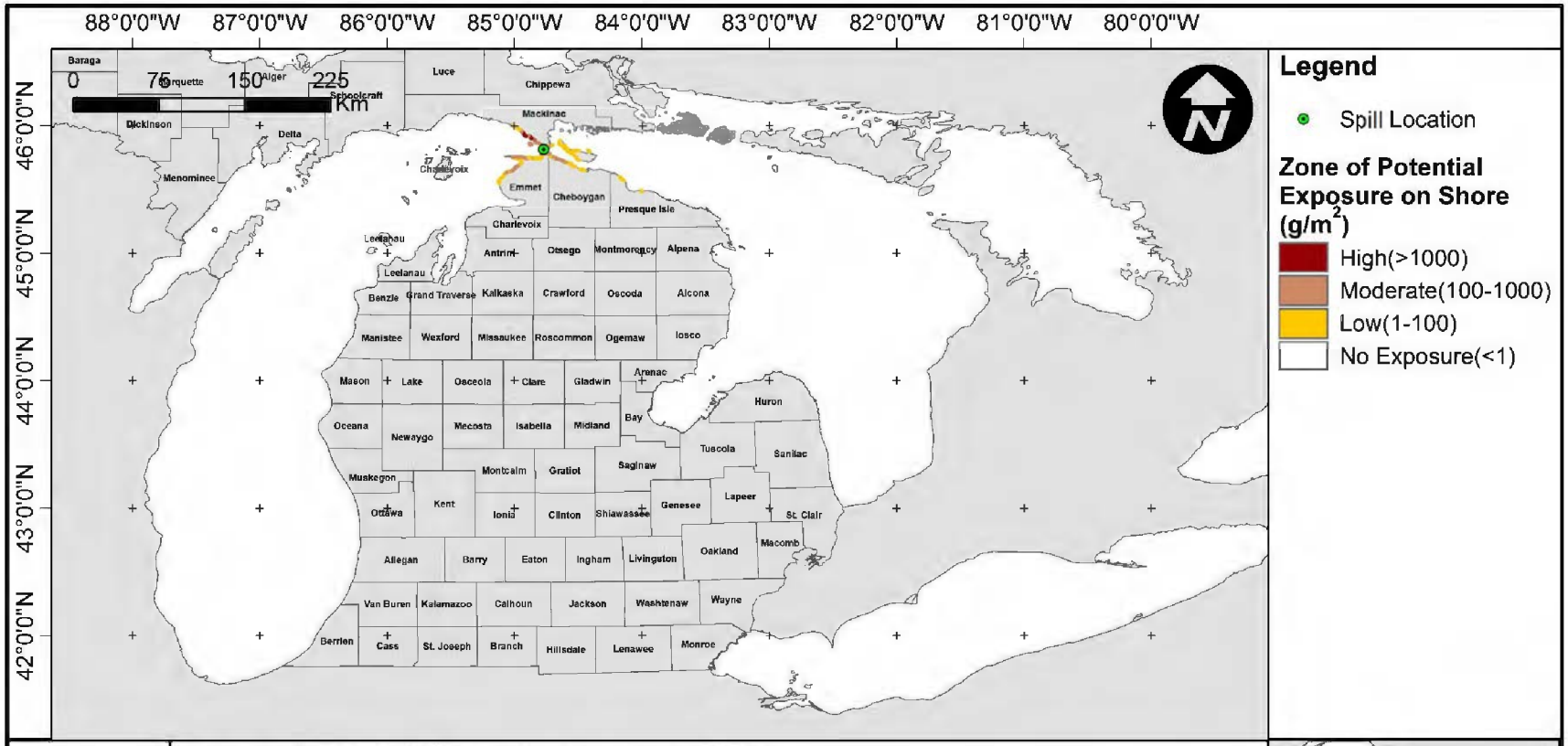
Arrival Time at Shore =1g/m^2 (combined 30 simulations, overview)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
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Leelanau
Benzie
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Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
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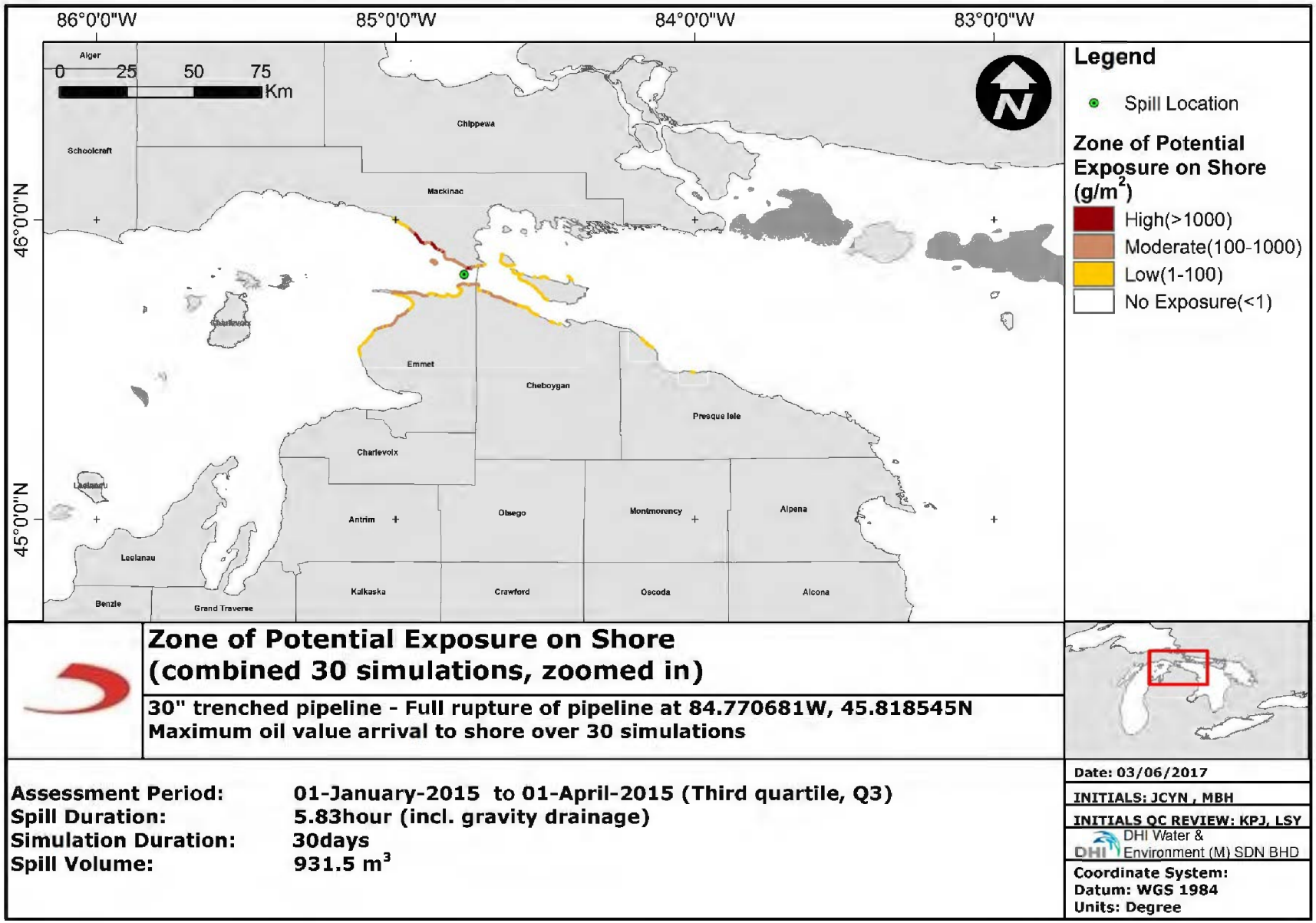


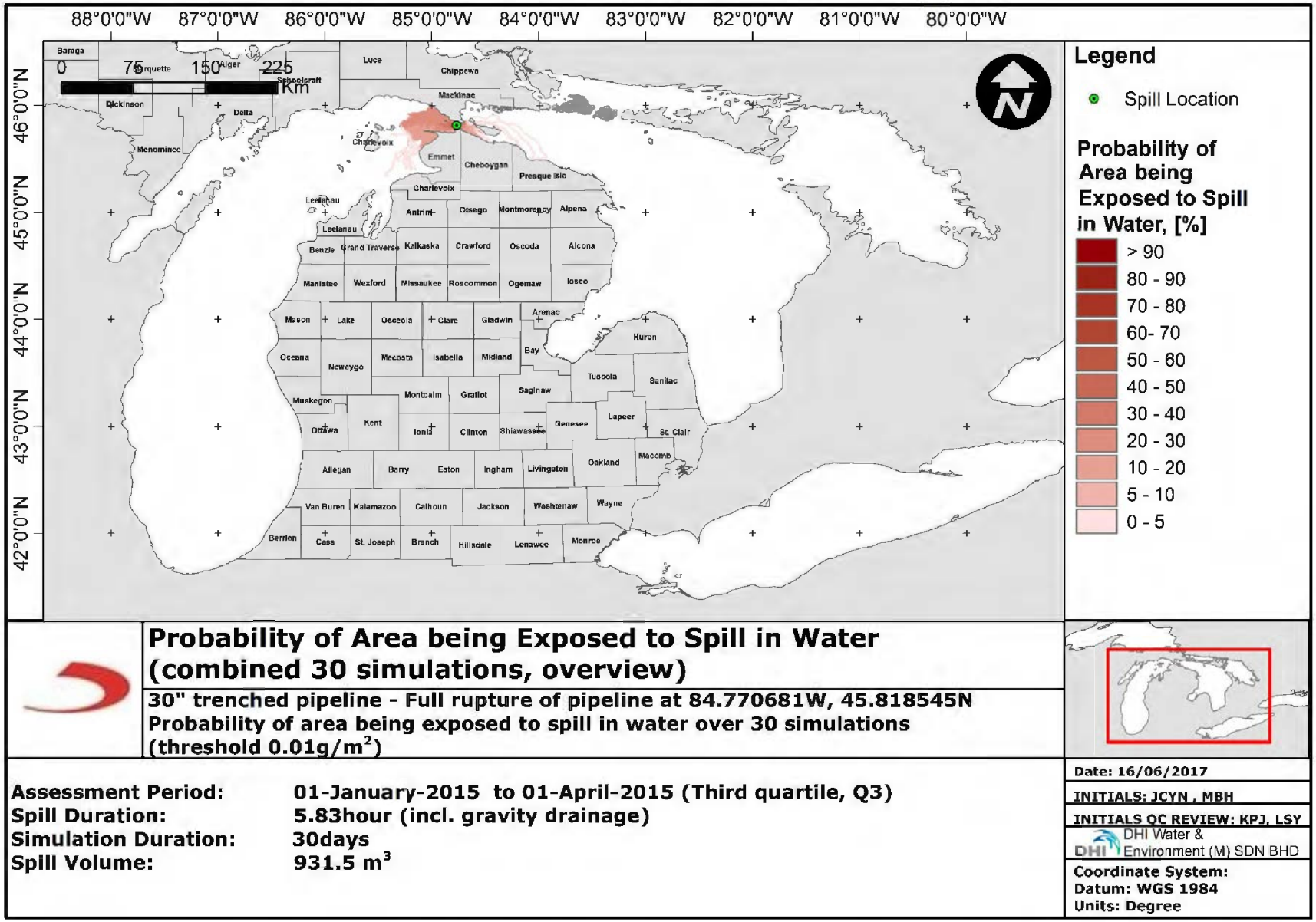
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
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Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

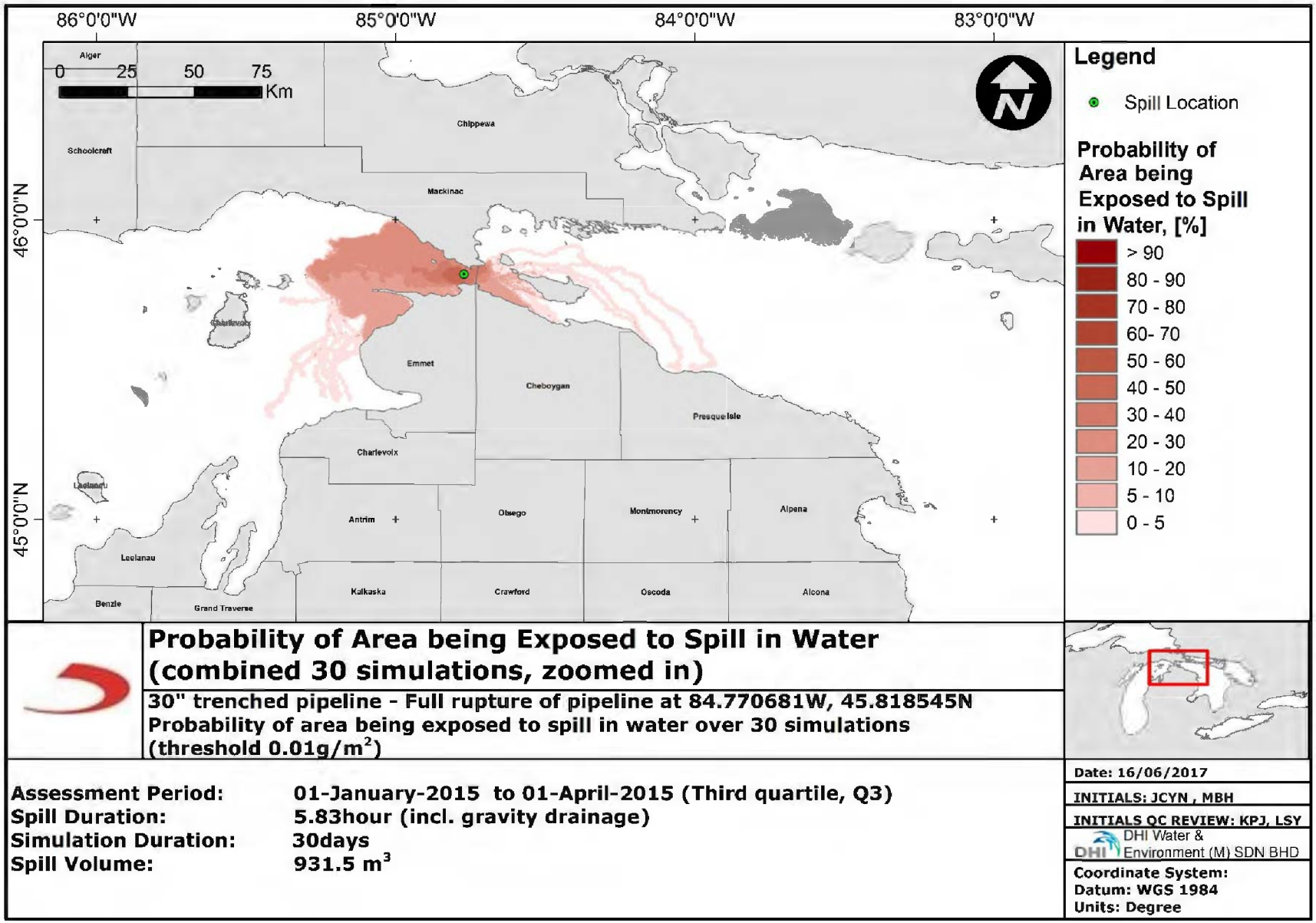


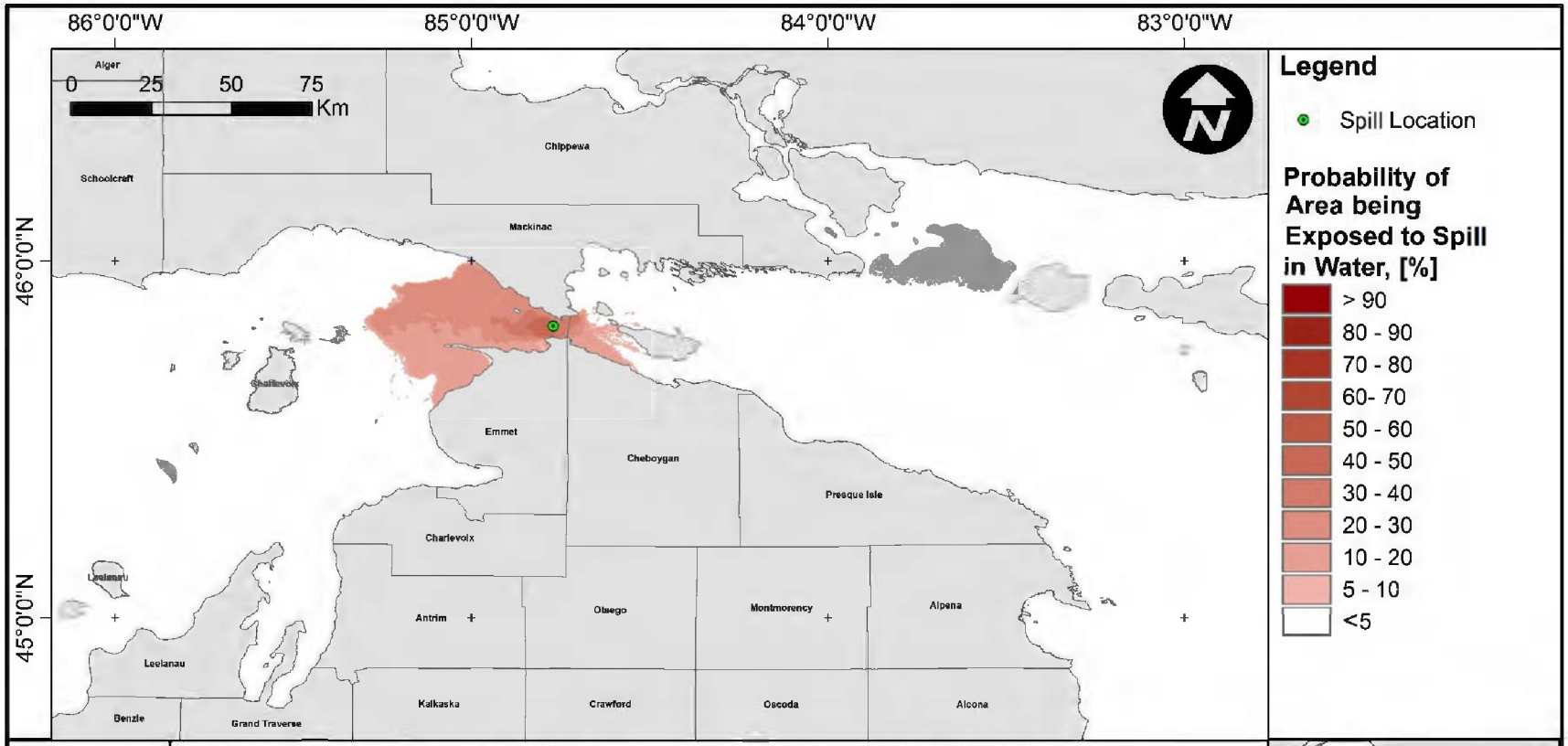
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 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



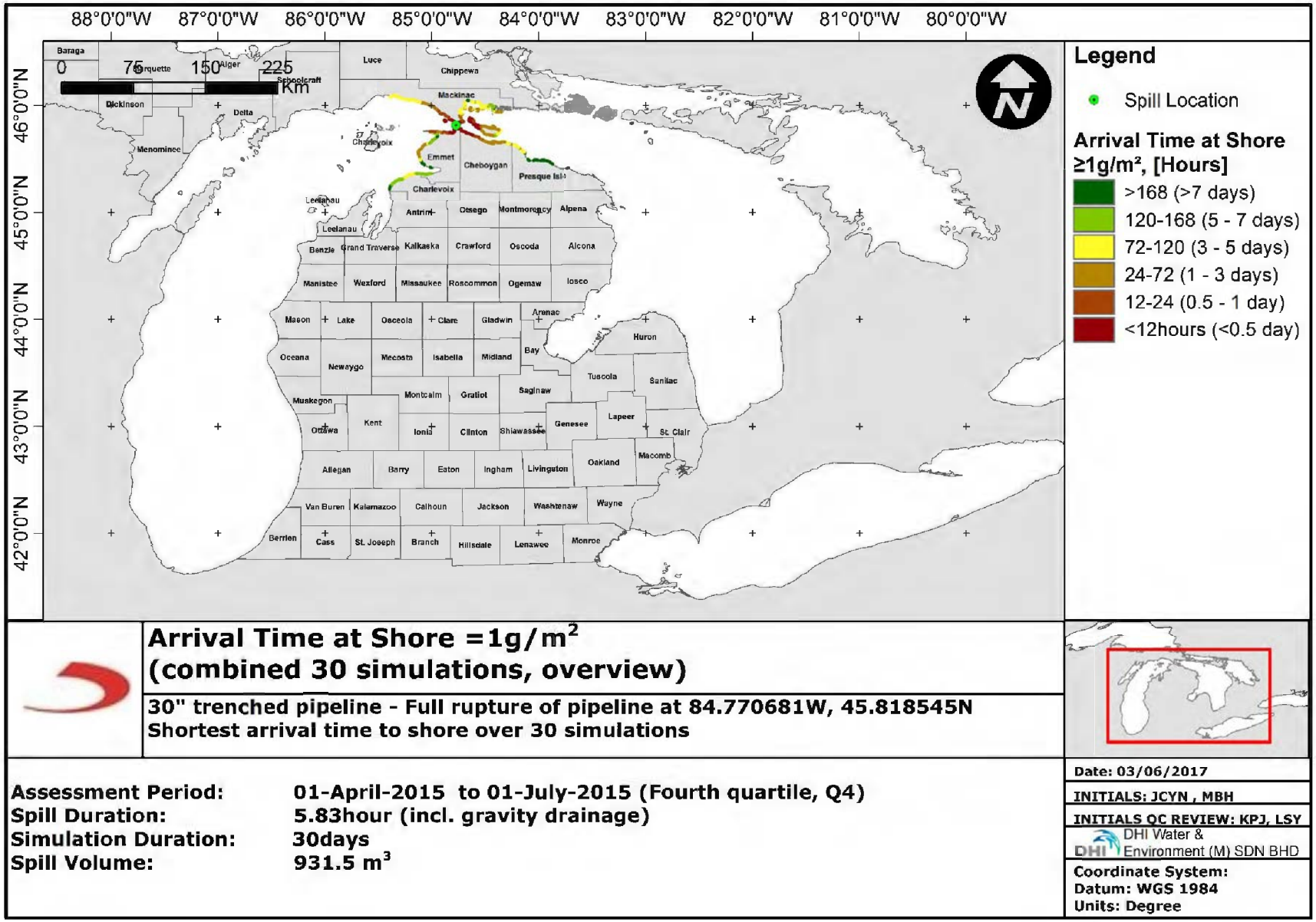
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

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

Q4

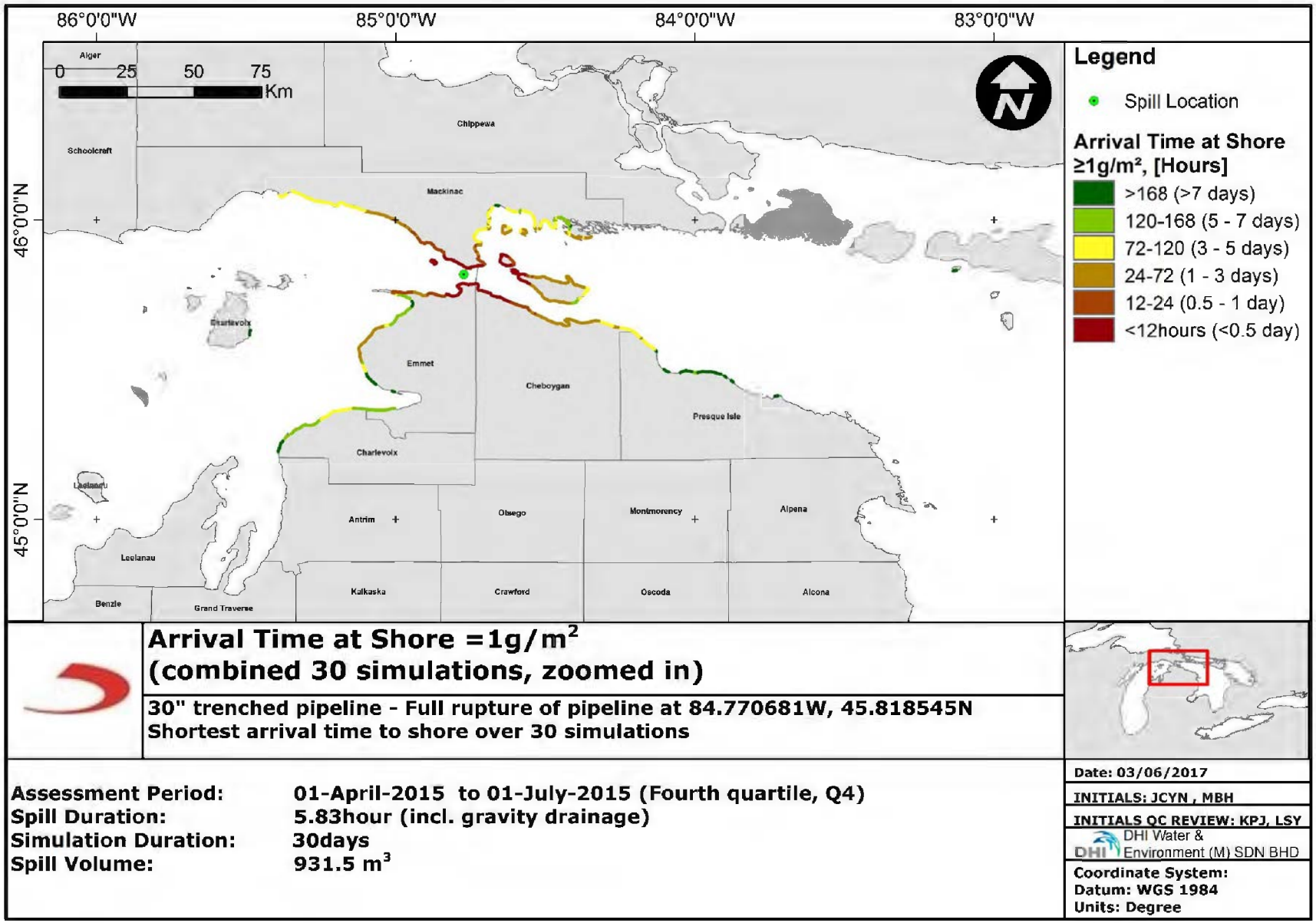


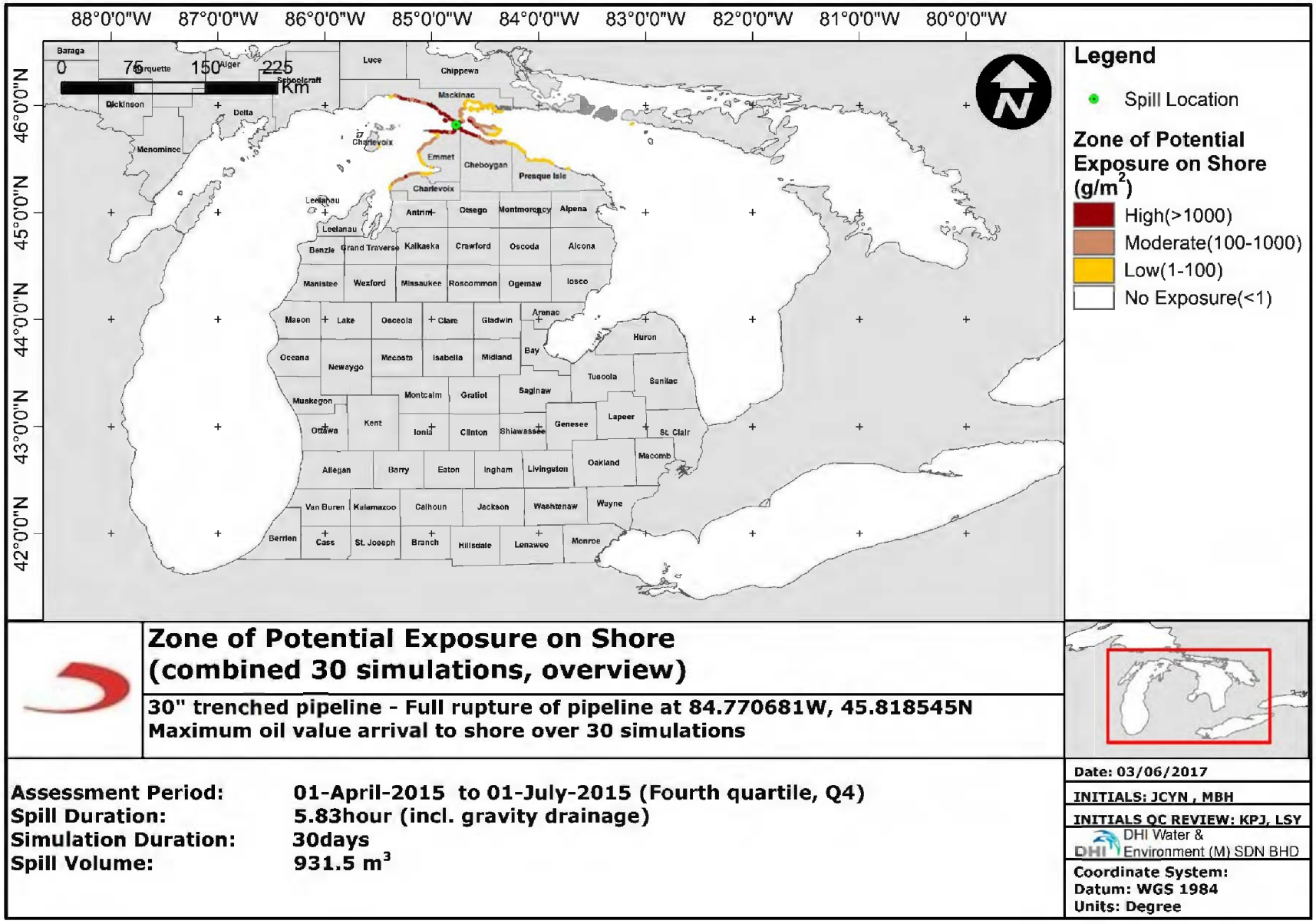
Arrival Time at Shore =1g/m² (combined 30 simulations, overview)

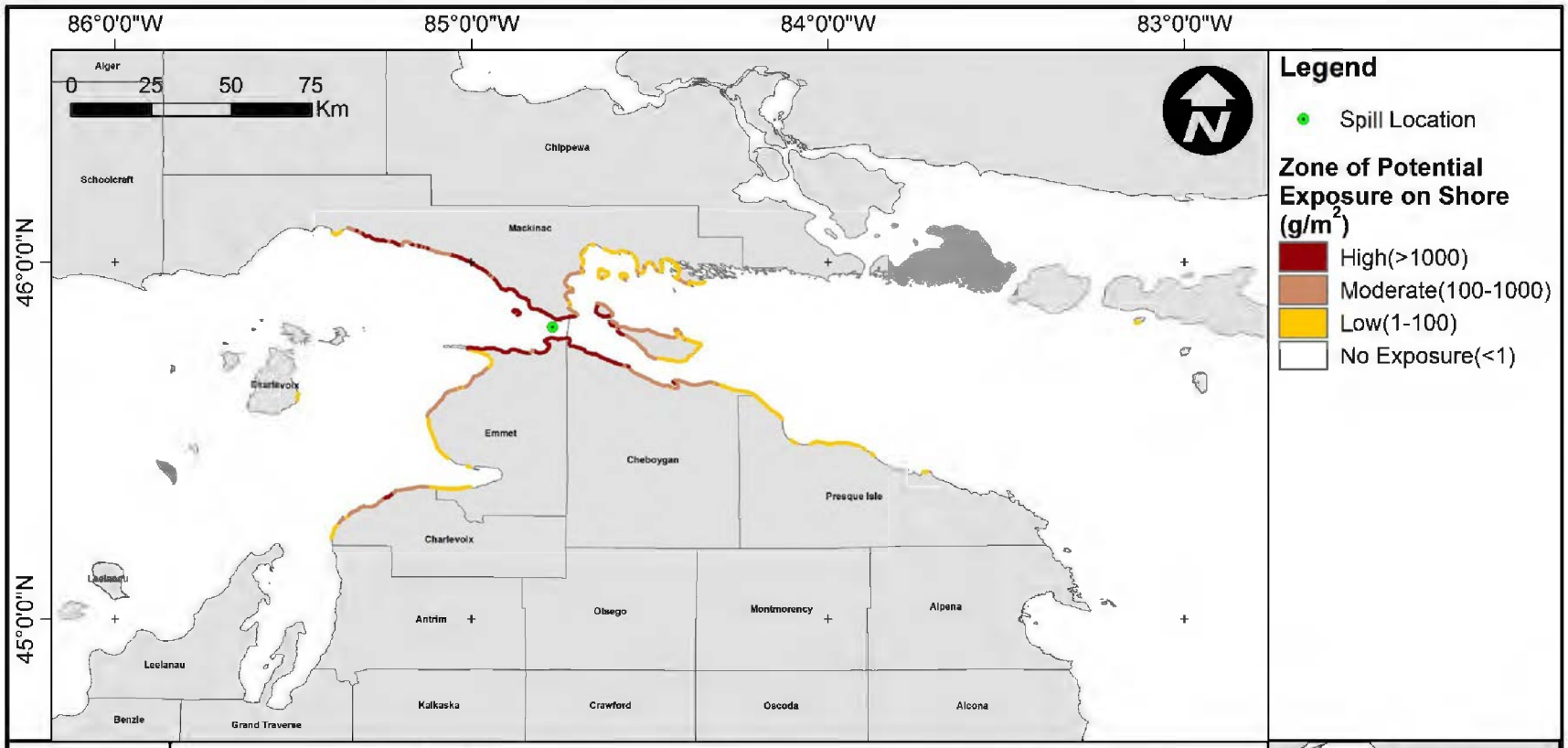
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
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45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
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Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
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12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
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46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, overview)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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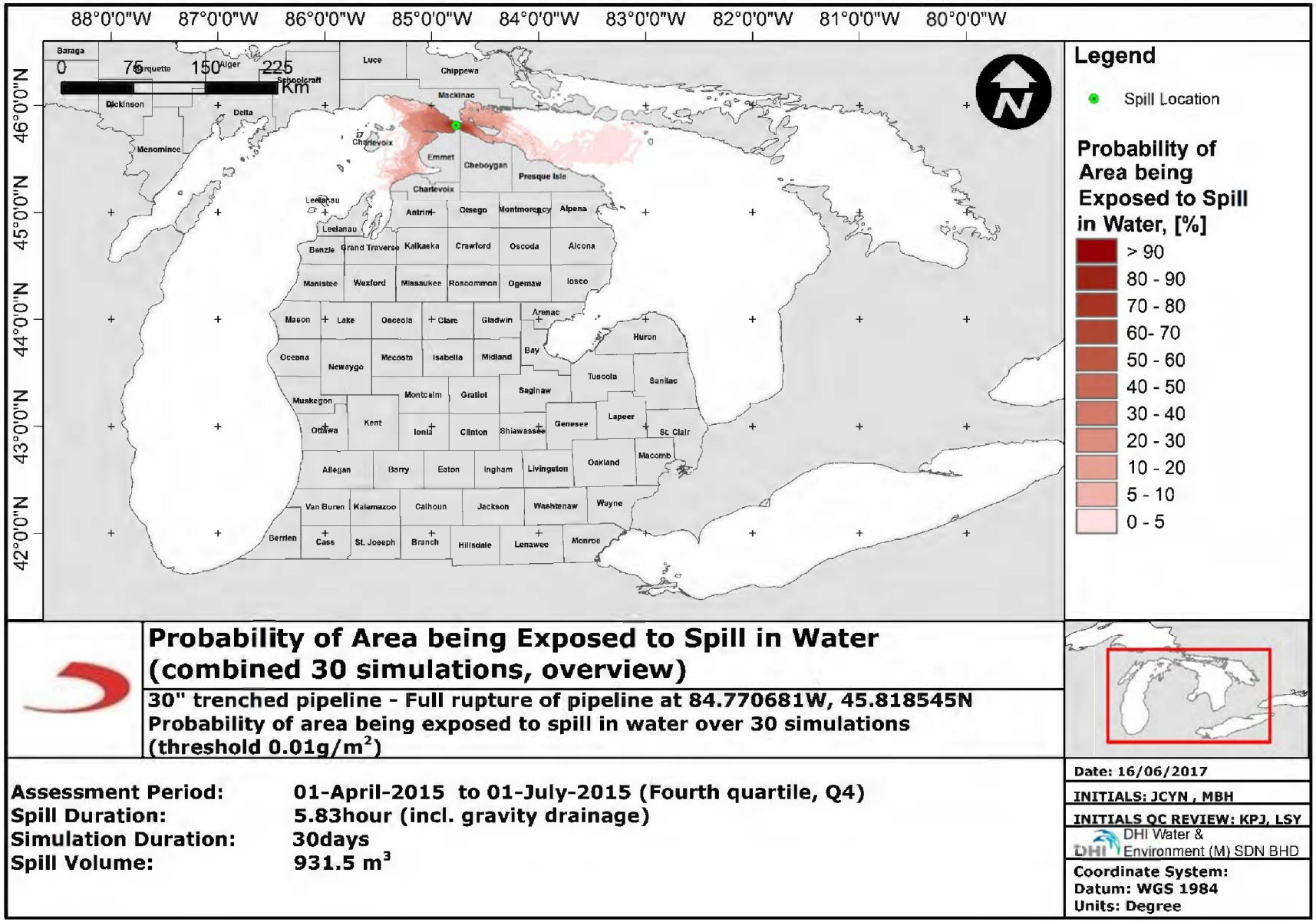


Zone of Potential Exposure on Shore (combined 30 simulations, zoomed in)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
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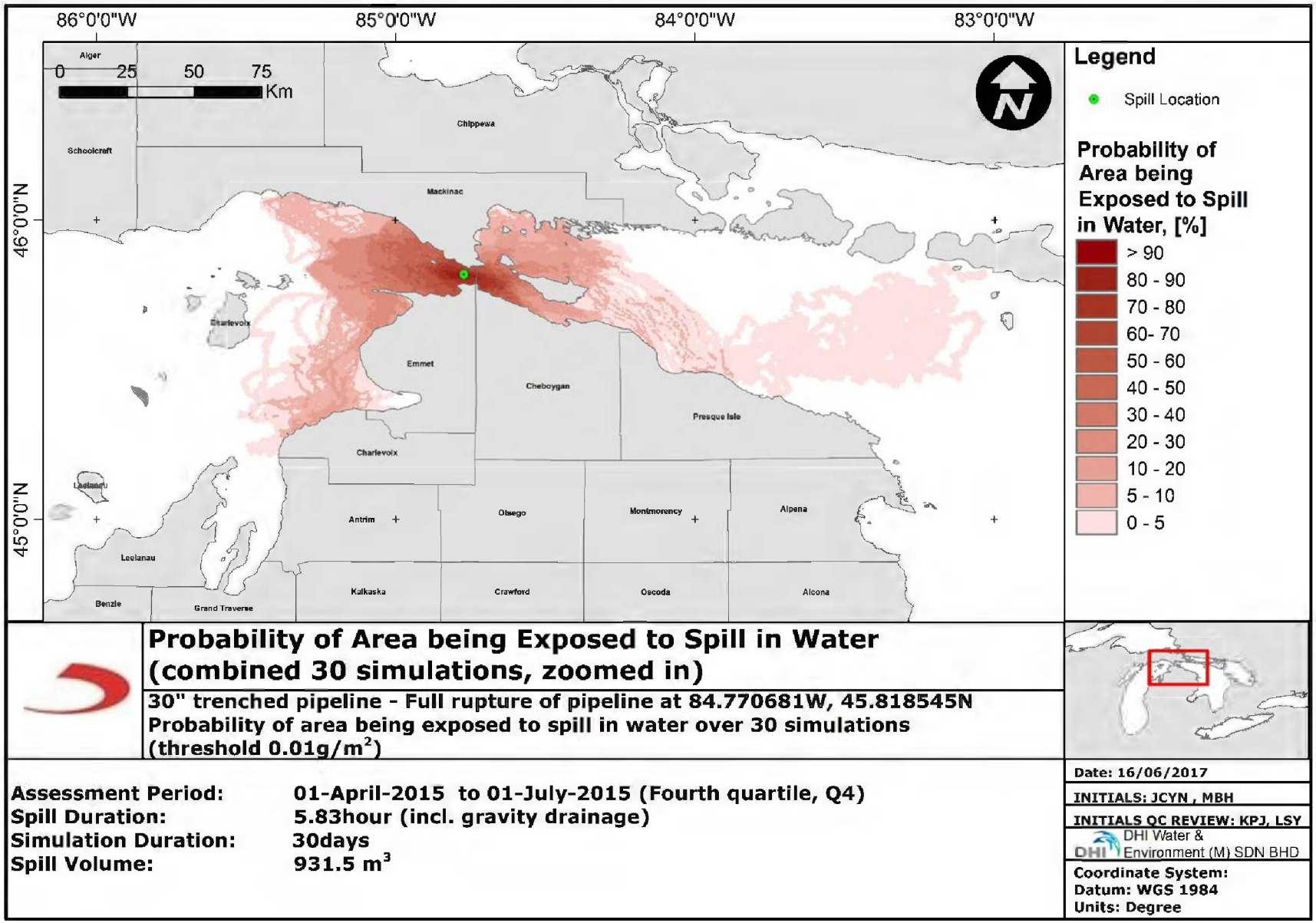


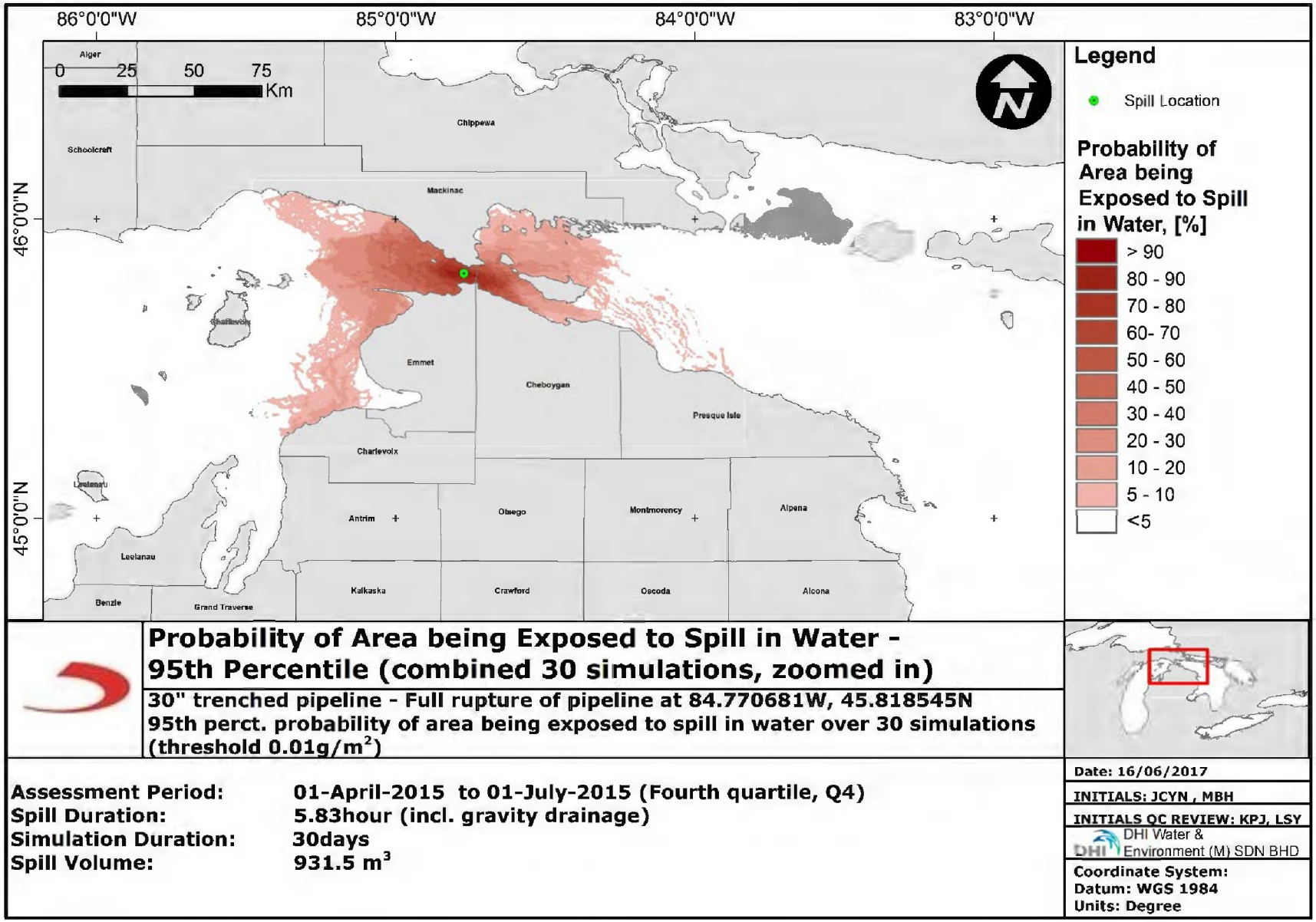
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
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0 25 50 75
Km
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Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
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40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 5.83hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 931.5 m³
Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
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Coordinate System:
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Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

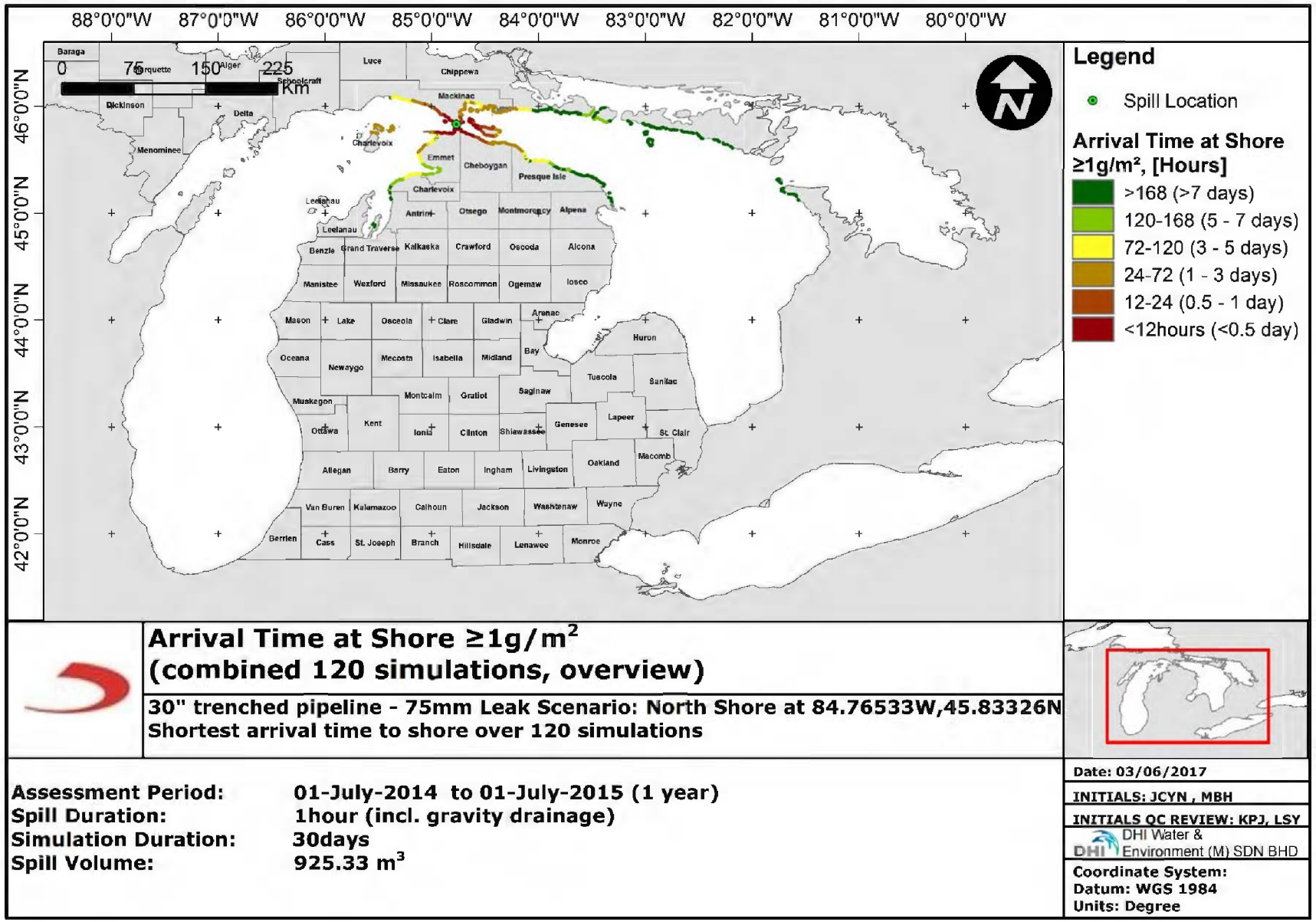
30" trenched pipeline - Full rupture of pipeline at 84.770681W, 45.818545N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**5.83hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**931.5 m^3**

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

Set 2
30” Trenched Pipeline – 75 mm Leak at Northern Shore

1 year

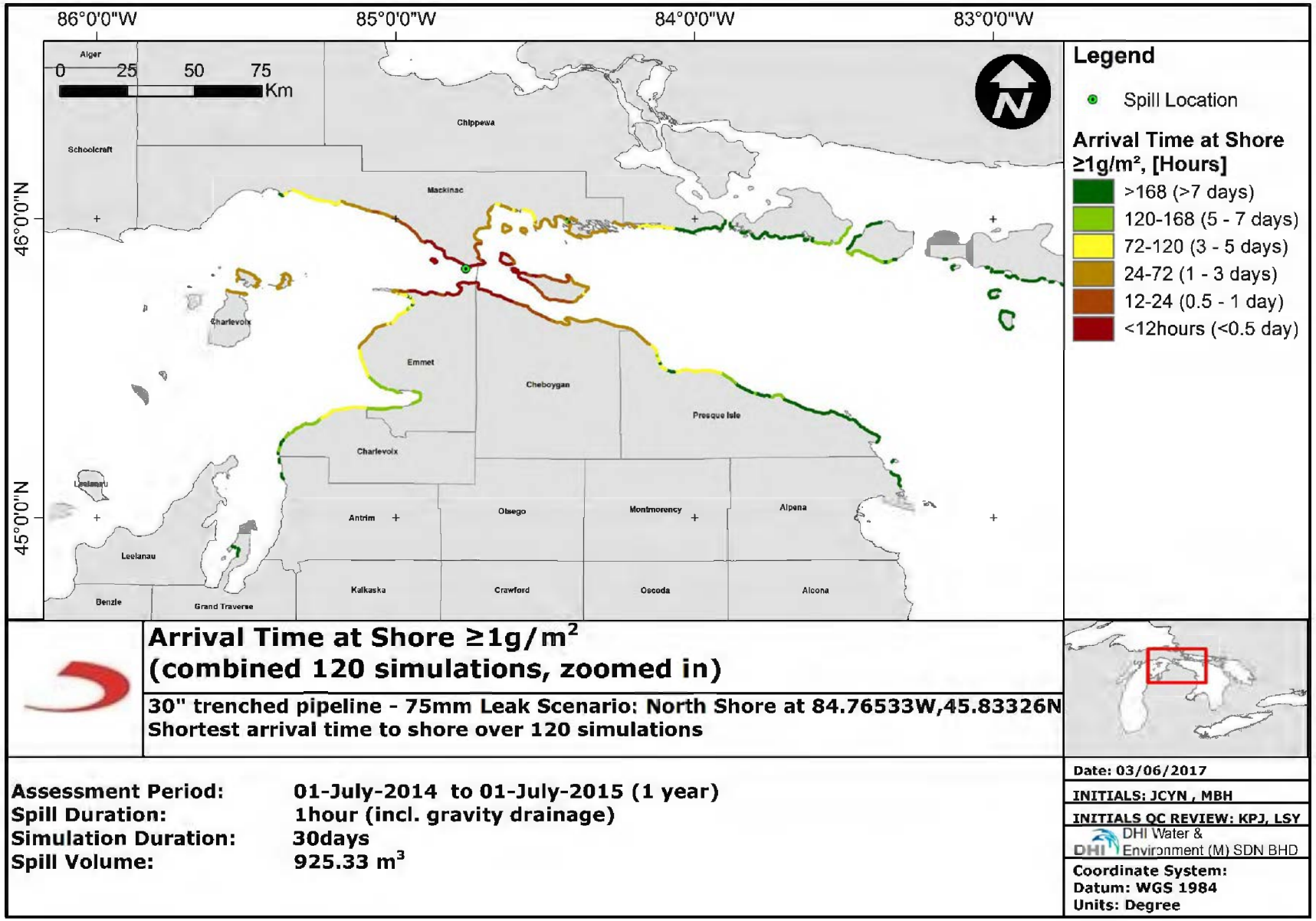


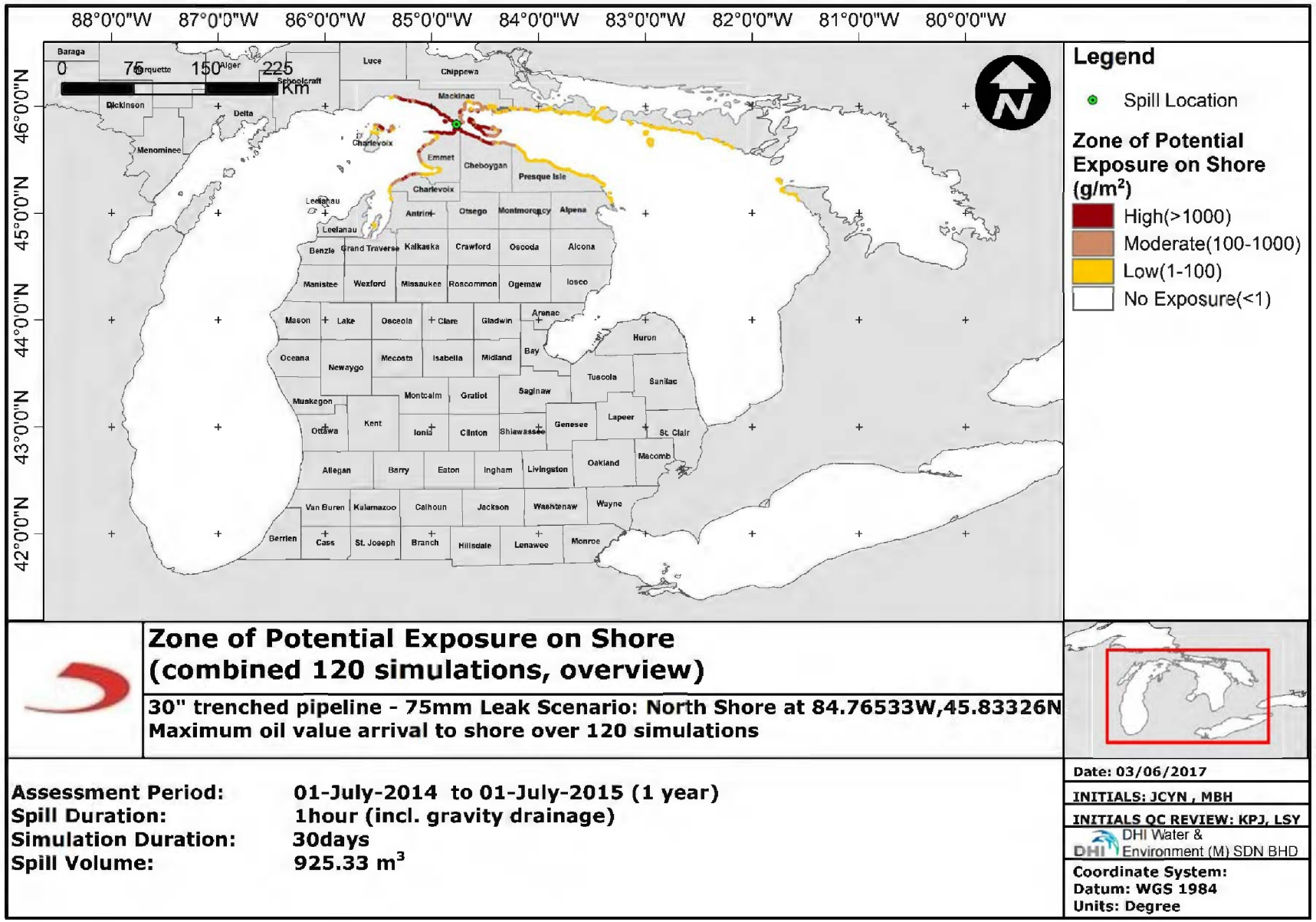
Arrival Time at Shore ≥1g/m² (combined 120 simulations, overview)

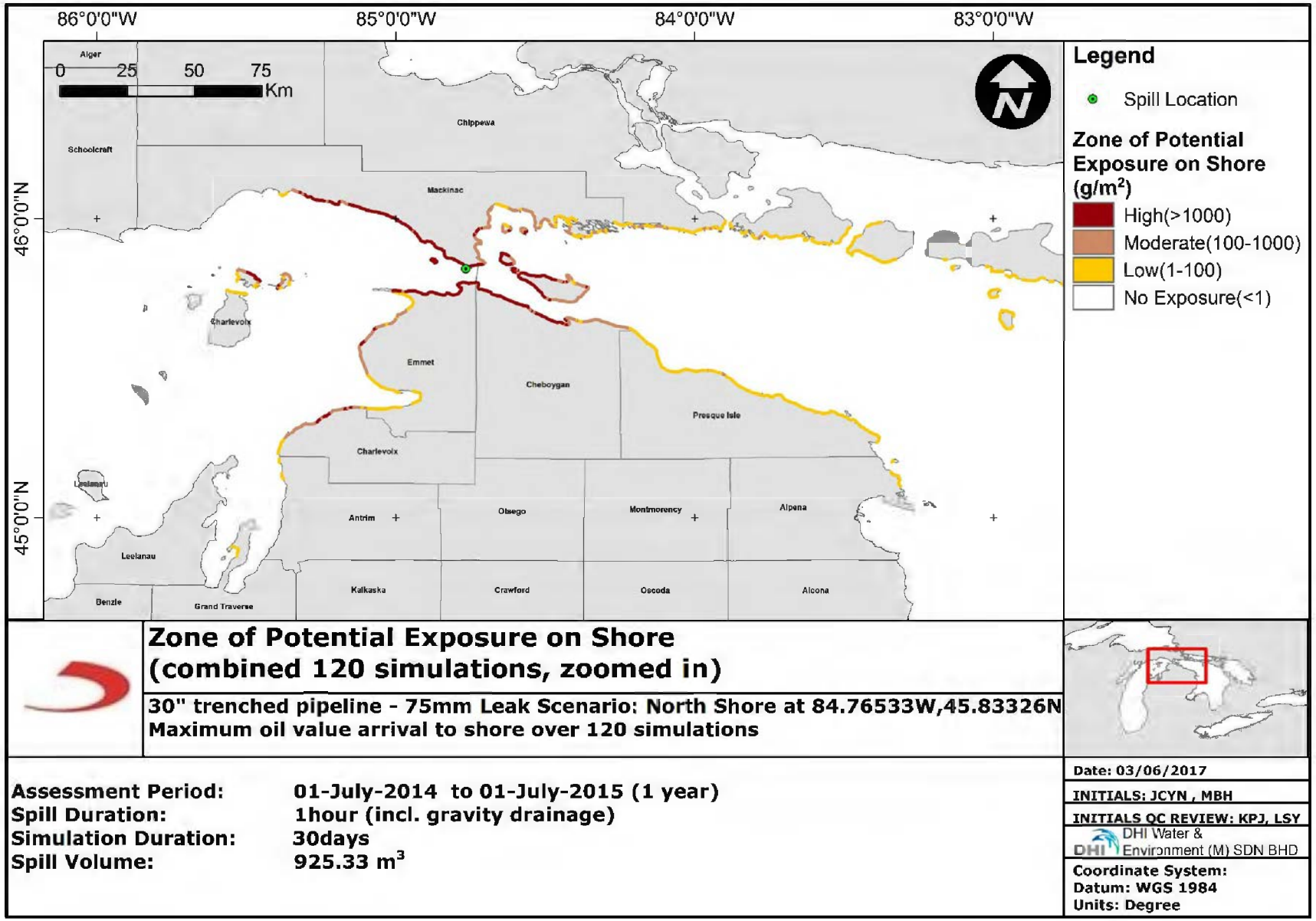
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Shortest arrival time to shore over 120 simulations

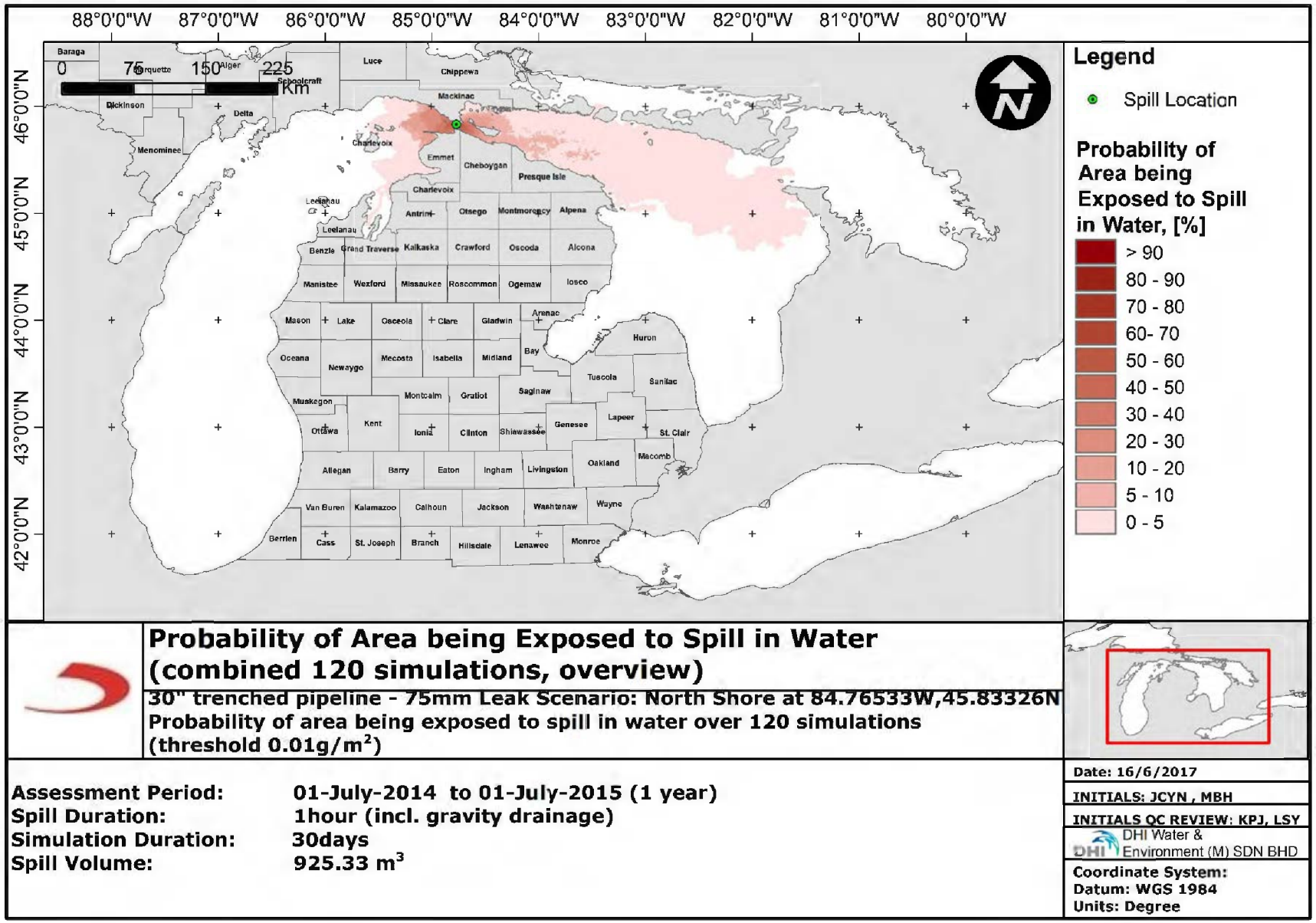
Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
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Mackinac
Charlevoix
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Otsego
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Alpena
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Grand Traverse
Kalkaska
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Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 120 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Shortest arrival time to shore over 120 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
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46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 120 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Maximum oil value arrival to shore over 120 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
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86°0'0"W
85°0'0"W
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0 25 50 75
Km
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(combined 120 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Maximum oil value arrival to shore over 120 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
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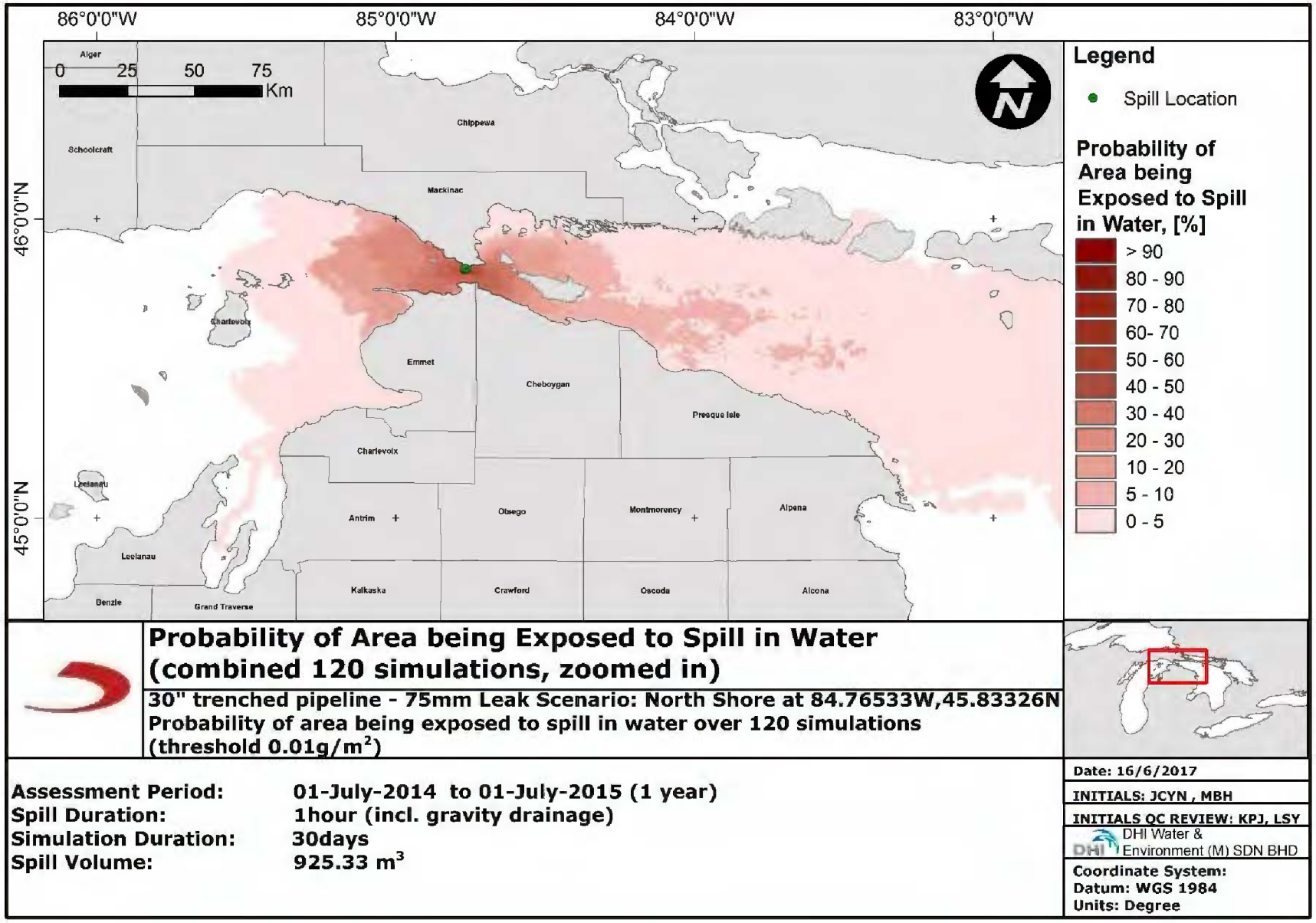


Probability of Area being Exposed to Spill in Water (combined 120 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
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)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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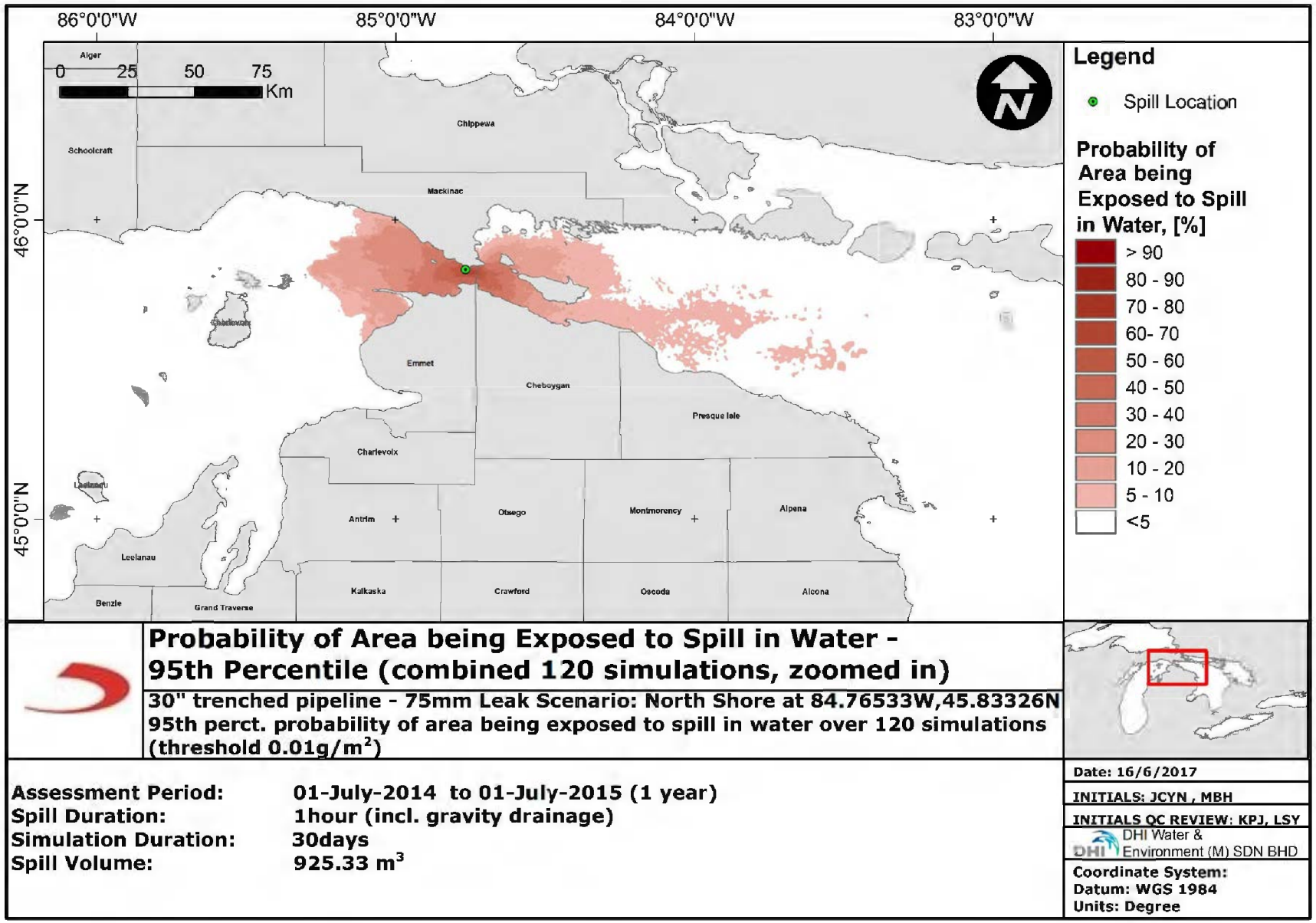


Probability of Area being Exposed to Spill in Water (combined 120 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
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)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
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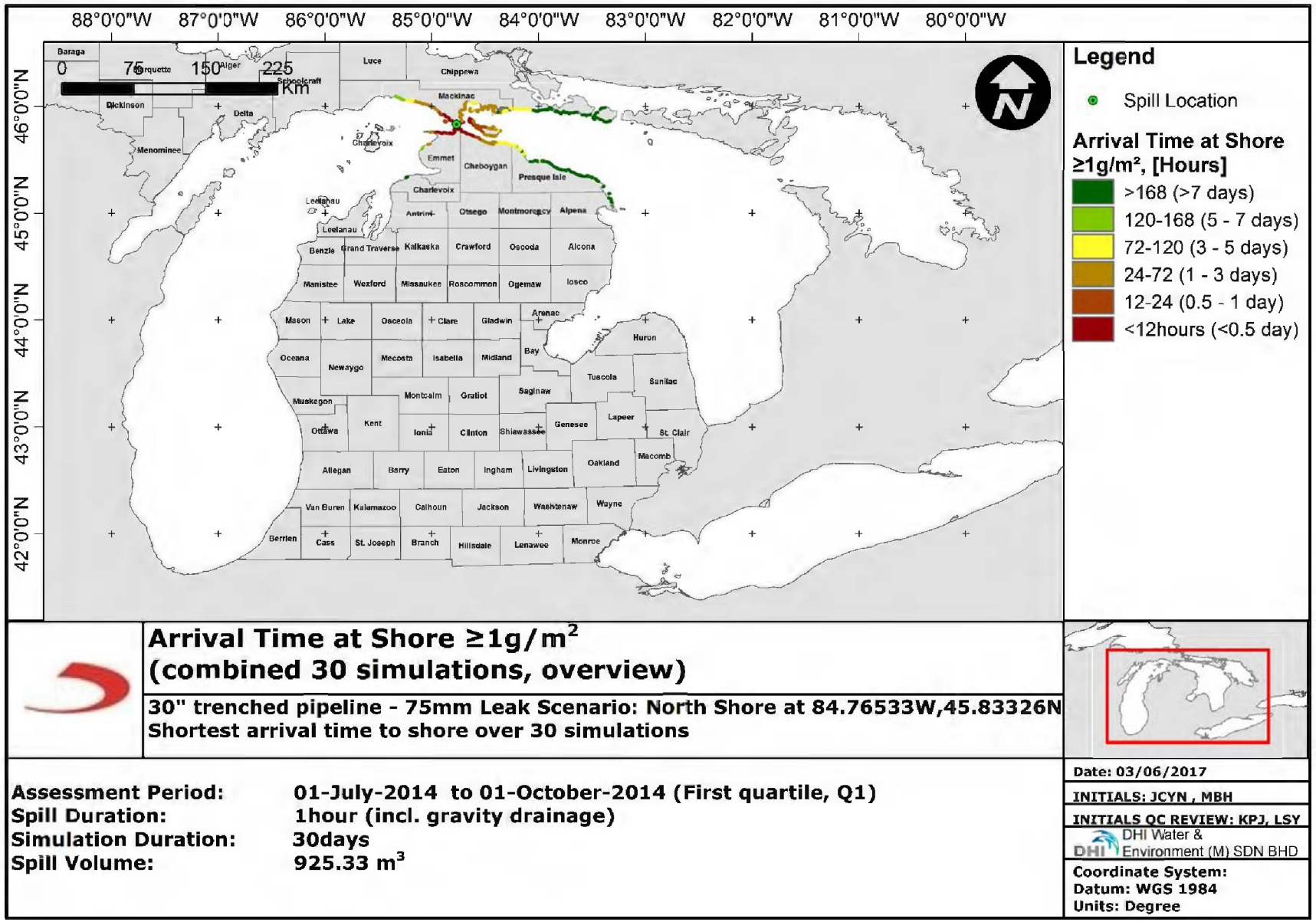
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 120 simulations, zoomed in)

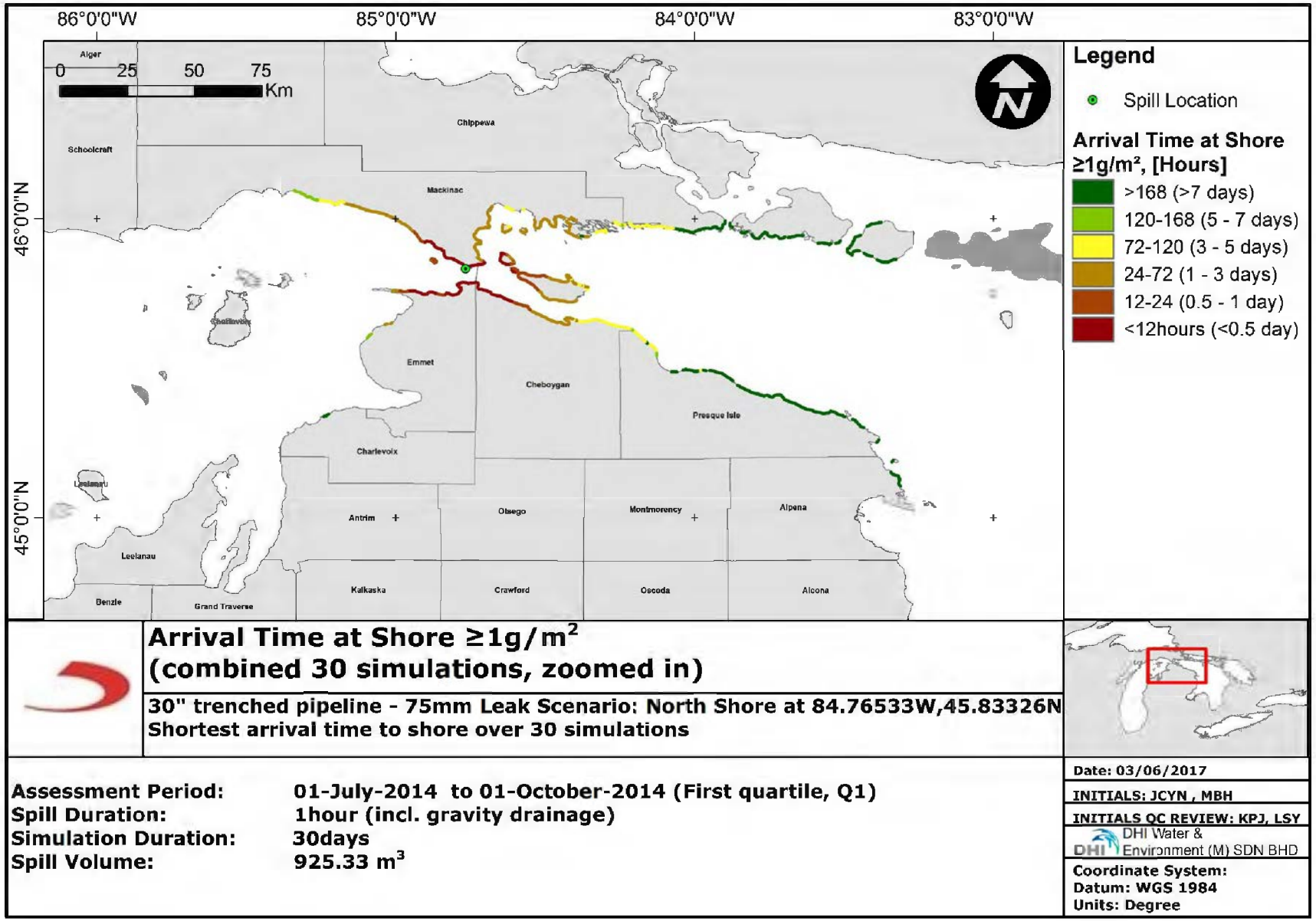
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
95th perct. probability of area being exposed to spill in water over 120 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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Units: Degree

Q1


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
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>168 (>7 days)
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72-120 (3 - 5 days)
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<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 30 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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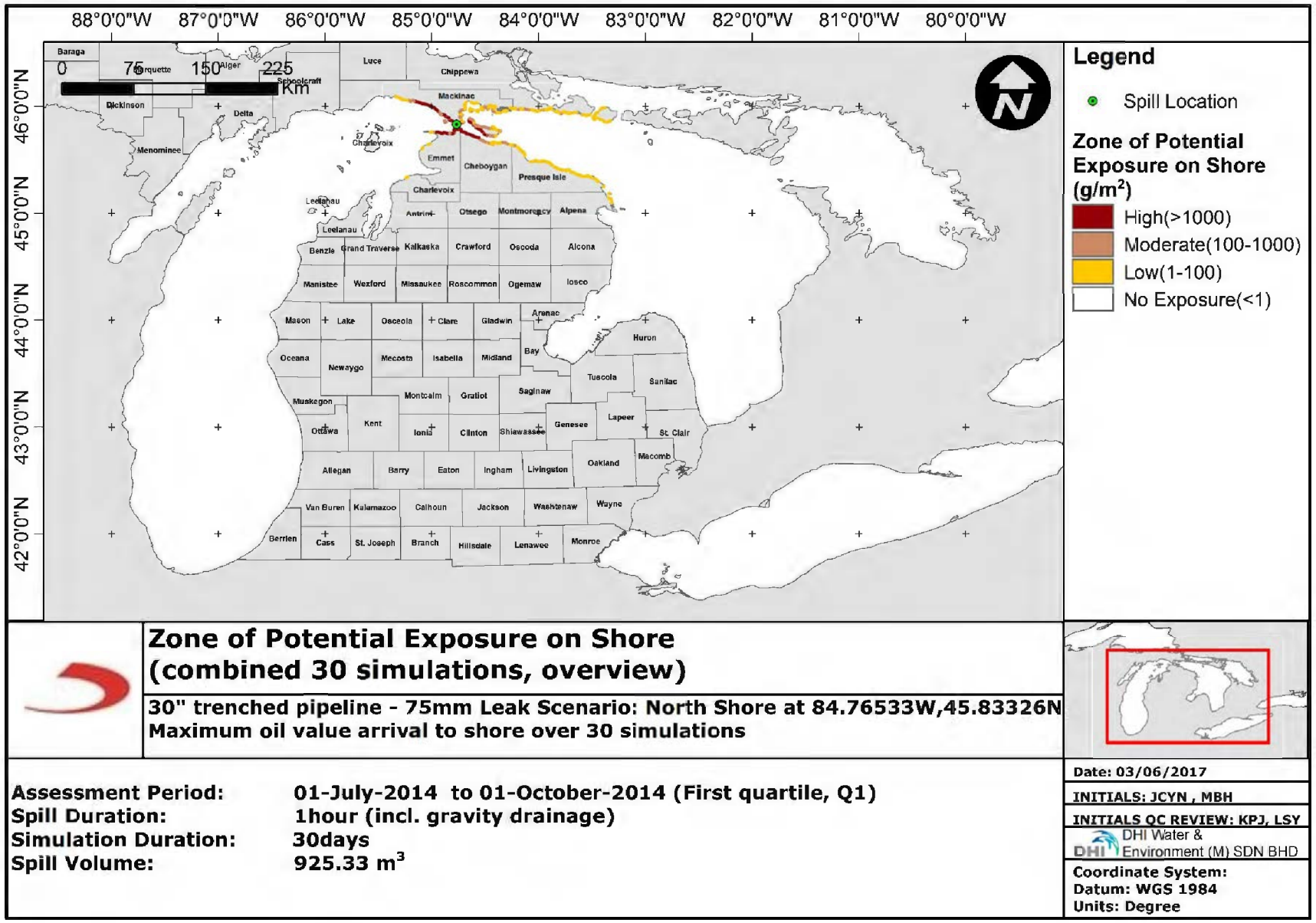


Arrival Time at Shore ≥1g/m² (combined 30 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
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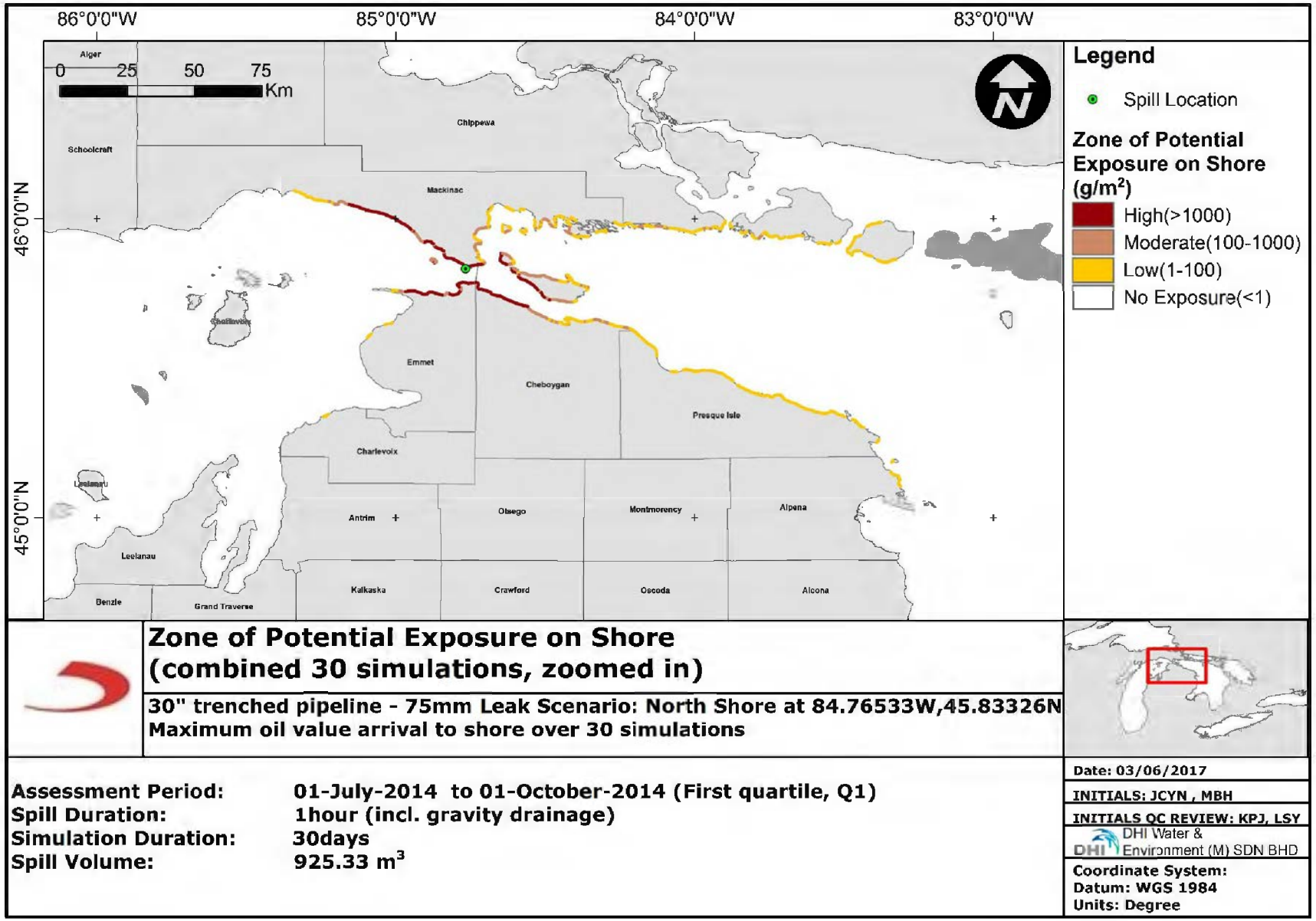


Zone of Potential Exposure on Shore (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
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Datum: WGS 1984
Units: Degree

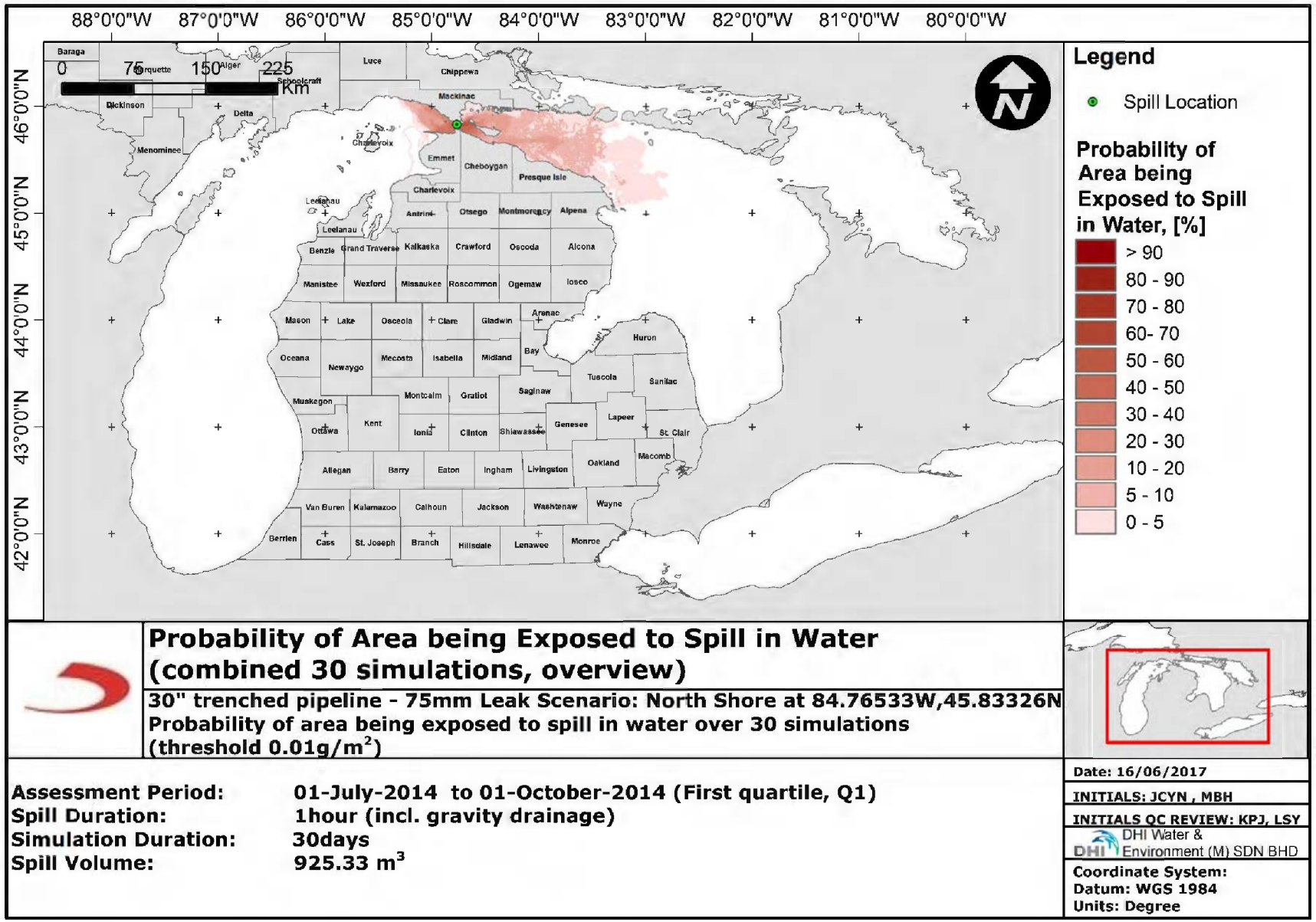


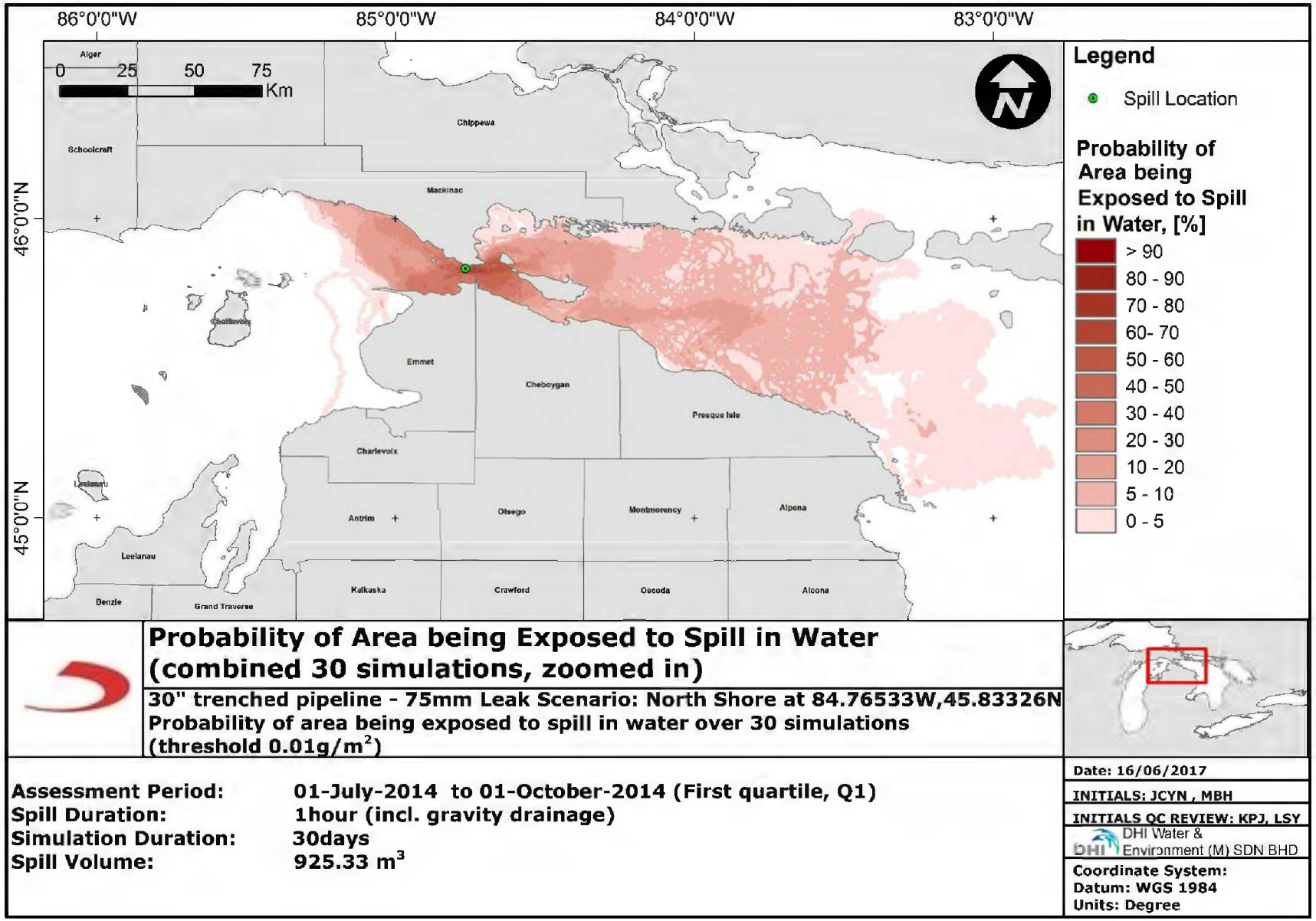
Zone of Potential Exposure on Shore (combined 30 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 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

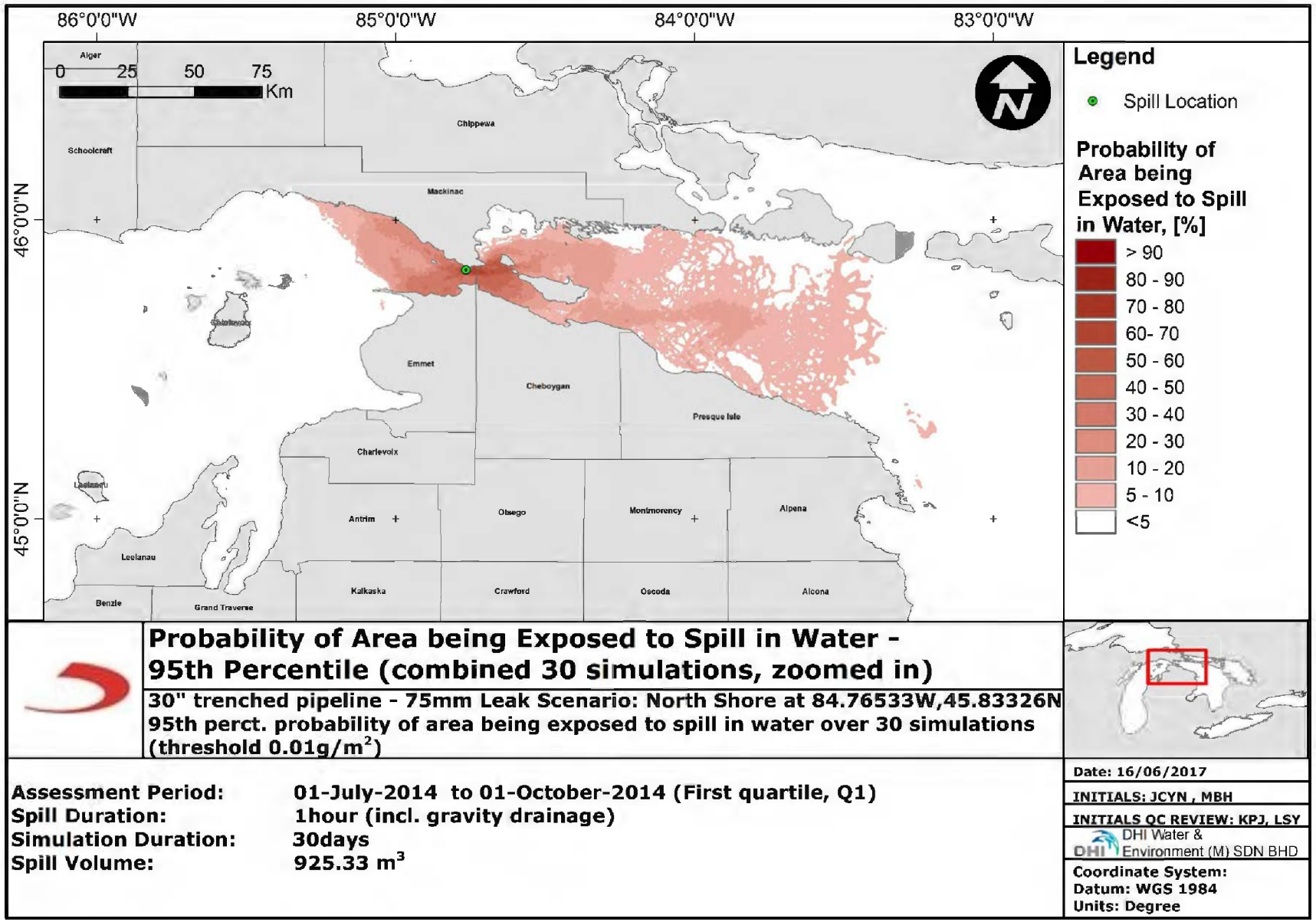


Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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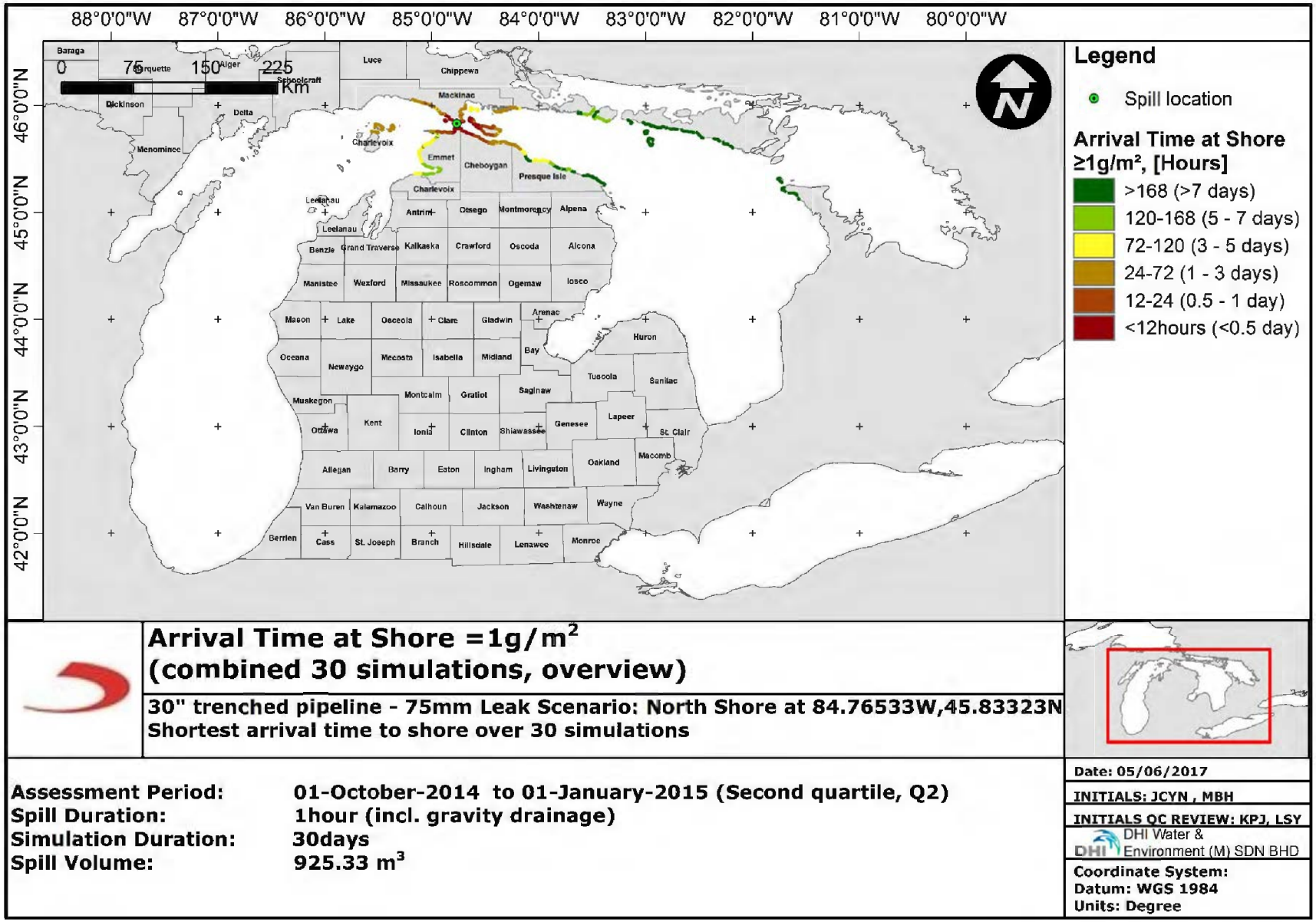
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

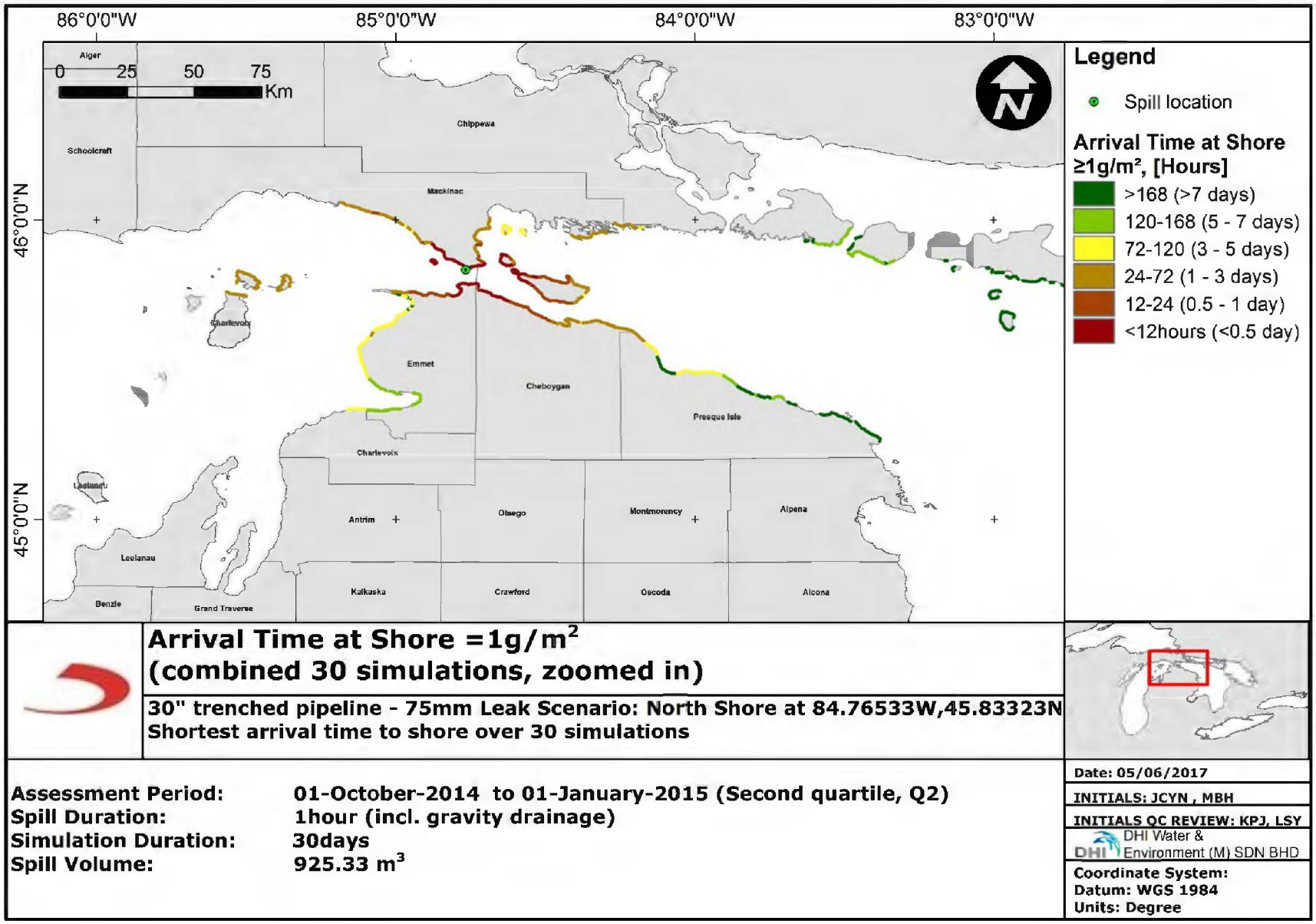
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

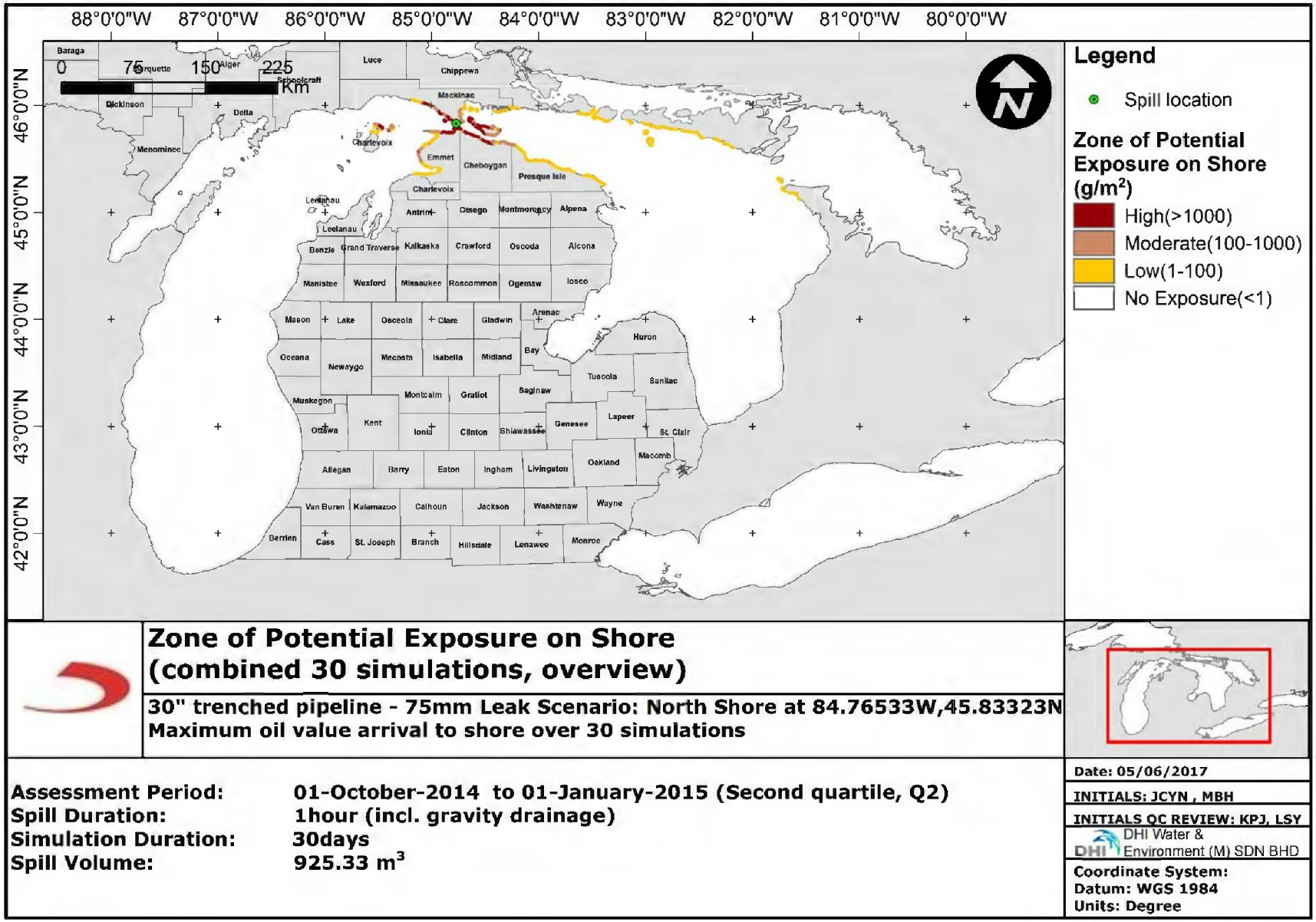
Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

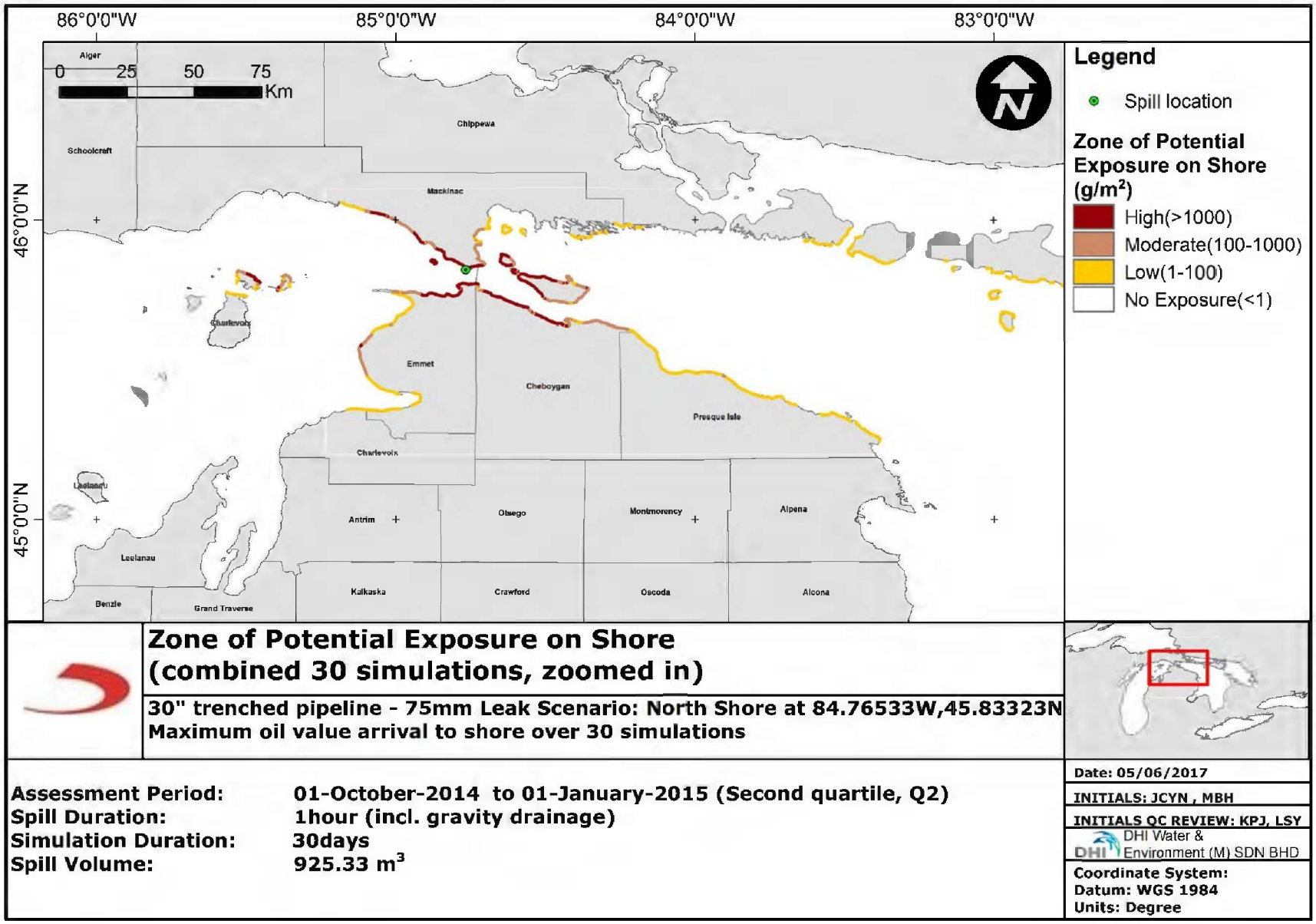
Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

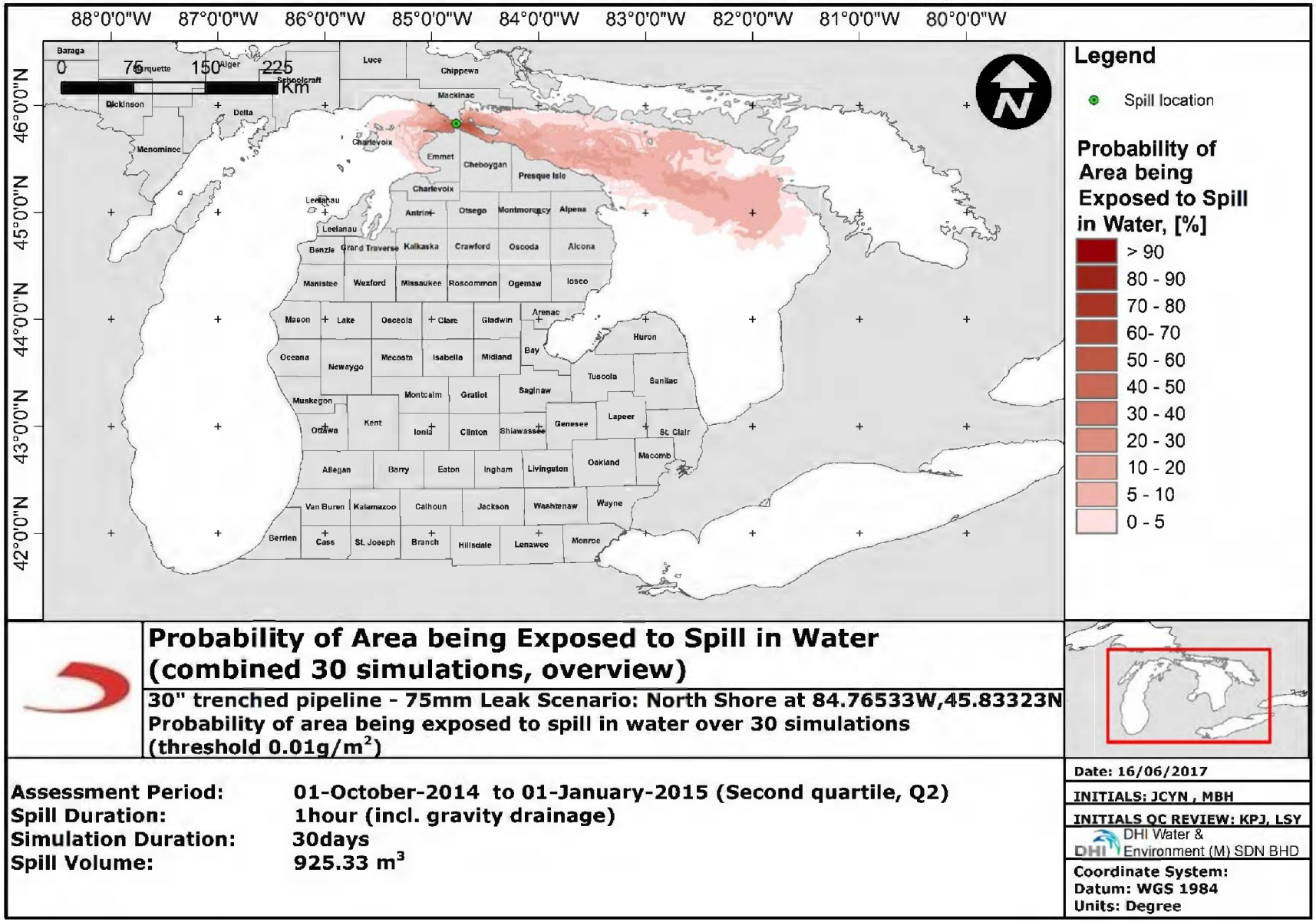
Q2

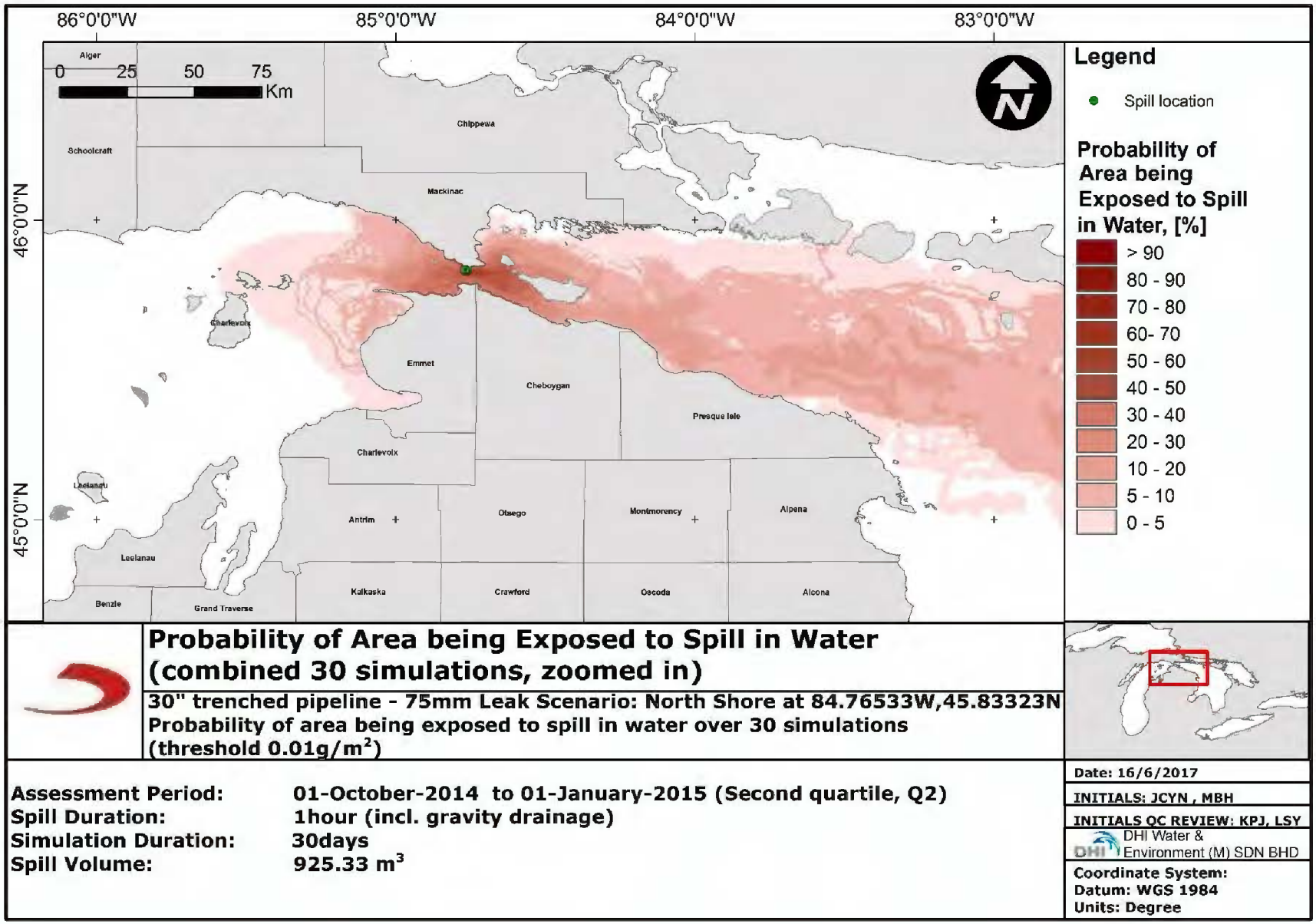

88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83323N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83323N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


88°0'0"W
87°0'0"W
86°0'0"W
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84°0'0"W
83°0'0"W
82°0'0"W
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80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
km
Legend
Spill location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83323N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
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84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Antrim
Otsego
Montmorency
Alpena
Leelanau
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Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
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No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83323N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
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88°0'0"W
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45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83323N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 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

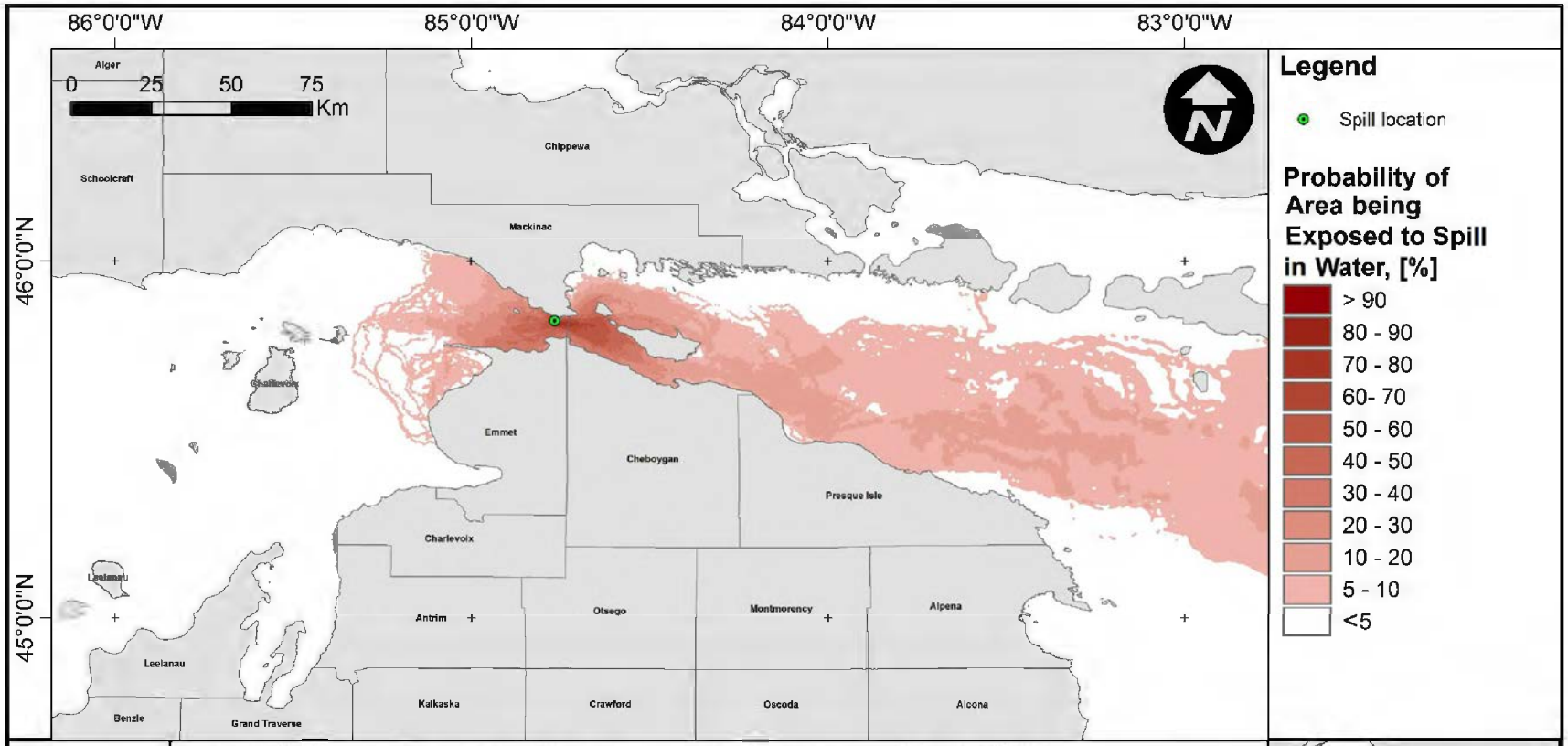


Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83323N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree



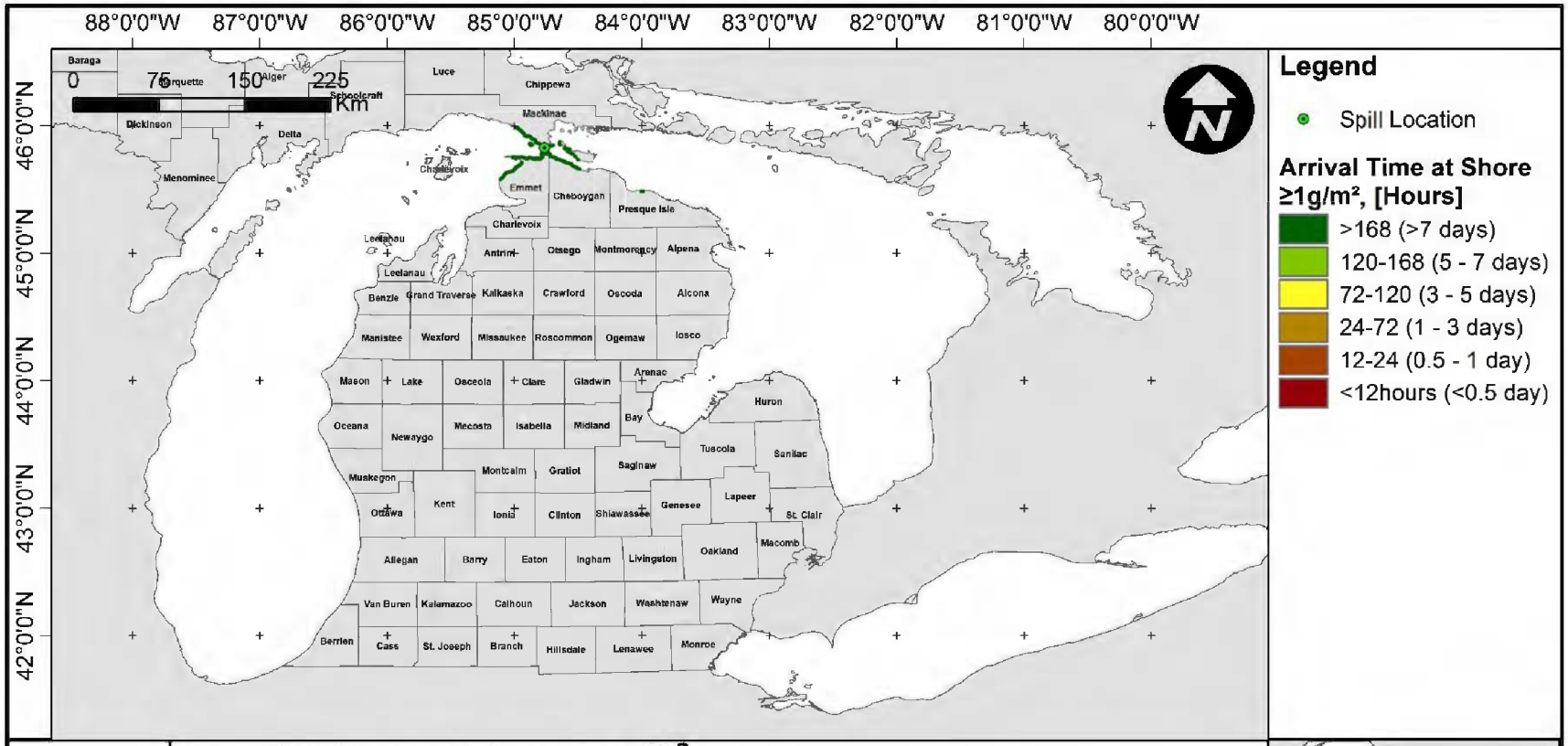
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83323N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

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

Q3

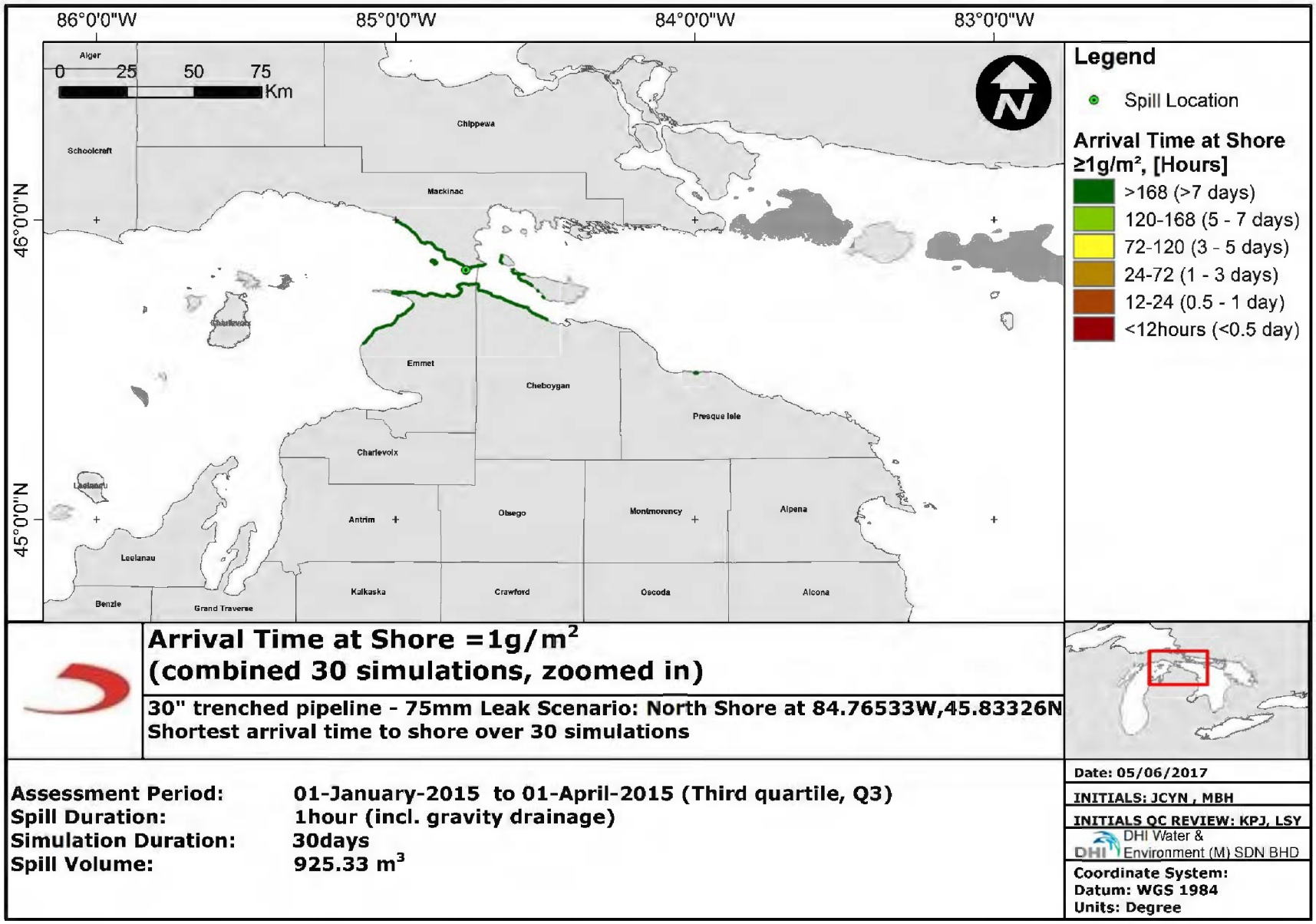


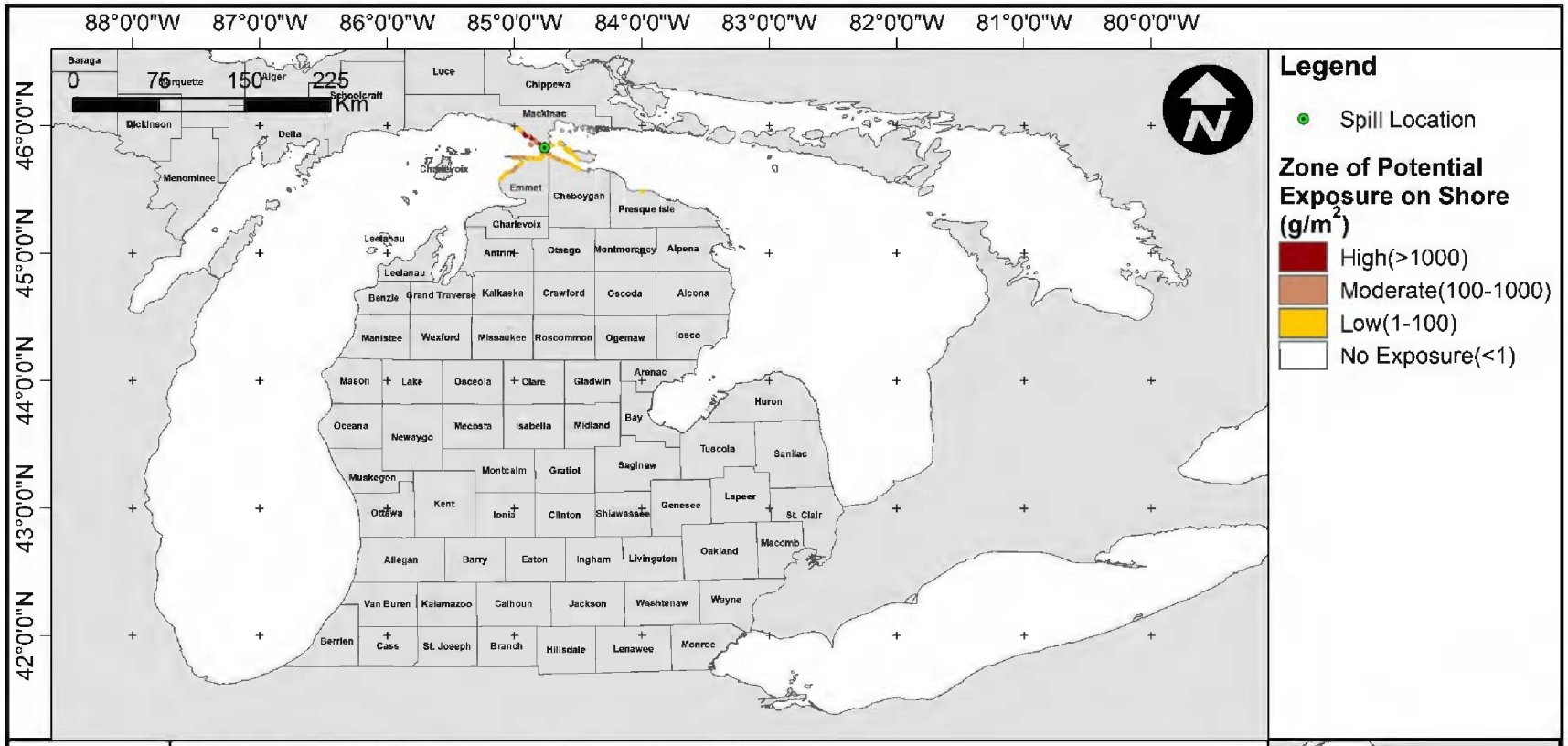
Arrival Time at Shore =1g/m^2 (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
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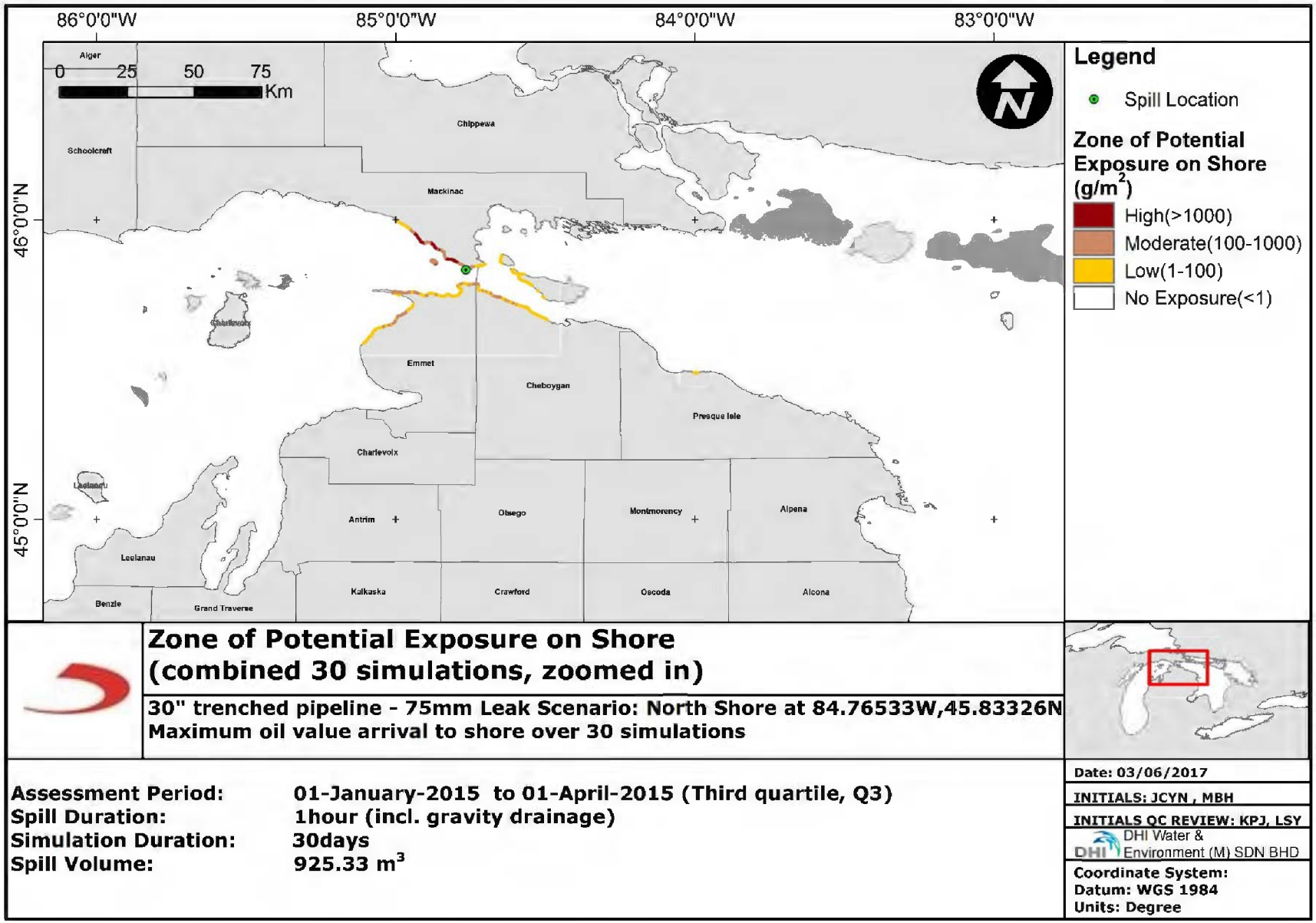


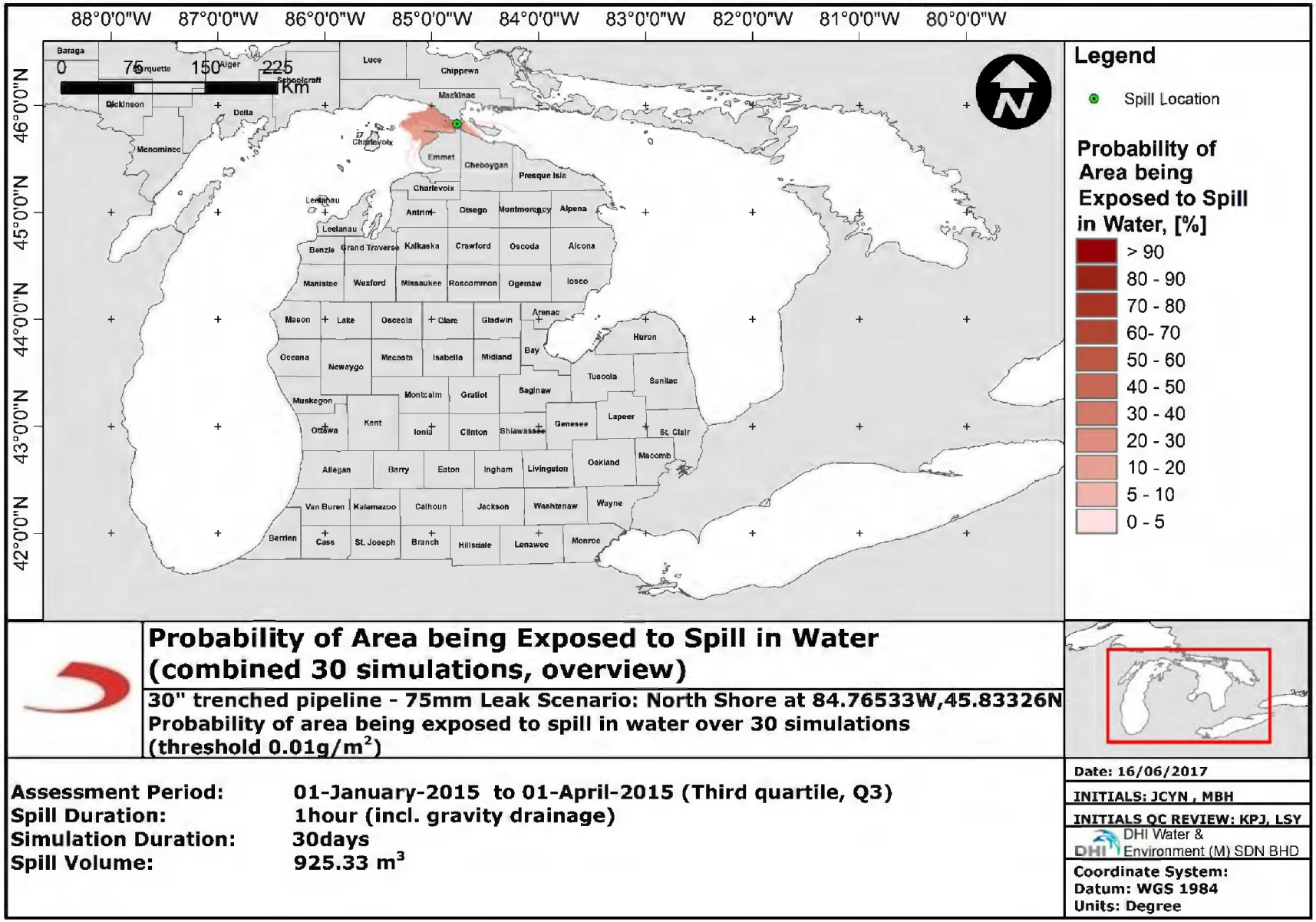
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
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Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

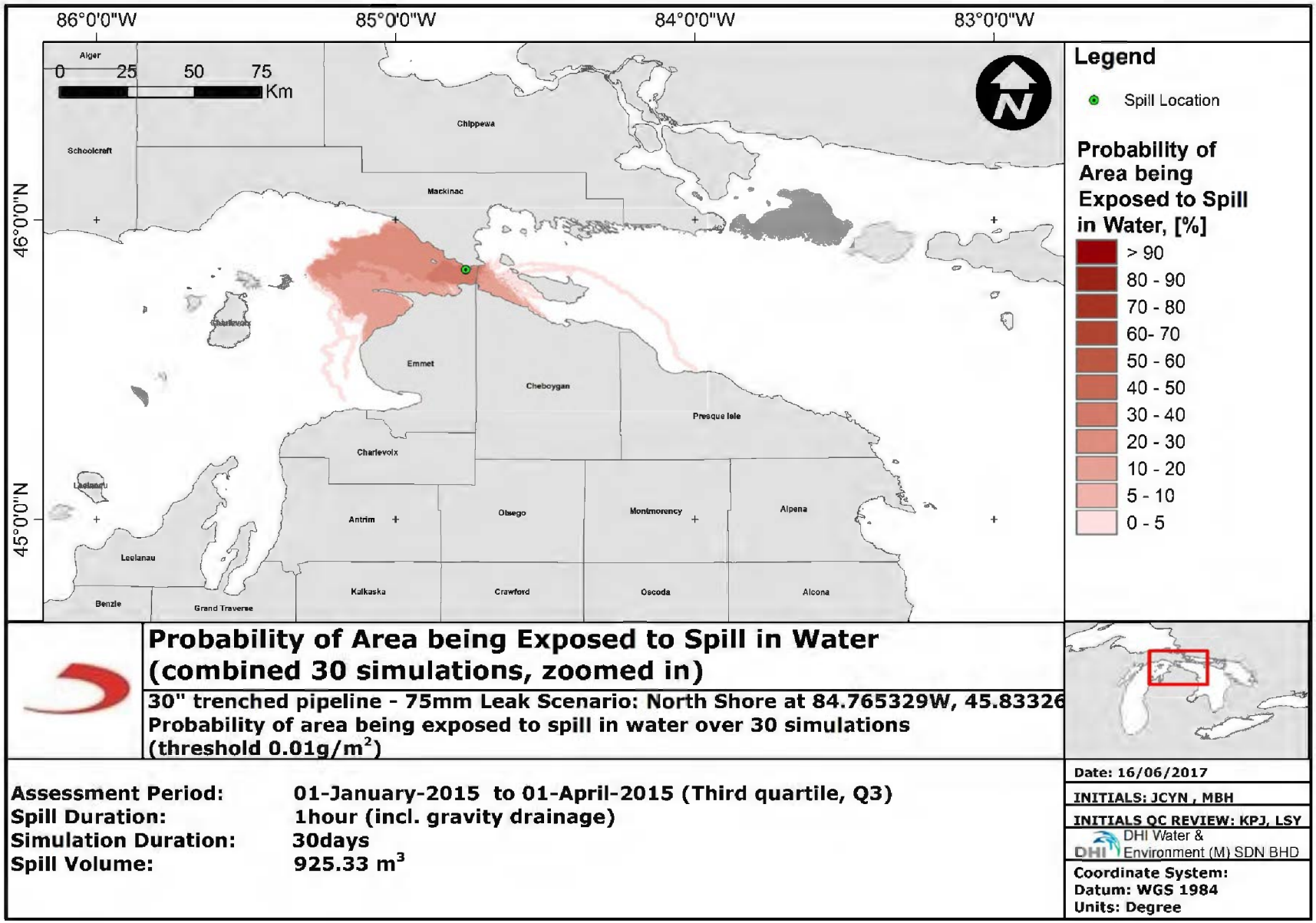


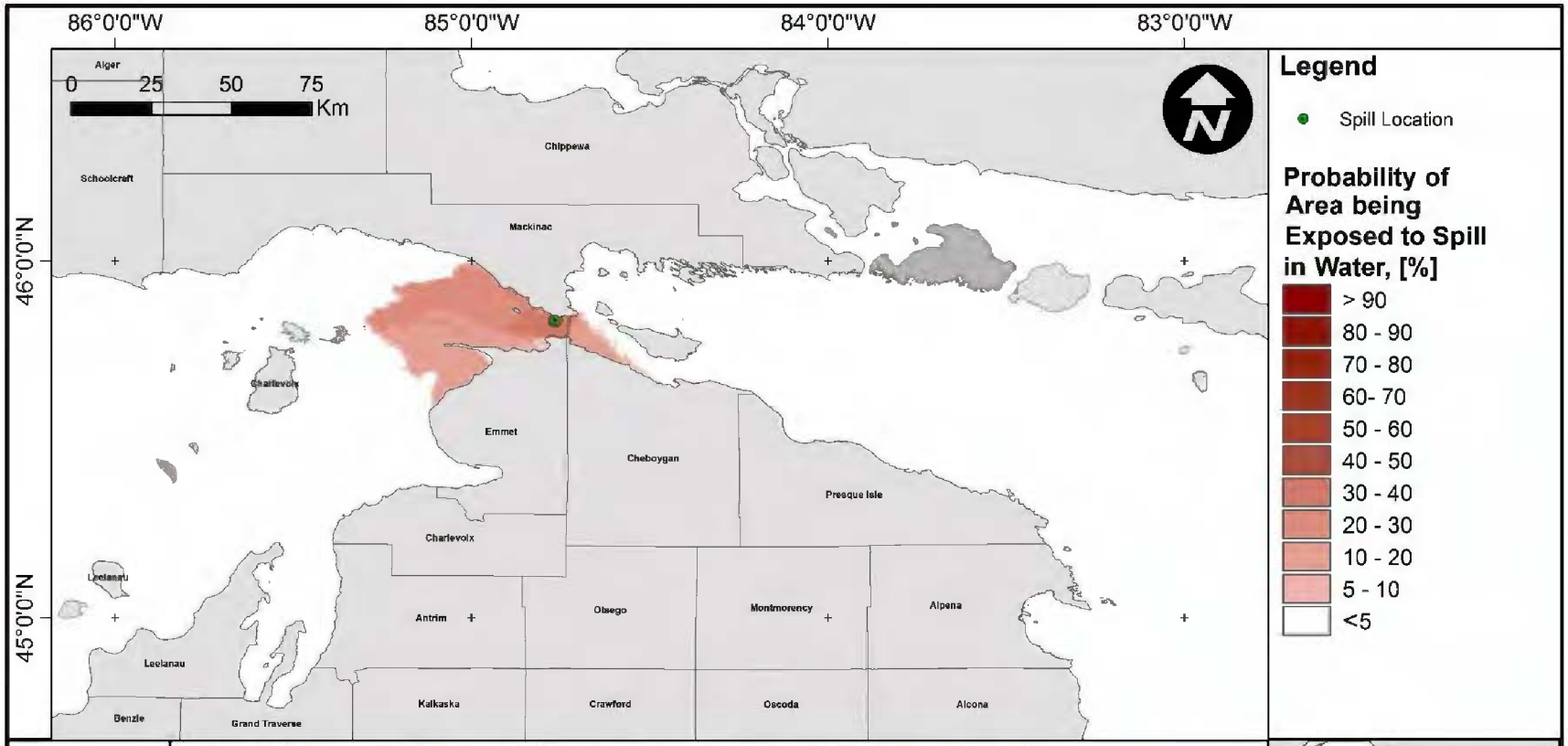
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
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Schoolcraft
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Mackinac
Charlevoix
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Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.765329W, 45.83326
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 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



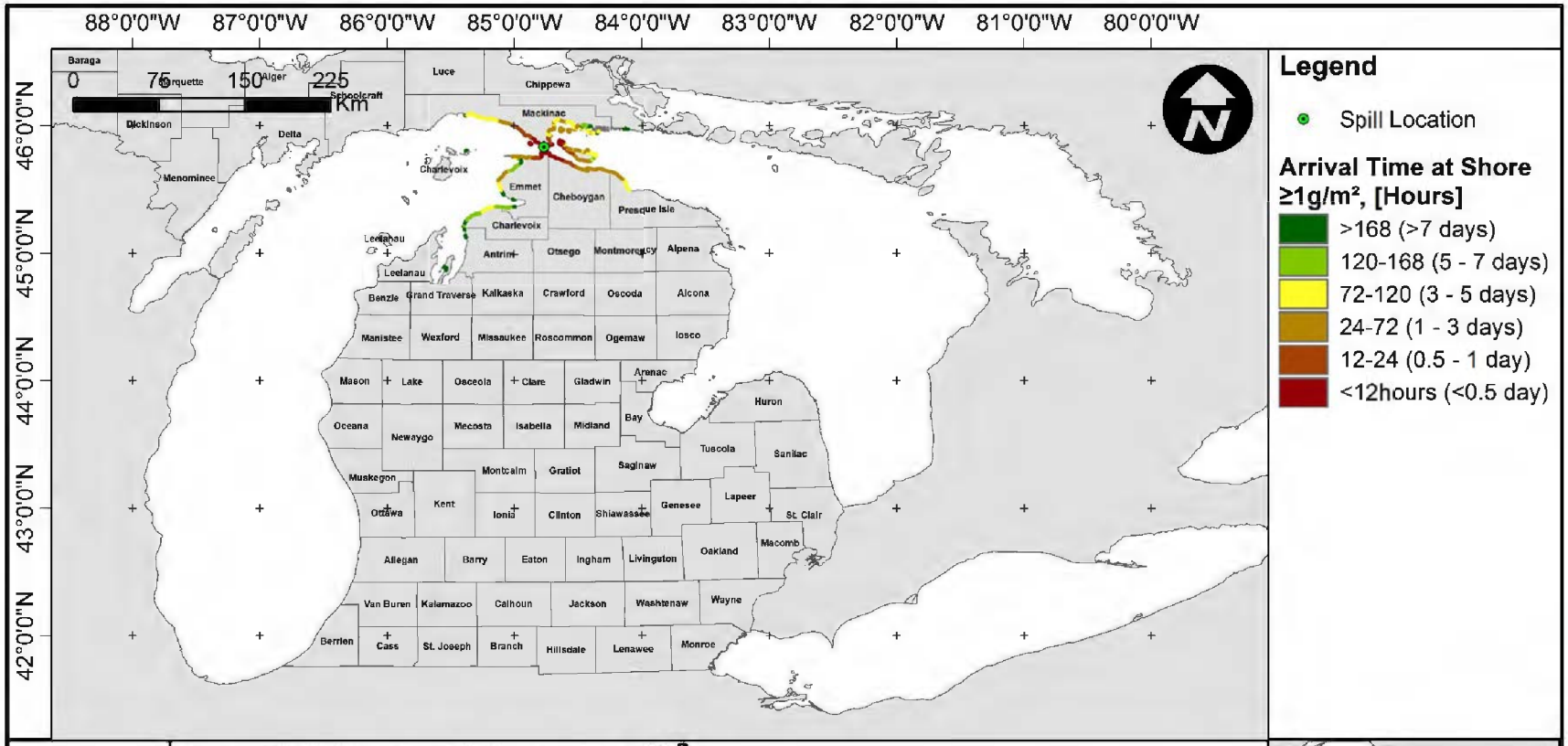
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

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

Q4

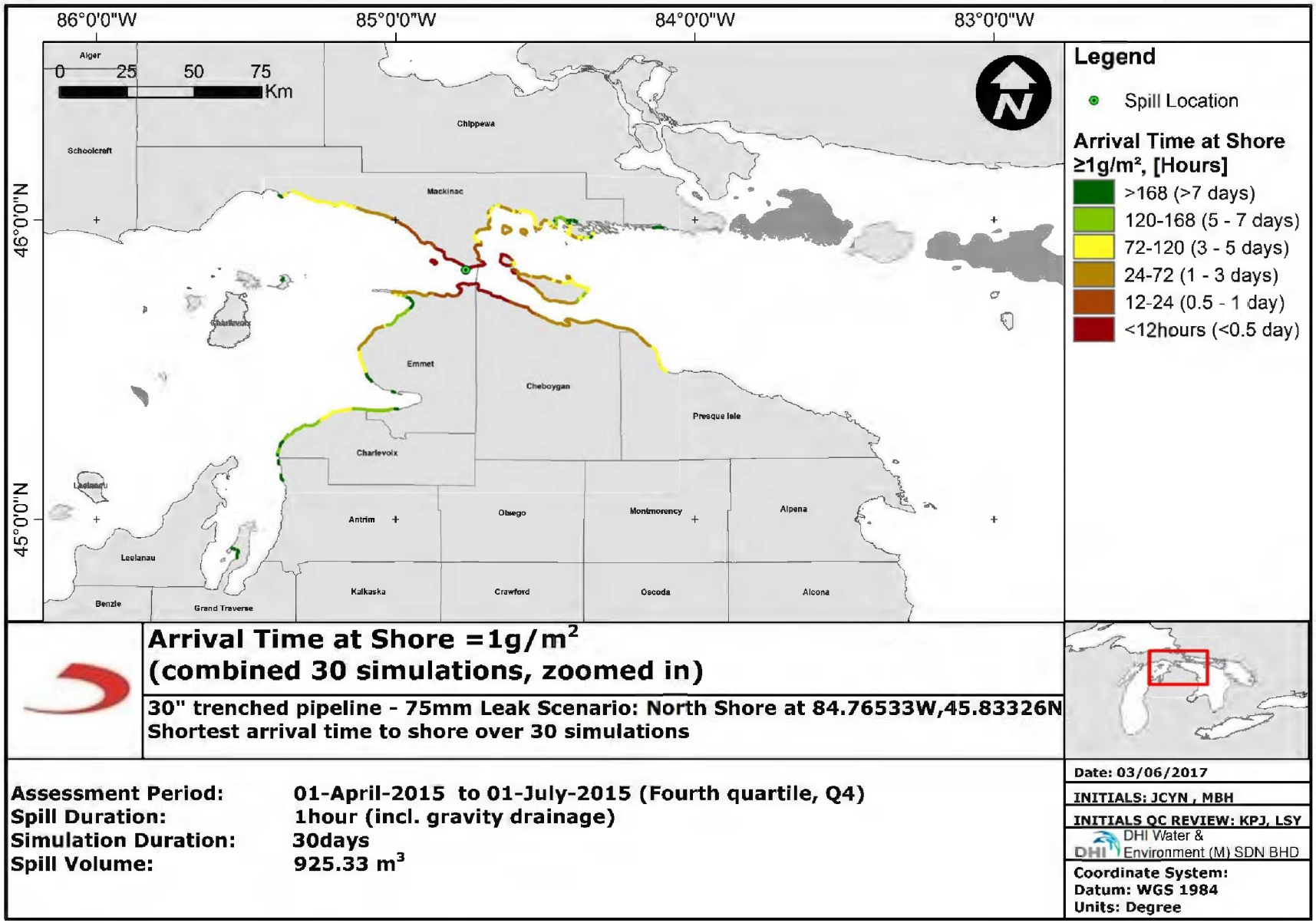


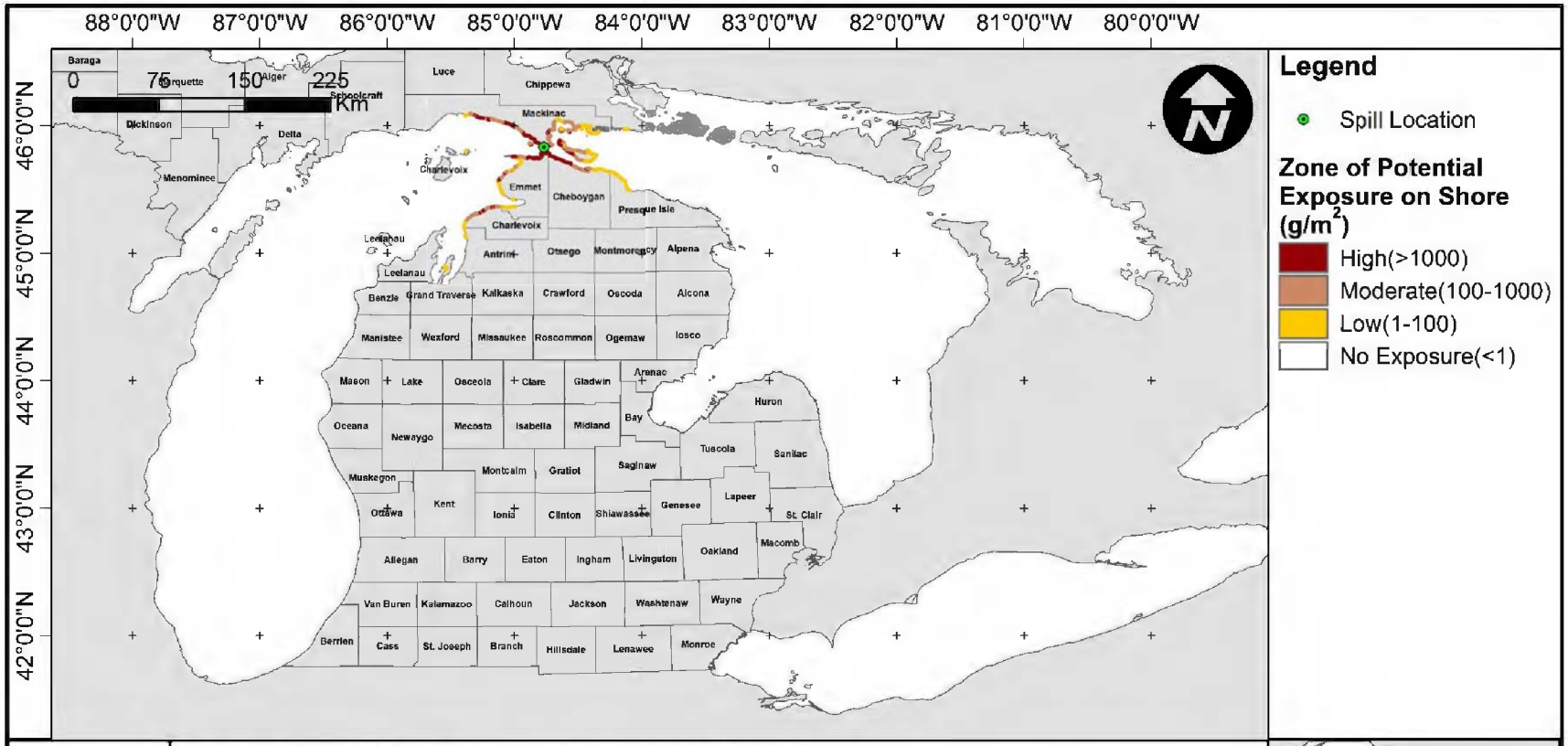
Arrival Time at Shore =1g/m^2 (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Emmet
Cheboygan
Presque Isle
Charlevoix
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

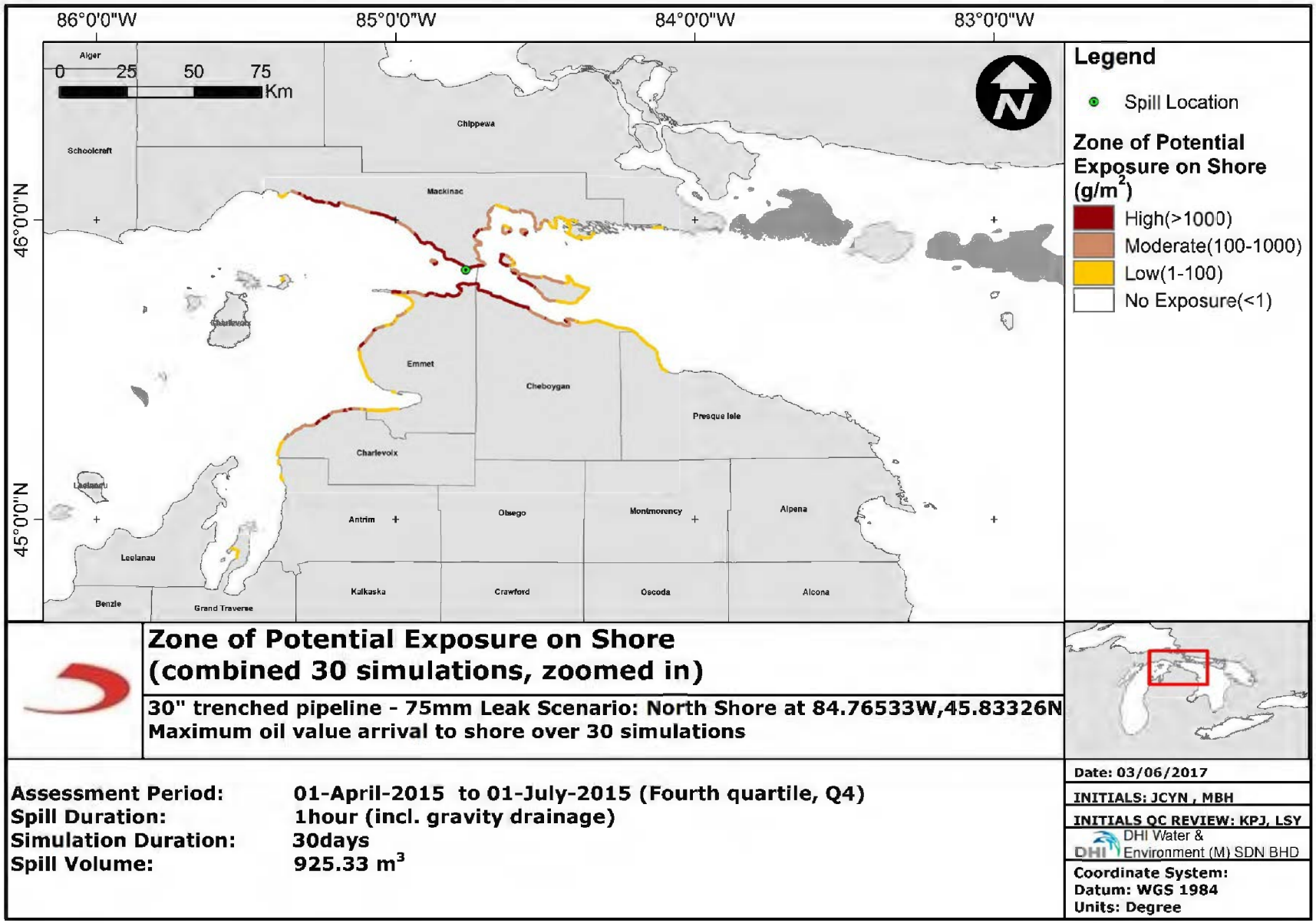


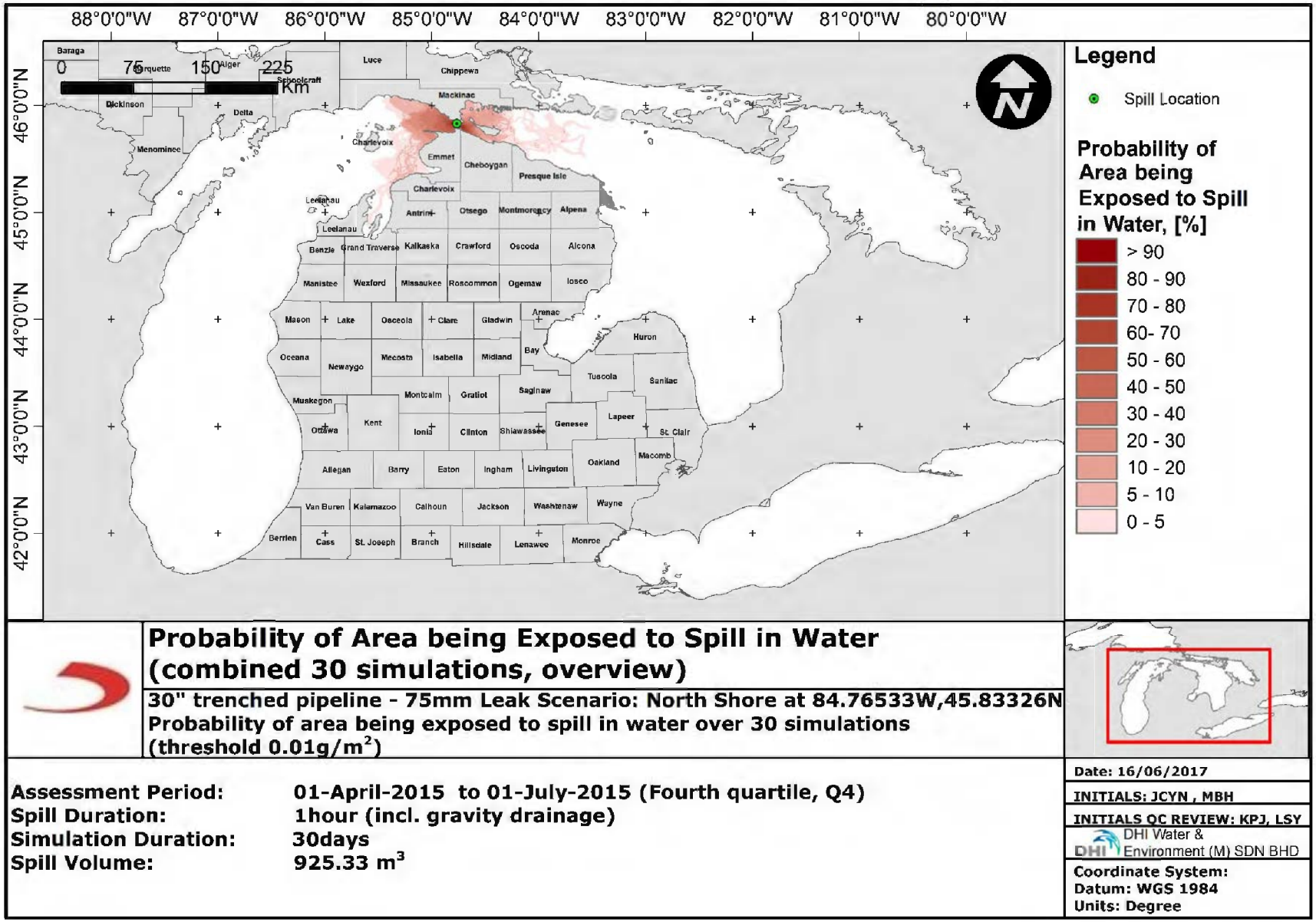
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

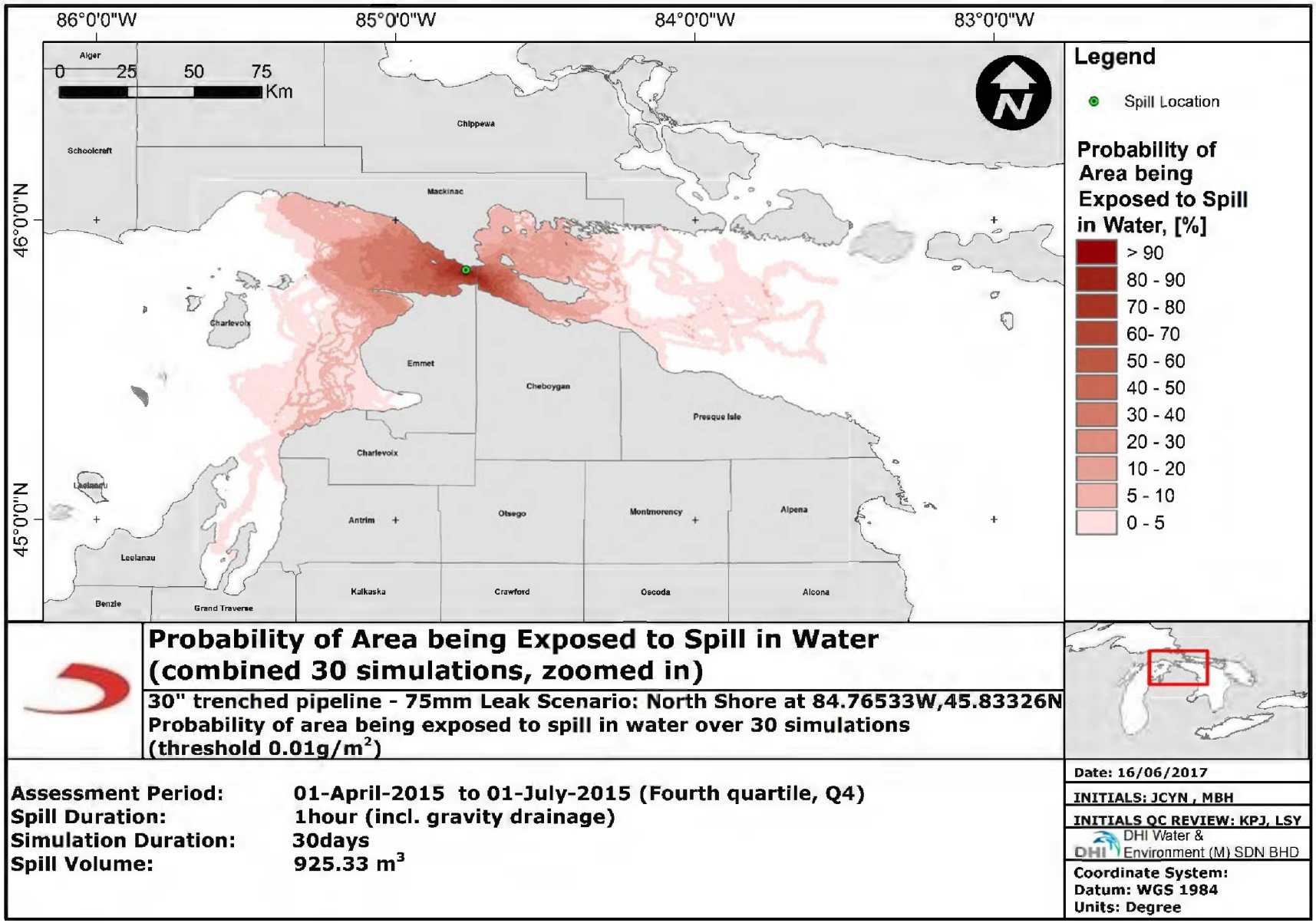
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Maximum oil value arrival to shore over 30 simulations

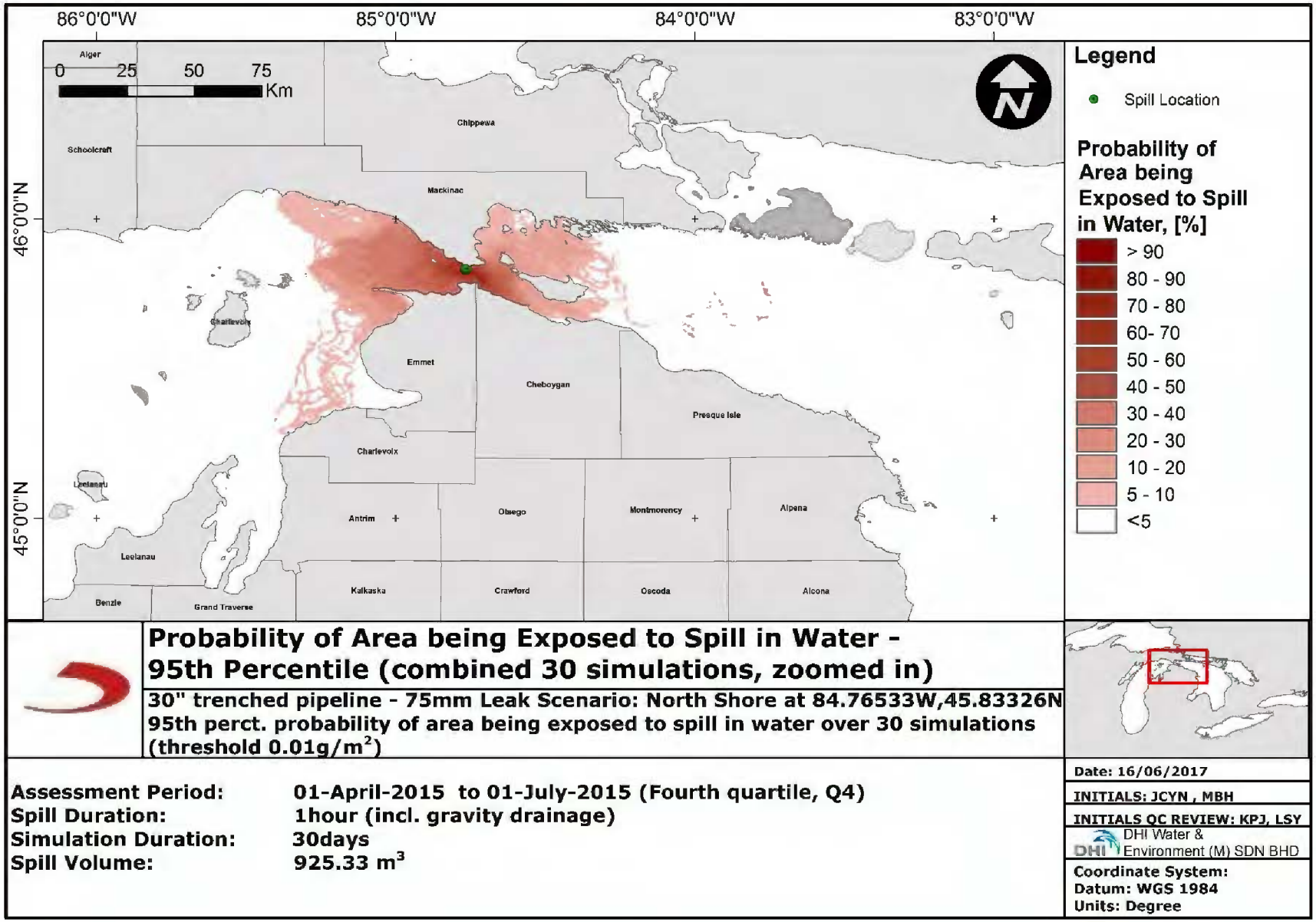
Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**925.33 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Emmet
Cheboygan
Presque Isle
Charlevoix
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

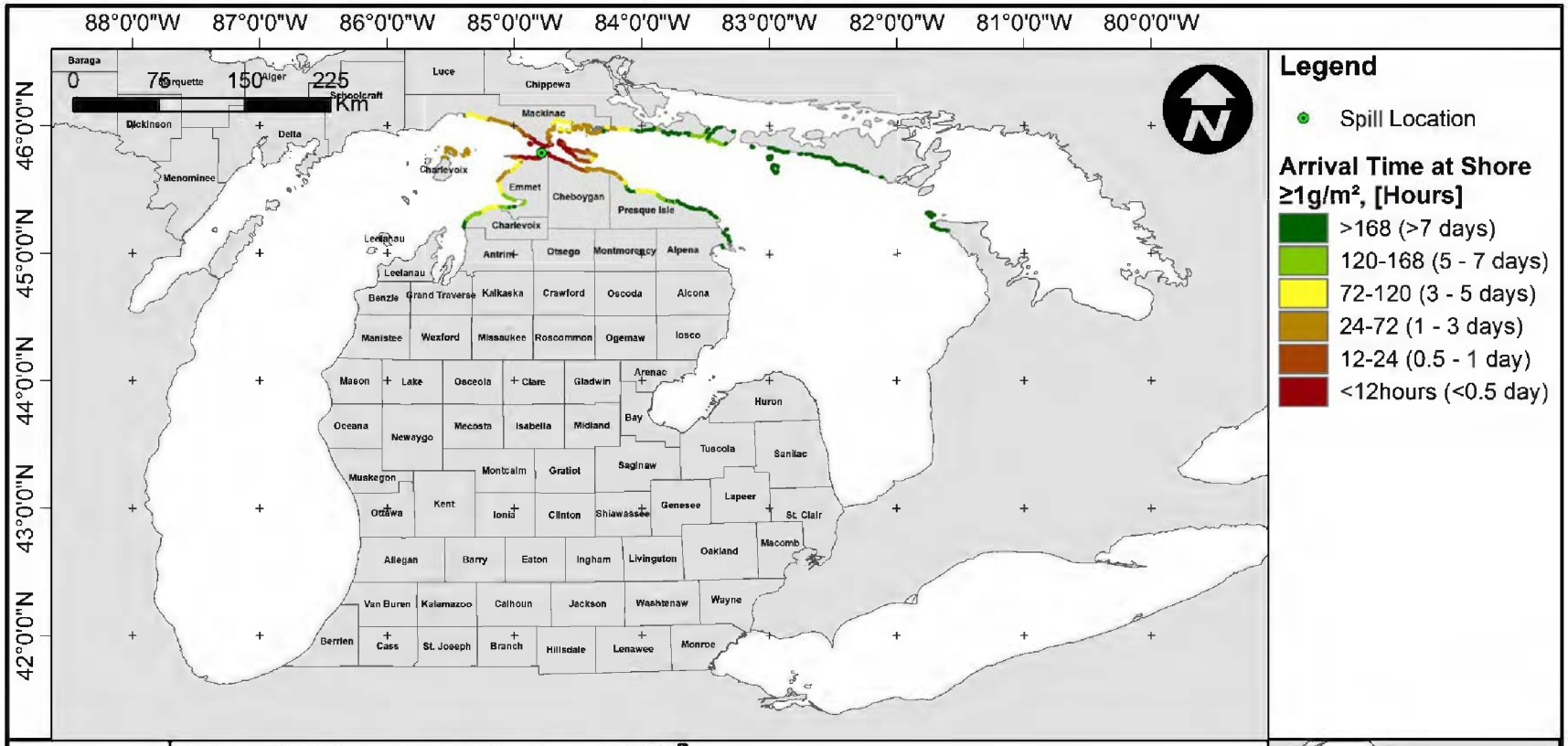

88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
<5
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: North Shore at 84.76533W,45.83326N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m2)
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 1hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 925.33 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

Set 3
30” Trenched Pipeline – 75 mm Leak at Southern Shore

1 year

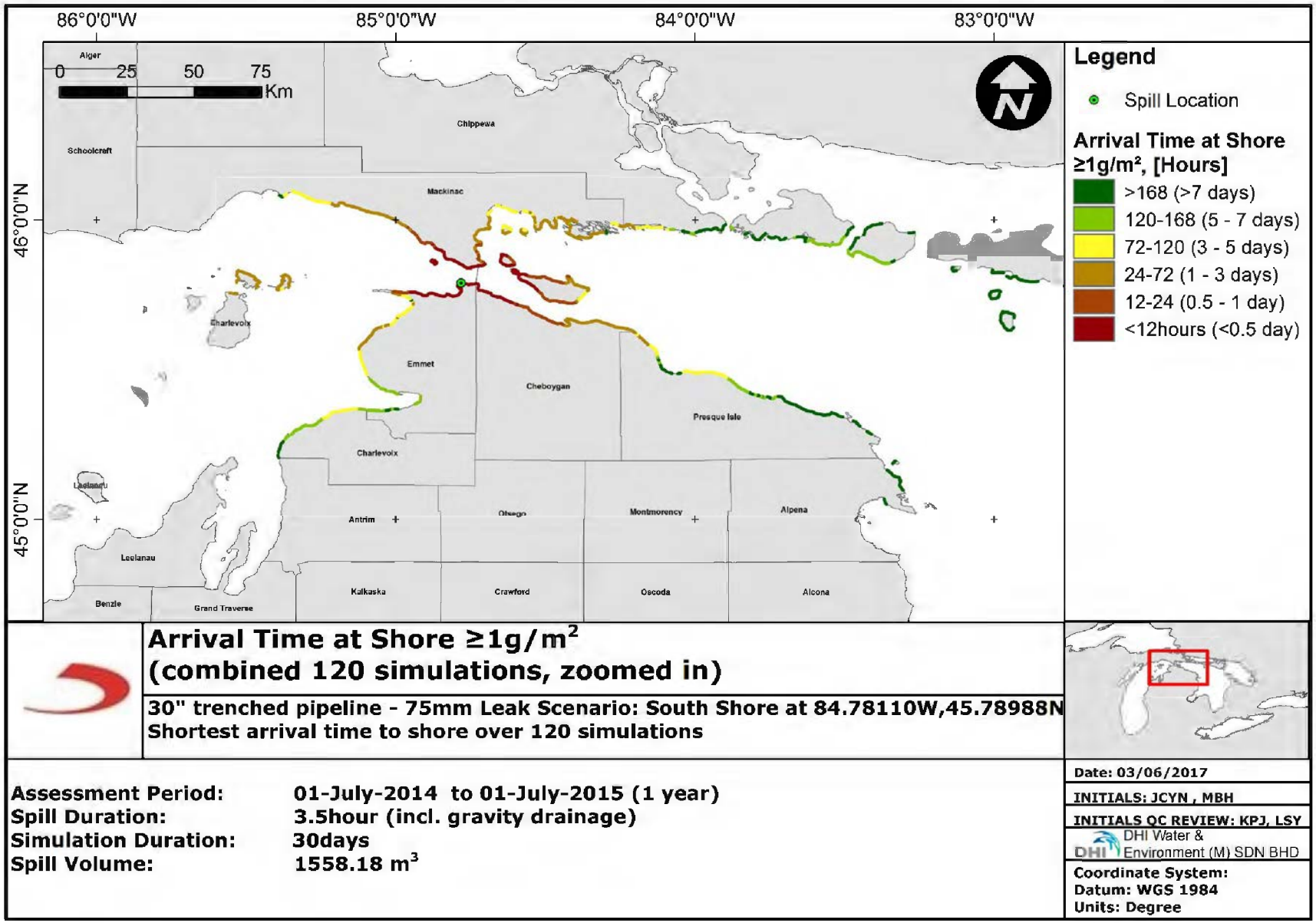


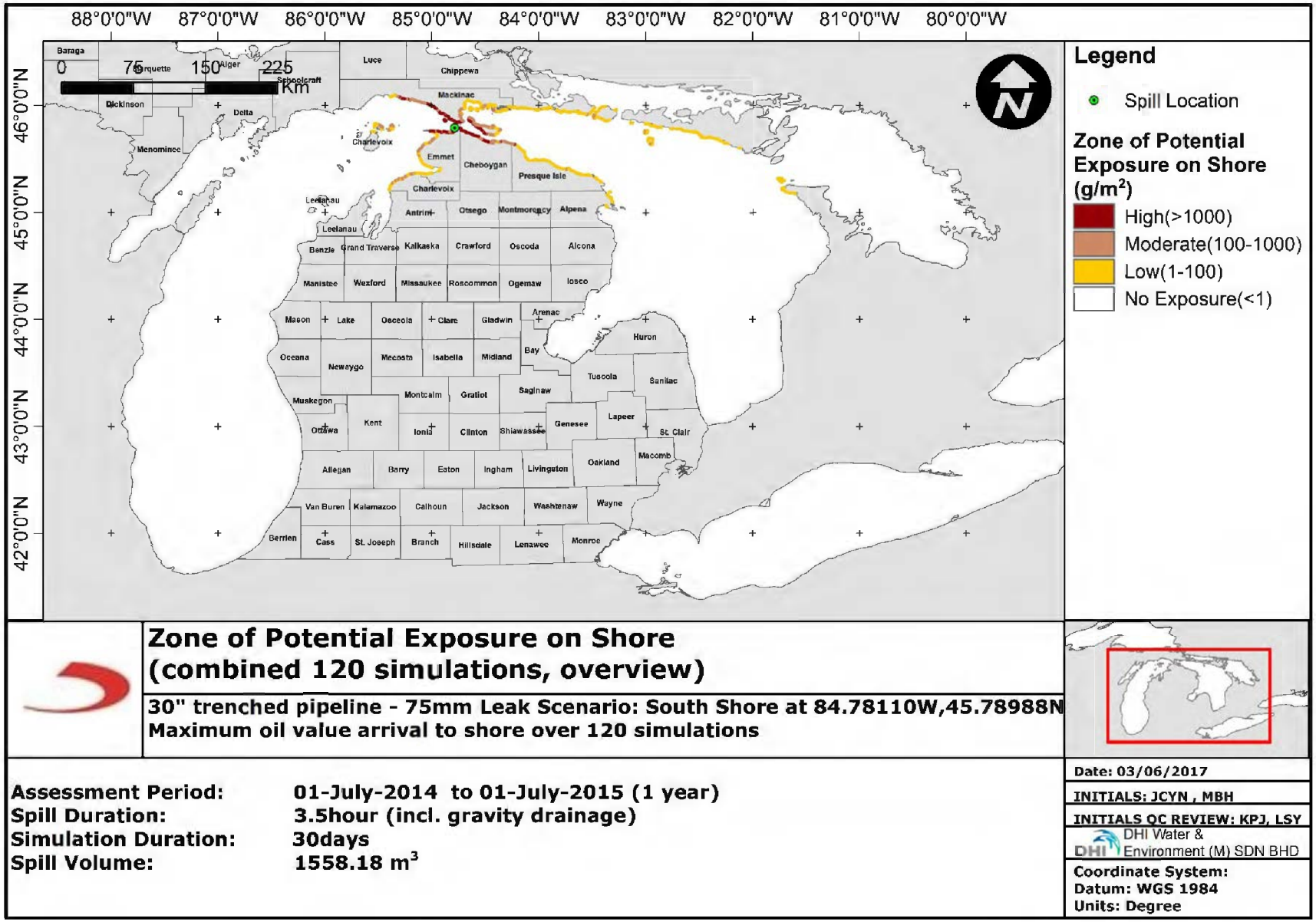
Arrival Time at Shore ≥1g/m²
(combined 120 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 120 simulations

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 120 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 120 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

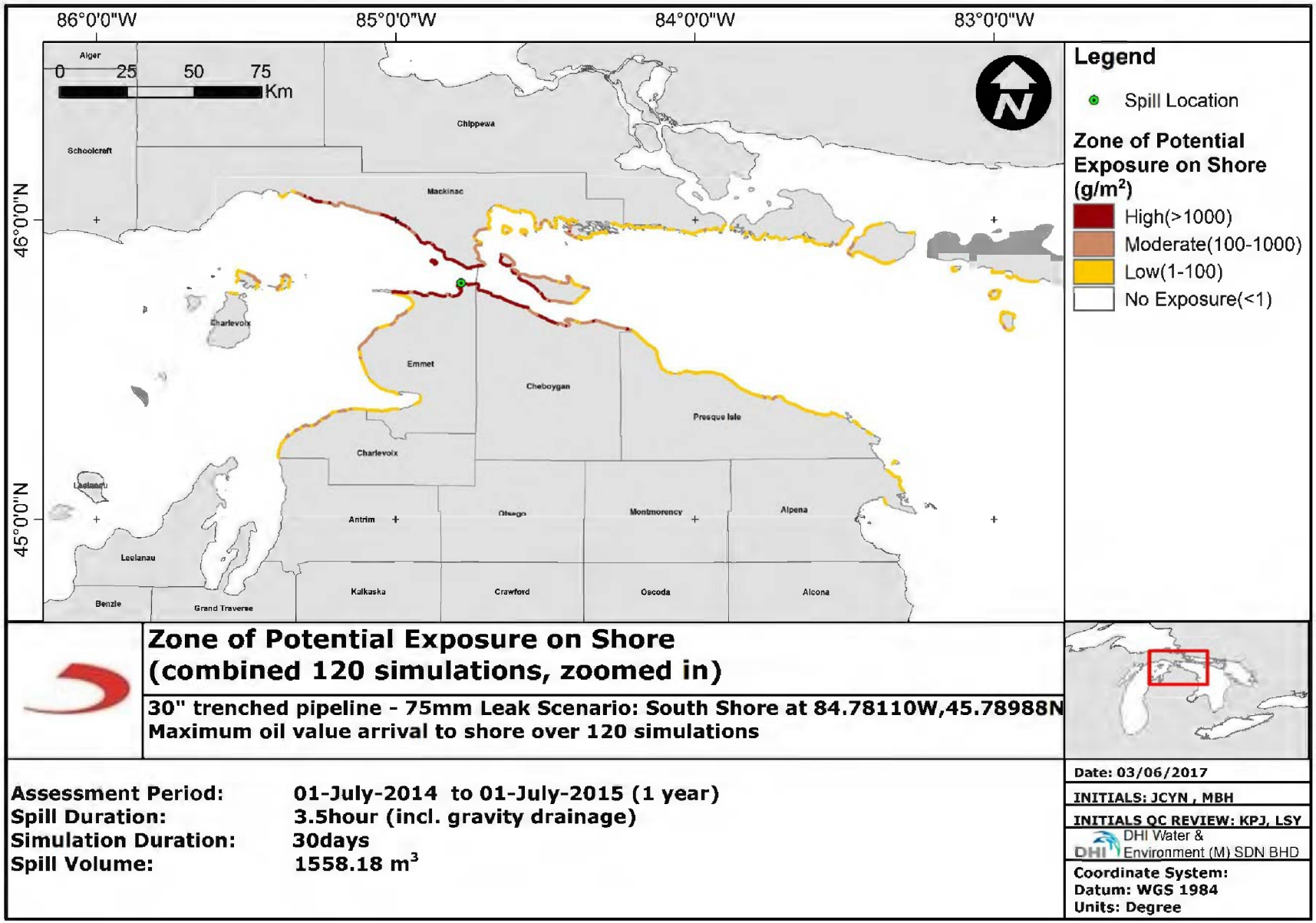


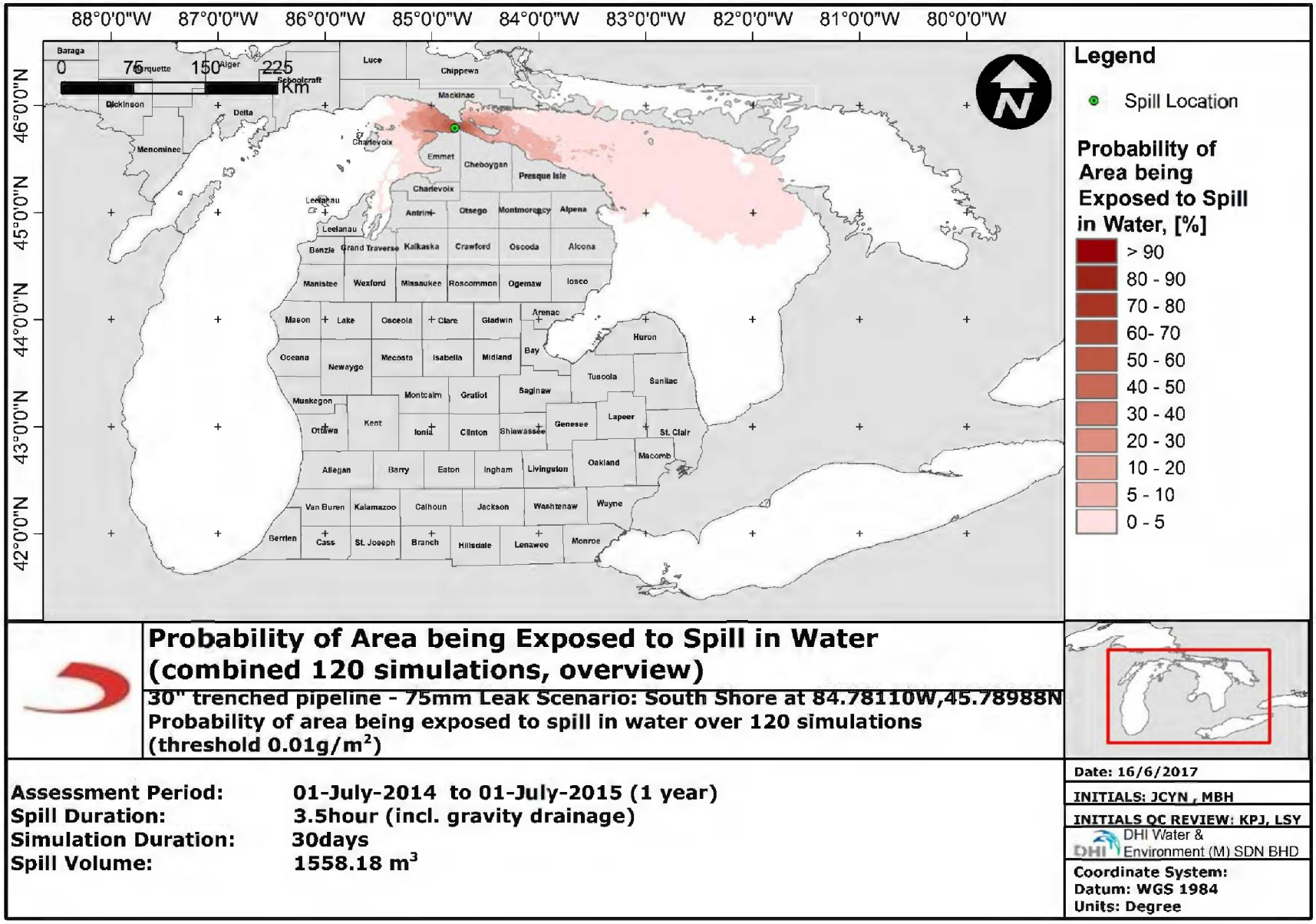
Zone of Potential Exposure on Shore (combined 120 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Maximum oil value arrival to shore over 120 simulations

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 120 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Maximum oil value arrival to shore over 120 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

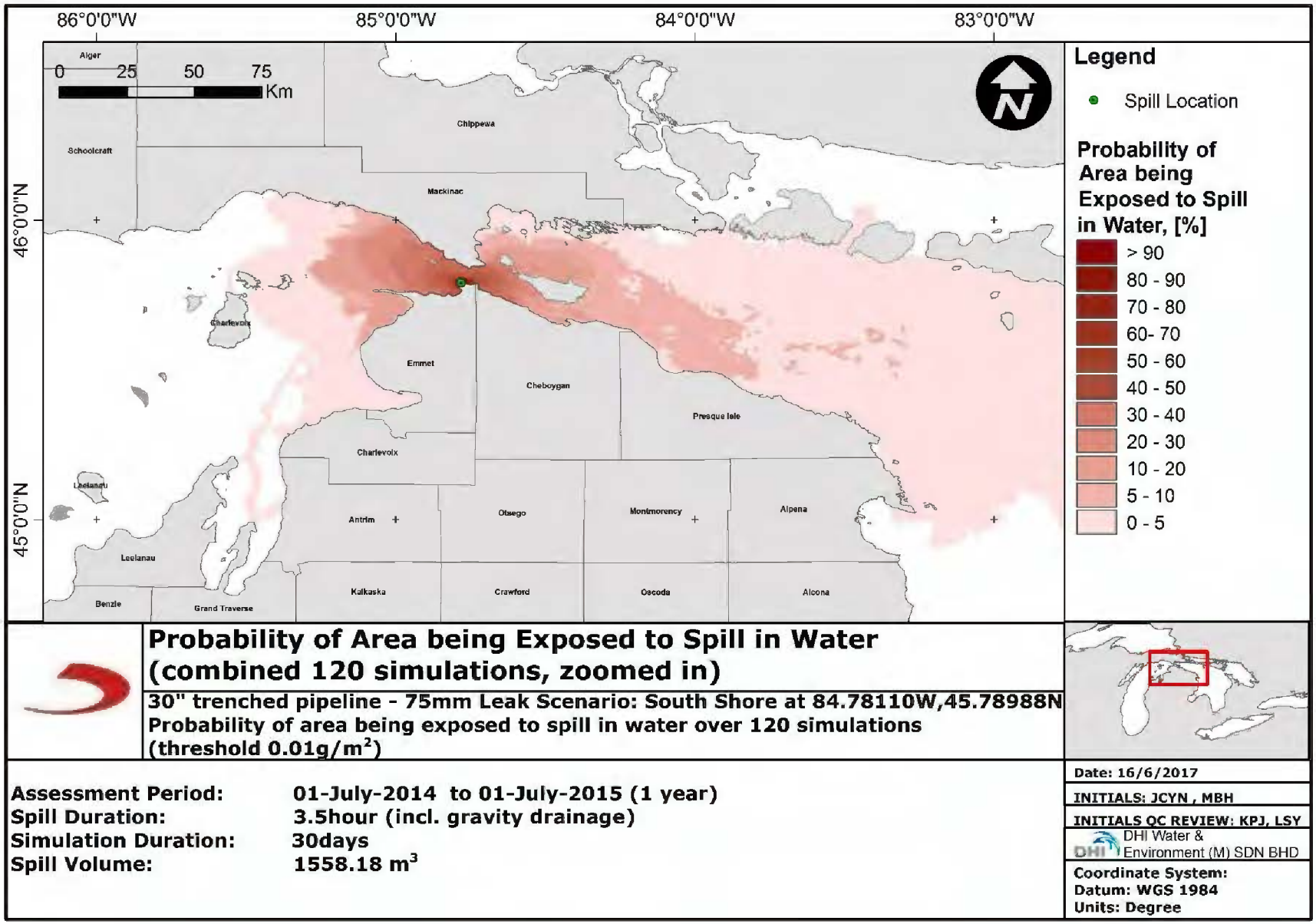


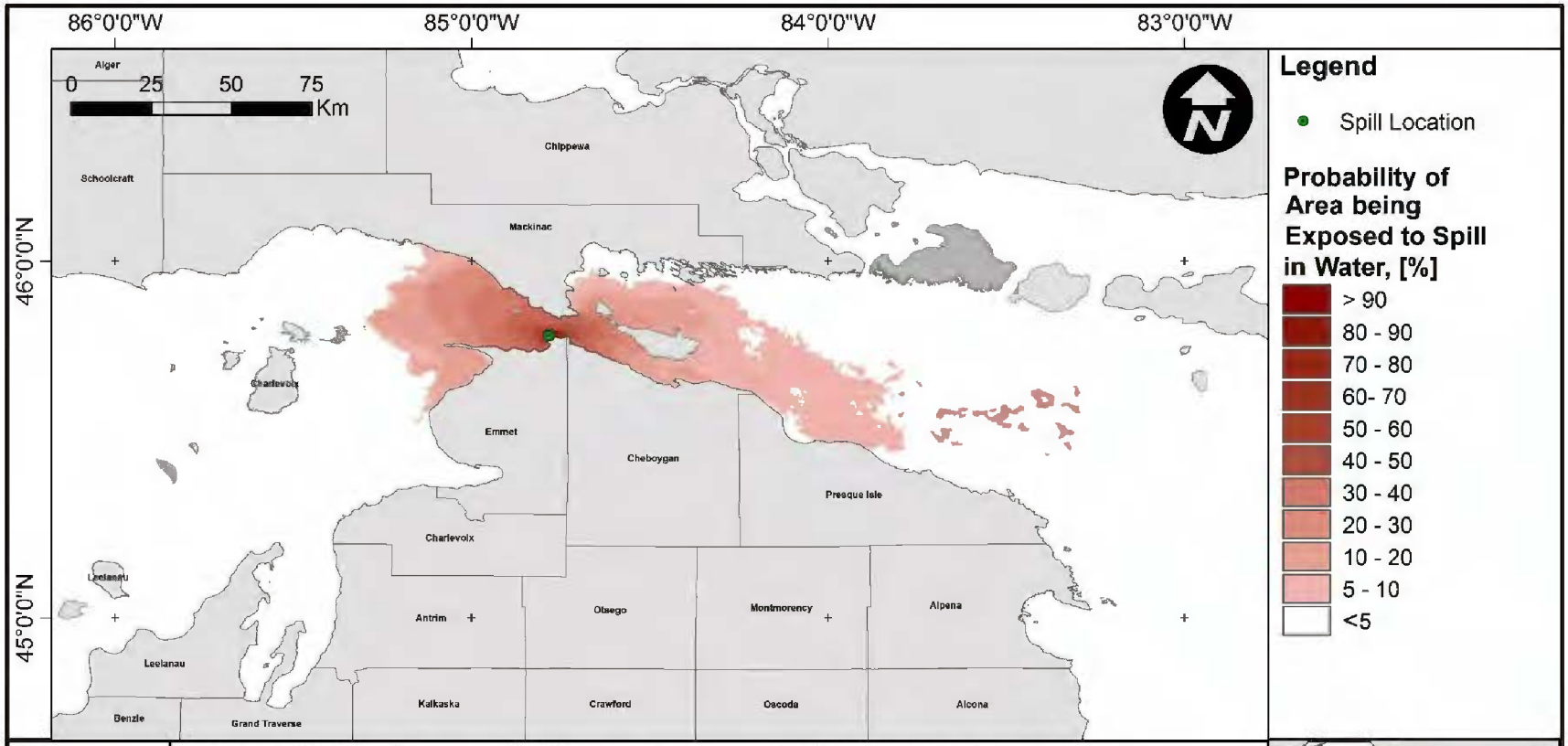
Probability of Area being Exposed to Spill in Water (combined 120 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
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)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
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Mackinac
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Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 120 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
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: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree



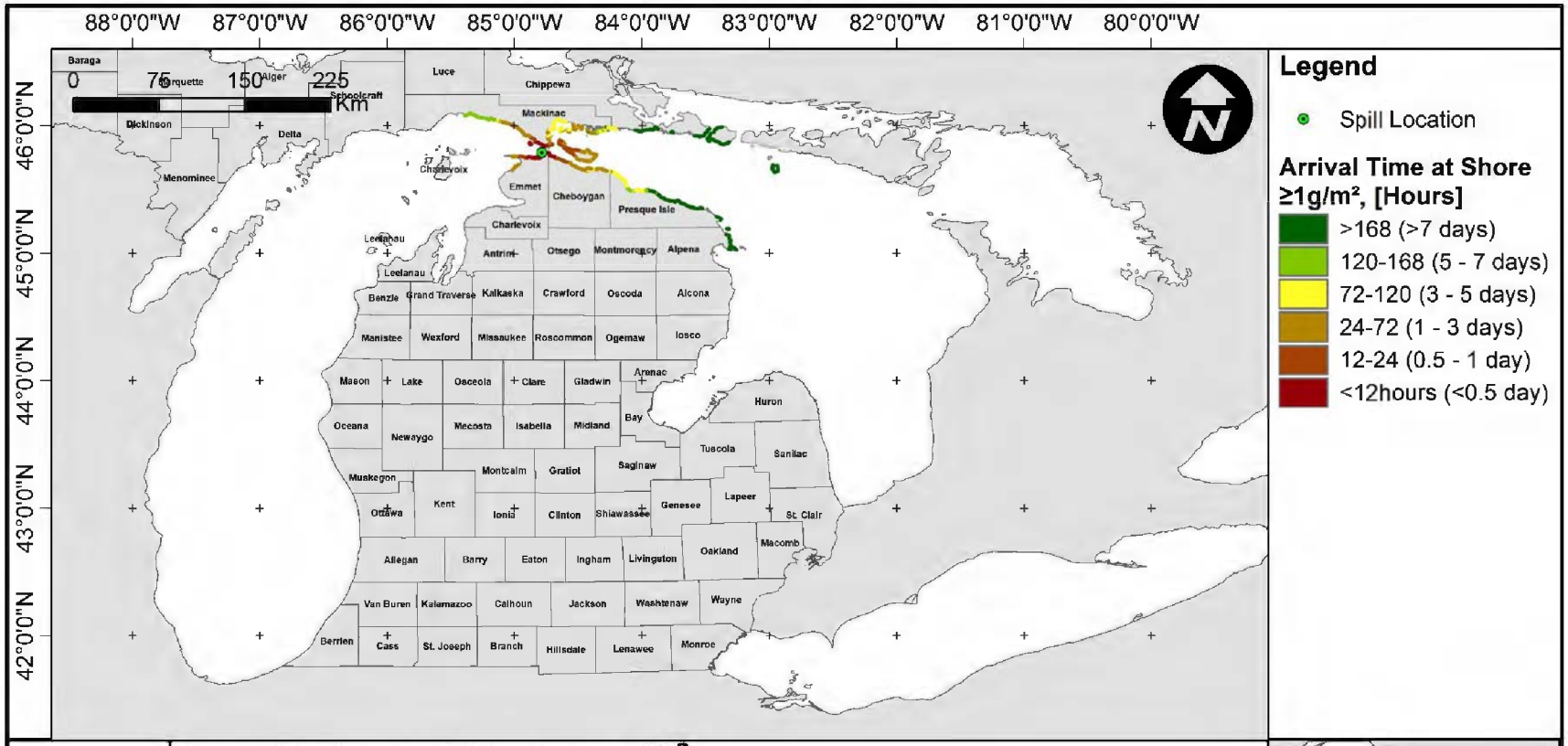
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 120 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
95th perct. 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)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

Q1

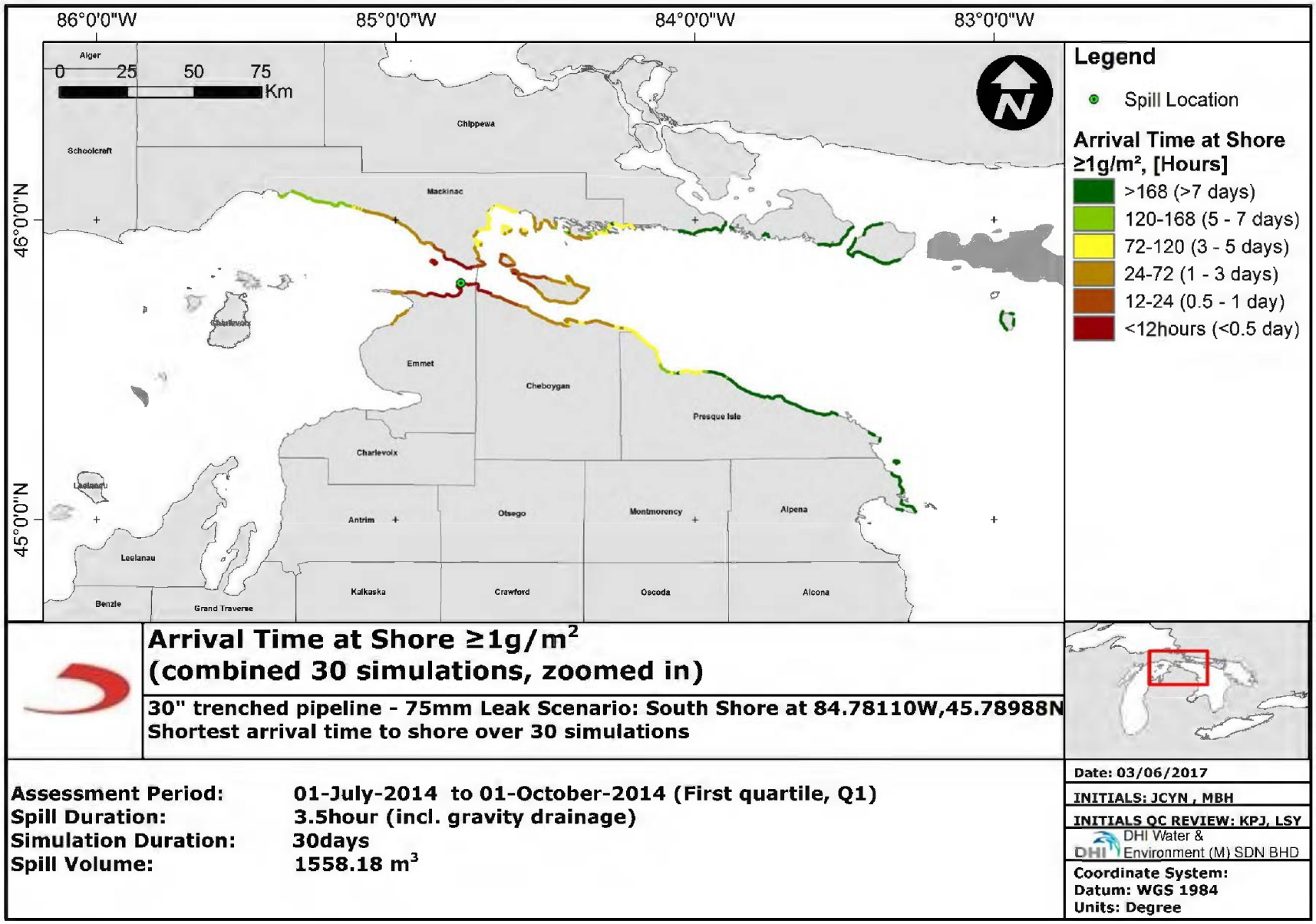


Arrival Time at Shore ≥1g/m² (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

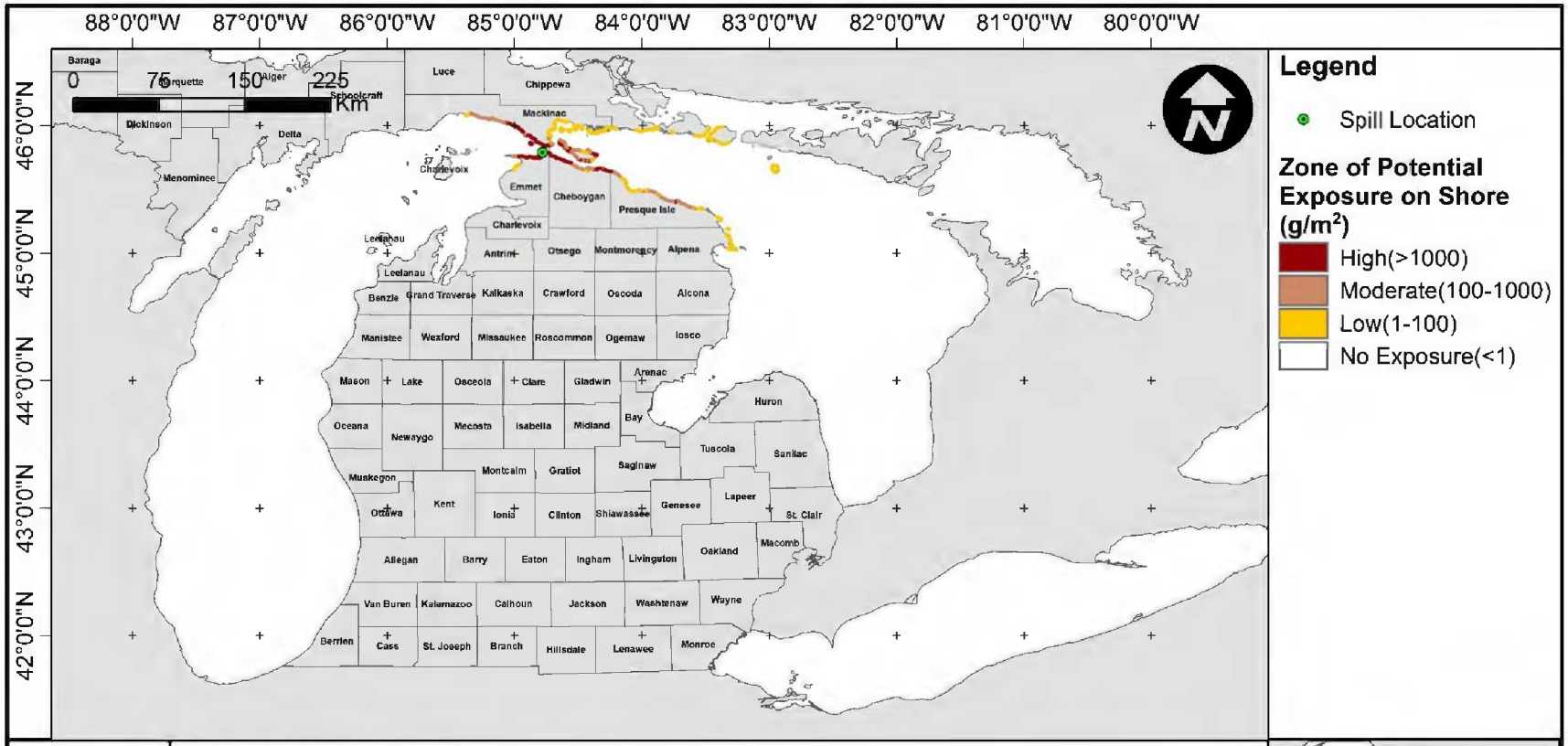


Arrival Time at Shore ≥1g/m²
(combined 30 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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Units: Degree

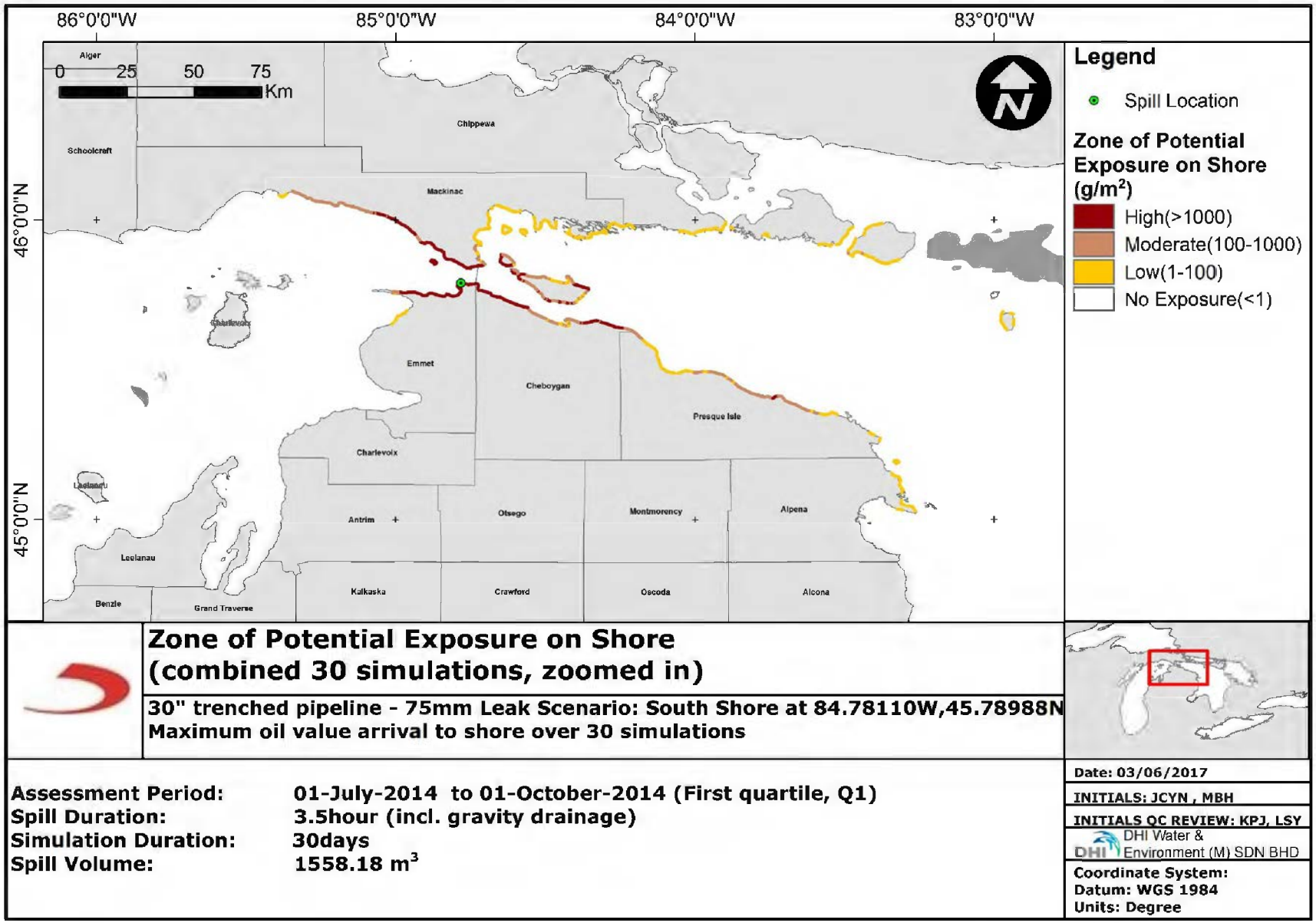


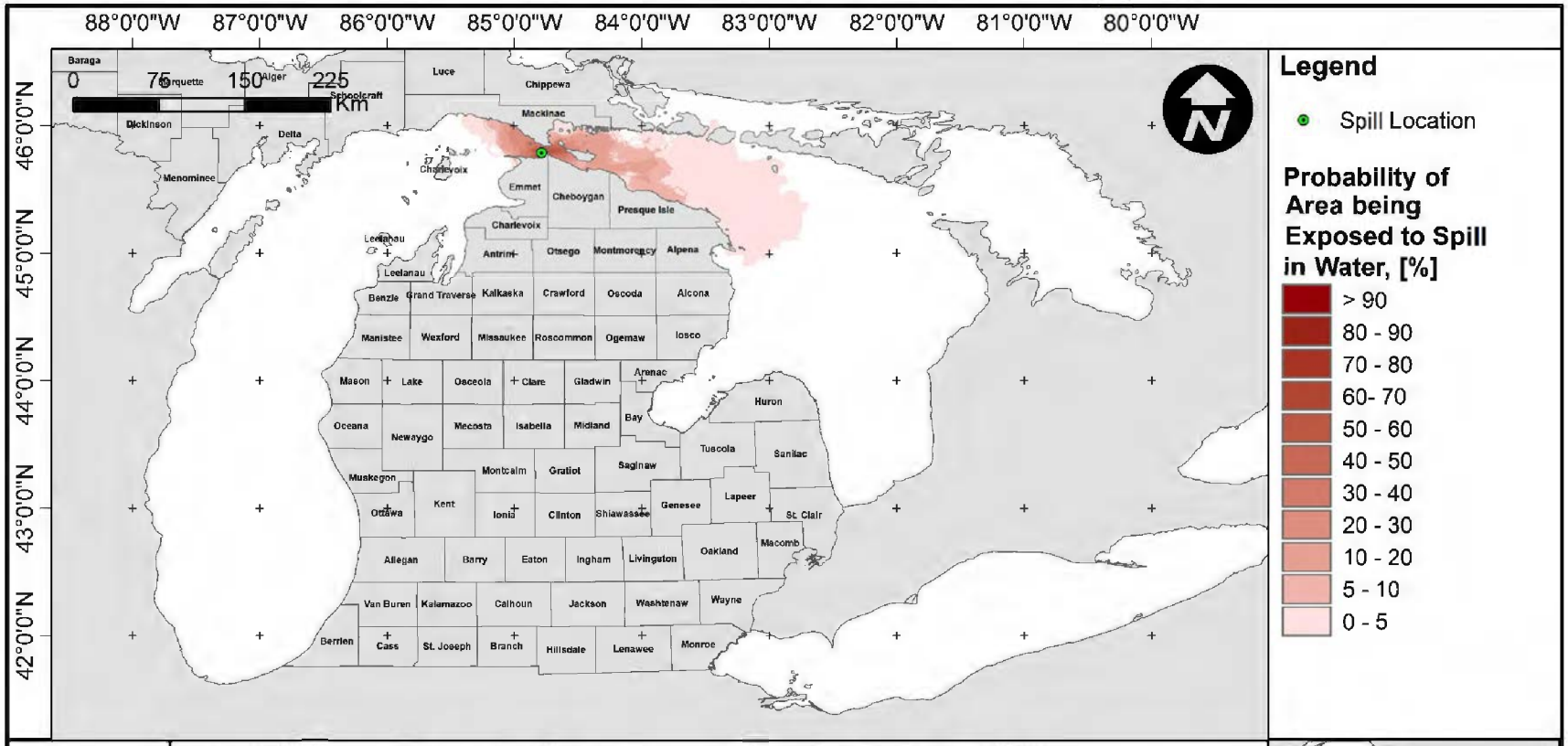
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
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Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
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Datum: WGS 1984
Units: Degree

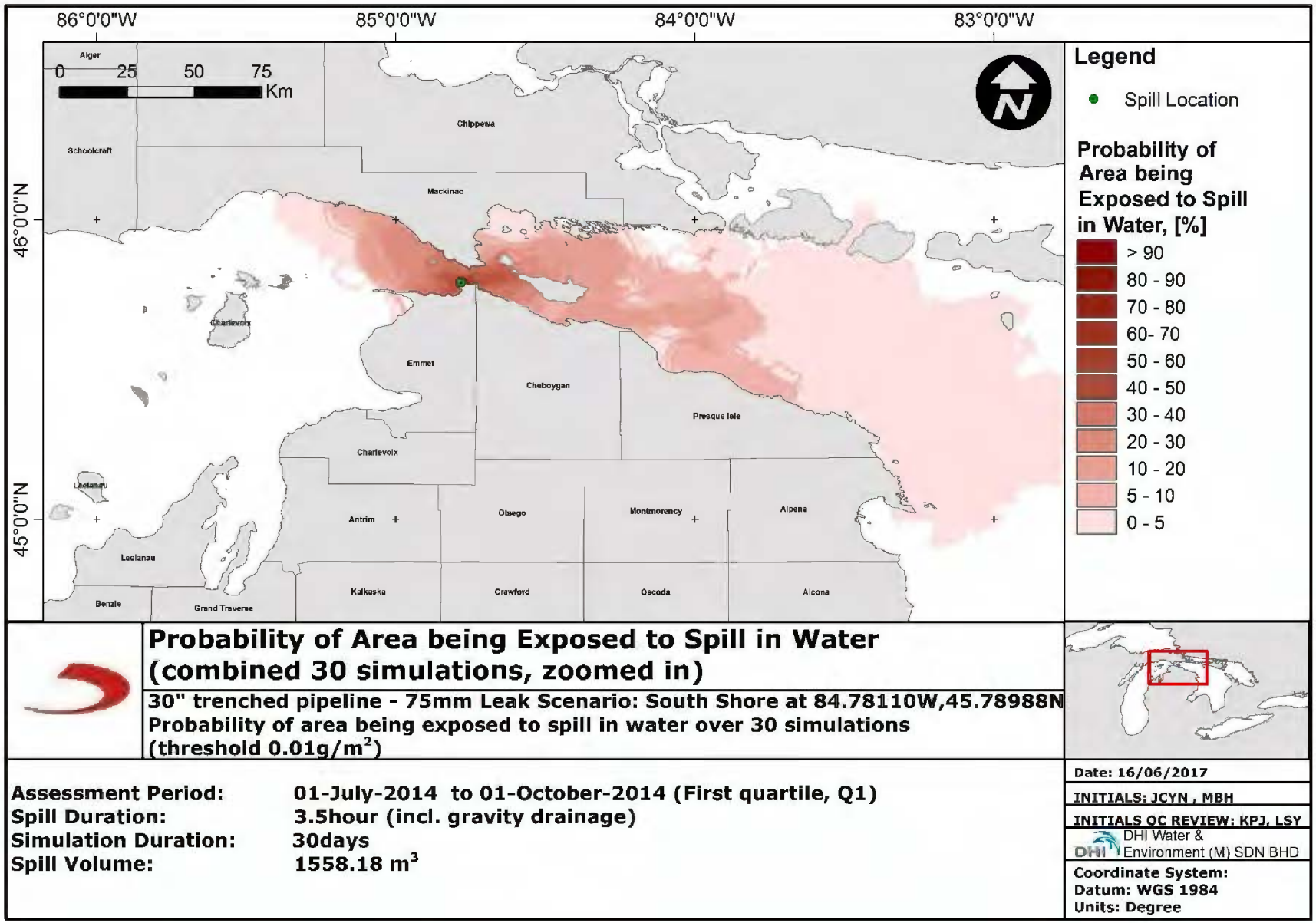


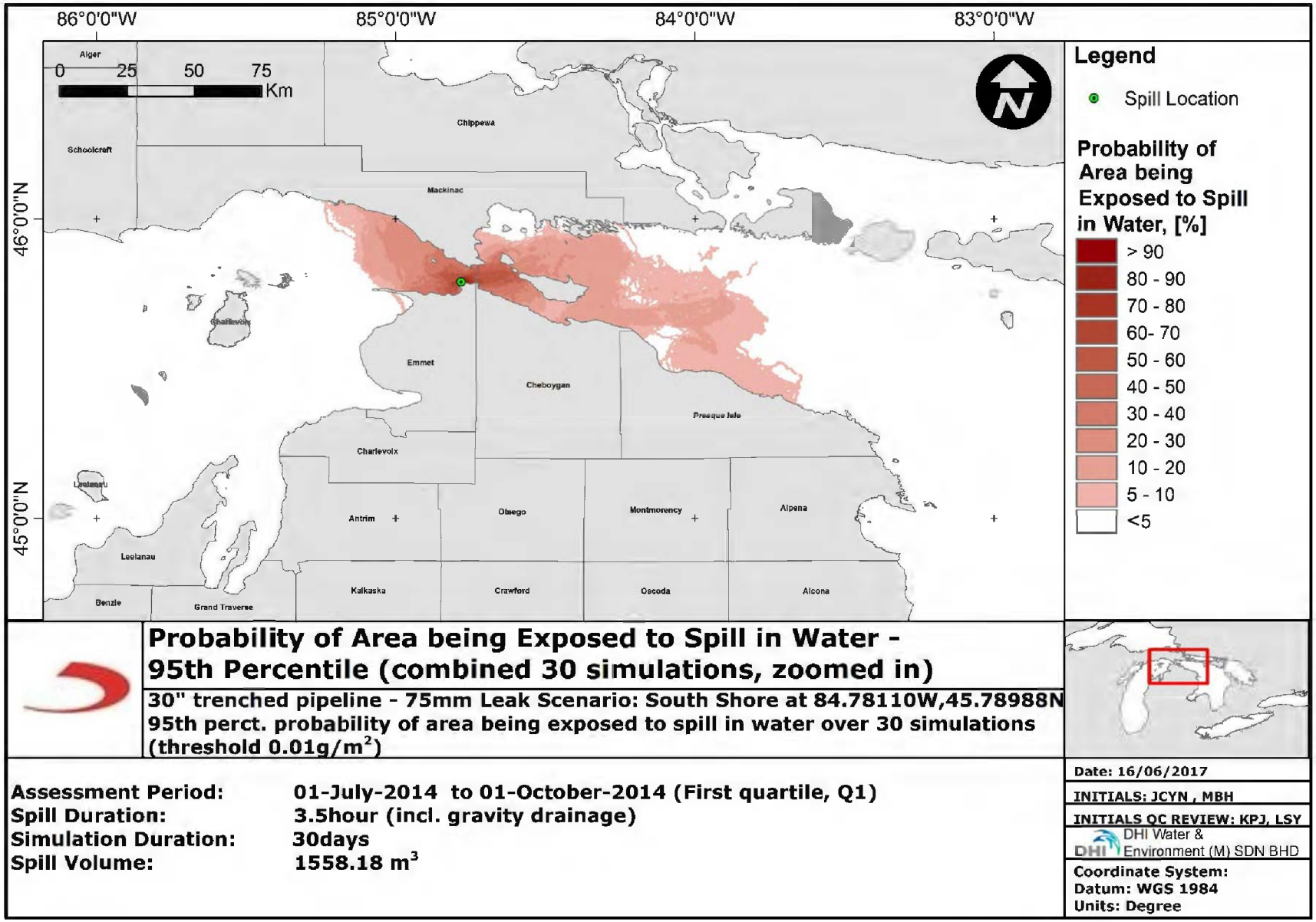
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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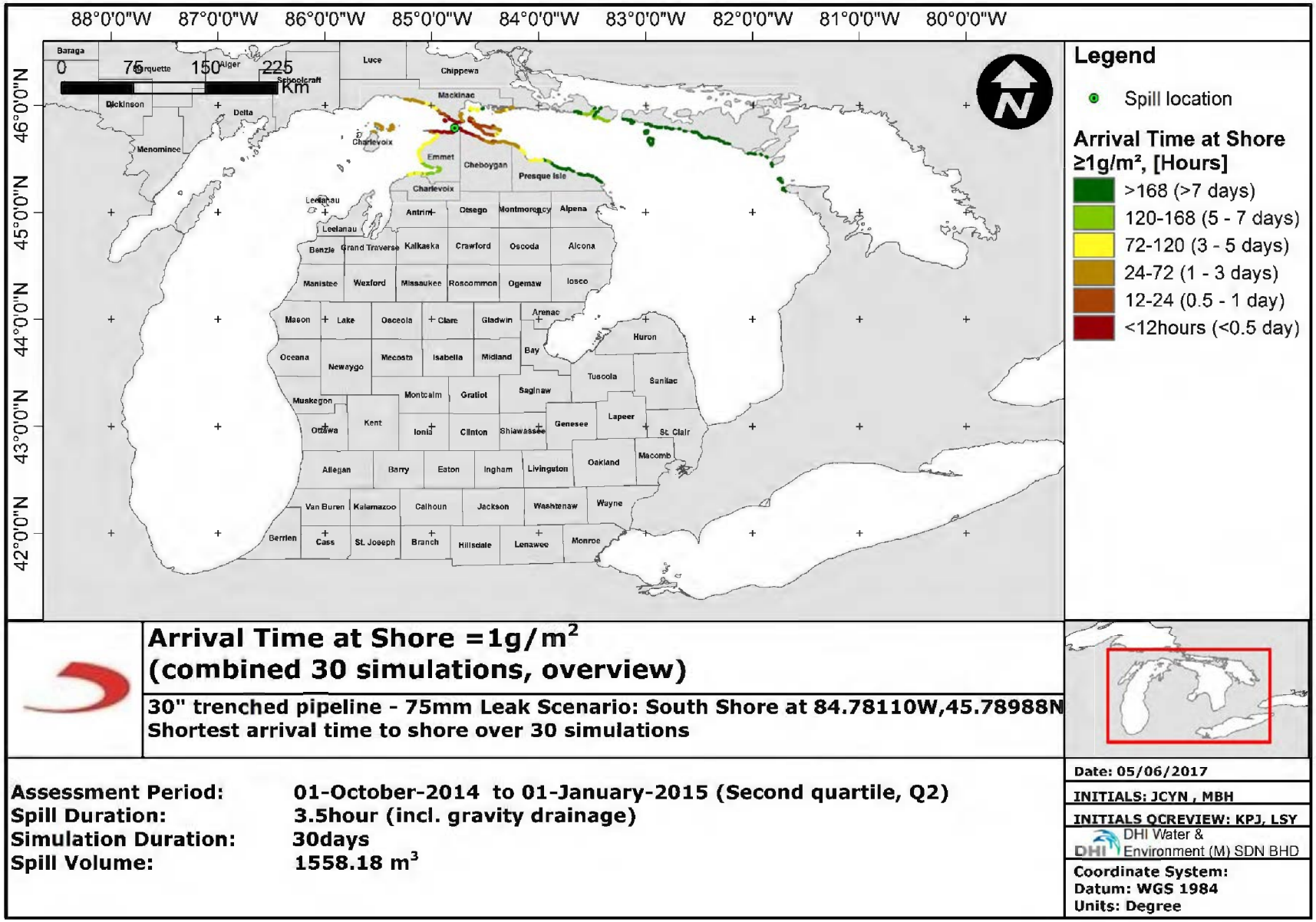
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

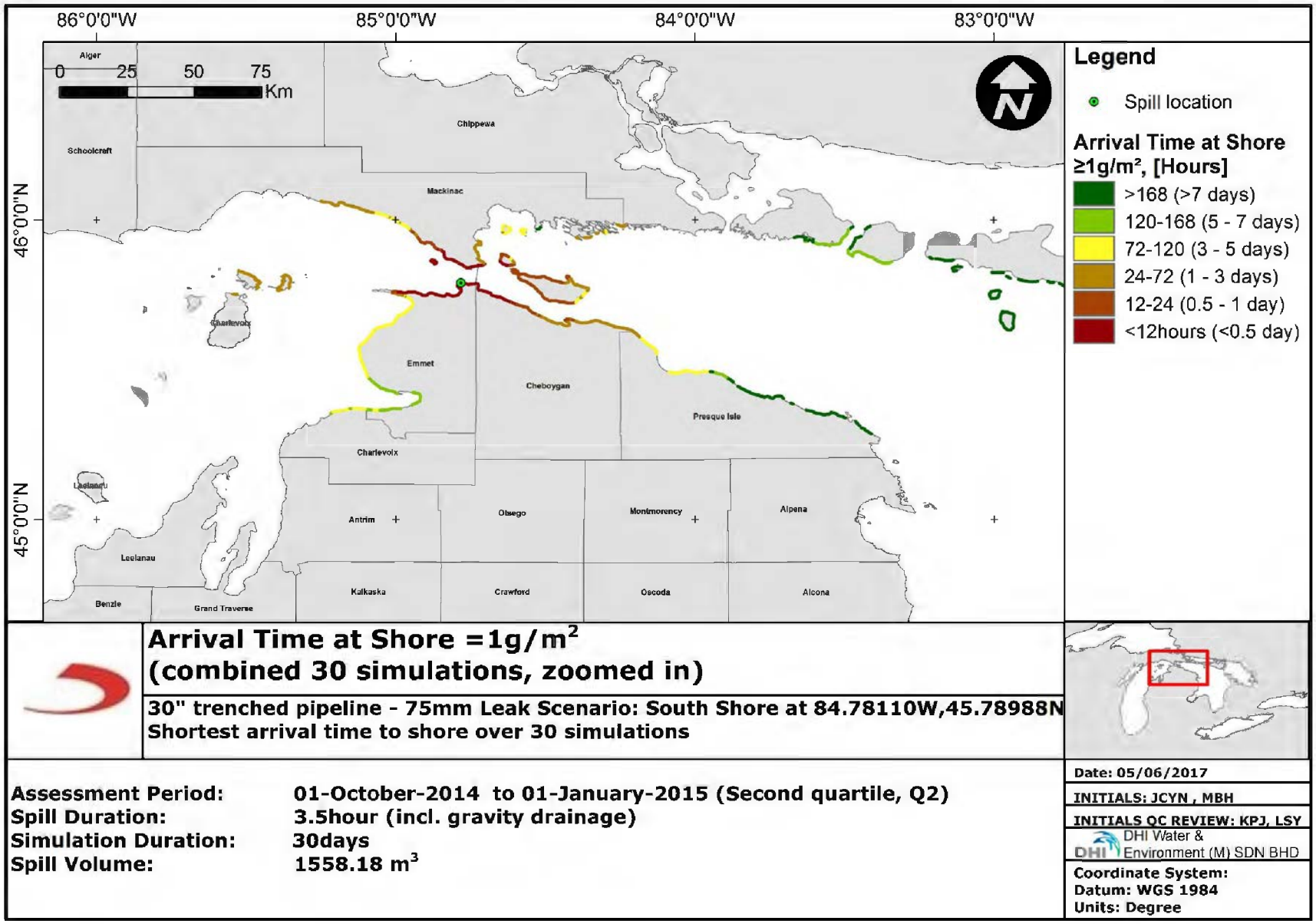
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

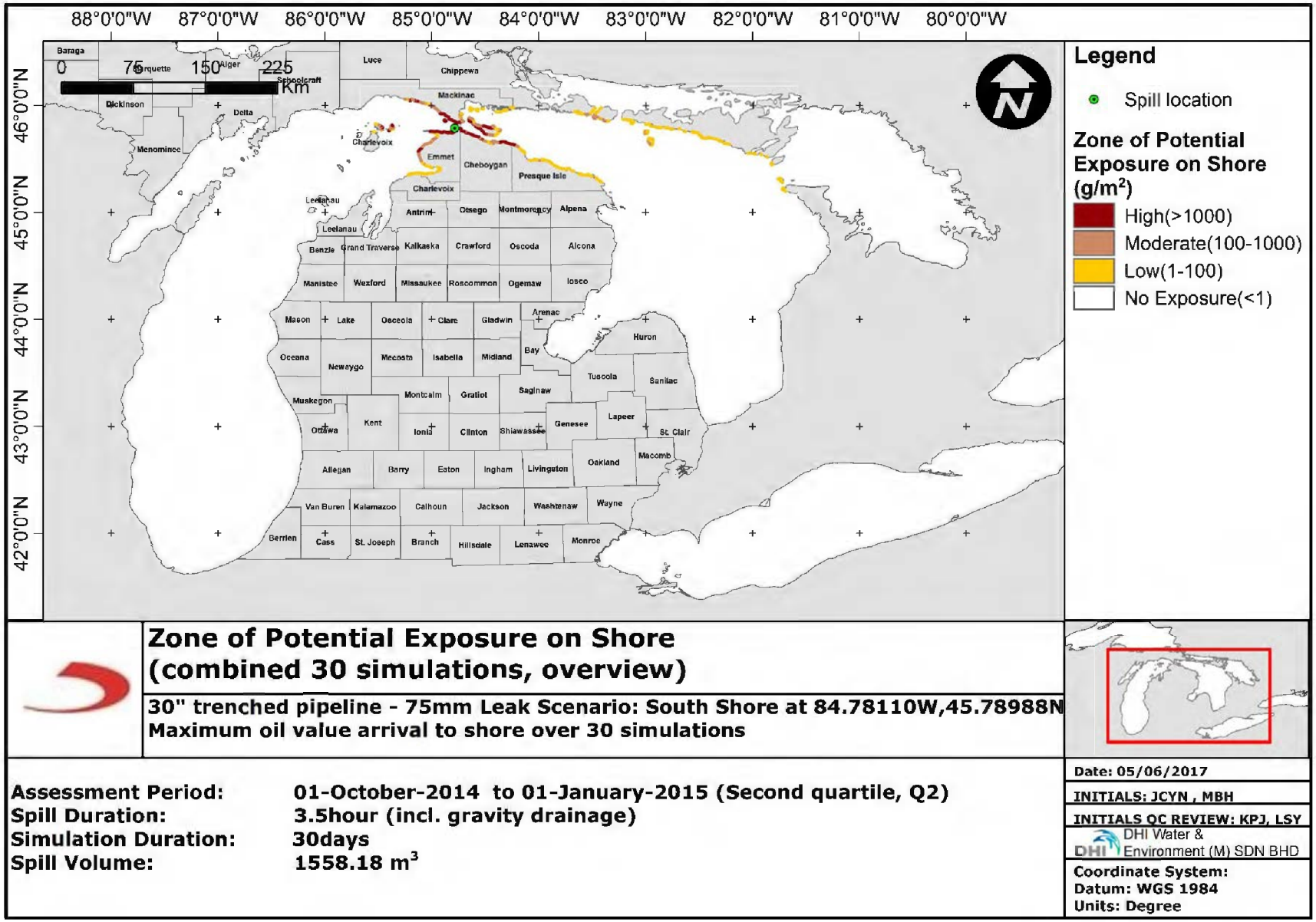
Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

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

Q2


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QCREVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
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Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

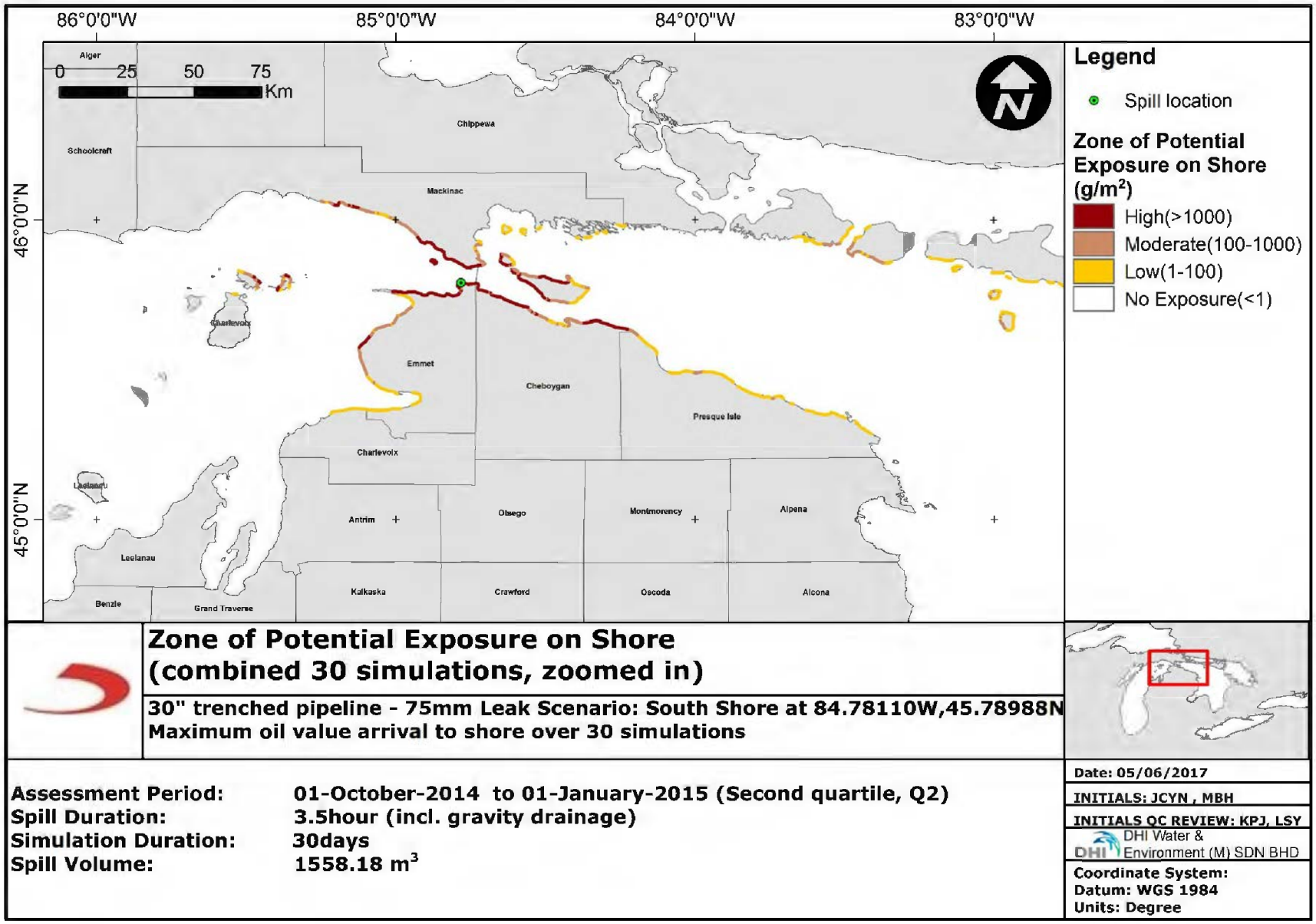


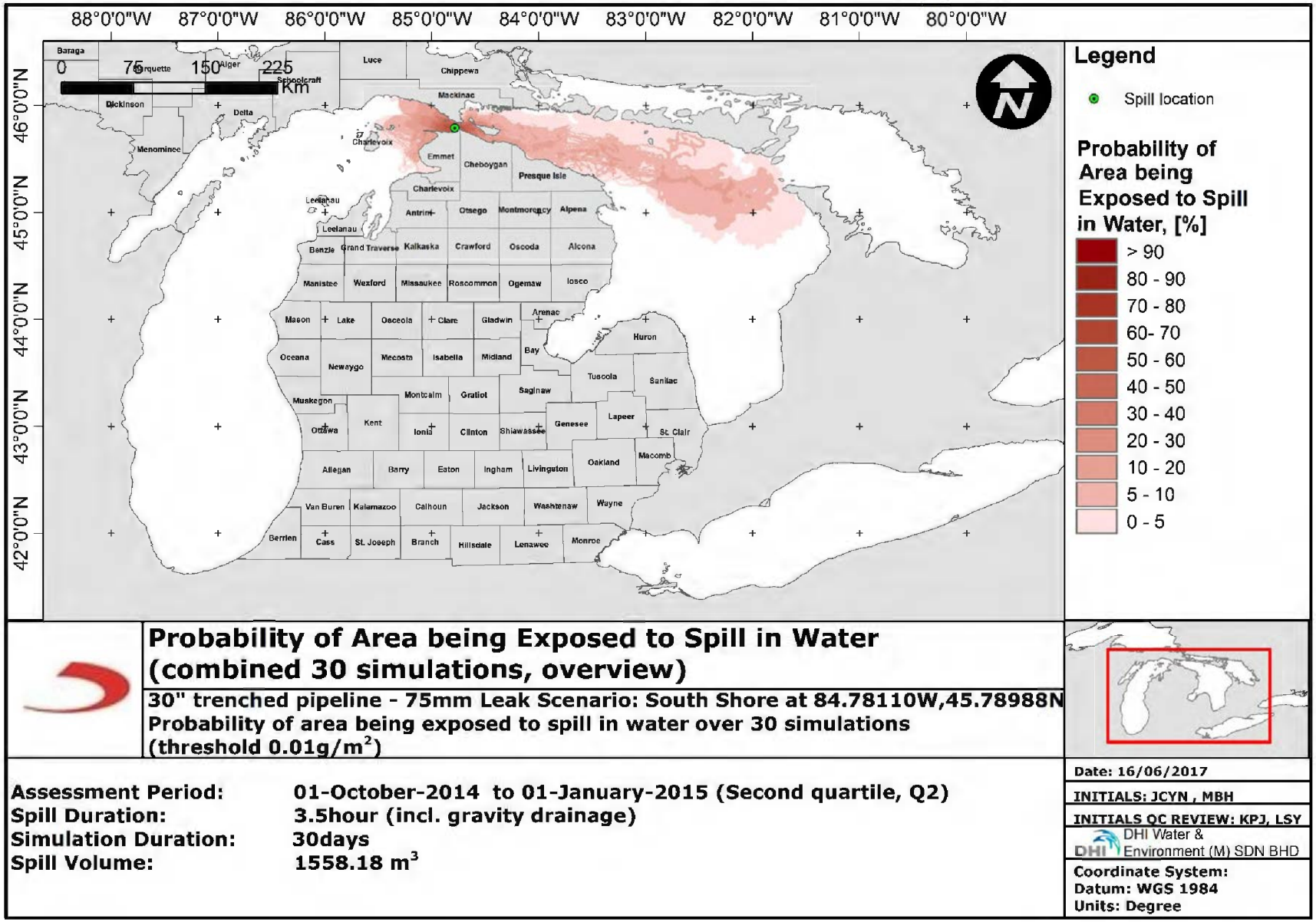
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 05/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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Units: Degree

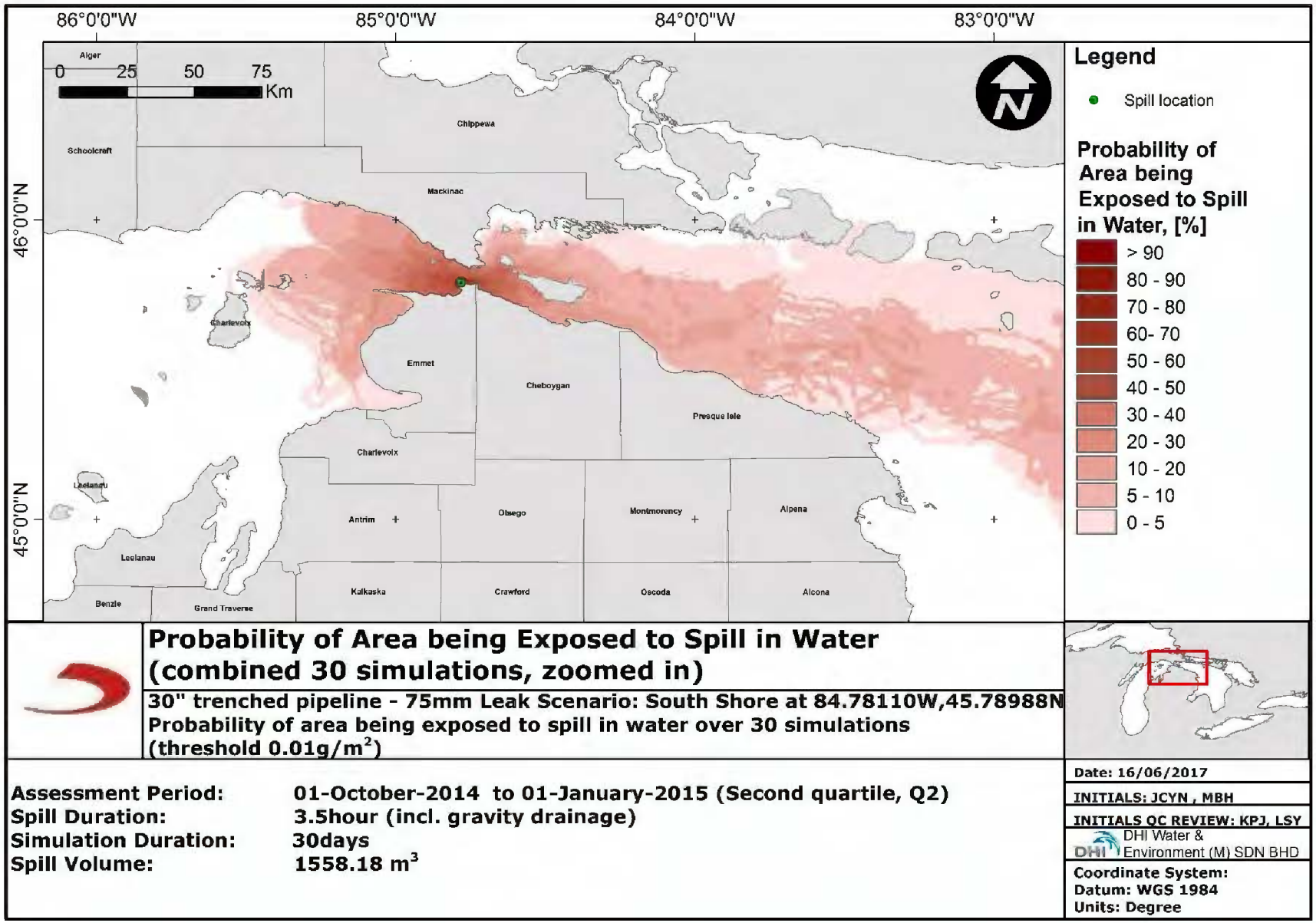


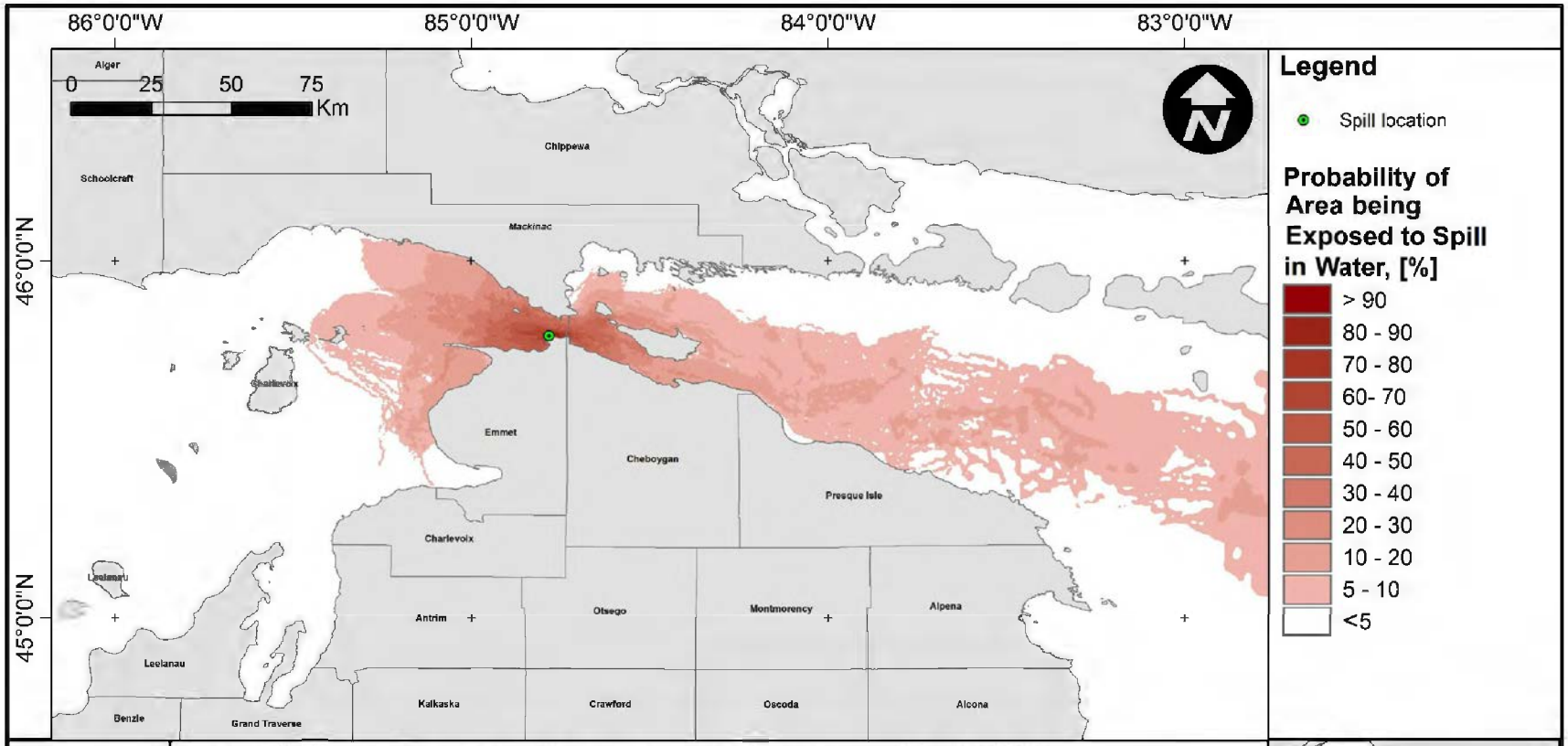
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m2)
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m3
Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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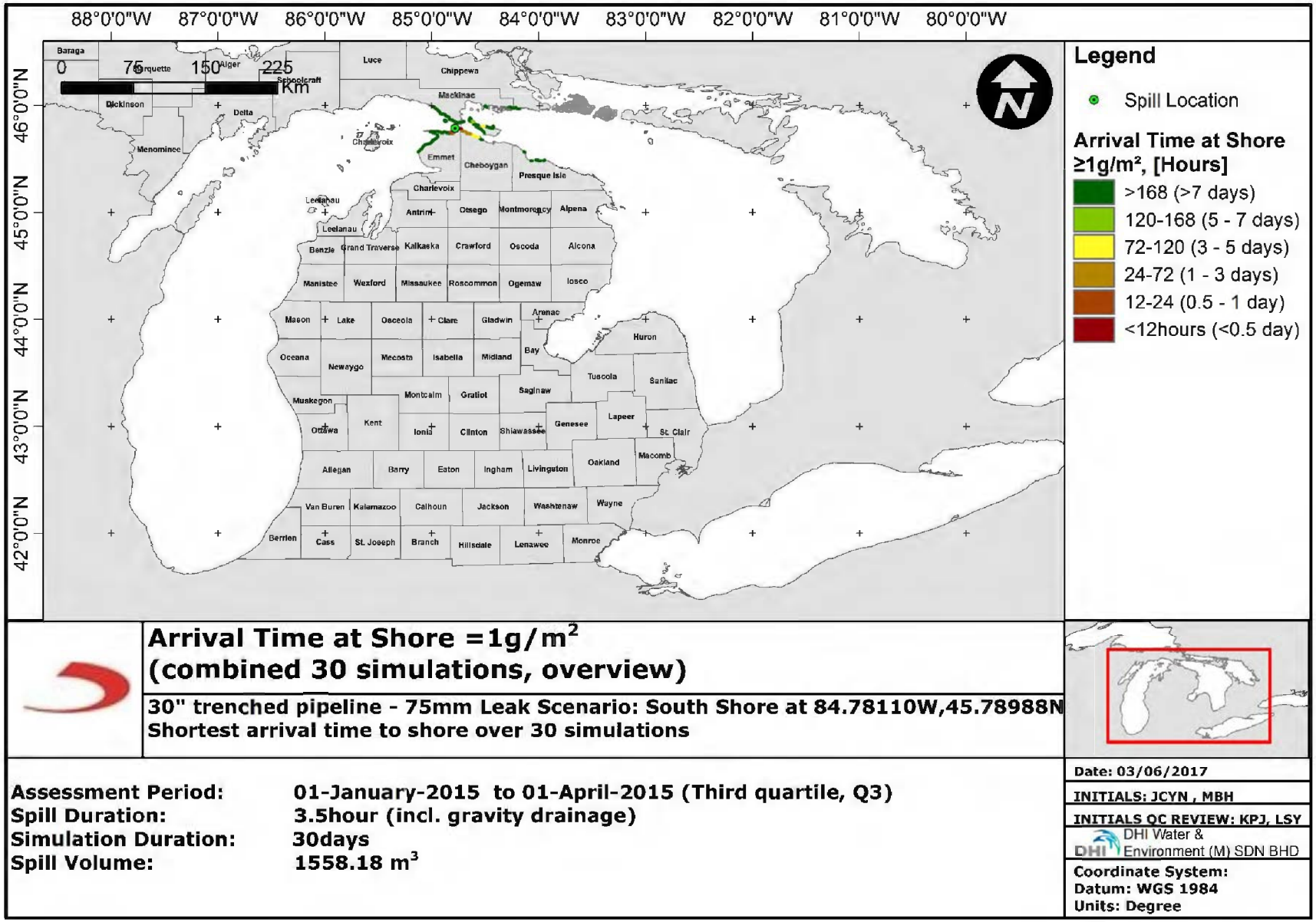
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

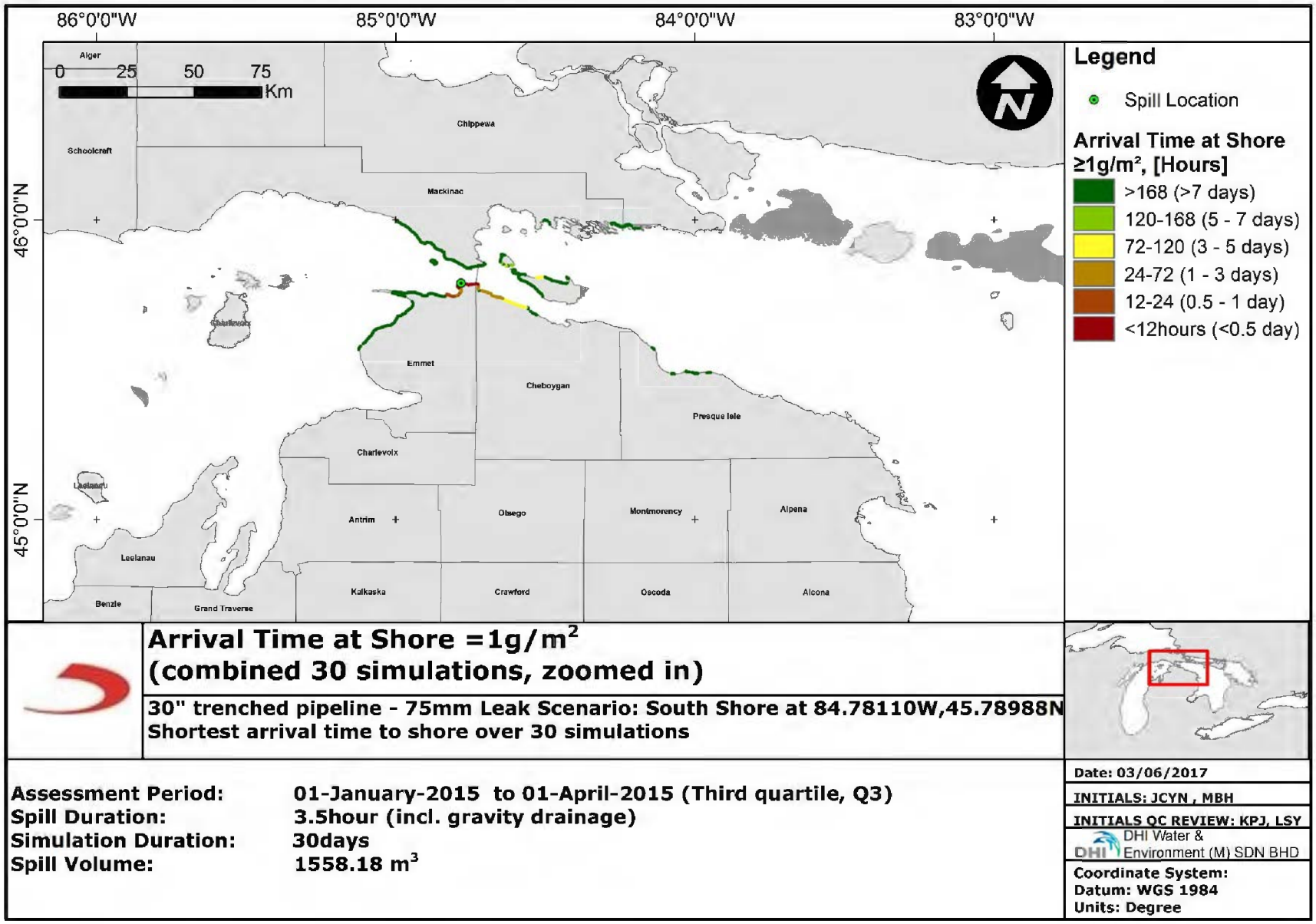
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

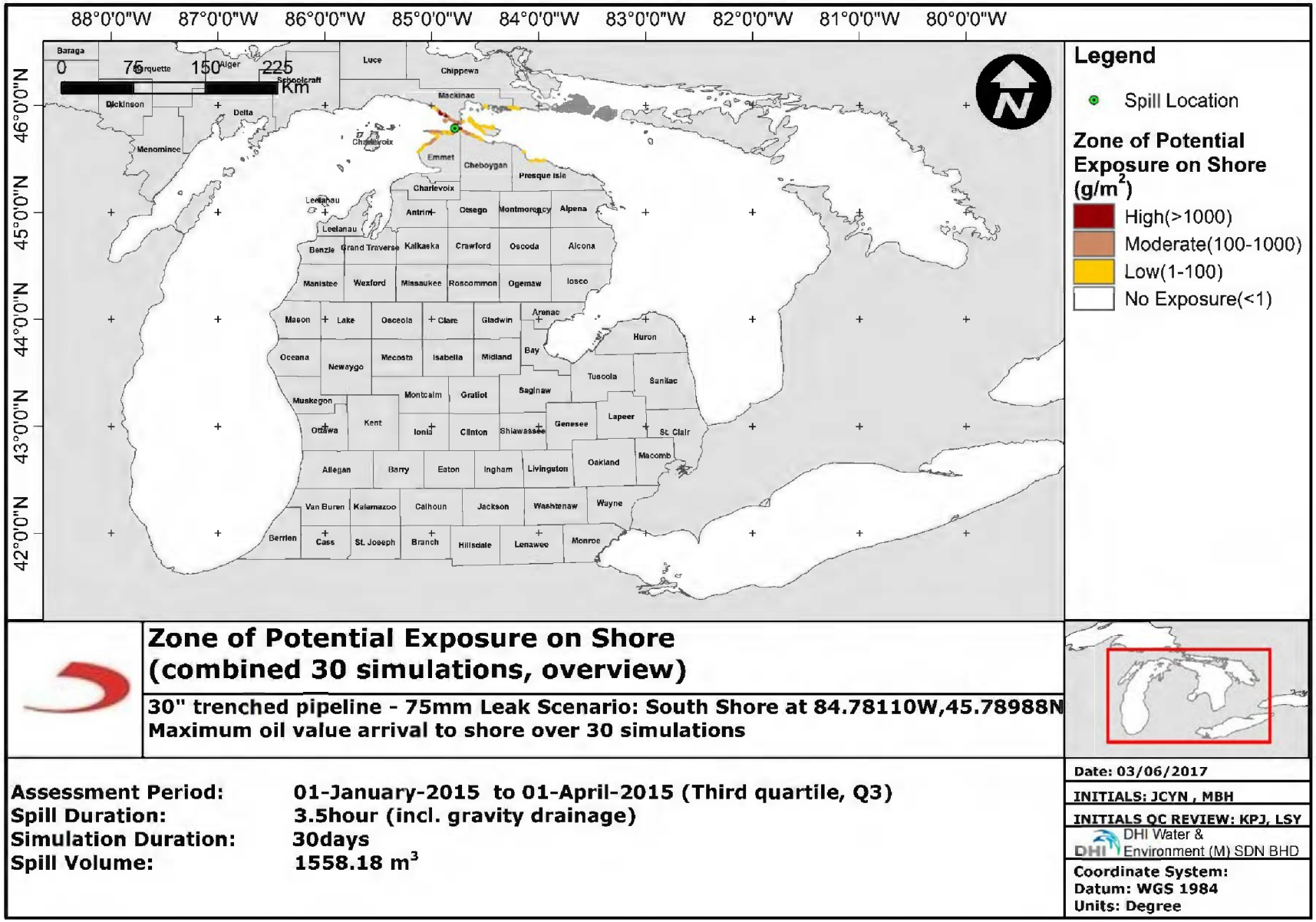
Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

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

Q3


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
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Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
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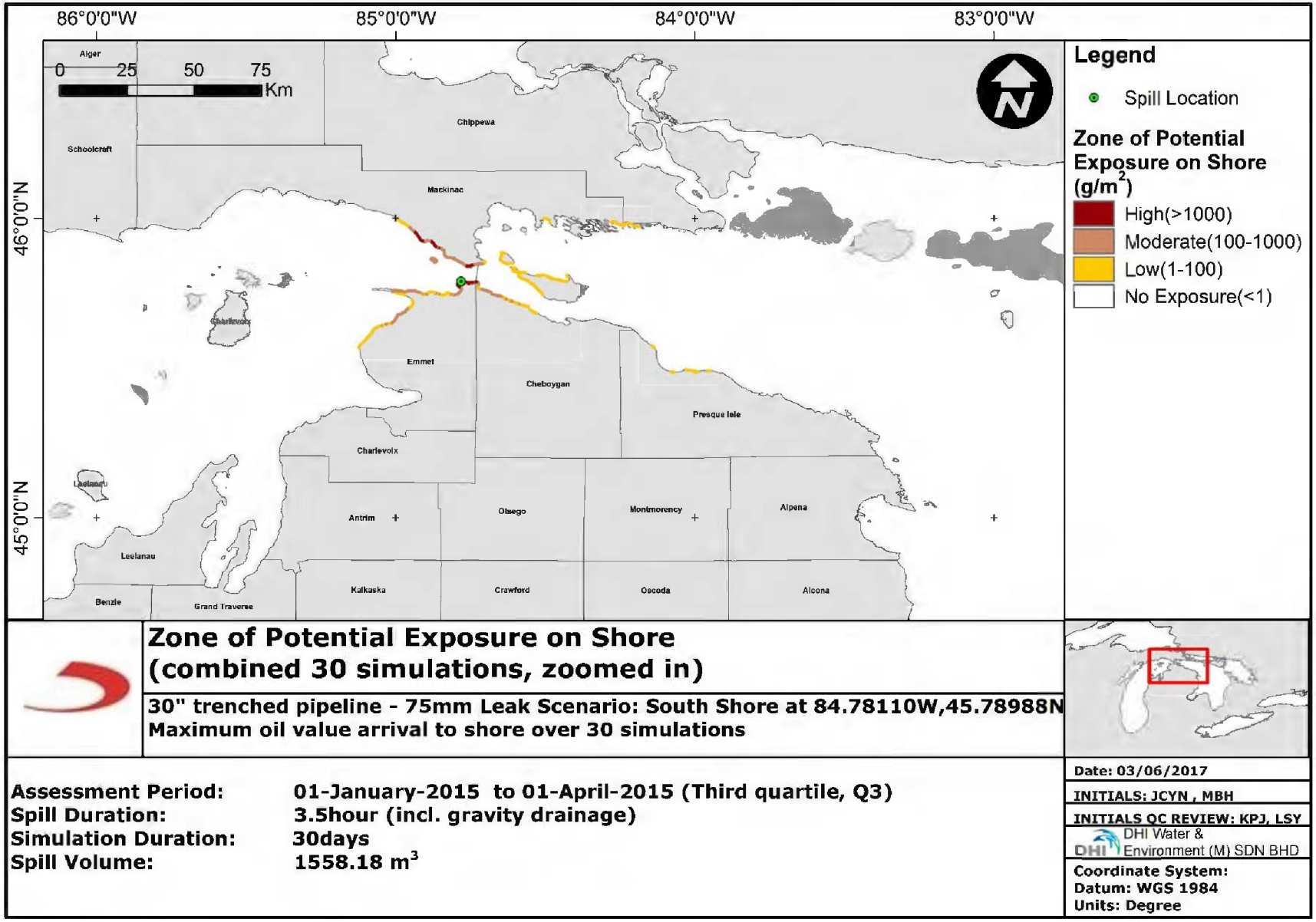


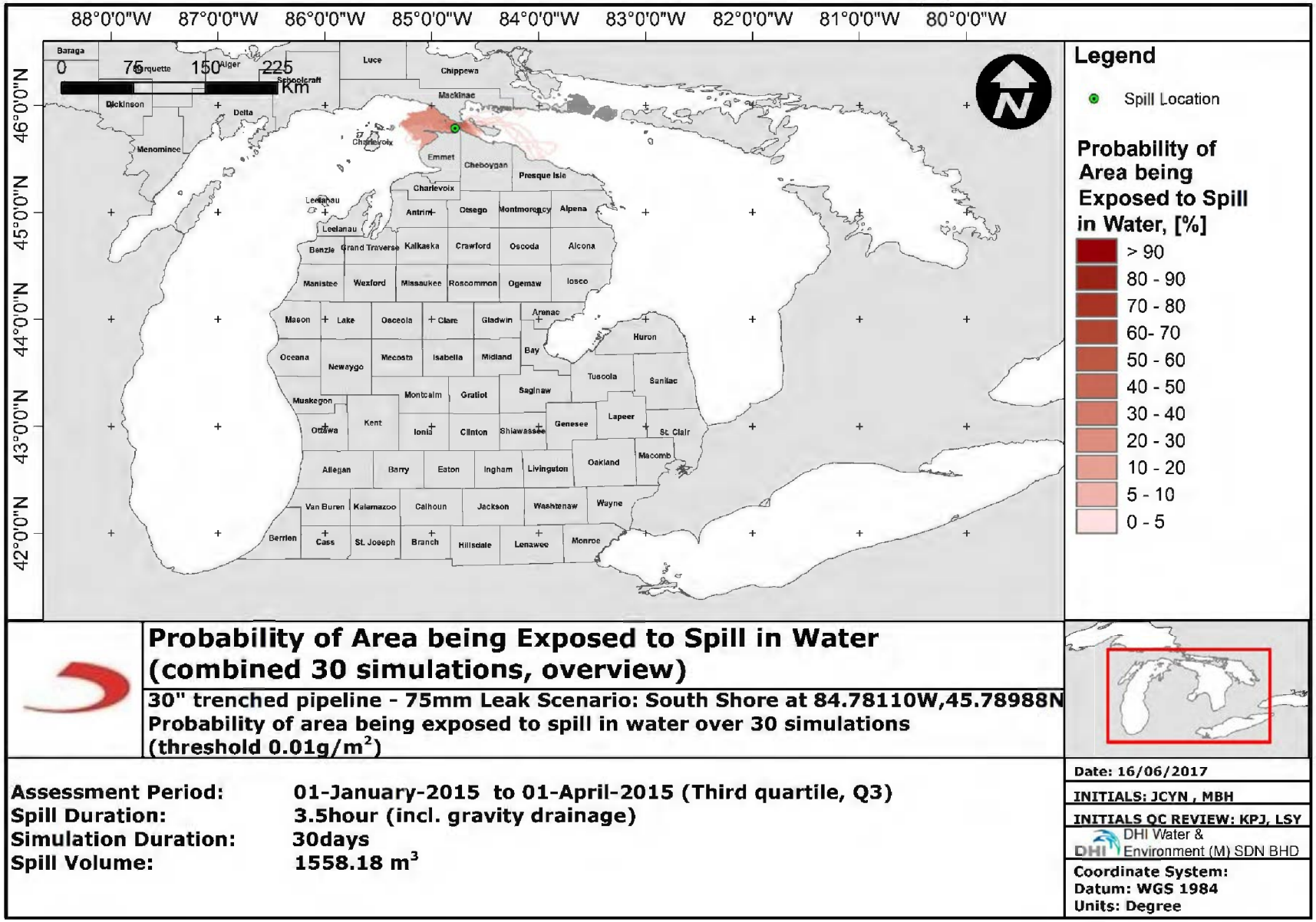
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
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Cheboygan
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Leelanau
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Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

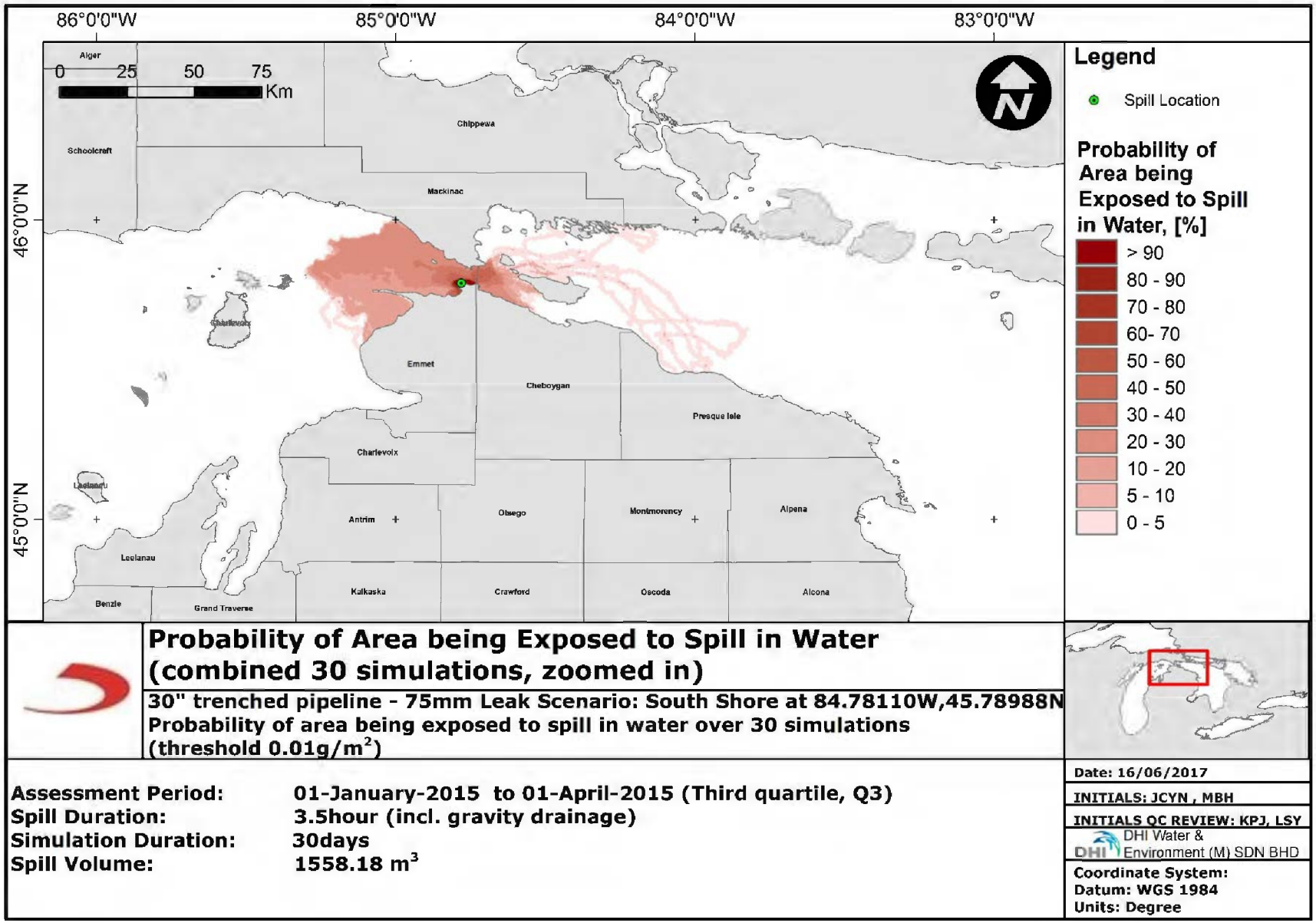


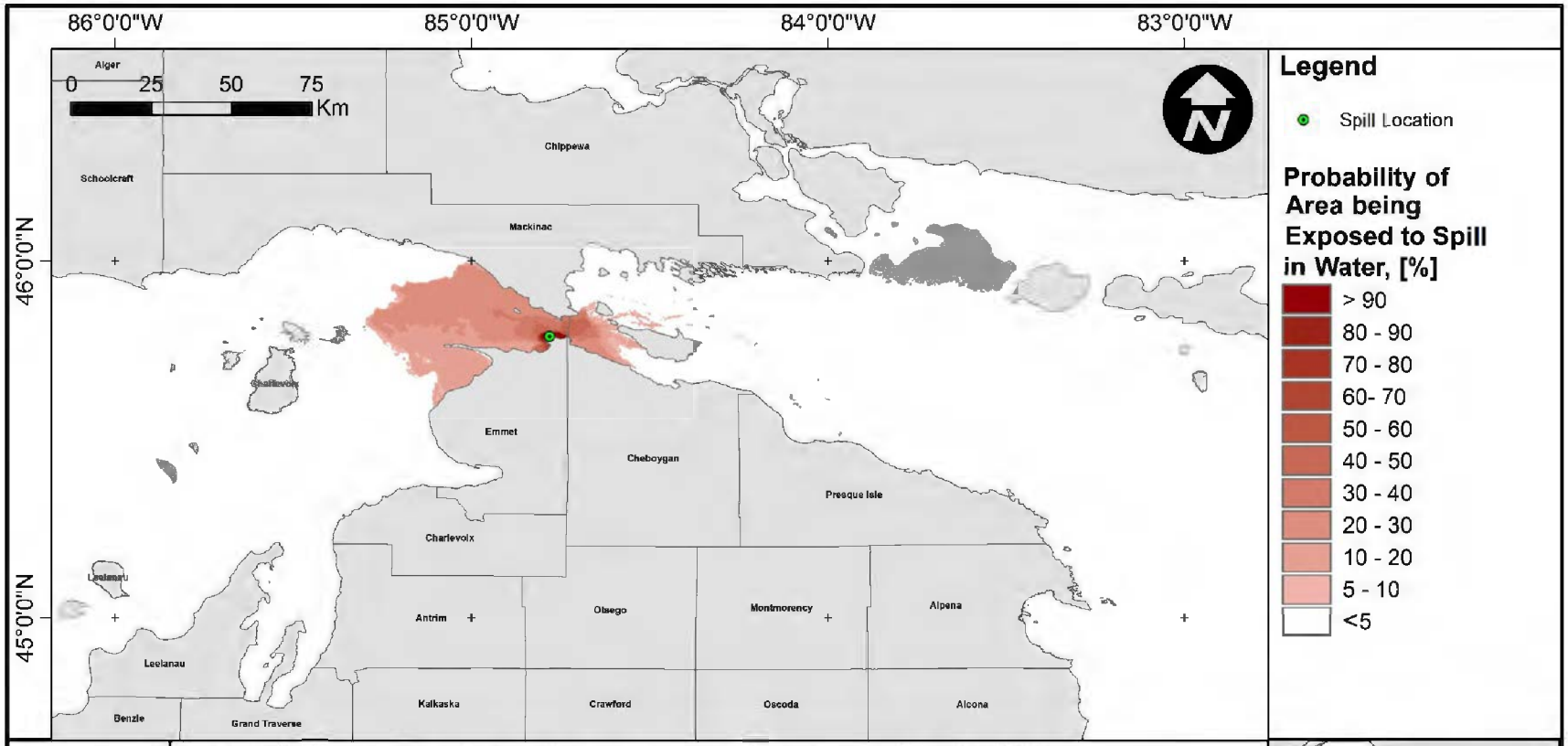
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
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0 25 50 75
Km
Alger
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Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
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Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 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



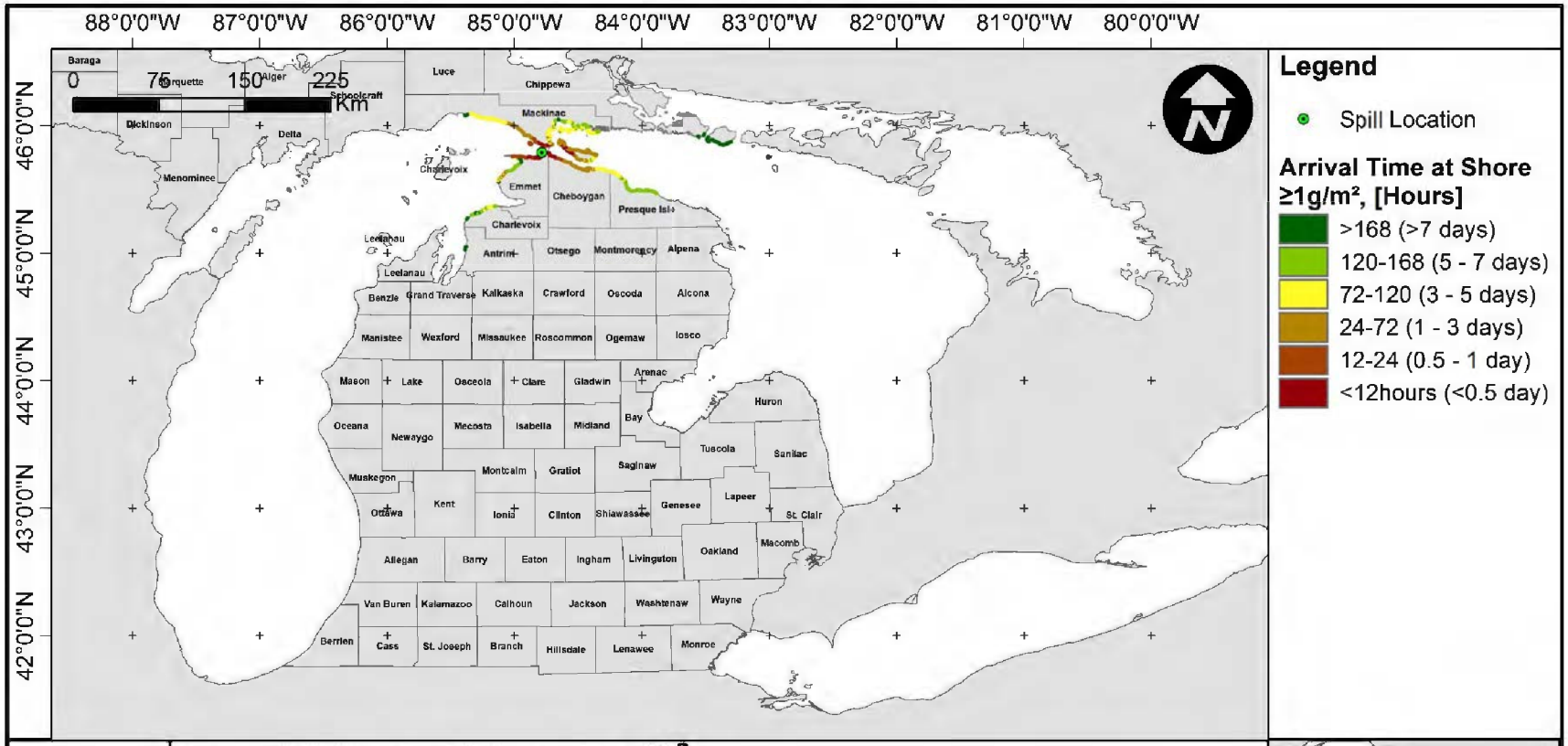
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

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

Q4

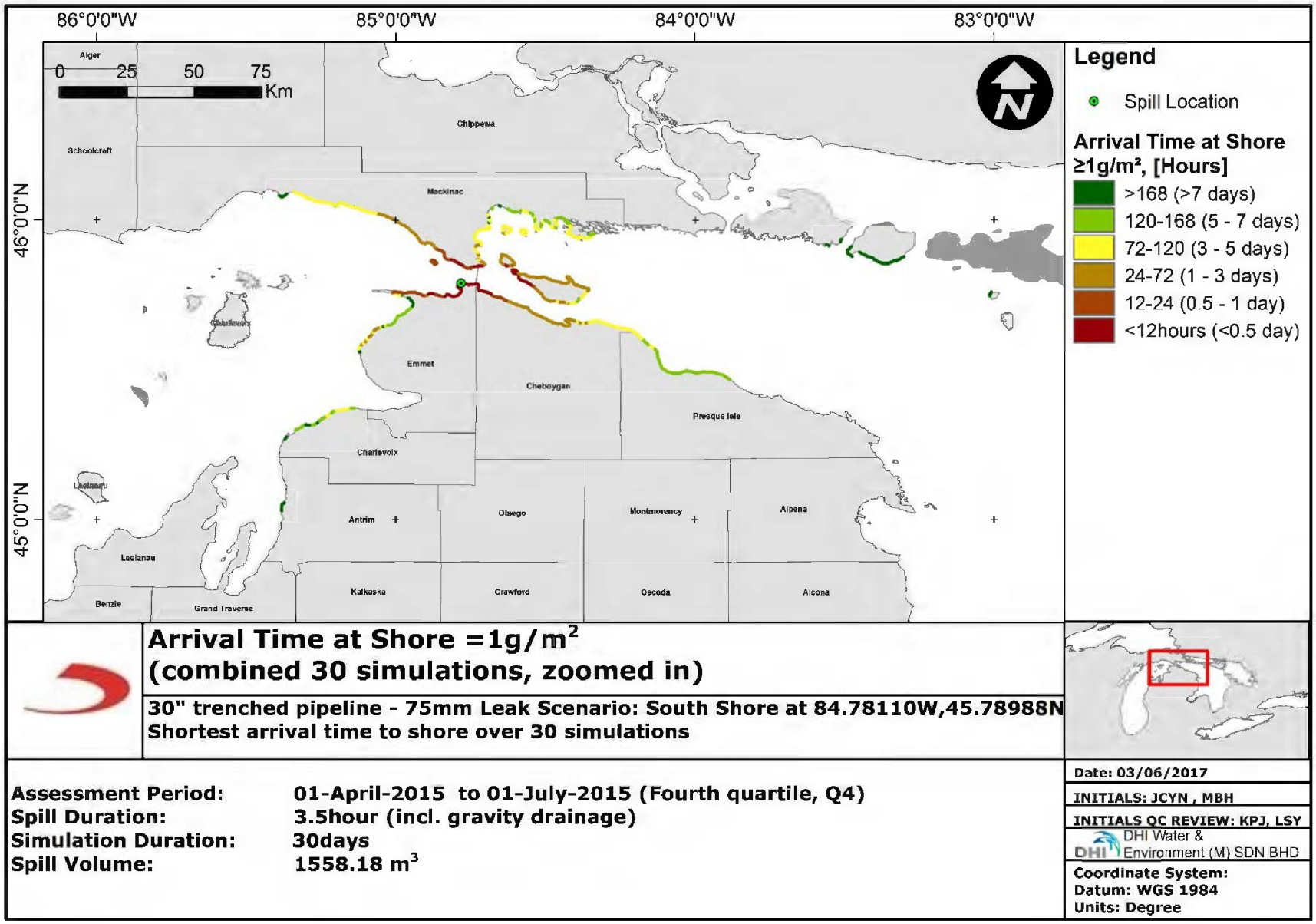


Arrival Time at Shore =1g/m² (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

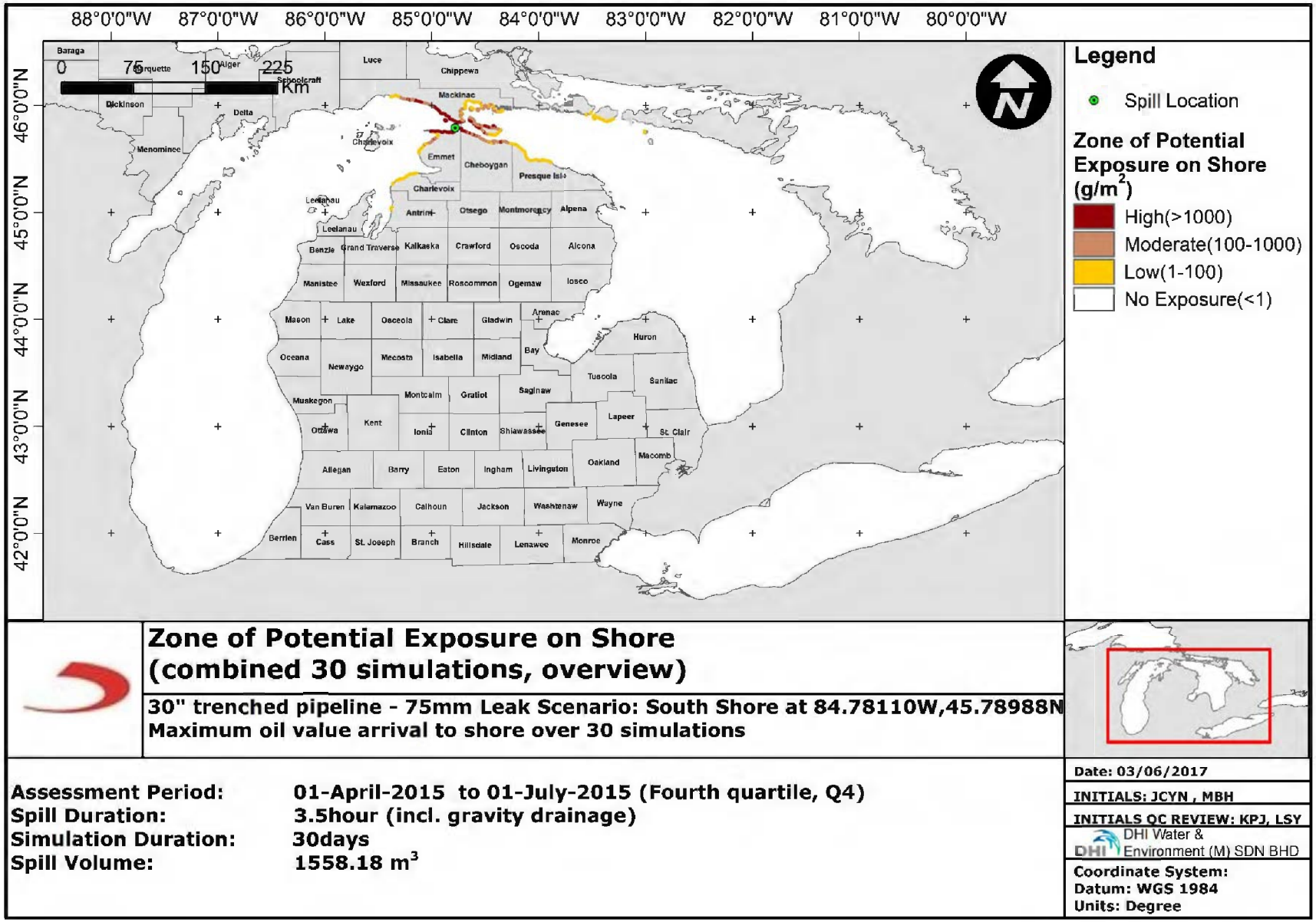


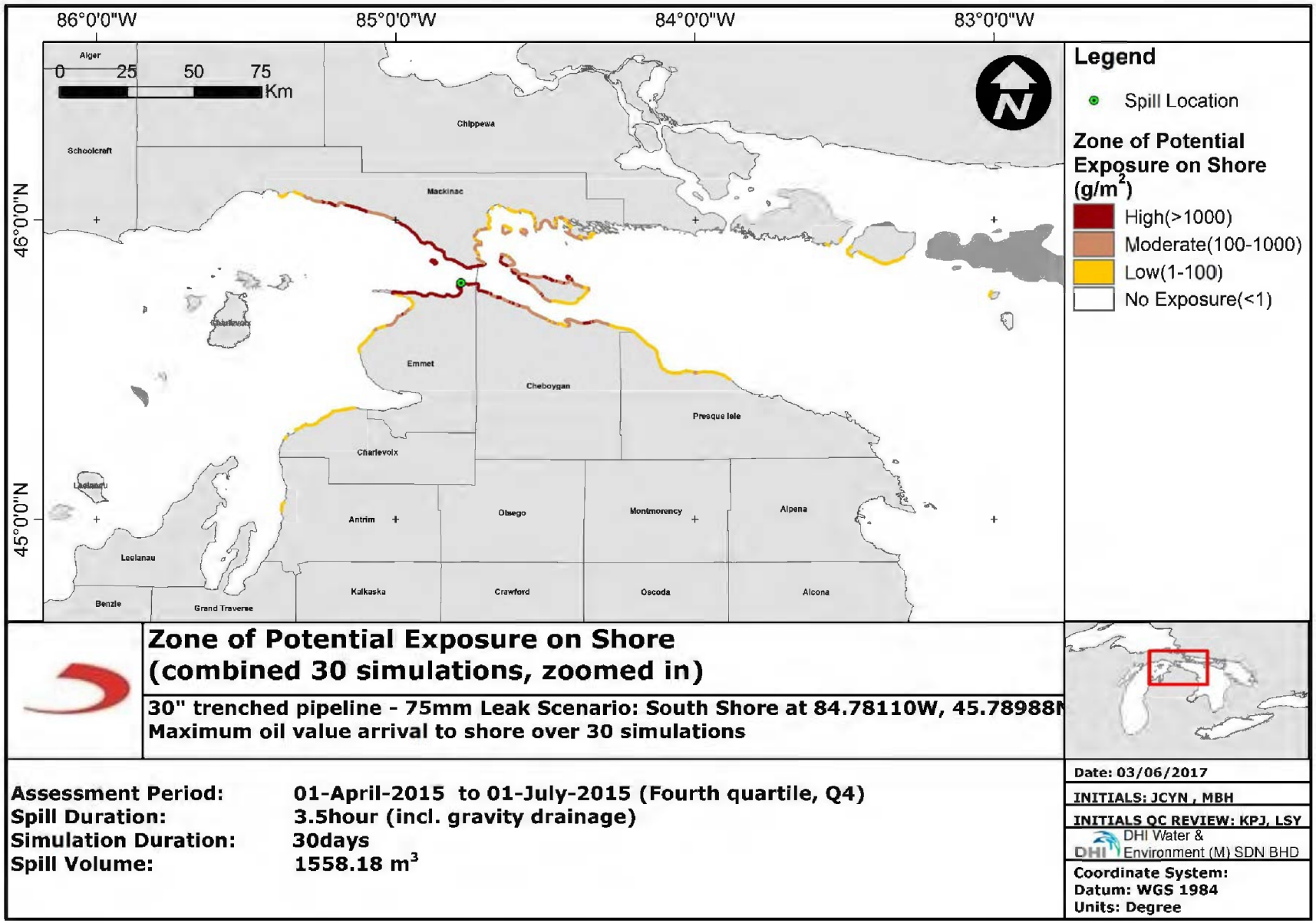
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)

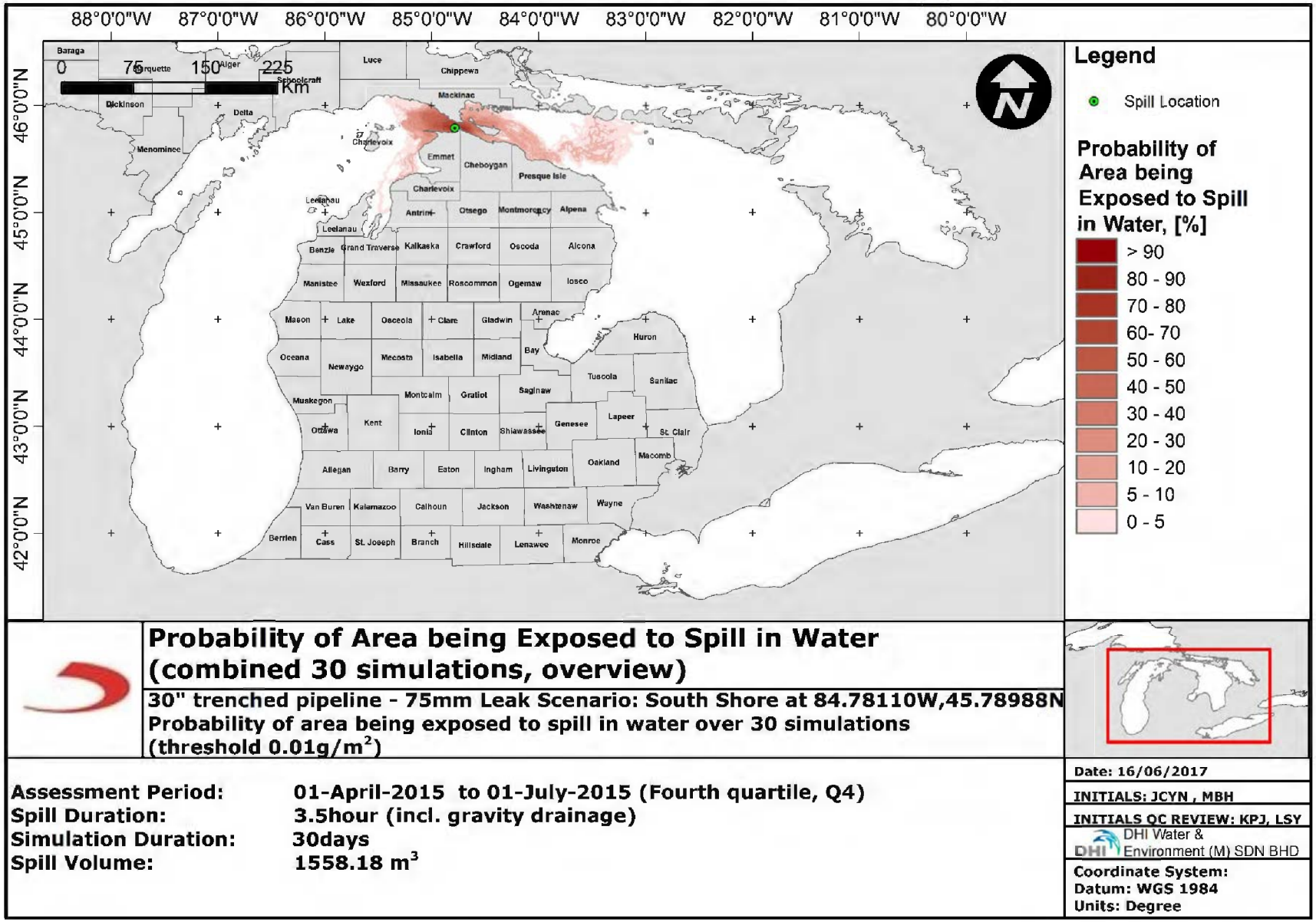
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, overview)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Emmet
Cheboygan
Presque Isle
Charlevoix
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W, 45.78988N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

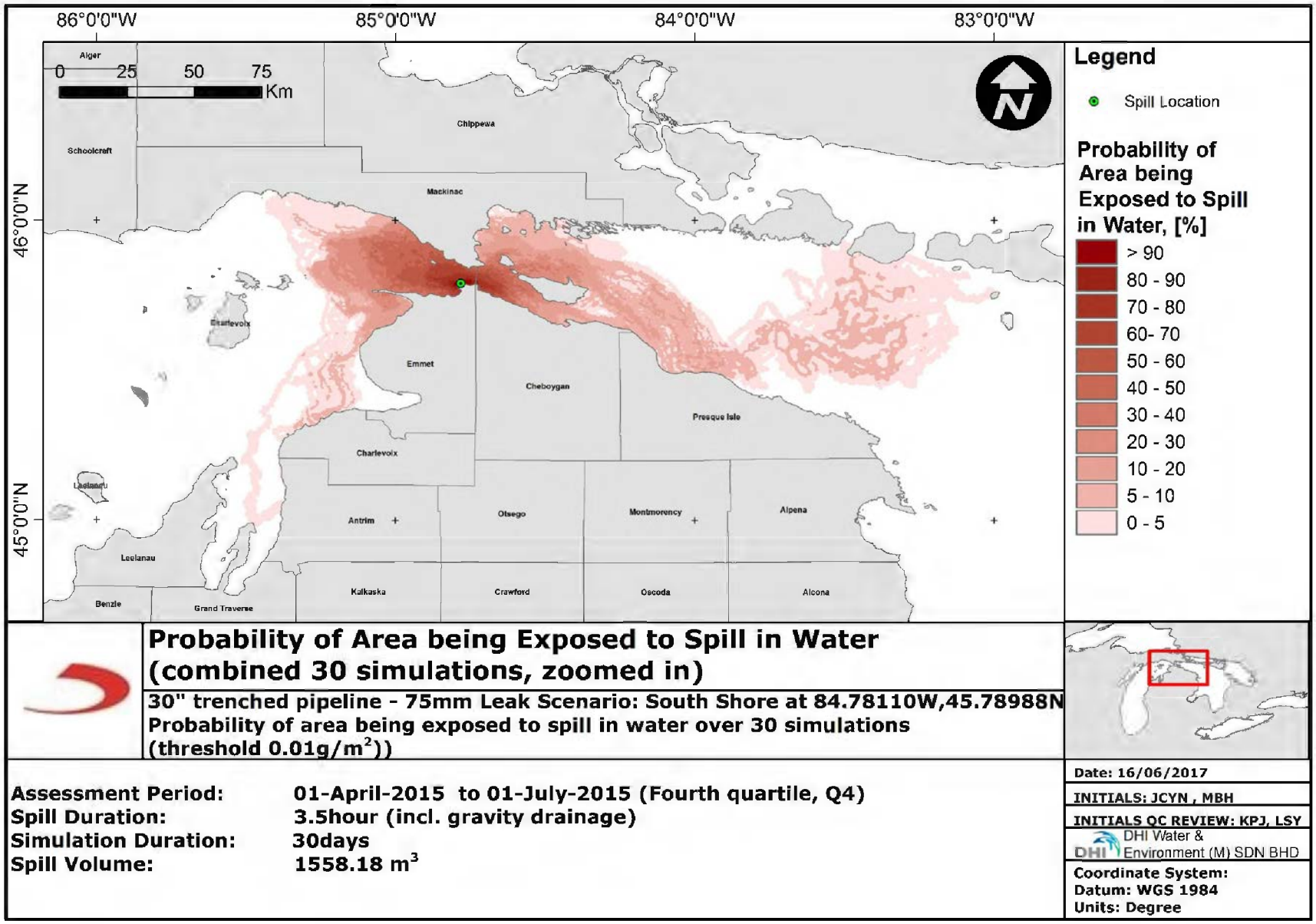


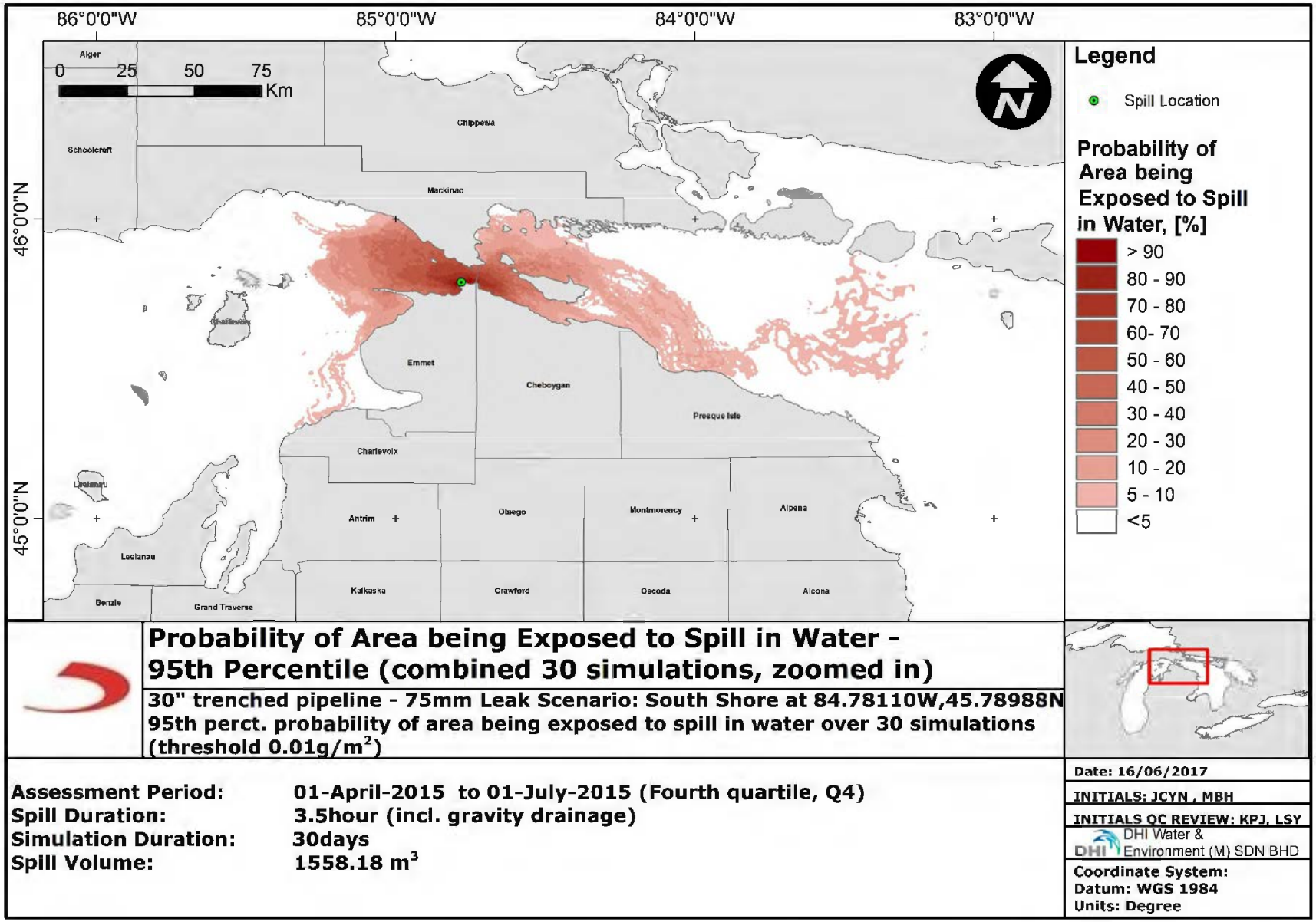
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²))
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 3.5hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 1558.18 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



Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

30" trenched pipeline - 75mm Leak Scenario: South Shore at 84.78110W,45.78988N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

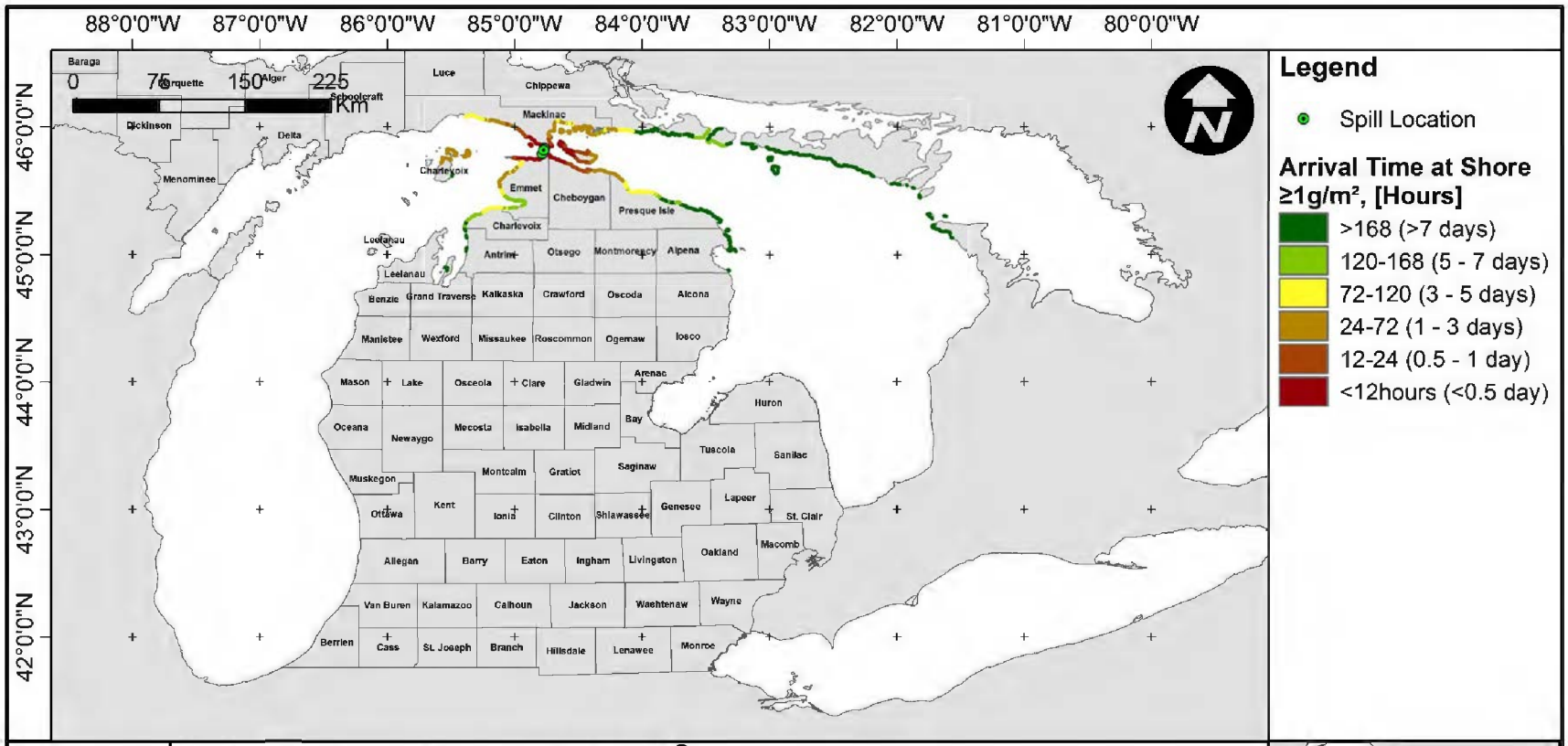
Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**3.5hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**1558.18 m^3**

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

Set 4 30” Trenched Pipeline – 360 Simulations Combined

ENBDNR0002247

1 year

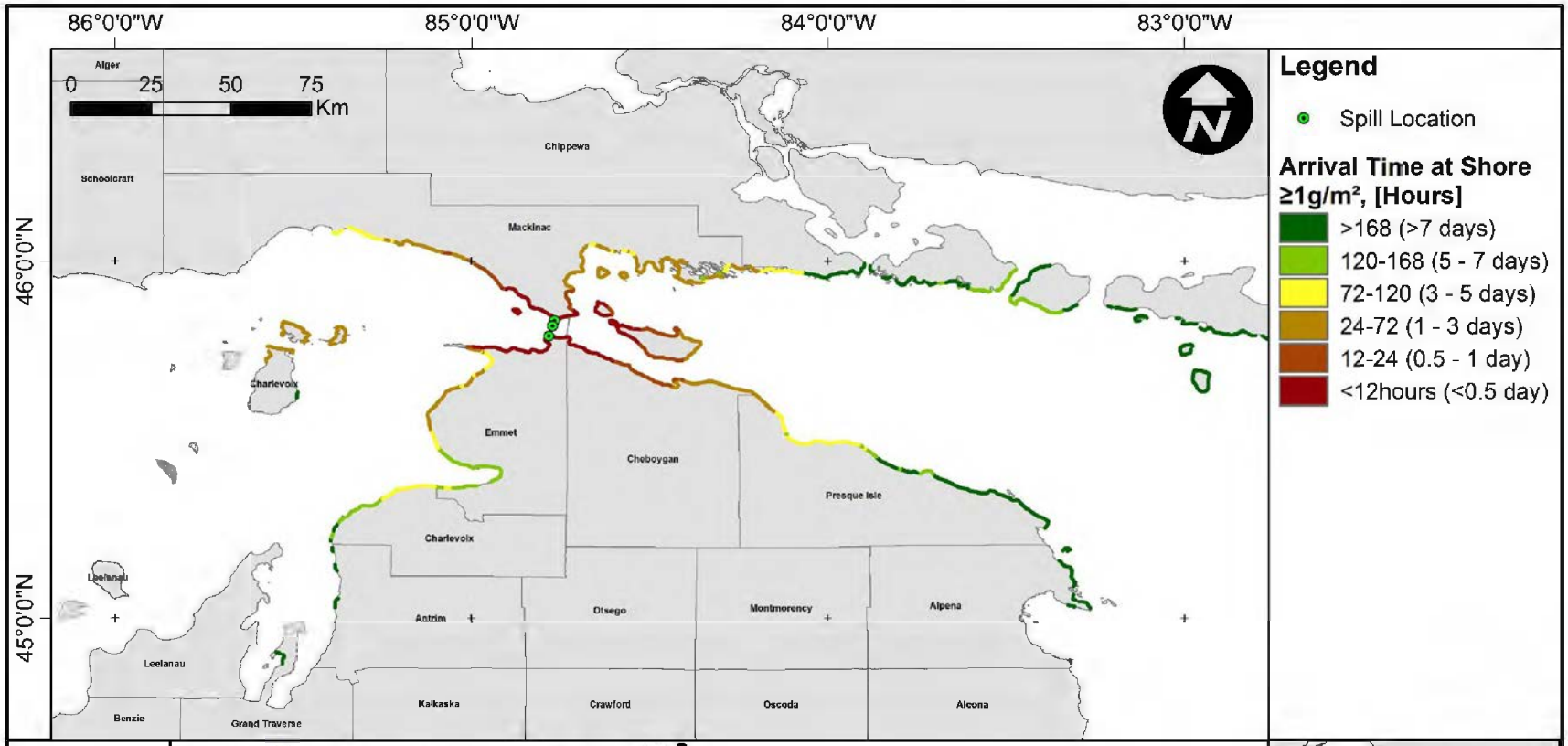


Arrival Time at Shore ≥1g/m² (combined 360 simulations, overview)

30" trenched pipeline
Shortest arrival time to shore over 360 simulations

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

Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

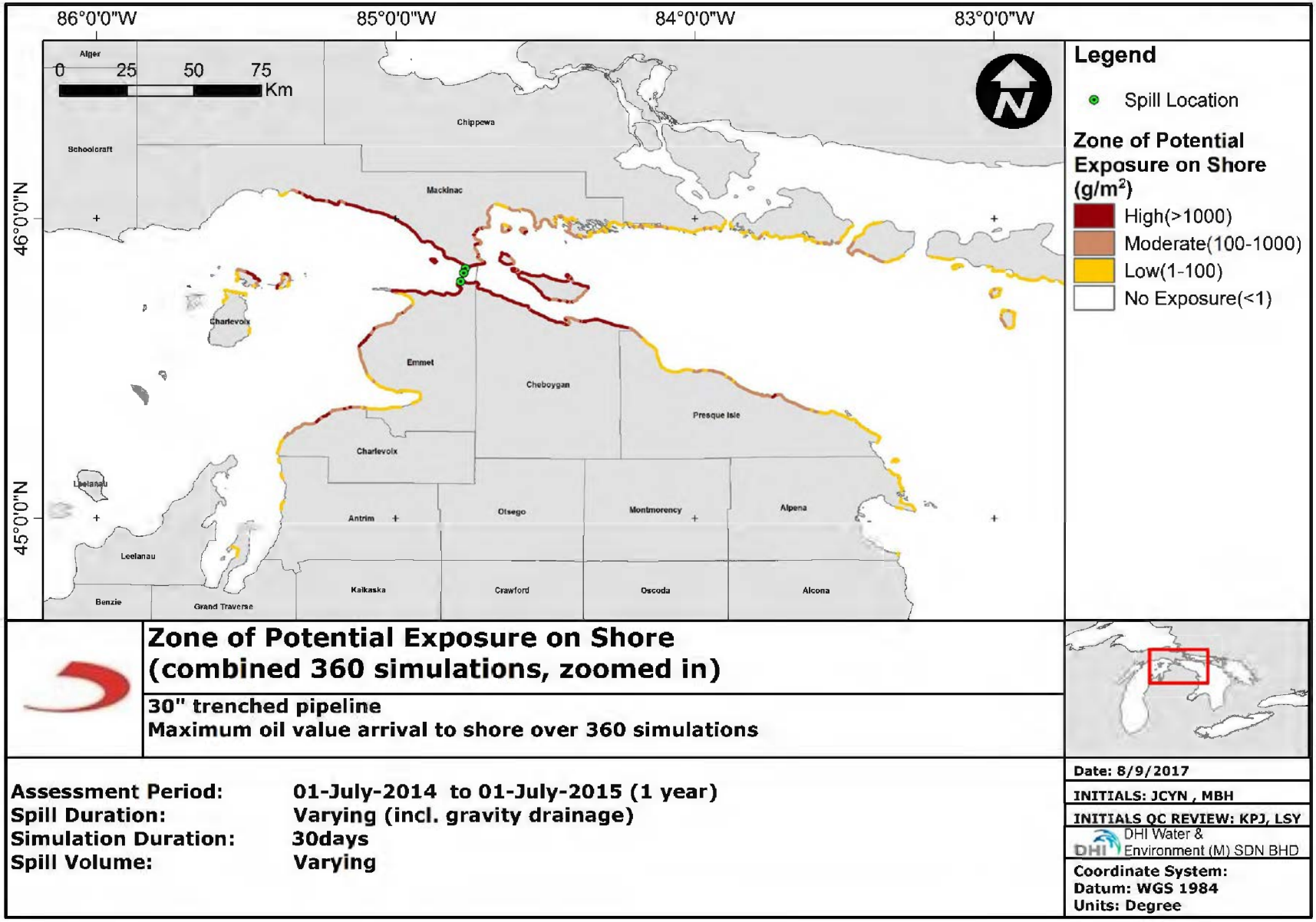


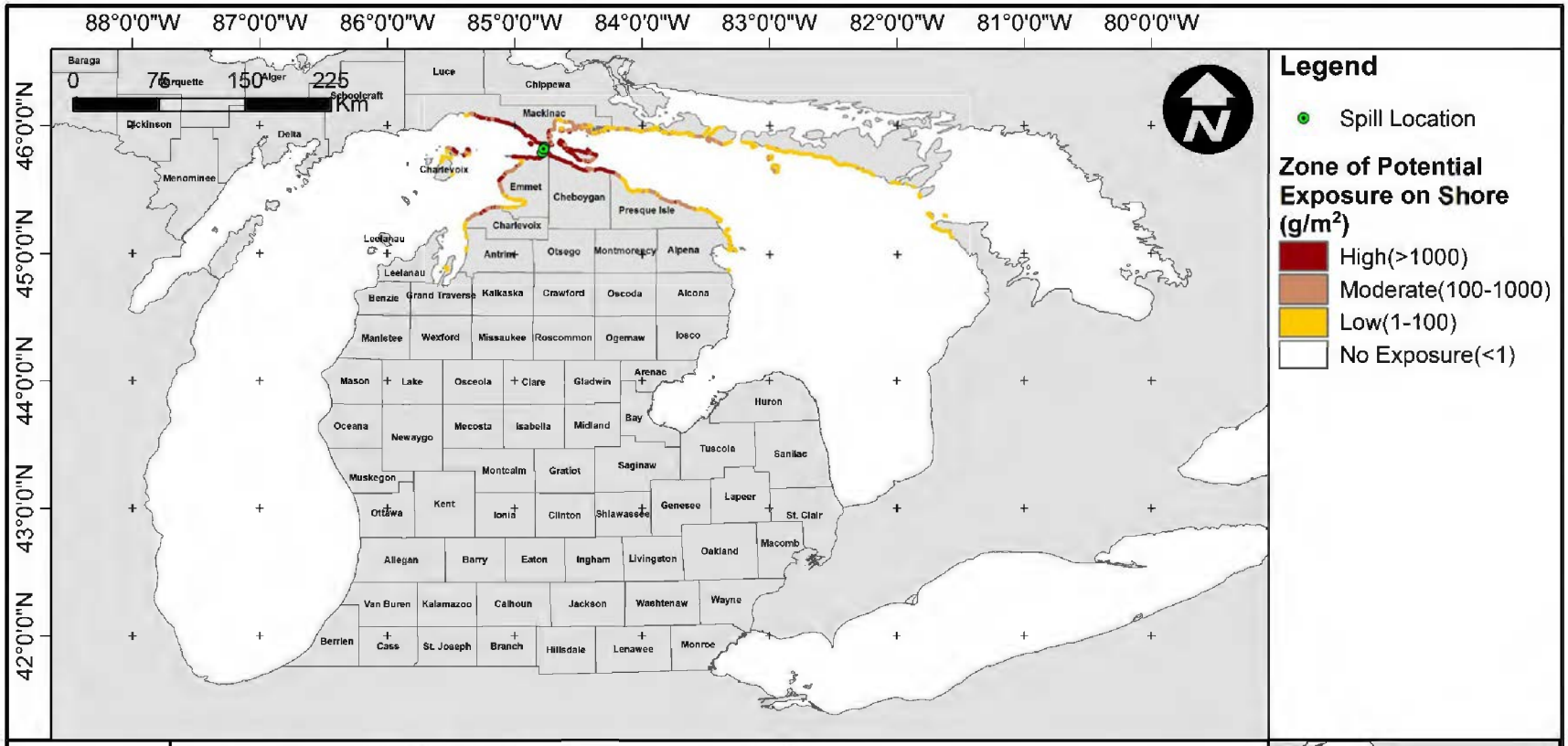
Arrival Time at Shore ≥1g/m² (combined 360 simulations, zoomed in)

30" trenched pipeline
Shortest arrival time to shore over 360 simulations

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

Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 360 simulations, zoomed in)
30" trenched pipeline
Maximum oil value arrival to shore over 360 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: Varying (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: Varying
Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

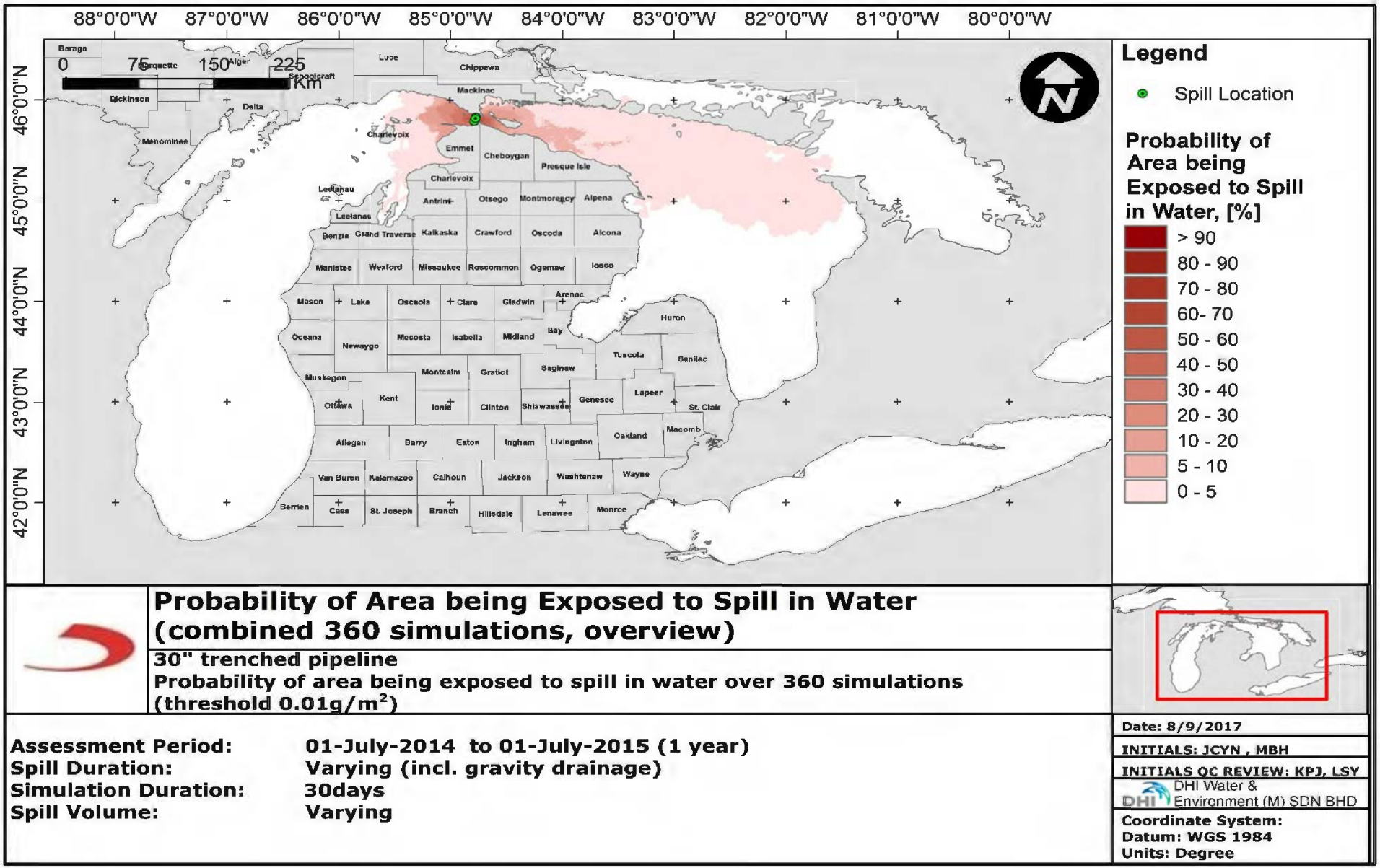


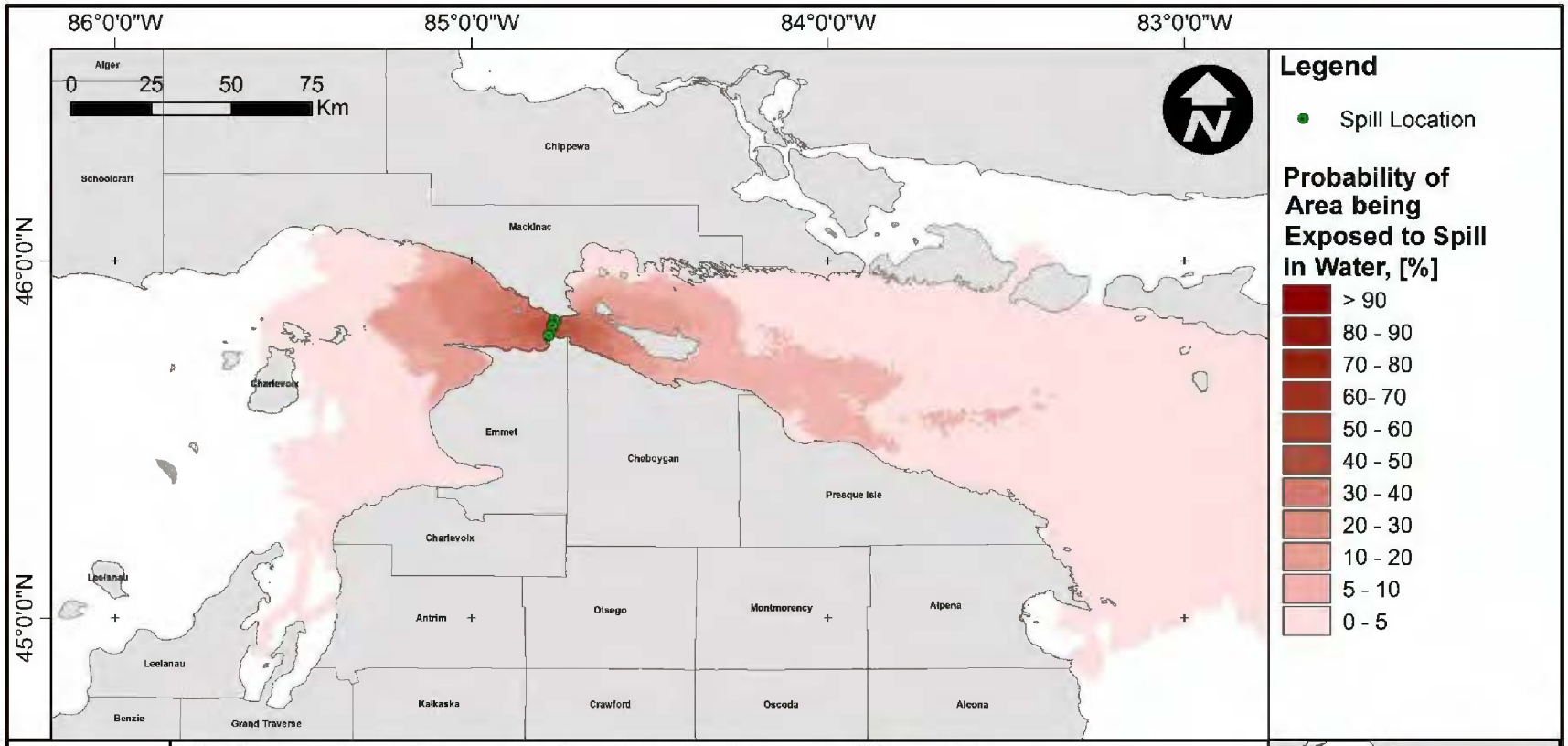
Zone of Potential Exposure on Shore (combined 360 simulations, overview)

30" trenched pipeline
Maximum oil value arrival to shore over 360 simulations

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

Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
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46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 360 simulations, overview)
30" trenched pipeline
Probability of area being exposed to spill in water over 360 simulations (threshold 0.01g/m²)
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: Varying (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: Varying
Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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Units: Degree

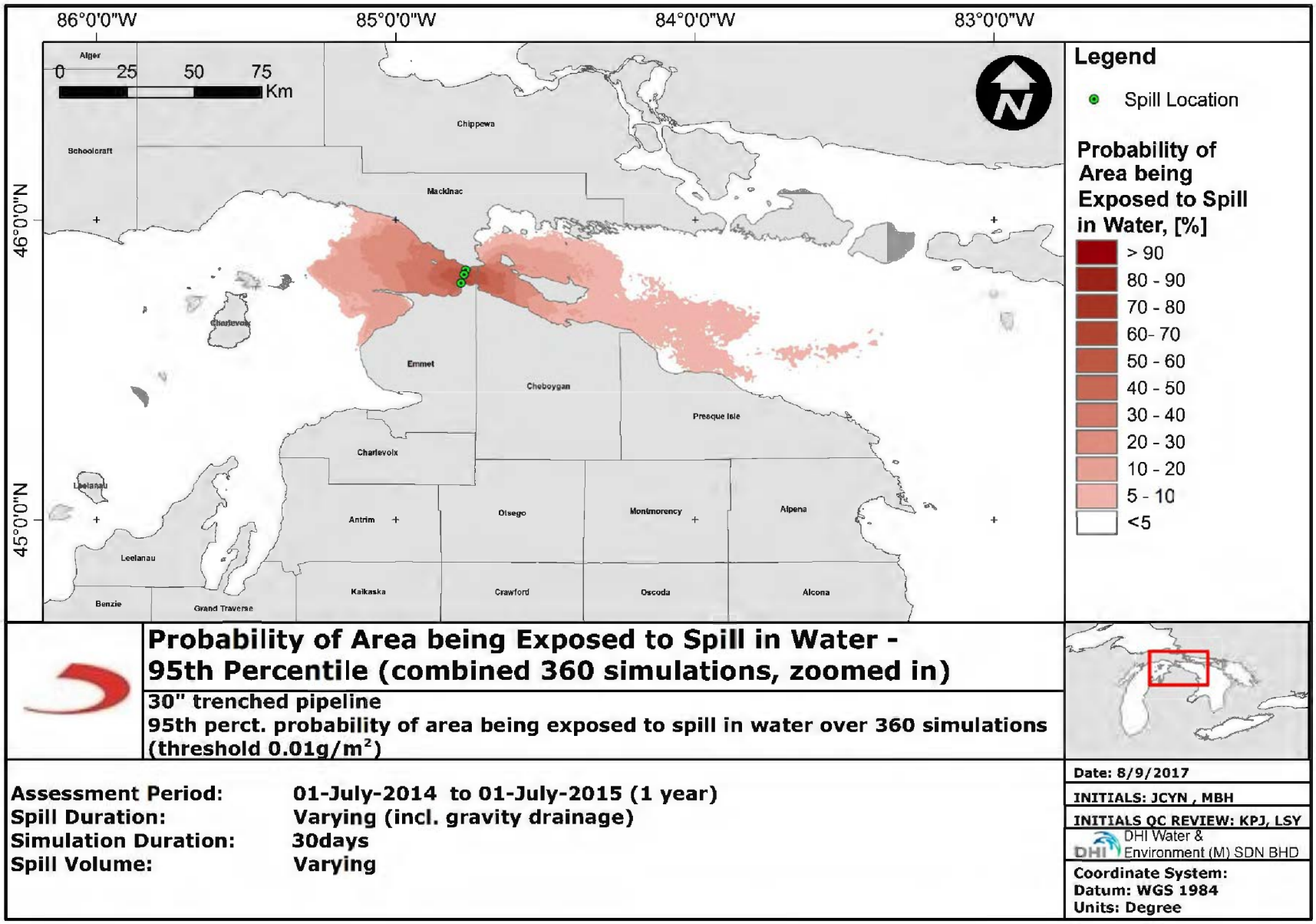


Probability of Area being Exposed to Spill in Water (combined 360 simulations, zoomed in)

30" trenched pipeline
Probability of area being exposed to spill in water over 360 simulations (threshold 0.01g/m^2)

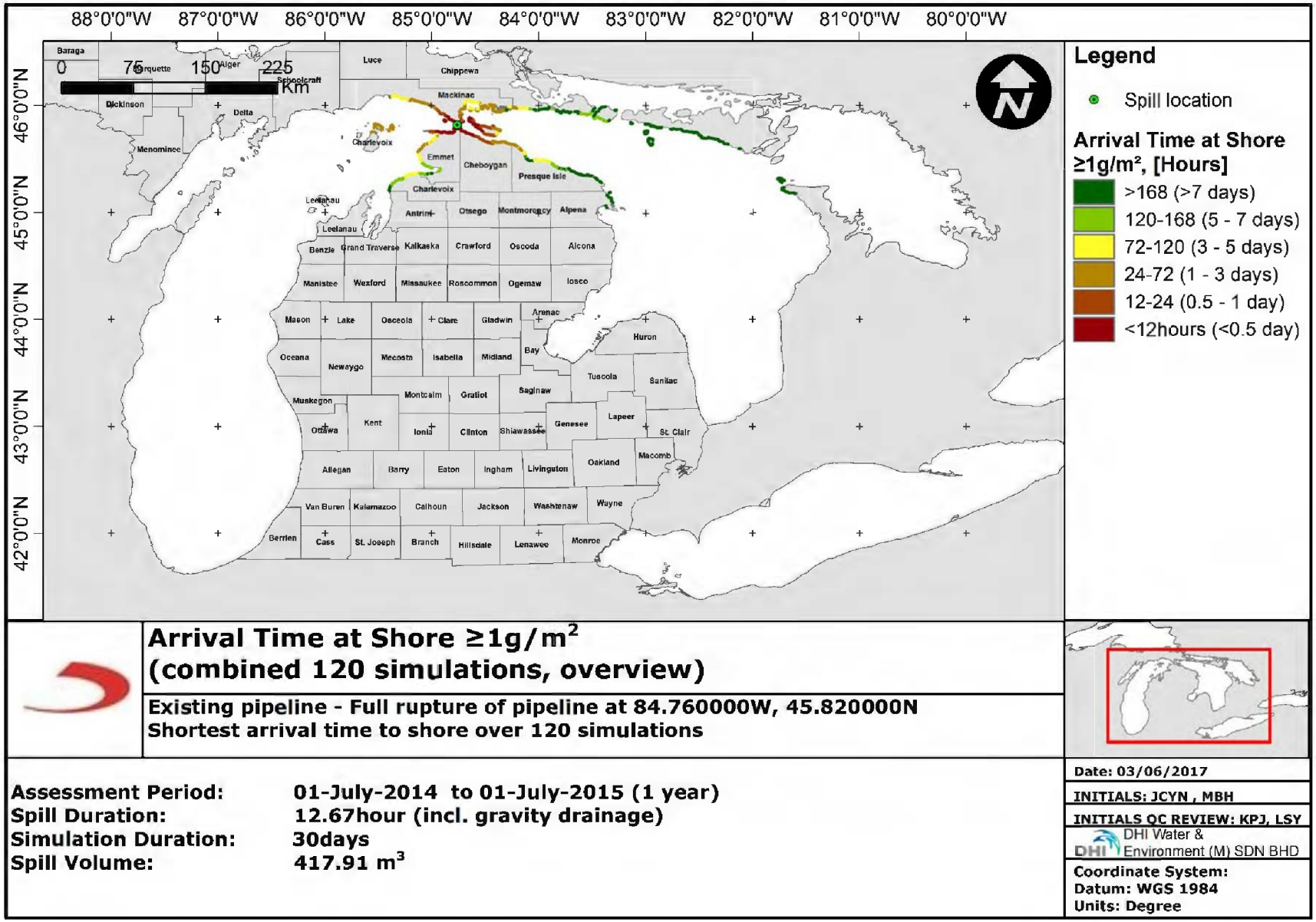
Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**Varying (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**Varying**

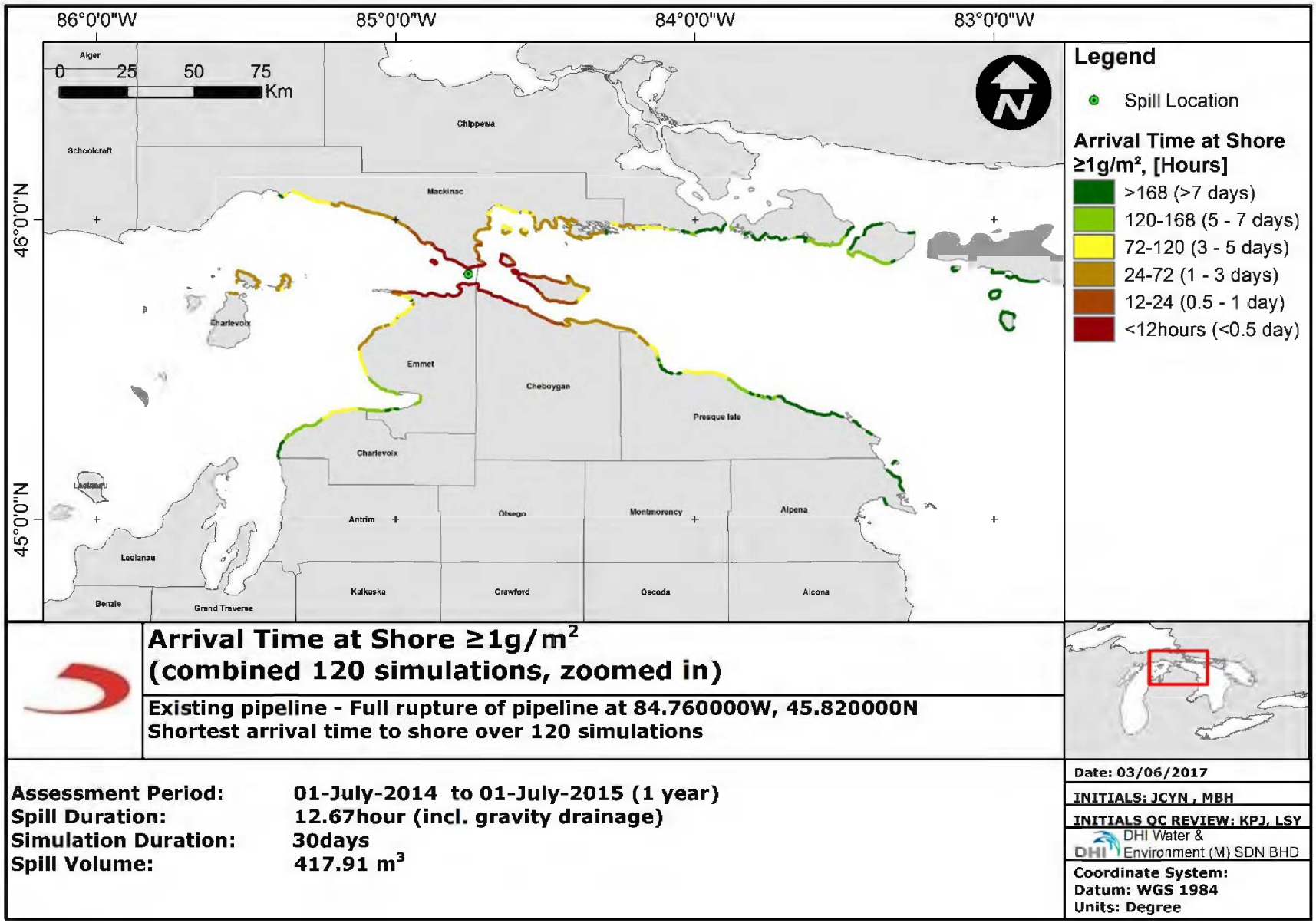
Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

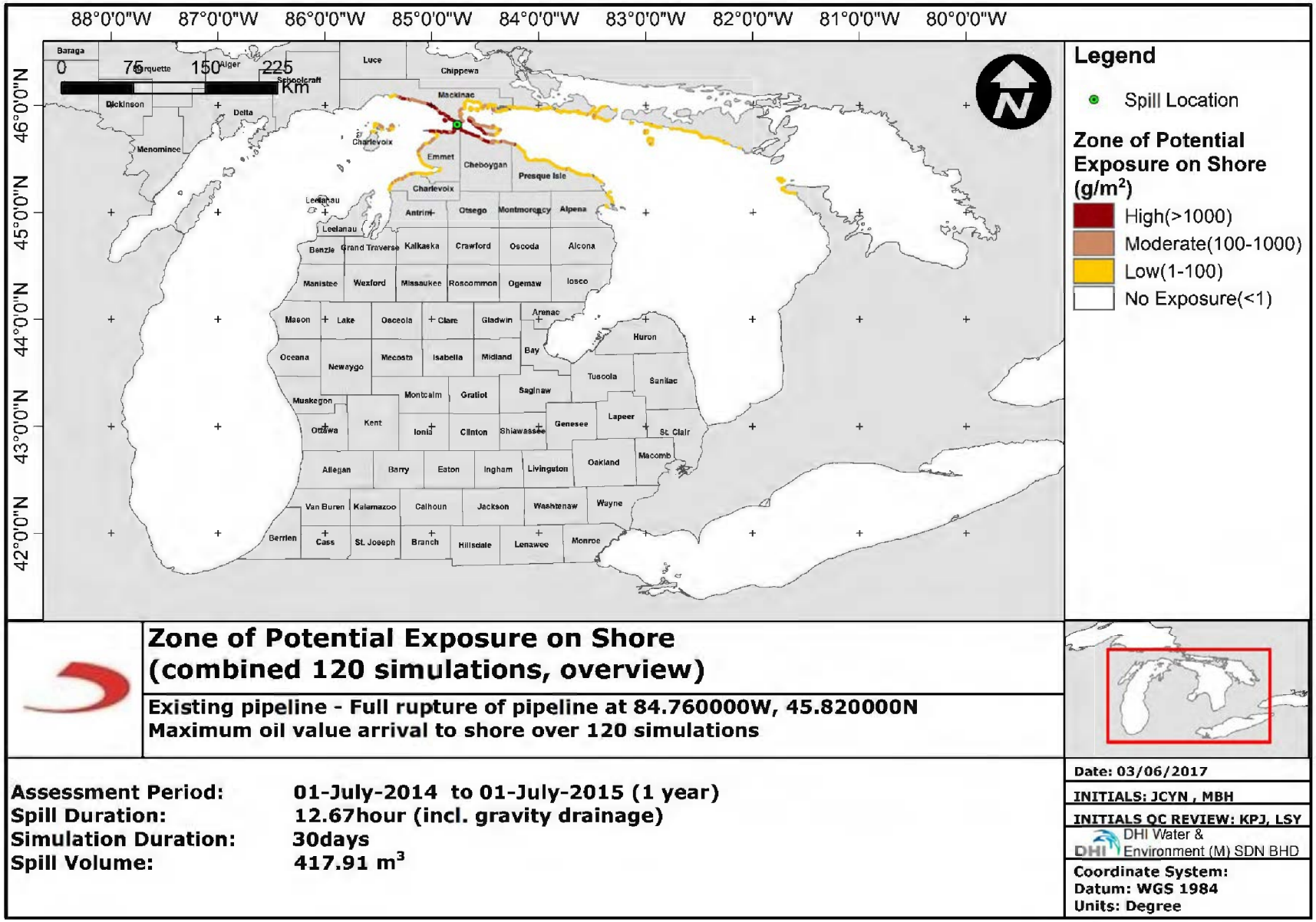

86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
<5
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 360 simulations, zoomed in)
30" trenched pipeline
95th perct. probability of area being exposed to spill in water over 360 simulations (threshold 0.01g/m²)
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: Varying (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: Varying
Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

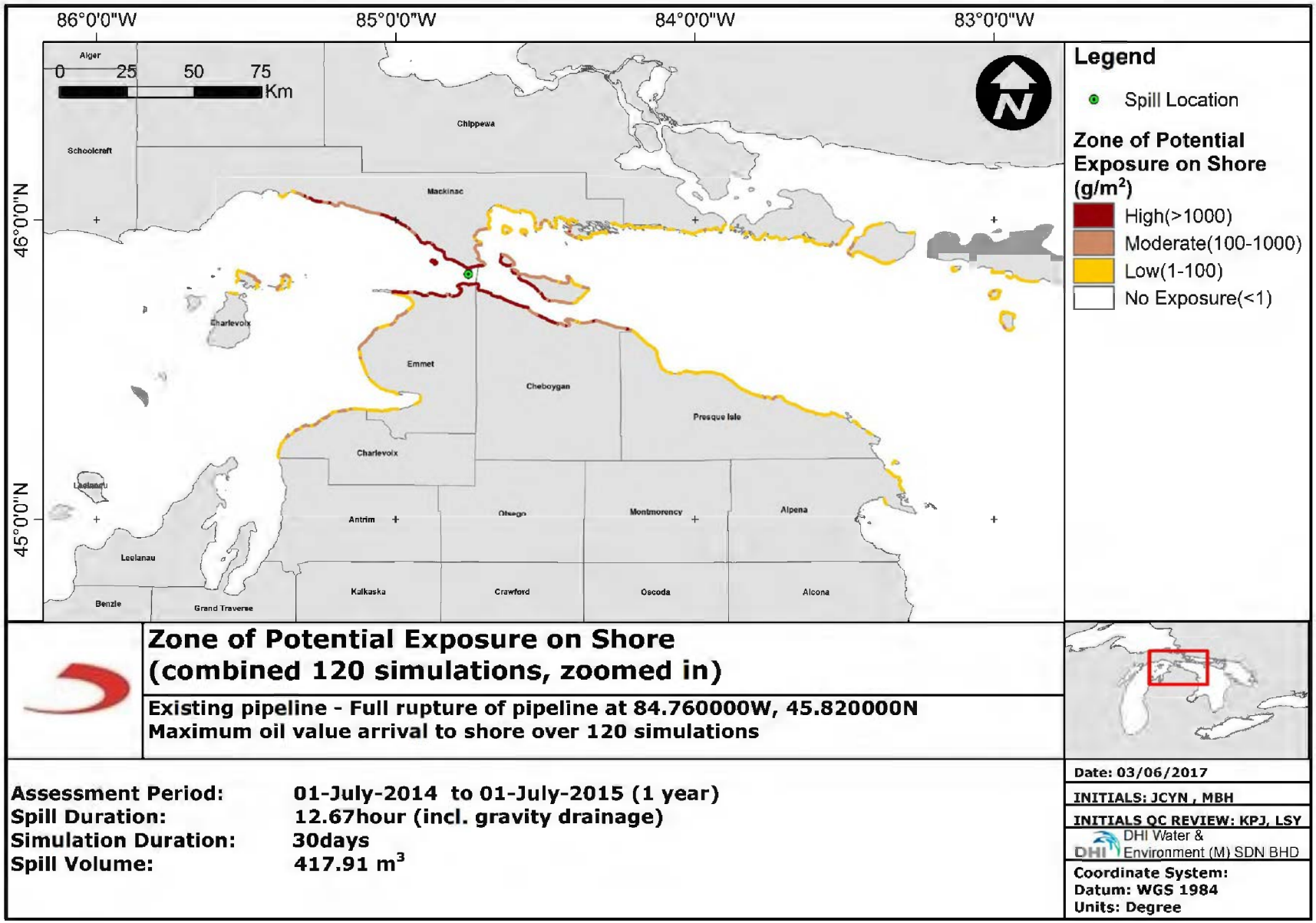
Set 5
Existing Pipeline – Full rupture

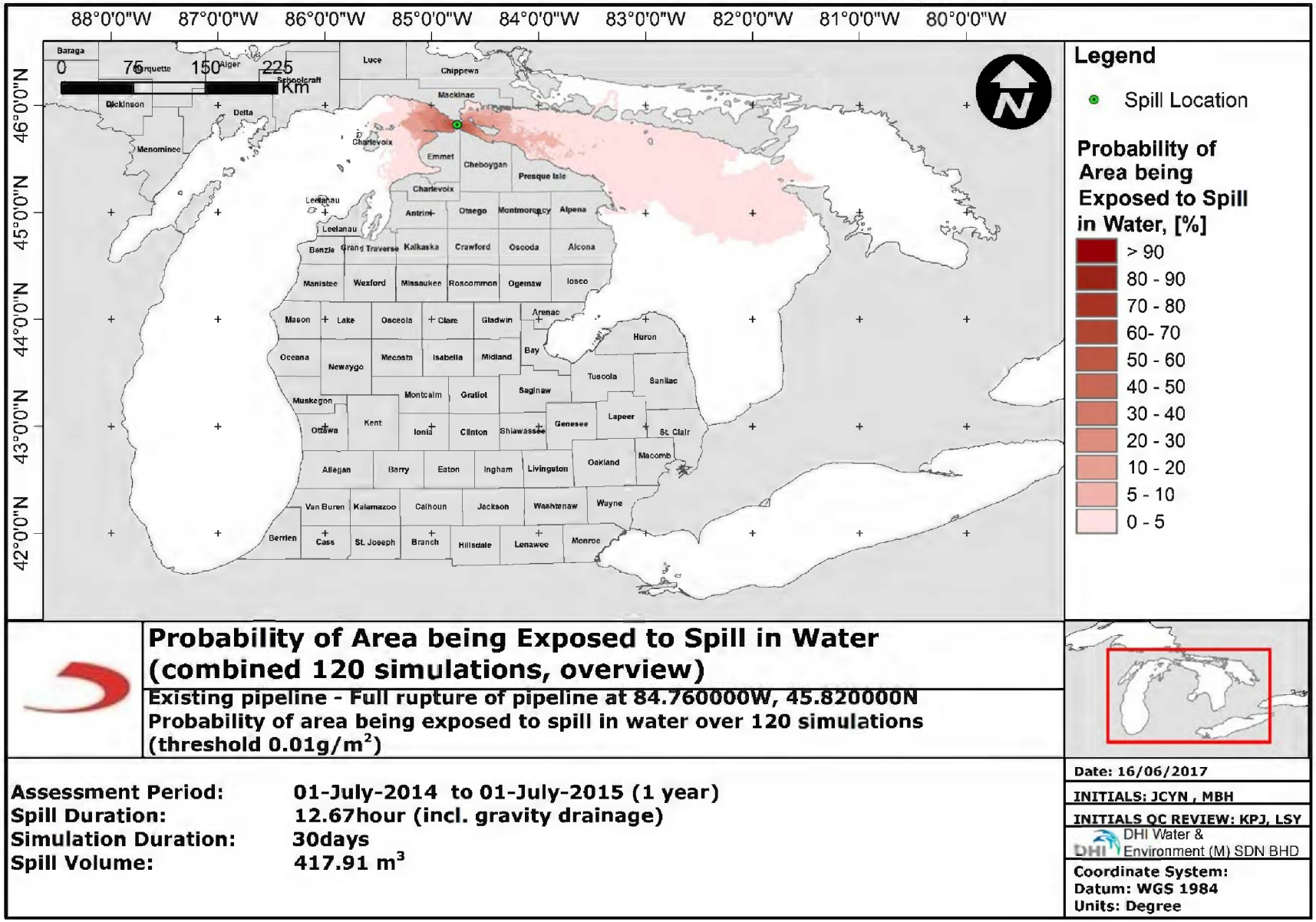
1 year


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 120 simulations, overview)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 120 simulations
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: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 120 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 120 simulations
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: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 120 simulations, overview)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 120 simulations
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: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
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Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 120 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 120 simulations
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: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

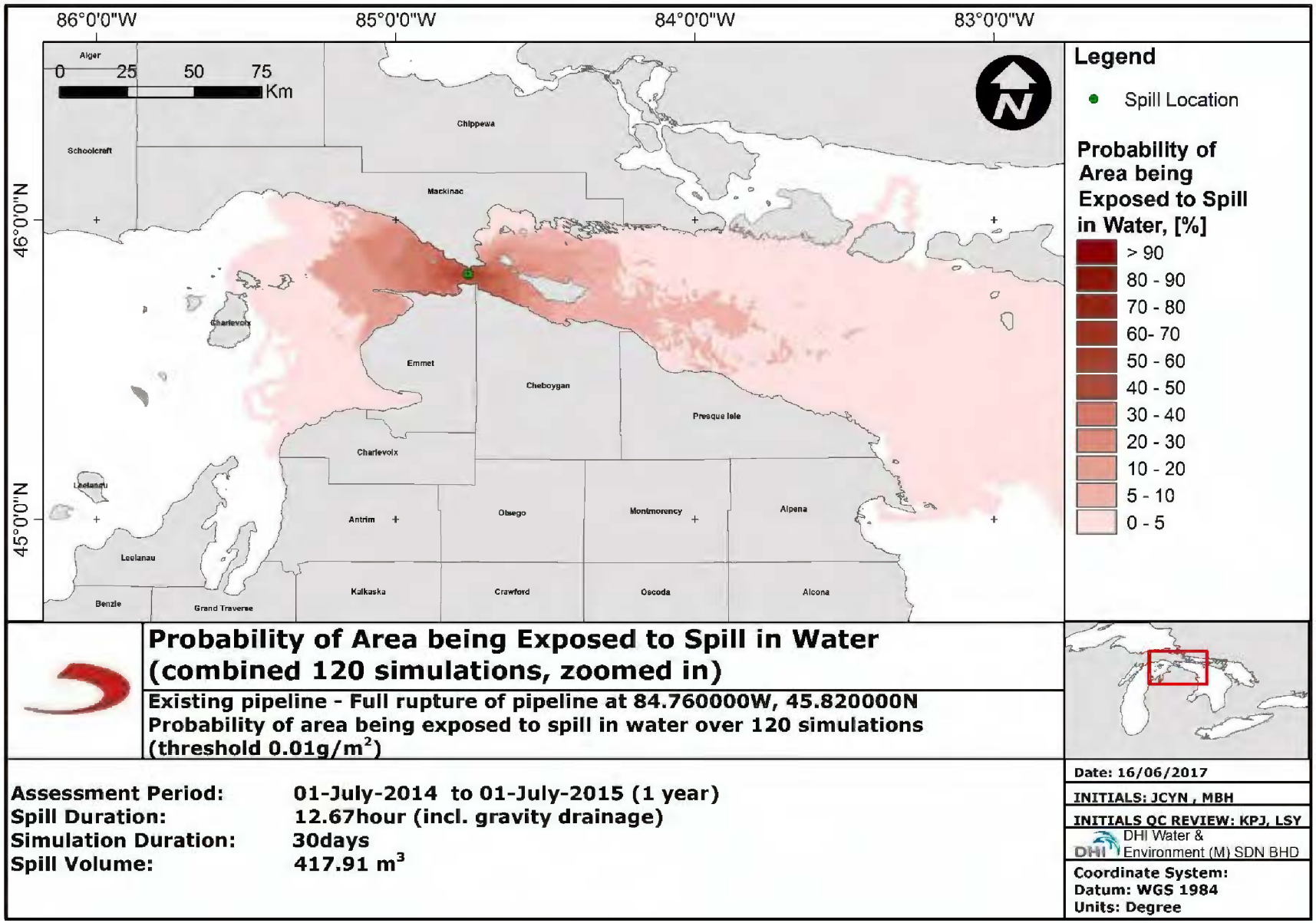


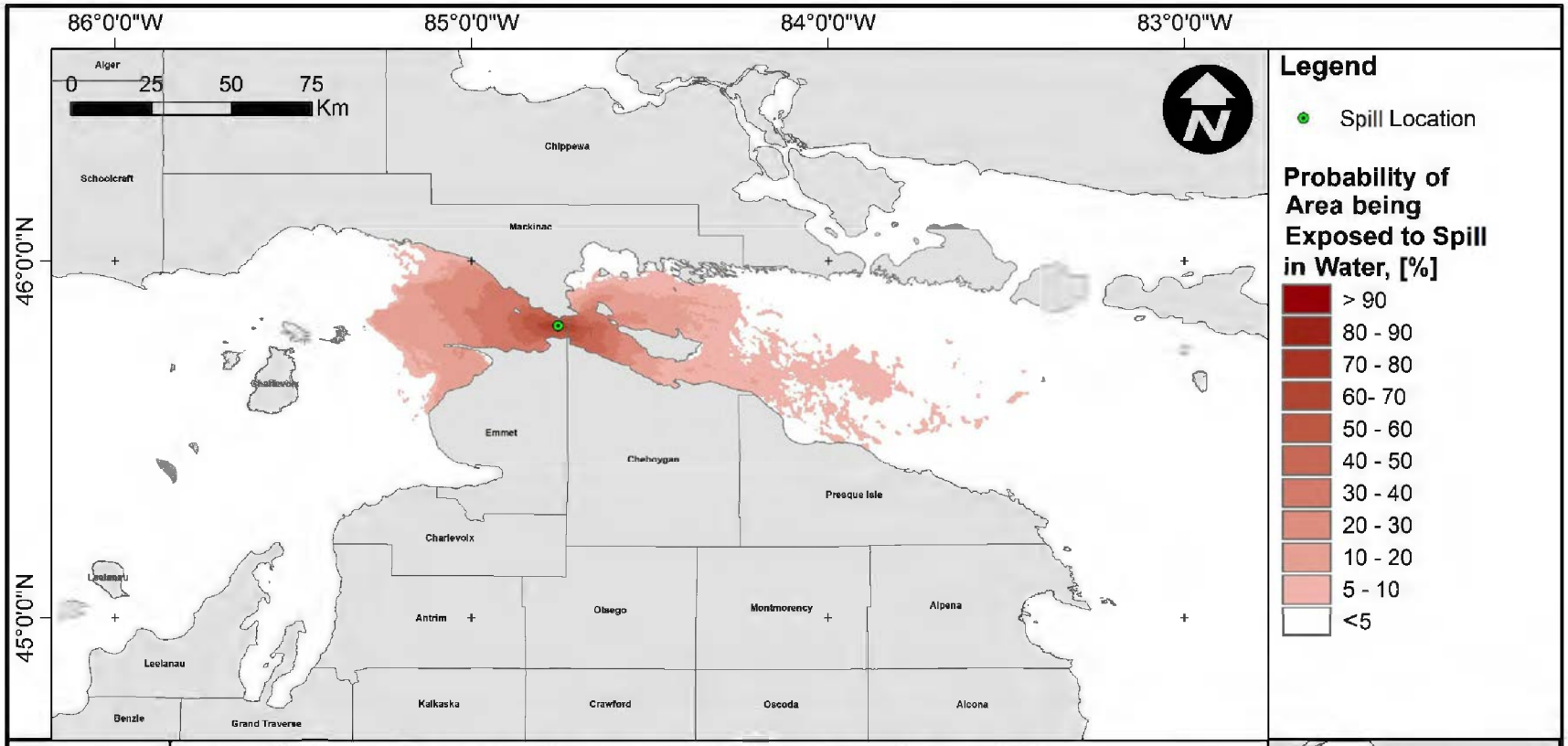
Probability of Area being Exposed to Spill in Water (combined 120 simulations, overview)

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/m^2)

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 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
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/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



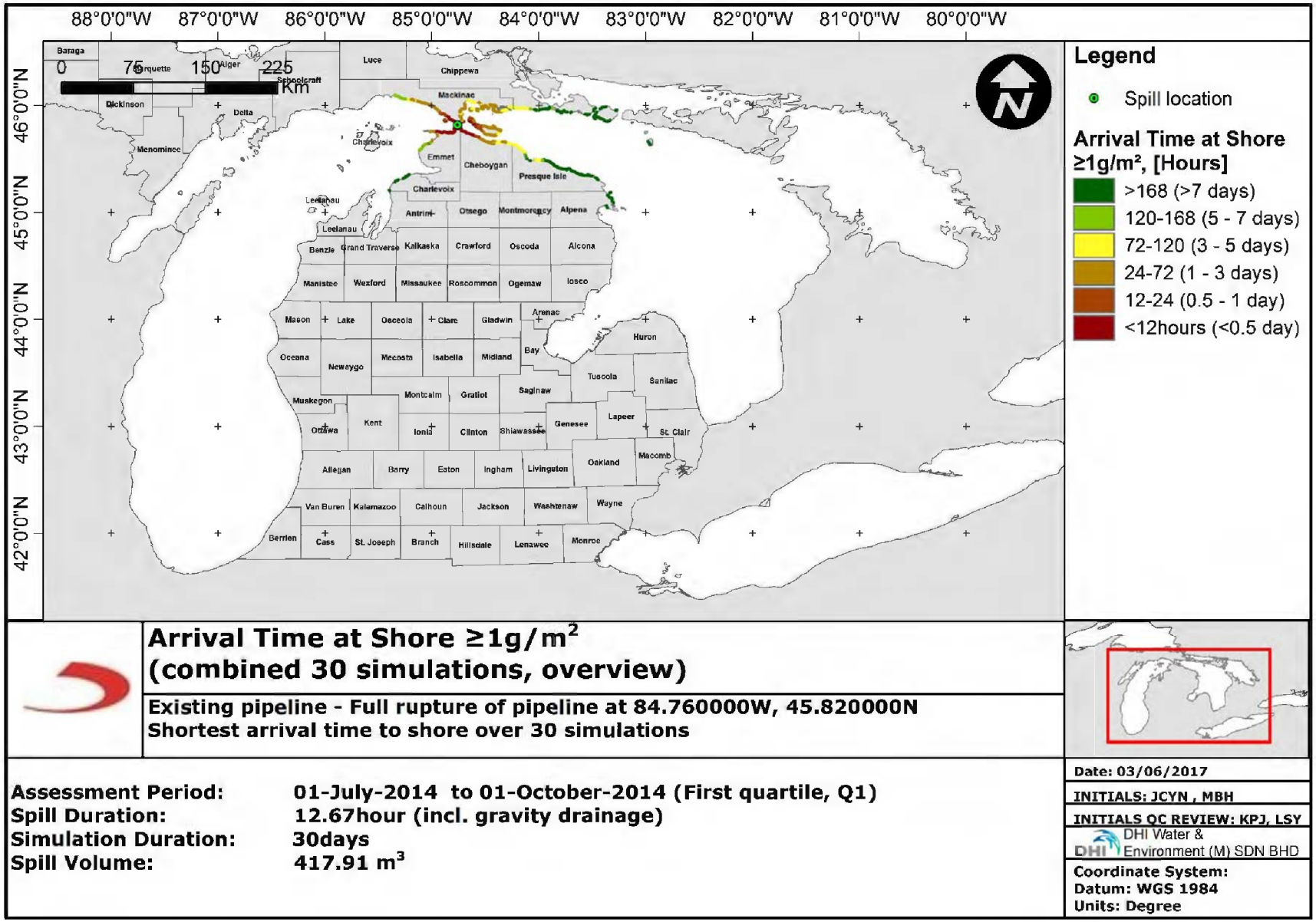
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 120 simulations, zoomed in)

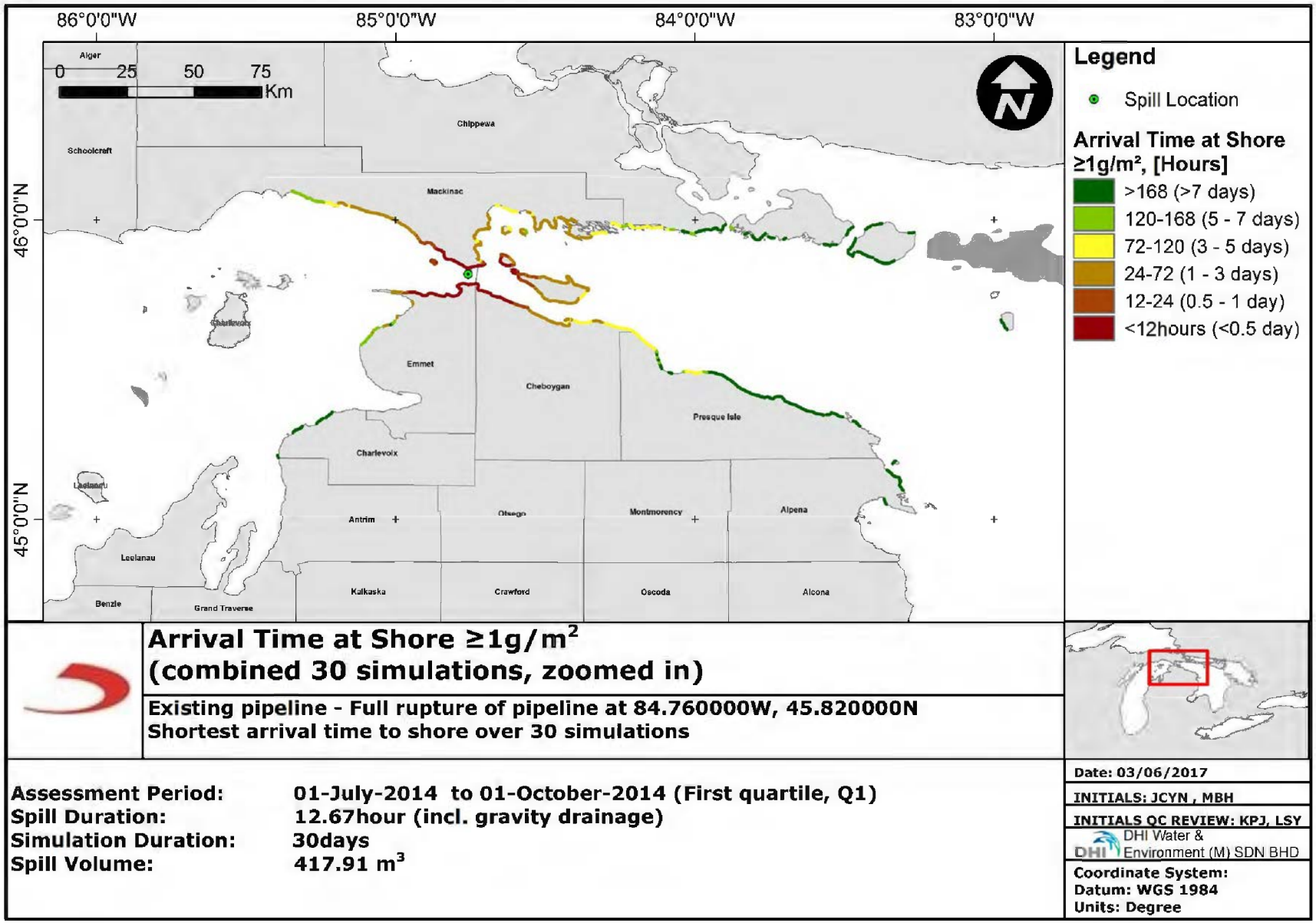
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
95th perct. probability of area being exposed to spill in water over 120 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

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

Q1


88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
46°0'0"N
45°0'0"N
44°0'0"N
43°0'0"N
42°0'0"N
0
75
150
225
Km
Legend
Spill location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 30 simulations, overview)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 12.67hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 417.91 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

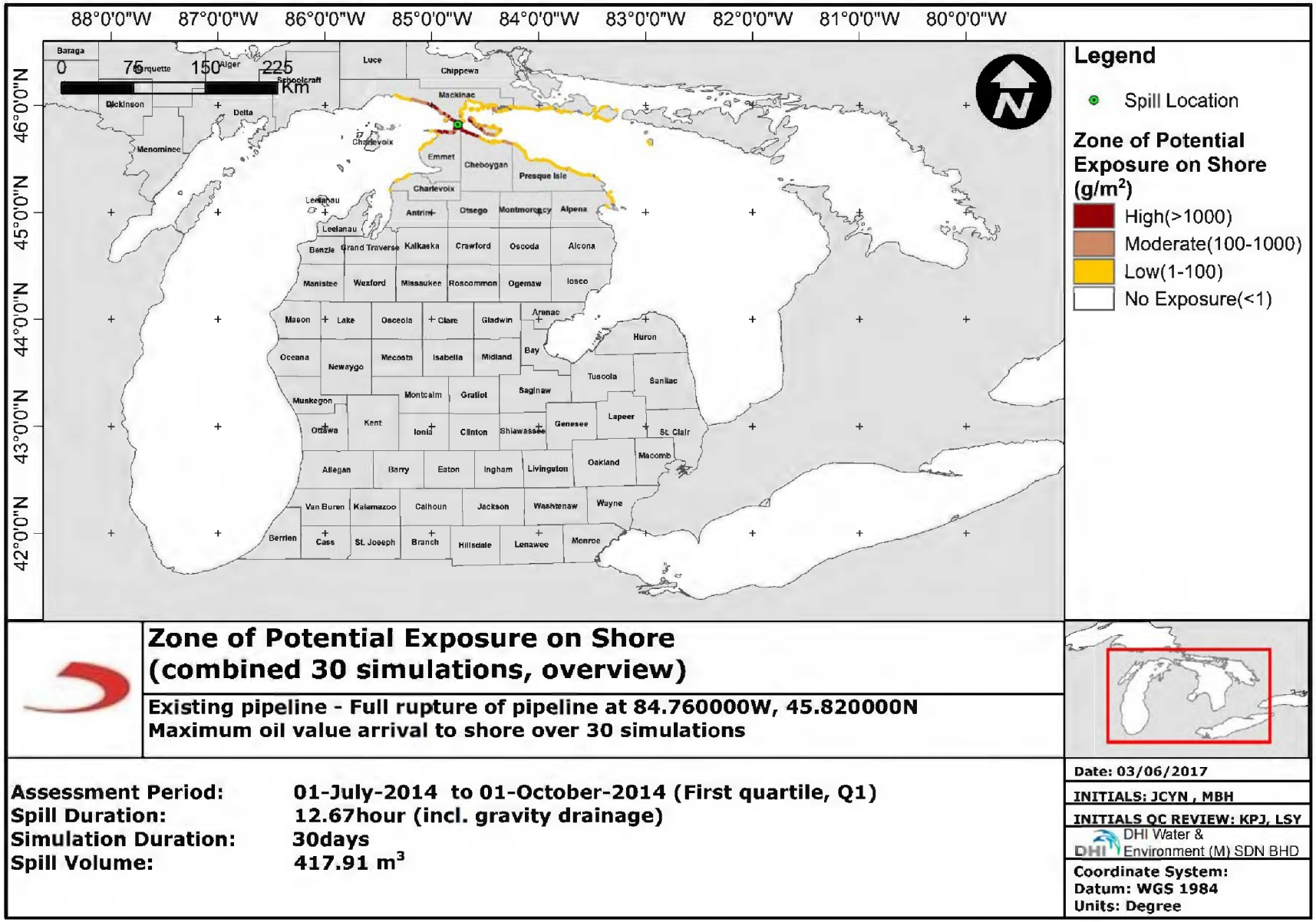


Arrival Time at Shore ≥1g/m² (combined 30 simulations, zoomed in)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

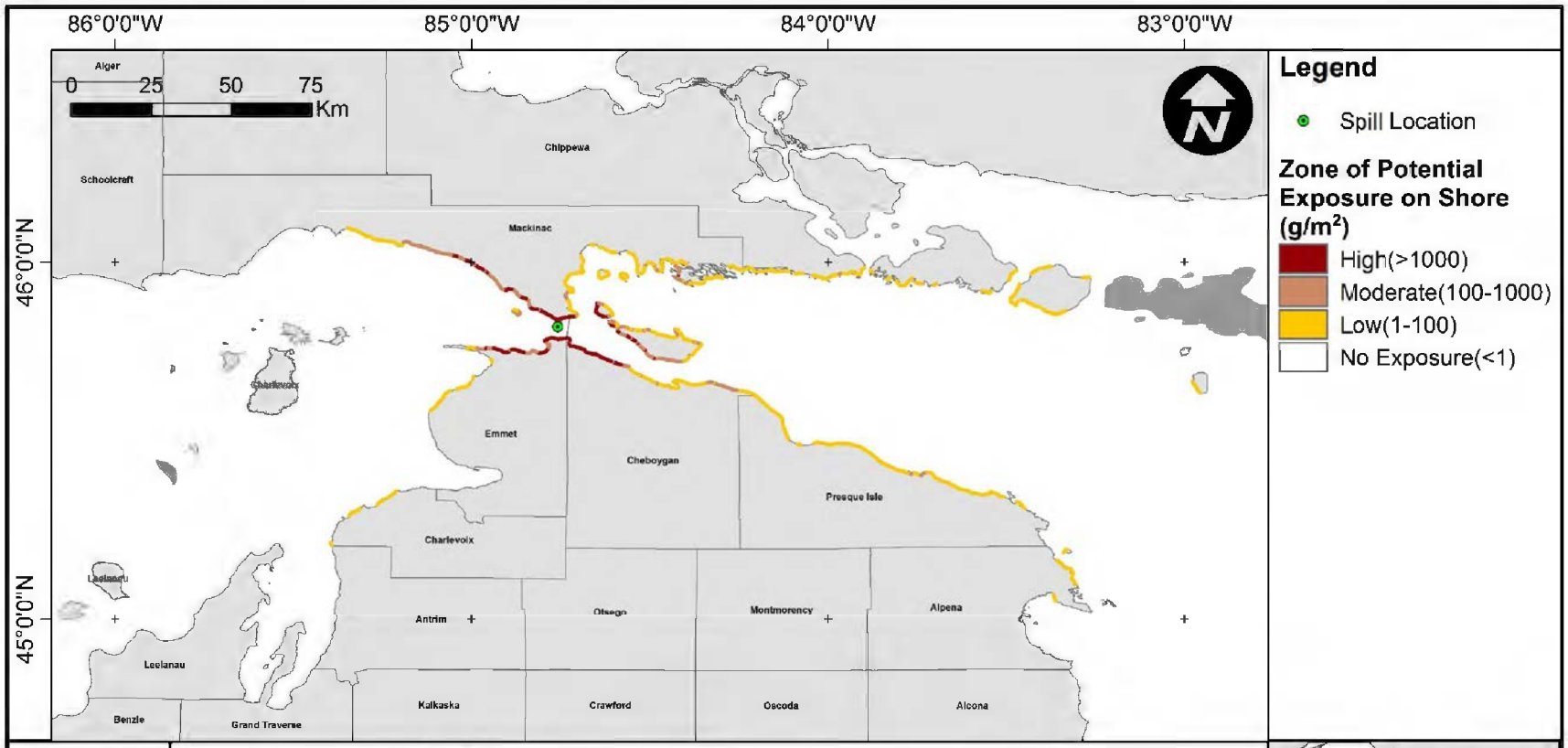


Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

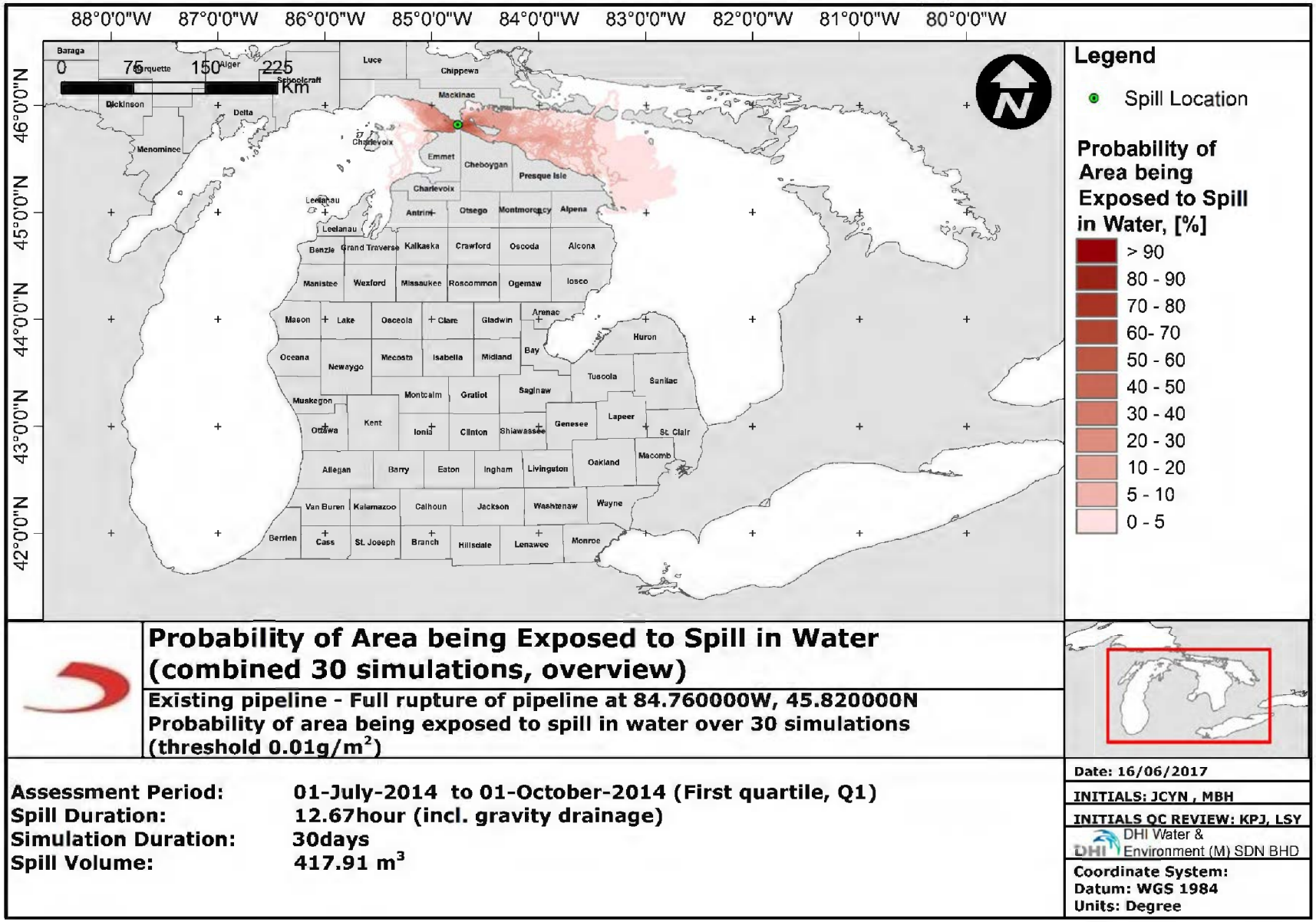


Zone of Potential Exposure on Shore (combined 30 simulations, zoomed in)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

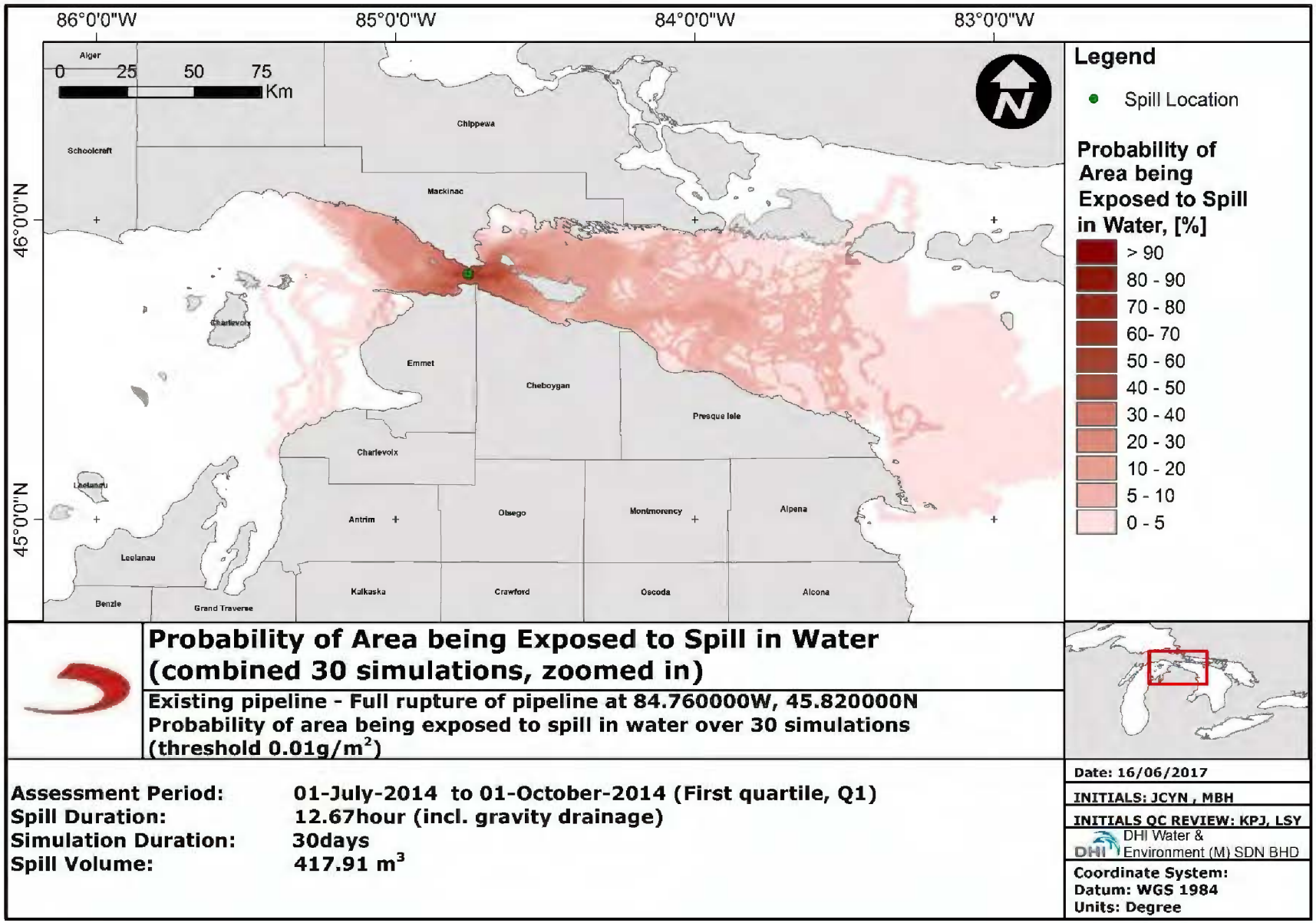


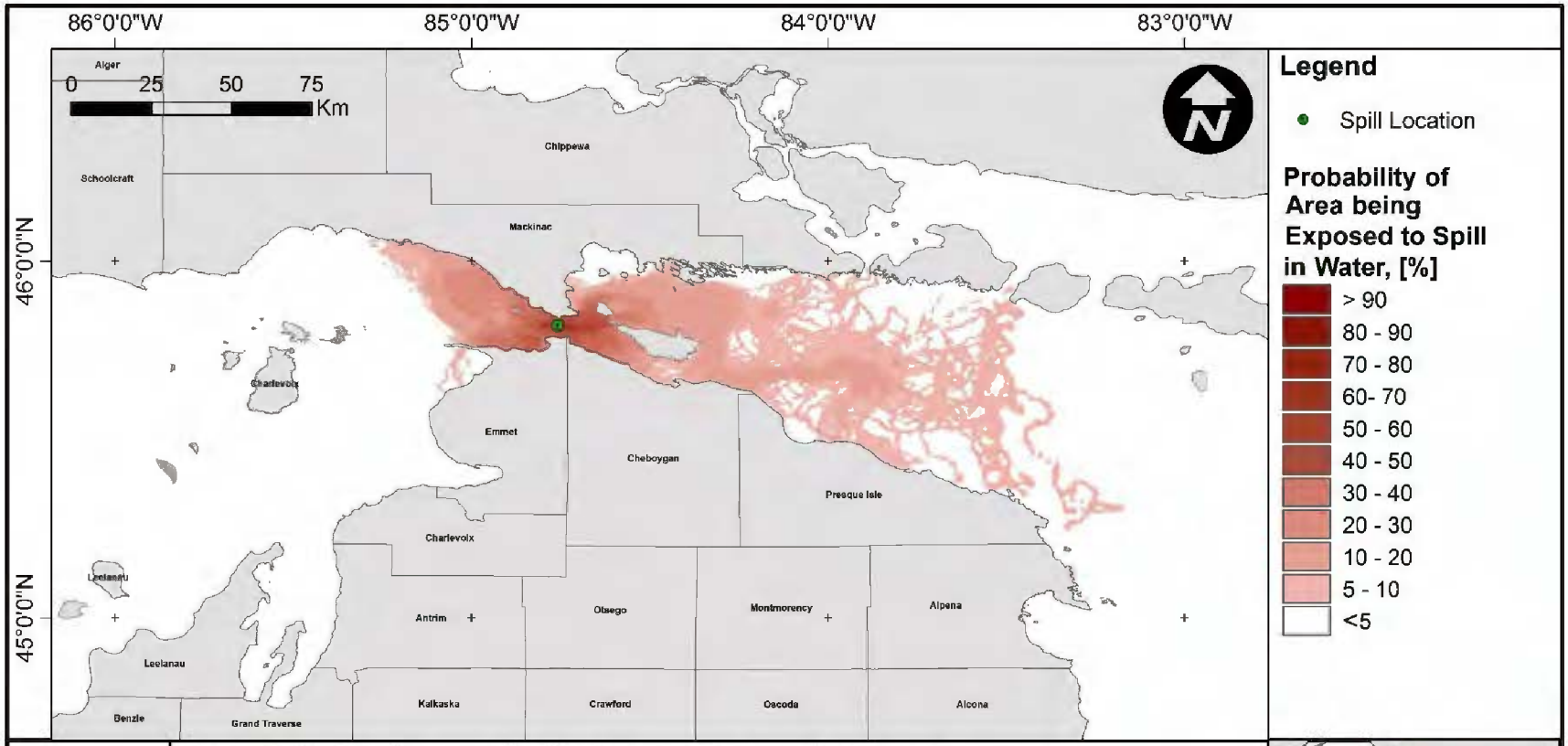
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
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



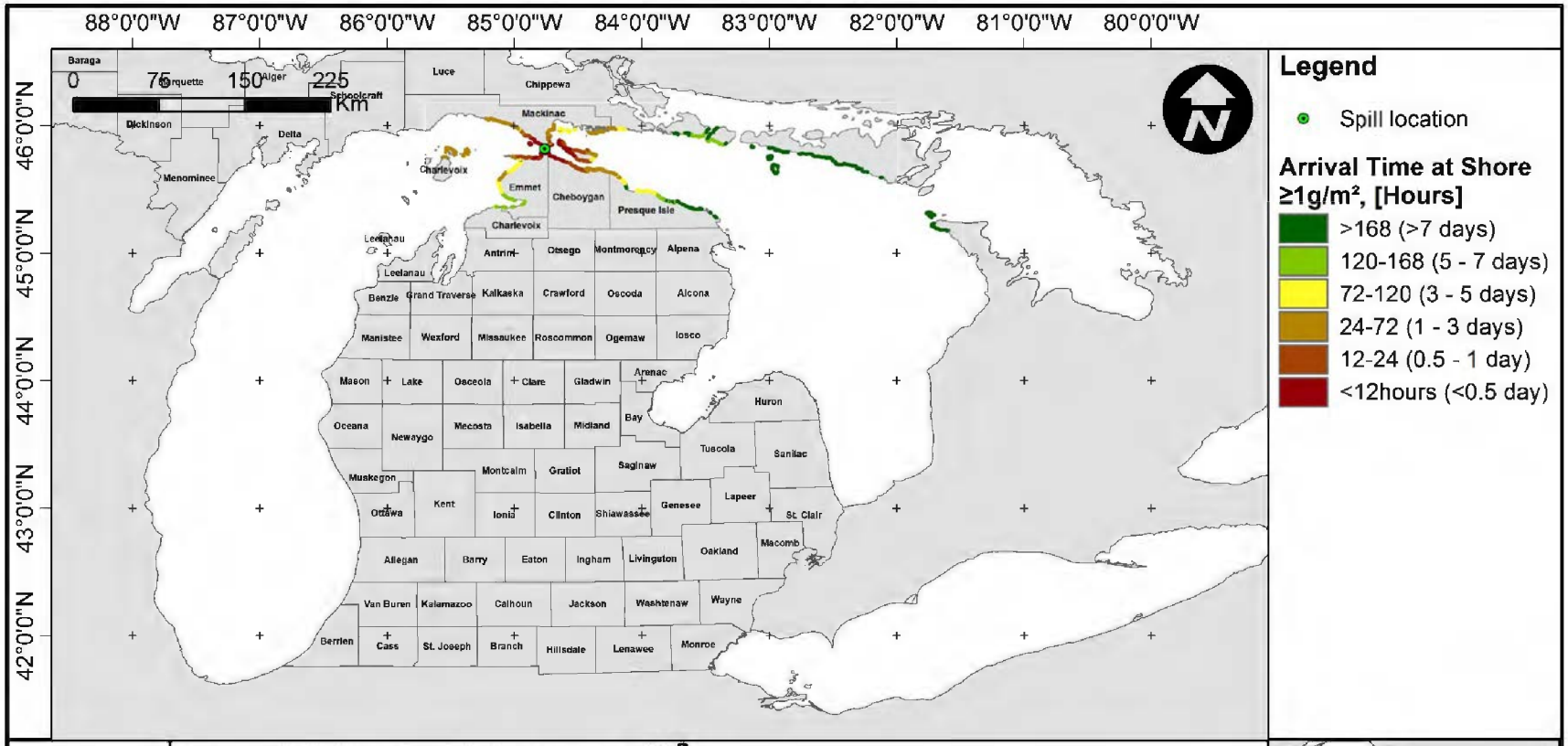
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

Q2

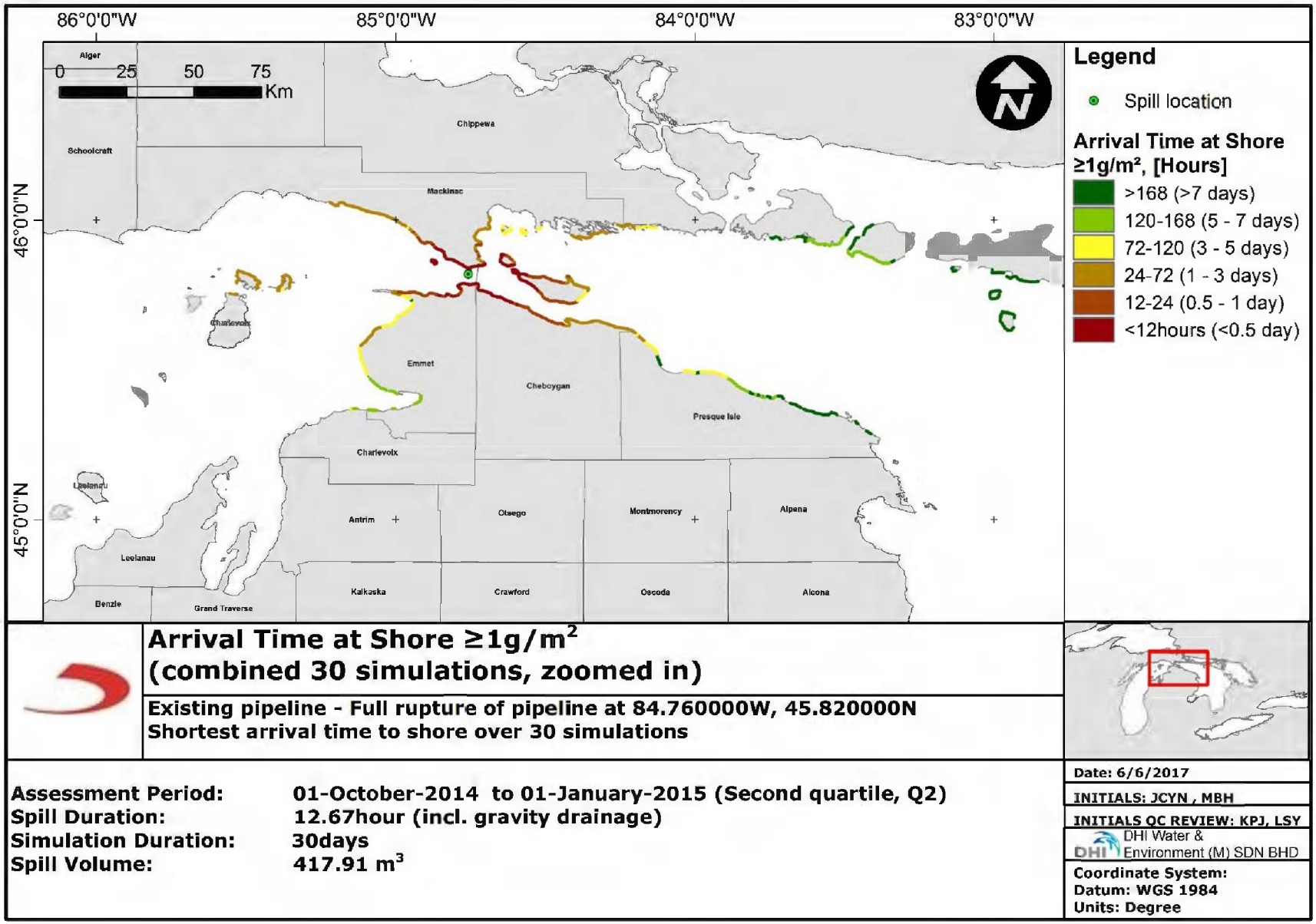


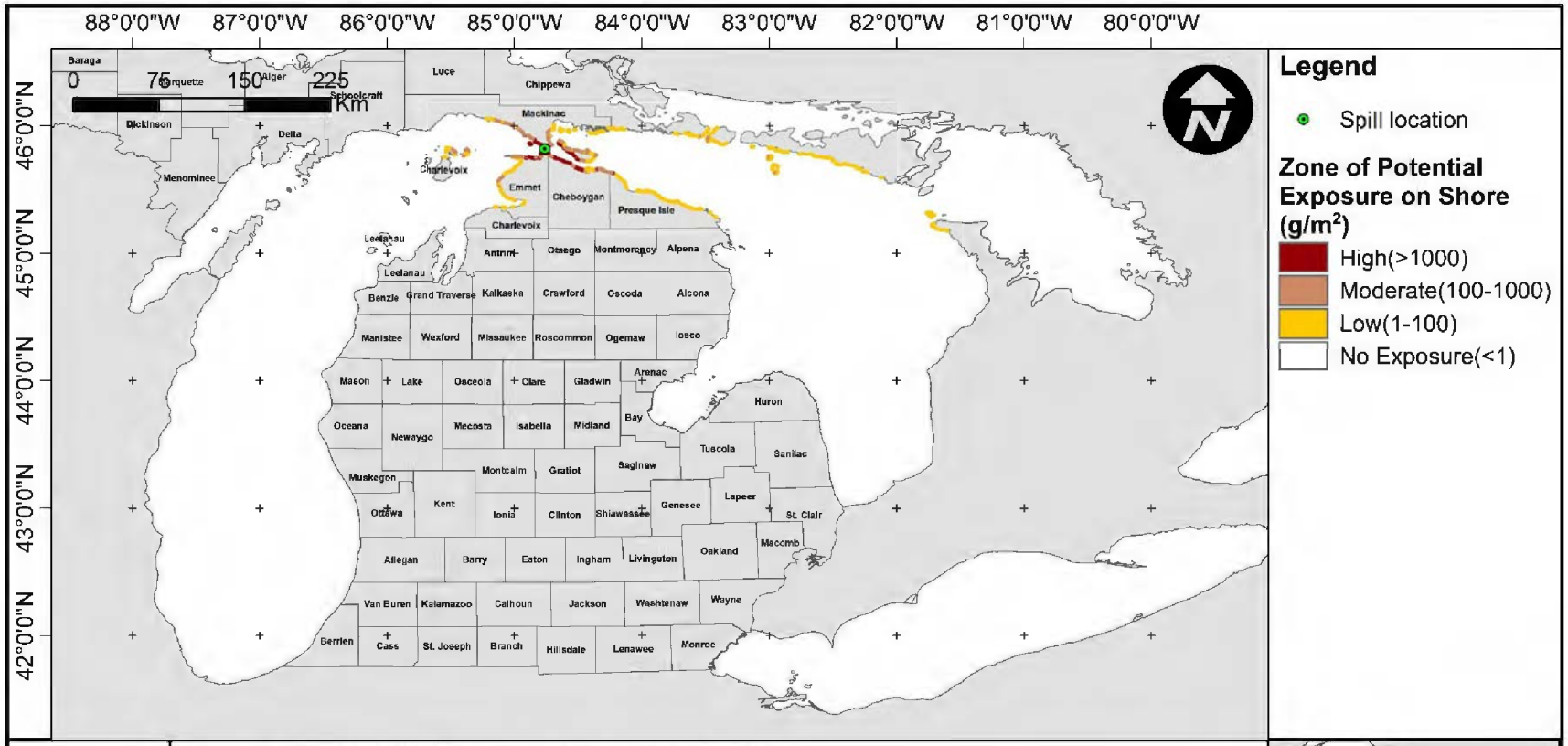
Arrival Time at Shore ≥1g/m² (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 30 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 12.67hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 417.91 m³
Date: 6/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

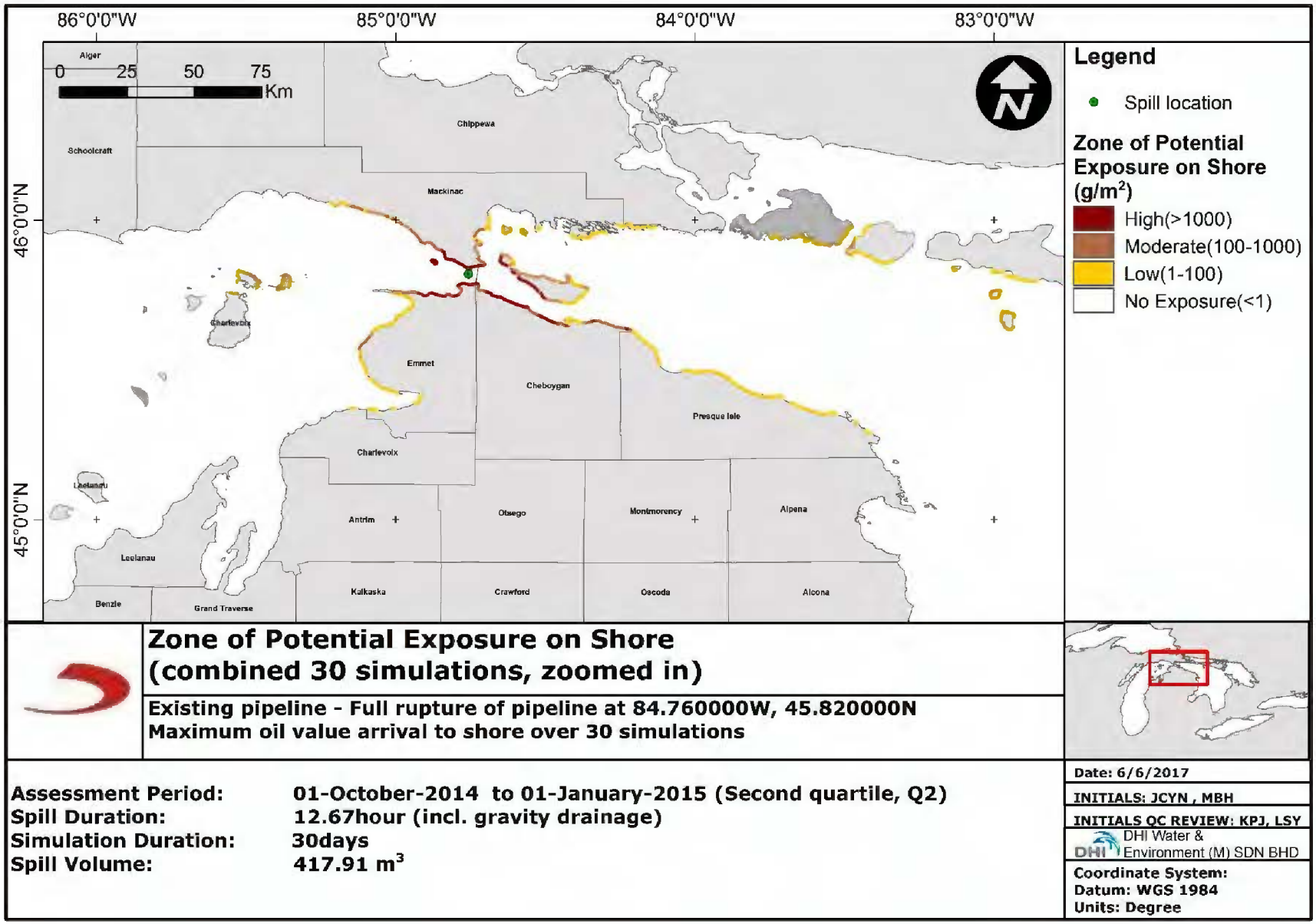


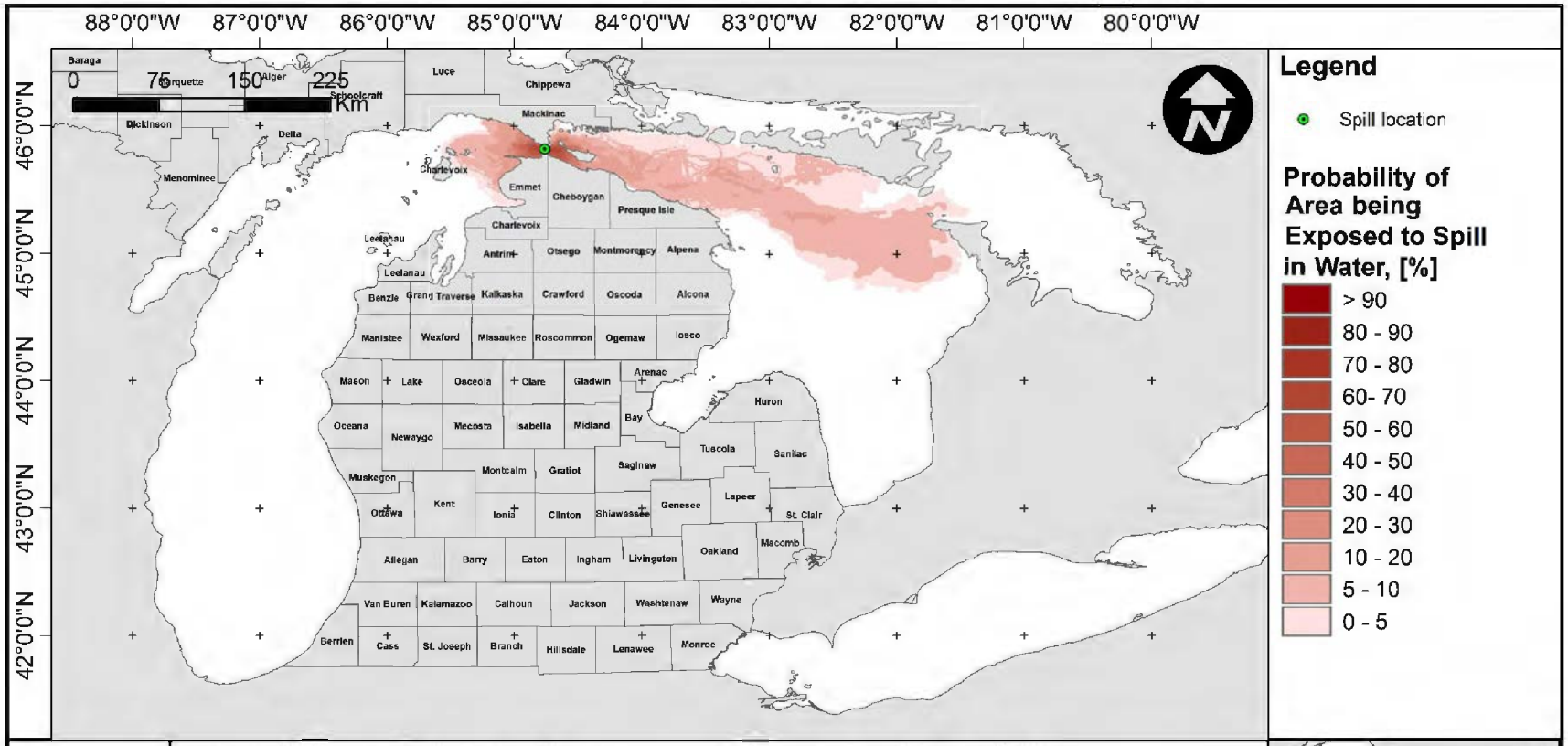
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
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Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 12.67hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 417.91 m³
Date: 6/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

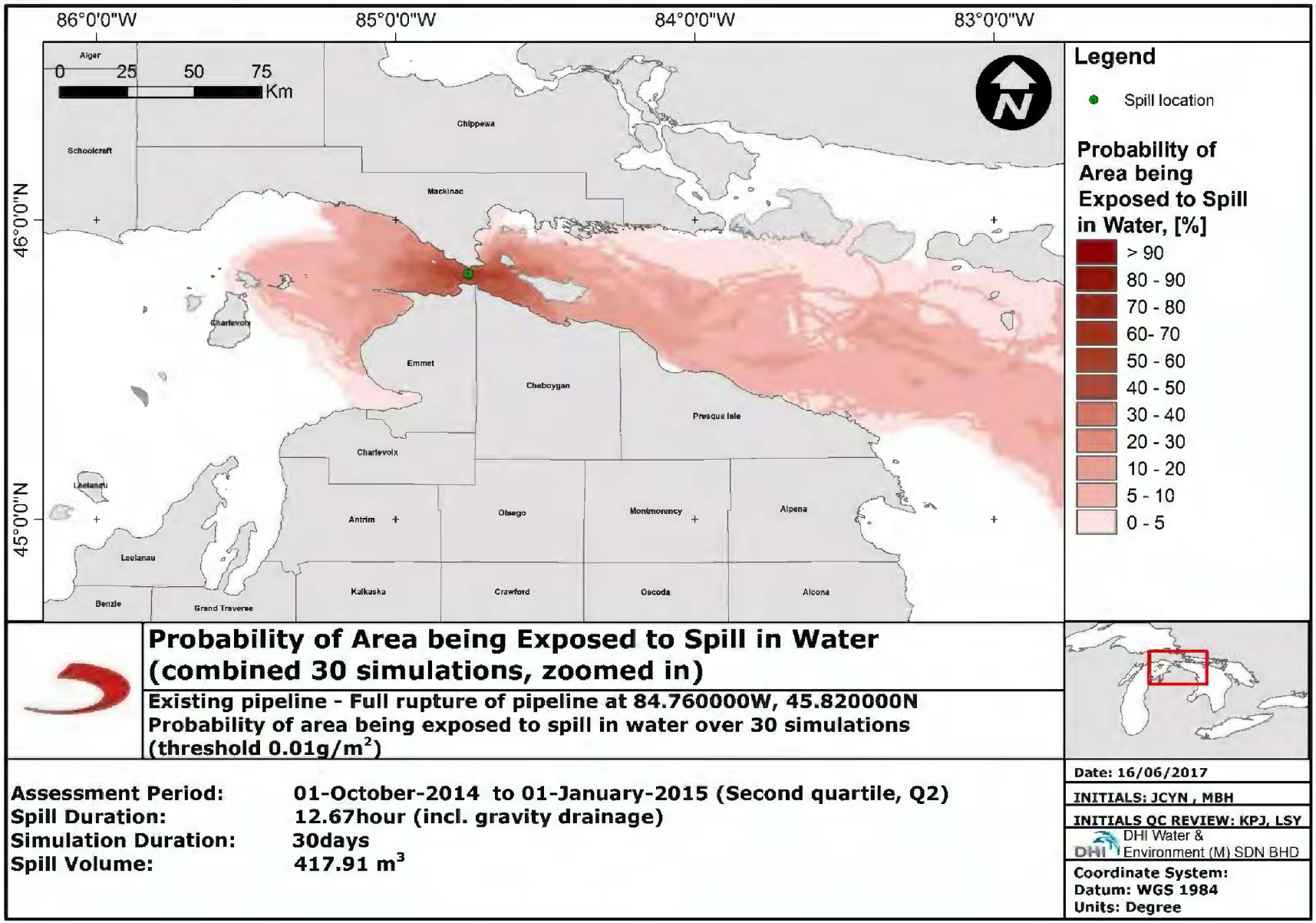


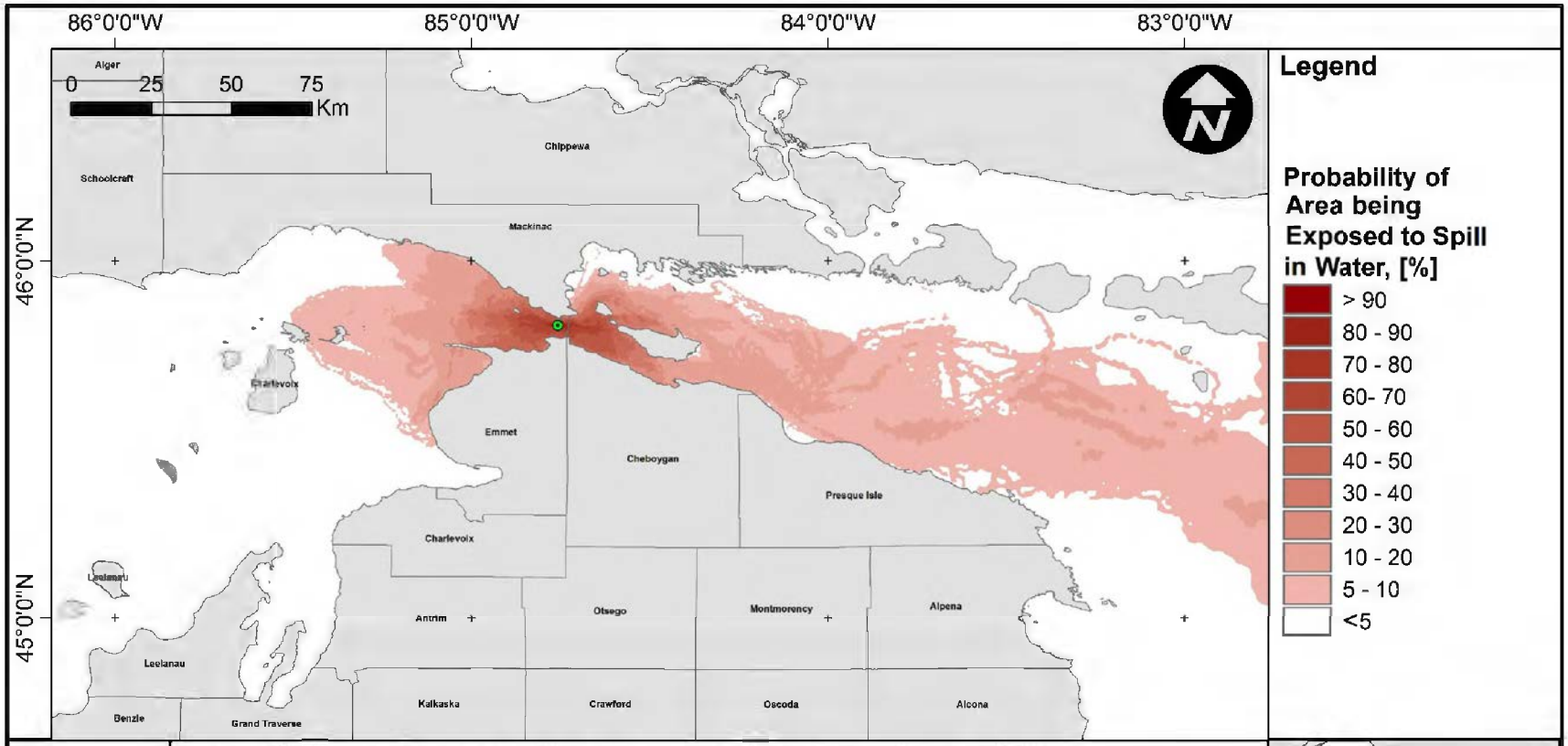
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
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Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m2)
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
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



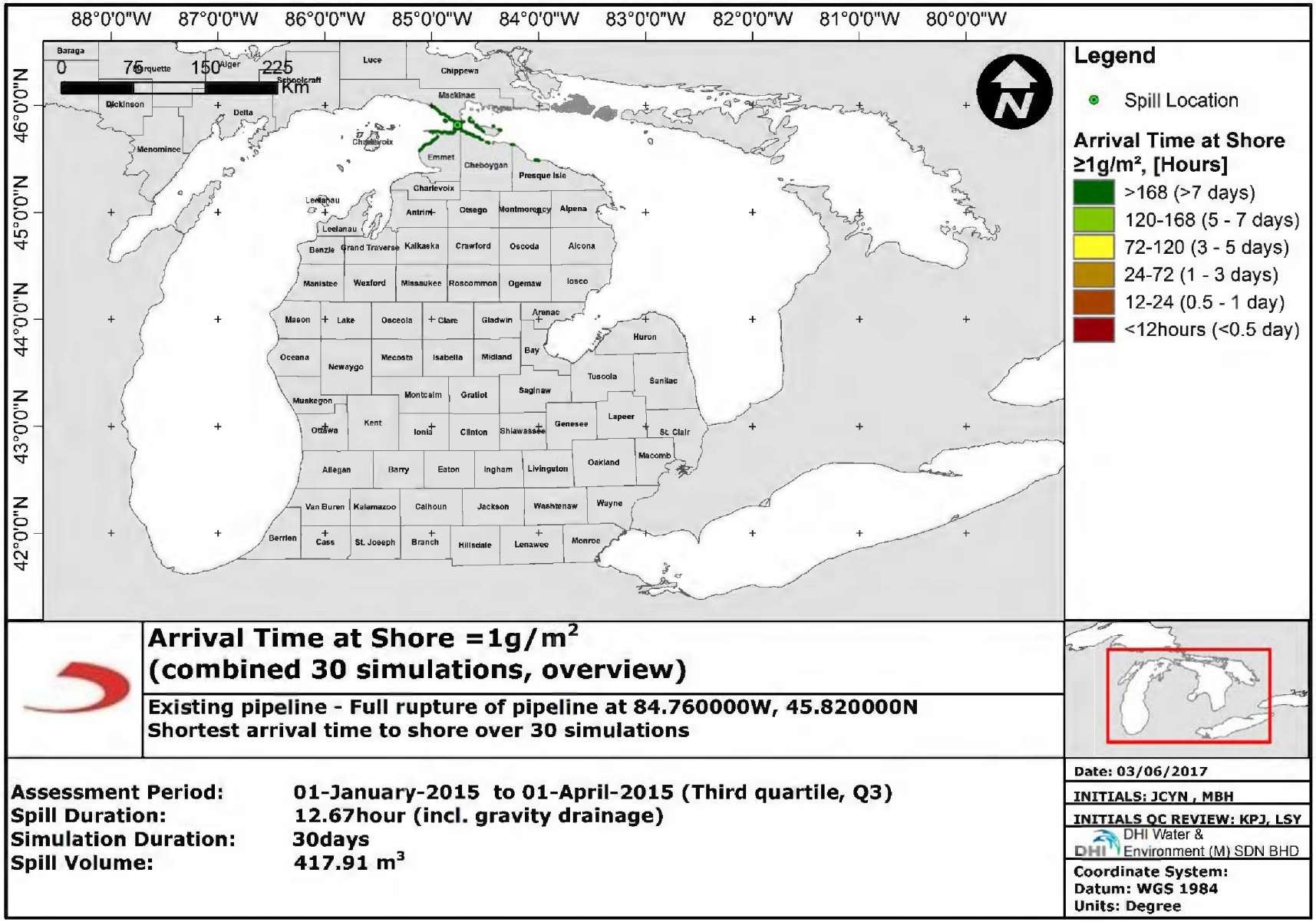
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

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

Q3

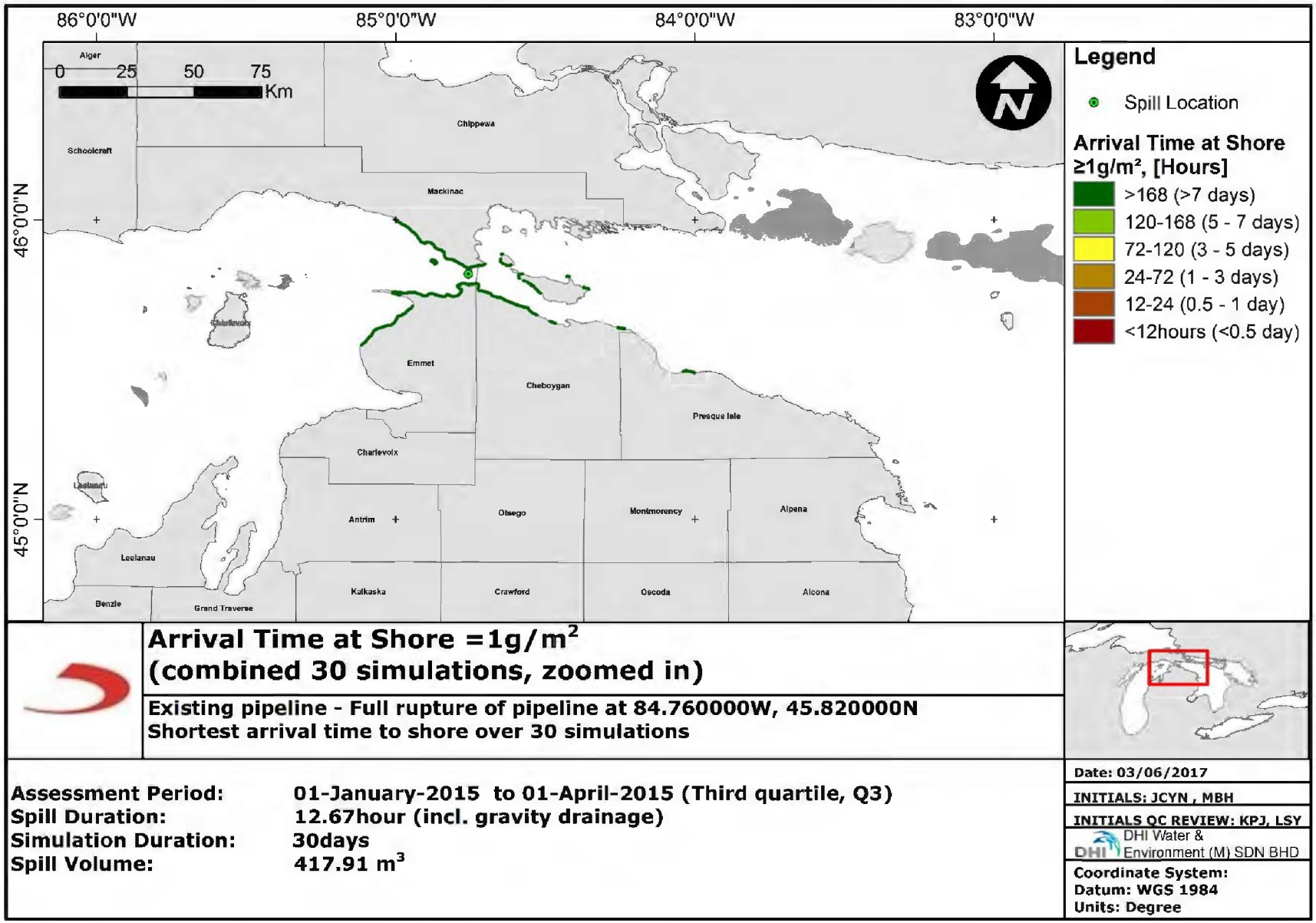


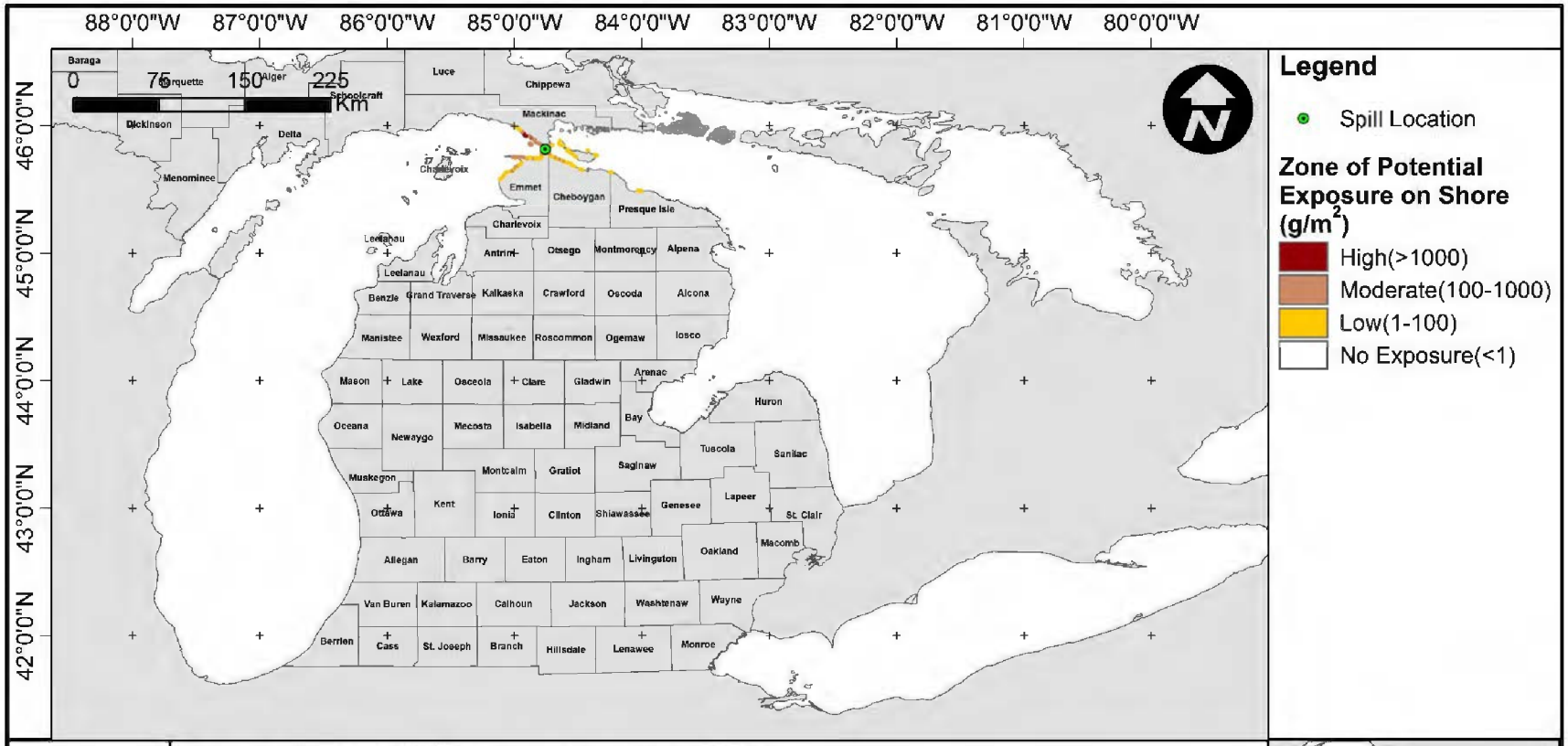
Arrival Time at Shore =1g/m^2 (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 12.67hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 417.91 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

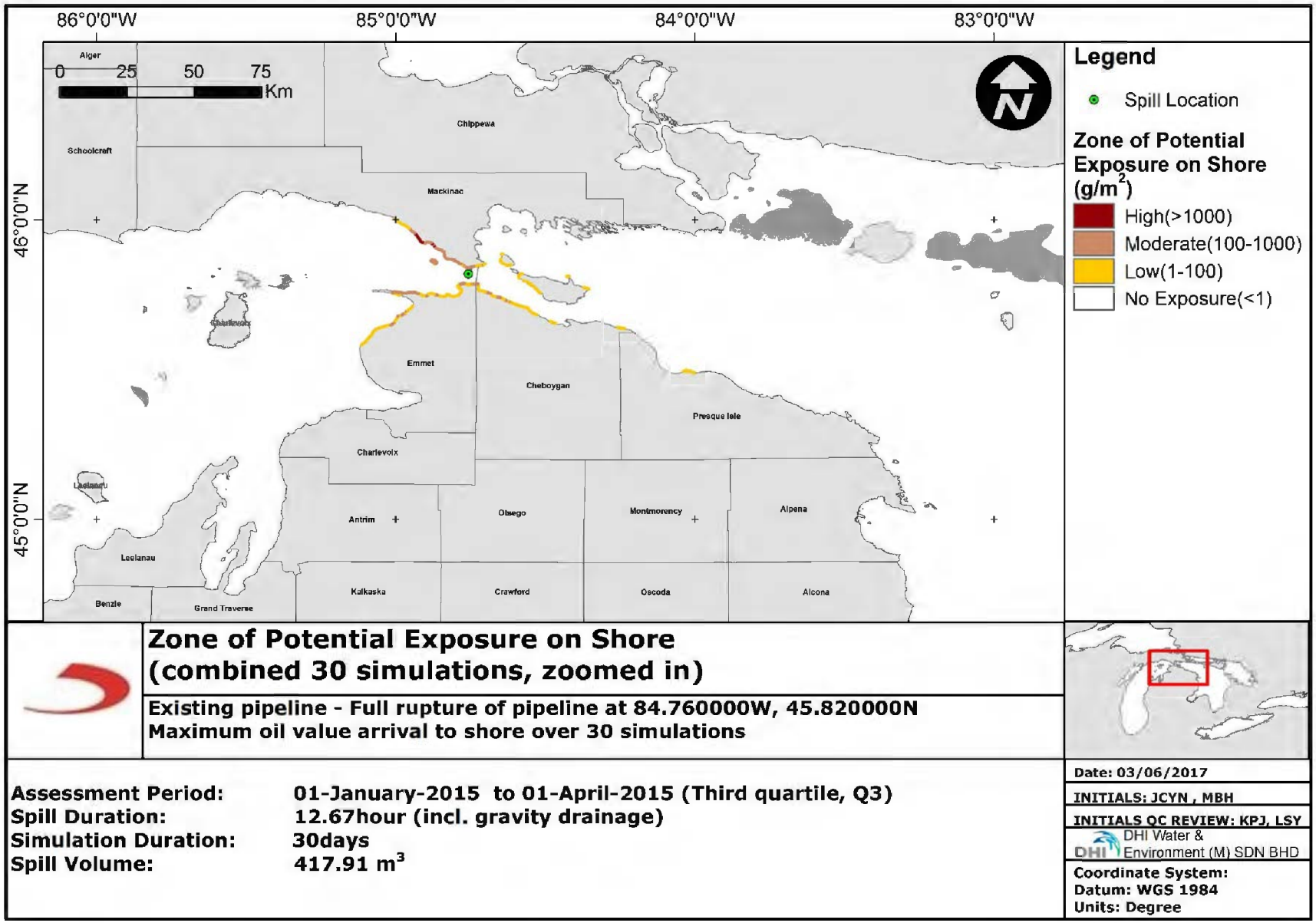


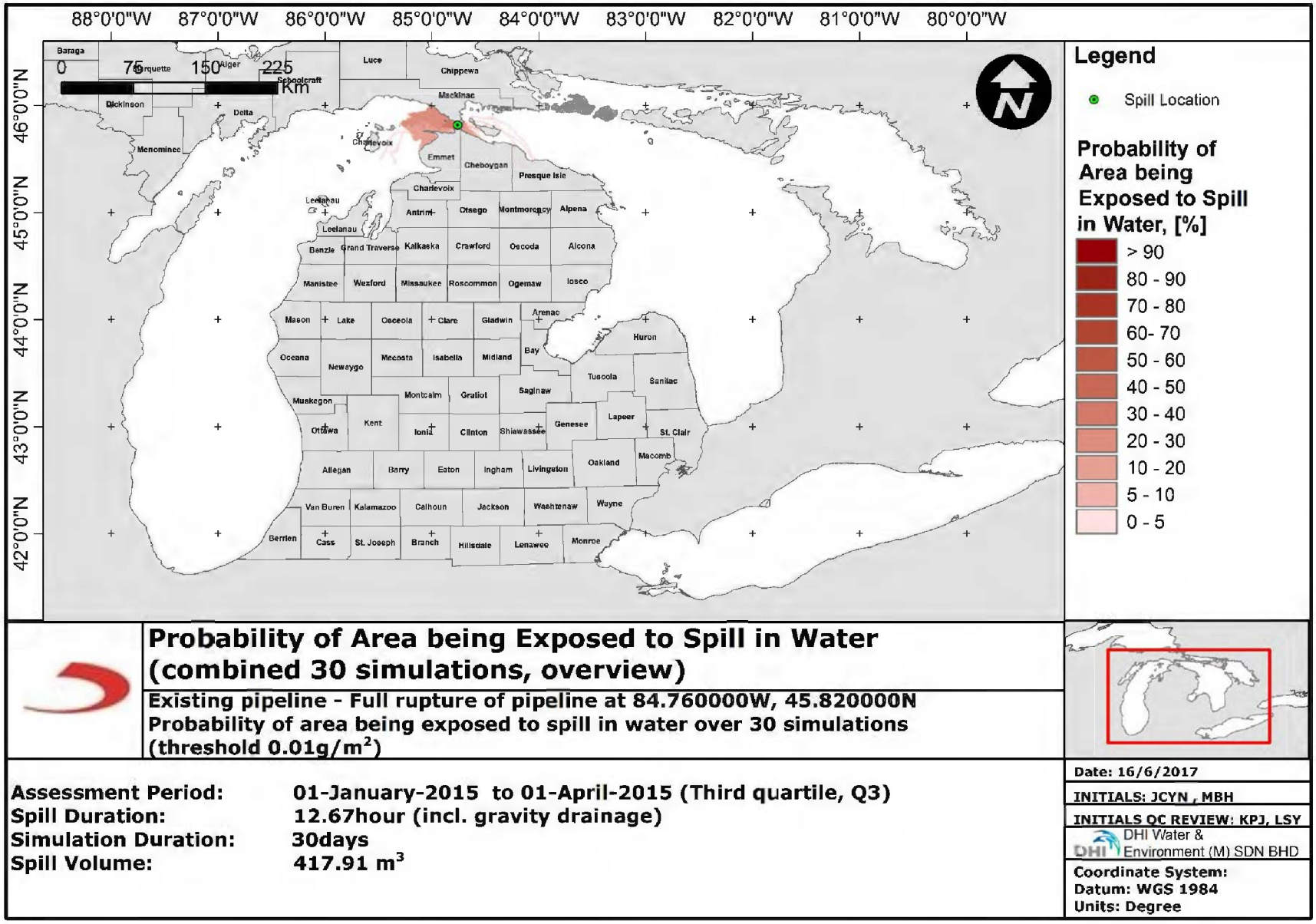
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Leelanau
Antrim
Otsego
Montmorency
Alpena
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 12.67hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 417.91 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

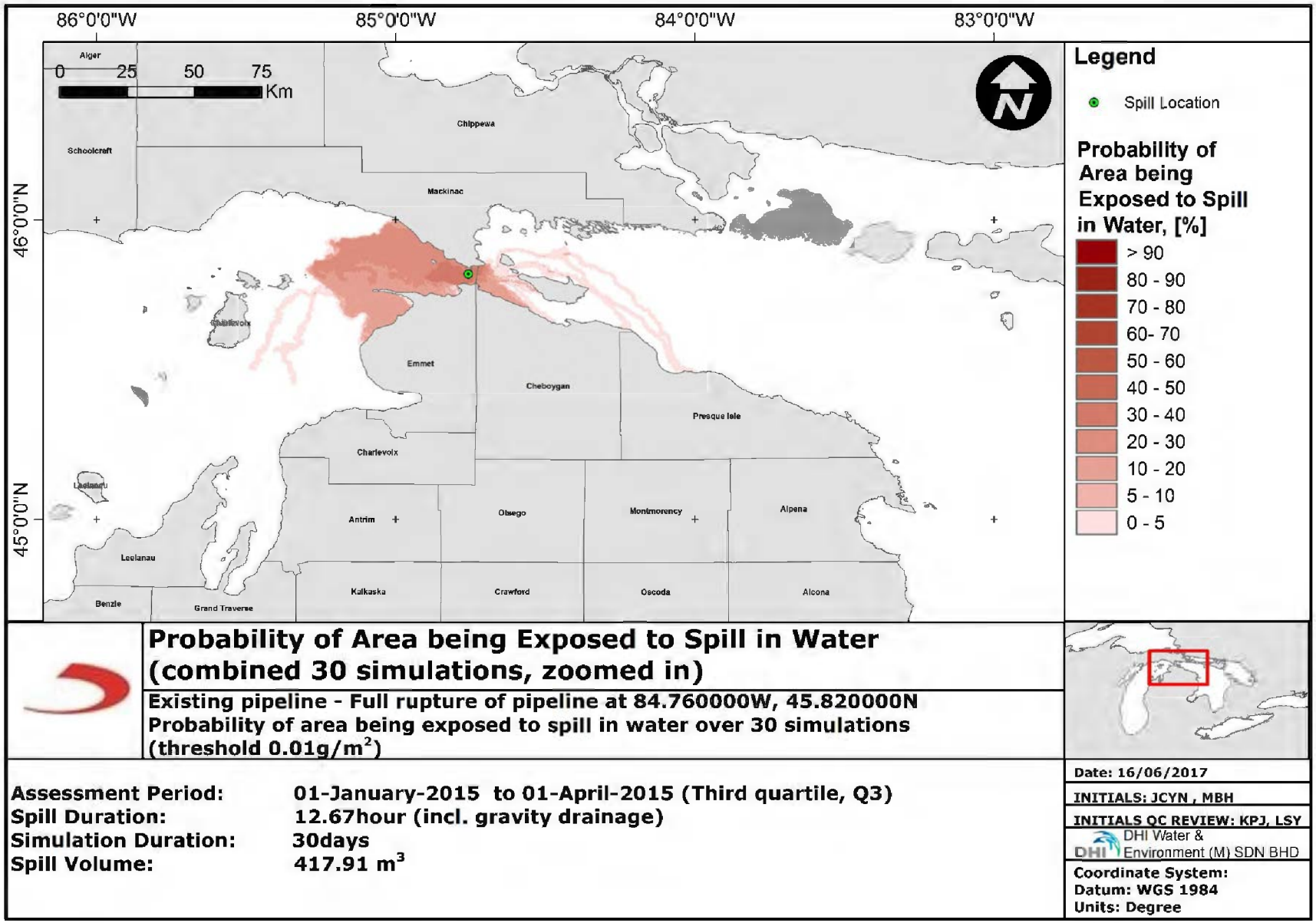


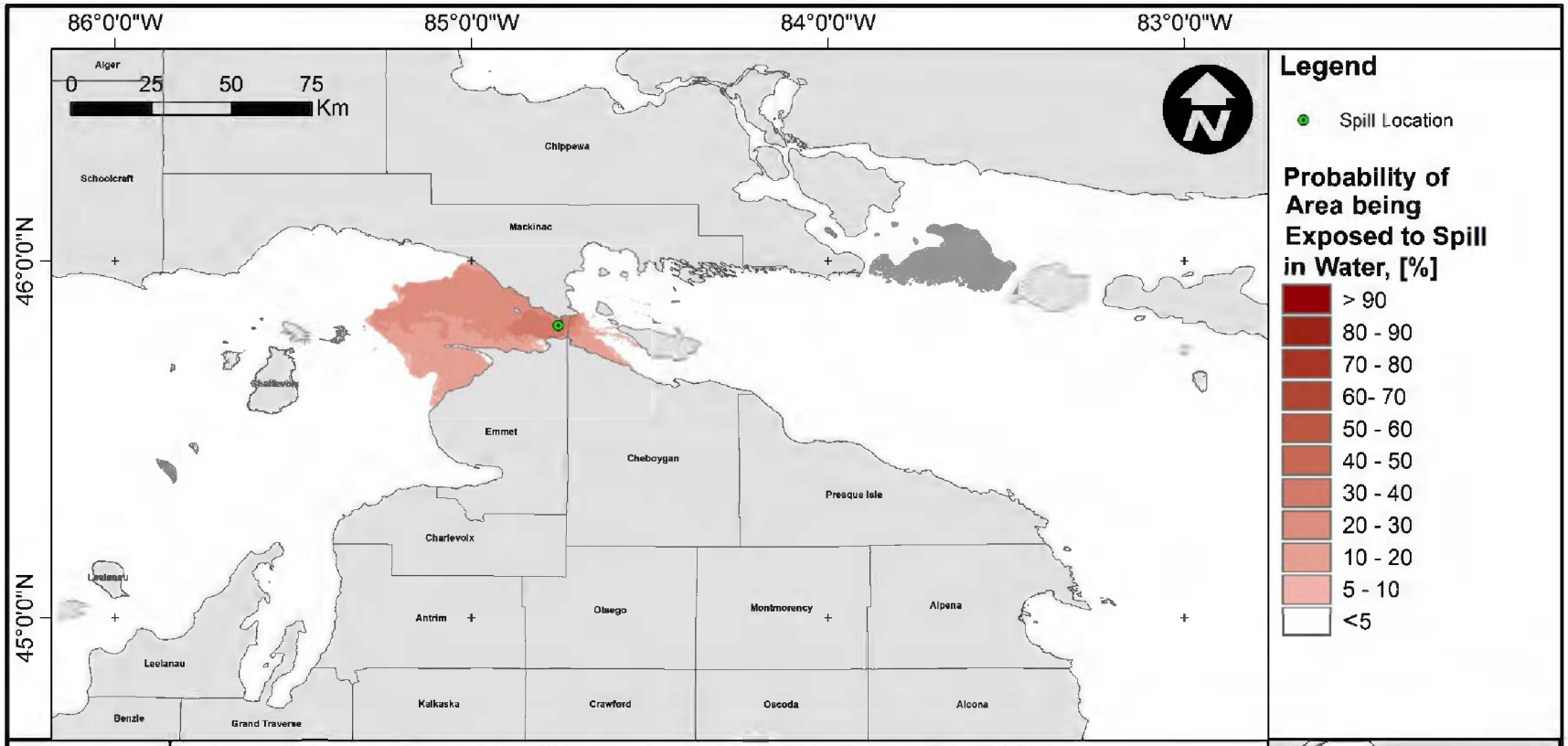
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
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



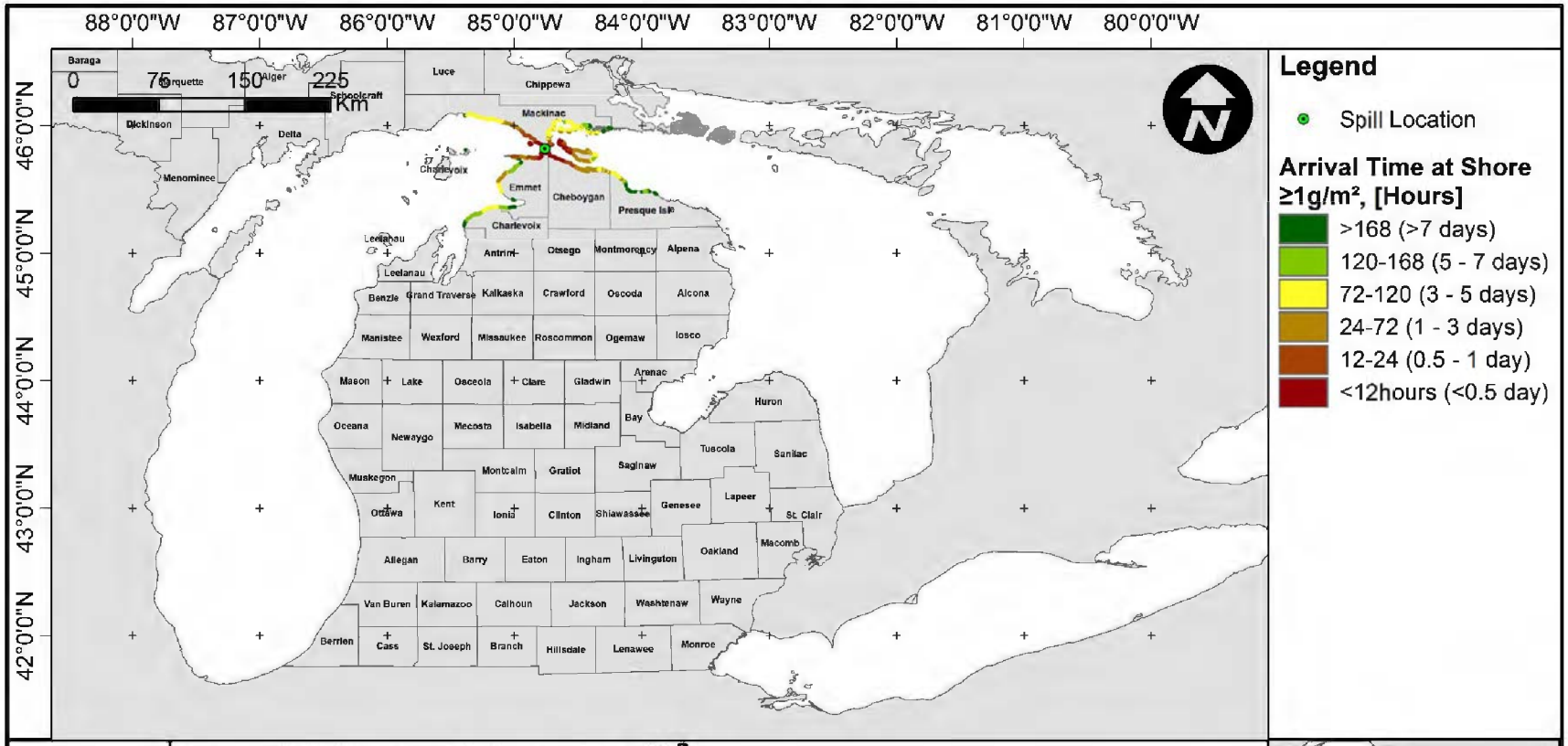
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

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

Q4

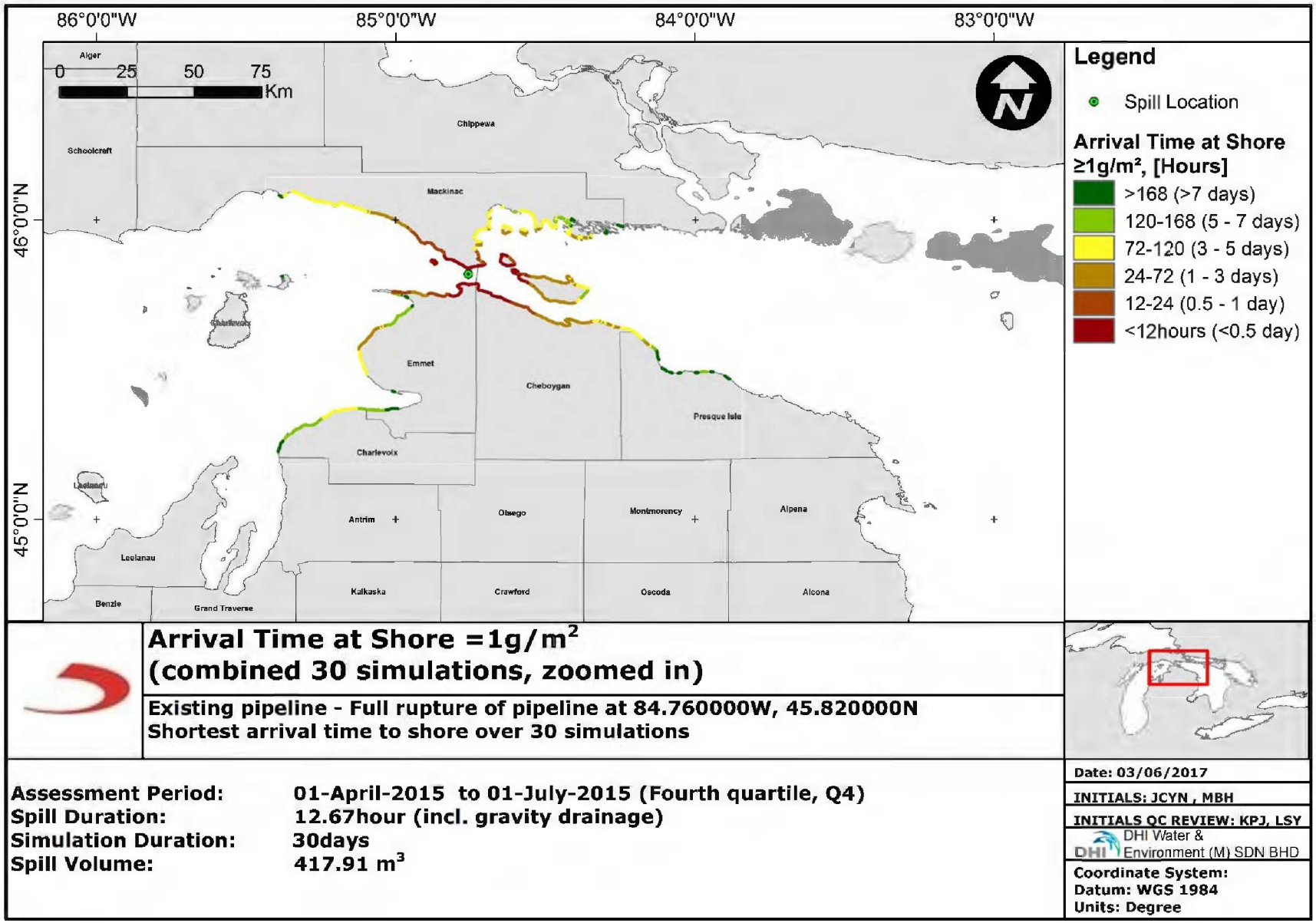


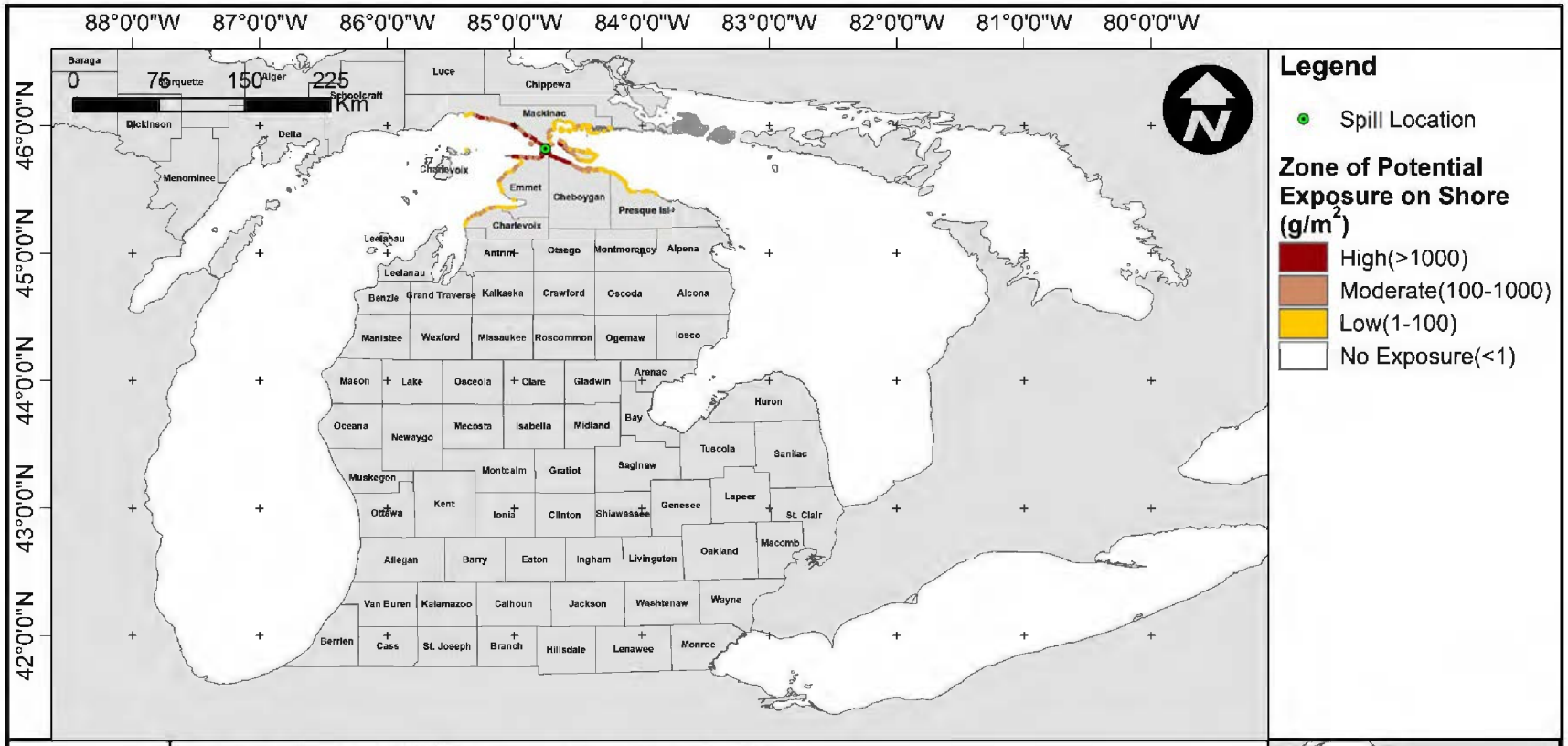
Arrival Time at Shore =1g/m^2 (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Emmet
Cheboygan
Presque Isle
Charlevoix
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 12.67hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 417.91 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

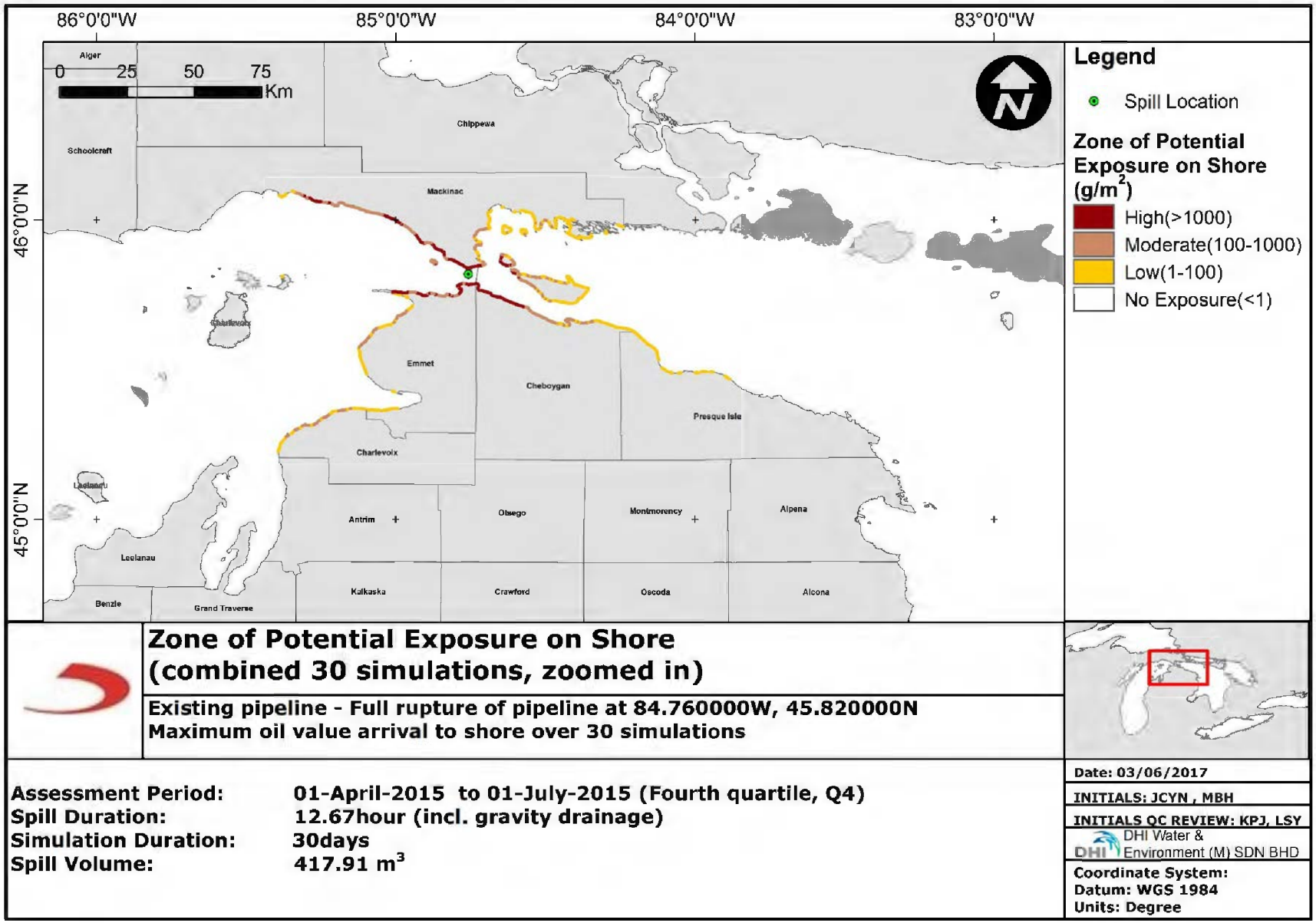


Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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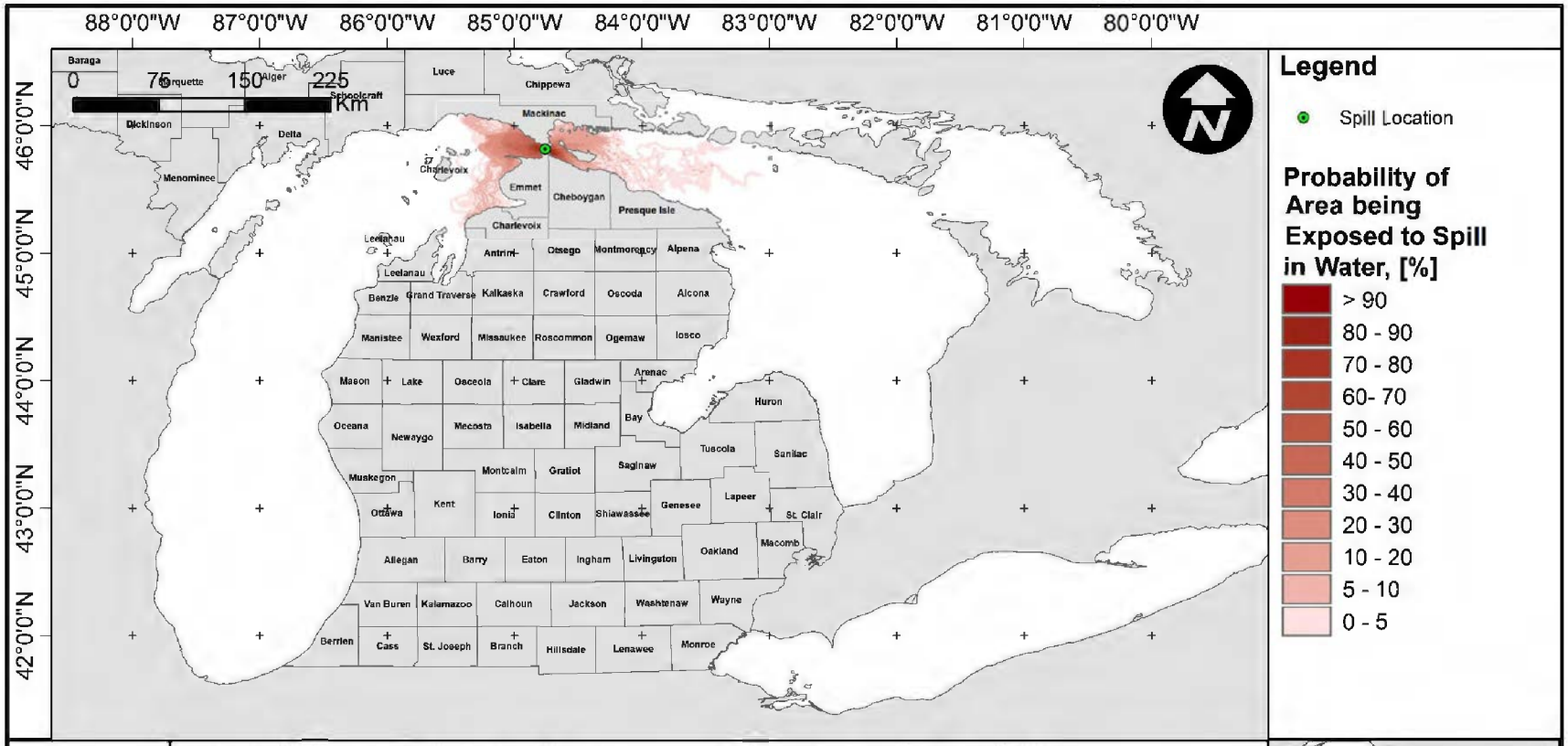


Zone of Potential Exposure on Shore (combined 30 simulations, zoomed in)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
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Coordinate System:
Datum: WGS 1984
Units: Degree

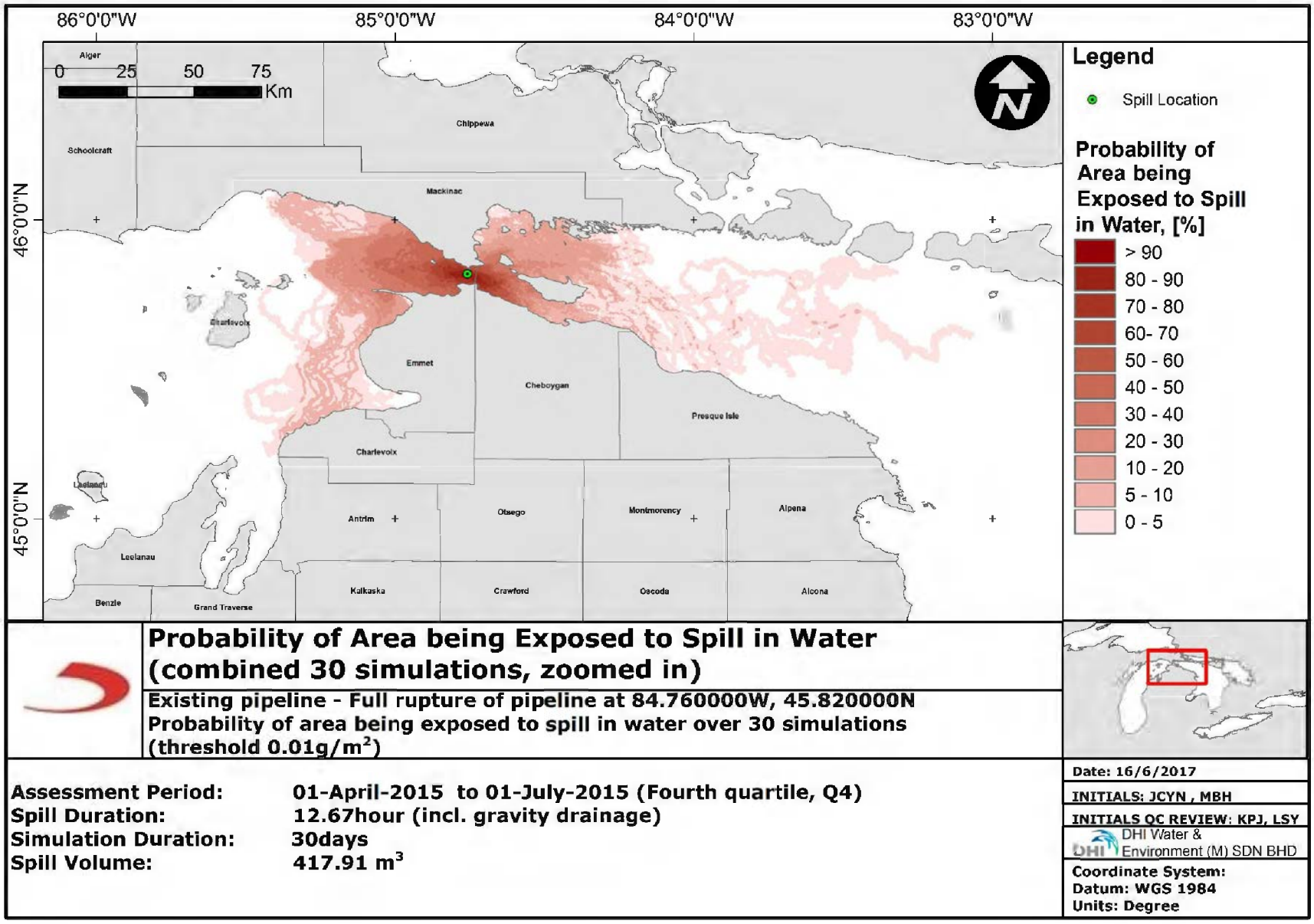


Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

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

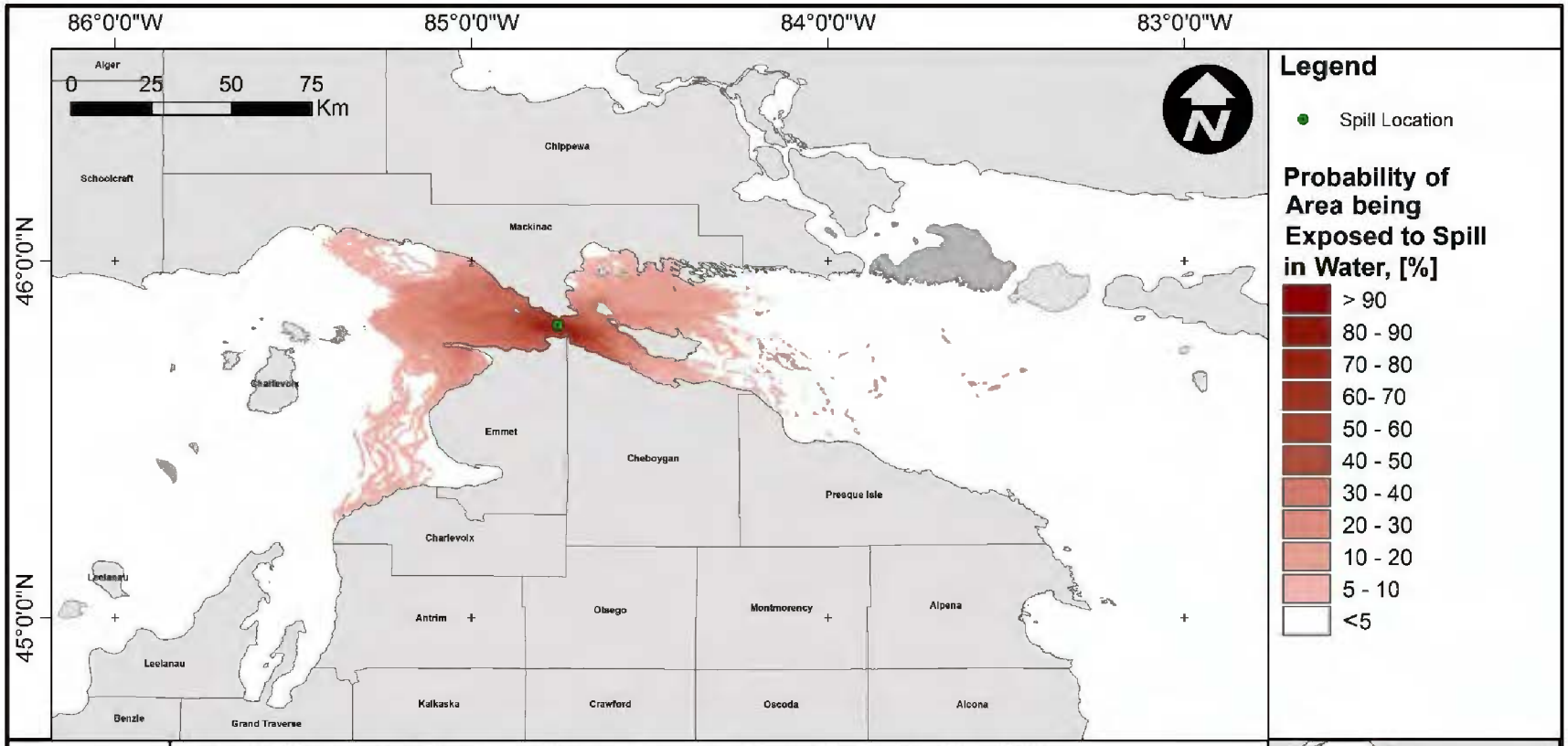


Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)

Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

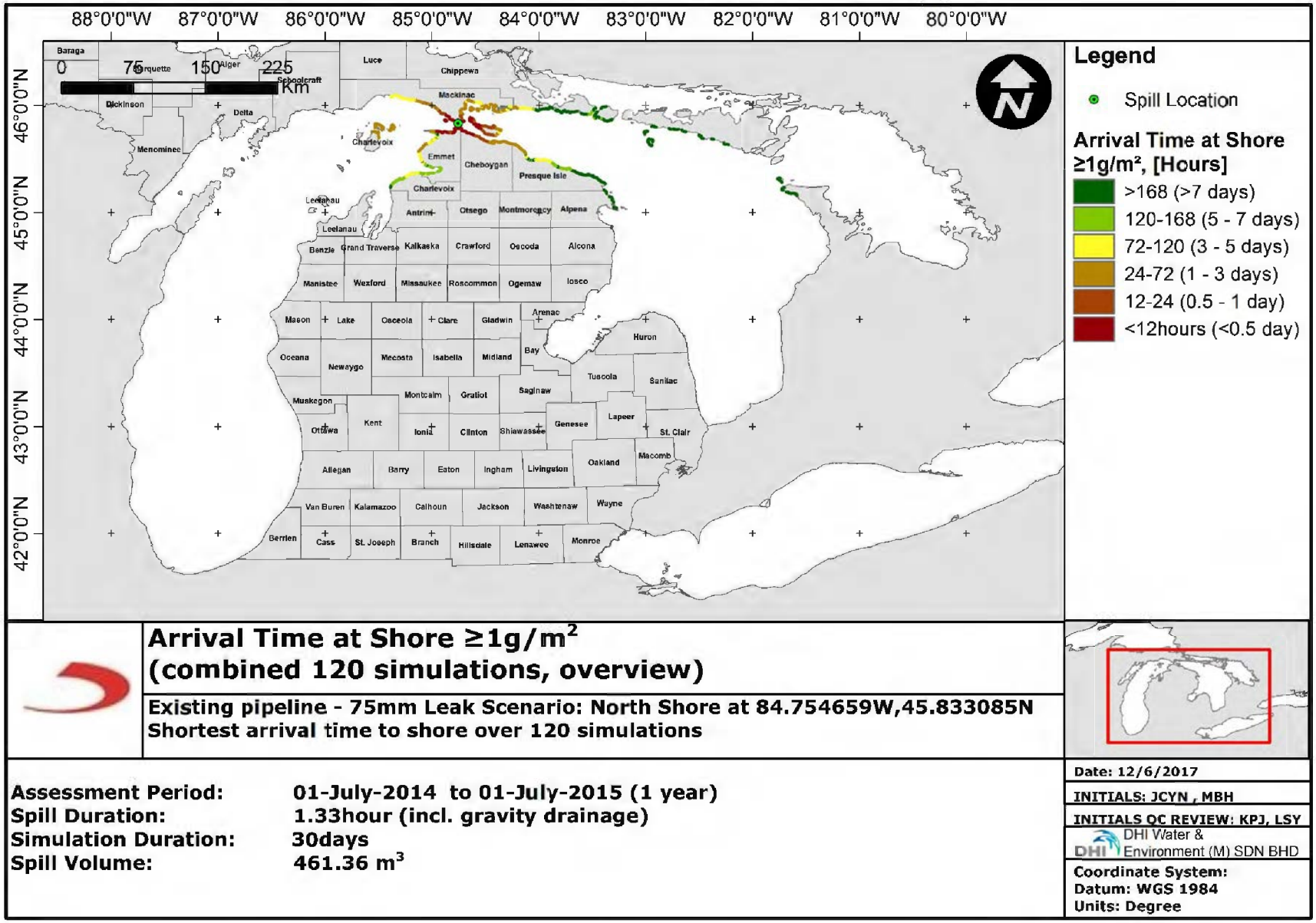
Existing pipeline - Full rupture of pipeline at 84.760000W, 45.820000N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**12.67hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**417.91 m^3**

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

Set 6
Existing Pipeline – 75 mm Leak at Northern Shore

1 year

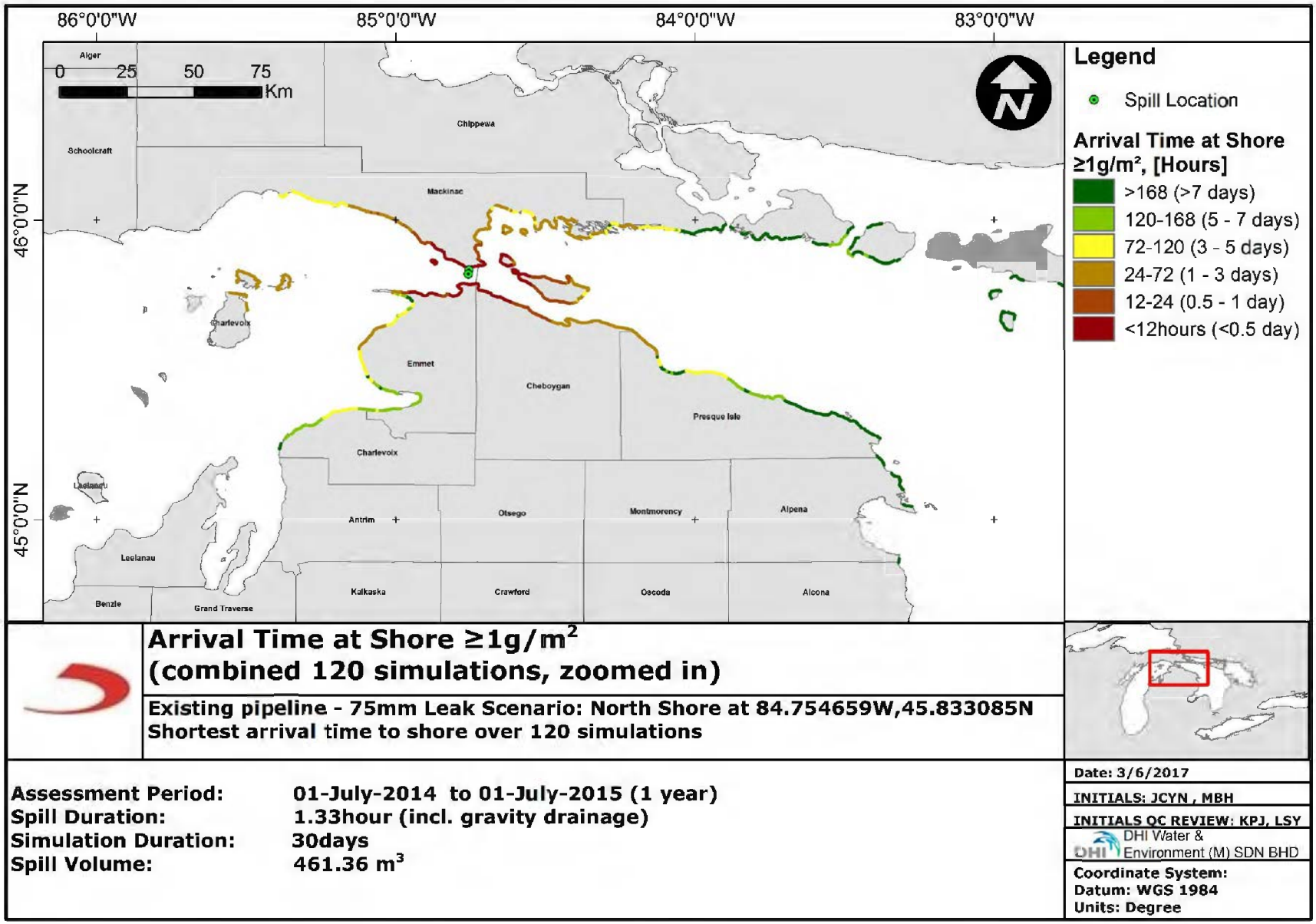


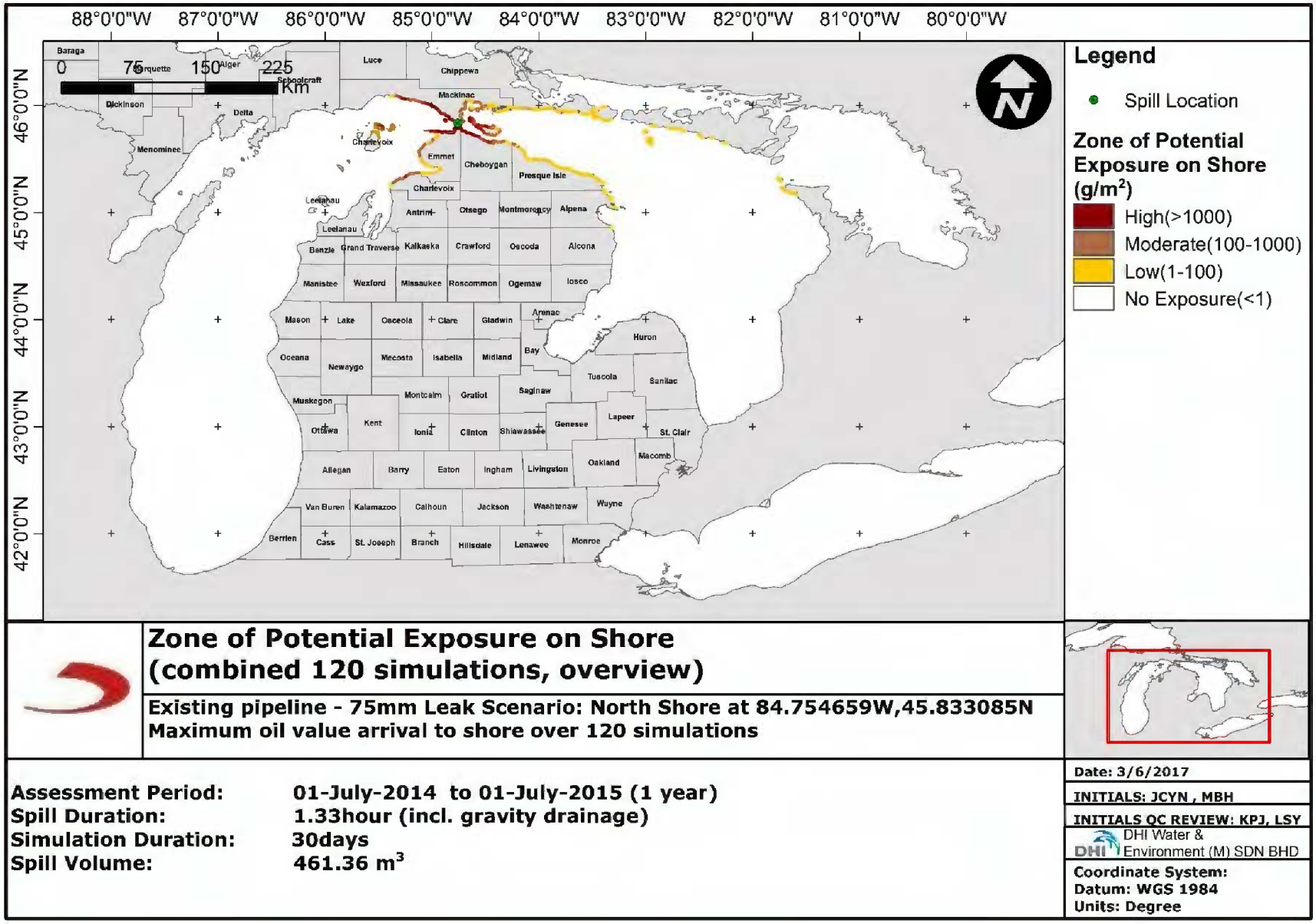
Arrival Time at Shore ≥1g/m² (combined 120 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 120 simulations

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 12/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
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Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 120 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 120 simulations
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 461.36 m³
Date: 3/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

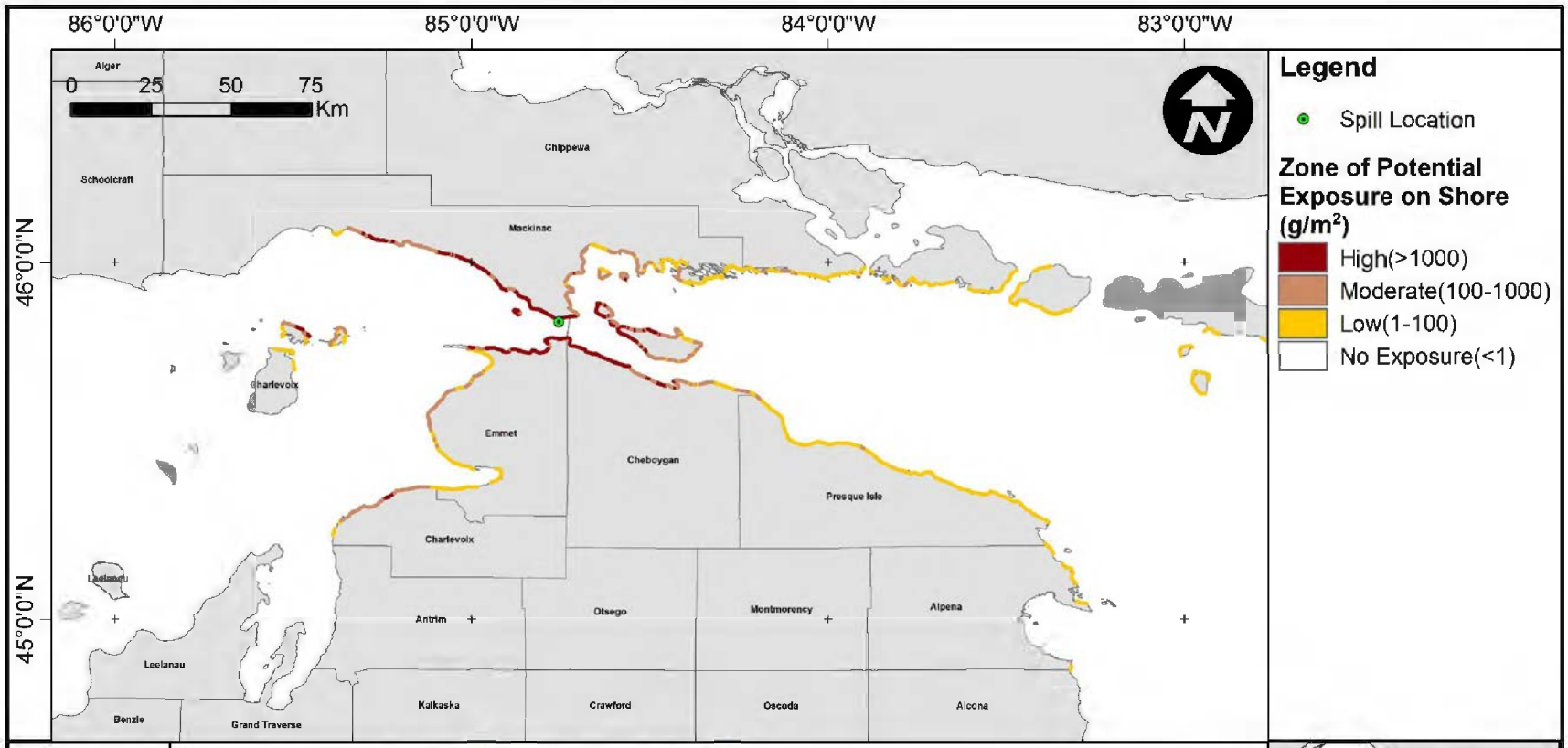


Zone of Potential Exposure on Shore (combined 120 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 120 simulations

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 3/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

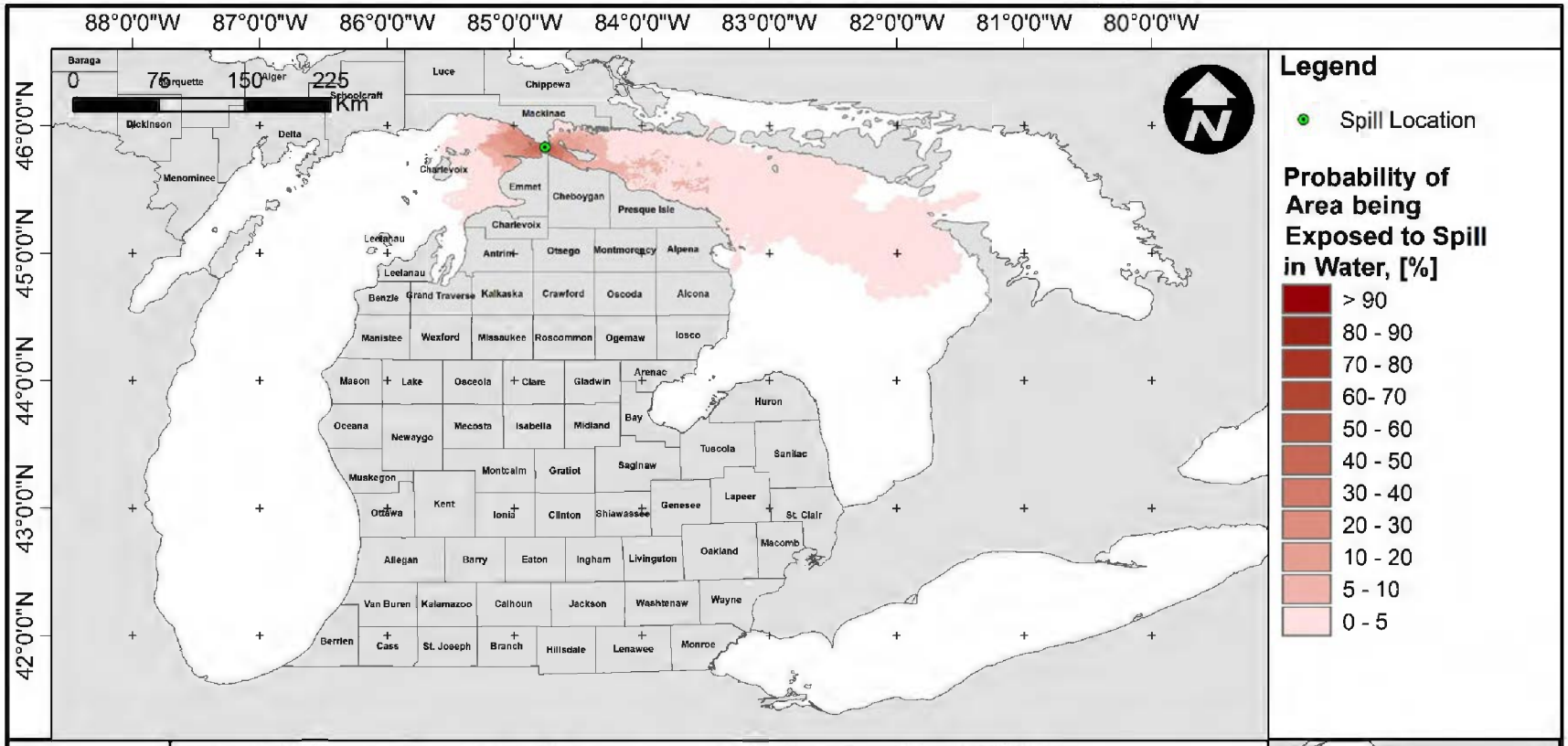


Zone of Potential Exposure on Shore (combined 120 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 120 simulations

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

Date: 3/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

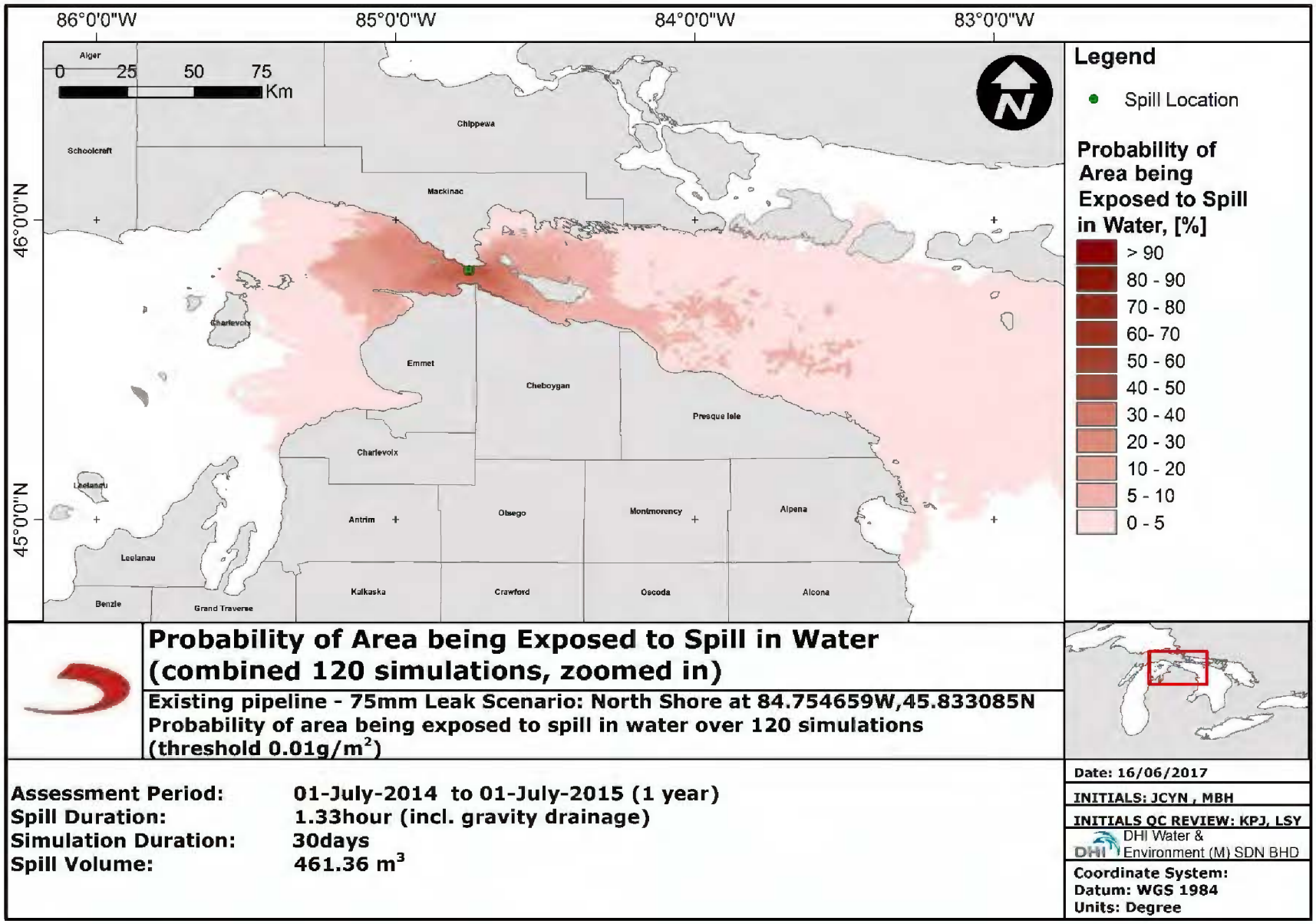


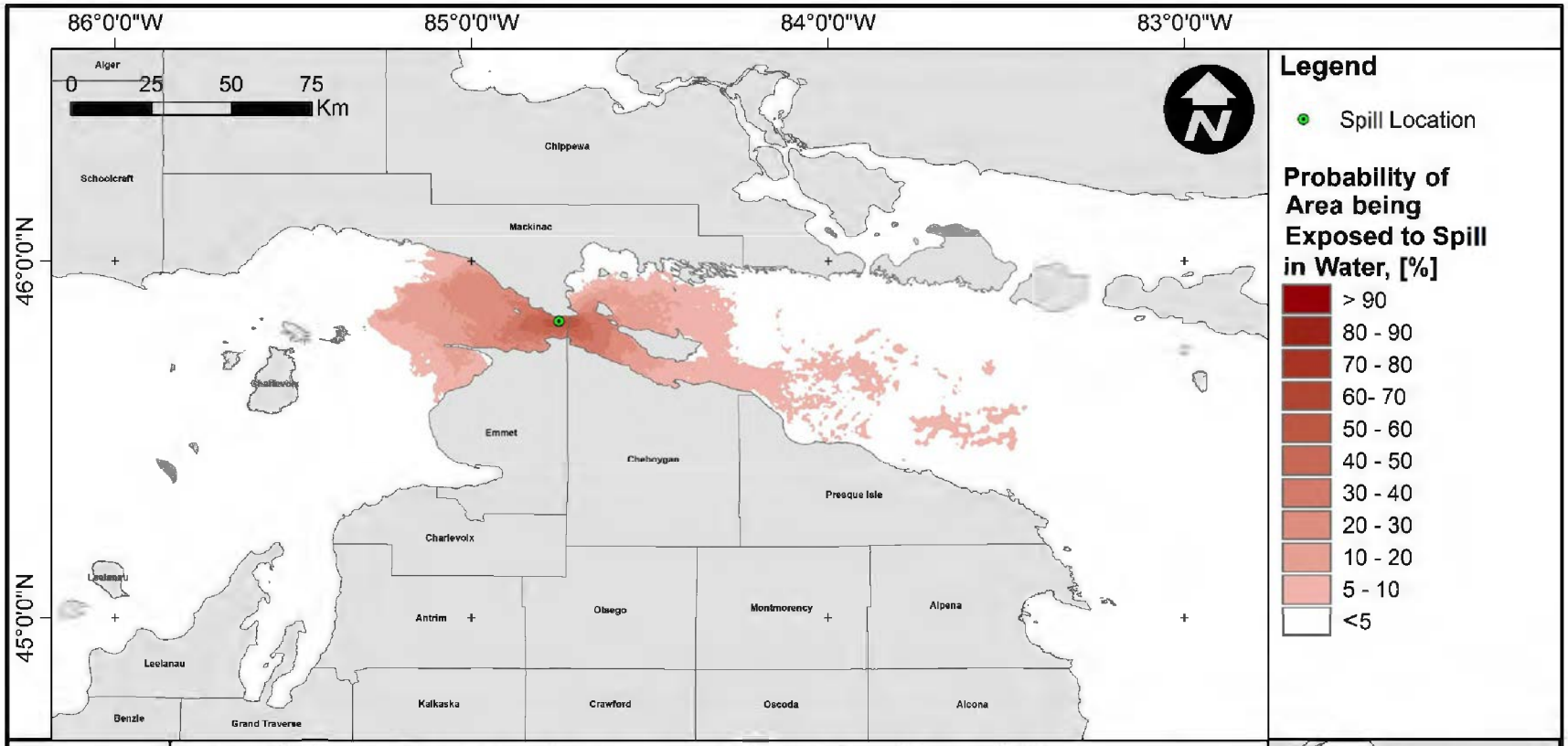
Probability of Area being Exposed to Spill in Water (combined 120 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
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)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
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Charlevoix
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Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 120 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
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: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 461.36 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



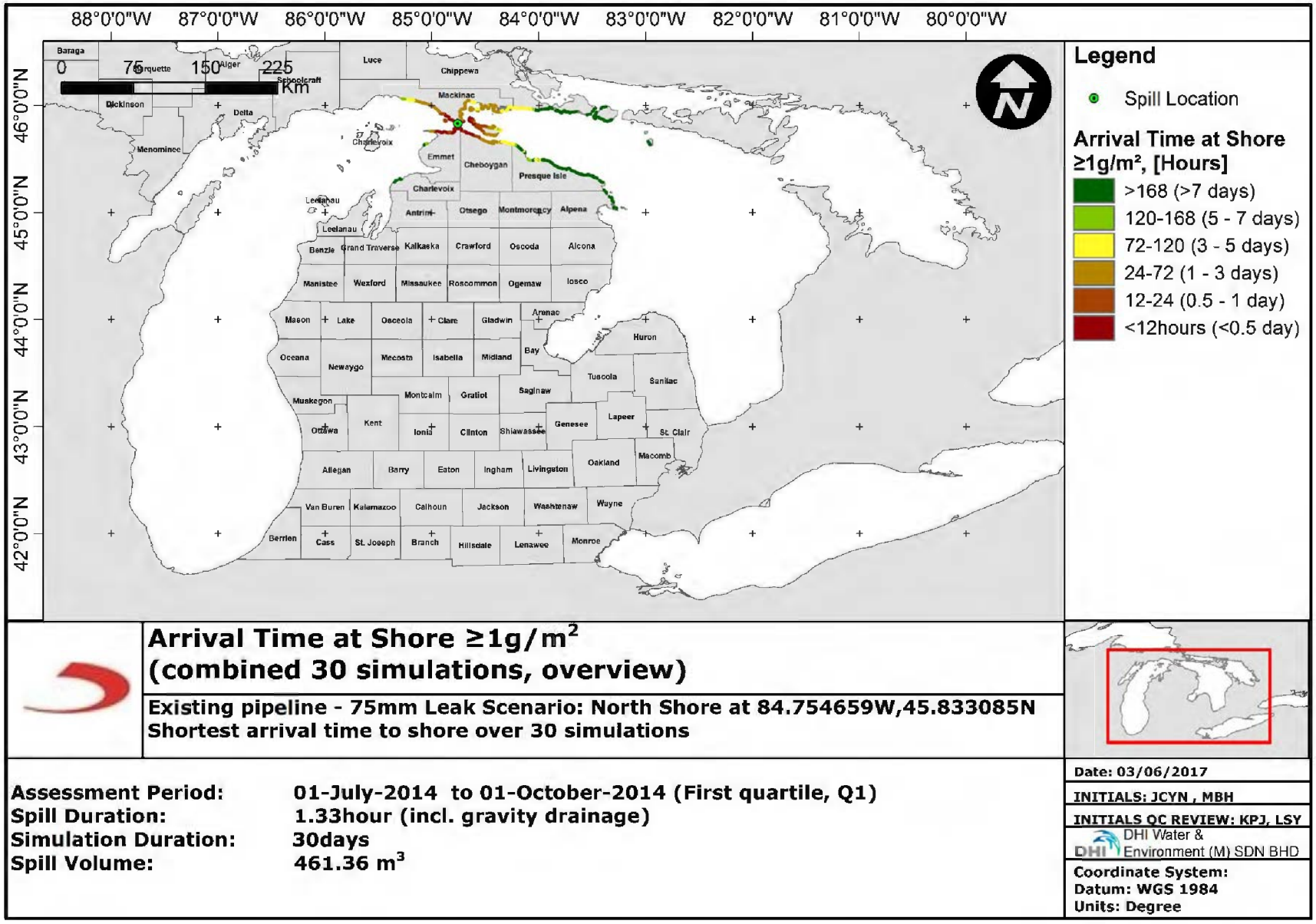
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 120 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
95th perct. 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)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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

Q1

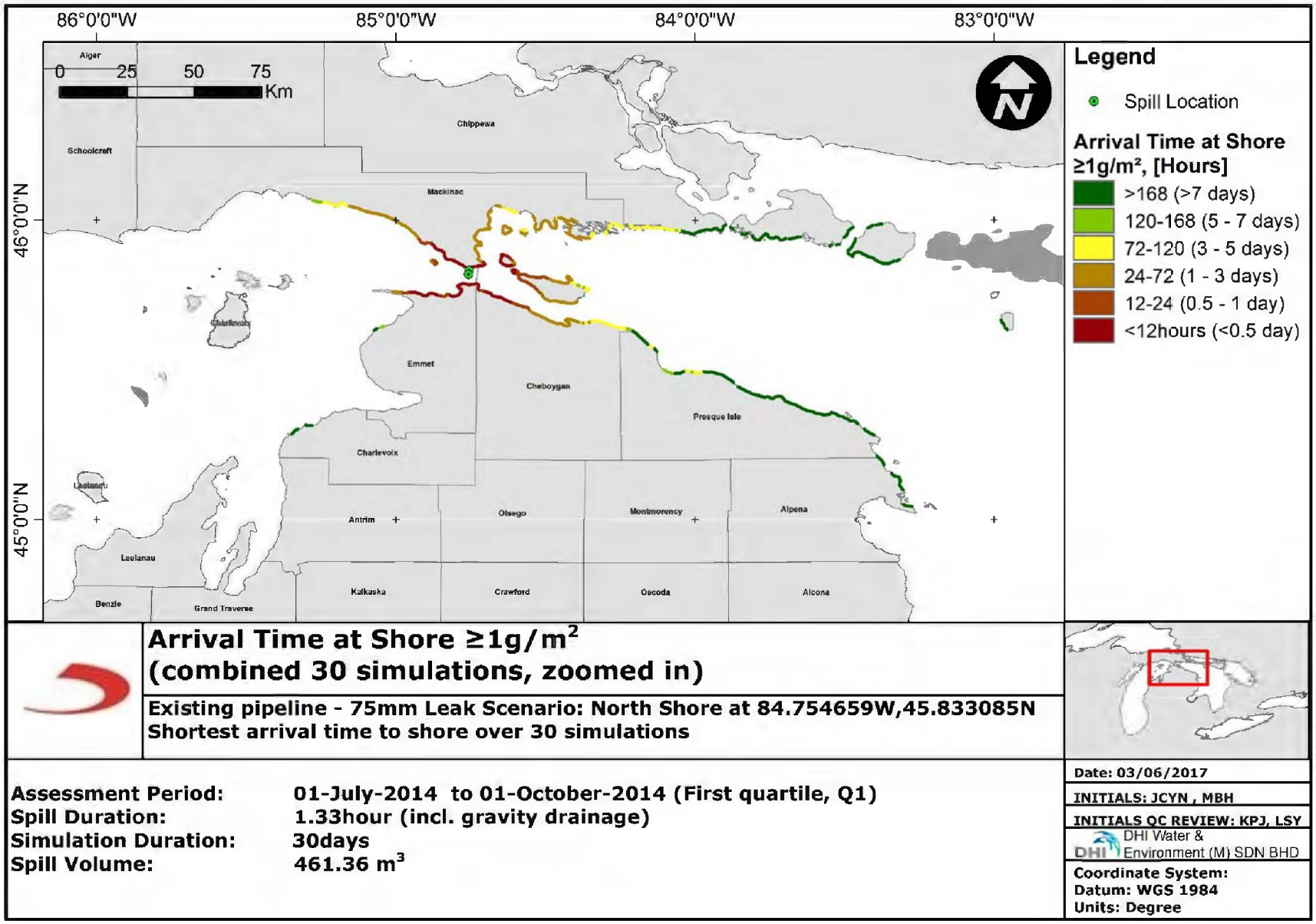


Arrival Time at Shore ≥1g/m² (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

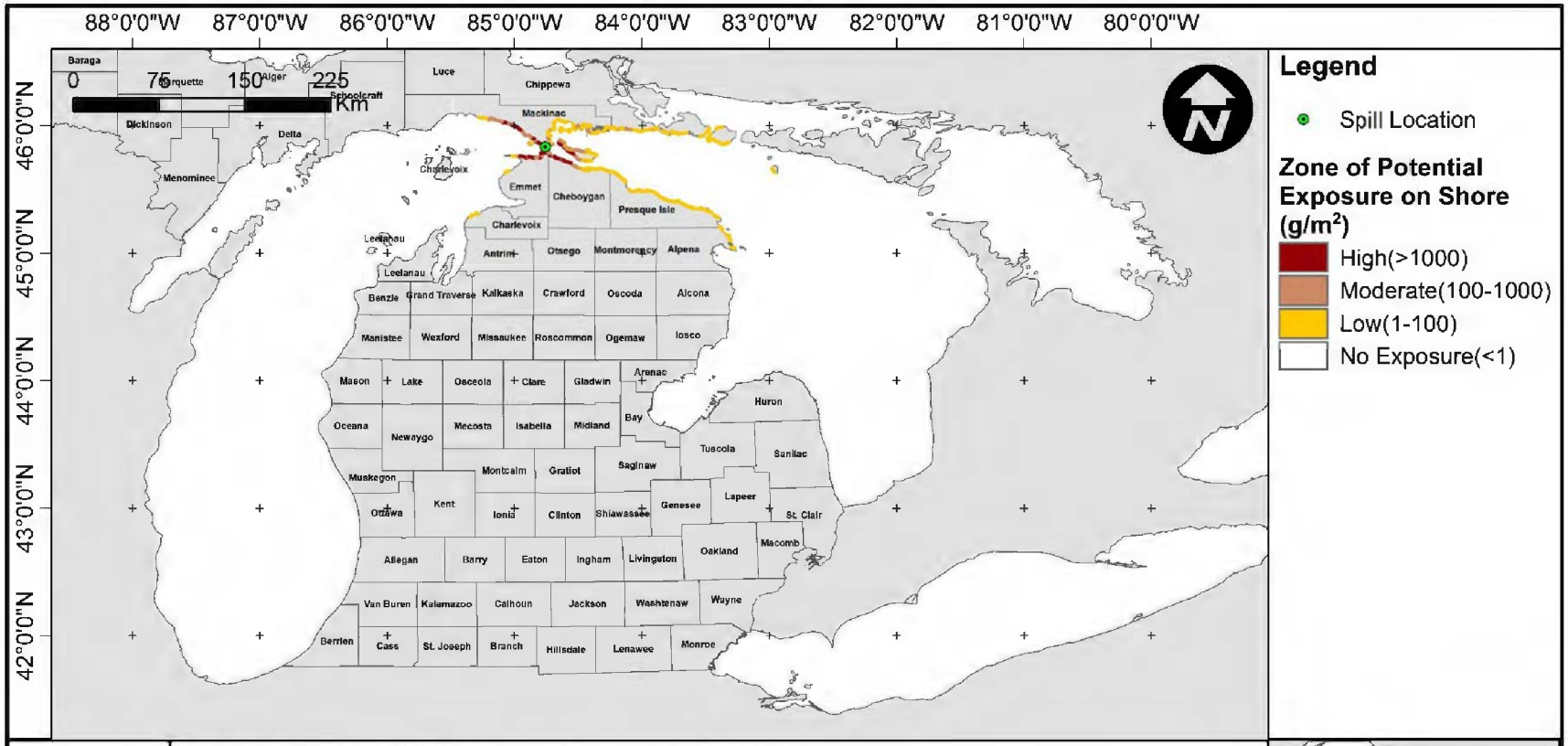


Arrival Time at Shore ≥1g/m² (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

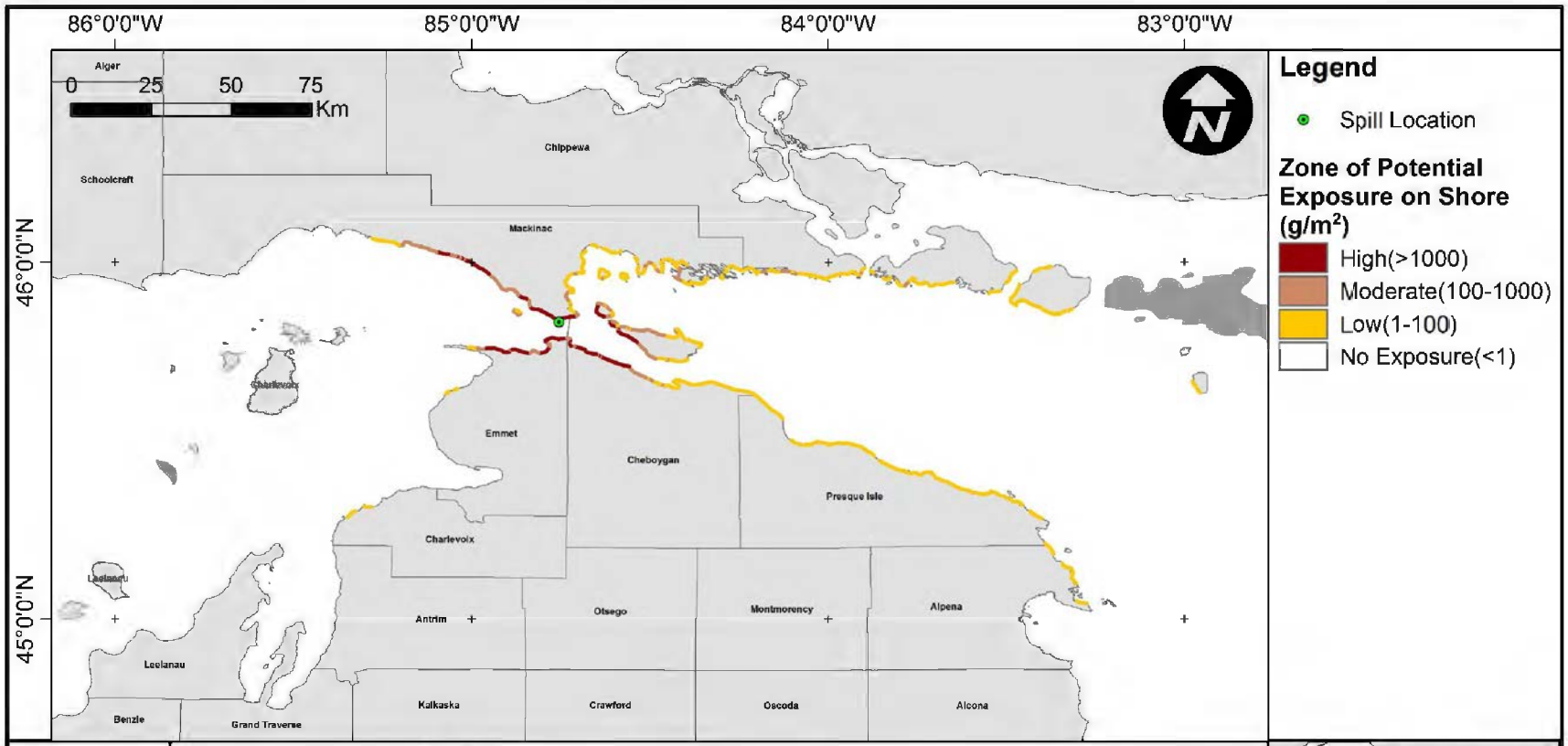


Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

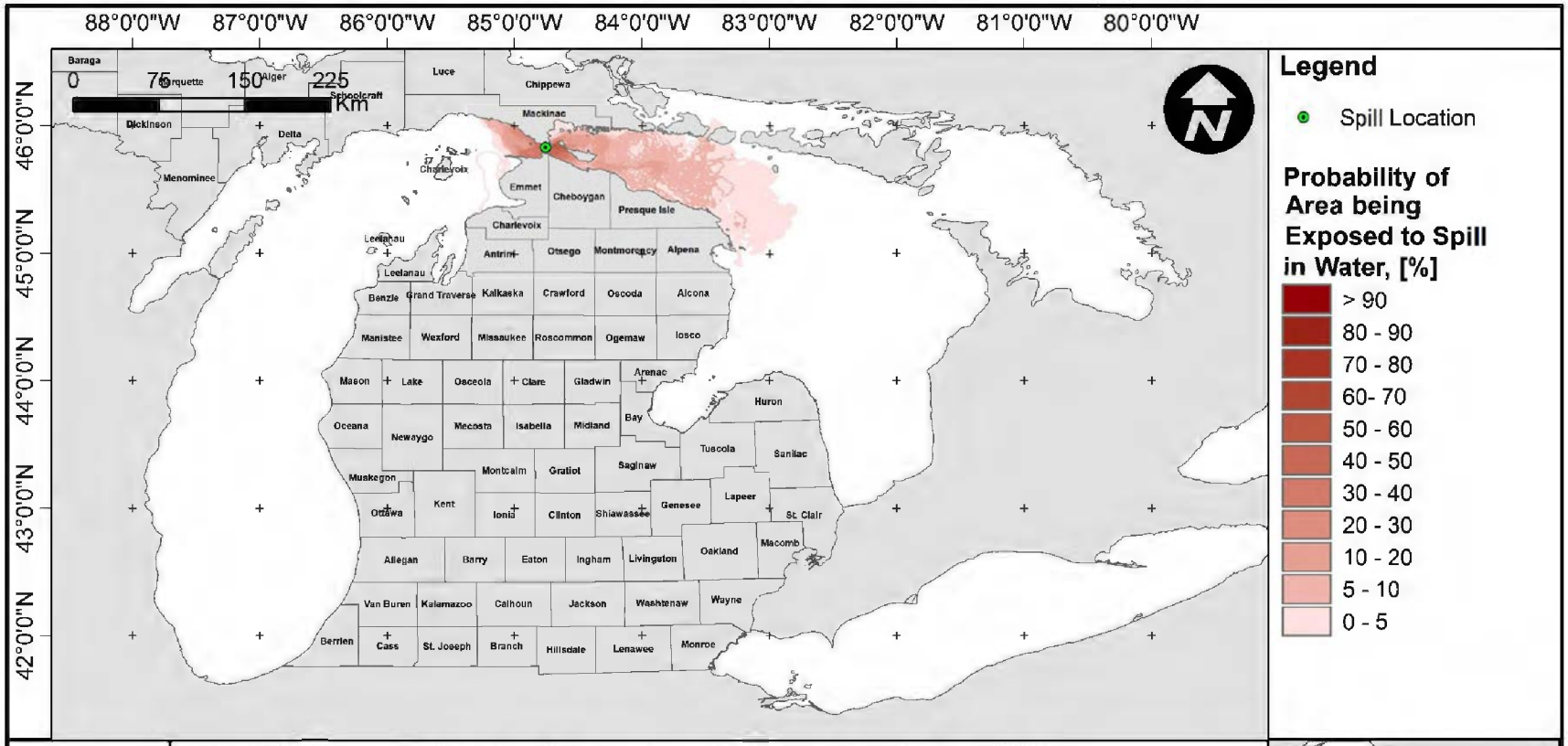


Zone of Potential Exposure on Shore (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

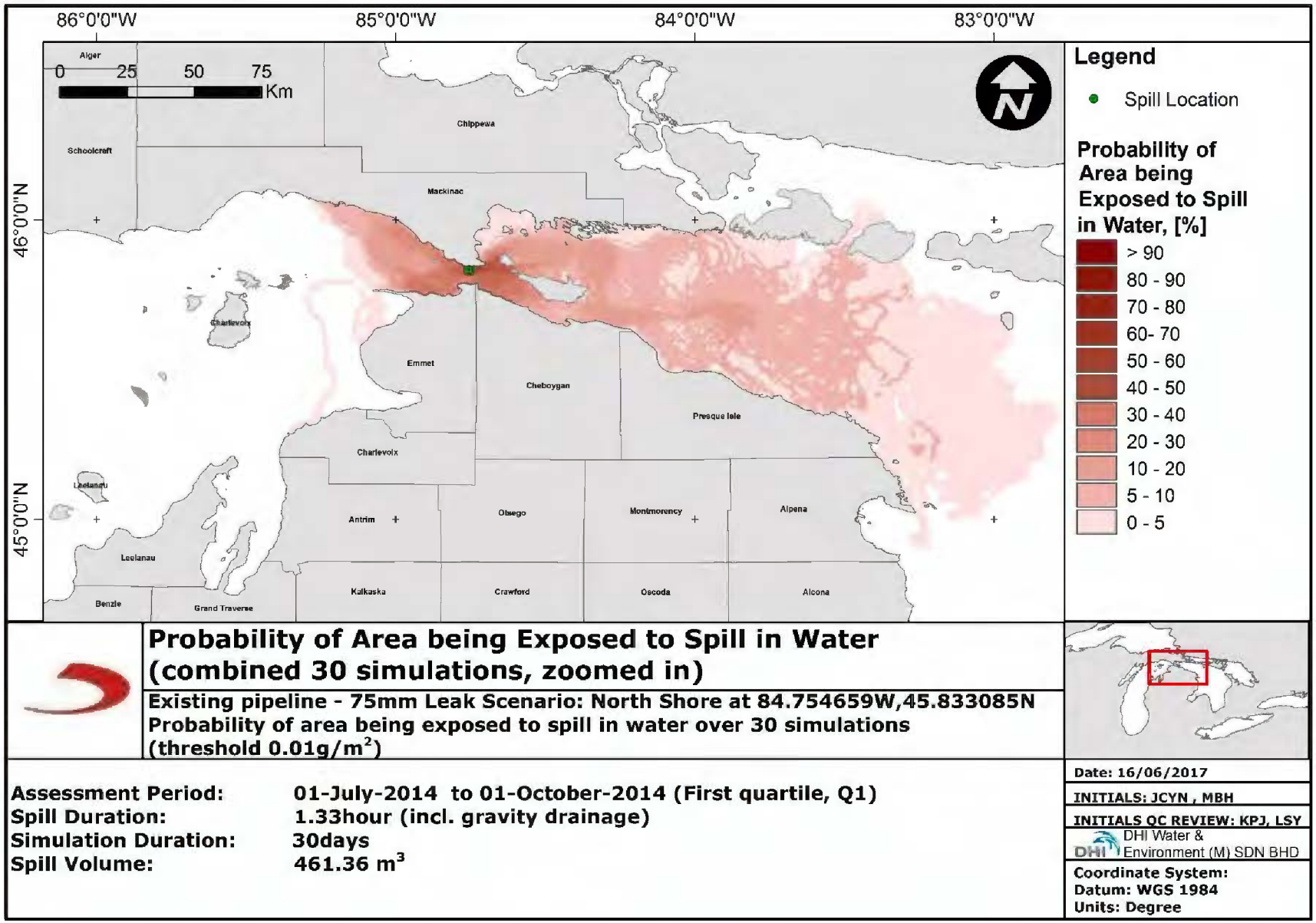


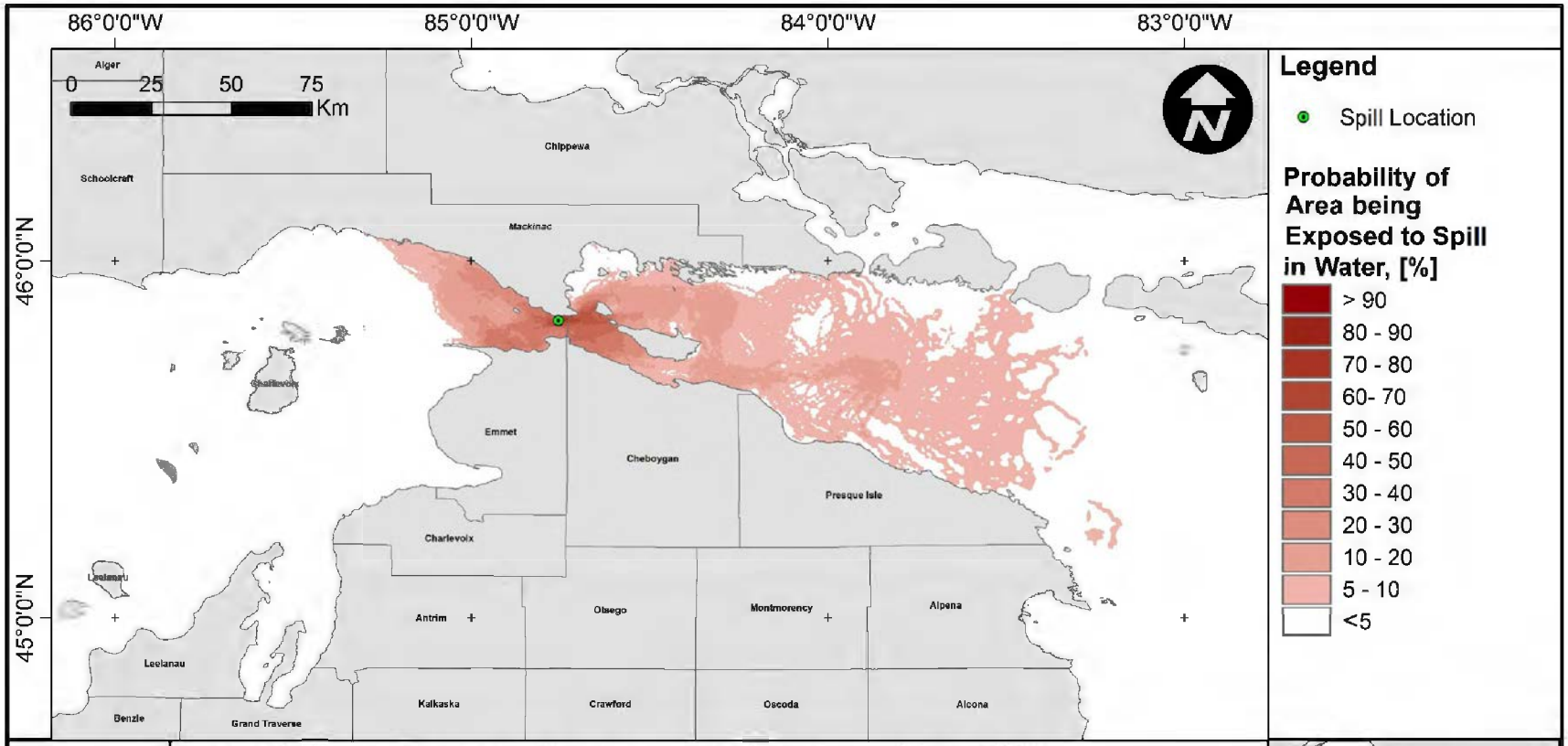
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m2)
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 461.36 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



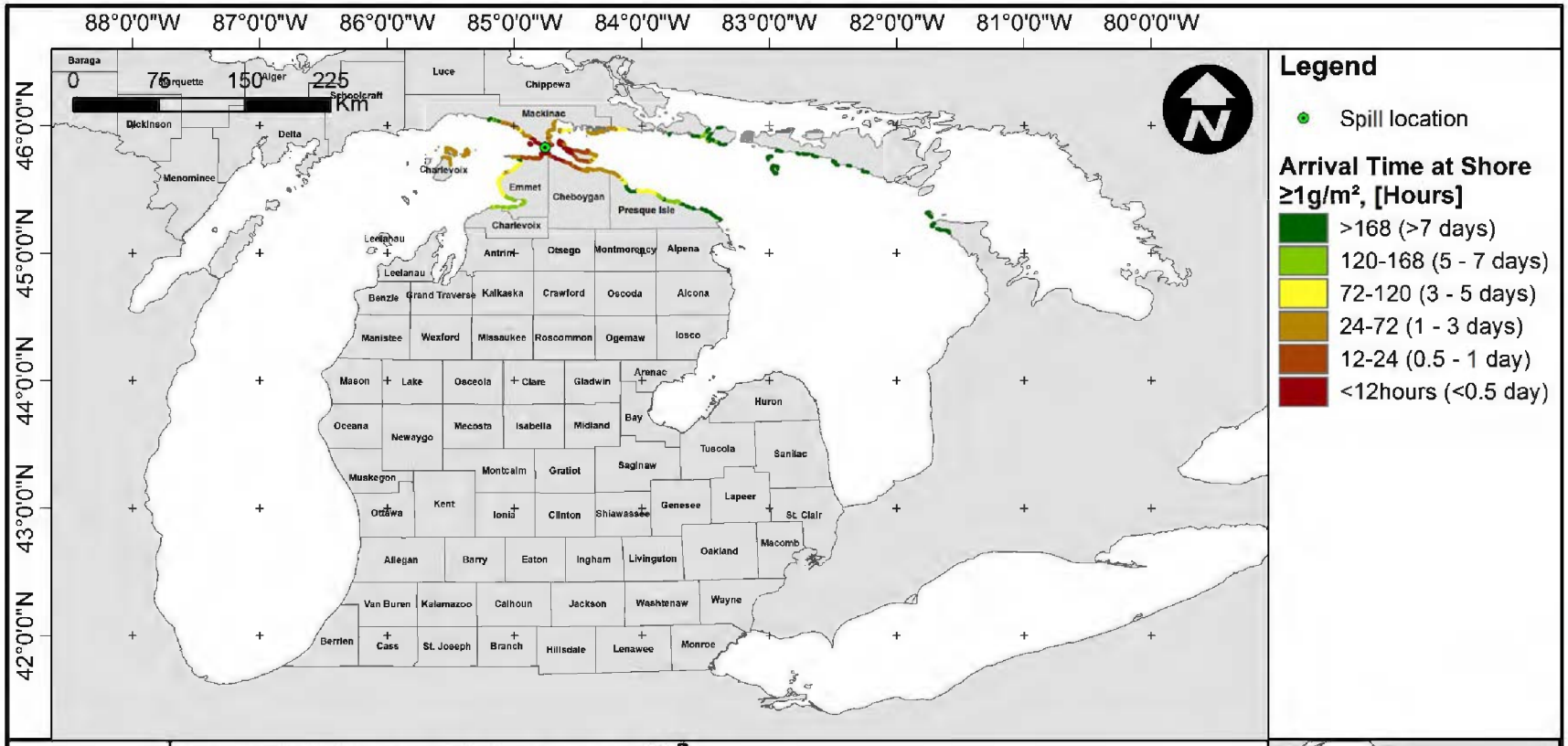
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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

Q2

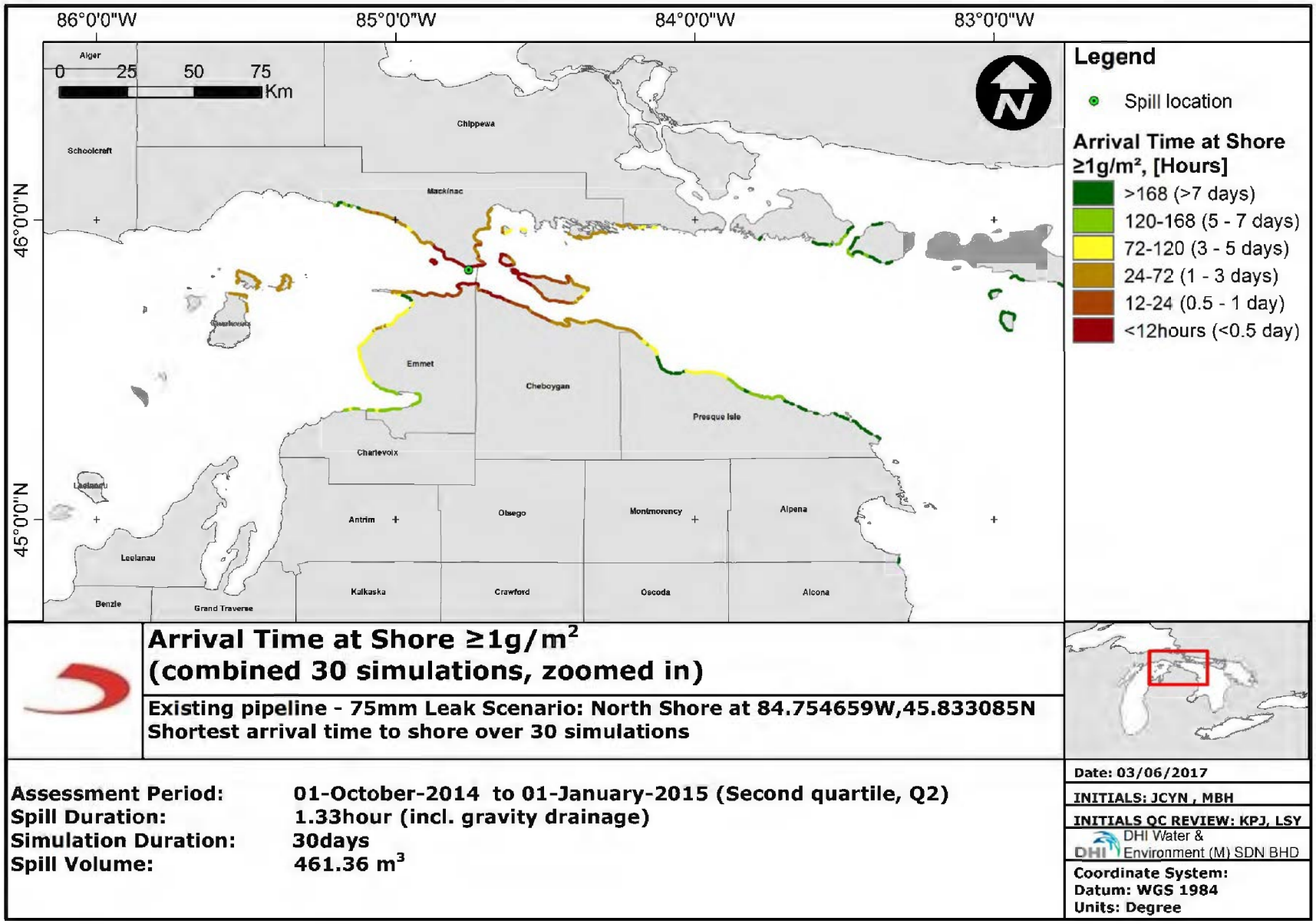


Arrival Time at Shore ≥1g/m² (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

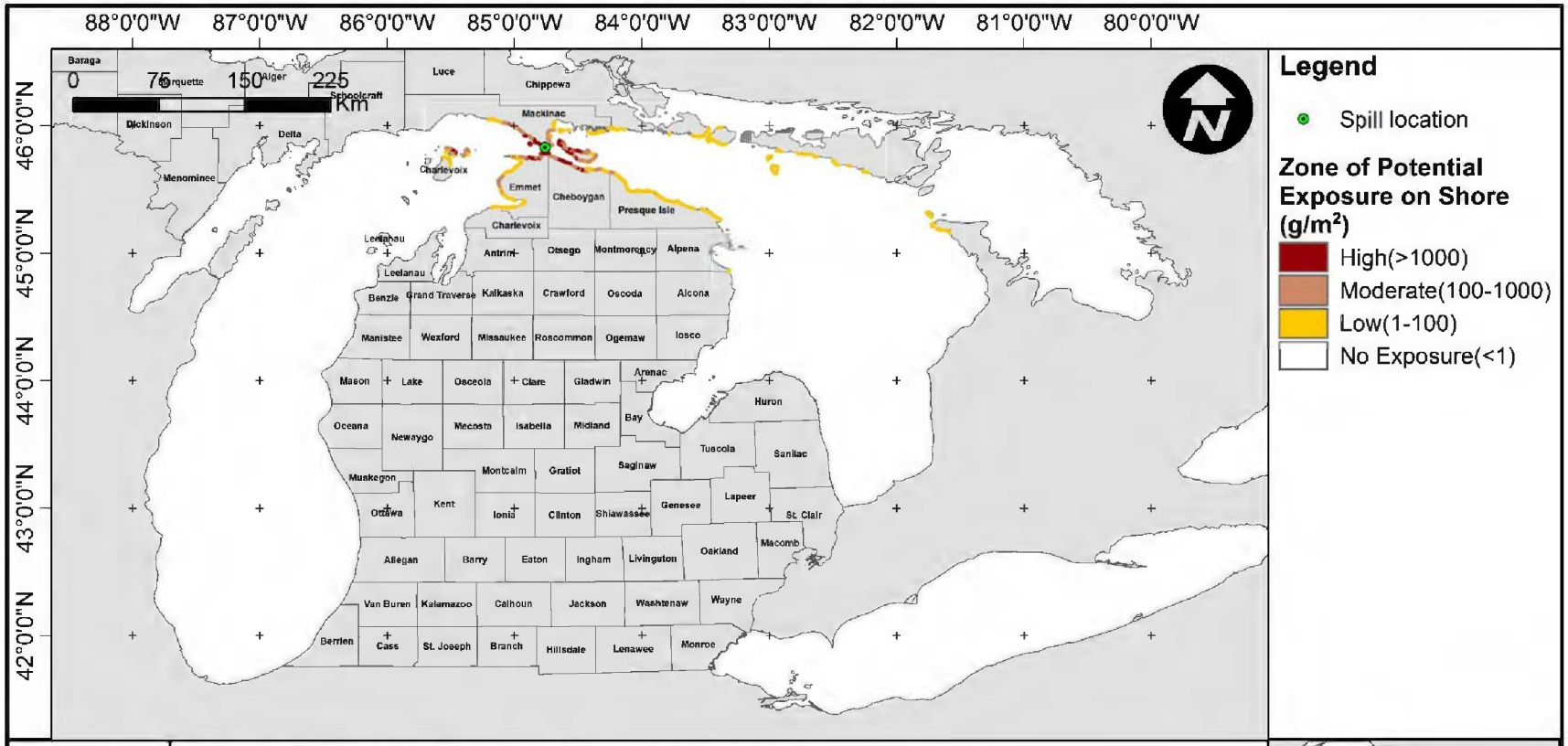


Arrival Time at Shore ≥1g/m²
(combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

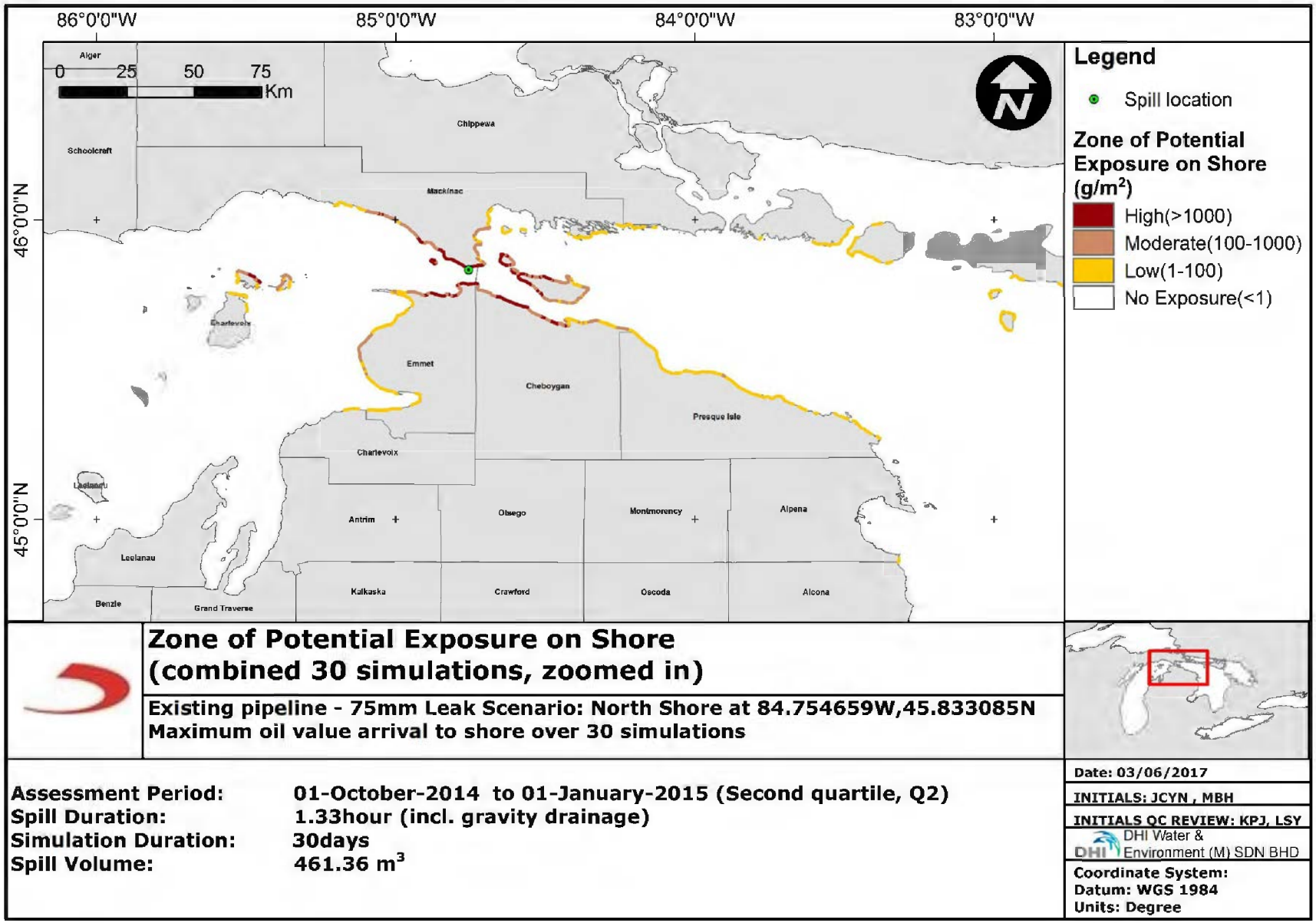


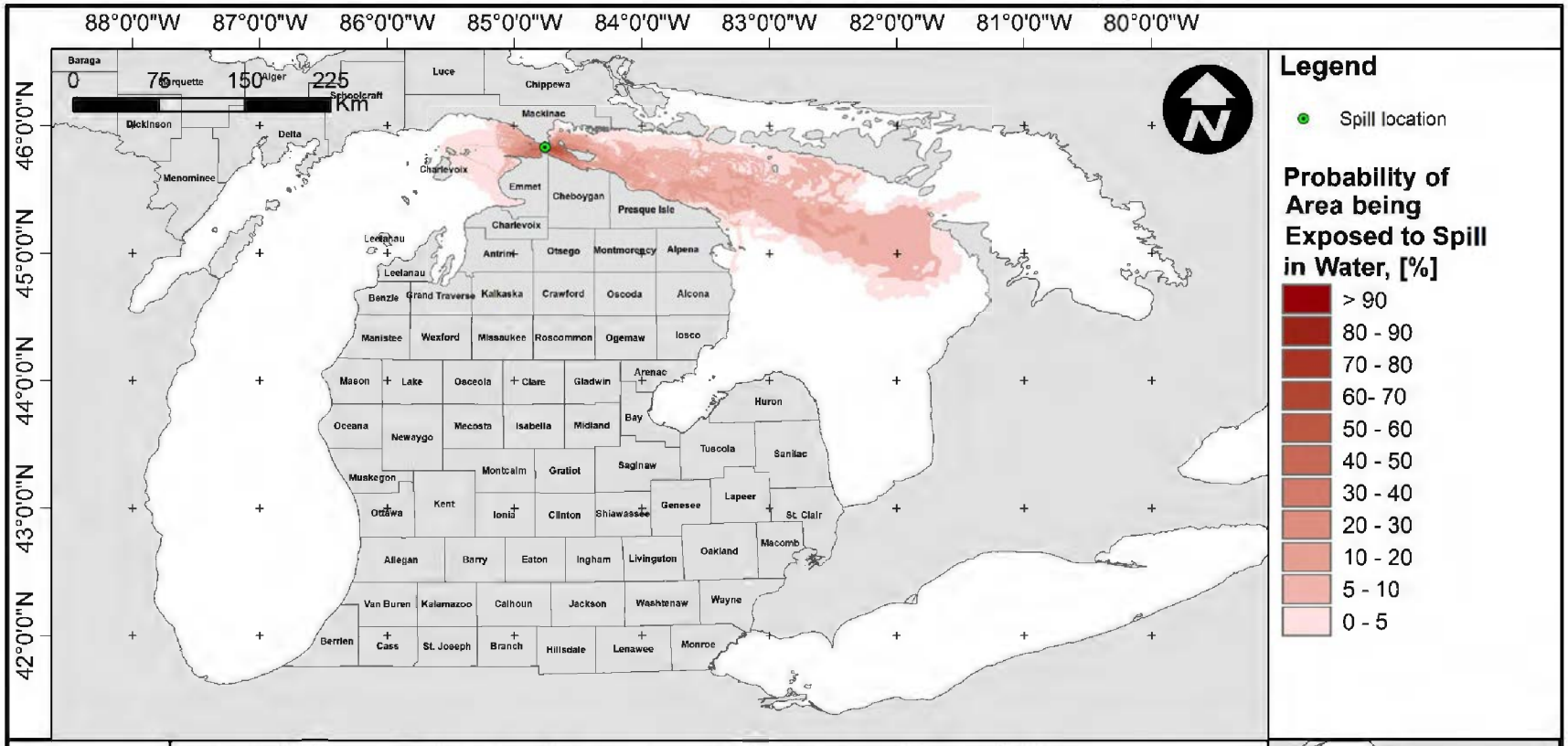
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
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Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 461.36 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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Units: Degree

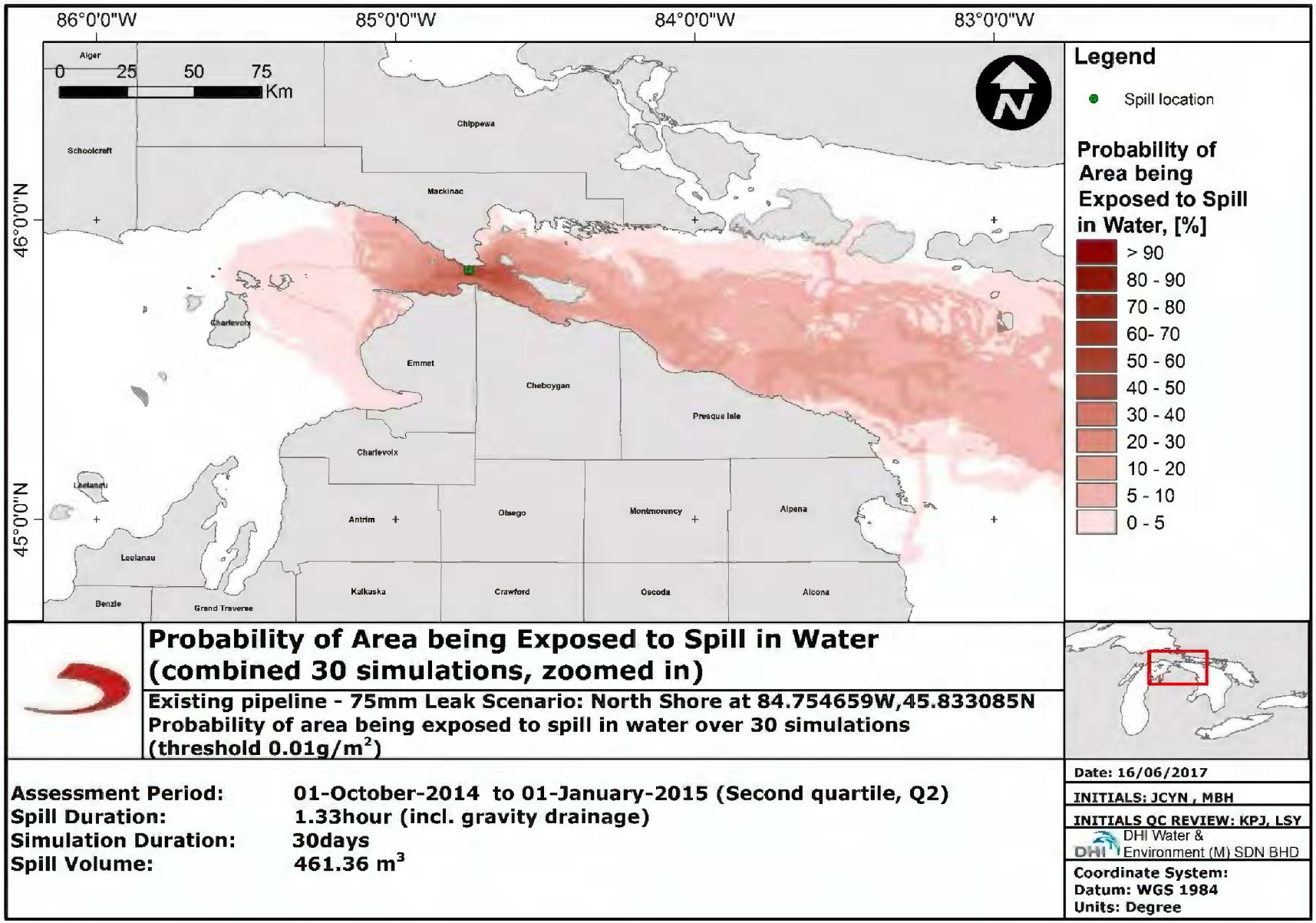


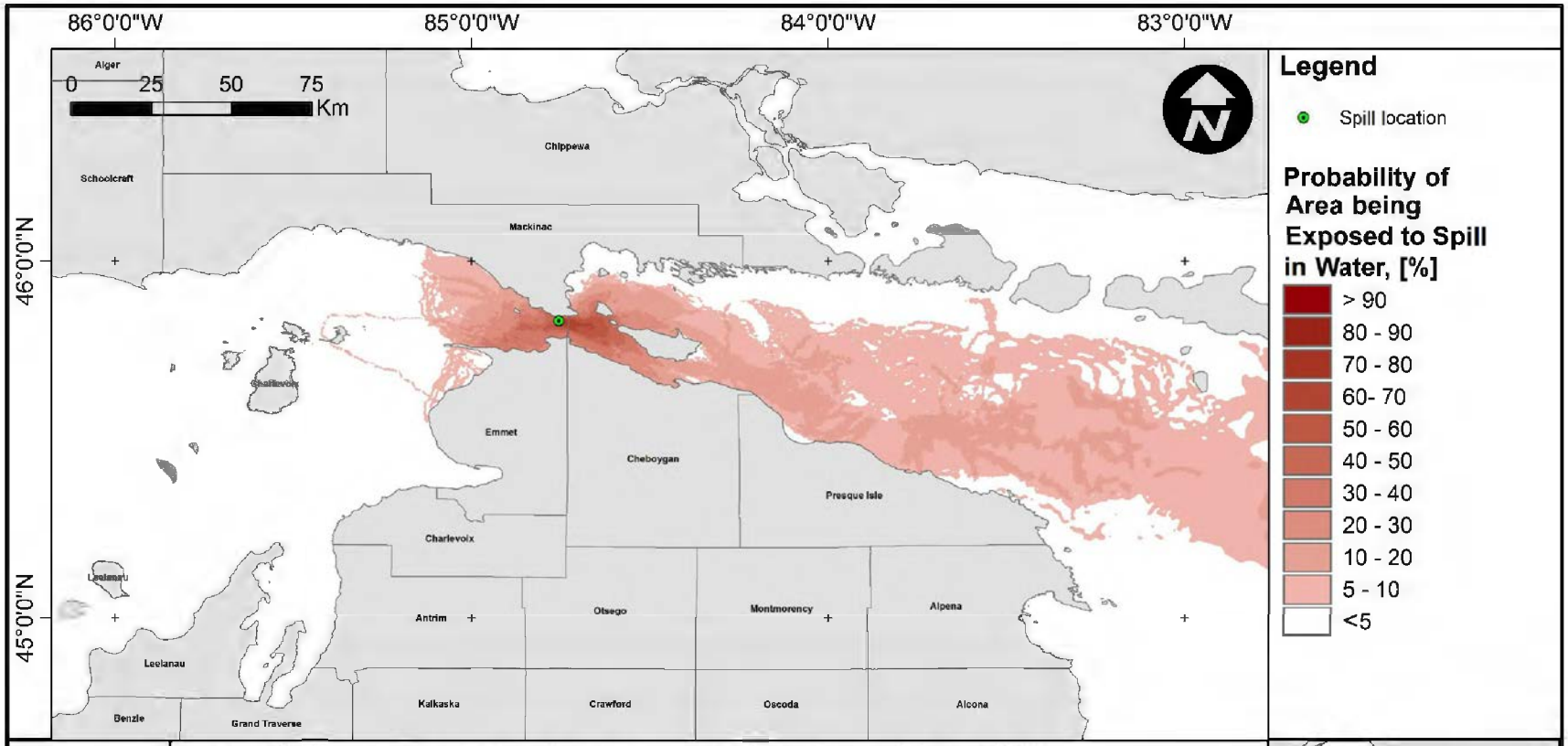
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
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Cheboygan
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Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 461.36 m³
Date: 16/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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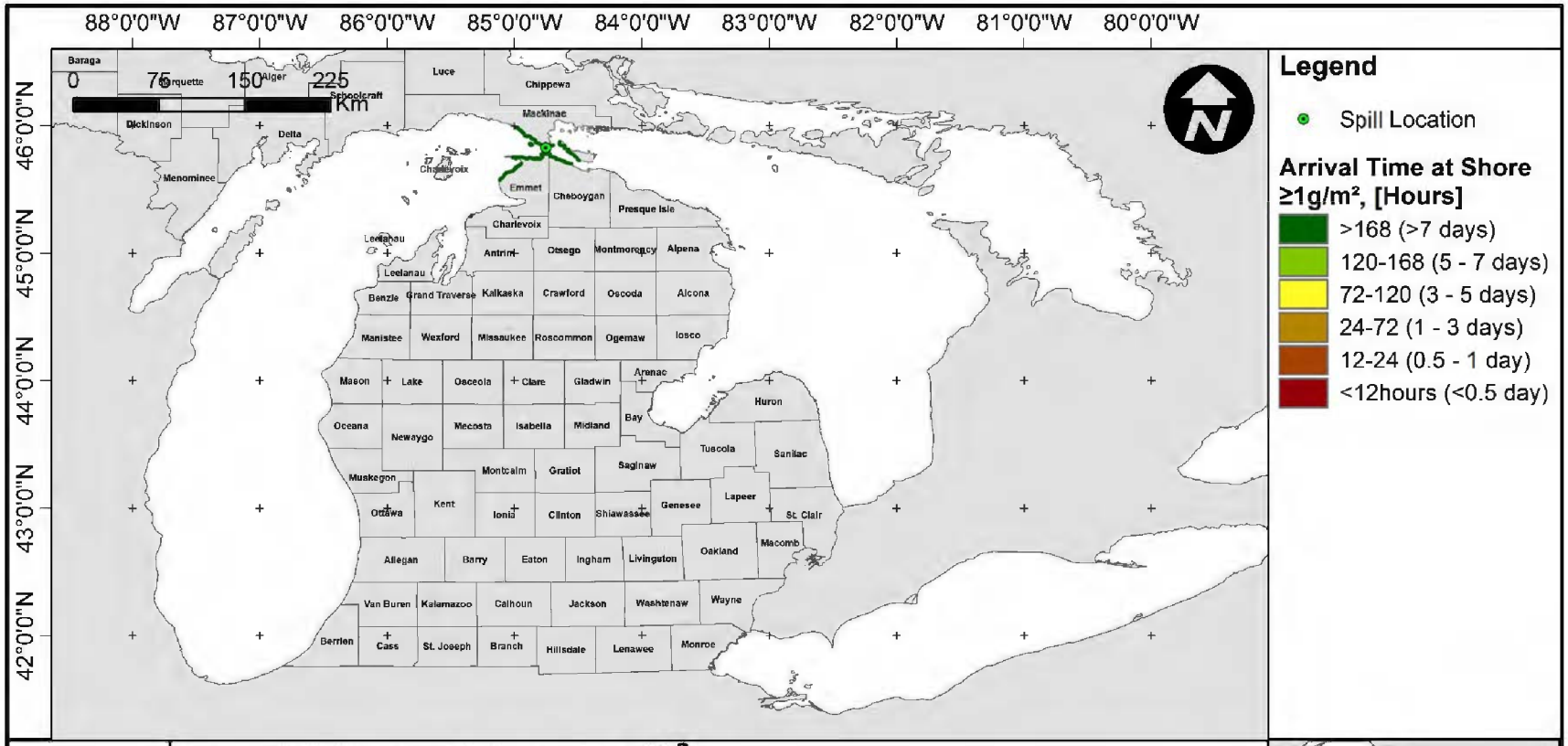
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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

Q3

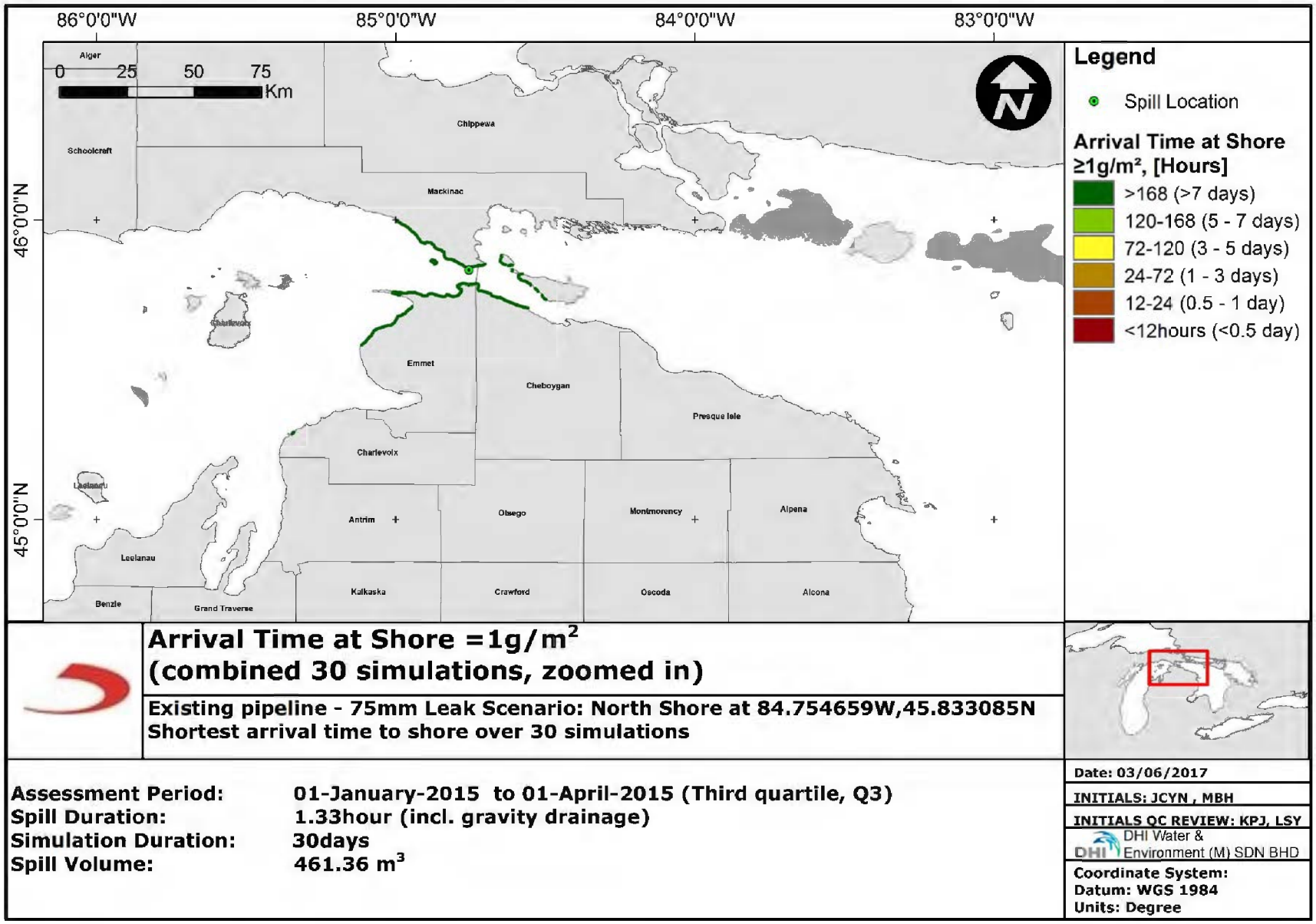


Arrival Time at Shore =1g/m² (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

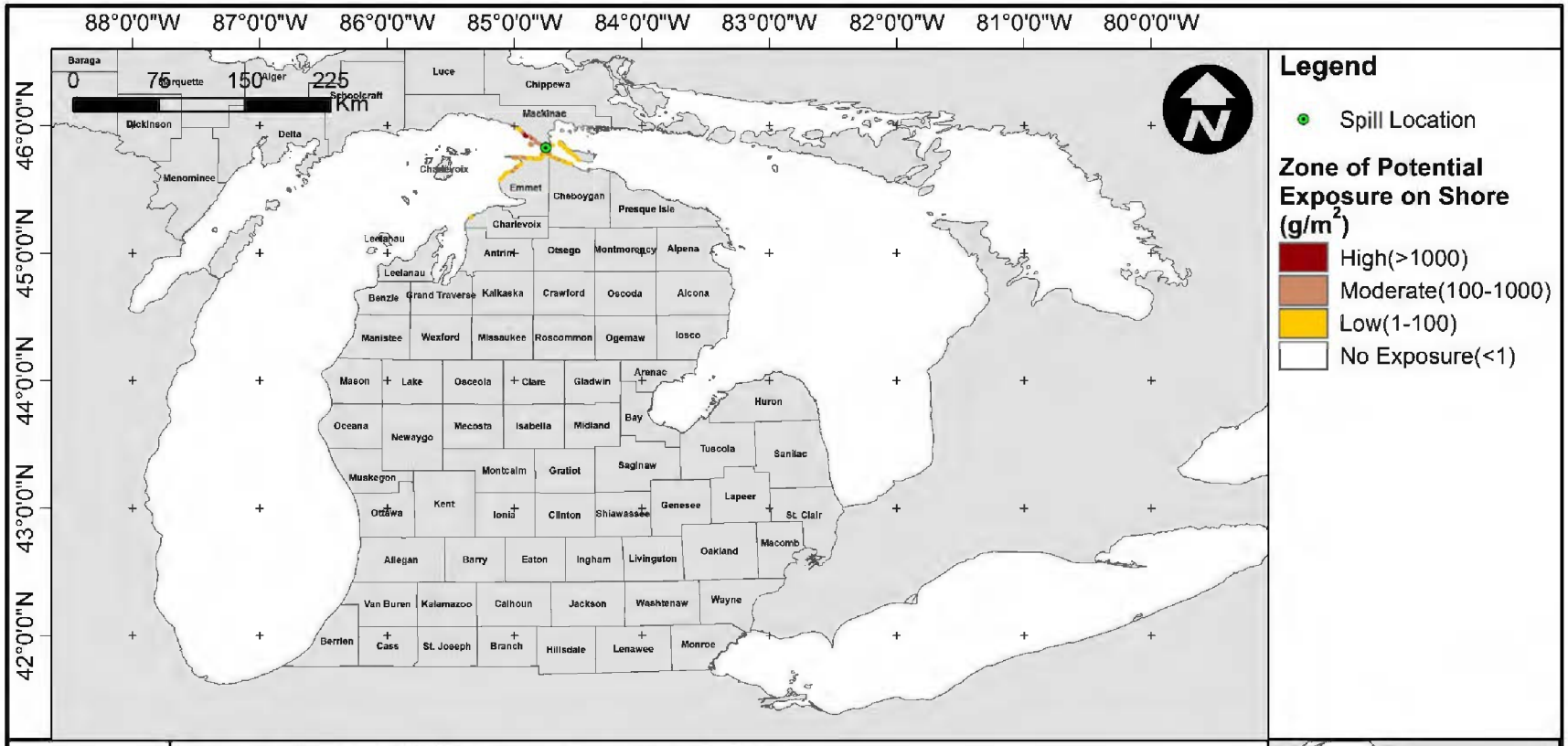


Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

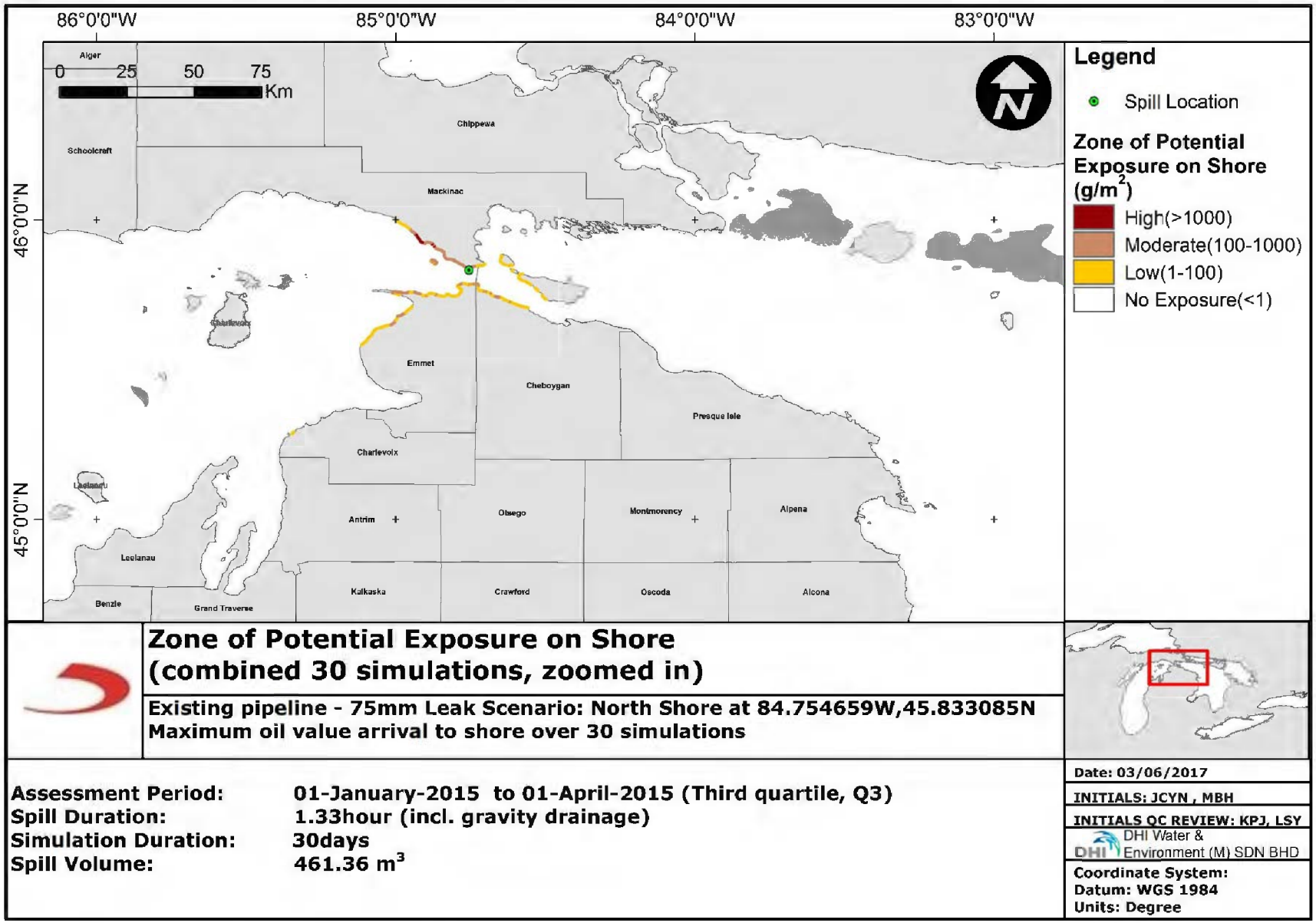


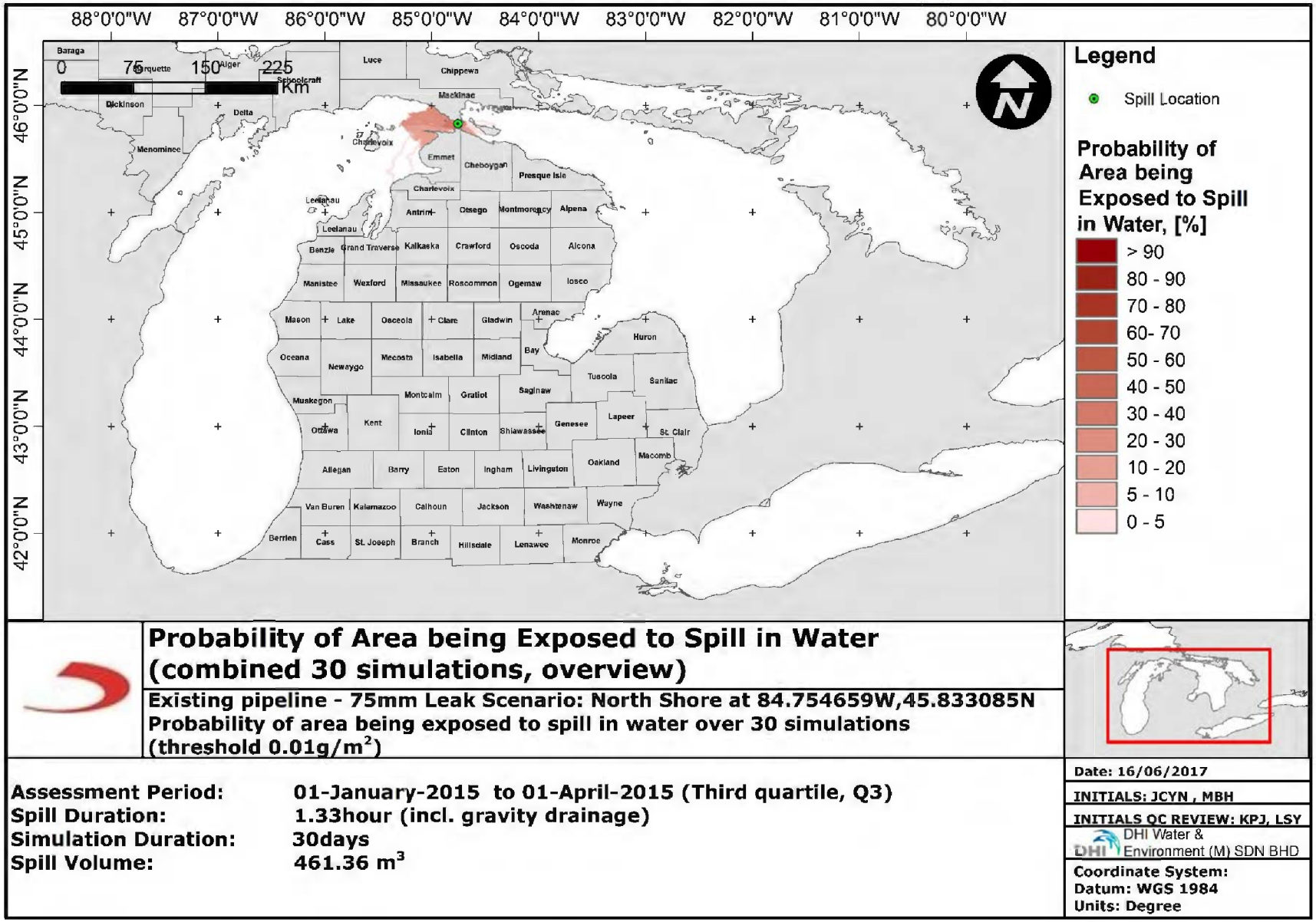
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
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Leelanau
Antrim
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Montmorency
Alpena
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 461.36 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

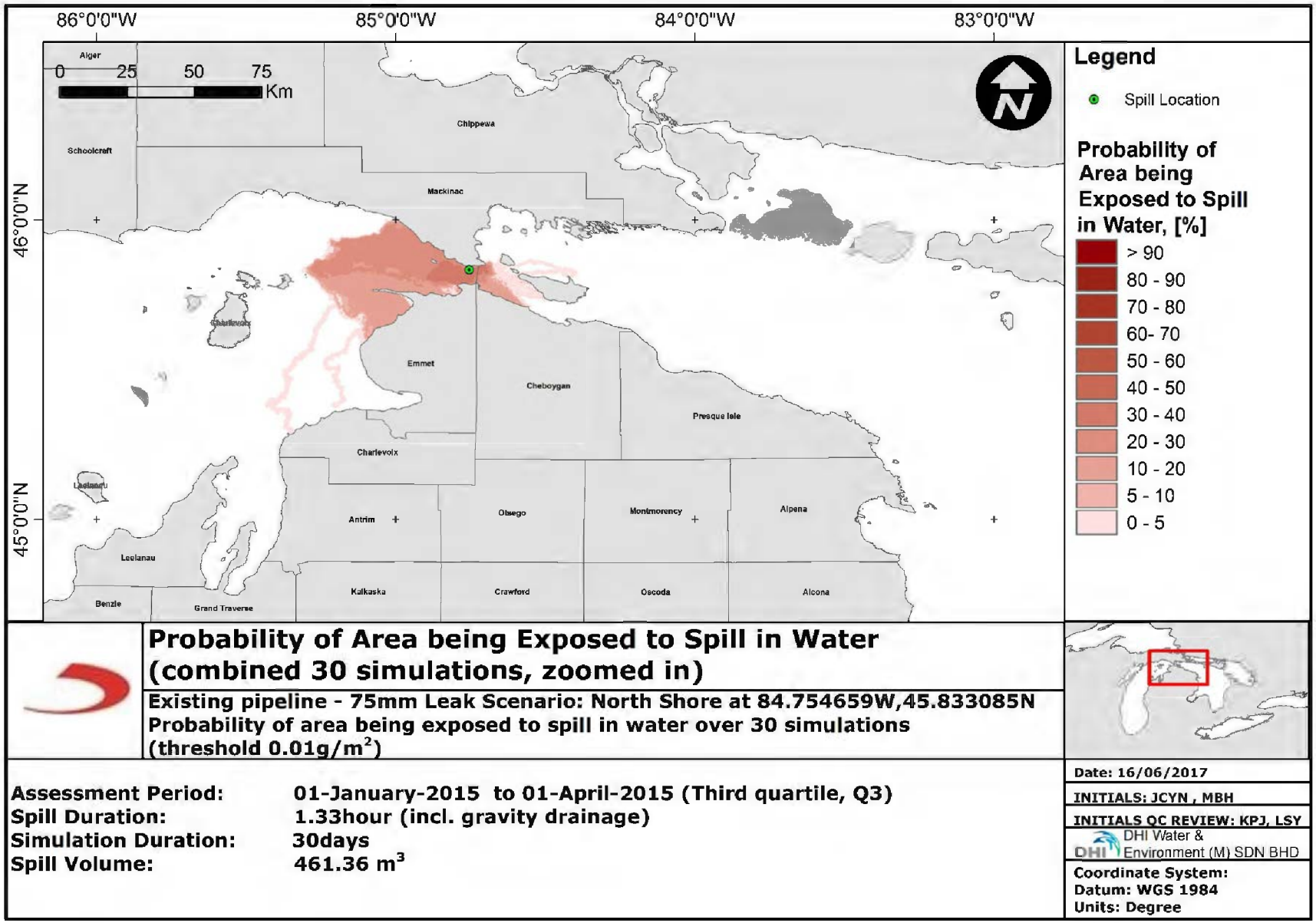


Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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

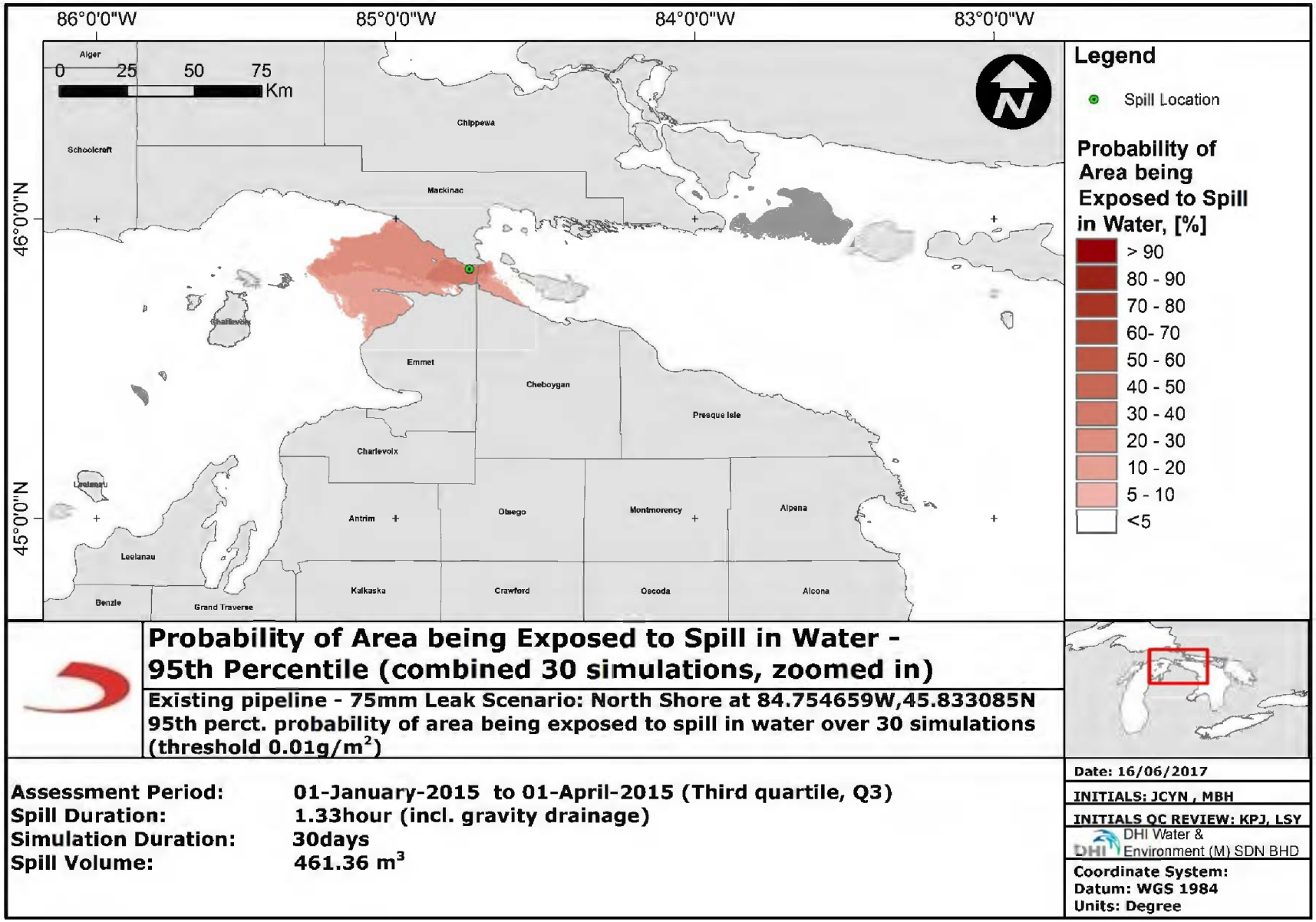


Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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



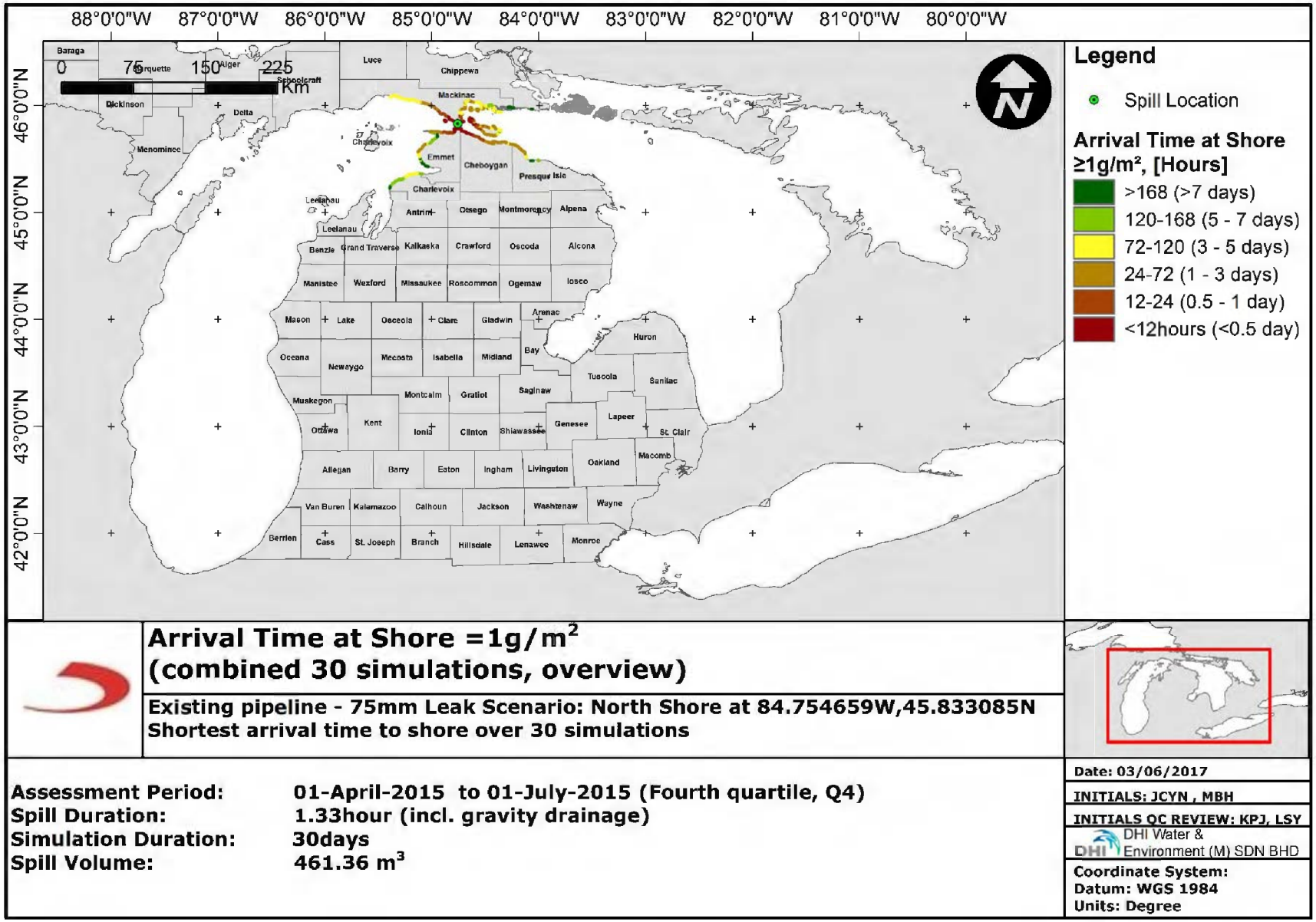
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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

Q4

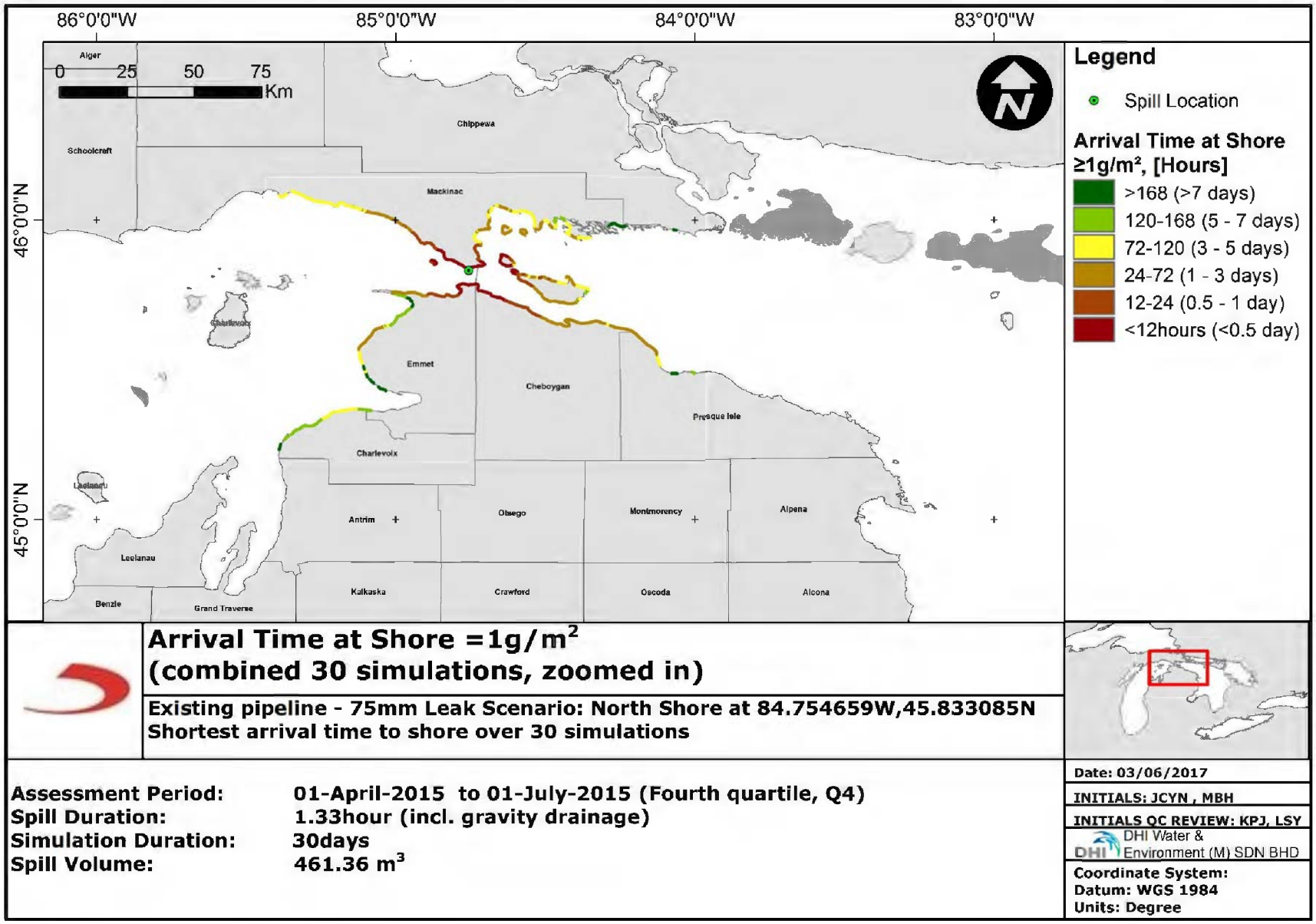


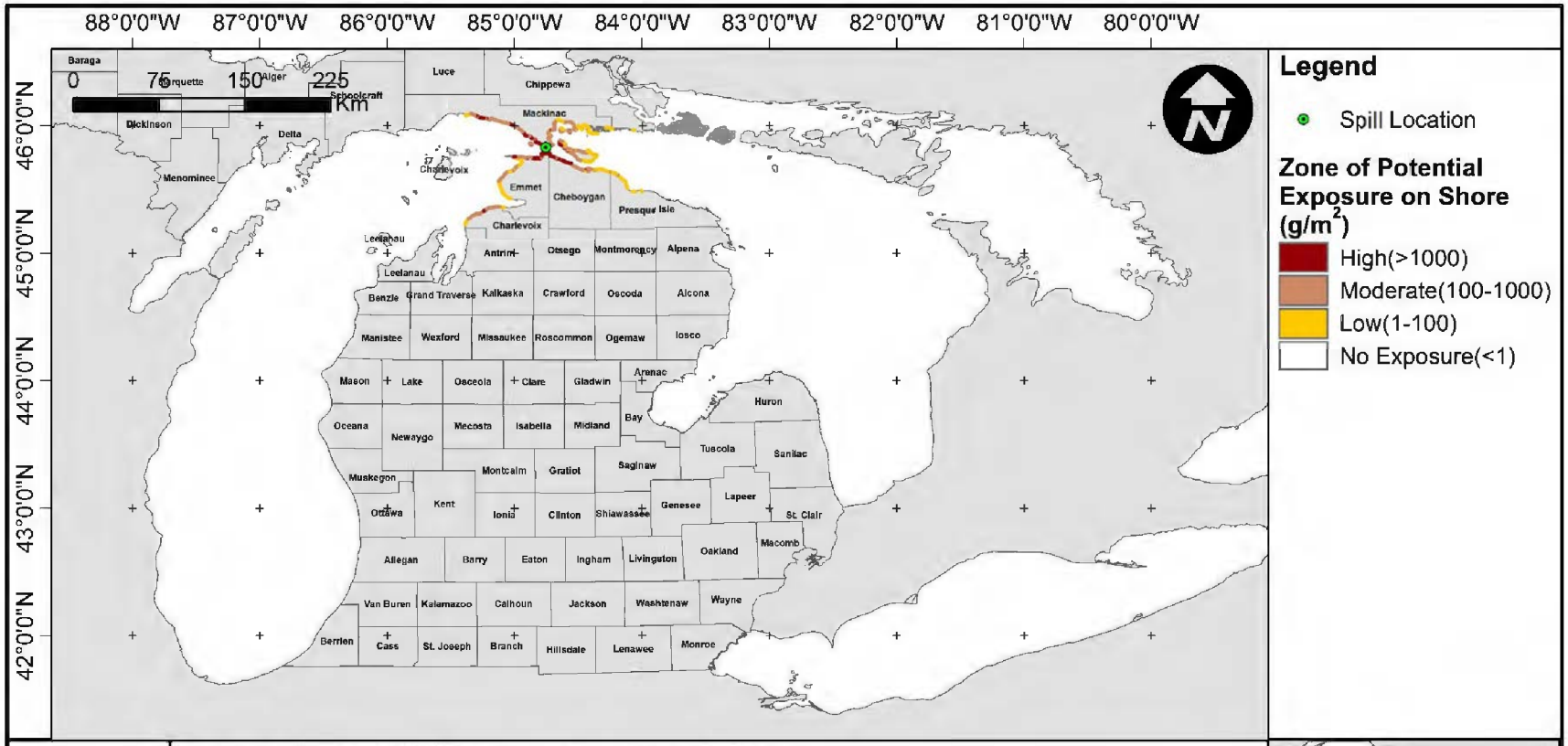
Arrival Time at Shore =1g/m² (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m³**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Emmet
Cheboygan
Presque Isle
Charlevoix
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 461.36 m³
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

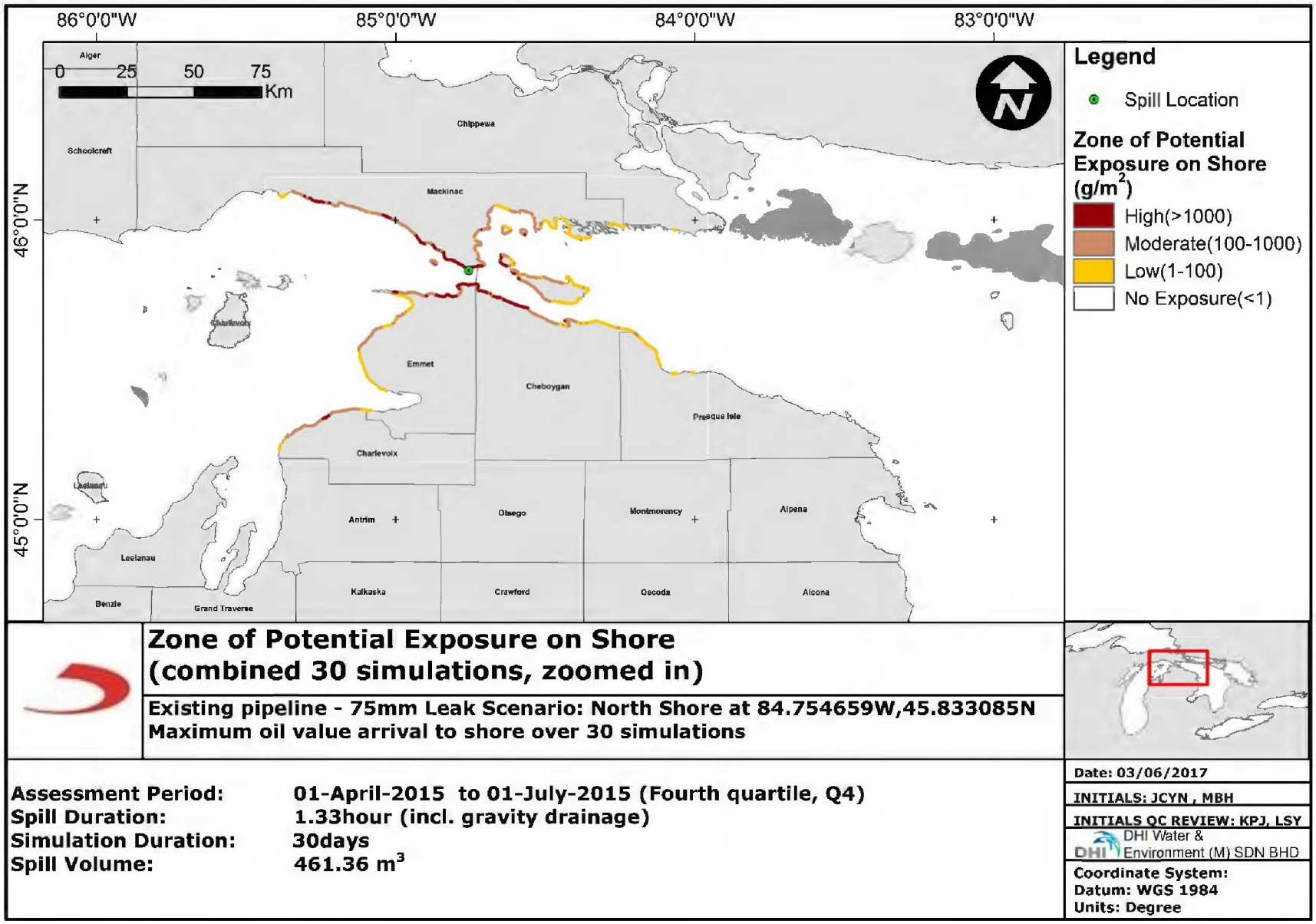


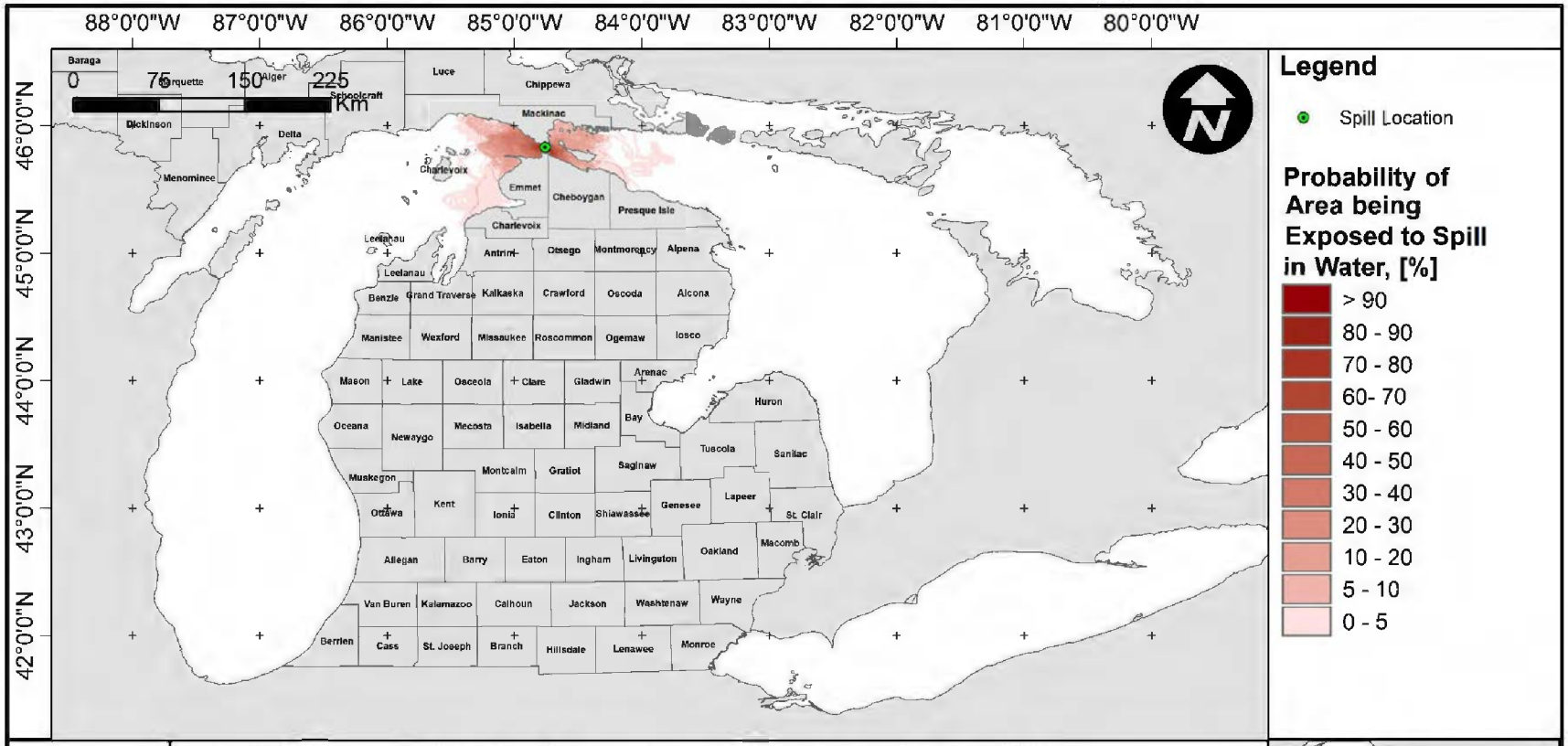
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Emmet
Cheboygan
Presque Isle
Charlevoix
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Zone of Potential Exposure on Shore (g/m2)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 461.36 m3
Date: 03/06/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

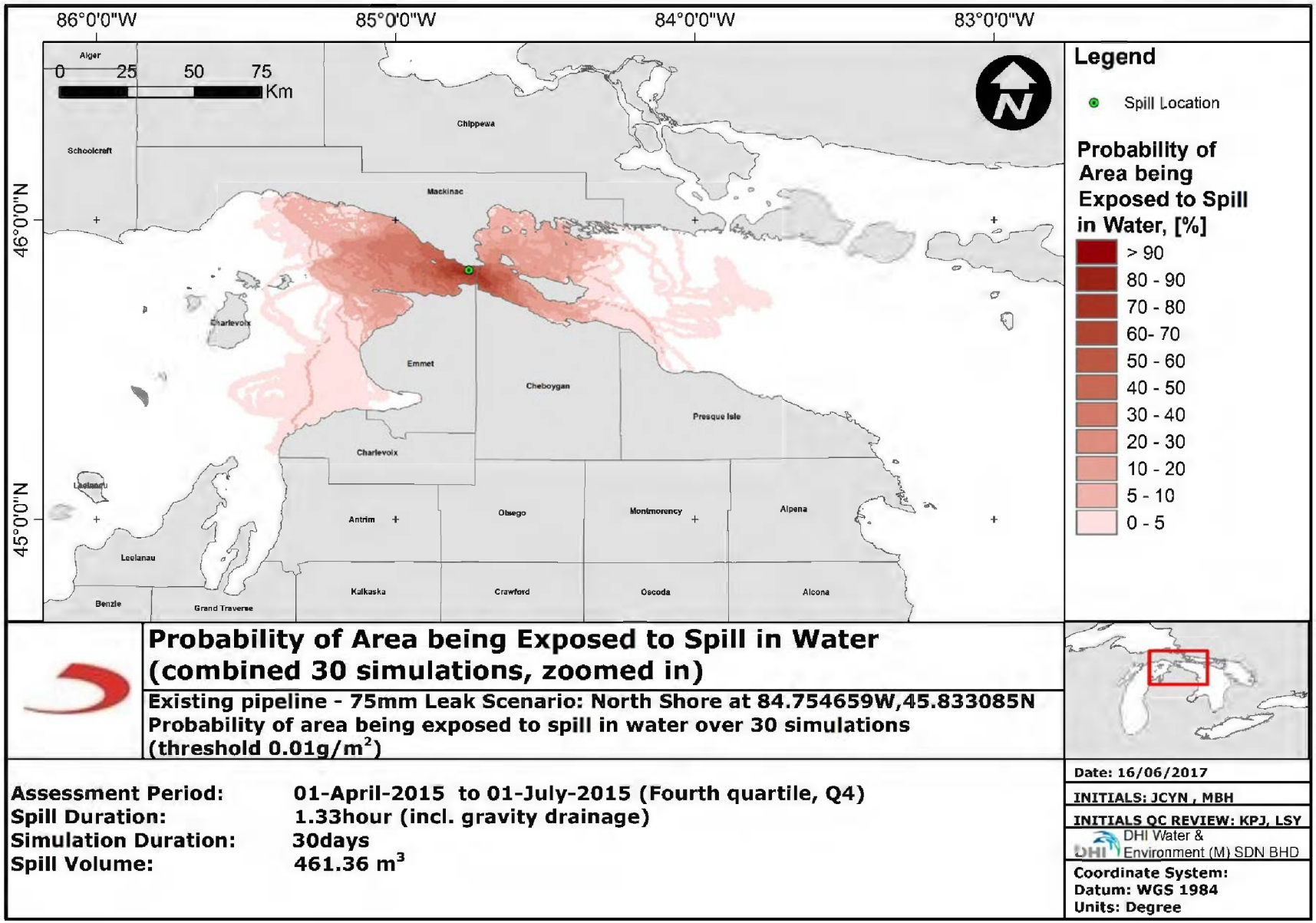


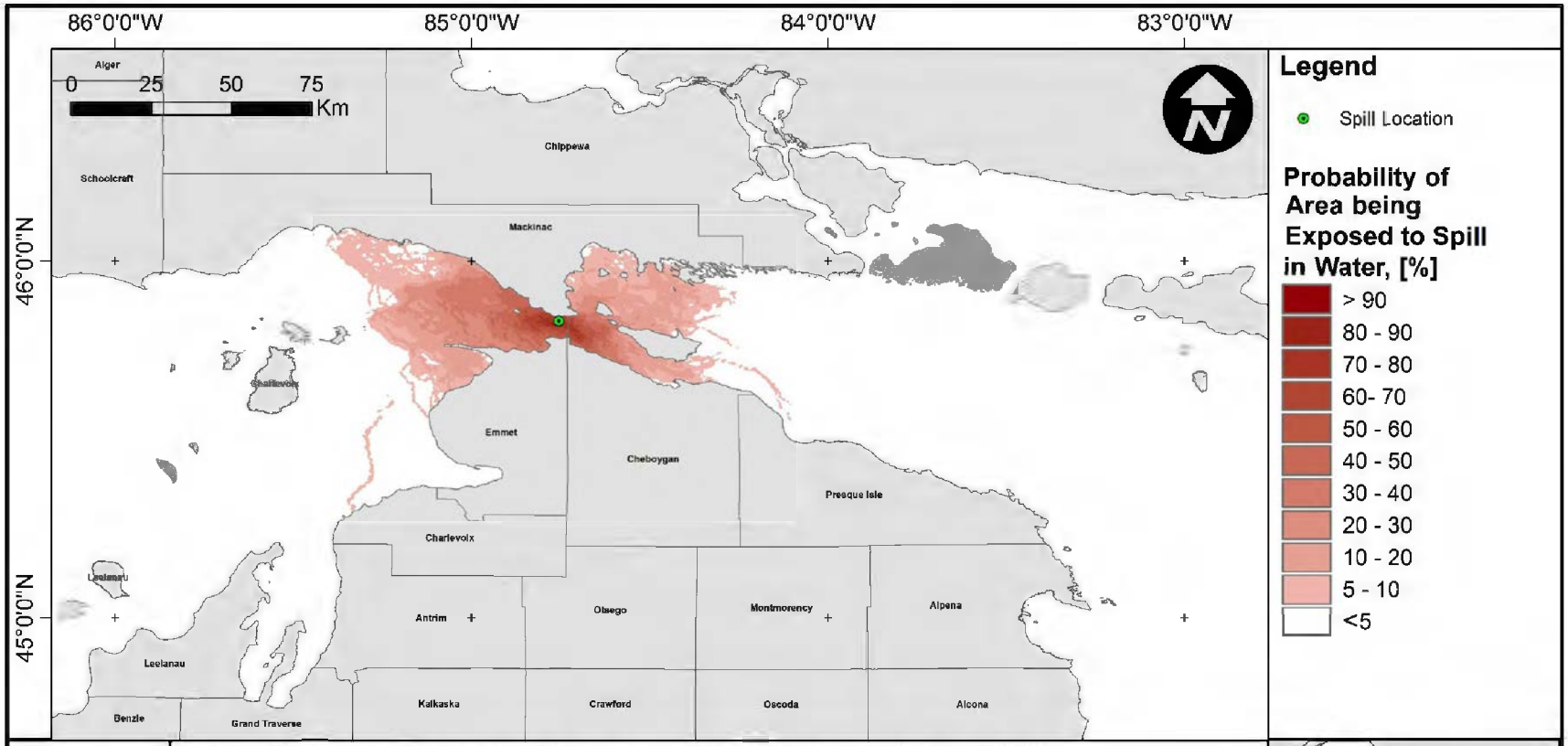
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
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Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 461.36 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



Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

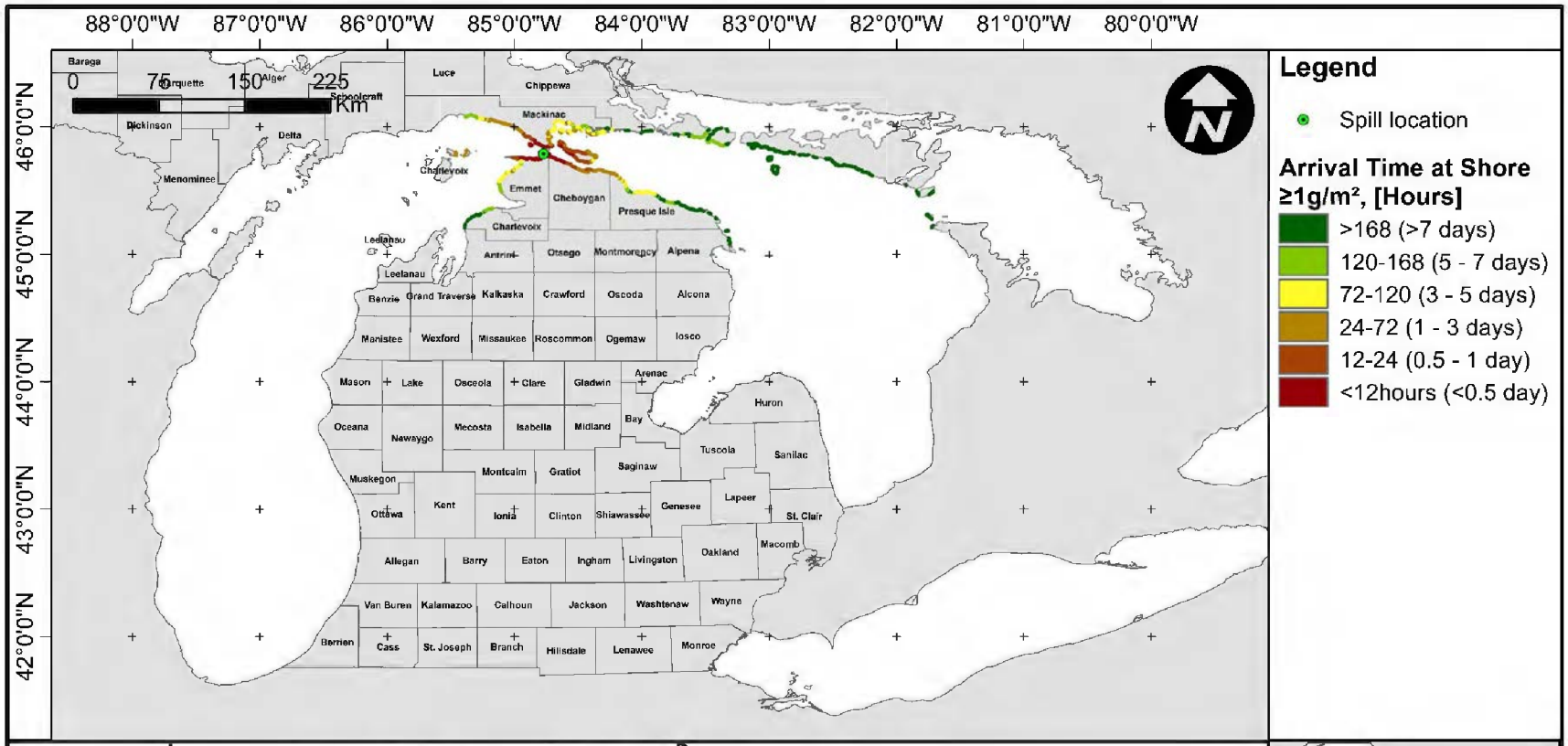
Existing pipeline - 75mm Leak Scenario: North Shore at 84.754659W,45.833085N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

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

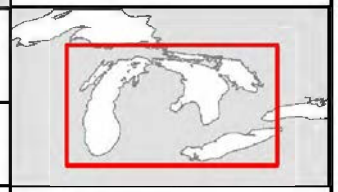
Set 7
Existing Pipeline – 75 mm Leak at Southern Shore

1 year



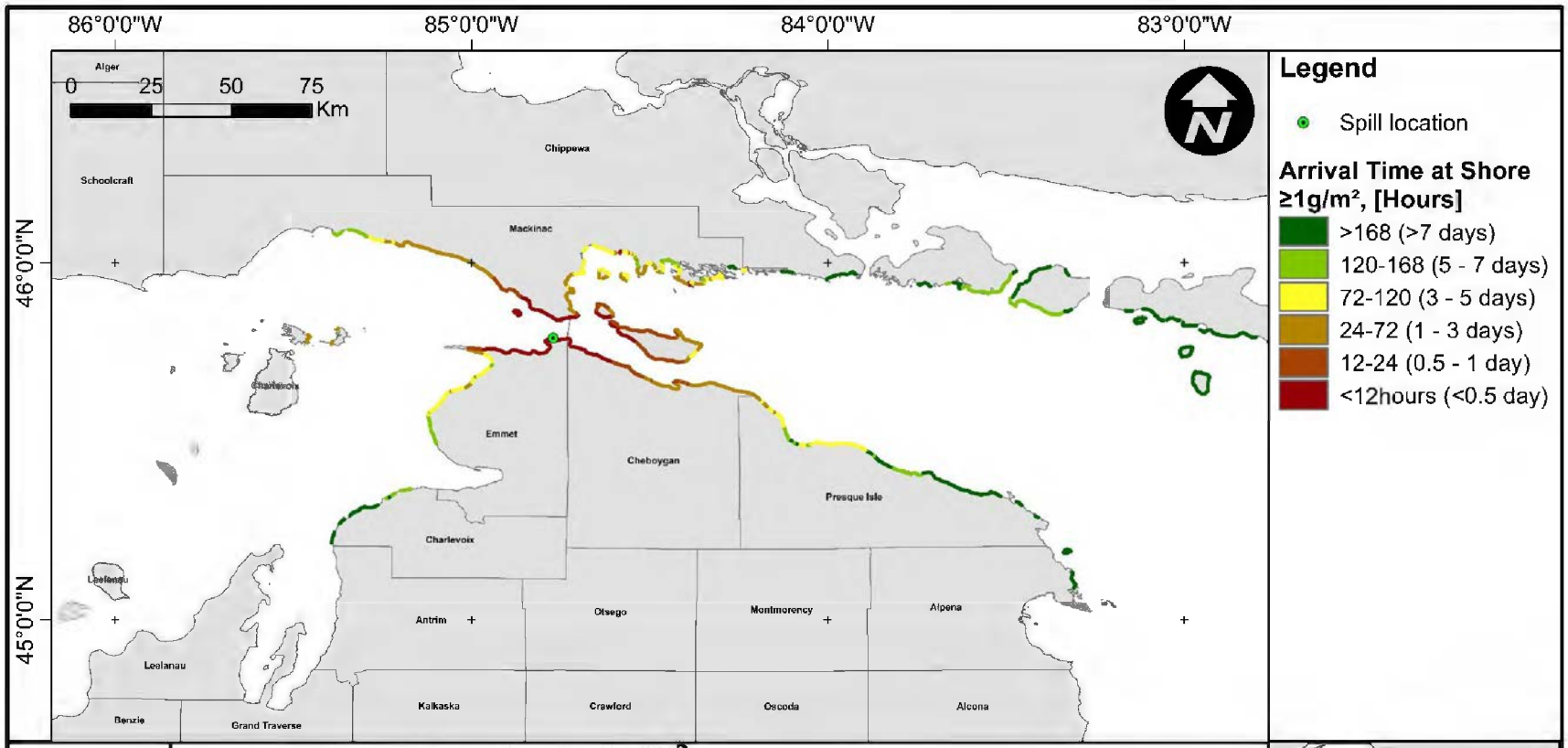
Arrival Time at Shore ≥1g/m² (combined 120 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 120 simulations



Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m³**

Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

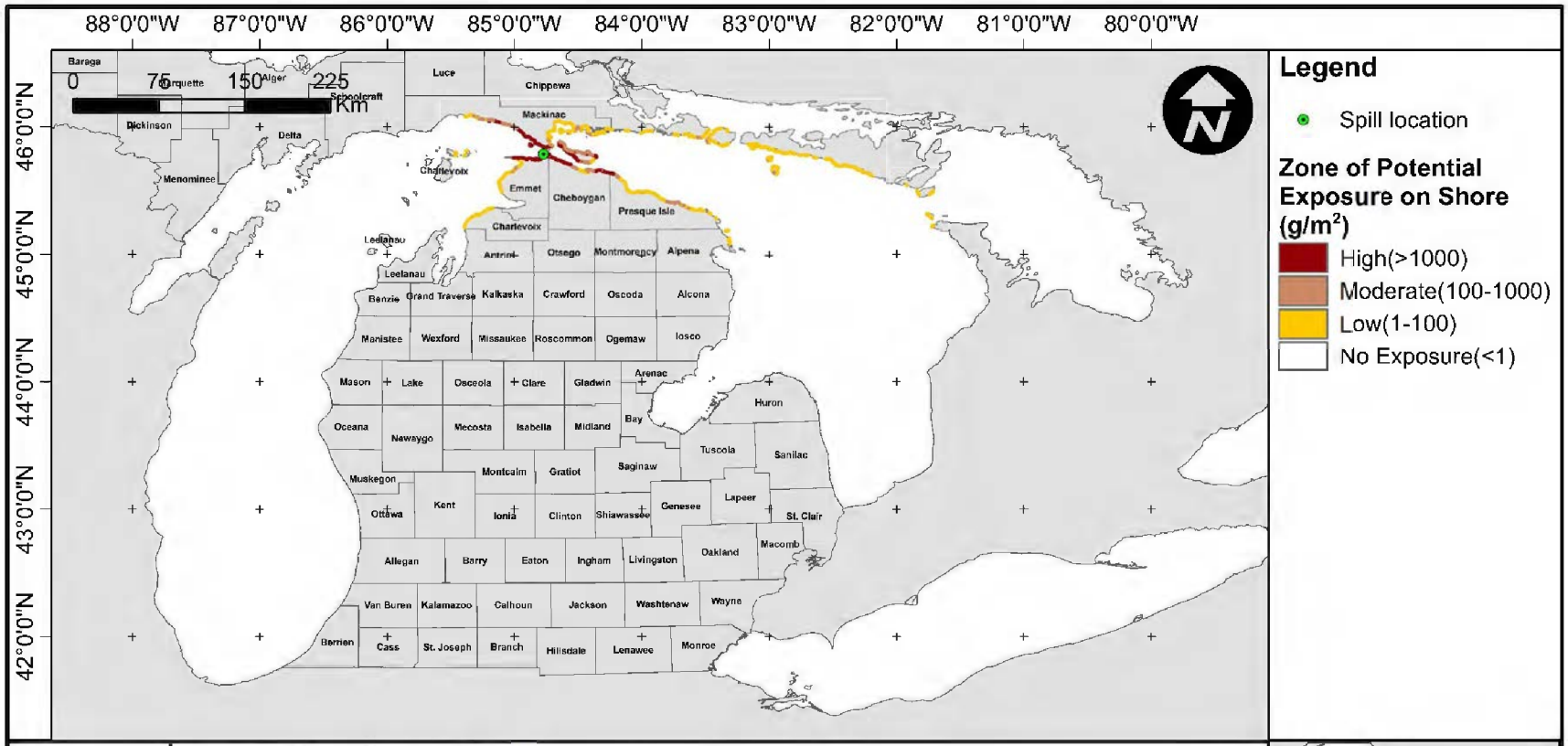


Arrival Time at Shore ≥1g/m² (combined 120 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 120 simulations

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m³**

Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree



Zone of Potential Exposure on Shore (combined 120 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 120 simulations

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

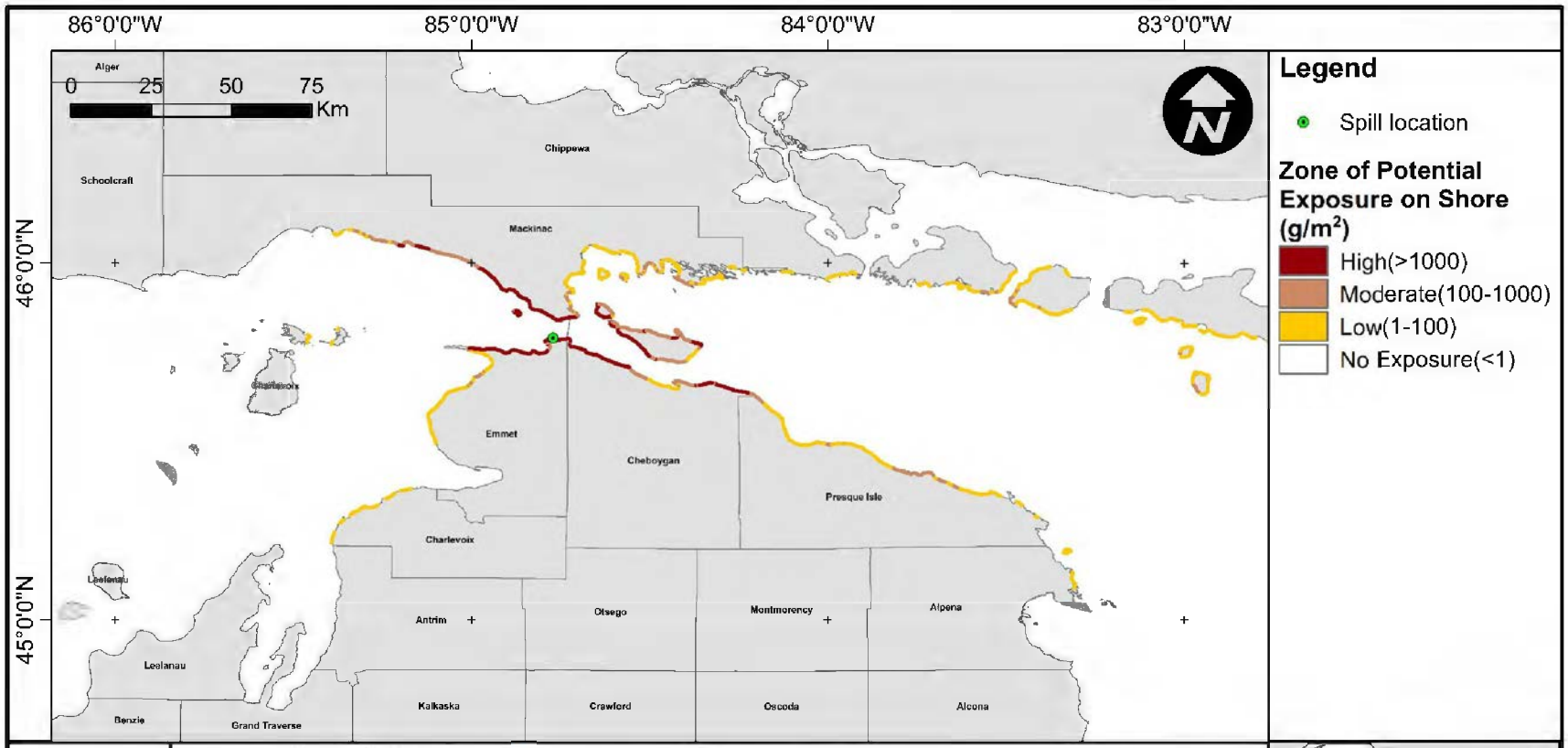
Date: 7/6/2017

INITIALS: JCYN , MBH

INITIALS QC REVIEW: KPJ, LSY

DHI Water & Environment (M) SDN BHD

Coordinate System:
Datum: WGS 1984
Units: Degree

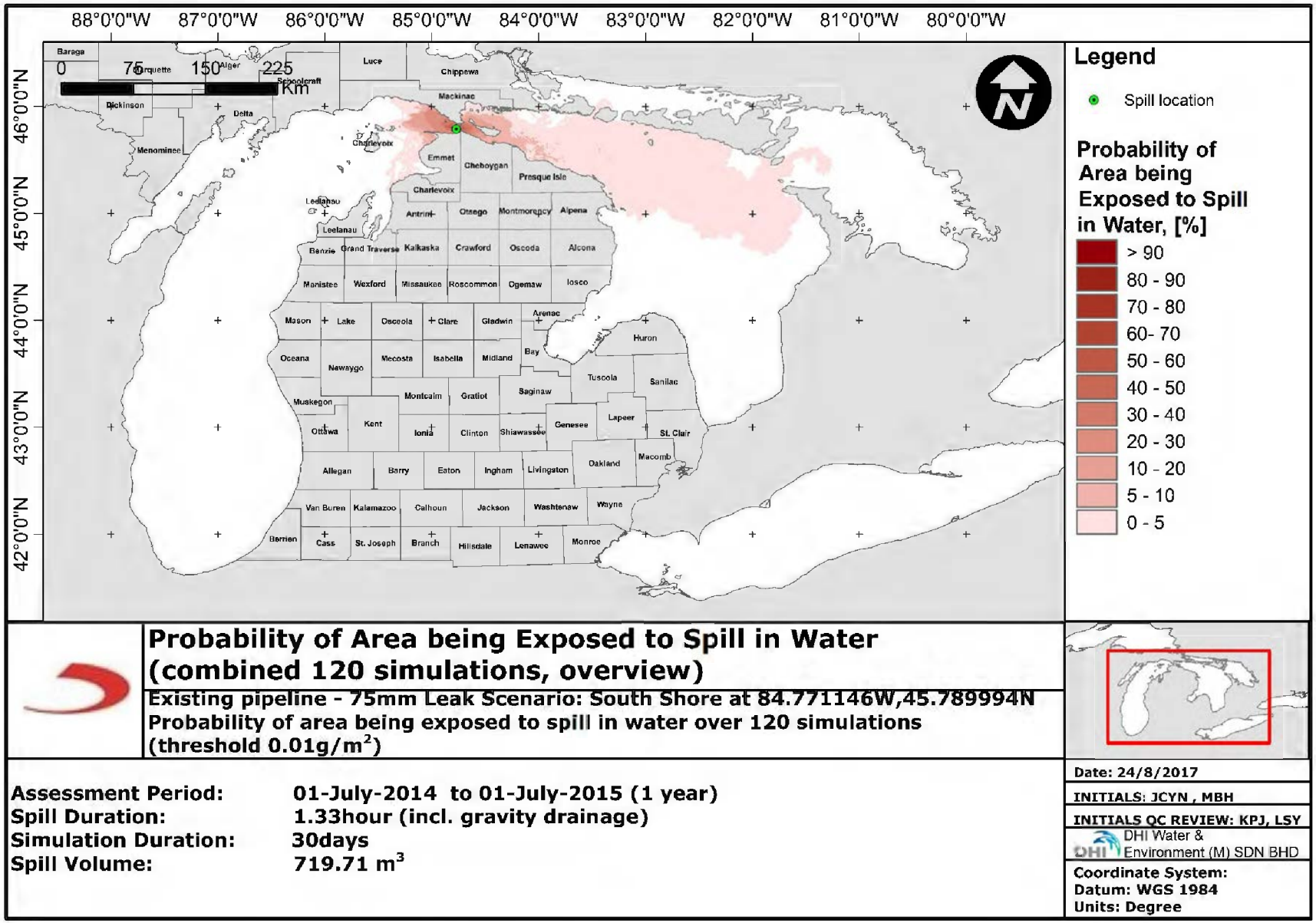


Zone of Potential Exposure on Shore (combined 120 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 120 simulations

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

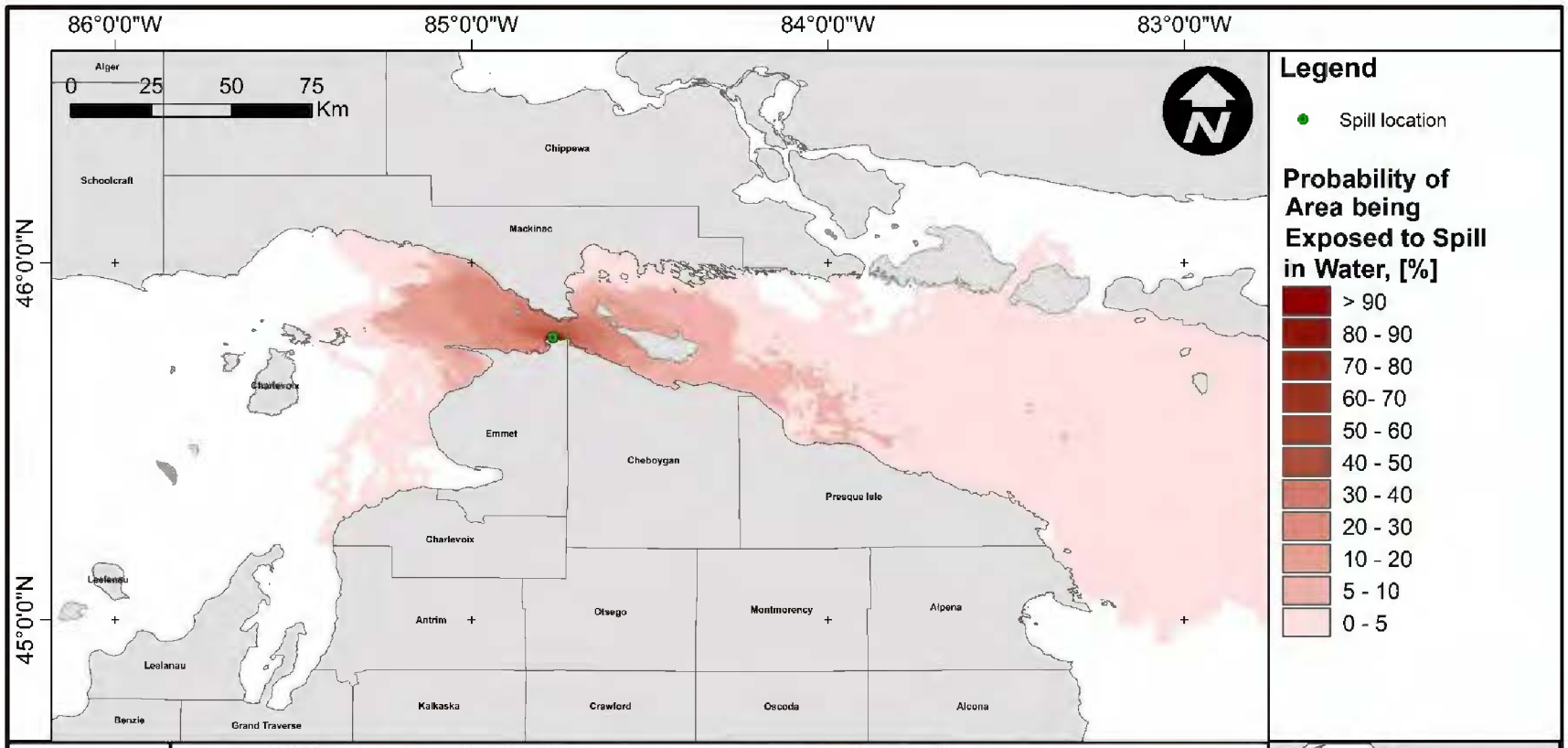


Probability of Area being Exposed to Spill in Water (combined 120 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
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)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 24/8/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

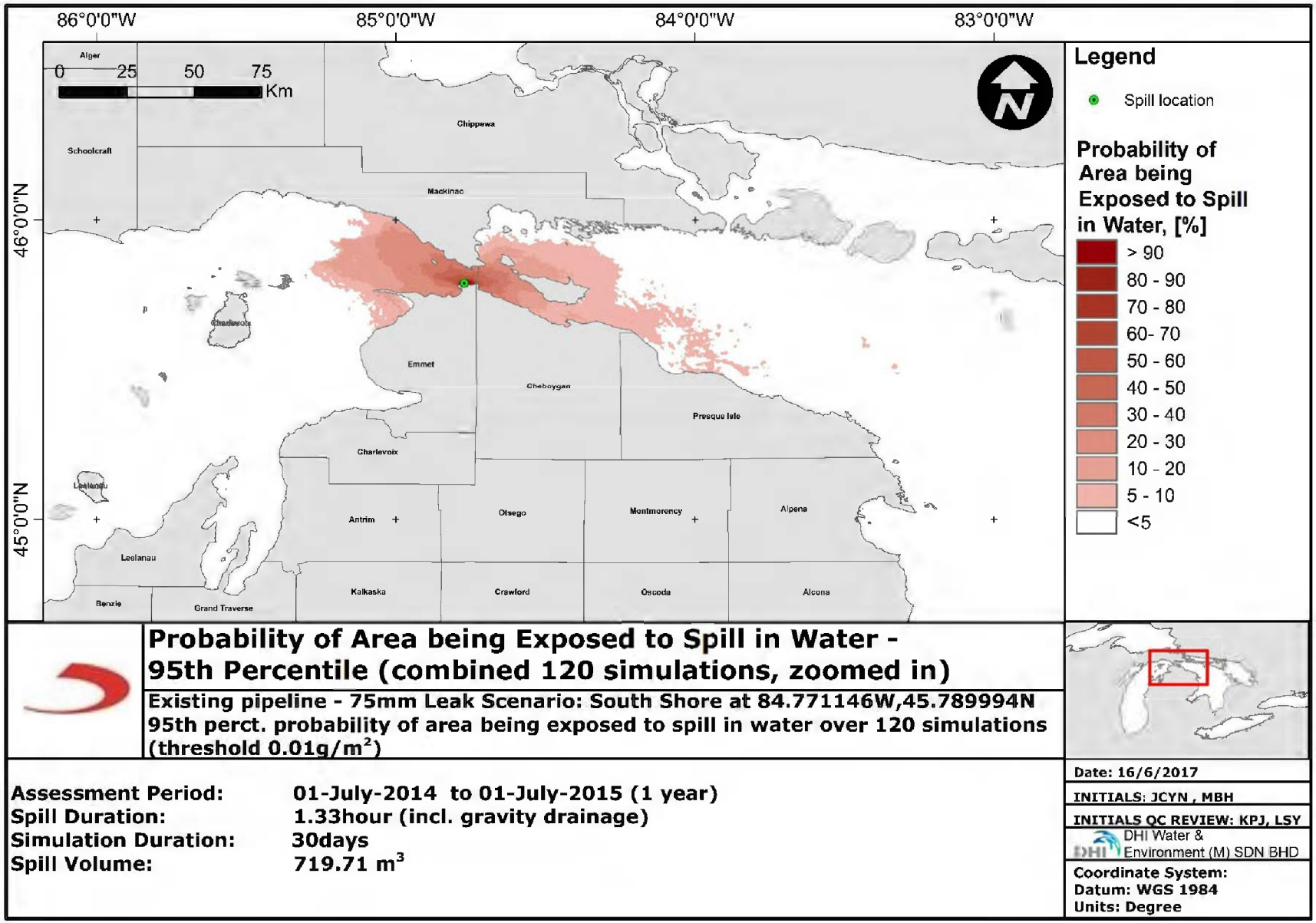


Probability of Area being Exposed to Spill in Water (combined 120 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
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)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree



Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 120 simulations, zoomed in)

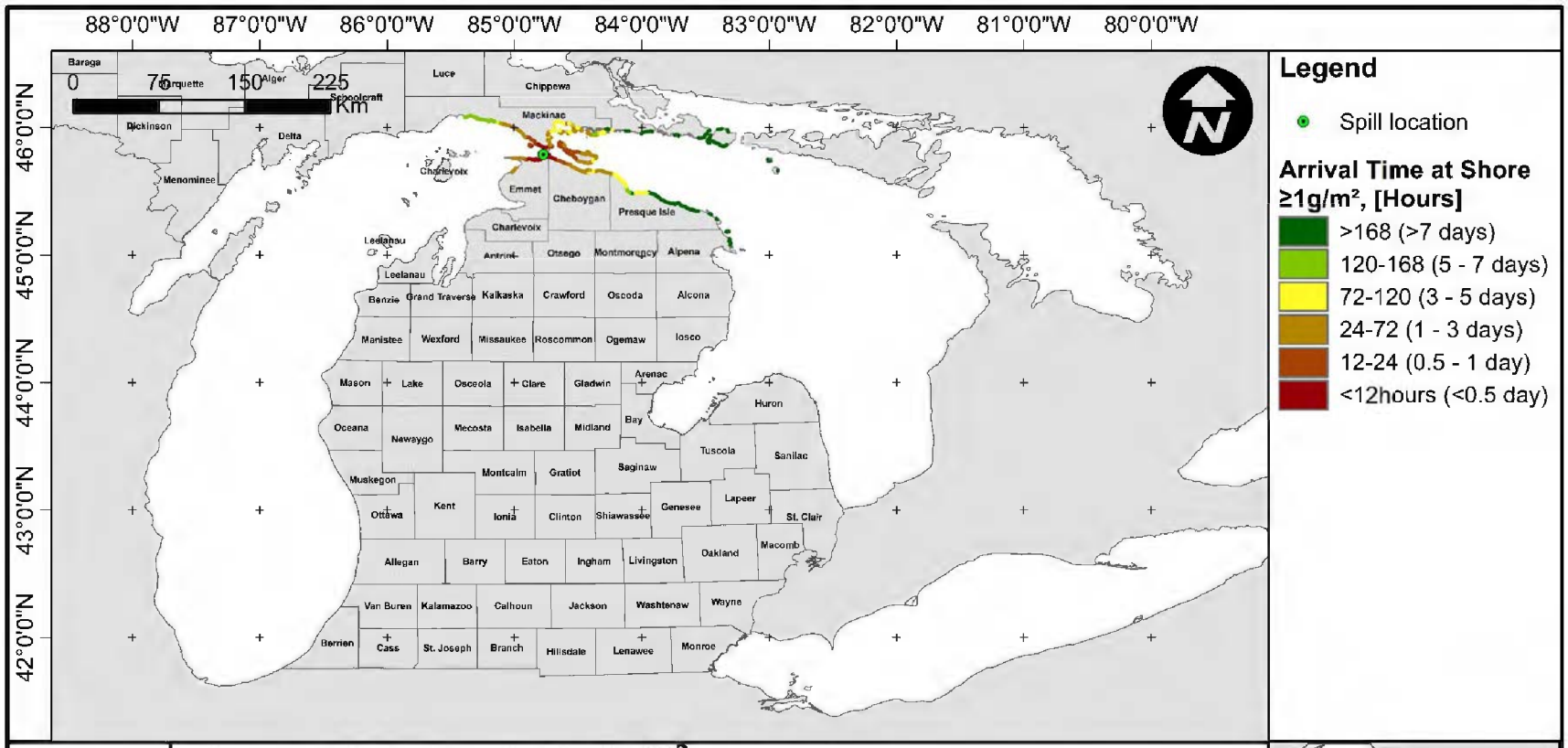
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
95th perct. probability of area being exposed to spill in water over 120 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-July-2015 (1 year)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

Q1

ENBDNR0002348

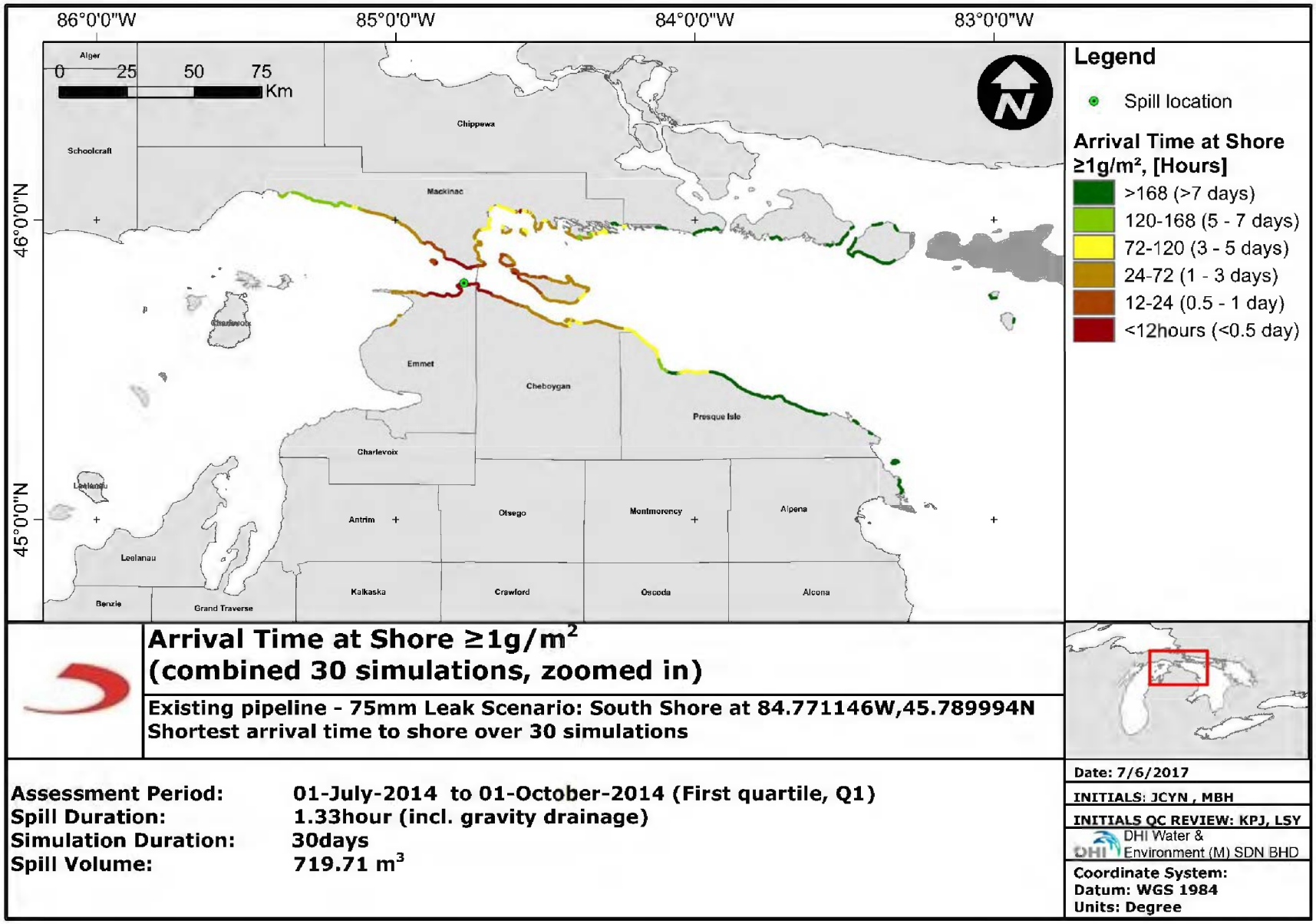


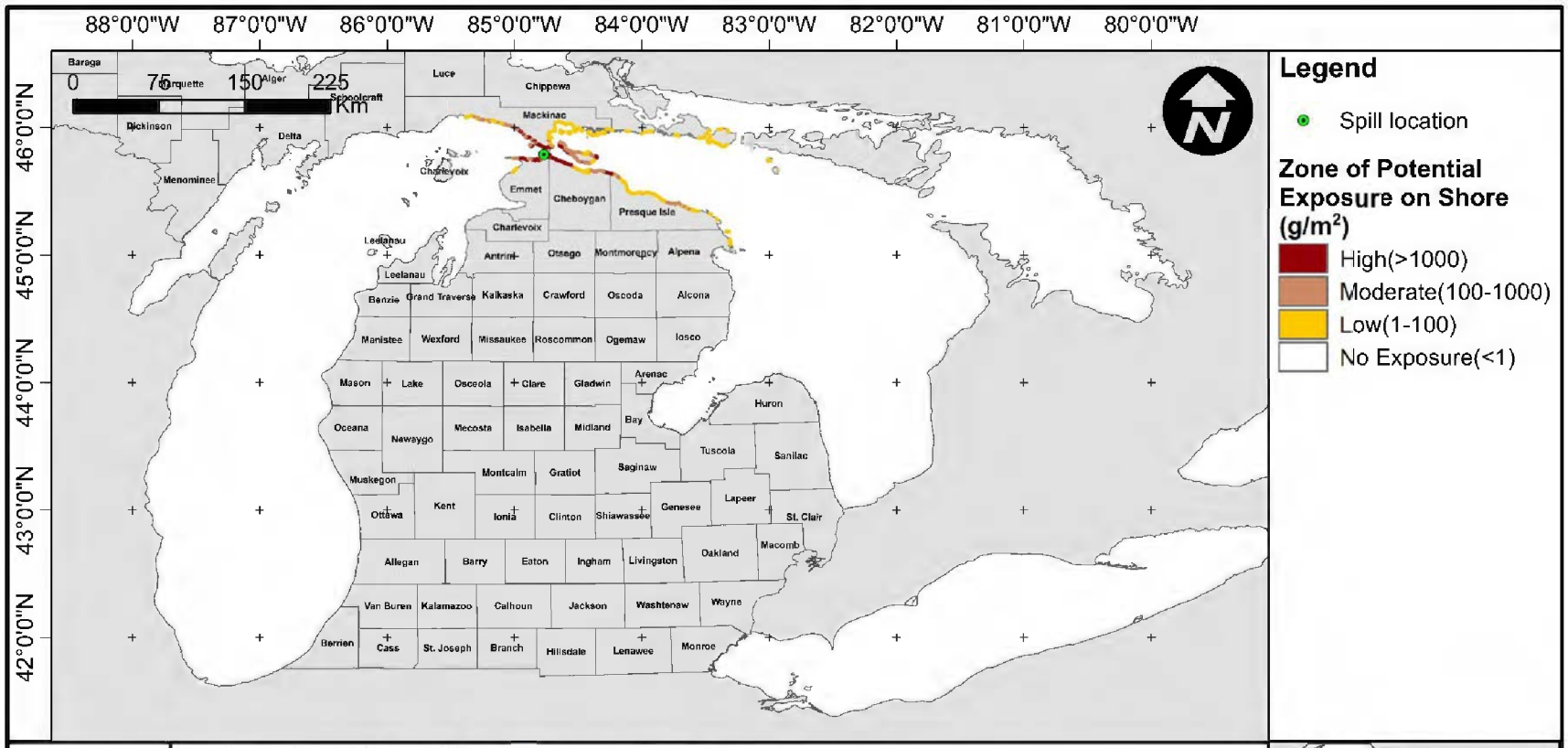
Arrival Time at Shore ≥1g/m² (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m³**

Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore ≥1g/m²
(combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 719.71 m³
Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

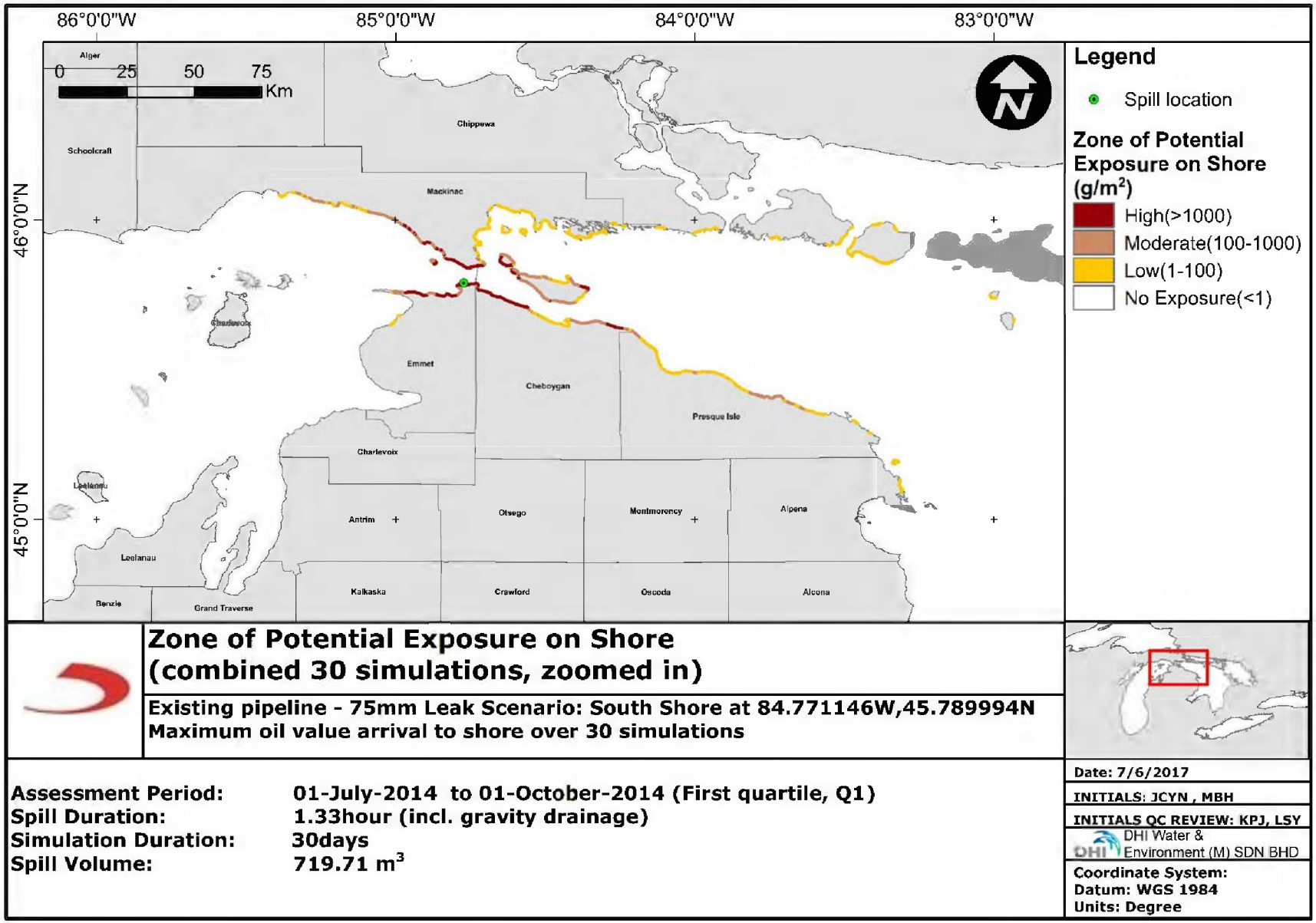


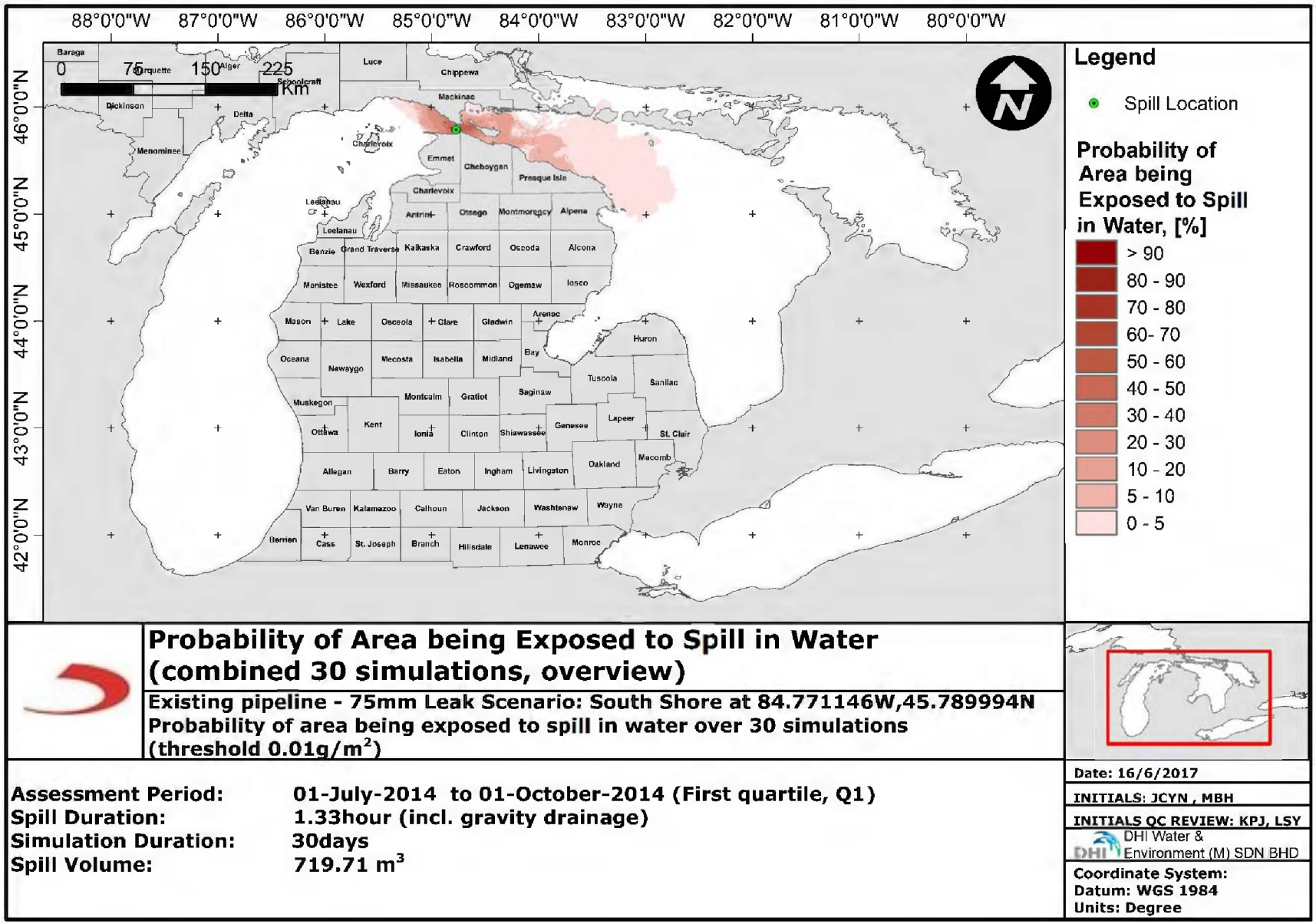
Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
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Cheboygan
Presque Isle
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Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Zone of Potential Exposure on Shore (g/m²)
High(>1000)
Moderate(100-1000)
Low(1-100)
No Exposure(<1)
Zone of Potential Exposure on Shore
(combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 30 simulations
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 719.71 m³
Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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Units: Degree

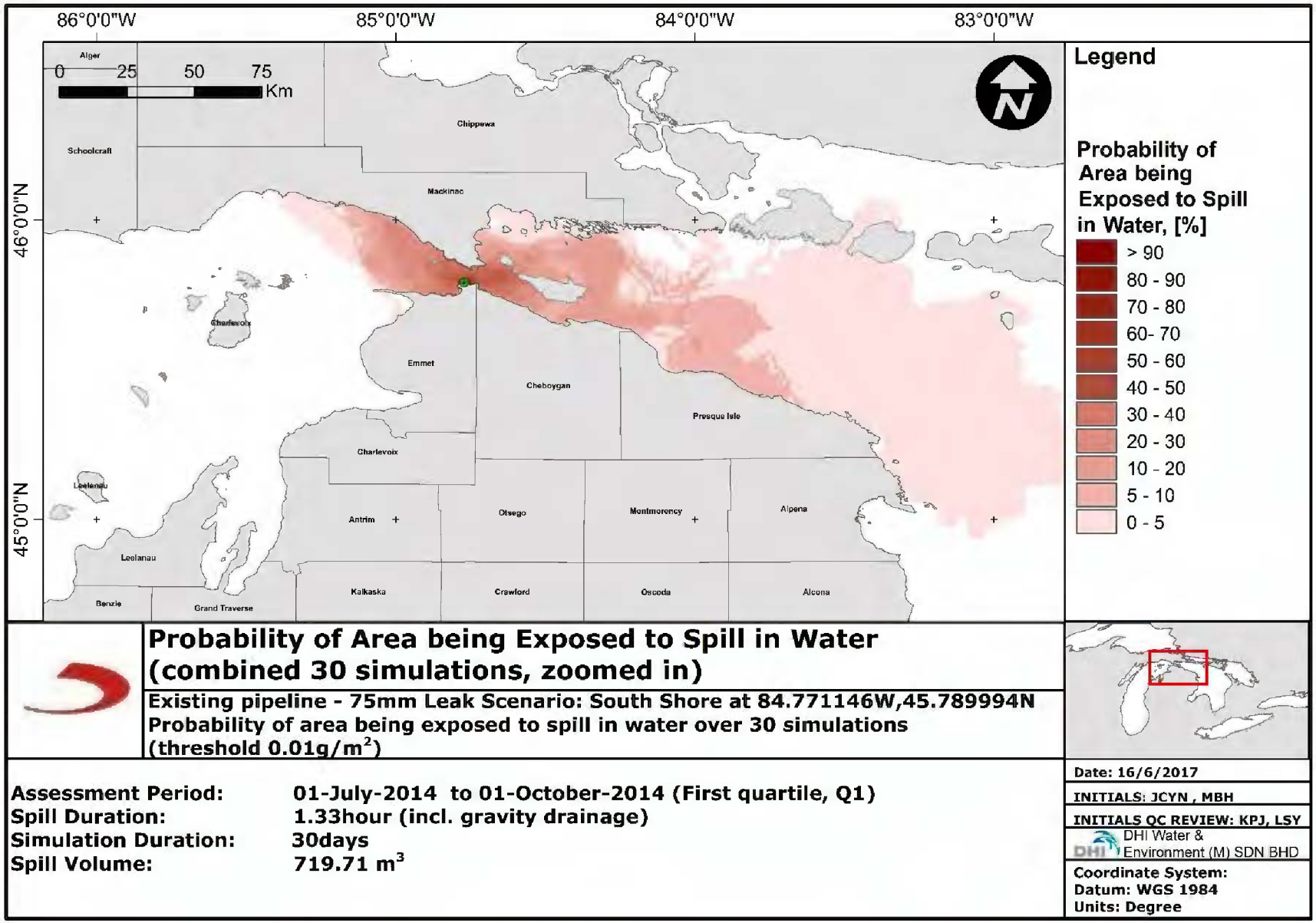


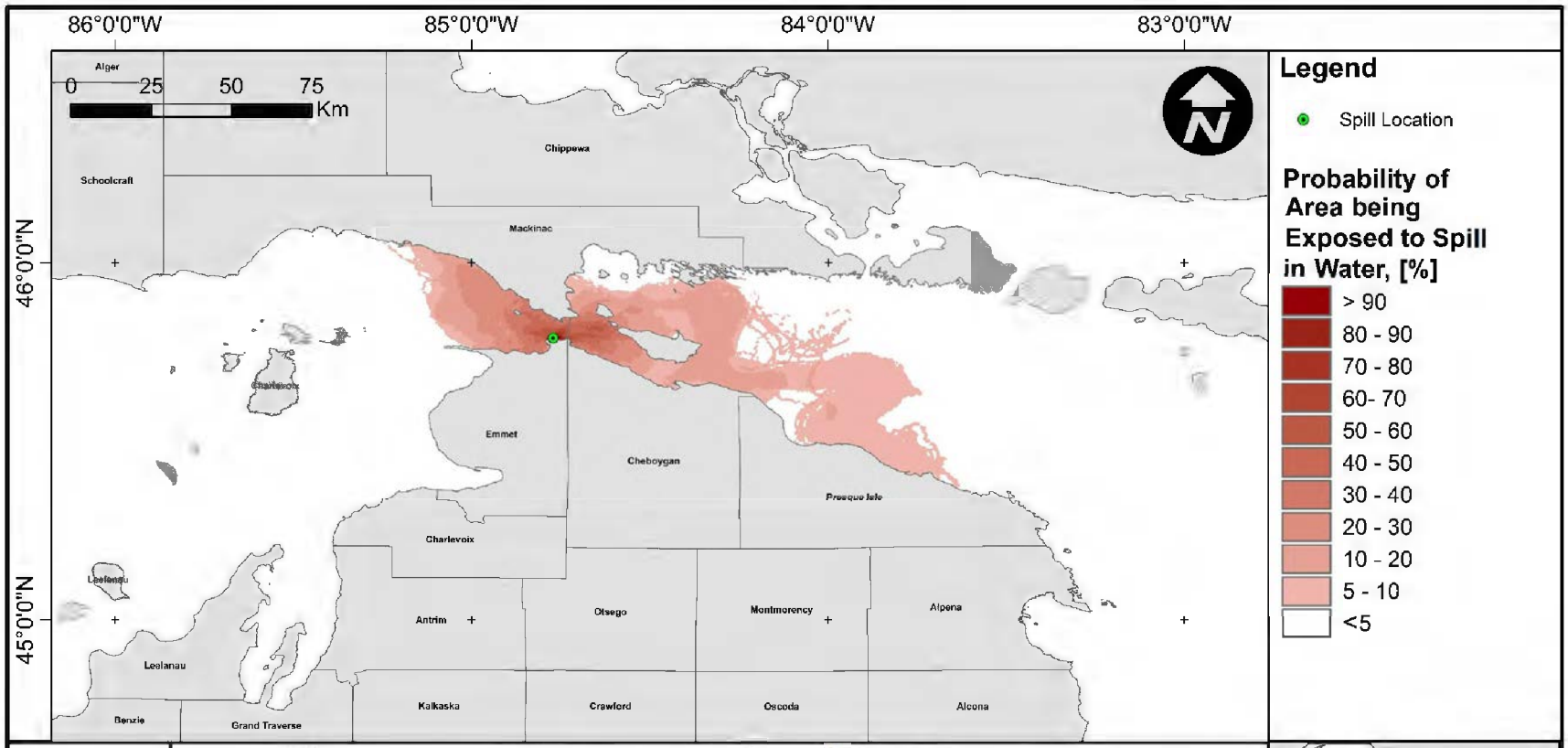
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
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Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m²)
Assessment Period: 01-July-2014 to 01-October-2014 (First quartile, Q1)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 719.71 m³
Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree



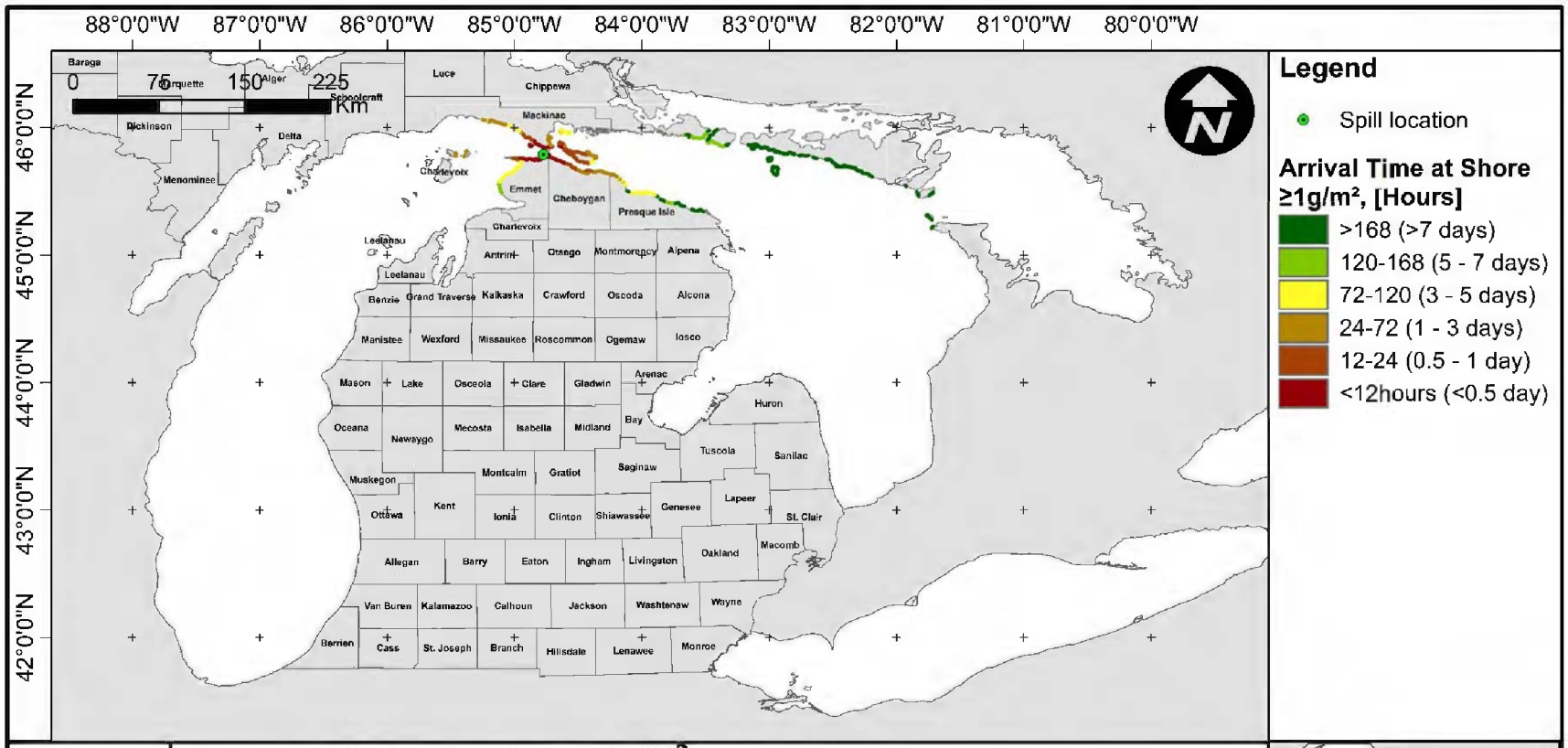
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-July-2014 to 01-October-2014 (First quartile, Q1)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**461.36 m^3**

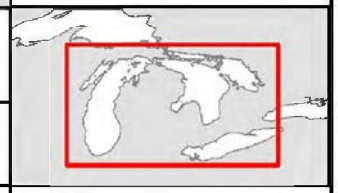
Date: 21/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

Q2



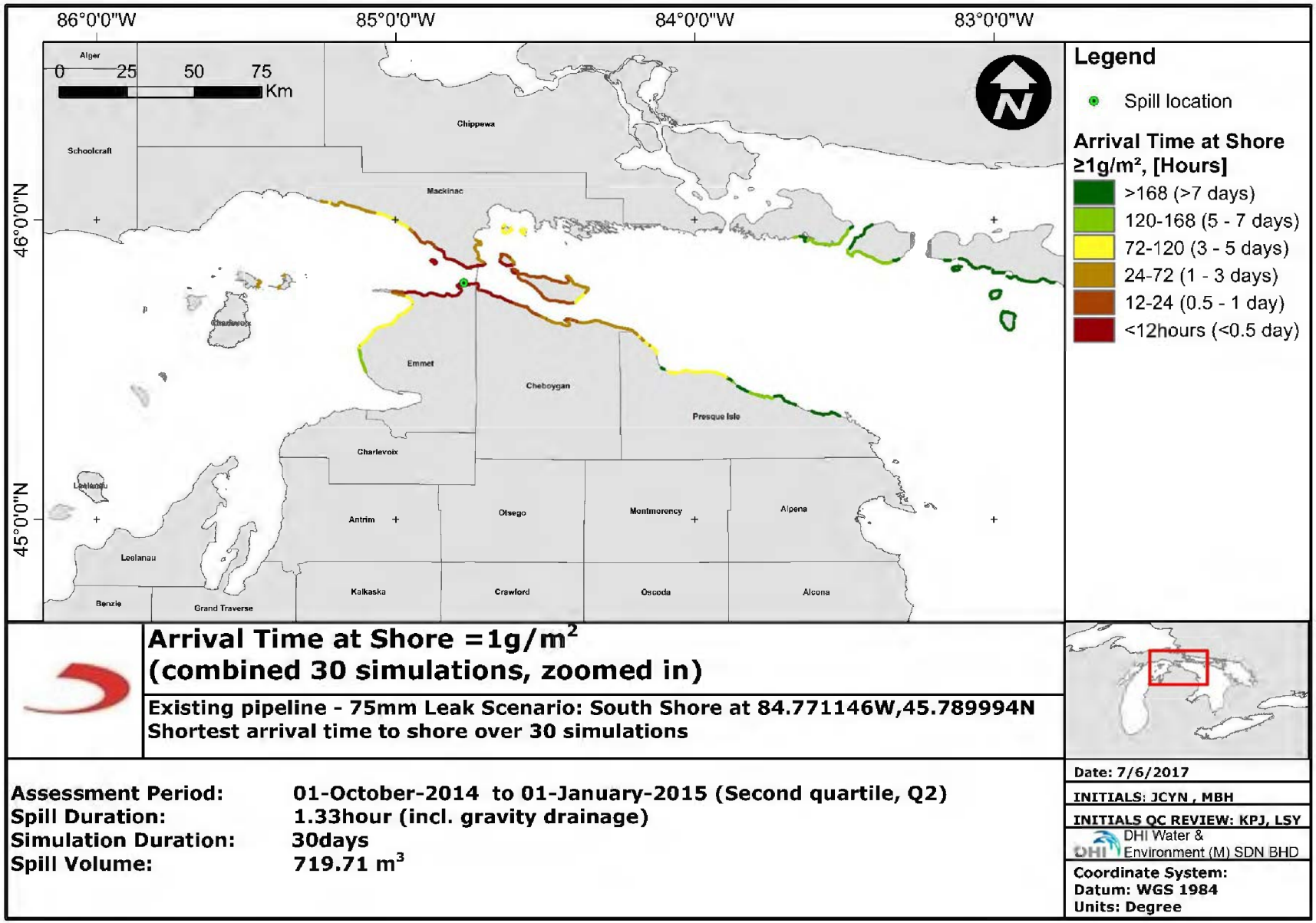
Arrival Time at Shore =1g/m^2 (combined 30 simulations, overview)

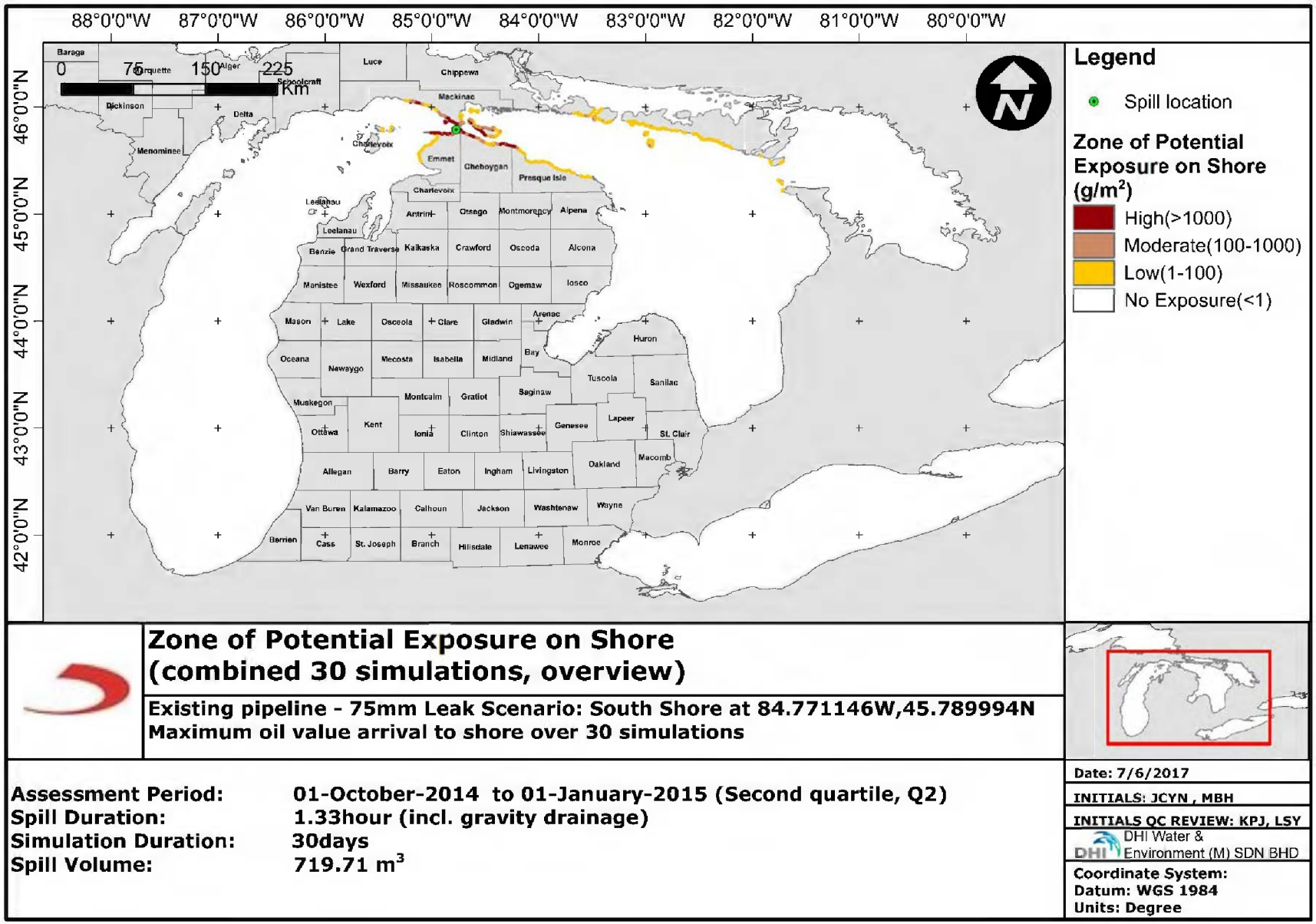
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 30 simulations



Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
24-72 (1 - 3 days)
12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 719.71 m³
Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
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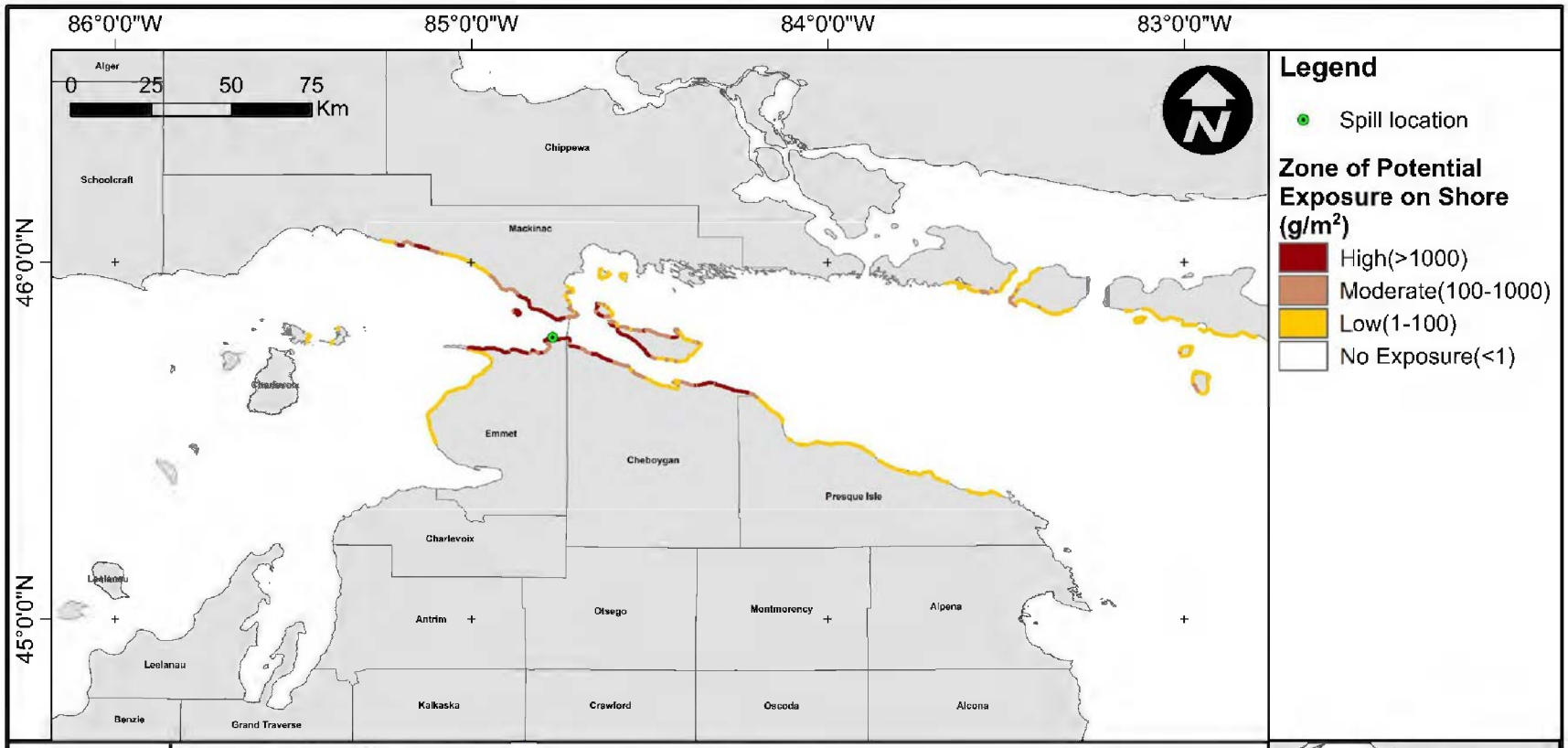


Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 7/6/2017
INITIALS: JCYN , MBH
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Zone of Potential Exposure on Shore (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

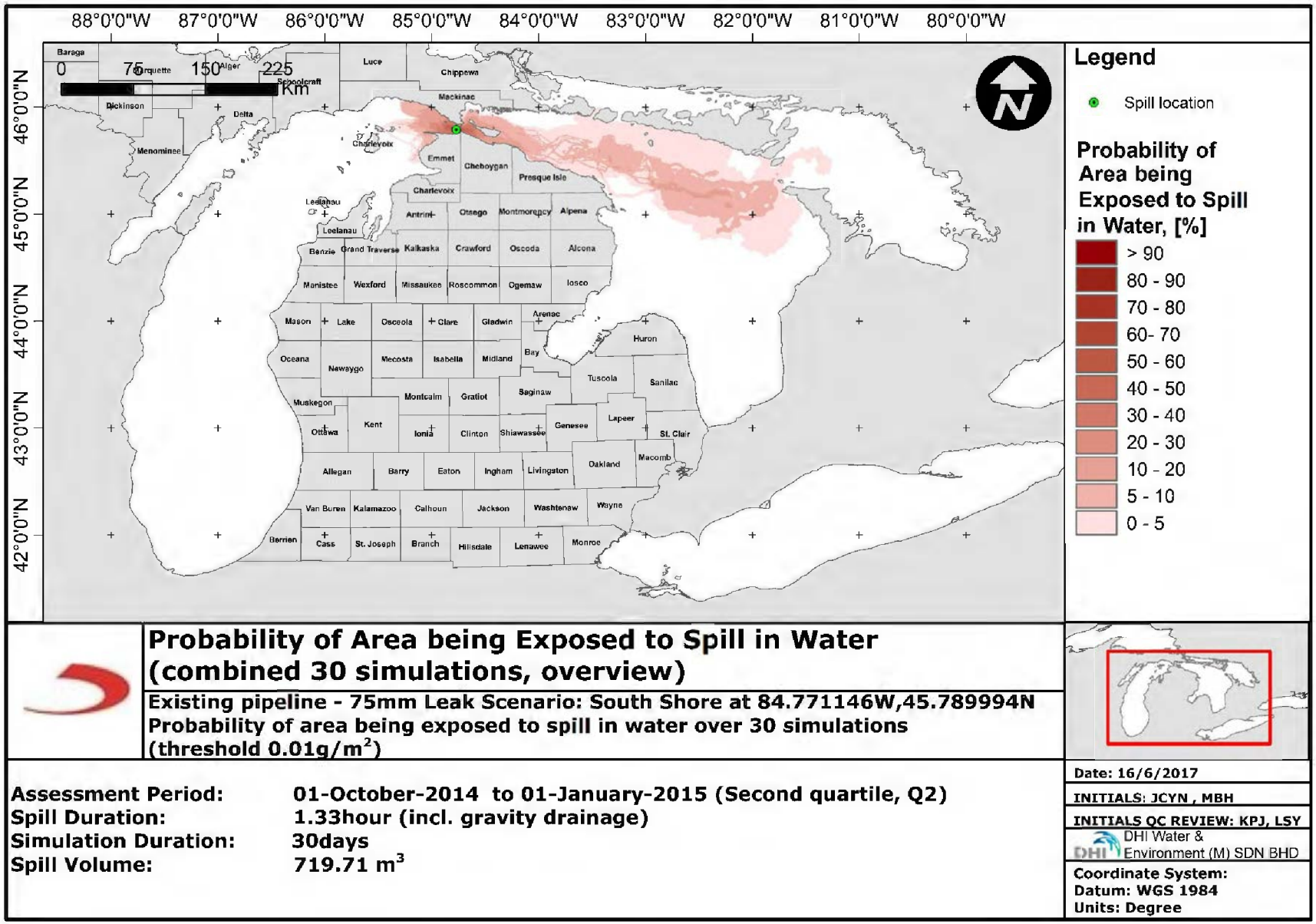
Date: 7/6/2017

INITIALS: JCYN , MBH

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Coordinate System:
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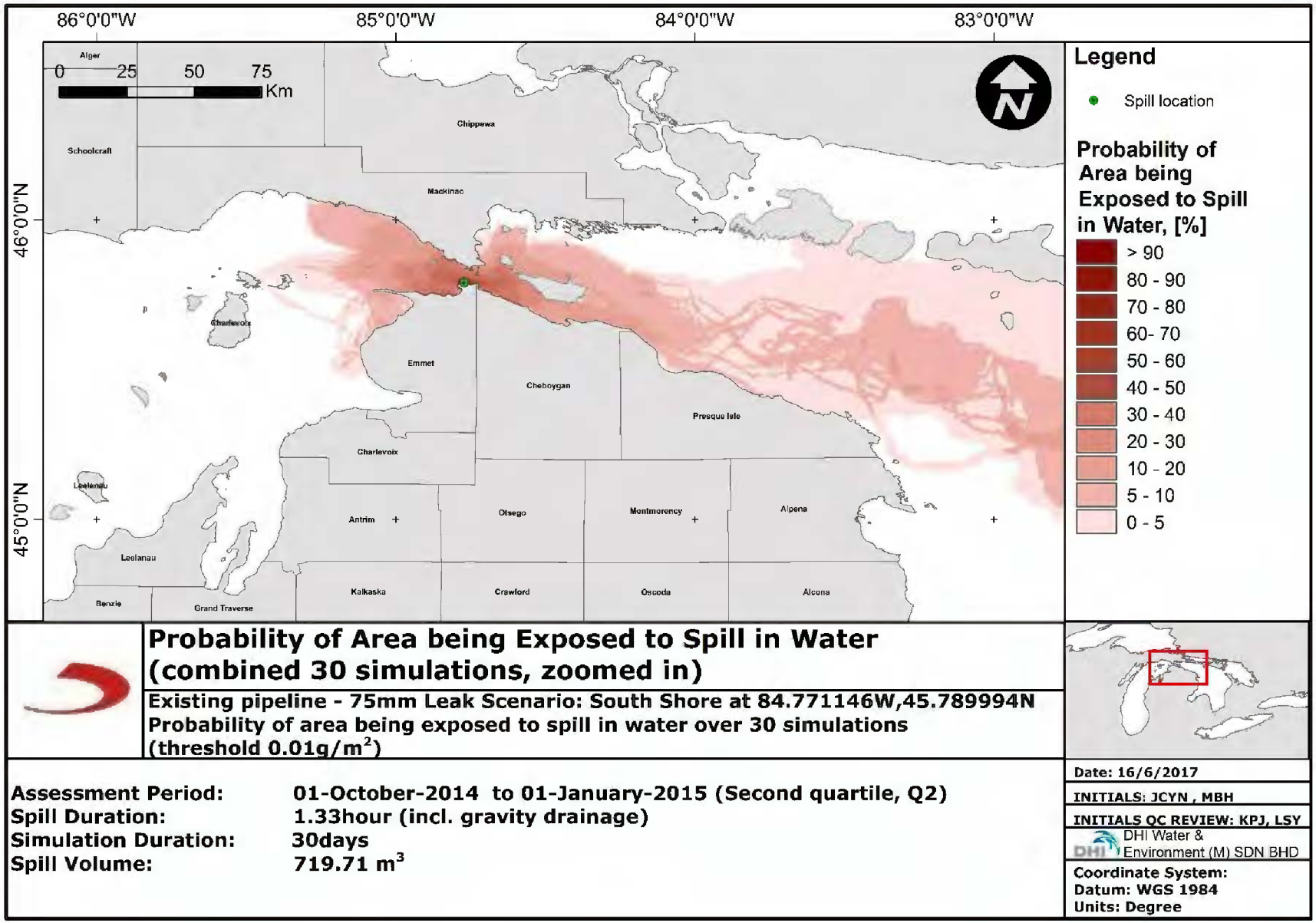


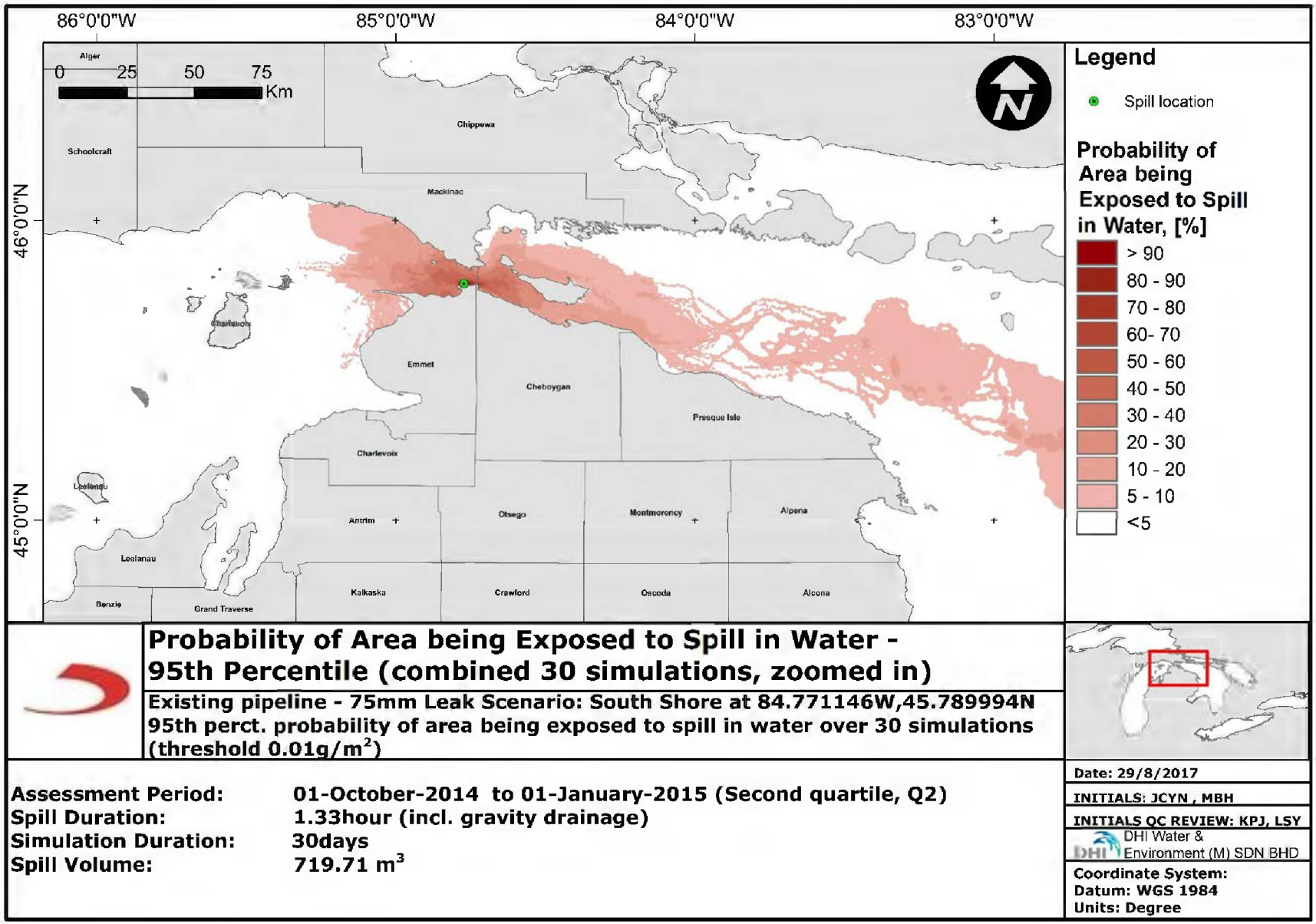
Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
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45°0'0"N
0 25 50 75
Km
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Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
0 - 5
Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m2)
Assessment Period: 01-October-2014 to 01-January-2015 (Second quartile, Q2)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 719.71 m3
Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
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Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-October-2014 to 01-January-2015 (Second quartile, Q2)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 29/8/2017

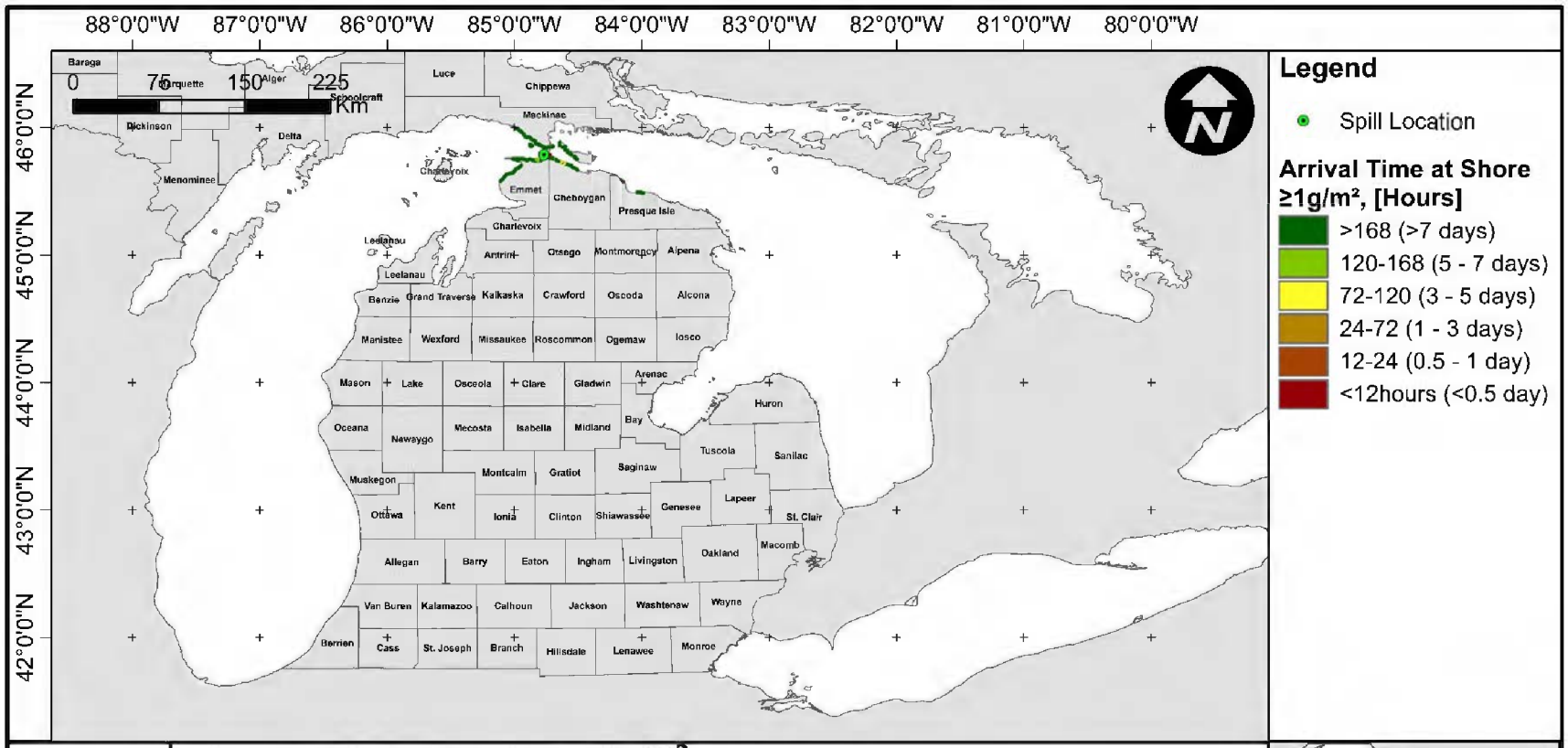
INITIALS: JCYN , MBH

INITIALS QC REVIEW: KPJ, LSY

DHI Water & Environment (M) SDN BHD

Coordinate System:
Datum: WGS 1984
Units: Degree

Q3

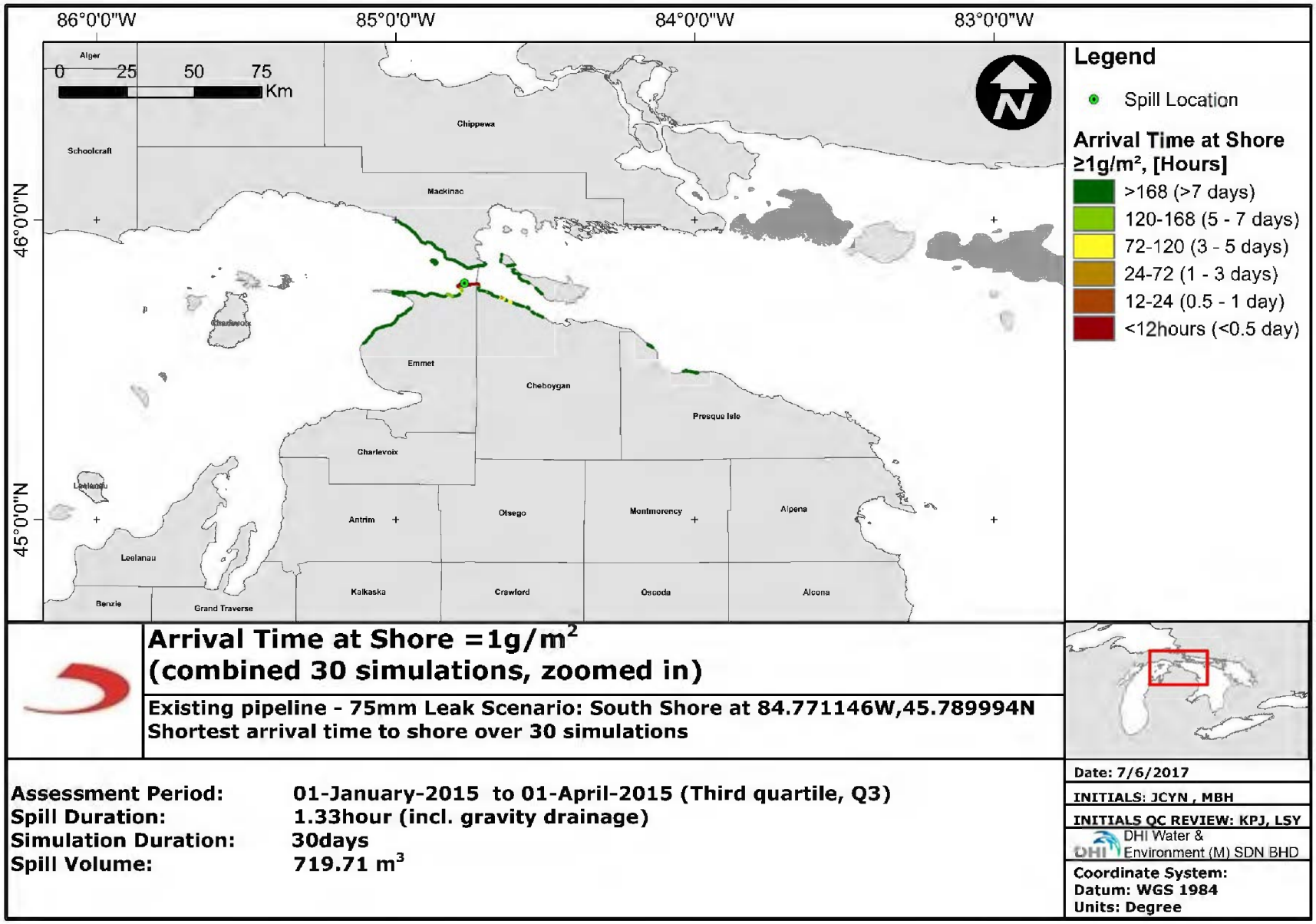


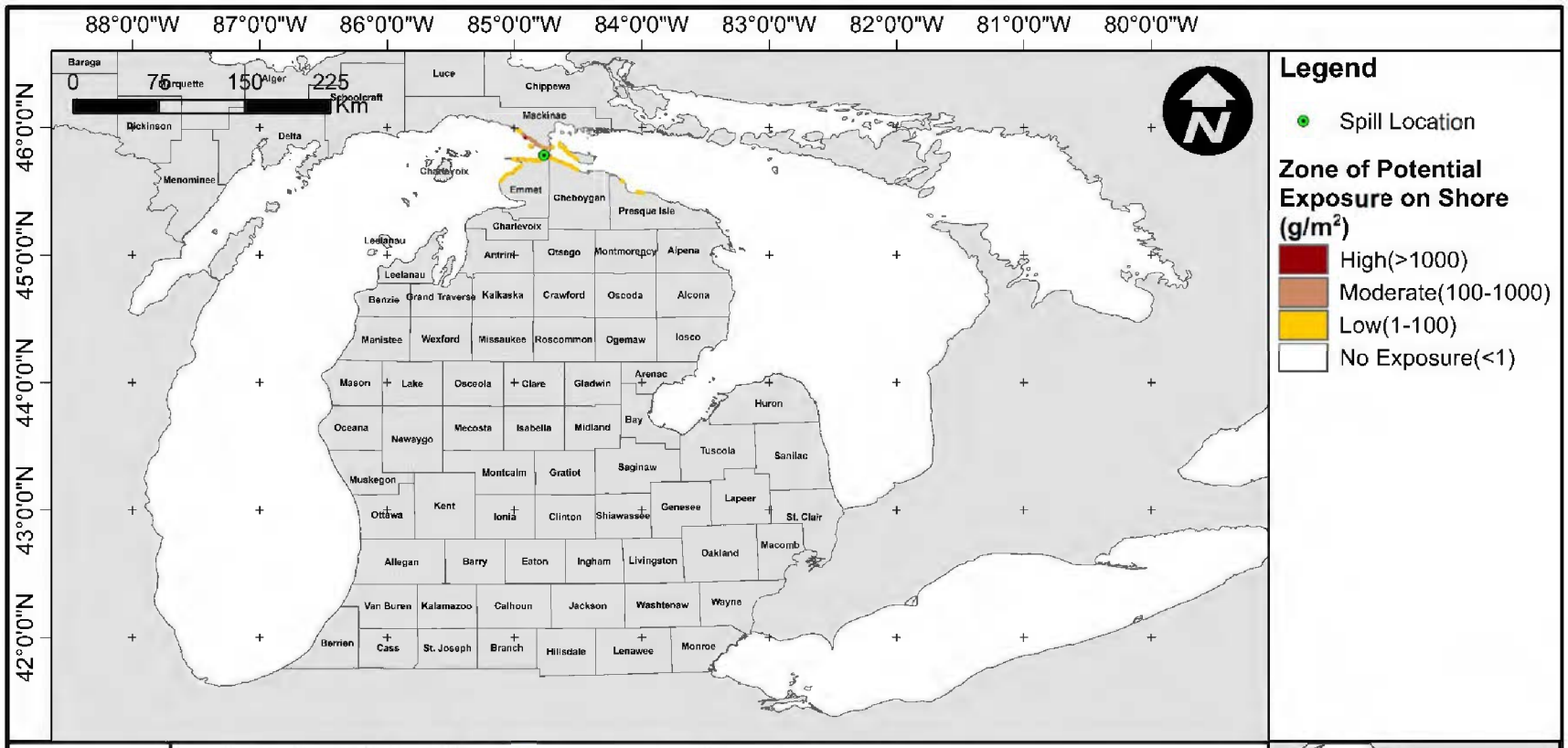
Arrival Time at Shore =1g/m^2 (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
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0 25 50 75
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Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
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Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-January-2015 to 01-April-2015 (Third quartile, Q3)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 719.71 m³
Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
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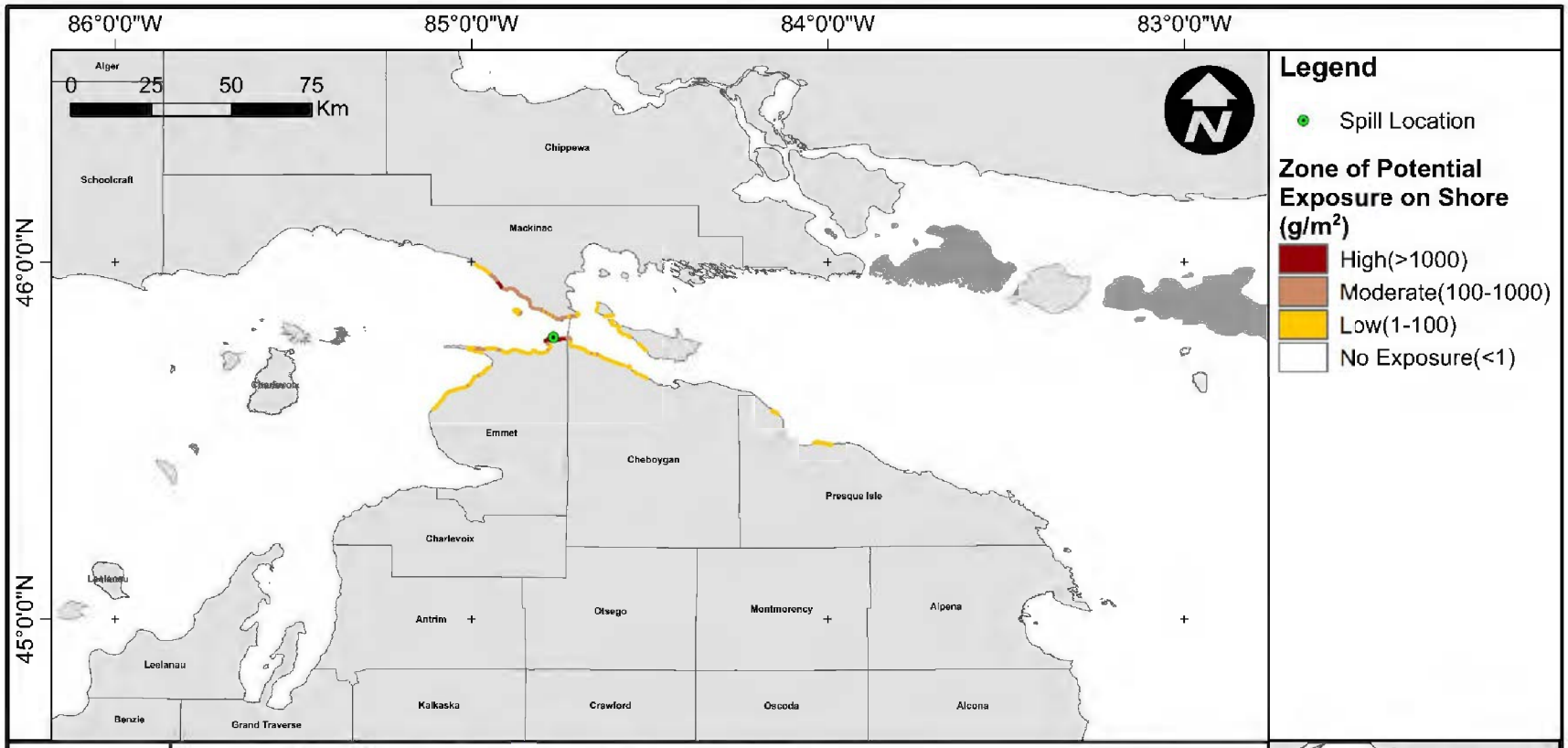


Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 7/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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Zone of Potential Exposure on Shore (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

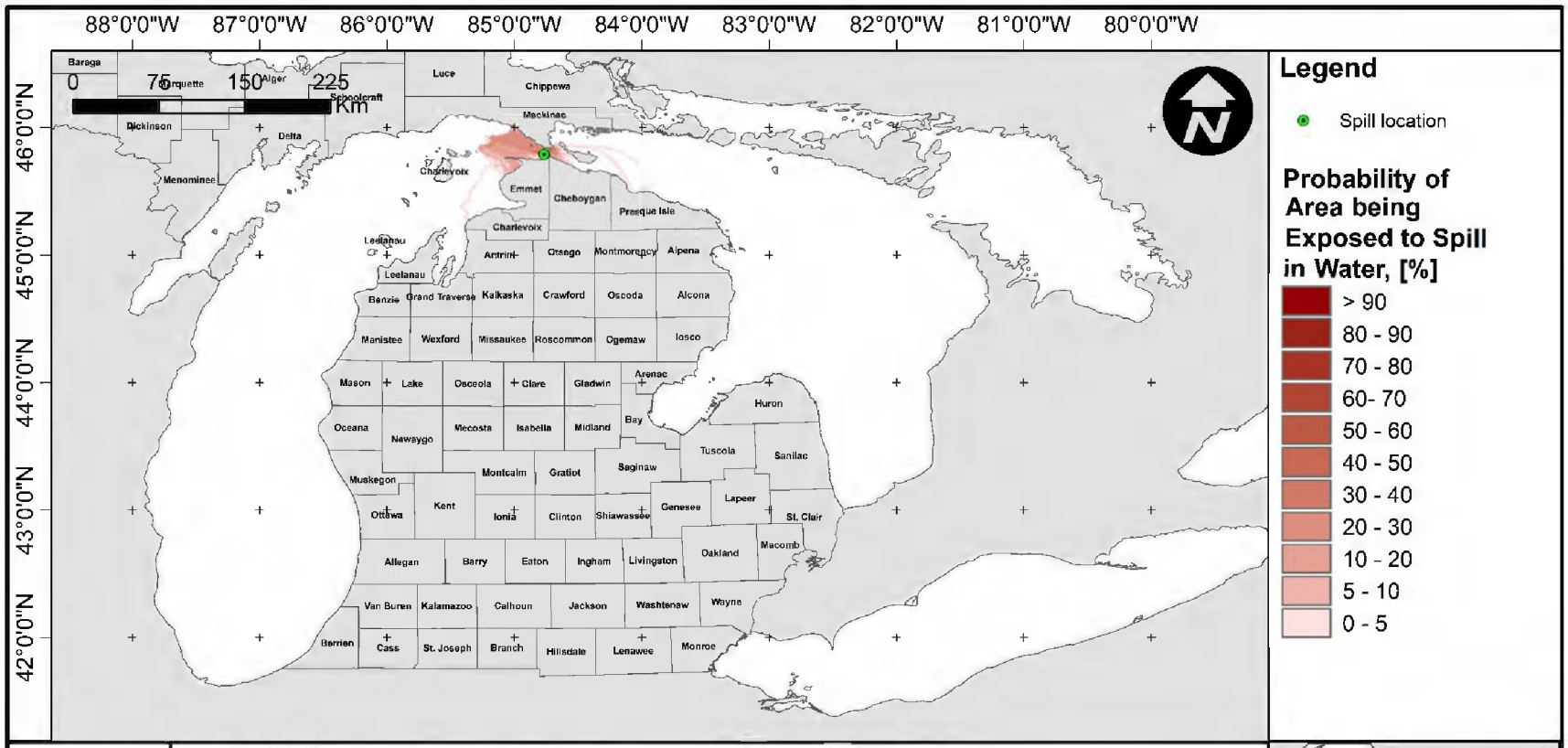
Date: 7/6/2017

INITIALS: JCYN , MBH

INITIALS QC REVIEW: KPJ, LSY

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Coordinate System:
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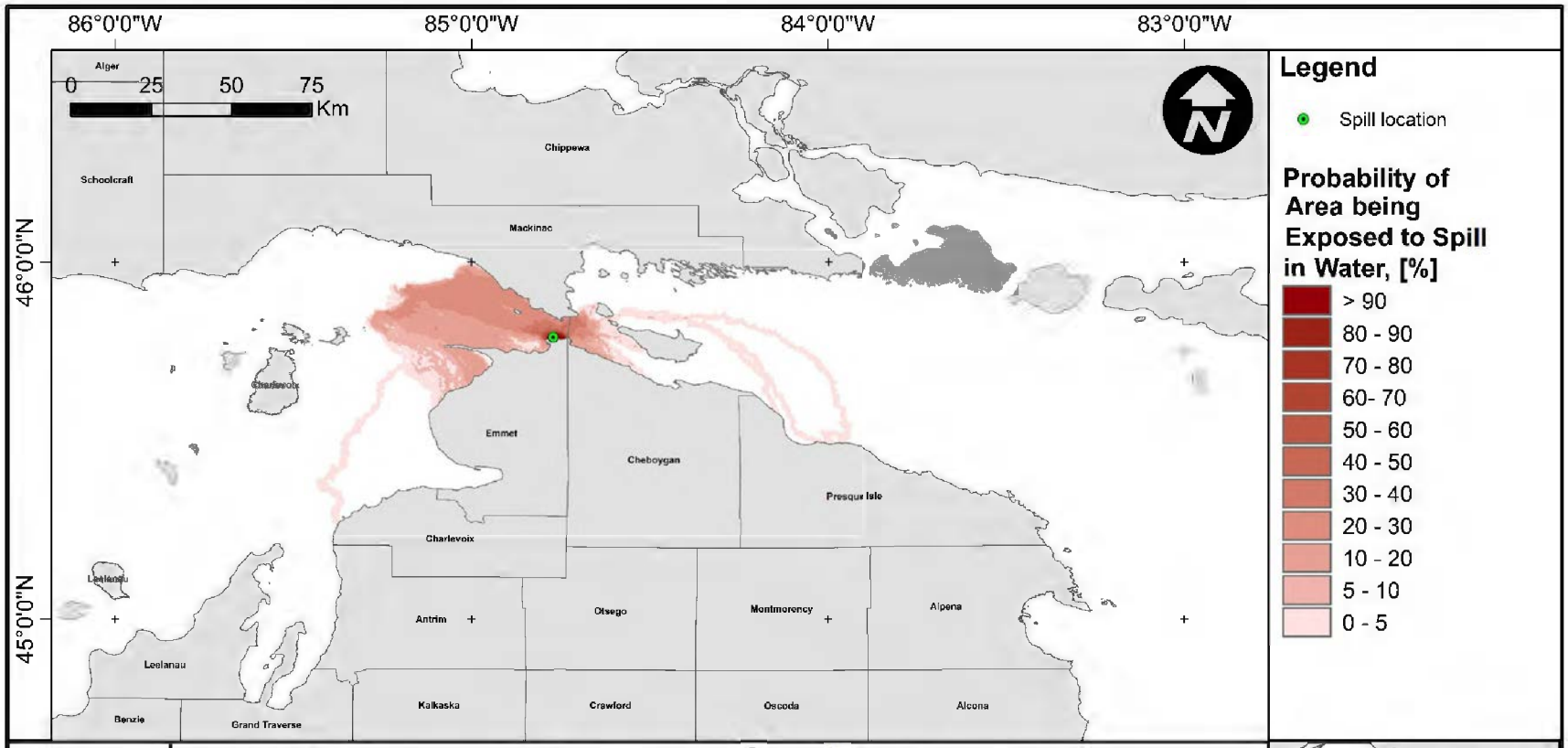


Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
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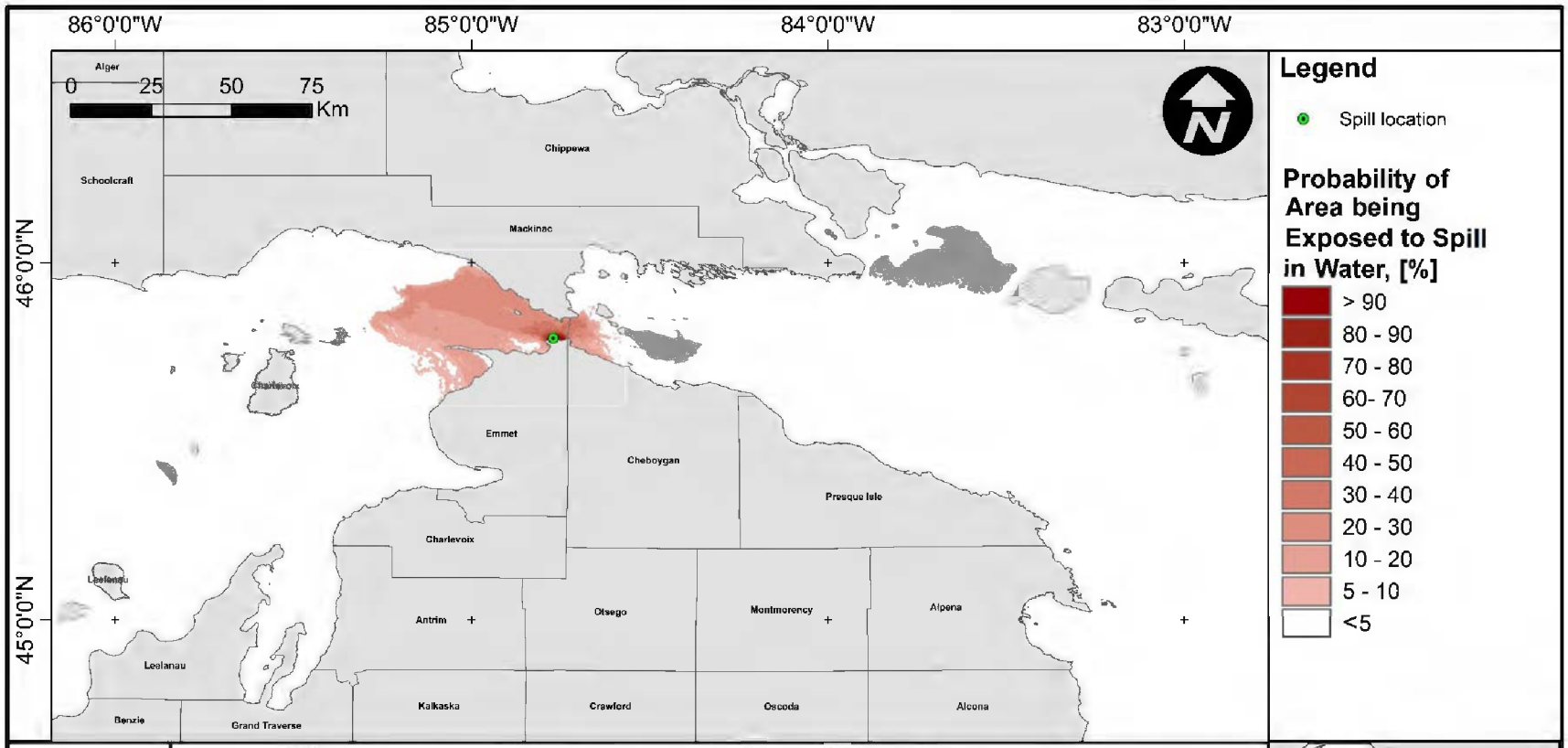


Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
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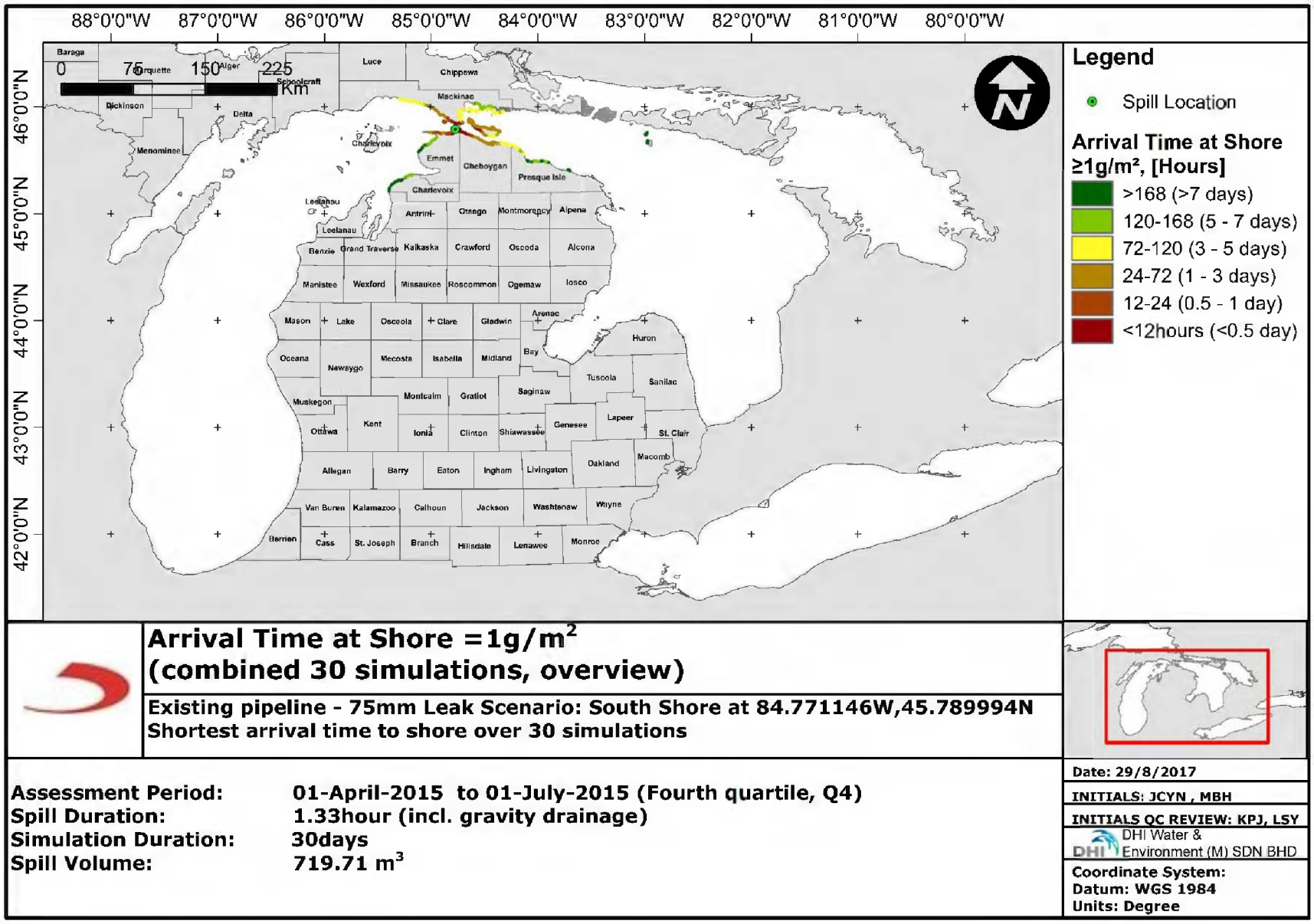
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-January-2015 to 01-April-2015 (Third quartile, Q3)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
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DHI Water & Environment (M) SDN BHD
Coordinate System:
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Units: Degree

Q4

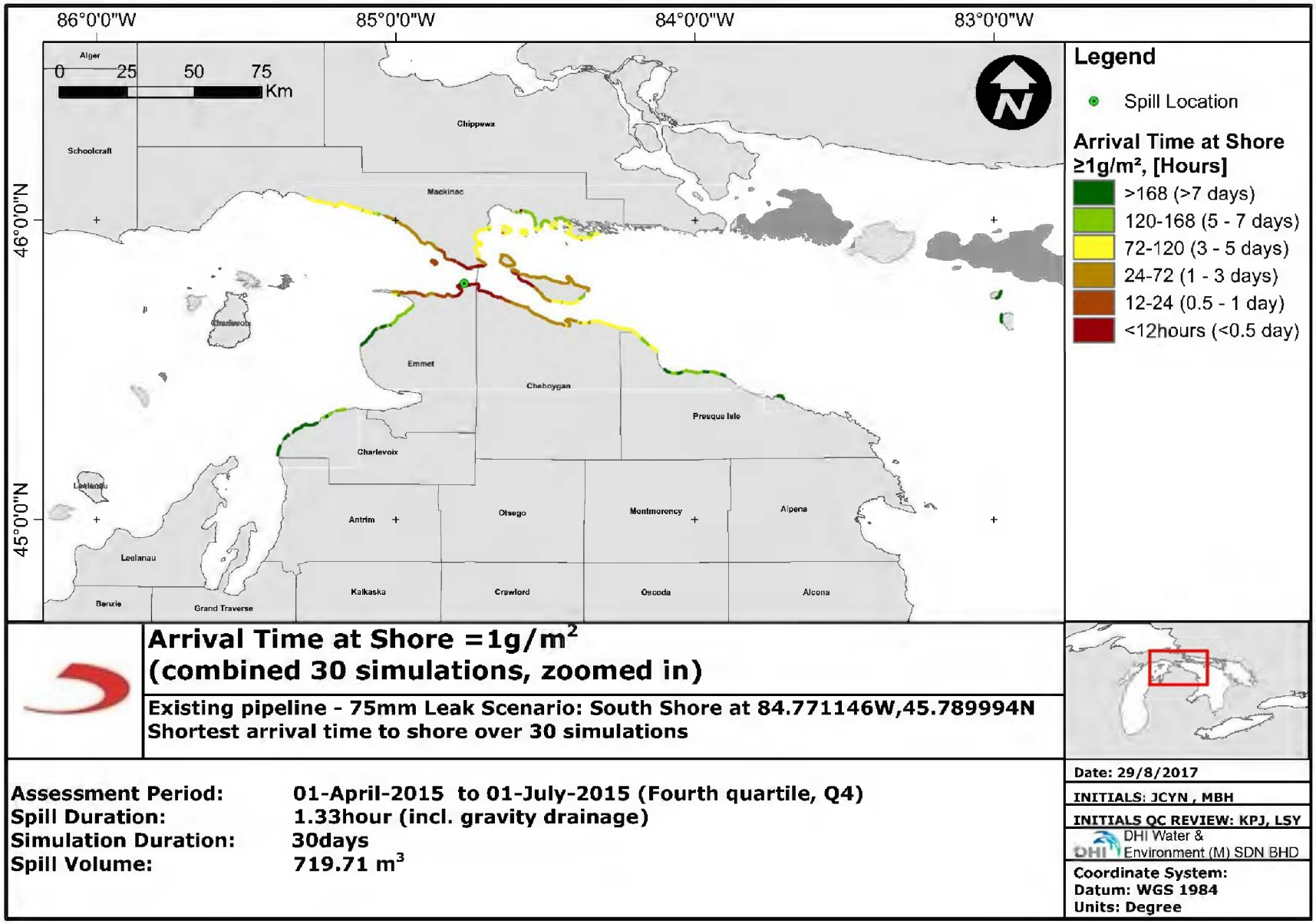


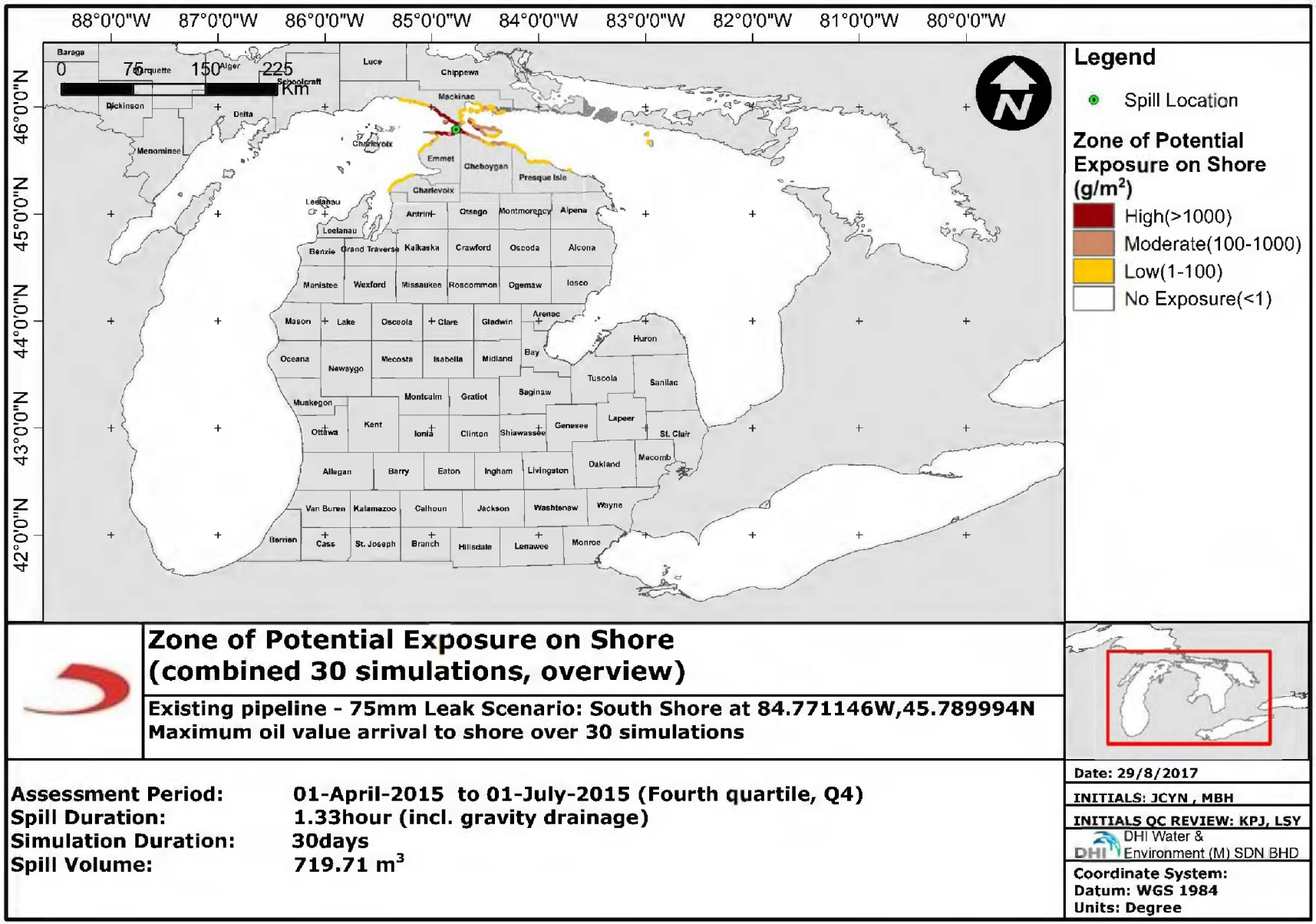
Arrival Time at Shore =1g/m^2 (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 29/8/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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86°0'0"W
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0 25 50 75
Km
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Alcona
Legend
Spill Location
Arrival Time at Shore ≥1g/m², [Hours]
>168 (>7 days)
120-168 (5 - 7 days)
72-120 (3 - 5 days)
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12-24 (0.5 - 1 day)
<12hours (<0.5 day)
Arrival Time at Shore =1g/m²
(combined 30 simulations, zoomed in)
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Shortest arrival time to shore over 30 simulations
Assessment Period: 01-April-2015 to 01-July-2015 (Fourth quartile, Q4)
Spill Duration: 1.33hour (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: 719.71 m³
Date: 29/8/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
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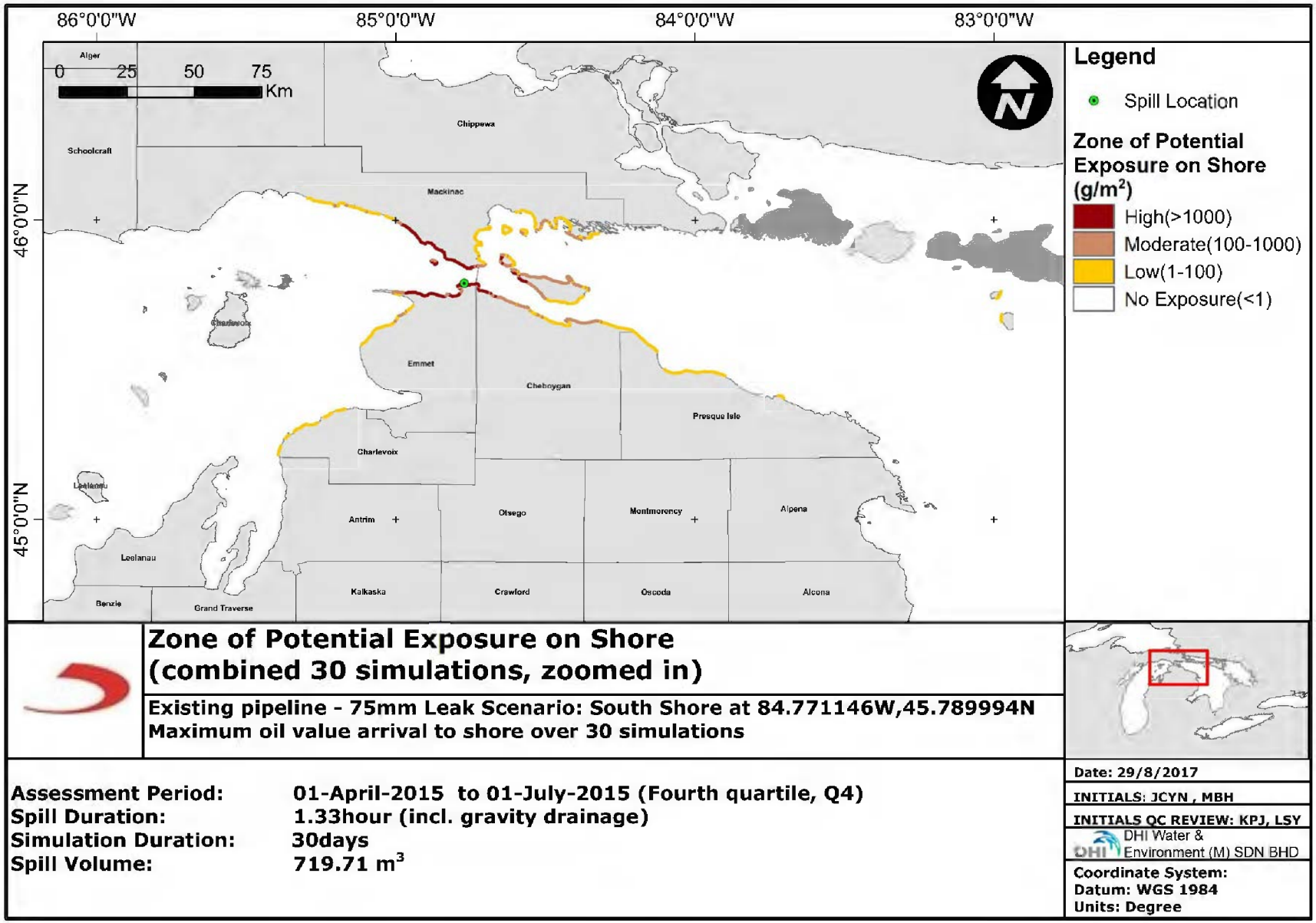


Zone of Potential Exposure on Shore (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 29/8/2017
INITIALS: JCYN , MBH
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Zone of Potential Exposure on Shore (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Maximum oil value arrival to shore over 30 simulations

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 29/8/2017

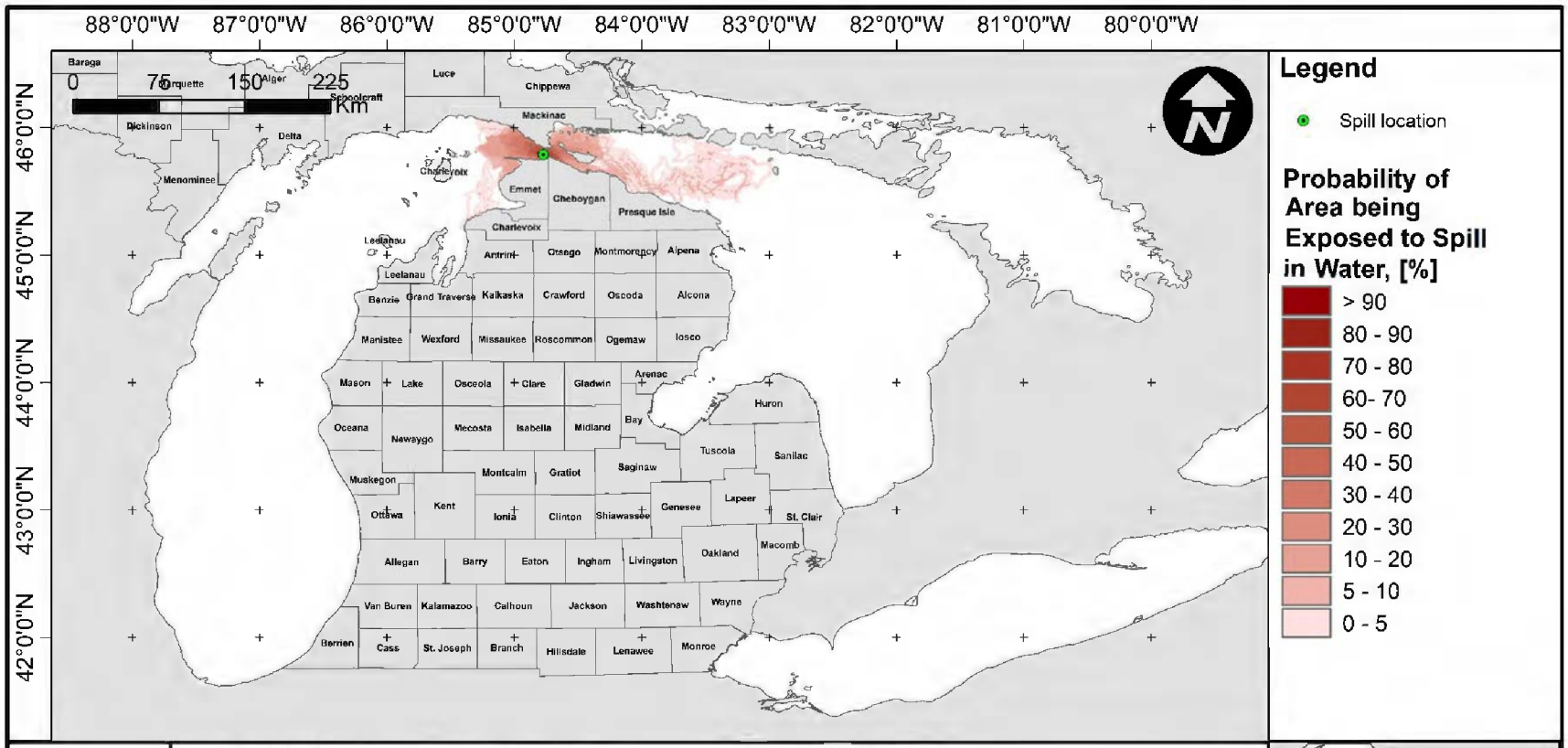
INITIALS: JCYN , MBH

INITIALS QC REVIEW: KPJ, LSY

DHI Water & Environment (M) SDN BHD

Coordinate System:
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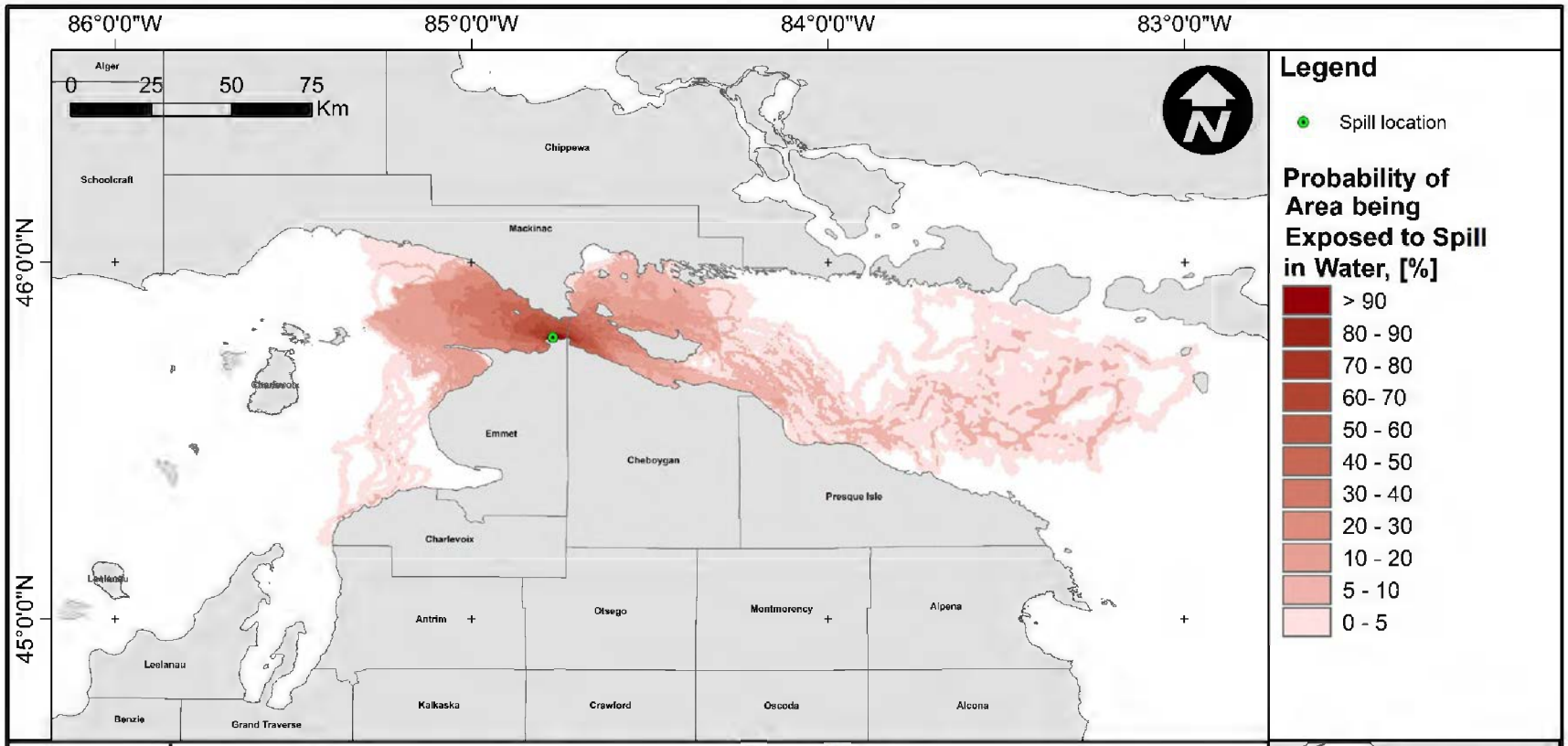


Probability of Area being Exposed to Spill in Water (combined 30 simulations, overview)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 16/6/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
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Probability of Area being Exposed to Spill in Water (combined 30 simulations, zoomed in)

Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
Probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

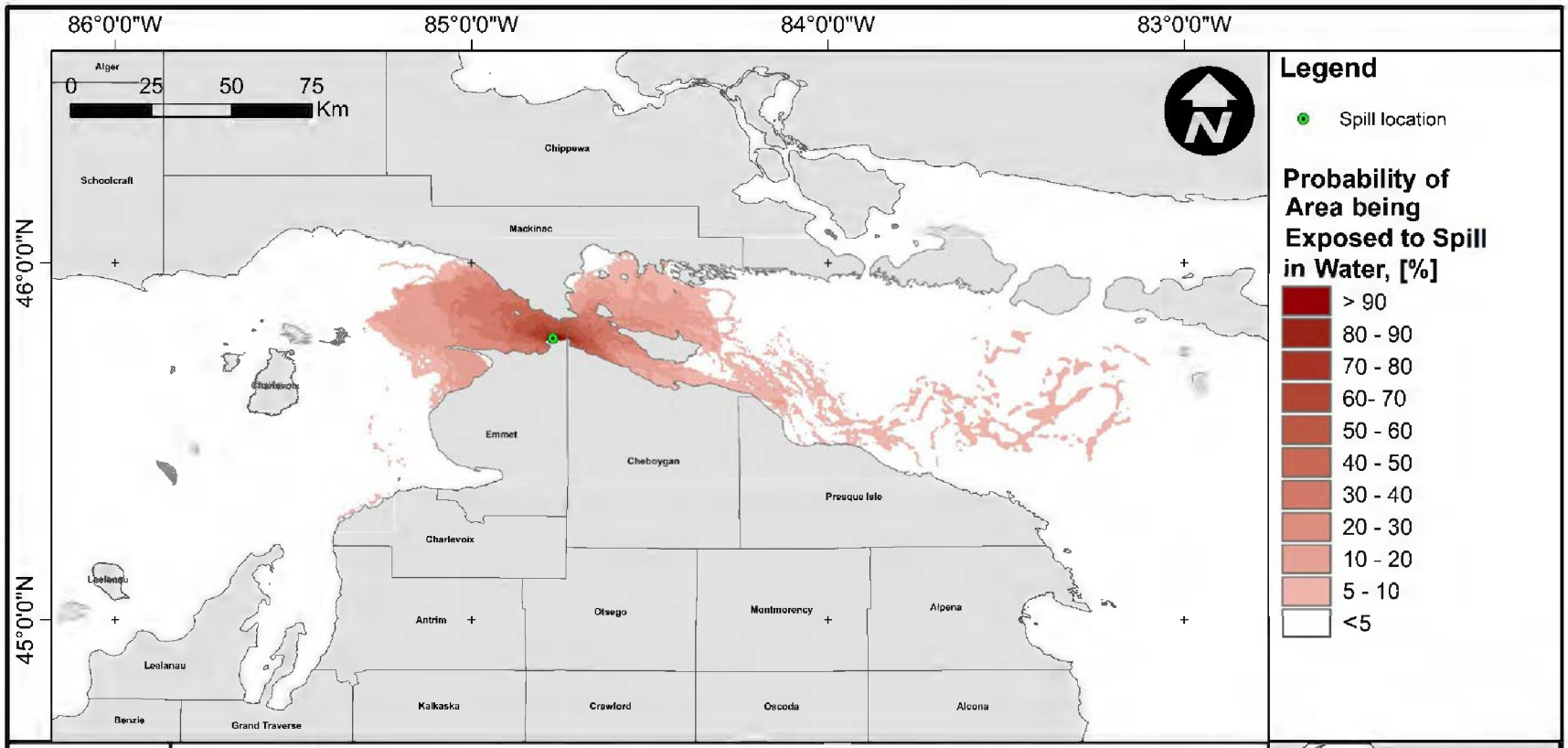
Date: 16/6/2017

INITIALS: JCYN , MBH

INITIALS QC REVIEW: KPJ, LSY

DHI Water & Environment (M) SDN BHD

Coordinate System:
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Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 30 simulations, zoomed in)

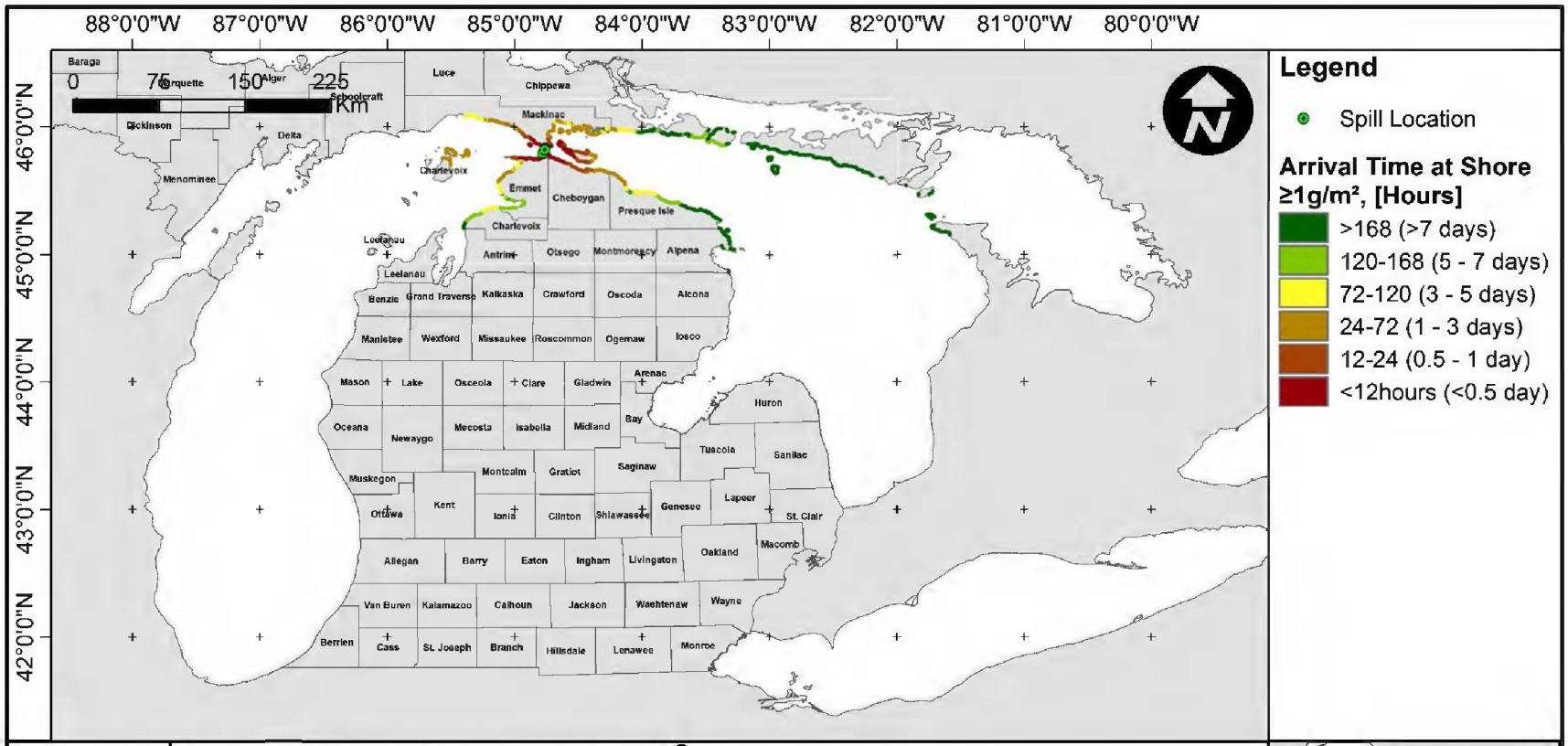
Existing pipeline - 75mm Leak Scenario: South Shore at 84.771146W,45.789994N
95th perct. probability of area being exposed to spill in water over 30 simulations (threshold 0.01g/m^2)

Assessment Period:	**01-April-2015 to 01-July-2015 (Fourth quartile, Q4)**
Spill Duration:	**1.33hour (incl. gravity drainage)**
Simulation Duration:	**30days**
Spill Volume:	**719.71 m^3**

Date: 16/6/2017
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Datum: WGS 1984
Units: Degree

Set 8
Existing Pipeline – 360 Simulations Combined

1 year

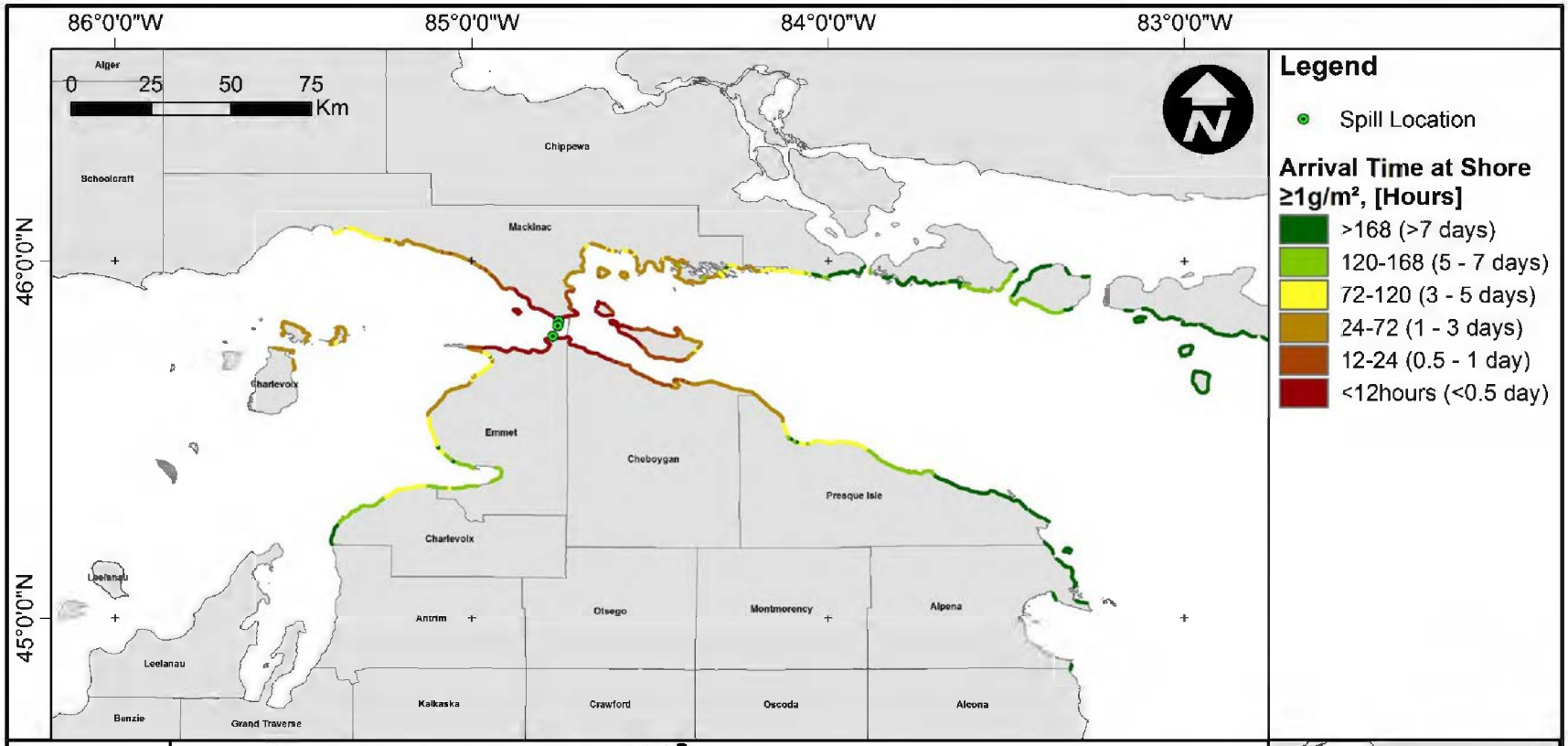


Arrival Time at Shore ≥1g/m² (combined 360 simulations, overview)

Existing pipeline
Shortest arrival time to shore over 360 simulations

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

Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

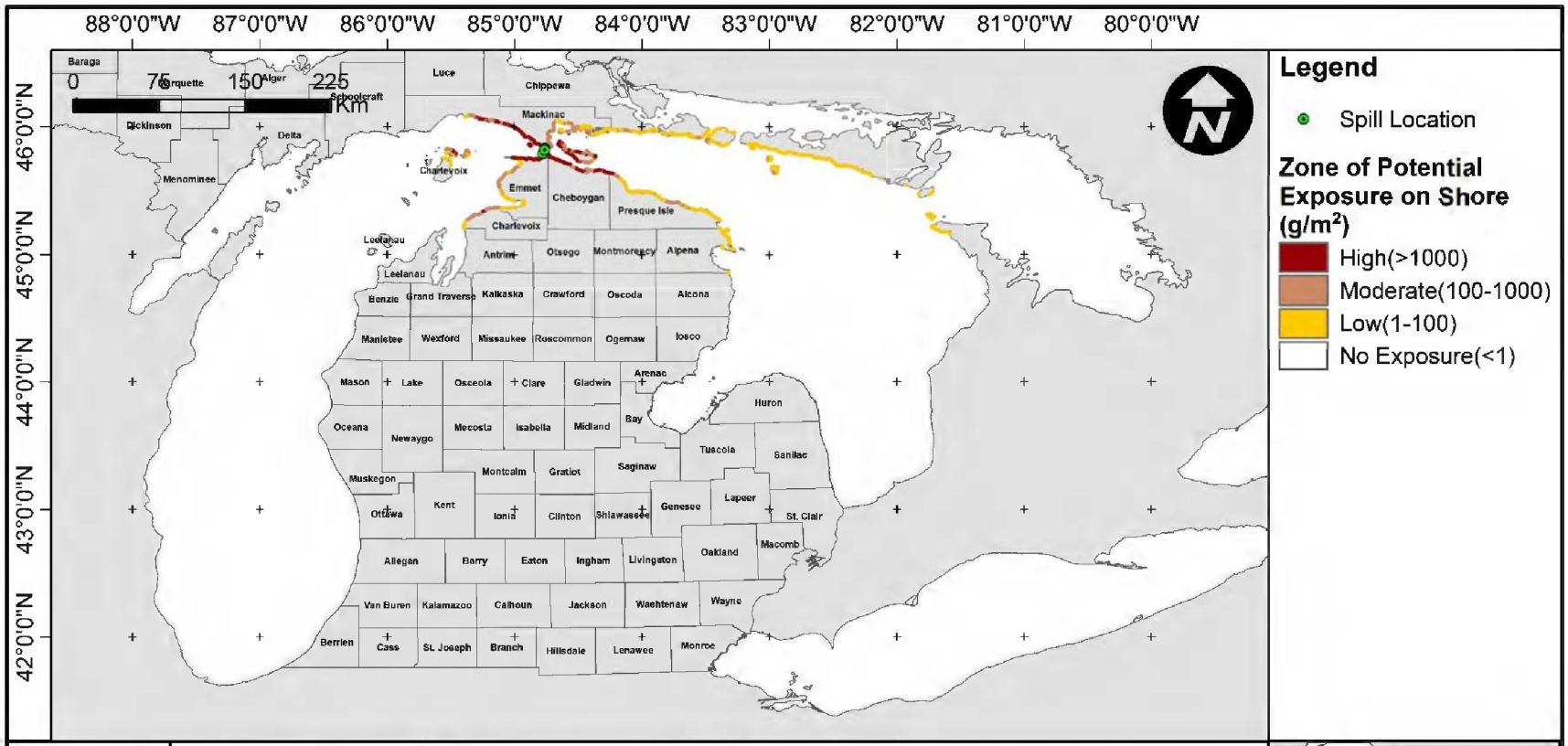


Arrival Time at Shore ≥1g/m² (combined 360 simulations, zoomed in)

Existing pipeline
Shortest arrival time to shore over 360 simulations

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

Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

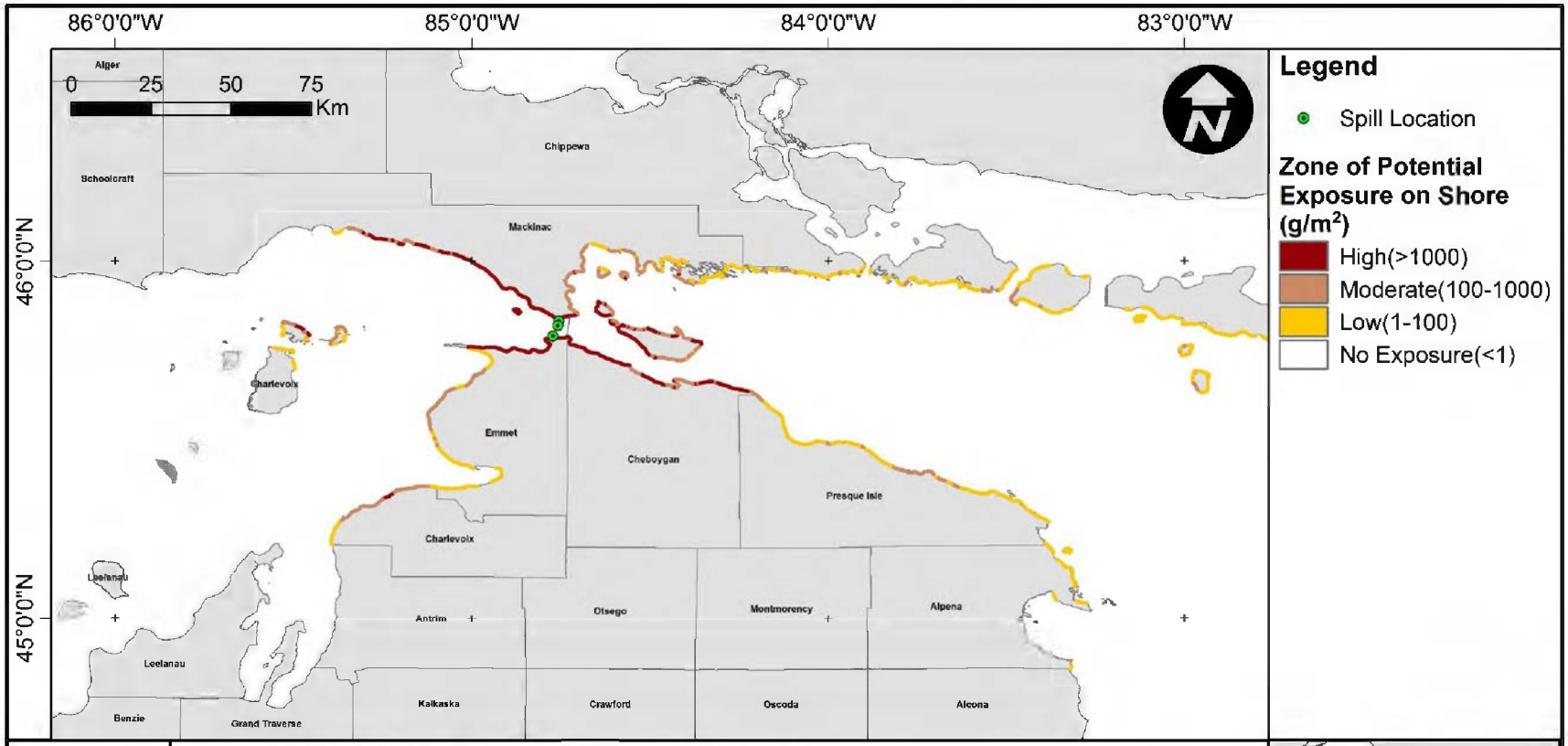


Zone of Potential Exposure on Shore (combined 360 simulations, overview)

Existing pipeline
Maximum oil value arrival to shore over 360 simulations

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

Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

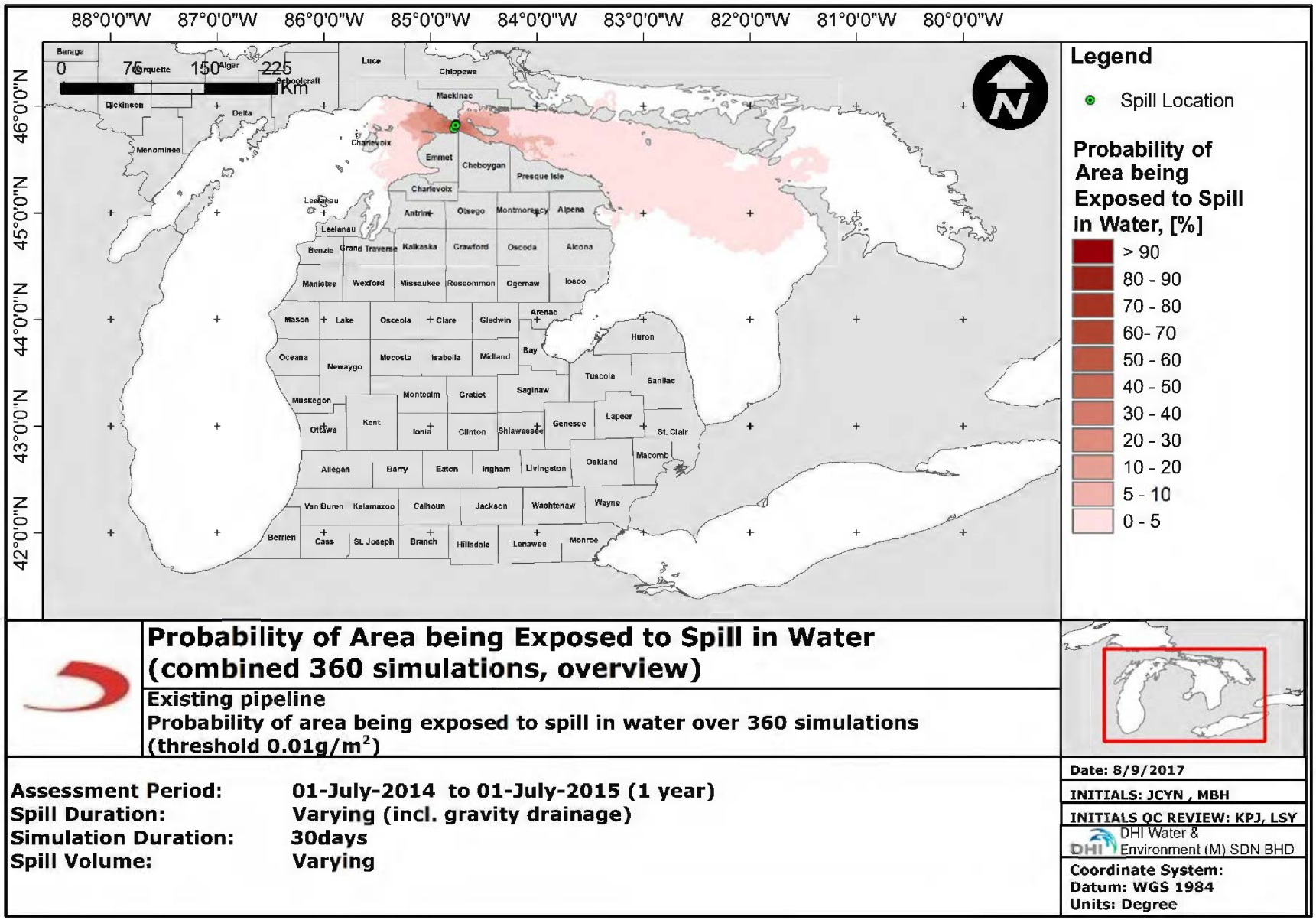


Zone of Potential Exposure on Shore (combined 360 simulations, zoomed in)

Existing pipeline
Maximum oil value arrival to shore over 360 simulations

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

Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

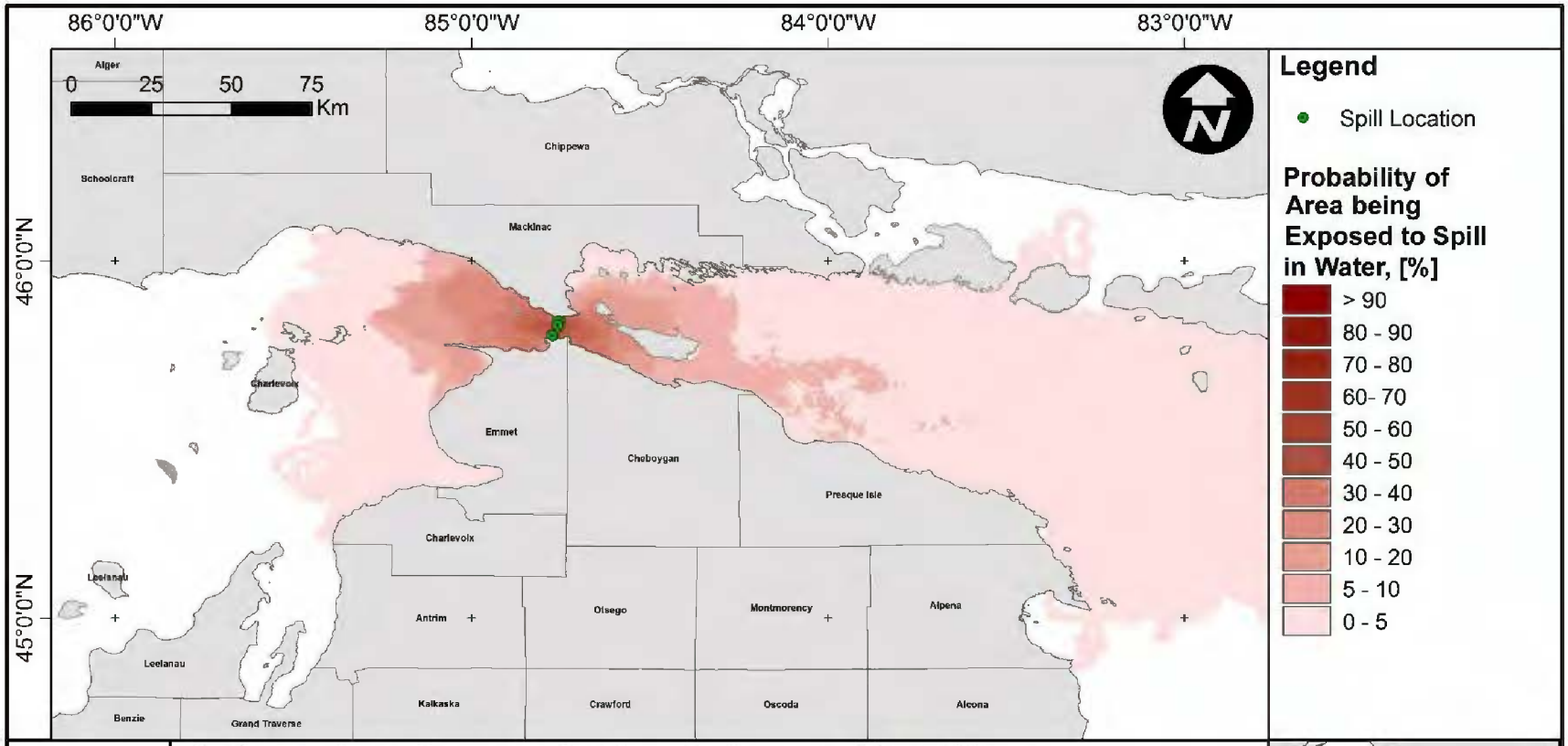


Probability of Area being Exposed to Spill in Water (combined 360 simulations, overview)

Existing pipeline
Probability of area being exposed to spill in water over 360 simulations (threshold 0.01g/m^2)

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

Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

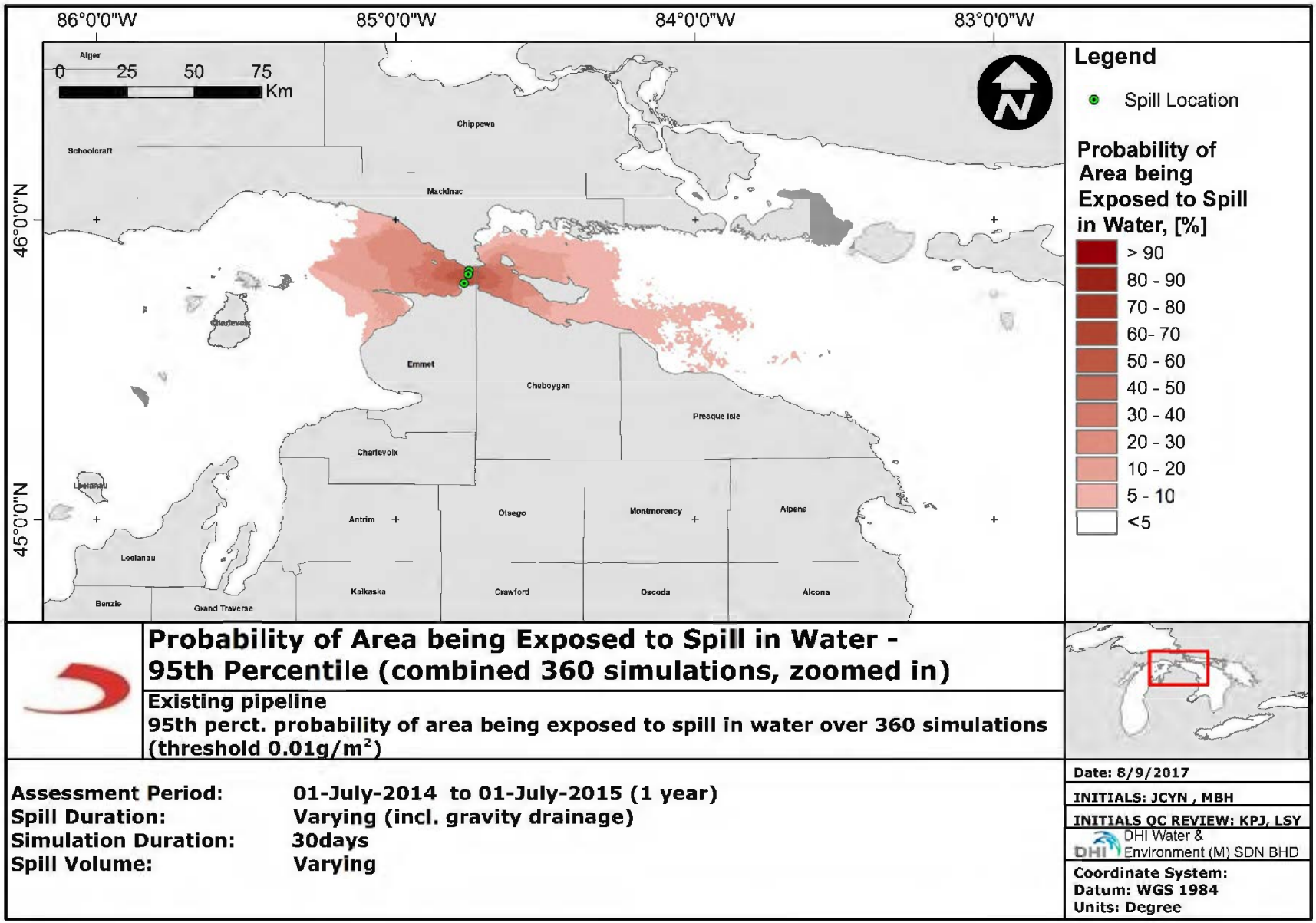


Probability of Area being Exposed to Spill in Water (combined 360 simulations, zoomed in)

Existing pipeline
Probability of area being exposed to spill in water over 360 simulations (threshold 0.01g/m^2)

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

Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree


86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
46°0'0"N
45°0'0"N
0 25 50 75
Km
Alger
Schoolcraft
Chippewa
Mackinac
Charlevoix
Emmet
Cheboygan
Presque Isle
Charlevoix
Leelanau
Antrim
Otsego
Montmorency
Alpena
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Legend
Spill Location
Probability of Area being Exposed to Spill in Water, [%]
> 90
80 - 90
70 - 80
60- 70
50 - 60
40 - 50
30 - 40
20 - 30
10 - 20
5 - 10
<5
Probability of Area being Exposed to Spill in Water - 95th Percentile (combined 360 simulations, zoomed in)
Existing pipeline
95th perct. probability of area being exposed to spill in water over 360 simulations (threshold 0.01g/m²)
Assessment Period: 01-July-2014 to 01-July-2015 (1 year)
Spill Duration: Varying (incl. gravity drainage)
Simulation Duration: 30days
Spill Volume: Varying
Date: 8/9/2017
INITIALS: JCYN , MBH
INITIALS QC REVIEW: KPJ, LSY
DHI Water & Environment (M) SDN BHD
Coordinate System:
Datum: WGS 1984
Units: Degree

Dynamic Risk

Attachment 3: Geotechnical Report: Independent Alternatives Analysis for the Straits Pipeline

Attachment 03, Geotechnical Report.pdf

Rev. 0 (September 26, 2017)

GEOTECHNICAL REPORT

INDEPENDENT ALTERNATIVES ANALYSIS FOR THE STRAITS PIPELINE

PIPELINE GEOHAZARD THREAT ASSESSMENT

PREPARED FOR

DYNAMIC RISK ASSESSMENT SYSTEMS INC.

CALGARY, AB

REVISION 0, 26 SEP 2017

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Appendix B – 2014 Span Repair Summary
Appendix C – Still Image Captures from ROV Video
Appendix D - Pipe Support Details
Appendix E – KGL Geological Model Report for the Straits Area

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EXECUTIVE SUMMARY

This report provides the results of a pipeline geohazard threat assessment for the Mackinac Straits area in Michigan. The Mackinac Straits is a body of water that joins Lake Michigan to the west and Lake Huron to the east and separates the upper and lower peninsulas of Michigan. The purpose of this geohazard study is to provide a geohazard threat assessment for the area surrounding the existing Enbridge pipeline system at the Straits as well as an adjacent area for 2 proposed alternative crossings. The work was carried out in support of Dynamic Risk Assessment System's project titled, "Independent Alternatives Analysis for the Straits Pipeline" (further referenced herein as "the Project").

A geohazard, simply stated, is a hazard specifically related to a geological or geotechnical "process or event". Examples include conditions such as unstable slopes, or events such as an earthquake. For the purposes and context of this report geohazards are defined as a class of threats to a pipeline system related to external loading in response to the occurrence of a geological process. The geohazard assessment process used for this project was to examine the published literature, examine the existing system performance and data, review the proposed alternative systems, and examine this in the context of the potential suite of geological hazards possible. Once a credible threat is identified it is explored and discussed to provide Dynamic with suitable information to translate threat identification into susceptibility for failure in the context of pipeline failure scenarios.

The available data was reviewed and it was determined that the only credible geohazard threat in the existing pipeline system and the proposed new trenched pipeline option is spanning. No geohazard threats were identified for the proposed pipeline tunnel alternative. Seismicity in the region is very low and with such gentle slopes in the submarine environment, typical hazards such as landslides and earthquakes, and fault ruptures have very low likelihood of presenting credible threats to the pipeline system.

Spanning is the loss of cover and supporting material from around the pipe by means of lake current erosion. Spanning is present to a significant extent on the existing approximately 11,000 ft long lakebed segments of the pipelines as evidenced by the 5700 ft and 5300 ft of total span length measured on the east and west lines respectively, in 2016 by Enbridge. A regular inspection and maintenance program is used by Enbridge to manage the growth of the spanning. Total span lengths have been dropping or remaining steady within the past 10 years as evidenced by Enbridge monitoring data. ILI Geopig Data provides further confirmation that the spanning is not contributing to movement of the pipeline.

It is apparent that a portion of the spanning was present at the time of construction, although it has progressed over time partly due to natural soil movement and partly due to current field perturbances related to constructed systems such as anchors, prominent pipeline segments and soil piles present on the bottom. Burying the pipeline within a profile consistent with the original ground contours will significantly reduce the driving forces of spanning.

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1.0 INTRODUCTION

1.1 GENERAL

This report provides the results of a pipeline geohazard threat assessment for an area that includes an approximately 5 mile long segment of Enbridge's Line 5 Pipeline where it crosses the Great Lakes at Mackinac Straits (the "Straits Crossing") in Michigan. Figure 1 shows the study area.

The Mackinac Straits is a body of water that joins Lake Michigan to the west and Lake Huron to the east and separates the upper and lower peninsulas of Michigan. The existing Enbridge pipeline system at the Straits crossing includes two parallel NPS24 pipes set about 1300' apart originally constructed in 1953. The existing pipelines were intended to lay directly on the lake bed below the -65' to -70' bathymetric contour. Above the -65' to -70' bathymetric contour the pipelines were placed in a trench and covered.

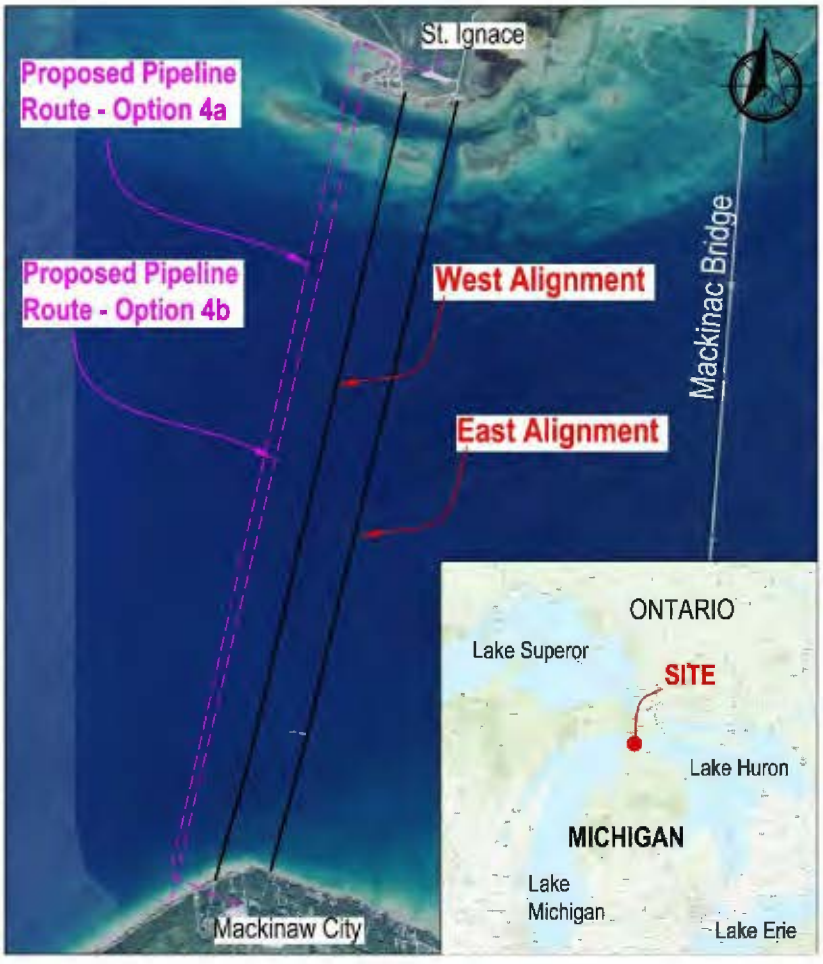


Figure 1 - General Study Area

The purpose of this study, as requested by Calgary, AB, based Dynamic Risk Assessment Systems Inc. (Dynamic Risk) is to provide a geohazard threat assessment for the area surrounding the existing Enbridge pipeline system at the Straits as well as an adjacent area for 2 proposed alternative crossings as shown in Figure 1.

The geohazard threat assessment provides supporting information for Dynamic Risk's project titled, "Independent Alternatives Analysis for the Straits Pipeline" (further referenced herein as "the Project"). Within the Project, the existing crossing location is identified as Alternative 5. The alternative pipeline crossings at the Straits are identified as Alternative 4a, a new NPS30 pipeline buried in a shallow trench in the lakebed across the Straits; and Alternative 4b, a new NPS30 pipeline installed in a tunnel constructed below the lakebed.

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Kelly Geotechnical Ltd. (KGL) carried out this assignment in accordance with the existing terms and conditions of the KGL-Dynamic Risk Subcontractor Agreement. No fieldwork was carried out as part of this assignment. Unless otherwise noted, all project information was provided to KGL from Dynamic Risk via project specific information sharing and use agreements.

1.2 USE OF THE REPORT

This report is provided to Dynamic Risk for the sole purpose of use as defined within the project assignment and as described within this report. The report includes recommendations that necessarily rely on the interpretation of the available project information, geological data, and research materials available and noted by the authors herein. The interpretation of geological conditions between available measured data points may differ from actual conditions between measured data points owing to natural variability that is difficult to quantify or precisely predict.

The information contained in this report has been prepared using generally accepted engineering practices. No warranty, whether implied or explicit, is given. This report was prepared for the purposes of supporting a risk assessment and does not constitute an engineered design, nor does it intend to, or otherwise influence or make recommendations in any way related to, the existing pipeline design or operating conditions for the Straits Crossing.

The report was prepared for the exclusive use of the Dynamic Risk Assessment Systems Inc. and for the specific area, use and conditions as set out. KGL accepts no responsibility for damages or losses related to any third party reliance on any information or recommendations included in this report, either in whole or in part. Please contact KGL if conditions change or are discovered to be otherwise different than those described herein.

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2.0 GEOHAZARD THREAT ASSESSMENT OVERVIEW

2.1 GENERAL DEFINITIONS

A hazard simply stated is a condition or event that might cause a failure or damage incident or anything that has the potential to cause harm to people, property, or the environment. A geohazard, simply stated, is a hazard specifically related to a geological or geotechnical "process or event". Examples include conditions such as unstable slopes, or events such as an earthquake. For the purposes and context of this report geohazards are defined as a class of threats to a pipeline system related to external loading in response to the occurrence of a geological process.

A geohazard threat assessment is defined as a process where the susceptibility of a pipeline, or pipeline segments, to potential geohazards is examined and characterized in a systematic way. Once defined in a geological context, threat data may be used in turn within a risk assessment process to characterize potential threats in terms of susceptibility, or the potential for failure. KGL understands that the Project will use the results of this threat assessment to support an overall quantitative risk assessment associated with the potential release of liquids from various pipeline options as noted in Section 1. Susceptibility in this case is defined the annual probability of loss-of-containment from a pipeline.

2.2 PROCESS STEPS

The threat assessment process used the following basic steps:

- The study area terrain is characterized from a geological perspective;
- Project area specific systems descriptions and information is reviewed to examine the context of ground interaction between project elements and the terrain;
- A general list of all possible geohazards is screened according to the general terrain and environmental conditions present in the area to establish a list of project specific geohazards (Primary Geohazard Screening); and
- Project specific geohazards are evaluated for the potential to occur, and if occurrence is credible or otherwise have more than a "theoretical potential for occurrence" level, a relative and/or quantitative level of occurrence is assigned.

2.3 COMMENTS ON SUSCEPTIBILITY AND GEOHAZARDS

Calculation of susceptibility for the purposes of using geohazard threat assessment data within a susceptibility framework can be conducted in many forms. This report does not set out to calculate susceptibility, instead it provides a description of the potential geohazard threats only. KGL understands that Dynamic Risk will calculate susceptibility.

The typical bounds of a geohazard assessment extend between overview level assignment of susceptibility using a qualitative approach (such as low, medium and high); through to fully quantitative means where significant amounts of detailed ground information is available. One potential approach that could be

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used is described in Equation 1 and is based on the work by Rizkalla et al. (2008)[1]. This describes how threat assessment data could be converted for use within a quantitative or semi-quantitative risk assessment. Note that susceptibility (S) at a line segment (j) is expressed as an equivalent to annual Failure Frequency (F_f), where over line segment j, failure frequency is defined as the product of the potential for the geohazard to occur $I_{(j)}$, the frequency of occurrence $F_{(j)}$, the unmitigated system vulnerability $V_{(j)}$, and the effects of the mitigations used in the segment $M_{(j)}$.

$$S_{(j)} = F_{f(j)} = I_{(j)} \times F_{(j)} \times V_{(j)} \times M_{(j)} \quad \text{Events per year} \quad \text{Eq. 1}$$

where
I = Occurrence factor ranging from 0 to 1
F = Frequency of occurrence (expressed in events per year)
V = Vulnerability factor ranging from 0 to 1
M = Mitigation factor ranging from 0 to 1

The context of "quantitative" outcomes in geohazard assessment processes as set out in Equation 1 and within this text must be understood to include uncertainty associated with lack of availability of comprehensive and site-specific soil, bedrock and groundwater data that describes conditions to a high degree of detail in addition to long-term slope stability performance records, stream channel performance and an accurate depiction of potential environmental influences from short and long term climate patterns. These are but a few of the variables that must be considered to fully characterize the behavior of the site specific terrain in a potential geohazard impact zone over the potential life of a project. As a result, engineering judgement must play a key role in the geohazard assessment process, both at the threat assessment stage and in assigning susceptibility values. The precise quantification of results from the use of such methods is not always possible. Estimates of several attributes within the project area are based on evidence and observations from several sources. An order-of-magnitude approach is often adopted to estimate quantitative assessment outcomes where supporting information is either absent, sparse, or otherwise not available.

In some cases geohazard impact areas may overlap one another. In some cases this is as a result of one geohazard triggering another, but it is not always the case. Examples of one triggering another could include ground shaking and liquefaction; or lateral migration and landsliding. It is also possible that they do not have a co-dependence, but are located in the same hazard space; an example could include ground shaking and scour. Where geohazards are present in the study areas and may have a co-dependency on an overlapping geohazard impact zone the relevant frequency and/or occurrence term of the failure frequency formula should be adjusted (often matched) to reflect the co-dependency (i.e. the frequency term of the trigger is also used in the dependent event). Where they are located in the same hazard space

[1] Rizkalla, M, R. Read and G. O'Neil, 2008. Chapter 6 Geohazard Management. In Rizkalla (ed.), Pipeline Geo-Environmental Design and Geohazard Management. ASME, New York , NY.

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with no co-dependency, there is no further consideration. This approach allows the overall quantitative assessment calculation to treat the threat identification within a susceptibility framework of each hazard separately along a specific (and sometimes overlapping) segment of a pipeline system.

3.0 SYSTEM DESCRIPTION

The detailed description of the attributes of the existing and proposed pipeline systems is presented in detail in Dynamic Risk's overall Project reporting. Only generalized descriptions of the options as initially described in Section 1 are provided below for the purposes of this report. An overview of the historic data related to the existing pipeline is provided for the purposes of supporting the geohazard threat assessment.

3.1 OPTION 5 – EXISTING PIPELINES

The Option 5 (existing) pipeline system includes two parallel NPS24 pipelines set about 1300' apart on the lake bed (East line and West line), running north-south perpendicular to Mackinac Strait between about 1.5 to 2.0 miles west of the Mackinac Bridge. The pipelines are buried from the shoreline down to a bathymetric contour of about -65' to protect the pipeline from ice scour and other related shoreline processes. Burial at design is reported as a minimum of 15' of cover to a bathymetric contour of -50', then tapering off to 0' at a bathymetric contour of -65'. Below these buried shoreline approaches, the existing pipelines were built to rest directly on the lakebed with no cover. High points were removed in several

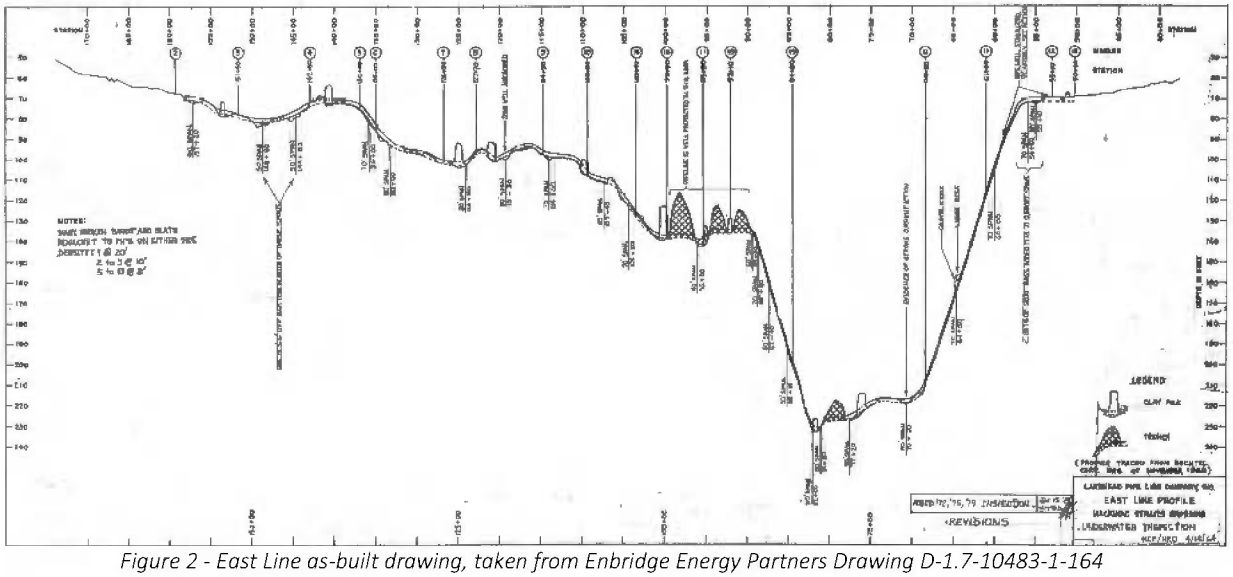


Figure 2 - East Line as-built drawing, taken from Enbridge Energy Partners Drawing D-1.7-10483-1-164

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areas during the original construction. Figure 2 shows the existing East Line profile and 1970's era inspection data taken from data available on Enbridge Energy Partners Drawing D-1.7-10483-1-164[2].

Note that Figure 2 depicts significant sized clay piles (i.e. presumably 10's of feet thick) that were placed in several areas along the lines after the line was pulled into position. Figure 2 also depicts areas of trenching below the shore cover sections, including an area in the deepest section of the crossing, areas where grout bags have been added to support spans, and includes notations for 23 individual spans totaling 1630'. Project reports, including references in Figure 2, describe that 1"x4" wooden planks/slats were strapped around the pipeline and coating systems prior to pulling it into place.

In addition to the information provided on Figure 2, several recent pipeline inspection reports were available in the project documents. KGL reviewed pipeline dive inspection reports prepared for Enbridge detailing inspection activities associated with dive inspection and repair and Remotely Operated Vehicle (ROV) inspections carried out in 2005[3], 2006[4], 2007[5], 2010[6], 2012[7], 2014[8], and 2016[9]. These reports provide a record of ongoing inspections and repairs of the pipeline and include detailed repair records and references to locations where the pipelines span open water between natural or artificially installed pipeline supports. An example of the artificial pipeline support is shown in Figure 3. The locations are defined in the reports as "spans" and each span is assigned a unique identifier. The 2014 report provides a suitable summary of the series of reports as follows, "*The focus of this* [inspection and maintenance] *project was to identify existing conditions and remediate any areas which could potentially compromise the safety of the pipelines… Past surveys and historical data have determined that intermittent areas of exposed pipeline have become unsupported along the crossing".* In addition to the reports noted above, the

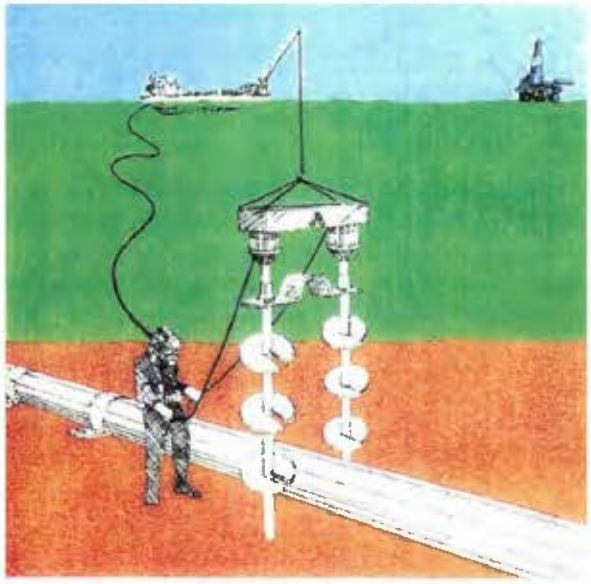


Figure 3 - Concept Anchor Installation (taken from Enbridge project data)

[2] http://www.michigan.gov/documents/ag/164-00-1_700-10483-01_523921_7.pdf
[3] Onyx Special Services Inc., Untitled Letter Report, 25 Aug 2005. 35 pages.
[4] Veolia ES Special Services, Inc., Untitled Letter Report. 27 Sep 2006. 14 pages.
[5] Veolia ES Special Services, Inc., Untitled Letter Report. 26 Oct 2007. 4 Pages.
[6] Veolia ES Special Services, Inc., 2010 Straits of Mackinac Pipeline Inspection & Repair Project. 28 Jan 2011. 9 pages
[7] Veolia ES Special Services, Inc., 2012 Straits of Mackinac Pipeline Inspection & Repair Project. 15 Nov 2012, 8 pages
[8] Ballard Marine Construction, Inc. 2014 Straits of Mackinac Pipeline Inspections and Maintenance Project. 13 Nov 2014. 9 pages.
[9] Ballard Marine Construction, Inc. 2016 Straits of Mackinac Pipeline Inspections and Maintenance Project. 3 Jan 2017. 9 pages.

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Project provided KGL with the ROV video from the 2010, 2012, 2014, and 2016 inspections for review, as well as the multi-beam echo-sounding (MBES) survey data collected during the 2014 and most recent 2016 inspections.

Additional data describing the existing pipelines was provided in 2013 20" GEOPIG™ Baker Hughes Pipeline Inspection Reports[10][11]. Both reports compared the July 2013 inertial tool data to a previous 2005 survey and described that "*...the reporting threshold is to report pipeline movements with differential bending strain exceeding 0.1%. No areas of pipeline movement [except in a rerouted section] meeting the reporting threshold were identified in this line*". Note that the rerouted segment is not within the submarine portion of the crossing, it is adjacent to the launch valve site.

Appendix A includes KGL drawings East-1 through East-9 and West-1 through West-10. A key plan showing the arrangement of the information is included. These drawings show detailed conditions along the existing pipelines and were produced using the 2016 MBES data provided by the Project, span log data, and observations from several of the available ROV videos. Figure 4 shows a typical image from the ROV videos used to support the assessment. Project chainage in the Appendix A drawings was developed for the purposes of referencing the pipelines for this assessment only and was set at zero from the north shoreline of the Straits and is expressed in horizontal kilometers for reference purposes within this report only.

The results of the pipeline marine inspections were available to the Project compiled in a document produced for Enbridge titled, "Line 5 Straits of Mackinaw 2014 Survey Inspection results". The compilation describes the location and historic lengths of each span (i.e. summarizes the 2005 through 2014 span lengths), identifies the support conditions at either end of each span, and presents the 2014 span height. The span logs identify about 260 individual spans on both lines, 133 on the east line and



Figure 4 - Typical still image taken from Project supplied ROV videos

[10] Baker Hughes Pipeline Inspection. July 31, 2013. Geometry Inspection Report ... (East Loop) http://www.michigan.gov/documents/ag/BHI_2013_GEOPIG_FINAL_REPORT_524004_7.pdf

[11] Baker Hughes Pipeline Inspection. July 30, 2013. Geometry Inspection Report ... (West Loop) http://www.michigan.gov/documents/ag/GEOPIG_FINAL_REPORT_Issue_1_-_West_Loop_524094_7.pdf

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127 on the west. 2016 data was added once received. The compiled span logs are reproduced and included for reference in Appendix B.

Still image captures taken from select videos along both pipelines are included in Appendix C.

A copy of the typical anchor design documents and installation details is included in Appendix D.

3.2 OPTION 4A AND 4B – PROPOSED STRAITS PIPELINE ALTERNATIVES

Option 4a and 4b are conceptual design options presented as part of the alternatives study and were prepared by Stantec on behalf of Dynamic Risk. The details of the proposed system design are presented in the Stantec Project reports.

For the purposes of examining susceptibility to geohazards, the proposed system attributes presented in the baseline designs were used along with baseline assumptions with respect to operating maintenance and inspections. The locations of the proposed Option 4A and 4B are shown in Figure 1.

The Option 4A alternative consists of a single NPS 30 steel pipeline installed in a trench with a minimum 1 m of cover on the lakebed throughout most of the profile with the exception of the shore approaches. Shore approaches will be buried much deeper to protect against ice scour and shoreline erosion processes.

The Option 4B alternative consists of a single NPS 30 pipeline constructed within a tunnel driven well below the lakebed from entry/exit shafts located on lands adjacent to the Straits. The tunnel is intended to be backfilled upon completion of the pipeline installation.

4.0 DATA SOURCES

Project specific data was provided and/or made available to KGL by the project team for the purposes of the assessment. In some cases the data used to support the analysis was made available for review, although it was subject to specific use and confidentiality agreement restrictions.

Additional data was collected from numerous sources including, but not limited to, existing publications, online sources, and internal project communications. Footnote references throughout this report describe the many sources of existing published data used for the purposes of the assessment.

This report also relies on findings presented in a separate KGL Geological Model report[12] provided to Dynamic Risk. The Geological Model report was prepared to summarize the geological conditions in the study area. The KGL Geohazard Report is included for reference in Appendix E of this report.

[12] Kelly Geotechnical Ltd. Report, "Independent Alternatives Analysis for the Straits Pipeline, Geological Model", prepared for Dynamic Risk, November 2016. 64 pages.

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5.0 PRIMARY GEOHAZARD SCREENING

5.1 SUMMARY OF GEOLOGICAL CONDITIONS

The project area covers a relatively small area through the Mackinac Straits. The previously prepared KGL geotechnical report presented a detailed description of the geological conditions. A brief summary is presented herein. For detailed information the reader is referred to the previous KGL report in Appendix E.

The geological conditions are used together with research and engineering judgement in the context of terrain analysis to "divide the area into units whose engineering characteristics are relatively uniform" using methods as set out by Cruden and Thompson (1987)[13]. This terrain assessment method can be used to support subsequent hazard zonation by a direct mapping methodology, similar to that as described in Soeters and van Westen (1996)[14] if specific zonation is required.

The Straits is a remnant channel associated with meltwater erosion and downcutting during the geologically recent development of the Great Lakes. It is likely this was a preferential erosion area due to the presence of the Mackinac Breccia zone through the underlying bedrock units. The present-day water level in the Straits is at an average of about 577.5 feet above sea level (fasl). The deepest segment of the Straits at the existing pipeline crossing is about 260' below the water surface, representing a base level of the lakebed of about 318' fasl. Slopes are gentle throughout the profile, generally less than 5%, although several continuous sections exist up to maximum of about 15%. The steep slope profiles generally exist on the north and south boundaries of a deep trough within the existing limits of the channel, located about 2/3 of the way across the Strait from the south shore.

Geological evidence suggests the potential for historic lake levels to have existed such that the Straits formed a river flowing east into the present-day Lake Huron basin. River erosion would likely have deepened the channel, possibly exploiting bedrock associated with dissolution of anhydrite and subsequent collapse and brecciation. In addition, evidence also suggests that four (4) potentially lower lake levels in the channel that could have formed and that they could include now submerged beach deposits. Evidence is also presented to show that after the lower lake levels and river channelization, the lake was up to 30' higher than present-day levels, most likely resulting in deposition of lakebed sediments throughout. The historic changes in the lake levels presents evidence that the deposits are likely to include mixtures of beach and outwash sands, lakebed lacustrine silt and clay, and potentially some glacial till. No specific geotechnical information on the lakebed sediment profile was available in the project documents other than specific conditions observed during the construction of the Mackinac Bridge (see Appendix E)

[13] Cruden, D.M. and Thompson, S. 1987. Exercises in Terrain Analysis. Pica Pica Press, Edmonton, AB, Canada.
[14] Soeters, R., and van Westen, C.J. (1996) Slope Instability Recognition, Analysis, and Zonation. Ch 8 In Landslides Investigation and Mitigation, Special Report 247, Transportation Research Board, National Research Council. National Academy Press, Washington, DC.

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and a comment in the 1954 Bechtel Corporation Final Report[15] where it stated, *"...grab bucket samples had been taken up to depths of 135 feet and that these samples indicated that the Straits bottom was made up of stiff red clay mixed with sand and gravel".*

Observations were available by reviewing the project ROV videos and span logs that describe screw anchor installation conditions. The submarine footage shows that excavation evidence is present throughout, and that several areas of cut appears to expose materials of a blocky character consistent with clays as described above. Figure 5 and Figure 6 show typical cuts observed. Span logs consistently define sand or clay conditions and the video logs confirm the installed anchors have penetrated the ground (only a few select anchor locations show exposed top flights). The nominal penetration to cover all three 3 flights, as set out in the anchor design references included in this report is about 2 m.



Figure 5 - Looking Southwest at the north end of Span W58A. Note previous cut. Taken from 2014 ROV Project video.

Bedrock in the area is noted to include green and red shale with intercalated thin beds of dolomite and irregular masses and beds of gypsum (Pointe aux Chenes Formation - Salina Group), and Dolomite, intercalated with thin beds of bluish to greenish-gray shale (St. Ignace Formation – Bass Islands Group) exist below the surficial materials. Bedrock geology interpretation was supported by the findings of the Mackinac Bridge foundations investigations report and various geological reports defining the rock conditions throughout the area.

[15] Bechtel Corporation, Job 2000, Lakehead Extension Final Report, 1 Feb 1954 (p. 19) http://www.michigan.gov/documents/ag/A1b2_Final_Report_1954_Pages16-31_523792_7.pdf

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Figure 6 - Pipeline visible through area of previous excavations as seen by presumably the clamshell bucket marks in clay materials

5.2 PROJECT SPECIFIC GEOHAZARDS LIST

Geohazards encompass a broad category of natural hazard processes. To evaluate the potential for a geohazard to exist, a systematic evaluation of whether a hazard is credible is first carried out against a known list of all potential geohazards. The comparative list is derived from Rizkalla et al. (2008). This reference presents 10 general geohazard categories, and within each category subdivisions of phenomenon, potential effects and loading direction that can be possible. This defines up to 40 individual geohazards and forms the basis for a primary geohazard screening. Table 1 presents a summary of these categories and where relevant, subdivisons in each category for individual geohazards. Note that for the purposes of this report potential categories and subdivisions are not presented where they are deemed not relevant (examples include: alpine terrain, deserts) to the project area or conditions.

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Table 1 - General Geohazard Categories and Subdivisions (from Rizkalla et al, 2008)

Category[9]	Geohazard	Summary Description of Hazard[1]	Promote to Project Specific Geohazards List
Landslides / Mass Movement[2]	Deep Seated Landslide	Deep rotational or complex slope failure.	Yes
	Slope Creep	Gradual downslope movement of slopes under constant stress	Yes
	Rockfall or Rock Avalanche	Downslope movement of individual blocks or disaggregated rock mass.	Yes
	Debris Flow	Downslope movement of water-saturated debris	Yes
Tectonic / Seismicity	Fault Displacement	Movement along existing faults	Yes
	Liquefaction/Lateral Spread	Sudden loss of strength and/or movement of soil	Yes
	Dynamic Ground Motion	Ground shaking	Yes
Hydrotechnics	Vertical scour	Vertical hydraulic erosion of material over/under pipeline	Yes
	Channel Migration	Migration of a channel (lateral scour) in flood plain	Yes
	Buoyancy (pipe uplift)	Low soil mass with high groundwater failure or failure of mechanical buoyancy control	No[3]
	Rapid Lake Drainage	Breach causing rapid drainage and erosion	No[4]
	Coastal Inundation and Flooding	Change in lake level that can influence buoyancy and erosion	No[5]
Erosion	Various	Geohazards related to surface and subsurface overland water flow and wind erosion	No[6]
Geochemical	Acid Rock Drainage	Oxidation of sulphide minerals exposed in rock cuts	No[7]
	Karst Collapse	Ground subsidence due to sinkhole development below pipe	Yes
	Saline soil/bedrock	Saline groundwater reactions	No[8]
Unique Soil Structure	Boulder/Cobble/Rock indentation	Interaction with shallow rock and the pipe	Yes
	Static Liquefaction	Collapse of a unique (flocculated) soil structure	Yes
	Sensitive and Residual Soil	Rapid strength loss due to disturbance of sensitive or residual soils	Yes

Note:
1. Reader is referred to p237 to 242 of reference for detailed descriptions
2. Permafrost and snow avalanche related slope movement phenomenon omitted
3. Pipeline steel design controls buoyancy without the need of soil cover or tie-downs
4. Great Lakes not assumed to be subject to potential sudden and rapid drainage event consistent with effects
5. Pipeline designed for buoyancy control in the area of interest. Erosion included above lake only.
6. All erosion related geohazards, as defined for sub-aerial environment not possible in the submarine study area
7. Submarine environment assumed for purposes of this study to be below oxidizing zone
8. Bulk freshwater environment of Great Lakes to result in dilution and thus no saline concentrations in water or groundwater.
9. "Freezing of unfrozen ground", Thawing of Permafrost", "Desert and Sand Sea Geotechnics", and "Volcanic Activity" categories are not included since the environment does not support these types.

The results of Table 1 identify 13 project specific geohazards to be considered for the geohazard assessment. Notes included in the table describe why preliminary screening has discounted further consideration of the geohazard types or categories.

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6.0 THREAT IDENTIFICATION

The following sections present a discussion related to threat identification (where deemed applicable as noted in the table) for each project specific geohazard defined in the list in Table 1.

6.1 LANDSLIDES / MASS MOVEMENT GEOHAZARDS

The landslides and mass movement geohazards included in the project specific geohazards list include:

1. Deep-seated Landslides,
2. Slope Creep,
3. Rockfall or Rock Avalanche, and
4. Debris Flow

From a purely theoretical perspective these geohazards are considered beyond the primary screening level since the environment includes both soil and rock, and the terrain includes gentle slopes (up to a max of about 15%) where potential could exist for downslope gravity-driven movement. With the exception of soil creep that may occur and continue under a constant stress condition, the other three mechanisms (deep seated landslide, rockfall or rock avalanche, and debris flow) require a trigger to initiate failure. The approach to threat identification for the latter three geohazards was reviewed from the perspective of whether these hazards could be triggered (i.e. a review of the occurrence term from Equation 1). For the purposes of soil creep the determination focused on establishing whether there is a credible potential for a rupture incident given that the existing inspection program frequency represents a minimum for the future.

Landslide terrain characteristics were not visible in the KGL review of the detailed MBES data, nor were they present in the ROV video perspective available. KGL did not receive any specific reports or information from the Project team relevant to any past landslide incident within or adjacent to the pipeline right-of-way.

Wieczorek (1996) describes landslide triggering mechanisms[16] as being complex and often associated with several causes, but generally understood to include triggers from intense rainfall, rapid snowmelt, water level change, volcanic eruption, or earthquake shaking. Many of these triggers do not act in the submarine environment, with the exception of water level change and earthquake shaking. Water level changes are generally slow acting, allowing time for pore pressure equilibration in slopes, and earthquake shaking has a very low potential for occurrence in this region (see tectonics discussion below). Additional triggers could also include stress change due to excavations or material removal, although these must occur on a significant scale and be anthropogenic. Given the presence of the existing pipelines, powerlines and bridge infrastructure in the area it is not probable that large scale excavations or construction could be carried

[16] Wieczorek, G. F. 1996. Landslide Triggering Mechanisms. Ch 4 In Landslides Investigation and Mitigation, Special Report 247, Transportation Research Board, National Research Council. National Academy Press, Washington, DC.

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out or permitted without the knowledge of the pipeline operator to conduct specific studies related to the potential for mass movement associated with any project works in the area.

For the purposes of determining susceptibility to soil creep, constant stress drivers for this phenomenon result in very slow movement. Creep may be indicated in geomorphological characteristics of the terrain. However, visual observation alone is typically insufficient to define areas of creep. Creep is best defined using comparative surveys of pipeline position by modern ILI tool runs. Due to the very slow acting nature of creep, this geohazard is often (and in this case) neglected as a potential cause of rupture given existing ILI tool run frequencies and modern positional assessment methods that can define problematic areas and allow time for interventions well ahead of critical bending or rupture.

ILI data covering the period of 2005 to 2013 discussed previously in this report did not indicate any movement over that time period.

Given the discussion presented above, the project specific geohazards threats associated with landslides and mass movement are defined as follows:

- Theoretical only for Alternatives 4a and 5. No evidence of significant coherent soil mass movement was identified in the available information.
- Not credible Option 4b is not subject to mass movement. Rock falls and other potential soil and rock movement within the tunnel construction envelope are not considered geohazards owing to the plan to backfill the tunnel upon completion of pipe installation.

6.2 TECTONIC / SEISMICITY GEOHAZARDS

Damage to pipelines by seismic or tectonic activity is typically reported as a result of permanent ground movements associated with seismic shaking that triggers a landslide, surface fault rupture or liquefaction lateral spread. One method of screening for tectonic hazards is to assess the intensity of shaking that may be possible in the area, examine the potential for active faults, and assess liquefaction potential where ground shaking may be significant. Earthquake ground accelerations, expressed as a fraction of gravity, can be predicted in many ways and are provided as seismic hazard maps by the U.S. Geological Survey. For the purposes of threat identification, the potential for seismic activity anywhere on earth is non-zero and thus these hazards must be evaluated beyond primary screening.

Threats to infrastructure associated with this group of hazards requires first that shaking occurs, and second that shaking occurs to a magnitude and period sufficient to trigger specific geohazards. For the purposes of engineering assessment, a general method for evaluating the performance of structures as a result of shaking is to examine shaking that is quantified as Peak Ground Acceleration (PGA). PGA expresses site specific ground shaking as a percentage of the relative acceleration due to gravity and accounts for distance from source and geological conditions. PGA is used in engineering assessment in contrast to the more generalized and published total earthquake magnitude measurements such as Moment Magnitude (or previously Richter Scale) that express a single quantitative measure of the total energy released during an earthquake. There is no general correlation between earthquake magnitude and PGA as the latter is also affected by distance and depth to the seismic source, ground conditions, and other factors. The presence of an active seismic fault is required for the fault displacement condition, and

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the occurrence of liquefaction requires shaking in combination with the presence loosely deposited, saturated, fine-grained granular materials such as silt and sand.

The project is in an area of low seismic activity as shown on Figure 7, taken from United States national seismic hazard map by Petersen et al (2014)[17]. Figure 7 provides overview hazard mapping for the 1 in 2475 year exceedance case assuming very dense soil and soft rock in the upper 30 m from ground surface. The project area lies predominantly within a zone with predicted Peak Ground Accelerations of between 0.02 and 0.04 g. The assumption of dense soil and soft rock in the upper 30 m is generally consistent for outwash sands, bedrock, and glacial till, although it is not strictly applicable for lacustrine soils. These levels of potential firm ground shaking are extremely low and thus the occurrence factor for the purposes of susceptibility is a very small value. KGL found no documented evidence in the information reviewed for active faults in the region.

From an overview perspective, seismic geohazards are theoretically possible at the project site but are not considered to represent credible geohazard threats to the existing or potential alternative pipelines. For the case of Option 4b, the lack of active faulting indicates that the proposed tunnel envelope would not be considered susceptible to large strains associated with faulting.

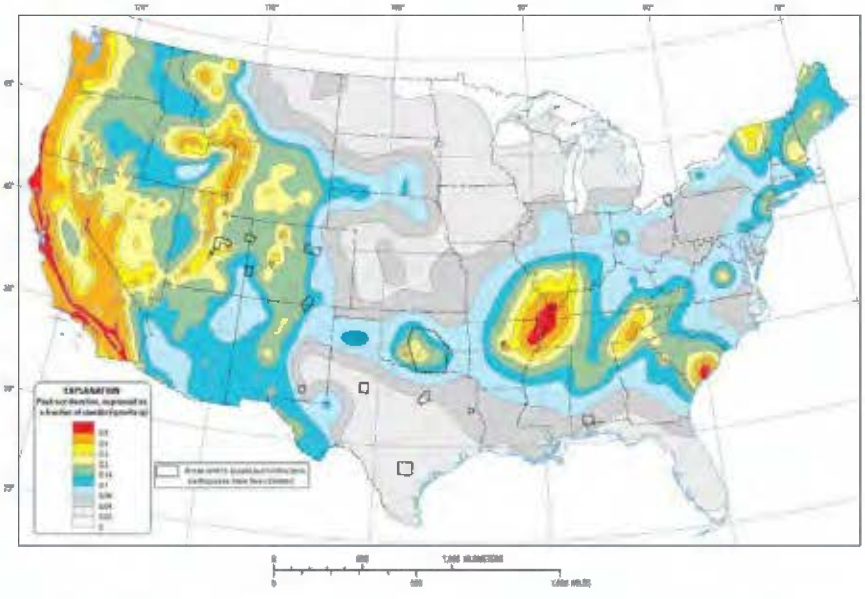


Figure 7 - Seismic hazard map taken from Peterson et al (2014)

[17] Petersen, MD, Moschetti, MP, Powers, PM, Mueller, CS, Haller, KM, Frankel, AD, Zeng, Yuehua, Rezaeian, Sanaz, Harmsen, SC, Boyd, OS, Field, Ned, Chen, Rui, Rukstales, KS, Luco, Nico, Wheeler, RL, Williams, RA, and Olsen, AH. 2014. Documentation for the 2014 update of the United States national seismic hazard maps: US Geological Survey Open-File Report 2014-1091, 243 p.

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6.3 HYDROTECHNICS GEOHAZARDS

For the purposes of the project specific geohazard susceptibility calculations for the hydrotechnical hazards category the following are included from the primary screening:

1. Vertical Scour (vertical material loss as a result of water flow), and
2. Channel Migration (lateral migration of channel)

For the submarine environment, these hydrotechnical geohazards are considered as a single "spanning" category. The spanning hydrotechnical geohazard is intended to encompass the potential for material loss below the pipeline (vertical component), and the potential that spanning will continue to occur and/or will occur in areas previously unaffected.

The project background data and reports include reference to frequent unsupported pipe segments that "span" between natural or artificial supports, survey and ROV video data showing unsupported segments of pipeline, and the identified presence of 260 individually defined spans. This evidence clearly establishes this geohazard is present and active.

Spanning is not a geohazard considered in Option 4b.

6.3.1 SPANNING GEOHAZARD BACKGROUND

Spanning in the geohazard context is described as the loss of support below the pipeline through removal of the materials by natural or "external" hydrotechnical processes. The hydrotechnical process driving the removal of soils from around and under the pipelines is driven by currents through the Straits. A review of the driving currents was undertaken to support the assessment of the spanning hazard.

In reference documents, the currents at Mackinac Straits are often described as "exceptionally strong and complex[18]". Researchers and modelling in the area notes that the currents are driven by wind driven water level differences, individual seiches in Lake Michigan and Lake Huron that drive water level differences in the Straits, and thermal stratification leading to density stratified flow[19]. While there is general agreement that the currents are driven by complex mechanisms, the results of recent modelling seems to be consistent with the original Bechtel project design current velocity assumption of a maximum around 1 m/s. For the purposes of the this report, DHI, subcontractor to Dynamic Risk for the Project, provided KGL with the results of the modelled bottom current data extracted at about 200 m intervals along the length of the existing submarine pipeline segments (Option 5) and along a profile parallel to Alternative 4a. A summary of these results is shown in Table 2. Note that the table shows that about 50% of the time in the Straits the bottom currents are low (below 0.1 m/s) and that bottom currents above 0.5

[18] Michigan Department of Attorney General, Michigan Department of Environmental Quality. July 2015. Michigan Petroleum Pipeline Task Force Report. P.43.
[19] Galagan, C., and McStay, L. 2013. Results from Oil Spill Model Simulations in Lake Michigan. Technical Report to Enbridge Pipelines by RPS ASA.

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m/s are rare, occurring annually for about 0.3 to 0.8% (up to about 3 days) in the period modelled (1 July 2015 to 1 July 2016).

Figure 8 is annual data from a single node with the highest recorded velocity, located about 3.21 km south of the north shore on the existing east line. The figure shows a 1 year period of bottom current velocities, consistent with the results shown in Table 2. Note that the peak currents, above about 0.5 m/s are relatively infrequent, and consistent with the general findings presented in Table 2.

Table 2 - Current Velocity Model Data along Alternative 5 Submarine Pipelines

Current Velocity Data Summary from Bottom Layer of DHI Model Along Each Pipeline						
Current and Current Direction Data	EAST LINE		WEST LINE		Alternative 4a	
	Records	Equivalent Cumulative time (days)	Records	Equivalent Cumulative time (days)	Records	Equivalent Cumulative time (days)
Total No. of records in 365 day model (30 min increments)	508,080		508,080		543,120	
Current <.1 m/s	47.19%	172.2	50.08%	182.8	57.64%	210.4
Current >=1 and <.3 m/s	46.62%	170.2	44.84%	163.7	38.40%	140.1
Current >=.3 and <.5 m/s	5.36%	19.6	4.54%	16.6	3.68%	13.4
Current >=.5 and <.7 m/s	0.78%	2.9	0.52%	1.9	0.29%	1.0
Current >=.7 and <1.0 m/s	0.05%	0.2	0.03%	0.1	0.00%	0.0
Current >1.0 m/s	0.00%	0.0	0.00%	0.0	0.00%	0.0
Current Direction (Northerly 315 to 045)	10.1%	36.8	7.4%	27.0	9.78%	35.7
Current Direction (Easterly 045 to 135)	42.6%	155.5	41.0%	149.8	40.14%	146.5
Current Direction (Southerly 135 to 225)	8.6%	31.6	13.9%	50.7	14.21%	51.9
Current Direction (Westerly 225 to 315)	38.7%	141.1	37.7%	137.5	35.87%	130.9

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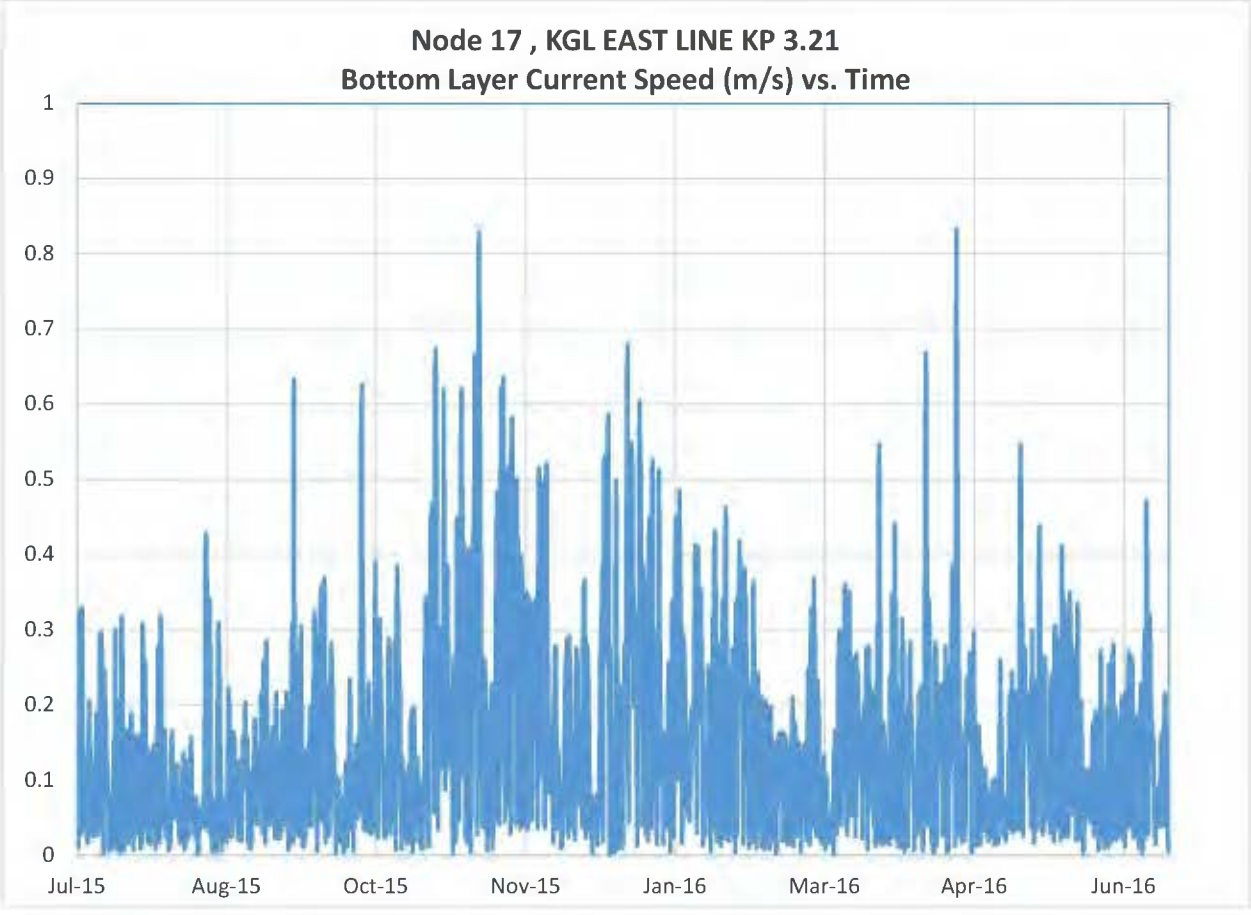


Figure 8 - Annual Current Velocity, Node 17, KP 3.21 East Line

In general the current model data is consistent with the findings of others in terms of the complexity of the annual changes in the area, and is consistent with maximum velocities previously stated where a maximum of about 1 m/s was noted. The reader is referred to the Dynamic Risk Report for a detailed discussion of the modelling assumptions, calculation methods, and correlations to local observed current data. It is worth noting that the model does not include detailed bottom bathymetry such as the pipeline location and anchors, instead it uses a lower resolution DEM grid of the wider lakebed areas throughout the region.

Following the current velocity data review, a desktop review of the underwater inspection span data was undertaken. This review looked at the behavior of spanning over time as measured by the underwater inspection teams. The data included making specific observations from the ROV videos at span locations, reviewing the original Bechtel drawing information in Figure 2, and noting the pipeline vertical profile from the drawings in Appendix A. Note that in many cases segments of the identified spans make up a single continuous span, defined as a segment of pipeline spanning and/or supported on artificial supports between natural soil contact areas. The west and east lines both have approximately 60 continuous spans. The maximum continuous span area measures between about 325 ft and 335 ft on each of the existing lines, although it is noted these include numerous artificial supports to reduce the individual span lengths.

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Summary data for individual span lengths and maximum individual span lengths are presented below in Table 3 and Table 4.

The results in Tables 3 and 4 show that there is typically only minor changes, although an outlier to this finding is the initial two periods of reporting in the modern underwater inspection reports, notably 2005 and 2006 where a considerable jump in span length is reported. The results since the 2006 surveys have been relatively consistent.

Table 3 – West Line Span Data Summary

SPAN SUMMARY	WEST LINE UNDERWATER INSPECTION DATA						
	2016	2014	2012	2010	2007	2006	2005
Total Length of Spans (ft)	5339	5269	5212	5750	5795	5823	4378
Individual Spans (#)	120	117	97	94	97	57	74
Average length of individual span (ft)	44.5	45.0	53.7	61.2	59.7	102.2	59.2
Max Individual Span Length (ft)	71	71	90	126	132	131	108
Total Span Length Change from Previous Survey	+70	+57	-538	-45	-28	+1,445	N/A

Table 4 - East Line Span Data Summary

SPAN SUMMARY	EAST LINE UNDERWATER INSPECTION DATA						
	2016	2014	2012	2010	2007	2006	2005
Total Length of Spans (ft)	5702	5730	5751	5932	6008	5721	4560
Individual Spans (#)	131	130	105	98	99	90	68
Average length of individual span (ft)	45.5	44.1	54.8	60.5	60.7	63.6	67.1
Max Individual Span Length (ft)	72	72	88	114	116	120	129
Total Span Length Change from Previous Survey	-28	-21	-181	-76	+287	+1161	N/A

A review of the fixed spans and the reported span lengths (i.e. individual spans affixed on both ends to ground anchors) showed that the measurement precision for any given point may be on the order of up to +/- 3' in the span data. This is evidenced by the differences in reported fixed span lengths of between about 1 ft and 3 ft commonly reported between successive surveys of fixed spans. Given the fixity of the anchor systems, supported by a review of the video logs, GeoPIG data and review of the MBES, it is apparent that some inaccuracy of the surveyed lengths of the spans could be expected. As an example this source of precision accounts for nearly 31' of length differences reported between the 2014 and 2016 survey of the East Line. This is well below the differences seen in the 2005 to 2006 data.

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In reviewing the video data and the high resolution 2016 MBES survey, it was noted that a portion of the spanning segments have evidence that the pipe was not originally in contact with the ground. Examples of this are shown in several photo still taken from the ROV data such as areas with clam shell dredge excavation marks present below the pipeline, or areas where the pipeline was significantly elevated through overbends or sagbends as evidenced by the position through the initially constructed clay piles. In many areas where old excavations are present spanning is quite prevalent. This is also partly evident in several areas of the original Bechtel drawing shown above where spans were noted and illustrated.

It is also apparent in some areas that the local current field is disturbed by either clay piles, anchor supports, grout bags, or other prominences in the terrain that likely give rise to changes in the current field flowing around these objects. Particular locations include exposed anchor flights from pipe supports, eroded bag supports, and areas consistent with small localized scour hole development.

The original buried cover sections near the shoreline do not appear to have reports of any significant cover loss or spanning. The underwater marine inspections do not provide any detailed coverage of these sections and thus data is limited to the limited overlapping MBES coverage.

An attempt was made to examine the landscape level 3-dimensional changes across the field of view in the MBES data by comparing the 2016 and 2014 data. The comparison was not possible due to differences in the resolution between the 2 data sets. The assessment of changing span length, as provided by the annual survey compilation was the source of data used for examining spanning rates.

Based on a review of span inspection data over the time period 2005 – 2016 inclusive, it is apparent that the lengths of individual spans are for the most part diminishing over time (in part due to remedial activity), however there are individual spans that have lengthened. The fact that span development does not appear to be progressing rapidly (generally it is near the threshold of measurement precision as shown above) is consistent with the observation of excavation marks that still remain from the time of original construction, suggesting that the lake bottom in most areas is not highly mobile. This, in turn, might be attributed to the relatively low bottom layer currents. The erosion that is occurring is attributed to natural peak currents (infrequent) and the additional current velocities generated around preturbances in the current field through the introduction of the pipeline system to the bottom as well as the presence of vertical supports and other “pier-like” objects that perturb the current field causing local accelerations above a previously quasi-stabilized natural system. Burying a pipeline along a profile that was not subject to spanning through natural irregularities or arching through overbends or sag bends that are incompatible with the ground profile would be a suitable alternative to significantly reduce the potential for spanning to occur.

New design areas could be evaluated for natural spanning occurrence using modern high resolution MBES data plotted differentially over time to examine landscape level changes to an area prior to selecting a final route.

6.3.2 SPANNING THREAT SUMMARY

For the existing Straits pipelines, which lie on top of lake bottom below a bathymetric contour of about 65’, it is apparent that while span development is not generally rapid, significant lengthening of individual spans have been noted on an isolated basis. In that respect, spanning, and the factors associated with

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span-related threat mechanisms, such as water currents and the potential for vortex-induced vibration must be considered as a credible threat mechanisms.

The existing evidence suggests that the lake bottom is not highly mobile, likely owing largely to the relatively low bottom layer currents. Therefore, for the 30" trenched installation alternative, the buried condition of the pipeline will remove the source of turbulence that would otherwise be created during periods of peak current. This will act to inhibit lake bottom mobility and span development so that what limited mobility might exist could readily be managed through regular monitoring and maintenance.

Note that these are concept level findings only based on a generalized schematic only. A full spanning assessment on a new alignment should consider the use of high resolution elevation corrected differential MBES to measure bottom changes over a period of time, drop core sediment type sampling and bottom current velocity measurements in advance of construction to further quantify the findings.

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6.4 GEOCHEMICAL GEOHAZARDS SUMMARY

Two key mechanisms are included in the geochemical geohazards summary, acid rock drainage and karst collapse. Acid rock drainage (excluding environmental effects that may result) can lead to increased rates of corrosion by lowering the contact water pH levels as acid is generated through oxidation (weathering) of sulphide bearing rocks. Given the submarine nature of the study area and lack of proposed major rock cuts, acid rock drainage was discounted at the screening stage. Karst collapse includes the potential for inducing pipeline strain as a result of settlement or spanning where loss of support occurs over a solution cavity (sinkhole). Figure 12 below shows how the identified carbonate rocks and known karst features exist around the Straits area.

For karst collapse potential, the pipeline route would have to be located above carbonate bedrock units that contain marginally-stable solution cavities. Alternatively collapse (sinkhole) development could arise as a result of the collapse of underlying mine works, tunnel excavations or other underground openings that may be present. It is important to note that this assessment only considers karst collapse sinkholes. Collapse of tunnel excavations or other third party influences are beyond the scope of this assessment.

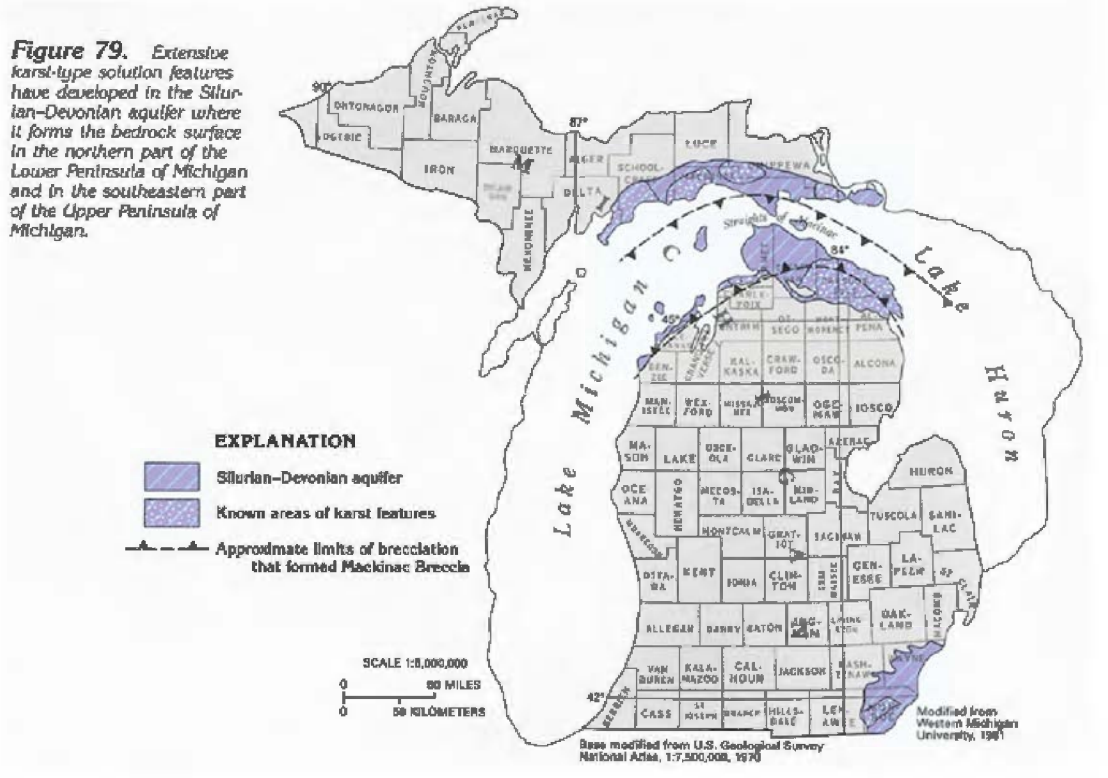


Figure 9 – Karst solution features map taken from USGS online Publications Warehouse

Figure 12 shows that the known karst areas are outside the immediate Straits of Mackinac project area. Further reducing the karst potential is the submarine nature of the project, since the development of sinkholes is related to the movement of groundwater through solution cavities. The low gradient groundwater flow created as a result of the positive influence of the relatively steady and saturated

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groundwater conditions in the sediments and bedrock below the lake level also contributes to a reduced potential for the development of sinkholes through ongoing dissolution of carbonates or anhydrites in the submarine environment.

The potential for karst collapse is present but is not considered to be a credible threat for the purposes of assessment for either Option 5, or Options 4a/4b. Note that for the purpose of tunneling feasibility, the potential for encountering a solution cavity may exist however pre-construction investigations and construction methods that incorporate pre-grouting of rock mass discontinuities can accommodate the presence of such occurrences. Backfilling of the tunnel with low-permeability materials and grouting will eliminate a hydraulic gradient towards the tunnel, therefore changes in groundwater flow, and possible ongoing dissolution of susceptible bedrock units is not considered a credible mechanism for this geohazard threat to occur.

6.5 UNIQUE SOIL STRUCTURE

Geohazards associated with the presence of unique soil conditions such as flocculated or sensitive soils are possible in the lacustrine environment, although this is typically associated with previously saline environments where they occur. It is understood that the geological descriptions from the Mackinac Bridge construction did not include reference to such soils though and with the high number of borings advanced for that project it is more likely that these soil types are not present than they are. It would require detailed geotechnical information for near surface soils to evaluate this potential geohazard, and since this does not exist it is considered beyond the scope of this report. Collapsible soil types, if present, would have likely manifested as flow slides. As noted above, landslide activity is not observed in the detailed bathymetric data or project records.

For the purposes of indentation related to difficult soils such as cobbles, boulders, or rock, it is noted that the existing pipeline system does not report any critical factors or incidents related to rocks or dents. For new pipelines, pre-construction trenching for the lake bottom pipelines should be suitable to remove critical rock outcrops that may cause pipeline ovalities, dents, or buckles that could lead to rupture. Given the ability to carefully observe construction and design activities, review QA/QC pipeline records and surveys, and to review records prior to placing a new pipeline constructed in the Straits this geohazard should not lead to a credible scenario for a loss of containment event given the regular and routine inspection processes that are currently in place and that would otherwise continue or be increased in the future. This geohazard is not present for a pipeline installed in a lined tunnel system.

7.0 CONCLUSIONS

A suite of possible geohazard mechanisms was reviewed in the context of geological and hydrological conditions in the Straits of Mackinac. Based on the foregoing, it is concluded that the only credible geohazard threat affecting the existing and future pipeline installations at the Straits of Mackinac is scour or "spanning" associated with lakebottom current erosion. From detailed review of MBES data and other information, the lakebottom current regime is affected by local perturbances associated with the existing pipelines, natural high points such as rock outcrops, and artificial mounds such as grout bags and soil piles. This in turn affects the scour potential around the pipeline. Locations where the existing pipelines are

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buried in a trench are less prone to scour development than those locations where the pipe was laid directly on the lakebottom. The following conclusions are drawn with respect to this spanning geohazard:

- Trenching and burial of a new pipeline is expected to effectively reduce or eliminate the conditions associated with spanning due to local perturbations to the current field by a bottom-laid pipeline. Maintenance of cover over a new buried pipeline would effectively eliminate spanning as a credible geohazard.
- Installation of a new pipeline in a backfilled and sealed tunnel in bedrock beneath the Straits using modern tunneling technology and including pre-construction investigation and grouting is expected to eliminate all credible geohazards.

8.0 LIMITATIONS & CLOSURE

KGL appreciates the opportunity to provide the comments and recommendations in this report to assist Dynamic Risk with a pipeline hazard assessment activities.

Please contact the undersigned if conditions change or are discovered to be otherwise different than those described herein.

Respectfully Submitted

Shane Kelly, M.Eng., P.Eng.
Senior Geotechnical Engineer

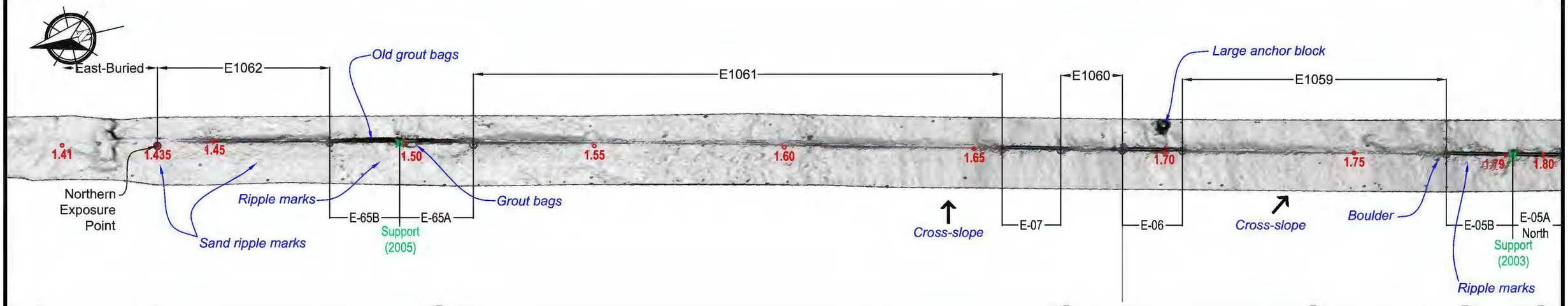
Reviewed By:

R.S. Read, M.Eng., P.Eng., P.Geo., P.Geol
Senior Geotechnical Engineer

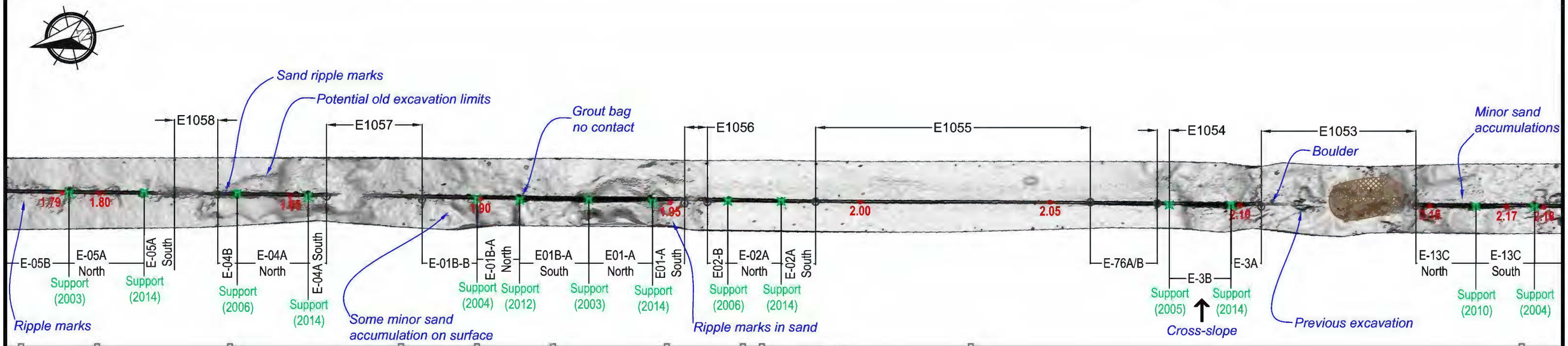
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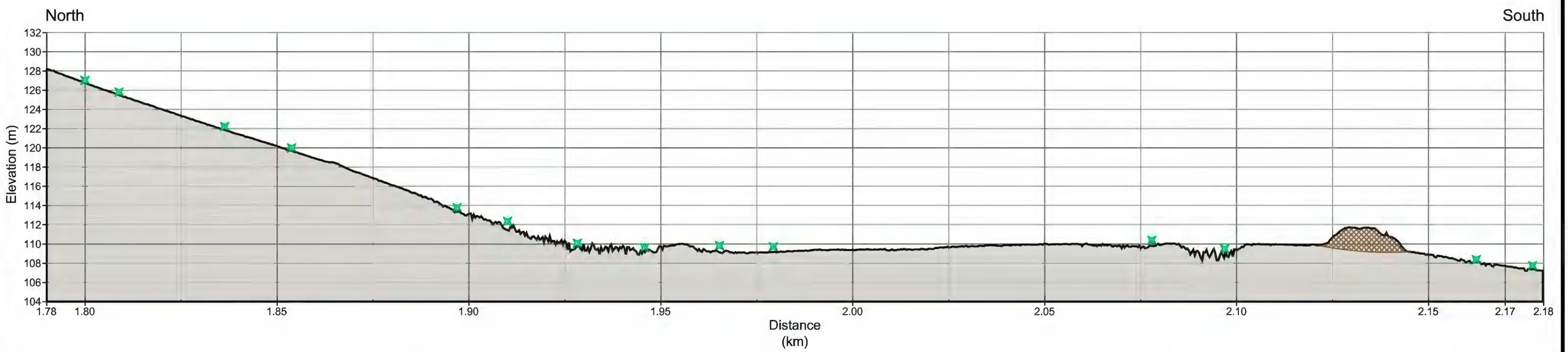
APPENDIX A

ENBDNR0002419


East-Buried
E1062
E1061
E1060
E1059
Old grout bags
Large anchor block
1.41
1.435
1.45
1.50
1.55
1.60
1.65
1.70
1.75
1.79
1.80
Northern Exposure Point
Sand ripple marks
Ripple marks
Grout bags
E-65B
E-65A
Support (2005)
Cross-slope
E-07
E-06
Cross-slope
Boulder
E-05B
E-05A North
Support (2003)
Ripple marks

| | | |





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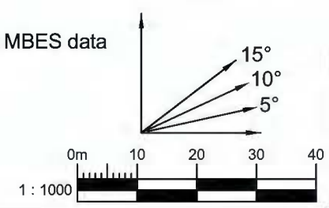
- SOIL ⊙ Soil Contact Location - 2014 Span Data
- ANCHOR Anchor Location (year built if known)
- KMo Approximate Kilometer Marker Reference Chainage
- Approximate Local Borrow Cover Soil
- *Sandy* Ground Condition Observations from
- *Boulders* Submarine Inspection Video Log Review
- E1000 Span Identifier

PROFILE:

—— 2016 Ground Surface taken from Project MBES data

NOTES:

1. Imagery from 2016 Surface, shown with slope shader ranging from 0° to 45°.
2. Segments with "1000" series identifiers contact the ground.
3. Profile vertically exaggerated by 2.5.



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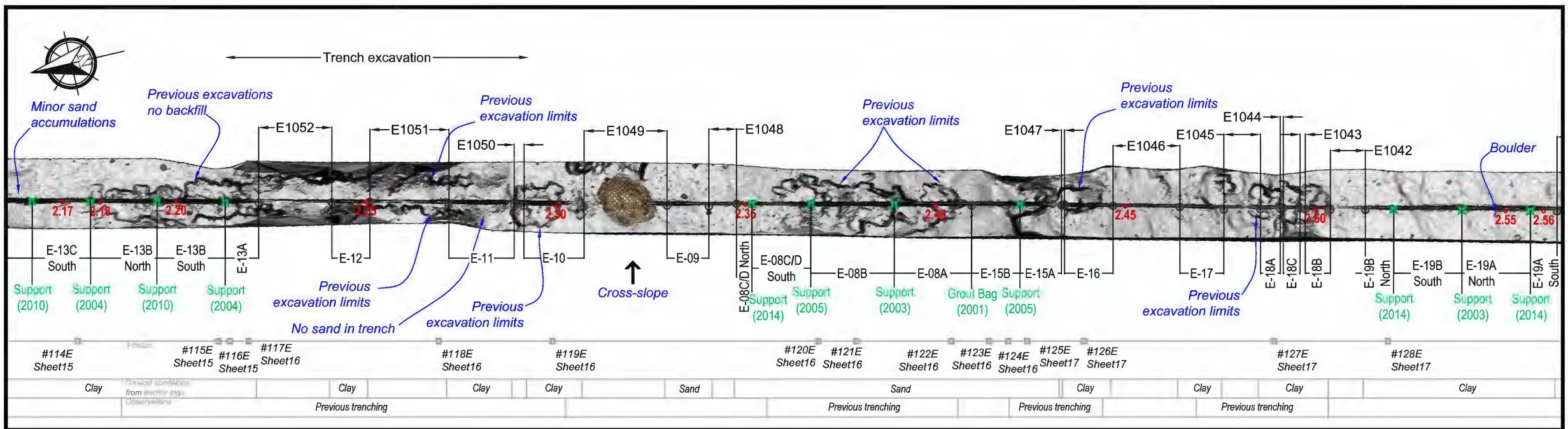
Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline

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LEGEND:

- SOIL — Soil Contact Location - 2014 Span Data
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PROFILE:

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15° 10° 5°

0m 10 20 30 40

1 : 1000

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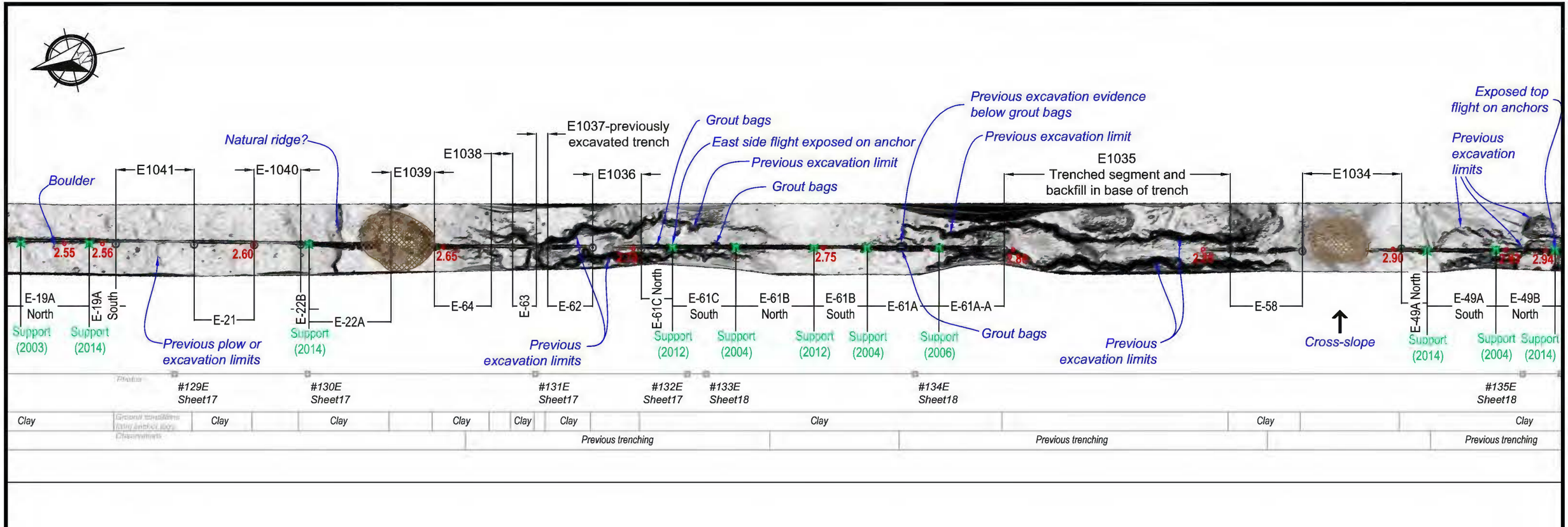
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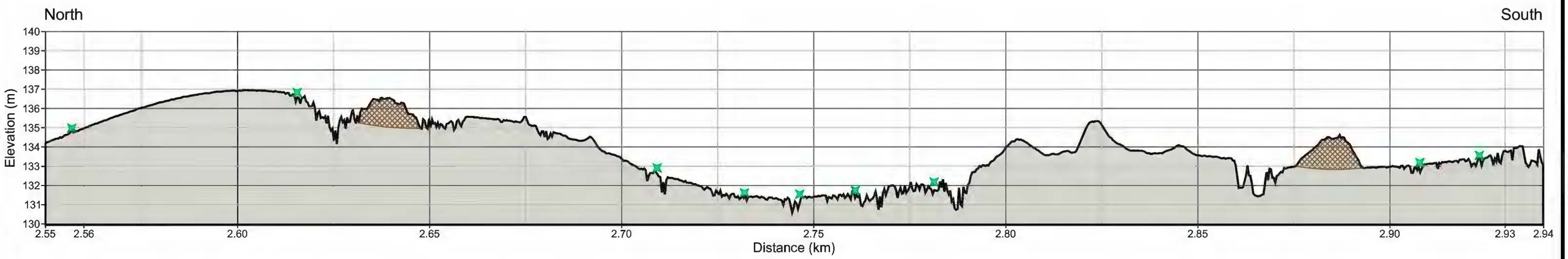
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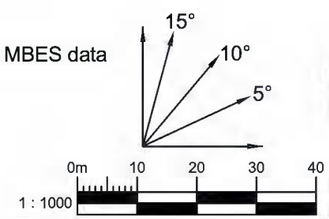
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PROFILE:

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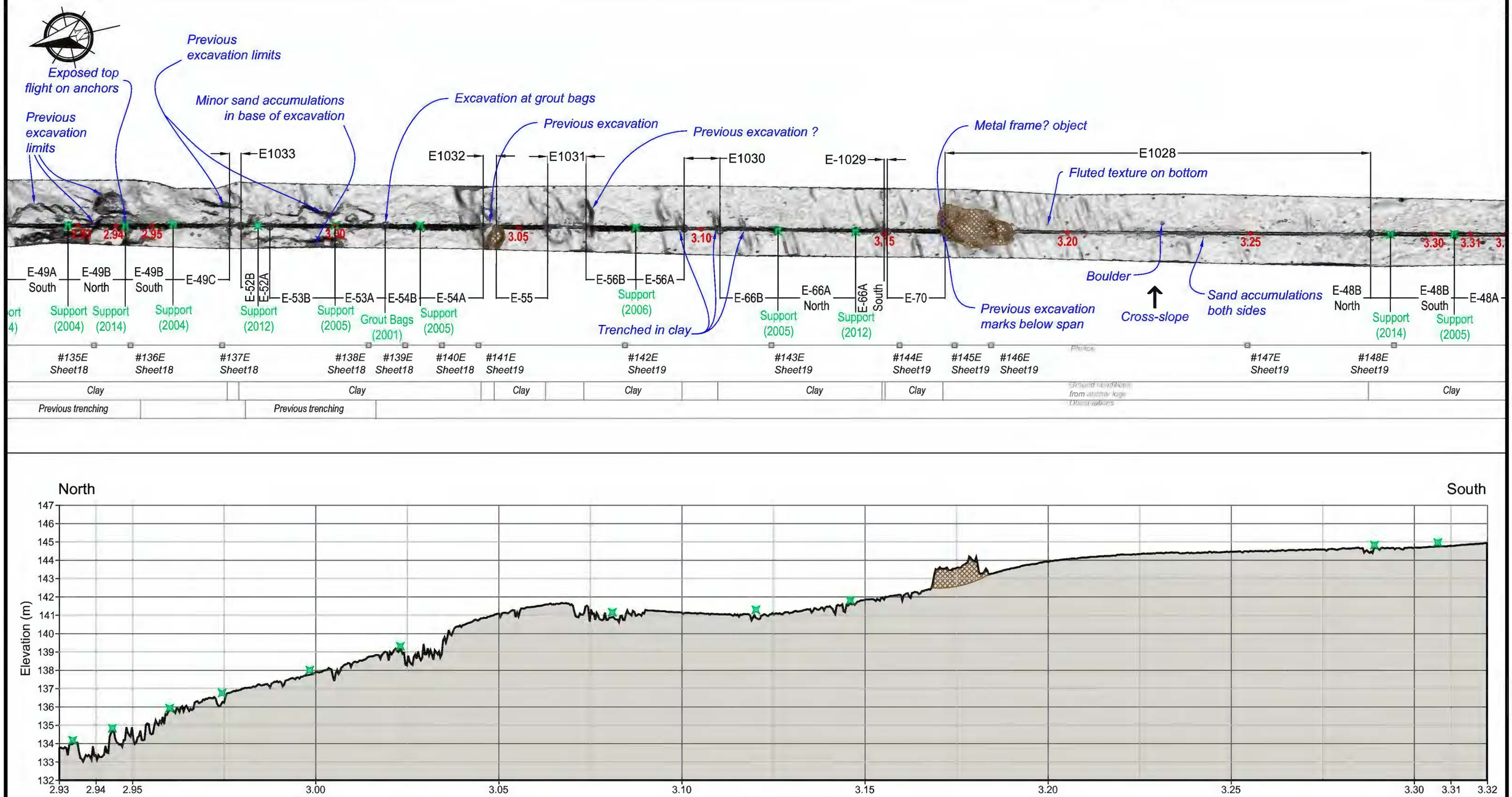
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LEGEND:

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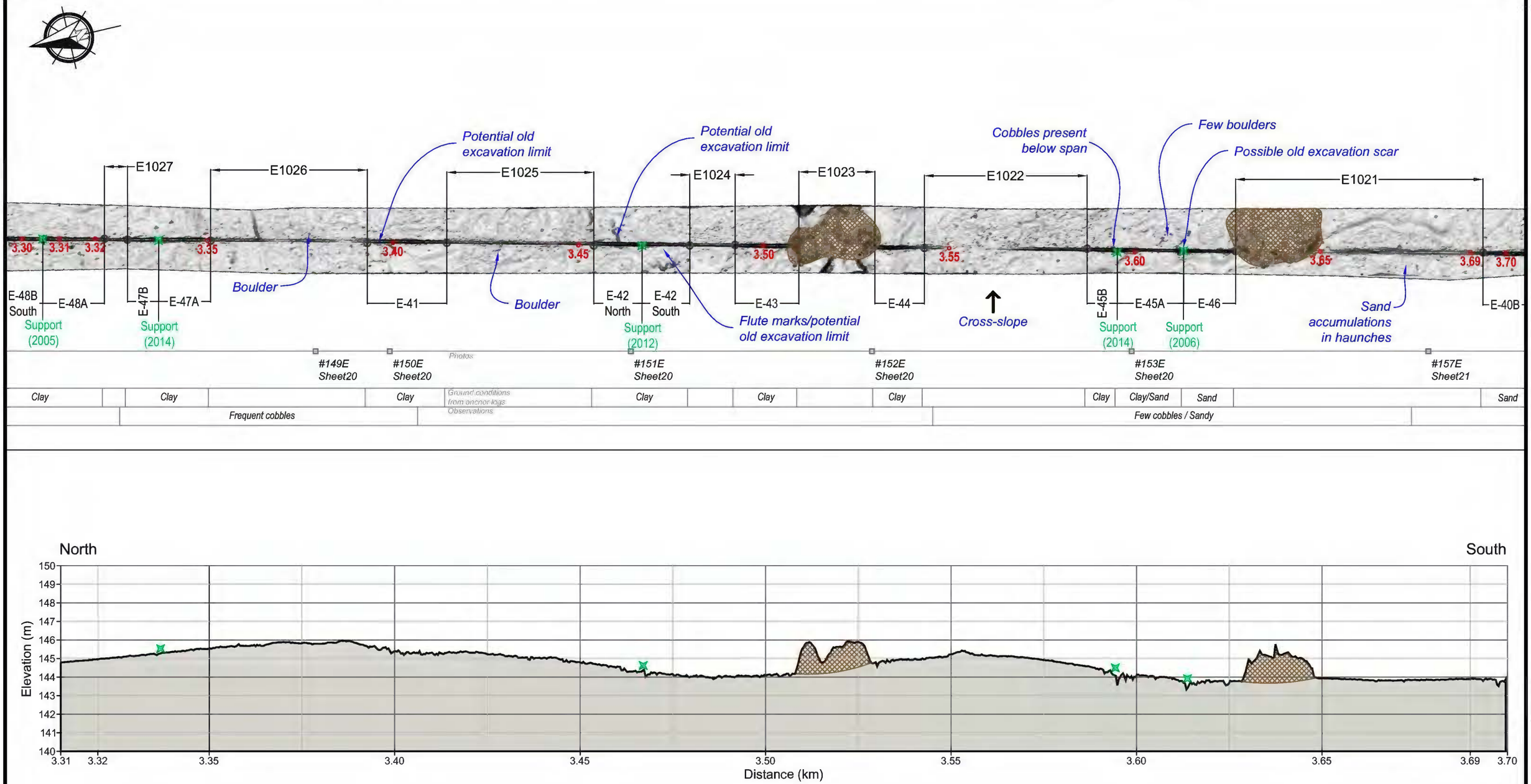
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EAST-5



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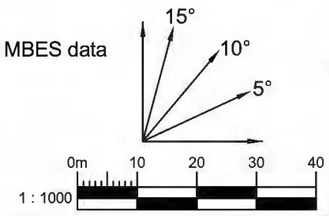
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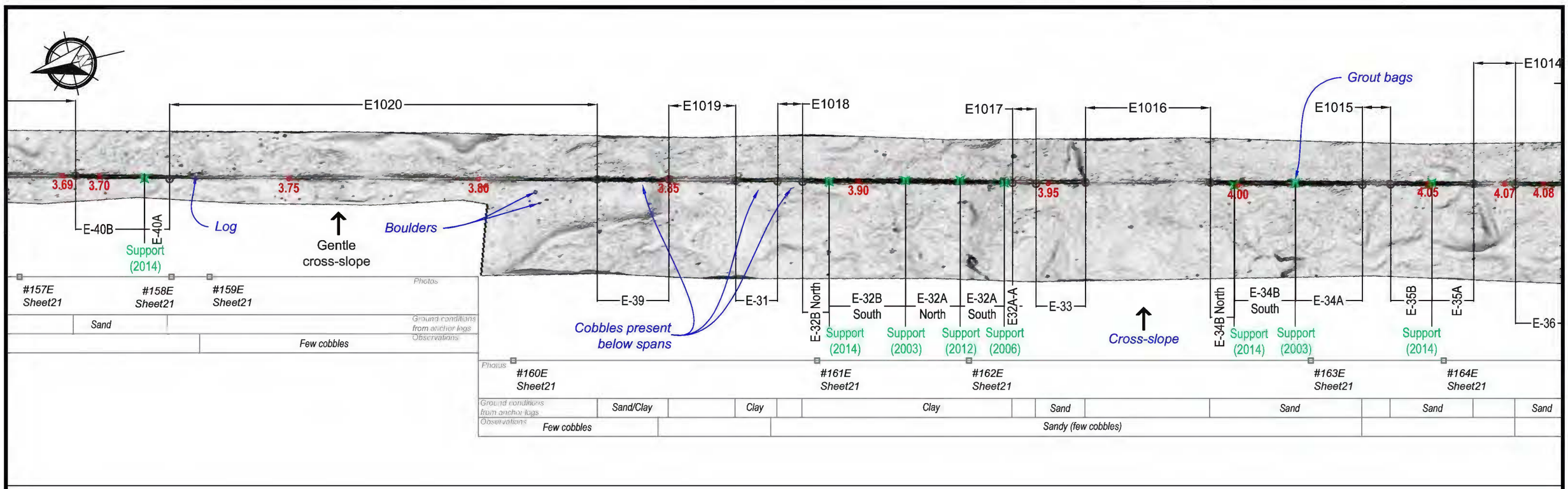
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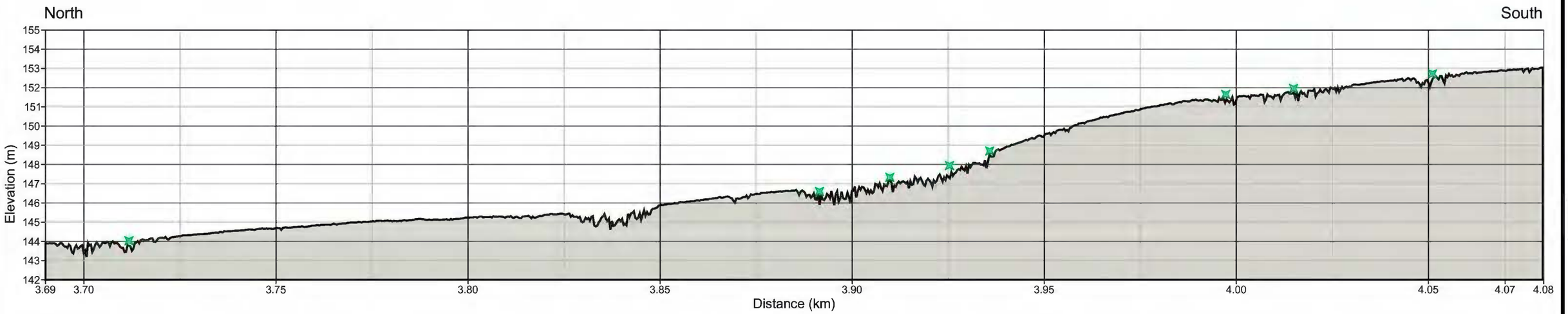
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EAST-6

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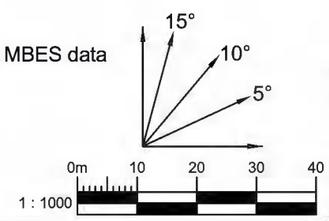
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PROFILE:

2016 Ground Surface taken from Project MBES data

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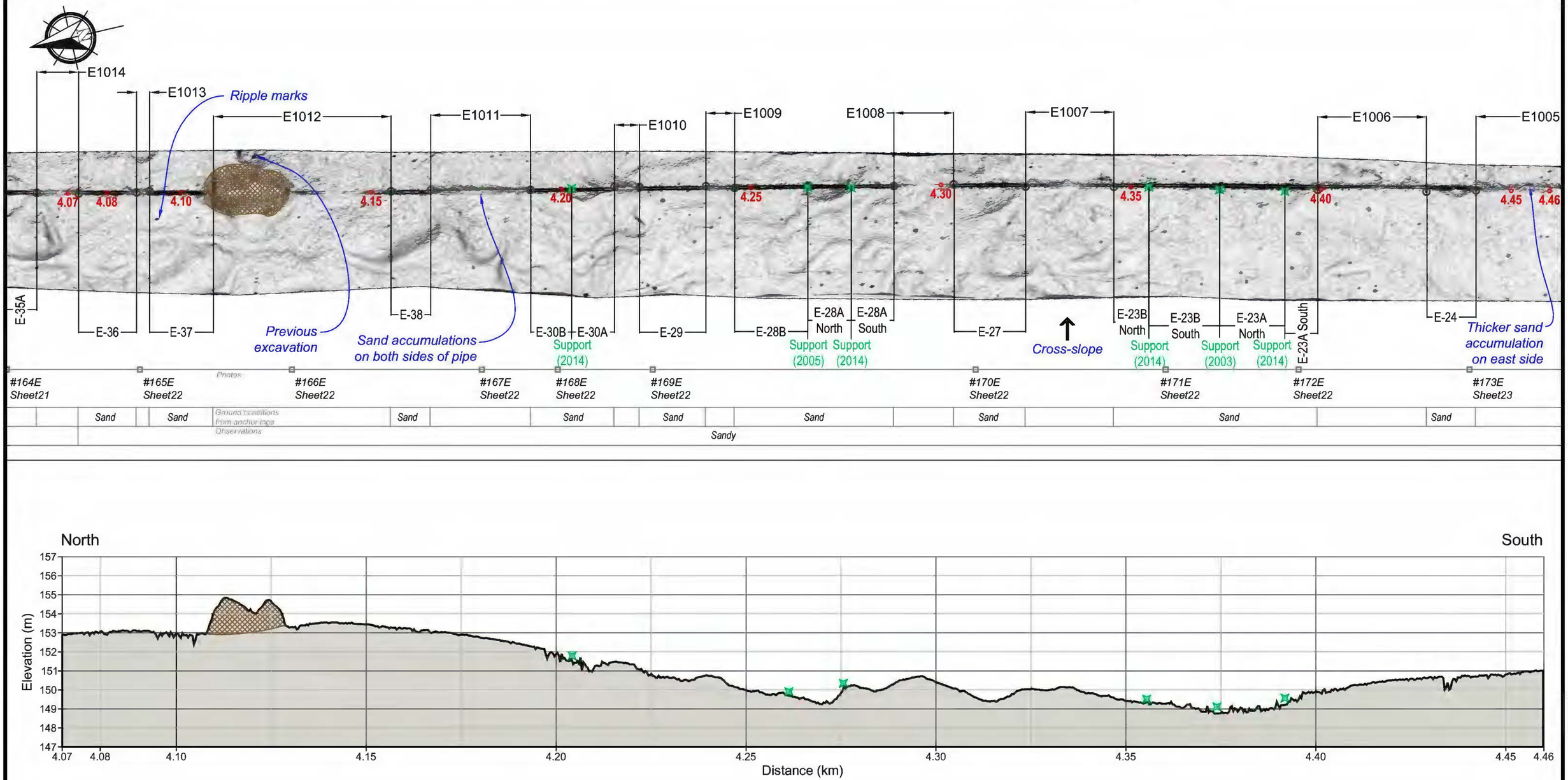
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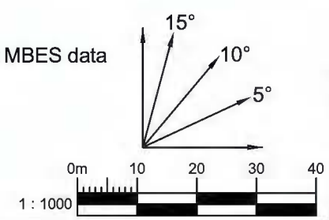
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PROFILE:

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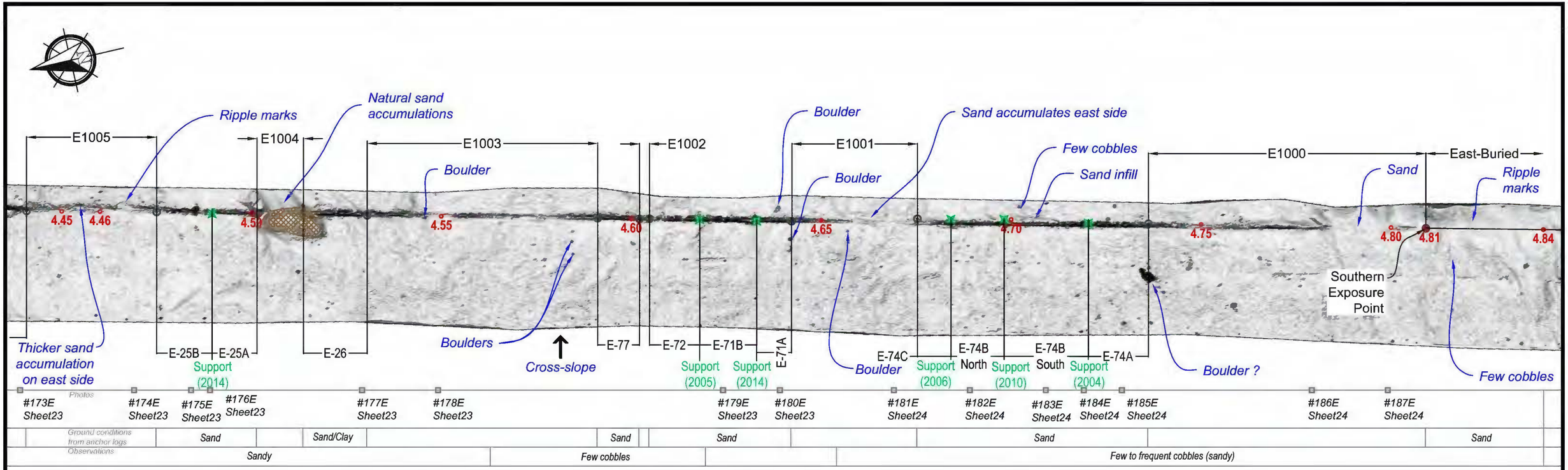
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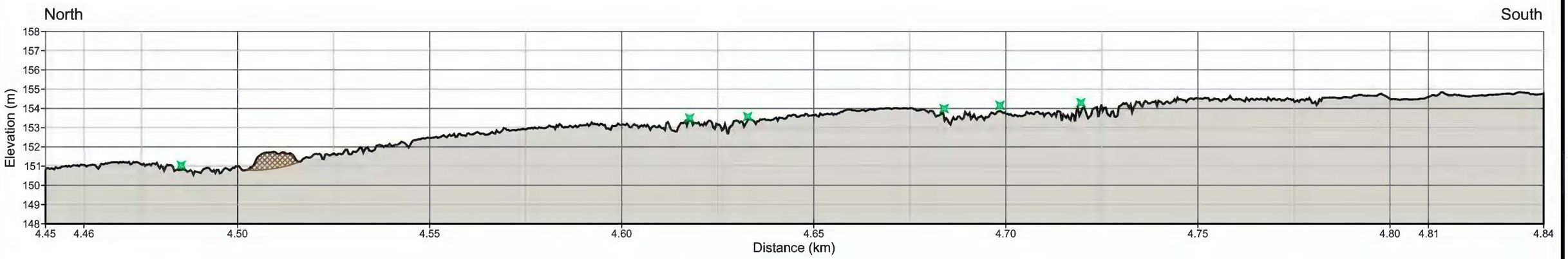
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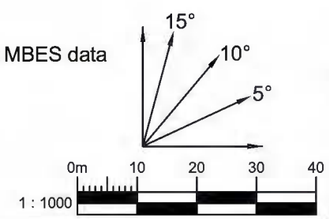
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- Approximate Local Borrow Cover Soil
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- *Boulders* — Submarine Inspection Video Log Review
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PROFILE:

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NOTES:

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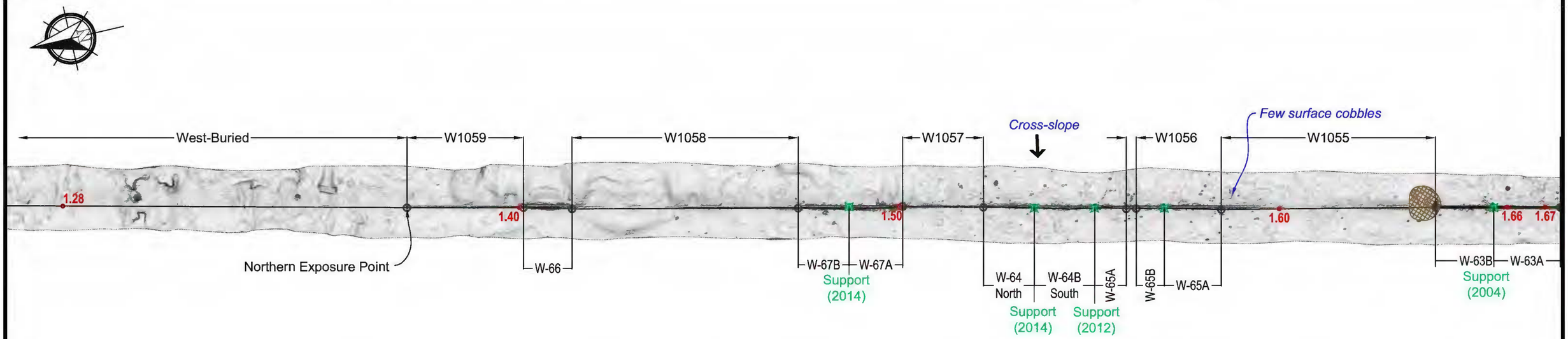
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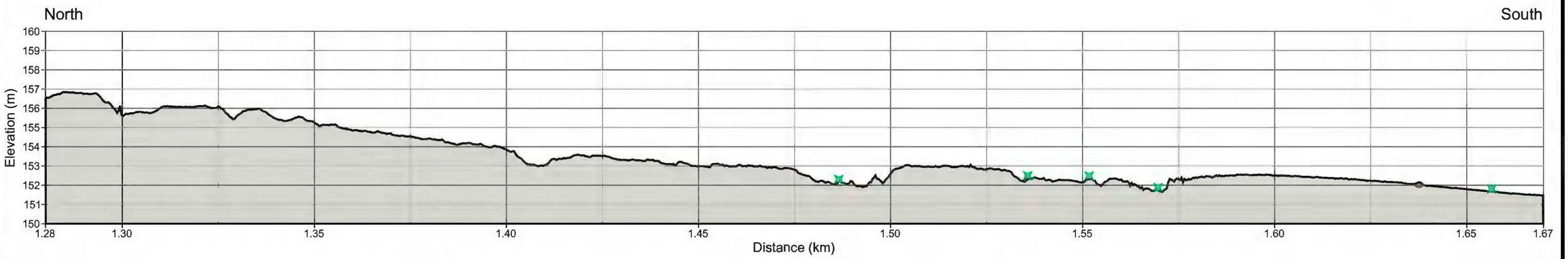
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EAST-9

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Piers	#1W Sheet1	#2W Sheet1	#3W Sheet1	#4W Sheet1	#5W Sheet1	#6W Sheet1	#7W Sheet1
Ground conditions from anchor logs		Sand	Sand		Sand	Sand	Sand
Observations	Sandy						



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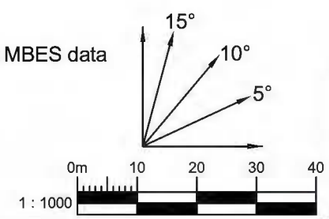
- SOIL — Soil Contact Location - 2014 Span Data
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PROFILE:

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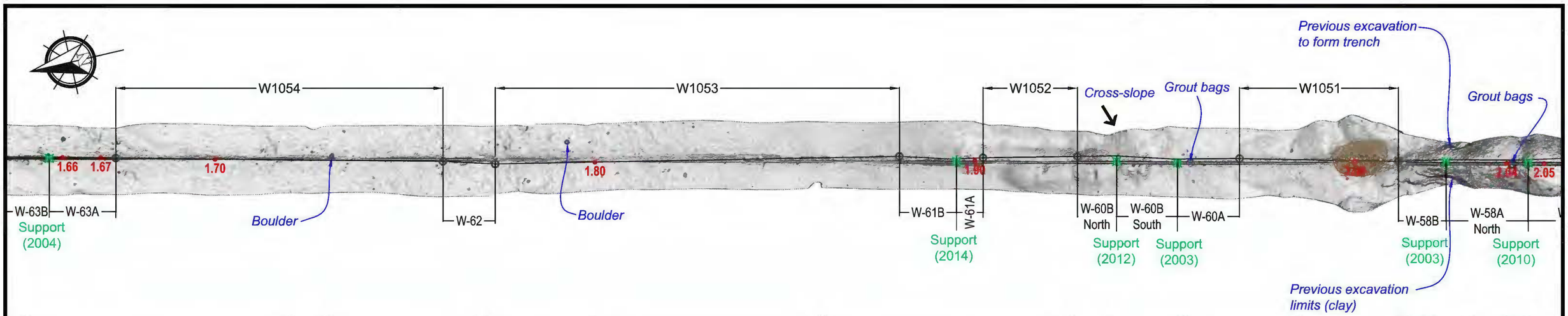
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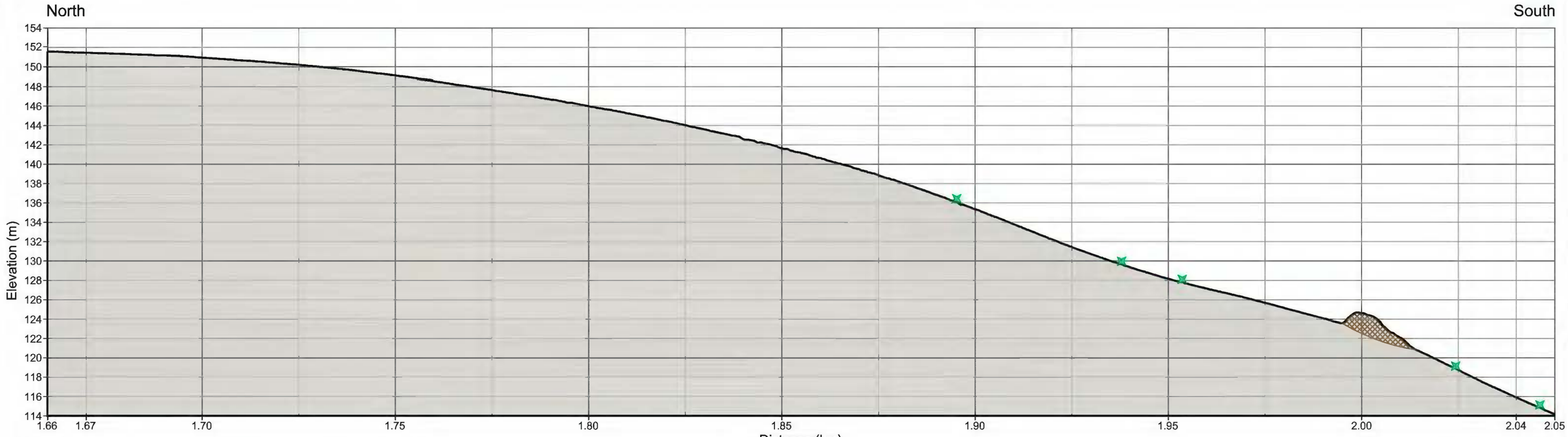
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WEST-1

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LEGEND:

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PROFILE:

2016 Ground Surface taken from Project MBES data

NOTES:

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15° 10° 5°

0m 10 20 30 40

1 : 1000

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Client: Dynamic Risk Assessment Systems Inc.

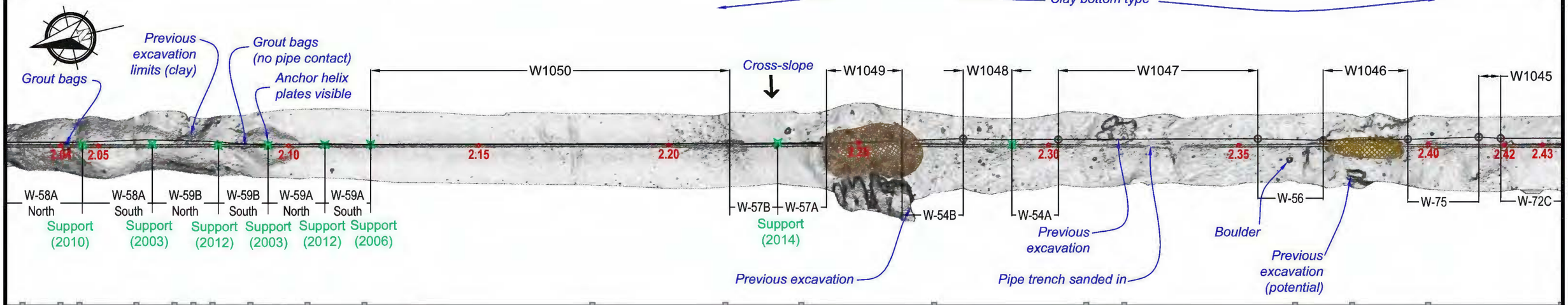
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Project #:	KGL-16-022
Drawing/Rev #:	Rev3

WEST-2

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LEGEND:

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15° 10° 5°

0m 10 20 30 40

1 : 1000

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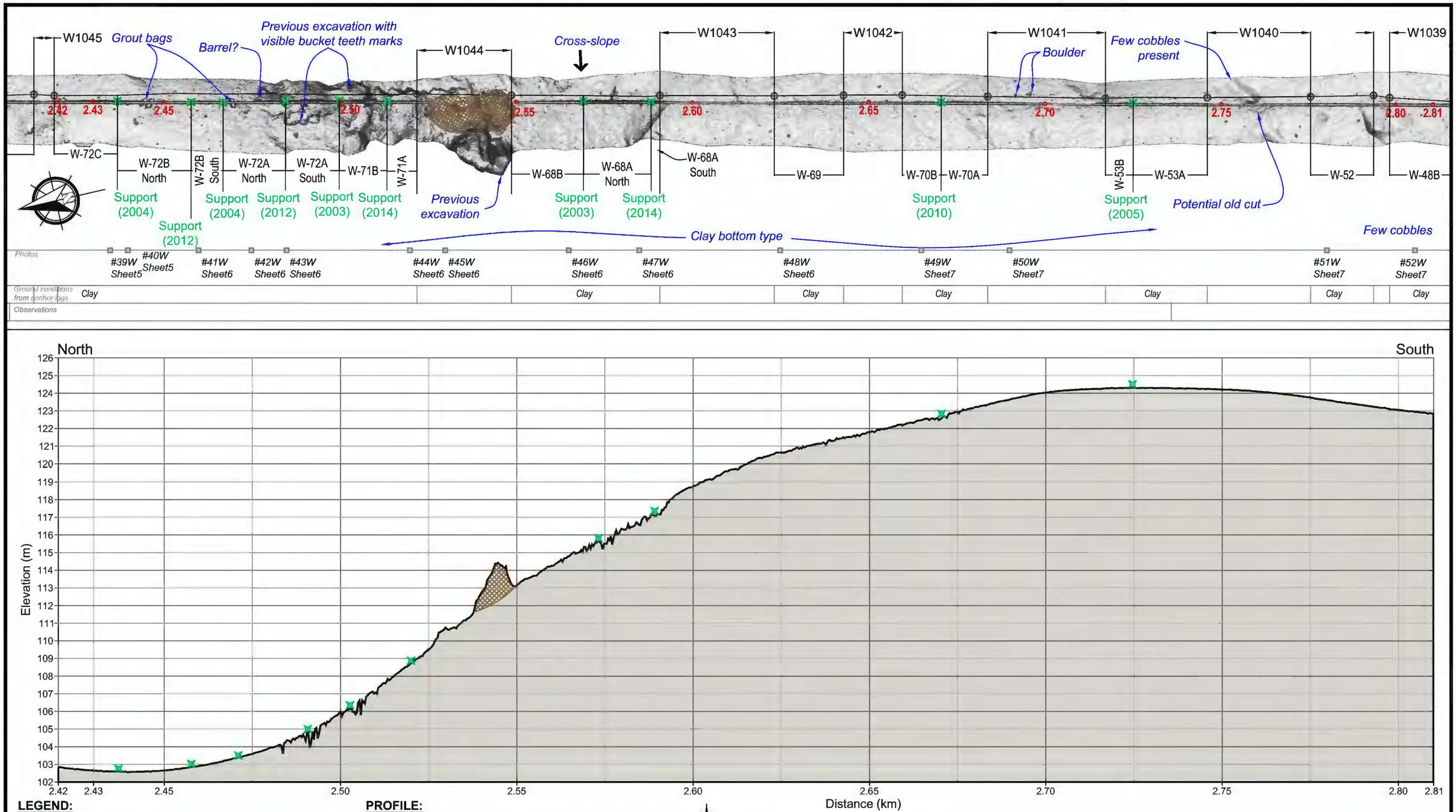
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WEST-3

ENBDNR0002431



LEGEND:

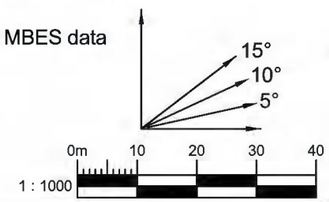
- SOIL — Soil Contact Location - 2014 Span Data
- ANCHOR — Anchor Location (year built if known)
- KMo — Approximate Kilometer Marker Reference Chainage
- Approximate Local Borrow Cover Soil
- Sandy Boulders — Ground Condition Observations from Submarine Inspection Video Log Review
- W1000 — Span Identifier

PROFILE:

2016 Ground Surface taken from Project MBES data

NOTES:

1. Imagery from 2016 Surface, shown with slope shader ranging from 0° to 45°.
2. Segments with "1000" series identifiers contact the ground.
3. Profile vertically exaggerated by 2.5.



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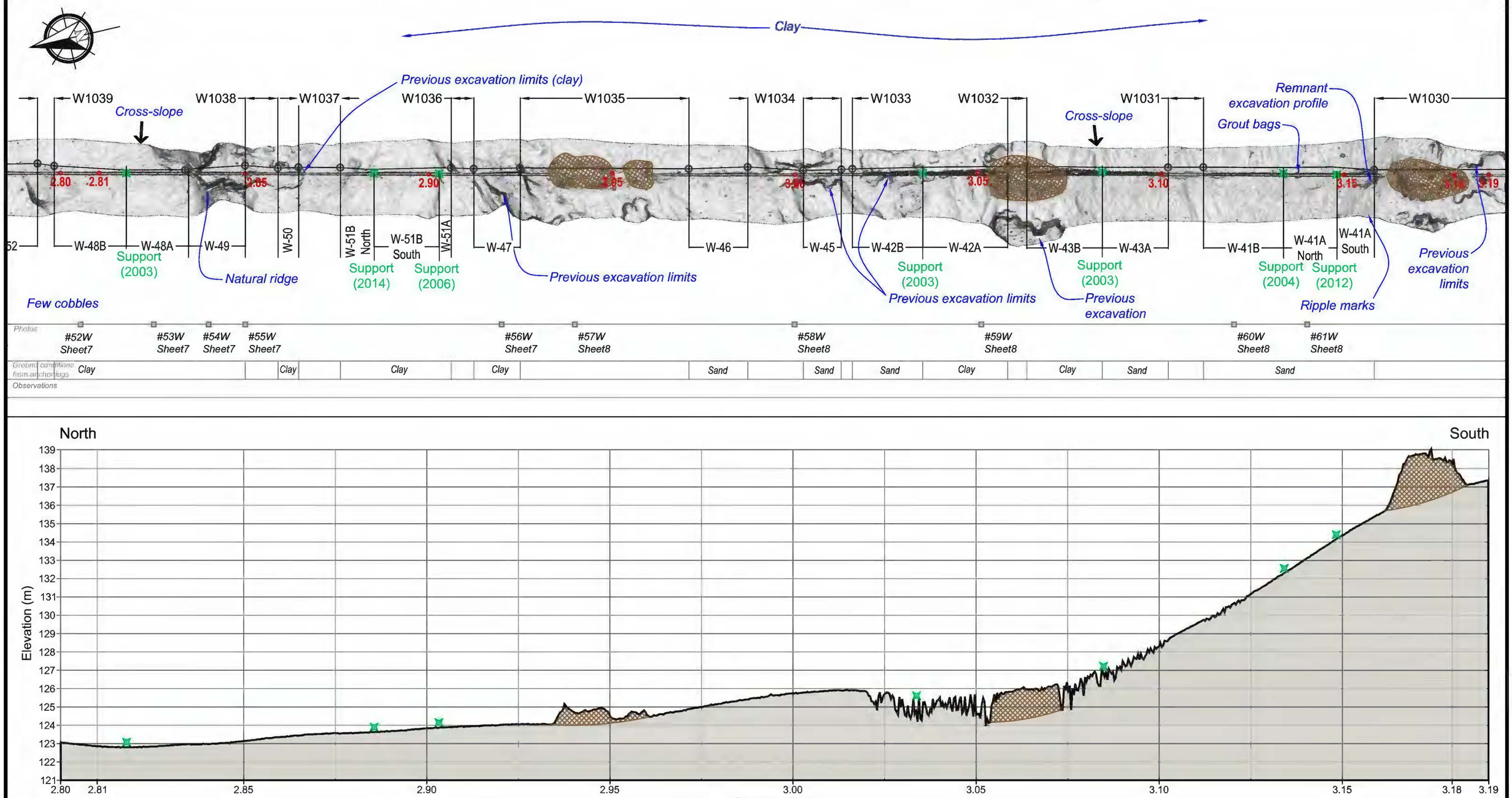
Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline

KELLY GEOTECHNICAL

Date:	2017-06-01
Drawn By:	Shelley Ruiz
Reviewed By:	Shane Kelly
Project #:	KGL-16-022
Drawing/Rev #:	Rev3

WEST-4

ENBDNR0002432



LEGEND:

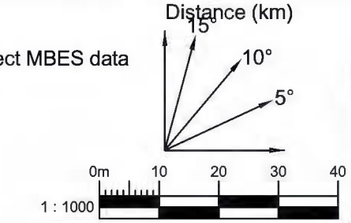
- SOIL ⊙ Soil Contact Location - 2014 Span Data
- ANCHOR Anchor Location (year built if known)
- KM₀ Approximate Kilometer Marker Reference Chainage
- Approximate Local Borrow Cover Soil
- Sandy Boulders Ground Condition Observations from Submarine Inspection Video Log Review
- ⊢W1000⊣ Span Identifier

PROFILE:

—— 2016 Ground Surface taken from Project MBES data

NOTES:

1. Imagery from 2016 Surface, shown with slope shader ranging from 0° to 45°.
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3. Profile vertically exaggerated by 5.



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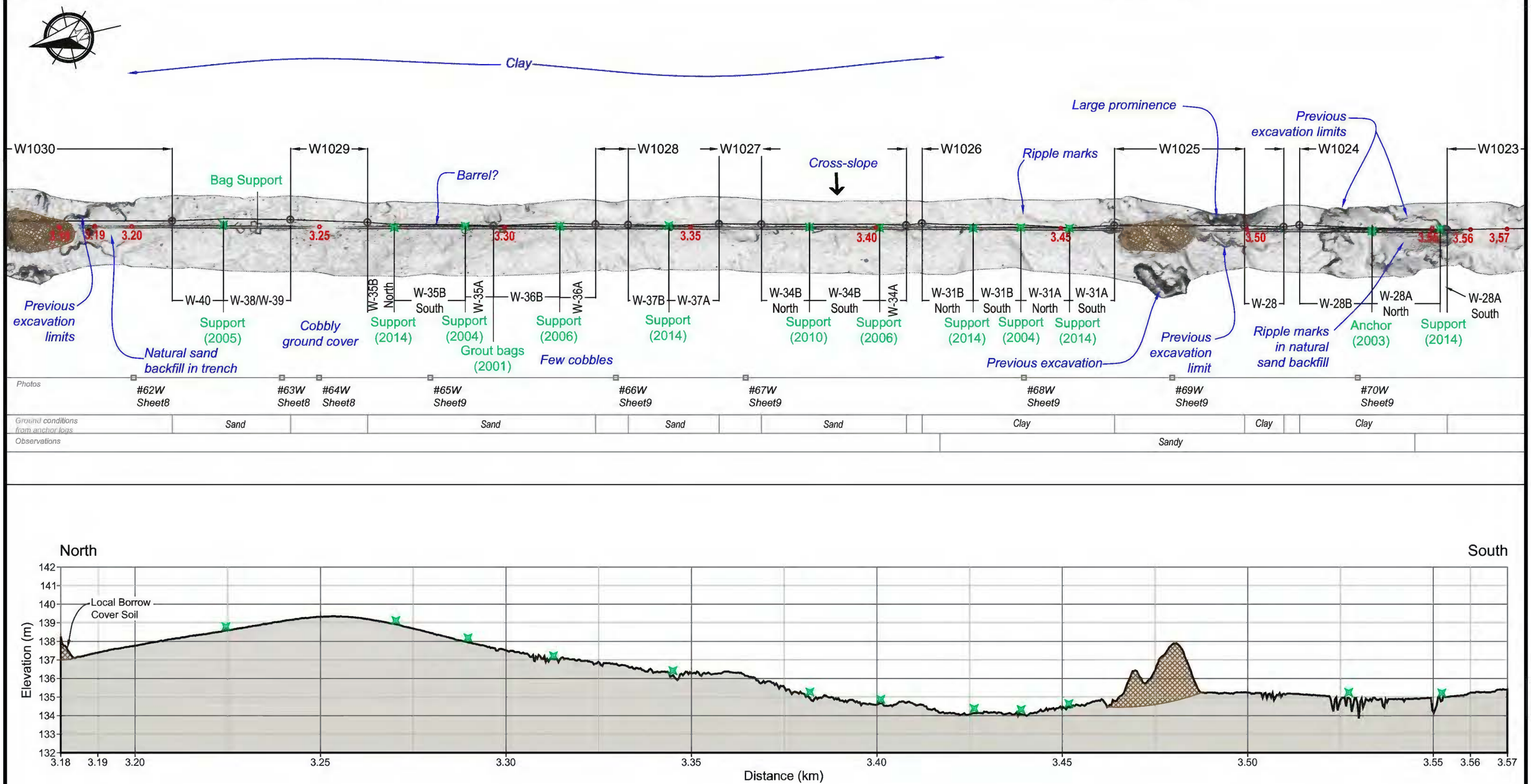
Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline

KELLY GEOTECHNICAL

Date:	2017-06-01
Drawn By:	Shelley Ruiz
Reviewed By:	Shane Kelly
Project #:	KGL-16-022
Drawing/Rev #:	Rev3

WEST-5

ENBDNR0002433



LEGEND:

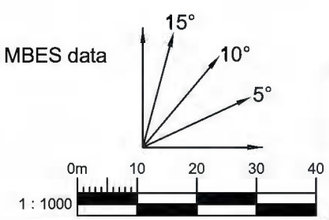
- SOIL ⊙ Soil Contact Location - 2014 Span Data
- ANCHOR Anchor Location (year built if known)
- KM₀ Approximate Kilometer Marker Reference Chainage
- Approximate Local Borrow Cover Soil
- *Sandy* Ground Condition Observations from
- *Boulders* Submarine Inspection Video Log Review
- W1000 Span Identifier

PROFILE:

—— 2016 Ground Surface taken from Project MBES data

NOTES:

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3. Profile vertically exaggerated by 5.



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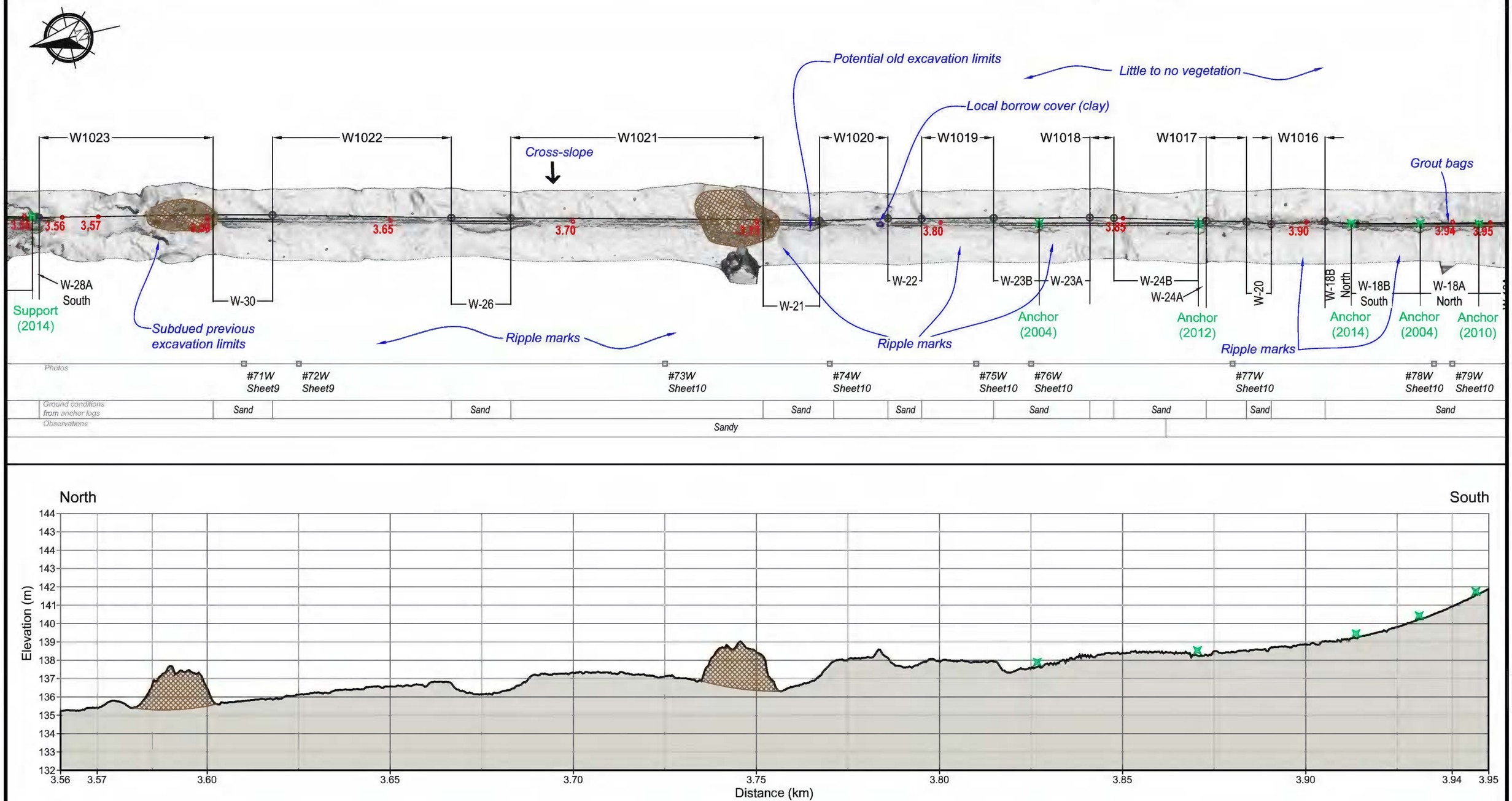
Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline

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Reviewed By:	Shane Kelly
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WEST-6

ENBDNR0002434



LEGEND:

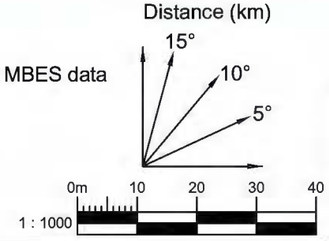
- SOIL — Soil Contact Location - 2014 Span Data
- ANCHOR — Anchor Location (year built if known)
- KM₀ — Approximate Kilometer Marker Reference Chainage
- Approximate Local Borrow Cover Soil
- *Sandy* — Ground Condition Observations from
- *Boulders* — Submarine Inspection Video Log Review
- W1000 — Span Identifier

PROFILE:

— 2016 Ground Surface taken from Project MBES data

NOTES:

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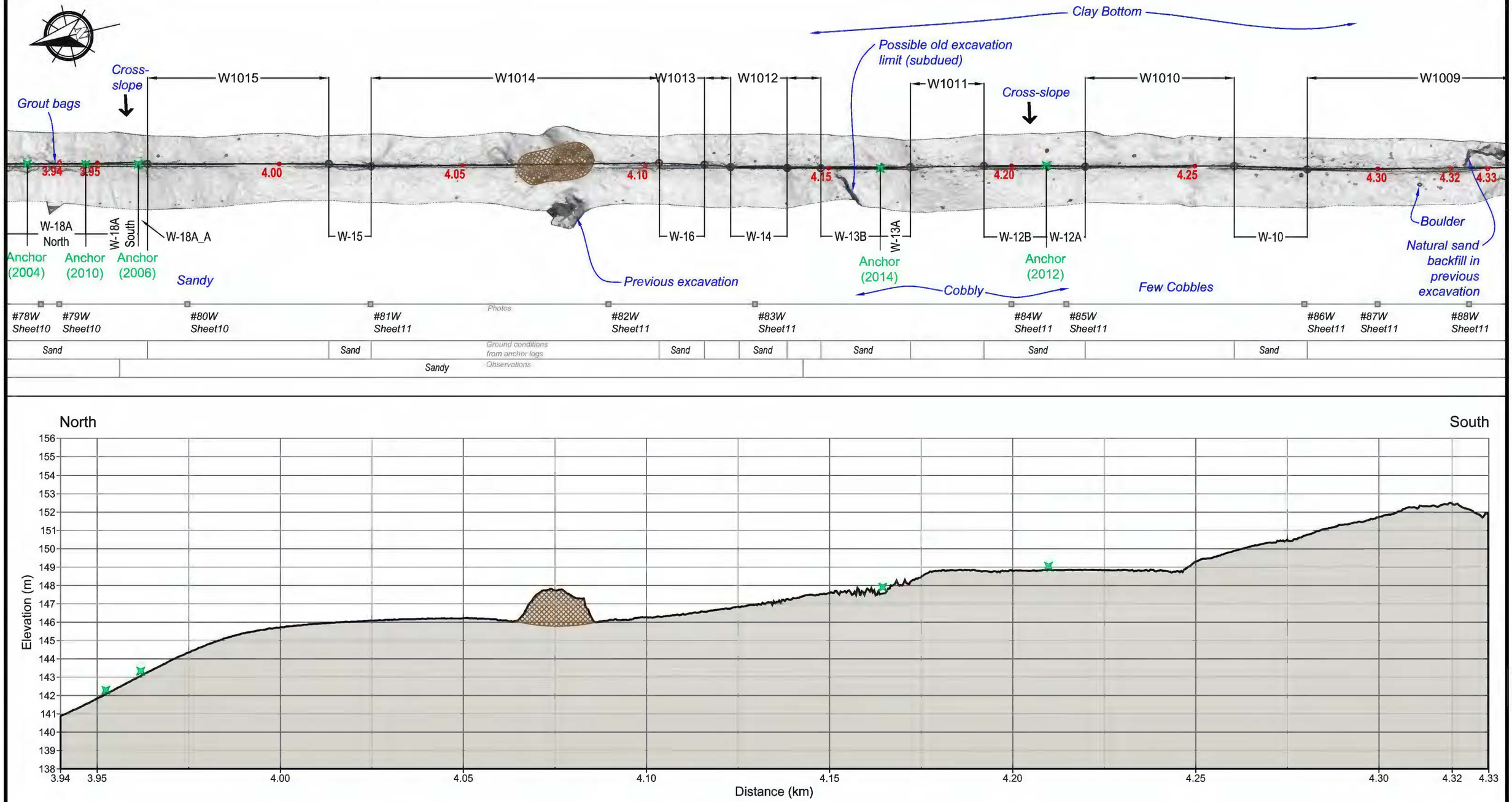
Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline

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Reviewed By:	Shane Kelly
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WEST-7

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LEGEND:

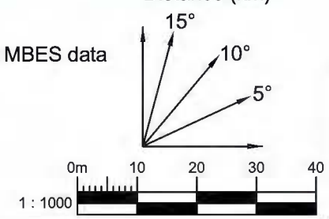
- SOIL — Soil Contact Location - 2014 Span Data
- ANCHOR — Anchor Location (year built if known)
- KM$_{00}$ — Approximate Kilometer Marker Reference Chainage
- Approximate Local Borrow Cover Soil
- *Sandy* — Ground Condition Observations from
- *Boulders* — Submarine Inspection Video Log Review
- W1000 — Span Identifier

PROFILE:

2016 Ground Surface taken from Project MBES data

NOTES:

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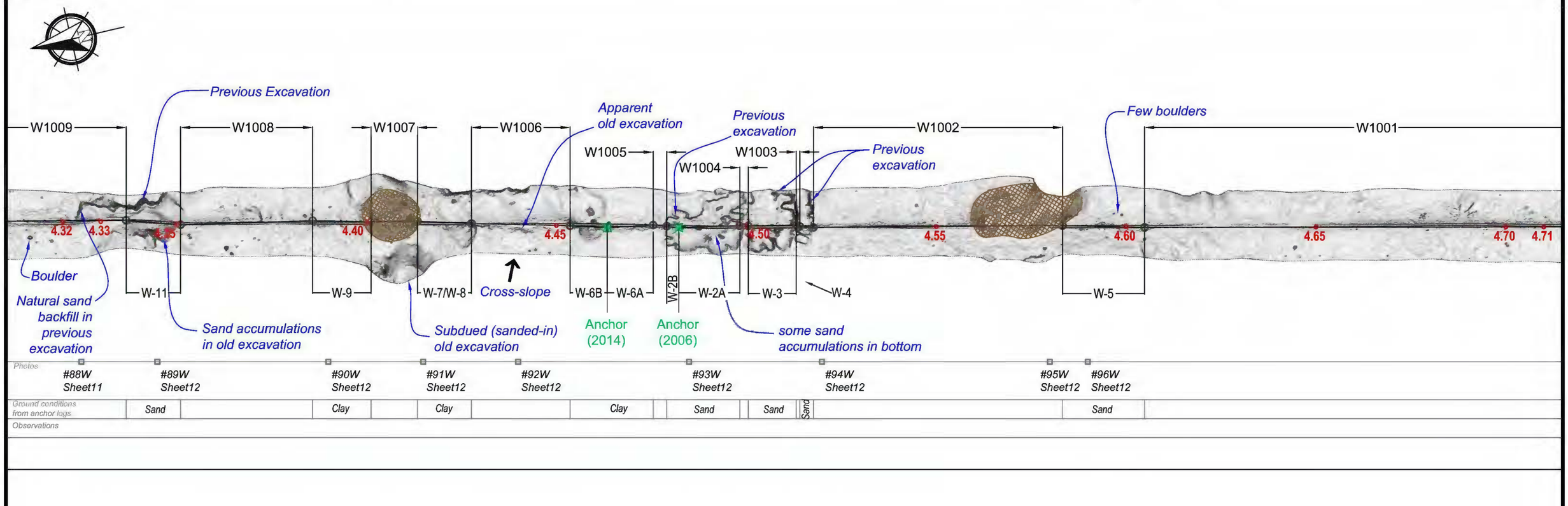
Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline

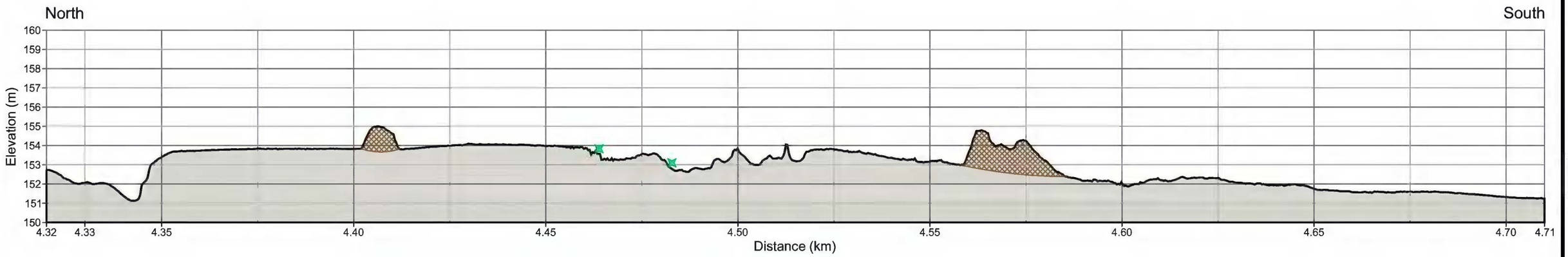
KELLY GEOTECHNICAL

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Reviewed By:	Shane Kelly
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LEGEND:

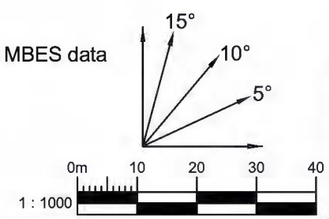
- SOIL — Soil Contact Location - 2014 Span Data
- ANCHOR — Anchor Location (year built if known)
- KM₀ — Approximate Kilometer Marker Reference Chainage
- Approximate Local Borrow Cover Soil
- *Sandy Boulders* — Ground Condition Observations from Submarine Inspection Video Log Review
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PROFILE:

2016 Ground Surface taken from Project MBES data

NOTES:

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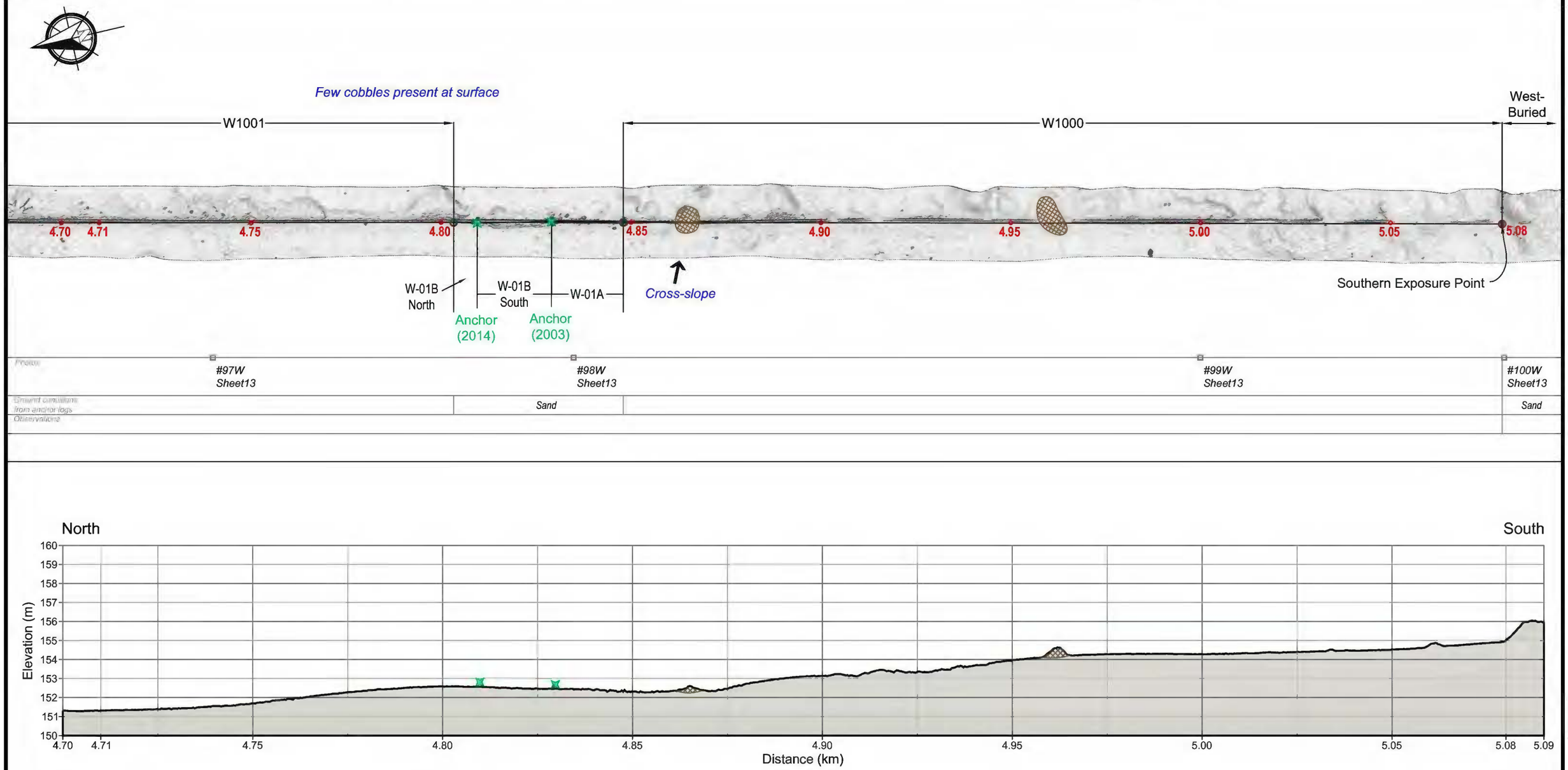
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WEST-9

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LEGEND:

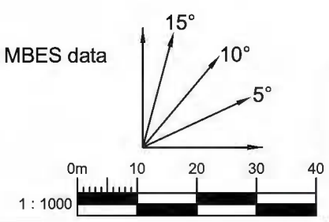
- SOIL — Soil Contact Location - 2014 Span Data
- ANCHOR — Anchor Location (year built if known)
- KM₀ — Approximate Kilometer Marker Reference Chainage
- Approximate Local Borrow Cover Soil
- *Sandy Boulders* — Ground Condition Observations from Submarine Inspection Video Log Review
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PROFILE:

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NOTES:

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Project #:	KGL-16-022
Drawing/Rev #:	Rev3

WEST-10

ENBDNR0002438

APPENDIX B

ENBDNR0002439

Span Identifier	2014 Length	2014 Span Height	2014 Support Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude
Southern Exposure Point	NA	NA	NA	NA	NA	NA	NA	NA	Only/Sand	66	45.79740051 N	84.76828612 W
E-75	NA	NA	NA	Silted In	70	69	73	80	NA	NA	NA	NA
									NA	NA	NA	NA
E-74A	50	0.5	240' to Bury	80	61	67	67	71	South/Sand	69	45.79803465 N	84.76803487 W
									North/Anchor (2004)	70	45.79817336 N	84.76798054 W
E-74B South	70	0.5	Shared Touch Down ^	56	109	100			South/Anchor (2004)	70	45.79817336 N	84.76798054 W
									North/Anchor (2010)	71	45.79836191 N	84.76790185 W
E-74B North	47	0.5	Shared Touch Down ^	48					South/Anchor (2010)	71	45.79836191 N	84.76790185 W
									North/Anchor (2006)	70	45.79848622 N	84.76785431 W
E-74C	28	1	Shared Touch Down ^	16	13	14			South/Anchor (2006)	70	45.79848622 N	84.76785431 W
									North/Sand	69	45.79855919 N	84.7678226 W
E-71A	30	0.5	111' to E74C North	76	87	86	86	84	South/Sand	71	45.79885179 N	84.76772027 W
									North/Anchor (2014)	71	45.79893197 N	84.76769084 W
E-71B	49	0.5	Shared Touch Down ^						South/Anchor (2014)	71	45.79893197 N	84.76769084 W
									North/Anchor (2005)	72	45.79906039 N	84.76764254 W
E-72	44	0.5	Shared Touch Down ^	40	40	38	36	48	South/Anchor (2005)	72	45.79906039 N	84.76764254 W
									North/Sand	72	45.79917455 N	84.76759603 W
E-77	37	1	9' to E-72	34	44	52	44	42	South/Sand	72	45.79919654 N	84.76758791 W
									North/Sand	72	45.799292 N	84.76754813 W
E-26	54	1	202' to E77	48	54	45	48	51	South/Clay	76	45.79982164 N	84.76734294 W
									North/Sand	76	45.7999639 N	84.76728235 W
E-25A	38	0.5	42' to E-26	87	91	85	84	96	South/Sand	81	45.80007298 N	84.76724349 W
									North/Anchor (2014)	80	45.80017387 N	84.76720464 W
E-25B	48	0.5	Shared Touch Down ^						South/Anchor (2014)	80	45.80017387 N	84.76720464 W
									North/Sand	79	45.80029924 N	84.76715103 W
E-24	44	0.5	114' to E25B	44	50	45	46	37	South/Sand	81	45.80059751 N	84.76703994 W
									North/Sand	82	45.80071223 N	84.76699755 W
E-23A South	28	0.5	96' to E-24	86	85	81	86	84	South/Sand	83	45.80096148 N	84.76690243 W
									North/Anchor (2014)	85	45.80103603 N	84.76687496 W
E-23A North	58	0.5	Shared Touch Down ^						South/Anchor (2014)	85	45.80103603 N	84.76687496 W
									North/Anchor (2003)	85	45.80118708 N	84.7668158 W
E-23B South	61	0.5	Shared Touch Down ^	66	87	86	90	90	South/Anchor (2003)	85	45.80118708 N	84.7668158 W
									North/Anchor (2012)	84	45.80134576 N	84.76674988 W
E-23B North	31	1	Shared Touch Down ^	26					South/Anchor (2012)	84	45.80134576 N	84.76674988 W
									North/Sand	83	45.80142404 N	84.76671263 W
E-27	63	0.5	78' to E23B North	58	69	65	66	74	South/Sand	82	45.80162764 N	84.76663722 W
									North/Sand	81	45.80179248 N	84.76657389 W
E-28A South	37	1	52' to E-27	70	81	73	74	81	South/Sand	82	45.80193012 N	84.76652267 W
									North/Anchor (2014)	83	45.8020281 N	84.76649157 W
E-28A North	38	1	Shared Touch Down ^						South/Anchor (2014)	83	45.8020281 N	84.76649157 W
									North/Anchor (2005)	83	45.80212884 N	84.76645585 W
E-28B	63	1	Shared Touch Down ^	66	69	65	64	72	South/Anchor (2005)	83	45.80212884 N	84.76645585 W
									North/Sand	81	45.80229567 N	84.76639508 W
E-29	59	1	25' to E28B	60	55	44	63	53	South/Sand	81	45.8023587 N	84.76636855 W
									North/Sand	79	45.80251327 N	84.76631514 W
E-30A	38	1	22' to E29	72	83	82	82	89	South/Sand	78	45.80256885 N	84.76629197 W
									North/Anchor (2014)	77	45.80267125 N	84.76626081 W

Span Identifier	2014 Length	2014 Span Height	2014 Support Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude
E-30B	36		Shared Touch Down ^						South/Anchor (2014)	77	45.80267125 N	84.76626081 W
									North/Sand	76	45.80276442 N	84.76622516 W
E-38	36	1	86 to E-30B	34	45	32	37	46	South/Sand	73	45.80299189 N	84.76614415 W
									North/Sand	72	45.80308618 N	84.76611094 W
E-37	56	1	155' to E-38	54	54	50	54	53	South/Sand	74	45.80349412 N	84.7659669 W
									North/Sand	74	45.80363883 N	84.76590965 W
E-36	50	0.5	12' to E-37	42	41	48	42	34	South/Sand	73	45.80366947 N	84.76589995 W
									North/Sand	73	45.80380204 N	84.76585057 W
E-35A	36	0.5	33' to E-36	60	67	66	67	63	South/Sand	73	45.80389819 N	84.76581718 W
									North/Anchor (2014)	75	45.80399347 N	84.7657808 W
E-35B	36	0.5	Shared Touch Down ^						South/Anchor (2014)	75	45.80399347 N	84.7657808 W
									North/Sand	76	45.80408779 N	84.76574484 W
E-34A	58	1	25' to E35B	58	62	54	61	59	South/Sand	77	45.80415409 N	84.76572209 W
									North/Anchor (2003)	79	45.80430605 N	84.76566353 W
E-34B South	53	1	Shared Touch Down ^	73	80	82	74	75	South/Anchor (2003)	79	45.80430605 N	84.76566353 W
									North/Anchor (2014)	78	45.80444616 N	84.76561487 W
E-34B North	21	1	Shared Touch Down ^						South/Anchor (2014)	78	45.80444616 N	84.76561487 W
									North/Sand	79	45.80450136 N	84.76558981 W
E-33	43	1	109 to E34B North	46	52	47	45	39	South/Sand	82	45.80478655 N	84.76548042 W
									North/Sand	86	45.80490015 N	84.76543833 W
E-32A-A	6		21' to E-33	Silted in	11	17			South/Clay	88	45.80495542 N	84.76541633 W
									North/Anchor (2006)	88	45.80497238 N	84.76541225 W
E-32A South	40	1	Shared Touch Down ^	47	92	89			South/Anchor (2006)	88	45.80497238 N	84.76541225 W
									North/Anchor (2012)	92	45.80507422 N	84.76536839 W
E-32A North	47	1.5	Shared Touch Down ^	40					South/Anchor (2012)	92	45.80507422 N	84.76536839 W
									North/Anchor (2003)	94	45.80519687 N	84.76532216 W
E-32B South	67	1	Shared Touch Down ^	88	87	97	85	79	South/Anchor (2003)	94	45.80519687 N	84.76532216 W
									North/Anchor (2014)	96	45.80537562 N	84.76525738 W
E-32B North	22	1	Shared Touch Down ^						South/Anchor (2014)	96	45.80537562 N	84.76525738 W
									North/Clay	95	45.80543416 N	84.7652347 W
E-31	36	1	22' to E32B North	34	36	42	42	37	South/Clay	95	45.80549271 N	84.76521037 W
									North/Clay	96	45.80558613 N	84.76517358 W
E-39	63	1	58' to E-31	74	83	67	78	66	South/Clay	98	45.80573967 N	84.76511784 W
									North/Sand	98	45.80590475 N	84.76505337 W
E-40A	22	1	370' to E39	85	82	80	90	97	South/Sand	103	45.80688466 N	84.7646828 W
									North/Anchor (2014)	104	45.80694103 N	84.7646623 W
E-40B	60	1	Shared Touch Down ^						South/Anchor (2014)	104	45.80694103 N	84.7646623 W
									North/Sand	104	45.80709655 N	84.76459532 W
E-46	46	1	220' to E40B	86	93	82	72	58	South/Sand	104	45.80767814 N	84.76437691 W
									North/Anchor (2006)	104	45.80780151 N	84.76433045 W
E-45A	58	1	Shared Touch Down ^	53	50	49	62	72	South/Anchor (2006)	104	45.80780151 N	84.76433045 W
									North/Anchor (2014)	104	45.80795517 N	84.76427079 W
E-45B	28	1	Shared Touch Down ^						South/Anchor (2014)	104	45.80795517 N	84.76427079 W
									North/Clay	102	45.80802708 N	84.76423847 W
E-44	45	1	144' to E45B	45	37	33	40	37	South/Clay	100	45.80840536 N	84.76408996 W
									North/Clay	98	45.8085226 N	84.76403879 W
E-43	56	1	67' to E44	54	54	59	54	54	South/Clay	102	45.80870068 N	84.76397628 W
									North/Clay	103	45.80884836 N	84.76391865 W

Span Identifier	2014 Length	2014 Span Height	2014 Support Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude
E-42 South	39	1.5	41' to E43	45	91	97	97	103	South/Clay	103	45.80895719 N	84.76388102 W
									North/Anchor (2012)	103	45.80906046 N	84.76384057 W
E-42 North	46	1.5	Shared Touch Down ^	52					South/Anchor (2012)	103	45.80906046 N	84.76384057 W
									North/Clay	101	45.80917946 N	84.7637909 W
E-41	71	1	130' to E42 North	70	74	77	68	84	South/Clay	98	45.80952345 N	84.76366022 W
									North/Clay	97	45.80971147 N	84.76358754 W
E-47A	45	1	141 to E41	76	75	75	74	75	South/Clay	98	45.81007932 N	84.76344236 W
									North/Anchor (2014)	100	45.81019925 N	84.76339755 W
E-47B	28	1	Shared Touch Down ^						South/Anchor (2014)	100	45.81019925 N	84.76339755 W
									North/Clay	100	45.8102734 N	84.76336643 W
E-48A	55	1.5	20' to E47	48	59	48	55		South/Clay	100	45.81032483 N	84.76334545 W
									North/Anchor (2005)	102	45.81047222 N	84.76329119 W
E-48B South	60	1	Shared Touch Down ^	67	66	82	68		South/Anchor (2005)	102	45.81047222 N	84.76329119 W
									North/Anchor (2014)	101	45.81063345 N	84.7632324 W
E-48B North	14		Shared Touch Down ^						South/Anchor (2014)	101	45.81063345 N	84.7632324 W
									North/Clay	101	45.81066737 N	84.76321778 W
E-79	NA	NA	NA	NA	Filled In	19	13		NA	NA	NA	NA
									NA	NA	NA	NA
E-70	52	1	380' to E48B	53	54	53	47	52	South/Clay	110	45.81167843 N	84.76283521 W
									North/Clay	111	45.81181537 N	84.76278221 W
E-66A South	22	1	3' to E70	22	97	89	97		South/Clay	111	45.81182421 N	84.76277945 W
									North/Anchor (2012)	111	45.81188319 N	84.7627559 W
E-66A North	72	0.5	Shared Touch Down ^	77					South/Anchor (2012)	111	45.81188319 N	84.7627559 W
									North/Anchor (2005)	113	45.81207618 N	84.76267988 W
E-66B	52	1	Shared Touch Down ^	56	89	89	81		South/Anchor (2005)	113	45.81207618 N	84.76267988 W
									North/Clay	113	45.81221358 N	84.76262661 W
E-56A	44	1.5	32' to E66B	45	44	33			South/Clay	113	45.81229737 N	84.76259107 W
									North/Anchor (2006)	114	45.81241142 N	84.76254418 W
E-56B	46	2	Shared Touch Down ^	44	42	48			South/Anchor (2006)	114	45.81241142 N	84.76254418 W
									North/Clay	112	45.81253217 N	84.76250017 W
E-55	46	1	35' to E56B	45	46	41	50	43	South/Clay	113	45.8126226 N	84.76246303 W
									North/Clay	114	45.81274368 N	84.76241929 W
E-54A	57	3	11' to E55	58	62	59	66		South/Clay	114	45.81277307 N	84.76240561 W
									North/Anchor (2005)	121	45.81292344 N	84.76234556 W
E-54B	33	2.5	Shared Touch Down ^	32	37	39	29		South/Anchor (2005)	121	45.81292344 N	84.76234556 W
									North/Grout Bag (2001)	122	45.8130088 N	84.76231479 W
E-53A	44	3	Grout Bags ^	44	38	33	43		South/Grout Bag (2001)	122	45.8130088 N	84.76231479 W
									North/Anchor (2005)	124	45.81312414 N	84.76226755 W
E-53B	60	3	Shared Touch Down ^	57	64	71	63		South/Anchor (2005)	124	45.81312414 N	84.76226755 W
									North/Clay	127	45.8132822 N	84.76221172 W
E-52A	10	2.5	11' toE53B	9	15	14	18		South/Clay	127	45.81330927 N	84.76220265 W
									North/Anchor (2012)	128	45.81333405 N	84.76219074 W
E-52B	8	3	Shared Touch Down ^	8					South/Anchor (2012	128	45.81333405 N	84.76219074 W
									North/Clay	128	45.81335562 N	84.76218435 W
E-49C	51	2	8 to E-52	48	46	36	53	44	South/Clay	129	45.81337589 N	84.76217535 W
									North/Anchor (2004)	133	45.81351091 N	84.76212131 W
E-49B South	42	2	Shared Touch Down ^	86	85	82	87	101	South/Anchor (2004)	133	45.81351091 N	84.76212131 W
									North/Anchor (2014)	136	45.81362344 N	84.76208421 W

Span Identifier	2014 Length	2014 Span Height	2014 Support Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude
E-49B North	45	2	Shared Touch Down ^						South/Anchor (2014)	136	45.81362344 N	84.76208421 W
									North/Anchor (2004)	139	45.81374064 N	84.76203766 W
E-49A South	67	1	Shared Touch Down ^	87	75	93	95	86	South/Anchor (2004)	139	45.81374064 N	84.76203766 W
									North/Anchor (2014)	140	45.81391998 N	84.76197483 W
E-49A North	23	1	Shared Touch Down ^						South/Anchor (2014)	140	45.81391998 N	84.76197483 W
									North/Clay	141	45.81397636 N	84.7619502 W
E-58	62'	3	87 to E49A North	60	51	66	61	61	South/Clay	141	45.81420665 N	84.76187126 W
									North/Clay	144	45.81436938 N	84.76180643 W
E-61A-A	57	3	196' to E58	52	47	59			South/Clay	137	45.81488776 N	84.76160874 W
									North/Anchor (2006)	145	45.81503694 N	84.76155307 W
E-61A	63	4	Shared Touch Down ^	65	61	68	120	129	South/Anchor (2006)	145	45.81503694 N	84.76155307 W
									North/Anchor (2004)	145	45.81520235 N	84.76149042 W
E-61B South	46	4	Shared Touch Down ^	52					South/Anchor (2004)	145	45.81520235 N	84.76149042 W
									North/Anchor (2012)	148	45.81532105 N	84.76144352 W
E-61B North	70	3	Shared Touch Down ^	62	114	113	115	125	South/Anchor (2012)	148	45.81532105 N	84.76144352 W
									North/Anchor (2004)	147	45.81550142 N	84.76137607 W
E-61C South	57	3	Shared Touch Down ^	61	85	90	83	78	South/Anchor (2004)	147	45.81550142 N	84.76137607 W
									North/Anchor (2012)	142	45.81564713 N	84.76132398 W
E-61C North	29	2.5	Shared Touch Down ^	31					South/Anchor (2012)	142	45.81564713 N	84.76132398 W
									North/Clay	139	45.81572031 N	84.76129539 W
E-62	39	1.5	41' to E61C	37	32	29	38	34	South/Clay	135	45.81582864 N	84.76125214 W
									North/Clay	130	45.81593382 N	84.76121499 W
E-63	21	1	9' to E61	18	23	22	22	15	South/Clay	129	45.81595831 N	84.76120677 W
									North/Clay	130	45.81601262 N	84.7611857 W
E-64	49	1	20' to E63	52	47	51	48	52	South/Clay	132	45.81606385 N	84.76116825 W
									North/Clay	132	45.81619121 N	84.76111823 W
E-22A	70	4	38 to E64	76	80	74	76	79	South/Clay	130	45.81629124 N	84.76108022 W
									North/Anchor (2014)	130	45.81647888 N	84.76100317 W
E-22B	7	1	Shared Touch Down ^						South/Anchor (2014)	130	45.81647888 N	84.76100317 W
									North/Clay	130	45.81649739 N	84.76099431 W
E-21	53	0.5	40' to E22	50	43	48	52	51	South/Clay	128	45.81660352 N	84.76095383 W
									North/Clay	129	45.81674293 N	84.7608986 W
E-20	NA	NA	NA	NA	Filled In	23	25		NA	NA	NA	NA
									NA	NA	NA	NA
E-19A South	23	0.5	67 to E21	75	87	76	78	107	South/Clay	133	45.81692151 N	84.76083215 W
									North/Anchor (2014)	136	45.8169808 N	84.76080731 W
E-19A North	60	0.5	Shared Touch Down ^						South/Anchor (2014)	136	45.8169808 N	84.76080731 W
									North/Anchor (2003)	140	45.81714033 N	84.7607472 W
E-19B South	58	1	Shared Touch Down ^	82	75	80	81	73	South/Anchor (2003)	140	45.81714033 N	84.7607472 W
									North/Anchor (2014)	144	45.81729393 N	84.76068901 W
E-19B North	24	0.5							South/Anchor (2014)	144	45.81729393 N	84.76068901 W
									North/Clay	145	45.81735826 N	84.76066463 W
E-18B	22	0.5	33'to E19B North	23	25	22	25	16	South/Clay	148	45.81744163 N	84.76063246 W
									North/Clay	151	45.81749679 N	84.76061139 W
E-18C	15	0.5	6' to E18B	Silted in	16				South/Clay	151	45.81750978 N	84.7606076 W
									North/Clay	154	45.81754778 N	84.760593 W
E-18A	17	0.5	4' to E18C	16	21	22	18	29	South/Clay	154	45.8175558 N	84.76058925 W
									North/Clay	156	45.81759883 N	84.76057257 W

Span Identifier	2014 Length	2014 Span Height	2014 Support Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude
E-17	38	0.5	33' to E18A	39	36	40	31	44	South/Clay	161	45.81768298 N	84.76054041 W
									North/Clay	167	45.81778351 N	84.7605004 W
E-16	42	2.5	58' to E17	38	48	36	38	47	South/Clay	175	45.81793523 N	84.76044082 W
									North/Clay	184	45.81804614 N	84.76039472 W
E-15A	28	1	4' to E16	31	29	25	28		South/Sand	184	45.81805592 N	84.76039102 W
									North/Anchor (2005)	192	45.81812989 N	84.7603635 W
E-15B	50	1	Shared Touch Down ^	52	52	51	47		South/Anchor (2005)	204	45.81812989 N	84.7603635 W
									North/Grout Bag (2001)	203	45.81826147 N	84.76031158 W
E-08A	58	1	Grout Bags ^	56	54	65	56	62	South/Grout Bag (2001)	203	45.81826147 N	84.76031158 W
									North/Anchor (2003)	216	45.81841688 N	84.7602534 W
E-8B	69	2	Shared Touch Down ^	70	71	66	73		South/Anchor (2003)	216	45.81841688 N	84.7602534 W
									North/Anchor (2005)	224	45.81859712 N	84.76018457 W
E-08C/D South	58	3	Shared Touch Down ^	76	39	79	97		South/Anchor (2005)	224	45.81859712 N	84.76018457 W
					20				North/Anchor (2014)	227	45.81875079 N	84.7601283 W
E-08C/D North	18	2	Shared Touch Down ^						South/Anchor (2014)	227	45.81875079 N	84.7601283 W
									North/Sand	227	45.8187984 N	84.76010964 W
E-09	35	0.5	25 to E08C/D North	41	33	33	40	39	South/Sand	229	45.81886442 N	84.76009022 W
									North/Sand	230	45.81895739 N	84.76005737 W
E-10	47	2	72 to E09	52	50	49	44		South/Clay	229	45.81914977 N	84.75998662 W
									North/Clay	230	45.81927332 N	84.75993637 W
E-11	66	2	4' to E10	63	70	74	69		South/Clay	230	45.81928482 N	84.75993198 W
									North/Clay	228	45.819459 N	84.75986295 W
E-12	34	1	58' to E11	39	41	88	81	81	South/Clay	228	45.81963584 N	84.75979216 W
									North/Clay	227	45.81972489 N	84.75975827 W
E-13A	29	1	65' to E12	27	32	40	34	36	South/Clay	228	45.81989427 N	84.75969496 W
									North/Anchor (2004)	230	45.81997078 N	84.75966271 W
E-13B South	58	1	Shared Touch Down ^	56	106	116	112	115	South/Anchor (2004)	230	45.81997078 N	84.75966271 W
									North/Anchor (2010)	228	45.82012417 N	84.75960843 W
E-13B North	57	1	Shared Touch Down ^	56					South/Anchor (2010)	228	45.82012417 N	84.75960843 W
									North/Anchor (2004)	226	45.82027847 N	84.75955349 W
E-13C South	51	1.5	Shared Touch Down ^	48	107	105	99	102	South/Anchor (2004)	226	45.82027847 N	84.75955349 W
									North/Anchor (2010)	225	45.82041043 N	84.75949691 W
E-13C North	52	1.5	Shared Touch Down ^	56					South/Anchor (2010)	225	45.82041043 N	84.75949691 W
									North/Clay	216	45.82055076 N	84.75944415 W
E-3A	27	1	133' to E13C North	87	76	68	90	62	South/Clay	217	45.82090248 N	84.75931622 W
									North/Anchor (2014)	221	45.82097424 N	84.75928534 W
E-3B	53	1	Shared Touch Down ^						South/Anchor (2014)	221	45.82097424 N	84.75928534 W
									North/Anchor (2005)	217	45.82111266 N	84.75922939 W
E-76A/B	58	1	11' to E3B	58	10	18			South/Clay	217	45.82114141 N	84.75921794 W
									North/Clay	217	45.82129123 N	84.75915826 W
E-02A South	15	0.5	238' to E76A/B	76	80	80			South/Sand	218	45.82192295 N	84.75892028 W
									North/Anchor (2014)	218	45.82195983 N	84.75890383 W
E-02A North	55	0.5	Shared Touch Down ^						South/Anchor (2014)	218	45.82195983 N	84.75890383 W
									North/Anchor (2006)	218	45.82210278 N	84.75884748 W
E-02B	26	0.5	Shared Touch Down ^	32	30	33			South/Anchor (2006)	218	45.82210278 N	84.75884748 W
									North/Sand	216	45.82217149 N	84.75882614 W
E-01A South	28	2.5	20' to E02B	81	85	84	88	88	South/Sand	216	45.82222505 N	84.75880875 W
									North/Anchor (2014)	217	45.82229766 N	84.75878027 W

Span Identifier	2014 Length	2014 Span Height	2014 Support Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude
E-01A North	53	2	Shared Touch Down ^						South/Anchor (2014)	217	45.82229766 N	84.75878027 W
									North/Anchor (2003)	217	45.82244184 N	84.7587229 W
E-01B-A South	53	3	Shared Touch Down ^	39	100	96	96	107	South/Anchor (2003)	217	45.82244184 N	84.7587229 W
									North/Anchor (2012)	212	45.82258353 N	84.75866685 W
E-01B-A North	43	2	Shared Touch Down ^	53					South/Anchor (2012)	212	45.82258353 N	84.75866685 W
									North/Anchor (2004)	206	45.82269559 N	84.75862499 W
E-01B-B	48	2	Shared Touch Down ^	82	62	74	68	65	South/Anchor (2004)	206	45.82269559 N	84.75862499 W
									North/Sand	197	45.82282173 N	84.75857538 W
E-04A South	17	1	83' to E-01B-B	84	82	84	101		South/Sand	186	45.82304007 N	84.75848688 W
									North/Anchor (2014)	185	45.82308056 N	84.7584657 W
E-04A North	59	1	Shared Touch Down ^						South/Anchor (2014)	185	45.82308056 N	84.7584657 W
									North/Anchor (2006)	176	45.8232365 N	84.75840367 W
E-04B	19	1	Shared Touch Down ^	20	26	23	101		South/Anchor (2006)	176	45.8232365 N	84.75840367 W
									North/Sand	173	45.82328669 N	84.75838476 W
E-05A South	27	1	37' to E04B	80	75	82	77	74	South/Sand	169	45.82338631 N	84.75834799 W
									North/Anchor (2014)	166	45.82345562 N	84.75831776 W
E-05A North	55	1	Shared Touch Down ^						South/Anchor (2014)	166	45.82345562 N	84.75831776 W
									North/Anchor (2003)	157	45.82360285 N	84.75826104 W
E-05B	67	1	Shared Touch Down ^	65	63	62	57	61	South/Anchor (2003)	157	45.82360285 N	84.75826104 W
									North/Sand	146	45.8237806 N	84.75819081 W
E-06	52	1	228' to E-05B	60	60	76	65	67	South/Sand	116	45.8243827 N	84.75795786 W
									North/Sand	111	45.82452008 N	84.75790456 W
E-07	52	0.5	54' to E06	62	72	74	69	70	South/Sand	104	45.82465949 N	84.75784771 W
									North/Sand	97	45.82479445 N	84.75779612 W
E-65A	62	0.5	458' to E07	64	67	67	59		South/Sand	66	45.82600507 N	84.75733017 W
									North/Anchor (2005)	66	45.82617024 N	84.75726365 W
E-65B	61	1	Shared Touch Down ^	61	60	65	64		South/Anchor (2005)	66	45.82617024 N	84.75726365 W
									North/Sand	66	45.8263332 N	84.75720272 W
Northern Exposure Point	NA	NA	148' to E-65B	NA	NA	NA	NA	NA	Only/Sand	62	45.82672766 N	84.75706154 W

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Southern Exposure Point	NA	NA	NA	NA	NA	NA	NA	NA	Only/Sand	65	45.79570801 N	84.77389377 W
W-01A	66	2.5	760' to pipe bury	65	79	63	66	71	South/Sand	74	45.79772369 N	84.77314096 W
									North/Anchor (2003)	75	45.79789806 N	84.77307274 W
W-01B South	59	2.5	Shared Touch Down ^	80	79	83	77	80	South/Anchor (2003)	75	45.79789806 N	84.77307274 W
									North/Anchor (2014)	75	45.79805619 N	84.7730173 W
W-01B North	21		Shared Touch Down ^						South/Anchor(2014)	75	45.79805619 N	84.7730173 W
									North/Sand	75	45.79810962 N	84.77299804 W
W-5	71	1	651' to W01B	70	81	83	80	74	South/Sand	75	45.79983894 N	84.77235059 W
									North/Sand	71	45.80002695 N	84.77228089 W
W-77	NA	----	----	Silted in	37	25	24	11	NA	NA	NA	NA
									NA	NA	NA	NA
W-4	12	1	215' to W5	16	13	18	18	14	South/Sand	70	45.8005966 N	84.77206933 W
									North/Sand	70	45.80062778 N	84.77205516 W
W-3	42	1.5	3' to W4	43	39	41	31	22	South/Sand	71	45.8006356 N	84.77205235 W
									North/Sand	71	45.80074826 N	84.77201133 W
W-2A	53	1.5	7' to W3	52	54	54	53		South/Sand	70	45.80076595 N	84.77200487 W
									North/Anchor (2006)	72	45.80090546 N	84.77195411 W
W-2B	12	1.5	Shared Touch Down ^	14	10	10	10		South/Anchor (2006)	72	45.80090546 N	84.77195411 W
									North/Sand	70	45.80093427 N	84.77193985 W
W-6A	40	2	11'to W2B	72	83	82	72	68	South/Clay	70	45.80096456 N	84.7719274 W
									North/Anchor (2014)	70	45.80107298 N	84.77189363 W
W-6B	32		Shared Touch Down ^						South/Anchor(2014)	70	45.80107298 N	84.77189363 W
									North/Clay	72	45.80115633 N	84.77185761 W
W-7	47	2	84' to W6	46	Merged	34	22	33	South/Clay	70	45.8013792 N	84.77176906 W
W-8					50	22	17	23	North/Clay	70	45.80150413 N	84.77171663 W
W-9	51	2.5	40' to W7-8	53	53	65	55	57	South/Clay	66	45.80160803 N	84.77167766 W
									North/Clay	72	45.80174235 N	84.77162408 W
W-11	48	2.5	114' to W-9	52	47	40	46	49	South/Sand	72	45.80204636 N	84.77152015 W
									North/Sand	77	45.80216995 N	84.77145889 W
W-10	66	3	183' to W-11	64	69	63	63	53	South/Sand	79	45.80265731 N	84.77128597 W
									North/Sand	83	45.80283001 N	84.77120879 W
W-12A	35	1.5	133' to W10	43	91	94	95	97	South/Sand	88	45.80318394 N	84.77107992 W
									North/Anchor (2012)	88	45.80327592 N	84.7710389 W
W-12B	56'	1.5	Shared Touch Down ^	46					South/Anchor (2012)	88	45.80327592 N	84.7710389 W
									North/Sand	88	45.80342375 N	84.77098542 W
W-13A	28'	3	65'to W12 North	83	87	90	76	75	South/Sand	86	45.80359866 N	84.7709303 W
									North/Anchor (2014)	90	45.80367382 N	84.77090546 W
W-13B	54		Shared Touch Down ^						South/Anchor (2014)	90	45.80367382 N	84.77090546 W
									North/Sand	91	45.8038143 N	84.7708486 W
W-14	51	1.5	31' to W13	54	51	74	62	48	South/Sand	92	45.803895 N	84.77081842 W
									North/Sand	94	45.80402656 N	84.7707635 W
W-16	40	0.5	24' to W14	44	45	42	48	36	South/Sand	94	45.8040894 N	84.77073743 W
									North/Sand	95	45.80419549 N	84.77069364 W
W-15	37	0.5	260' to W-16	37	38	39	45	37	South/Sand	96	45.80488293 N	84.7704441 W
									North/Sand	97	45.80498015 N	84.77040304 W
W-17				NA	Filled in	23	36	26	NA	NA	NA	NA
									NA	NA	NA	NA
W-18A_A	8	2	162' to W-15	14	15	15	16		South/Sand	105	45.80541373 N	84.77023722 W
									North/Anchor (2006)	106	45.80543625 N	84.77022891 W
W-18A South	42	2.5	Shared Touch Down ^	42	41	100	99		South/Anchor (2006)	106	45.80543625 N	84.77022891 W
									North/Anchor (2010)	113	45.80554847 N	84.7701857 W

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W-18A North	55	2	Shared Touch Down ^	55	55				South/Anchor (2010)	113	45.80554847 N	84.7701857 W
									North/Anchor (2004)	117	45.80569713 N	84.77013121 W
W-18B South	62	1	Shared Touch Down ^	82	91	93	87	95	South/Anchor (2004)	117	45.80569713 N	84.77013121 W
									North/Anchor (2014)	120	45.80586207 N	84.77007142 W
W-18B North	24		Shared Touch Down ^						South/Anchor (2014)	120	45.80586207 N	84.77007142 W
									North/Sand	120	45.80592331 N	84.77004434 W
W-20	22'	0.5	48' to W18B	27	47	45	46	49	South/Sand	122	45.80605223 N	84.77000235 W
									North/Sand	122	45.80610853 N	84.76997572 W
W-24A	12	2.5	38' to W-20	17	90	82	86	87	South/Sand	122	45.80620743 N	84.76993569 W
									North/Anchor (2012)	123	45.80623916 N	84.76992226 W
W-24B	70	2	Shared Touch Down ^	69					South/Anchor (2012)	123	45.80623916 N	84.76992226 W
									North/Sand	122	45.80642502 N	84.76984642 W
W-23A	49	0.5	21' to W-24 North	63	63	62	61	68	South/Sand	123	45.80648154 N	84.76982185 W
									North/Anchor (2004)	124	45.80661144 N	84.76977471 W
W-23B	36	1	Shared Touch Down ^	23	57	57	56	56	South/Anchor (2004)	124	45.80661144 N	84.76977471 W
									North/Sand	124	45.80670768 N	84.76973934 W
W-22	30	2	66' to W-23B	33	34	31	37	39	South/Sand	124	45.80688201 N	84.76967483 W
									North/Sand	123	45.80696092 N	84.76964449 W
W-21	51	2	61' to W-22	50	60	58	65	59	South/Sand	124	45.80712413 N	84.76958849 W
									North/Sand	126	45.80725987 N	84.76954174 W
W-25	NA			Silted in	9	30	34	41	NA	NA	NA	NA
									NA	NA	NA	NA
W-26	54	1	226' to W-21	53	66	71	72	64	South/Sand	126	45.8078569 N	84.76930883 W
									North/Sand	128	45.8079986 N	84.76925521 W
W-27	NA		NA	Silted in	12	17	23	19	NA	NA	NA	NA
									NA	NA	NA	NA
W-30	54	1.5	160 to W-26	57	62	62	62	60	South/Sand	130	45.80842054 N	84.76909002 W
									North/Sand	132	45.80856243 N	84.76903767 W
W-28A South	6	3	156' to W-30	70	77	77	84	73	South/Clay	132	45.80897784 N	84.76888725 W
									North/Anchor (2014)	133	45.80899415 N	84.76888196 W
W-28A North	65		Shared Touch Down ^						South/Anchor (2014)	133	45.80899415 N	84.76888196 W
									North/Anchor (2003)	135	45.80916534 N	84.76881592 W
W-28B	59	2	Shared Touch Down ^	67	70	50	58	58	South/Anchor (2003)	135	45.80916534 N	84.76881592 W
									North/Clay	133	45.80932154 N	84.76874888 W
W-28	35	1	15' to W28B	30	34	34	30	28	South/Clay	133	45.80936143 N	84.76873716 W
									North/Clay	133	45.80945076 N	84.76870155 W
W-76				Silted in	20	16	18		NA	NA	NA	NA
									NA	NA	NA	NA
W-31A South	38	0.5	116' to W-28	90	90	89	92	92	Clay	132	45.80975754 N	84.76858567 W
									North/Anchor (2014)	134	45.80985984 N	84.76855131 W
W-31A North	51		Shared Touch Down ^						South/Anchor (2014)	134	45.80985984 N	84.76855131 W
									North/Anchor (2004)	134	45.80999344 N	84.76849255 W
W-31B South	54	0.5	Shared Touch Down ^	78	75	86	83	84	South/Anchor (2004)	134	45.80999344 N	84.76849255 W
									North/Anchor (2014)	135	45.81014042 N	84.7684405 W
W-31B North	25		Shared Touch Down ^						South/Anchor (2014)	135	45.81014042 N	84.7684405 W
									North/Grout Bags (2001)	134	45.81020833 N	84.76841199 W
W-34A	26	0.5	14' to W-31B North	Silted in	17	10	17		South/Sand	134	45.81024645 N	84.76840035 W
									North/Anchor (2006)	134	45.81031762 N	84.76836946 W
W-34B South	64	1	Shared Touch Down ^	64	97	108	110		South/Anchor (2006)	134	45.81031762 N	84.76836946 W
									North/Anchor (2010)	133	45.81048695 N	84.76830706 W
W-34B North	38	1	Shared Touch Down ^	35					South/Anchor (2010)	133	45.81048695 N	84.76830706 W

Span Identifier	2014 Length	2014 Span Height	2014 Support Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude
W-34B North	58	1	Shared Touch Down ^	55					North/Sand	130	45.81058605 N	84.76827156 W
W-37A	43	1	37' to W-34B North	79	76	79	101		South/Sand	129	45.81068589 N	84.76823233 W
									North/Anchor (2014)	130	45.8108011 N	84.76819354 W
W-37B	36		Shared Touch Down ^						South/Anchor (2014)	130	45.8108011 N	84.76819354 W
									North/Sand	130	45.81089642 N	84.76815787 W
W-36A	37	1.5	29' to W37	37	38	39	38		South/Sand	127	45.81097249 N	84.76812596 W
									North/Anchor (2006)	127	45.81107112 N	84.76809122 W
W-36B	54	1.5	Shared Touch Down ^	50	51	53	49		South/Anchor (2006)	127	45.81107112 N	84.76809122 W
									North/Grout Bags (2001)	126	45.81121511 N	84.76804264 W
W-35A	27	0.5	Shared Touch Down ^	32	33	25	31	33	South/Grout Bags (2001)	126	45.81121511 N	84.76804264 W
									North/Anchor (2004)	125	45.81128571 N	84.76801092 W
W-35B South	61	0.5	Shared Touch Down ^	79	89	90	90	87	South/Anchor (2004)	125	45.81128571 N	84.76801092 W
									North/Anchor (2014)	121	45.81144798 N	84.76795339 W
W-35B North	24		Shared Touch Down ^						South/Anchor (2014)	121	45.81144798 N	84.76795339 W
									North/Sand	119	45.81150905 N	84.76792436 W
W-38	59	1	68' to W35B	Merged	47	36	31	34	South/Sand	120	45.81168887 N	84.76784301 W
W-39				53	26	27	31	17	North/Anchor (2005)	122	45.81184558 N	84.76778121 W
W-40	45	1	Shared Touch Down ^	44	50	46	44	54	South/Anchor (2005)	122	45.81184558 N	84.76778121 W
									North/Sand	124	45.81196638 N	84.76774431 W
W-41A South	37	1.5	170' to W40	42	90	87	88	87	South/Sand	131	45.8124196 N	84.76757785 W
									North/Anchor (2012)	138	45.8125168 N	84.76753502 W
W-41A North	48	1.5	Shared Touch Down ^	49					South/Anchor (2012)	138	45.8125168 N	84.76753502 W
									North/Anchor (2004)	143	45.8126456 N	84.76748895 W
W-41B	69	1	Shared Touch Down ^	66	73	73	68	65	South/Anchor (2004)	143	45.8126456 N	84.76748895 W
									North/Sand	150	45.81282522 N	84.76741618 W
W-43A	64	2	32 to W-41B	64	63	59	64	68	South/Sand	154	45.81290732 N	84.7673873 W
									North/Anchor (2003)	162	45.81307278 N	84.76732484 W
W-43B	65	2	Shared Touch Down ^	68	67	69	64	62	South/Anchor (2003)	162	45.81307278 N	84.76732484 W
									North/Clay	169	45.81324384 N	84.76726106 W
W-42A	71	1.5	18' to W43B	70	72	67	73	73	South/Clay	169	45.81329129 N	84.76724157 W
									North/Anchor (2003)	168	45.81348091 N	84.76717734 W
W-42B	67	1	Shared Touch Down ^	71	71	77	69	75	South/Anchor (2003)	168	45.81348091 N	84.76717734 W
									North/Sand	164	45.81366089 N	84.76711461 W
W-45	35	0.5	9' to W42B	27	25	27	26	24	South/Sand	163	45.81368538 N	84.76710678 W
									North/Sand	163	45.81377639 N	84.76707143 W
W-46	54	1	50' to W45	44	53	82	82	77	South/Sand	163	45.81390759 N	84.76701534 W
									North/Sand	163	45.81405037 N	84.76696836 W
W-47	41	1.5	150' to W46	37	61	69	67	62	South/Clay	172	45.81444824 N	84.76681747 W
									North/Clay	170	45.81455828 N	84.76677736 W
W-51A	16	1.5	20' to W47	14	14	11	20		South/Clay	170	45.81461201 N	84.76675686 W
									North/Anchor (2006)	170	45.81465648 N	84.7667401 W
W-51B South	58	1	Anchor	82	84	81	80		South/Anchor (2006)	170	45.81465648 N	84.7667401 W
									North/Anchor (2014)	174	45.81481348 N	84.76668449 W
W-51B North	24								South/Anchor (2014)	174	45.81481348 N	84.76668449 W
									North/Clay	172	45.81487608 N	84.76665789 W
W-50	20	0.5	38' to W51B	Filled in	23	18	26	12	South/Clay	172	45.81497406 N	84.76661907 W
									North/Clay	172	45.81502565 N	84.76660073 W
W-49	50	1.5	29' to W50	54	52	61	47	47	South/Clay	172	45.81510113 N	84.76656607 W
									North/Clay	170	45.81523798 N	84.76652427 W
W-48A	54	1	3' to W49	61	57	60	59	63	South/Clay	170	45.81524574 N	84.76652191 W
									North/Anchor (2003)	177	45.81539218 N	84.76646868 W
W-48B	63	1	Shared Touch Down ^	67	79	59	72	66	South/Anchor (2003)	177	45.81539218 N	84.76646868 W

Span Identifier	2014 Length	2014 Span Height	2014 Support Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	North/Clay	176	45.81555569 N	84.76639198 W
W-52	59	1	14' to W48B	60	91	61	63	66	South/Clay	175	45.81559247 N	84.76637538 W
									North/Clay	174	45.81574877 N	84.76632003 W
W-53A	69	1	96' to W52	67	77	67	75		South/Clay	169	45.8160056 N	84.76622468 W
									North/Anchor (2005)	169	45.81618886 N	84.76615963 W
W-53B	26	0.5	Shared Touch Down ^	25	31	42	39		South/Anchor (2005)	169	45.81618886 N	84.76615963 W
									North/Clay	170	45.81625886 N	84.76613285 W
W-70 A	42	0.5	109' to W53B	43	114	100	109		South/Clay	172	45.81654866 N	84.76602166 W
									North/Anchor (2010)	175	45.81666162 N	84.76597665 W
W-70 B	36	0.5	Shared Touch Down ^	25					South/Anchor (2010)	175	45.81666162 N	84.76597665 W
									North/Clay	175	45.81675578 N	84.76594127 W
W-69	64	0.5	55' to W70B	70	96	98	81	88	South/Clay	178	45.81690174 N	84.76588593 W
									North/Clay	182	45.81707239 N	84.76582266 W
W-68A South	11	1	105' to W69	77	85	75	83	69	South/Clay	190	45.81735651 N	84.7657183 W
									North/Anchor (2014)	192	45.8173852 N	84.76570621 W
W-68A North	66		Shared Touch Down ^						South/Anchor (2014)	192	45.8173852 N	84.76570621 W
									North/Anchor(2003)	191	45.81756257 N	84.7656429 W
W-68B	62	1	Shared Touch Down ^	60	43	48	41	50	South/Anchor (2003)	191	45.81756257 N	84.7656429 W
									North/Clay	196	45.81772359 N	84.76557989 W
W-71A	26	1	88' to W68B	77	84	81	84	67	SouthClay	217	45.81795369 N	84.76549024 W
									North/Anchor (2014)	224	45.81802422 N	84.76546477 W
W-71B	55		Shared Touch Down ^						South/Anchor (2014)	224	45.81802422 N	84.76546477 W
									North/Anchor (2003)	232	45.81816946 N	84.76541244 W
W-72A South	57	1.5	Shared Touch Down ^	57	105	107	108	108	South/Anchor (2003)	232	45.81816946 N	84.76541244 W
									North/Anchor (2012)	232	45.81831983 N	84.76535345 W
W-72A North	47	1	Shared Touch Down ^	47					South/Anchor (2012)	232	45.81831983 N	84.76535345 W
									North/Anchor (2004)	238	45.81844653 N	84.76530393 W
W-72B South	35	1.5	Shared Touch Down ^	36	100	100	98	99	South/Anchor (2004)	238	45.81844653 N	84.76530393 W
									North/Anchor (2012)	242	45.81854156 N	84.76526921 W
W-72B North	61	1.5	Shared Touch Down ^	61					South/Anchor (2012)	242	45.81854156 N	84.76526921 W
									North/Anchor (2004)	246	45.81870788 N	84.76521301 W
W-72C	54	2	Shared Touch Down ^	59	56	65	52	56	South/Anchor (2004)	246	45.81870788 N	84.76521301 W
									North/Clay	244	45.81885056 N	84.76516087 W
W-75	61	1	19' to W72C	52	77	57	54	44	South/Clay	243	45.81890246 N	84.76513828 W
									North/Clay	241	45.819066 N	84.76508084 W
W-56	57	1	72' to W75	59	67	58	60	61	South/Clay	237	45.81925852 N	84.76501189 W
									North/Clay	238	45.81940715 N	84.76495466 W
W-78				NA	Filled in	16	15		NA	NA	NA	NA
									NA	NA	NA	NA
W-54A	56	1	172' to W56	56	55	53	60		South/Clay	234	45.81986479 N	84.7647835 W
									North/Anchor (2005)	232	45.82001287 N	84.76473484 W
W-54B	51	1.5	26' to W54A	49	88	87	86		South/Clay	232	45.82008325 N	84.76470314 W
									North/Clay	232	45.8202238 N	84.76465785 W
W-57A	43	2.5	65' to W54B	79	77	67	78	75	South/Clay	230	45.82040018 N	84.76459954 W
									North/Anchor (2014)	230	45.8205126 N	84.76455633 W
W-57B	40		Shared Touch Down ^						South/Anchor (2014)	230	45.8205126 N	84.76455633 W
									North/Clay	228	45.82061962 N	84.76451859 W
W-59A-A				Silted in	6	33			NA	NA	NA	NA
									NA	NA	NA	NA
W-59A South	36	2.5	319' to W-57	45	90	91	130		South/Anchor (2006)	221	45.82146702 N	84.76420828 W
									North/Anchor (2012)	221	45.82156234 N	84.76416991 W

Span Identifier	2014 Length	2014 Span Height	2014 Support Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude
W-59A North	53	2.5	Shared Touch Down ^	47					South/Anchor (2012)	221	45.82156234 N	84.76416991 W
									North/Anchor (2003)	219	45.82170276 N	84.76412053 W
W-59B South	41	3	Shared Touch Down ^	52	104	97	100		South/Anchor (2003)	219	45.82170276 N	84.76412053 W
									North/Anchor (2012)	219	45.82180891 N	84.7640712 W
W-59B North	56	3	Shared Touch Down ^	45					South/Anchor (2012)	219	45.82180891 N	84.7640712 W
									North/Anchor (2003)	212	45.82195831 N	84.76401066 W
W-58A South	62	2	Shared Touch Down ^	62	126	132	131		South/Anchor (2003)	212	45.82195831 N	84.76401066 W
									North/Anchor (2010)	207	45.82212511 N	84.76395711 W
W-58A North	70	2.5	Shared Touch Down ^	70					South/Anchor (2010)	207	45.82212511 N	84.76395711 W
									North/Anchor (2003)	190	45.82230838 N	84.7638836 W
W-58B	35	1.5	Shared Touch Down ^	36	38	30	28		South/Anchor (2003)	190	45.82230838 N	84.7638836 W
									North/Clay	183	45.8224028 N	84.76385368 W
W-60A	56	1.5	137' to W58B	58	55	52	60	62	South/Clay	165	45.82276582 N	84.76370893 W
									North/Anchor (2003)	160	45.82291533 N	84.7636541 W
W-60B South	50	2	Shared Touch Down ^	70	90	91	86	89	South/Anchor (2003)	160	45.82291533 N	84.7636541 W
									North/Anchor (2012)	155	45.82304668 N	84.76359861 W
W-60B North	33	2	Shared Touch Down ^	20					South/Anchor (2012)	155	45.82304668 N	84.76359861 W
									North/Clay	148	45.82313538 N	84.76356789 W
W-79				Silted in	15	16			NA	NA	NA	NA
									NA	NA	NA	NA
W-61A	27	1	83' to W60B	72	80	85	79	84	South/Clay	135	45.82335415 N	84.76349054 W
									North/Anchor (2014)	132	45.82342456 N	84.76346306 W
W-61B	45		Shared Touch Down ^						South/Anchor (2014)	132	45.82342456 N	84.76346306 W
									North/Clay	125	45.82354201 N	84.76341513 W
W-62	44	1	351 to W61	46	49	45	44	38	South/Sand	91	45.82447624 N	84.76309011 W
									North/Sand	89	45.82459253 N	84.76304185 W
W-63A	54	1.5	282 to W-62	66	57	49	57	55	South/Sand	78	45.82534041 N	84.76275039 W
									North/Anchor (2004)	78	45.82548661 N	84.7626958 W
W-63B	53	1.5	Shared Touch Down ^	50	54	54	49	51	South/Anchor (2004)	78	45.82548661 N	84.7626958 W
									North/Sand	76	45.8256262 N	84.76264017 W
W-65A	50	1.5	185' to W-63B	77	90	82	86	80	South/Sand	74	45.82611694 N	84.76246404 W
									North/Anchor (2014)	74	45.82624713 N	84.76241517 W
W-65B	26		Shared Touch Down ^						South/Anchor (2014)	74	45.82624713 N	84.76241517 W
									North/Sand	74	45.82631462 N	84.76238826 W
W-64A	18	1	8' to W-65	20	90	89	90	80	South/Sand	73	45.82633776 N	84.76238098 W
									North/Anchor (2012)	73	45.82638189 N	84.76235928 W
W-64B South	29	1	Shared Touch Down ^	71					South/Anchor (2012)	73	45.82638189 N	84.76235928 W
									North/Anchor (2014)	73	45.8264624 N	84.7623333 W
W-64B North	46		Shared Touch Down ^						South/Anchor (2014)	72	45.8264624 N	84.7623333 W
									North/Sand	72	45.82658693 N	84.76228562 W
W-67A	41	2'	98' to W-64N	89	87	89	100	86	South/Sand	72	45.8268466 N	84.76218543 W
									North/Anchor (2014)	72	45.82695668 N	84.762151 W
W-67B	50		Shared Touch Down ^						South/Anchor (2014)	72	45.82695668 N	84.762151 W
									North/Sand	70	45.82708749 N	84.76210055 W
W-66	43	1.5	196' to W-67	67	41	45	45	44	South/Sand	70	45.82760434 N	84.76191151 W
									North/Sand	70	45.82771752 N	84.76186138 W
Northern Exposure Point	NA	NA	100' to W-66	NA	NA	NA	NA	NA	Only/Sand	65	45.82798472 N	84.76176355 W

APPENDIX C

ENBDNR0002451



Photo 1 W KP 1.375



Photo 2 W KP 1.395



Photo 3 W KP 1.440



Photo 4 W KP 1.500



Photo 5 W KP 1.530



Photo 6 W KP 1.625



Photo 7 W KP 1.650



Photo 8 W KP 1.720

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #1-8



Photo 9 W KP 1.730



Photo 10 W KP 1.770



Photo 11 W KP 1.800



Photo 12 W KP 1.860



Photo 13 KP 1.925



Photo 14 W KP 1.935



Photo 15 W KP 1.955



Photo 16 W KP 1.985

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #9-16



Photo 17 W KP 2.015



Photo 18 W KP 2.020



Photo 19 W KP 2.030



Photo 20 W KP 2.040



Photo 21 W KP 2.045



Photo 22 W KP 2.060



Photo 23 W KP 2.070

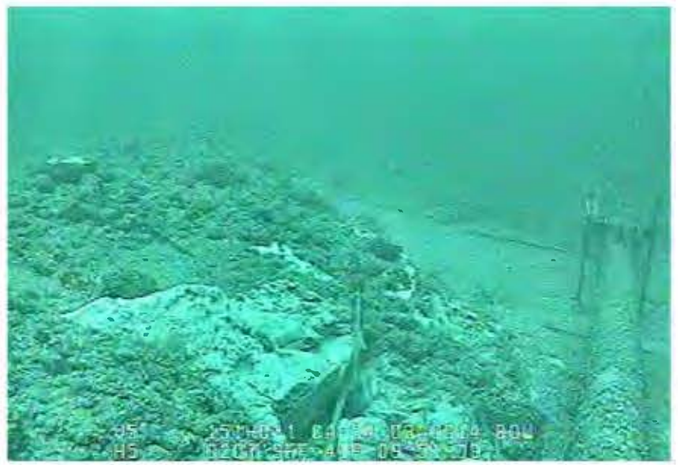


Photo 24 W KP 2.070

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #17-24



Photo 25 W KP 2.075



Photo 26 W KP 2.080



Photo 27 W KP 2.090



Photo 28 W KP 2.105



Photo 29 W KP 2.120

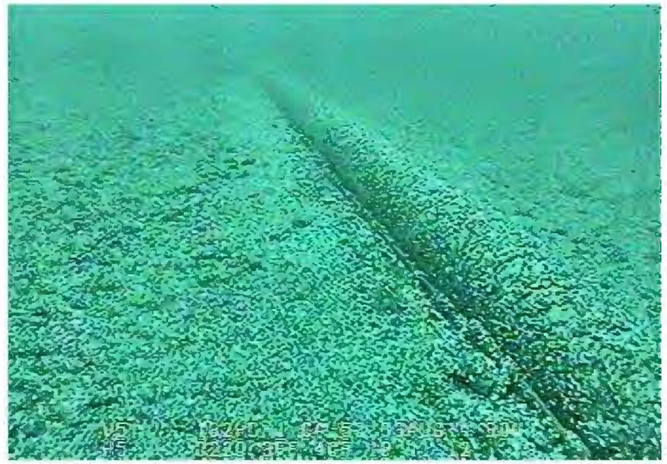


Photo 30 W KP 2.180



Photo 31 W KP 2.215



Photo 32 W KP 2.235

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #25-32



Photo 33 W KP 2.270



Photo 34 W KP 2.310



Photo 35 W KP 2.320



Photo 36 W KP 2.365

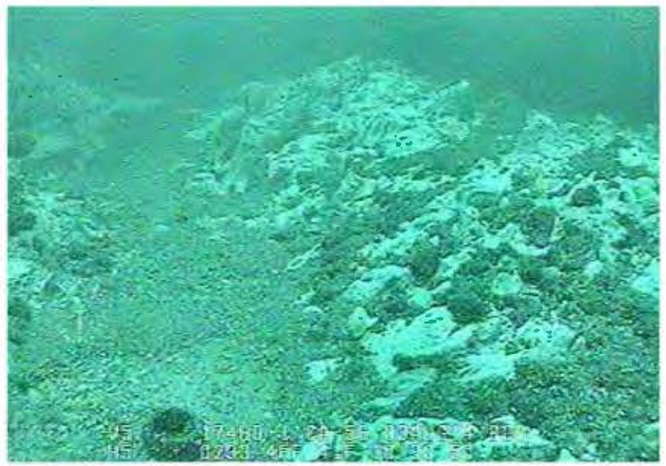


Photo 37 W KP 2.380



Photo 38 W KP 2.400



Photo 39 W KP 2.435



Photo 40 W KP 2.440

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #33-40



Photo 41 W KP 2.460



Photo 42 W KP 2.475



Photo 43 W KP 2.485



Photo 44 W KP 2.520



Photo 45 W KP 2.530



Photo 46 W KP 2.565



Photo 47 W KP 2.585



Photo 48 W KP 2.625

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #41-48



Photo 49 W KP 2.665

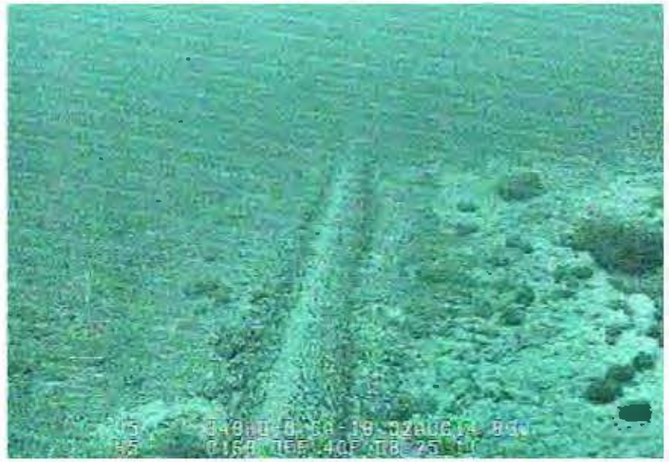


Photo 50 W KP 2.690



Photo 51 W KP 2.780

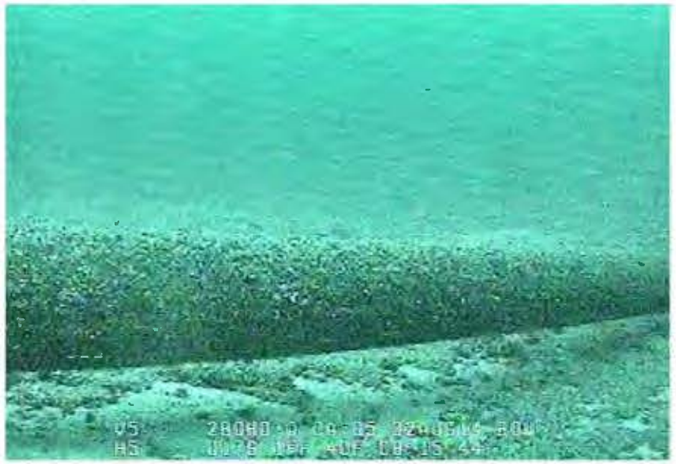


Photo 52 W KP 2.805



Photo 53 W KP 2.825



Photo 54 W KP 2.840



Photo 55 W KP 2.850



Photo 56 W KP 2.920

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #49-56

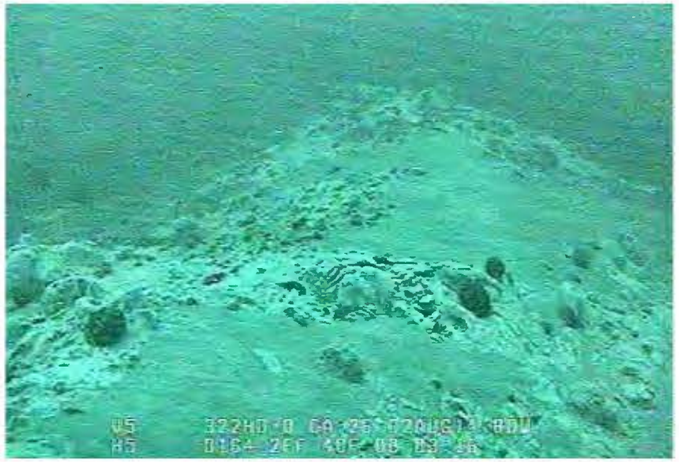


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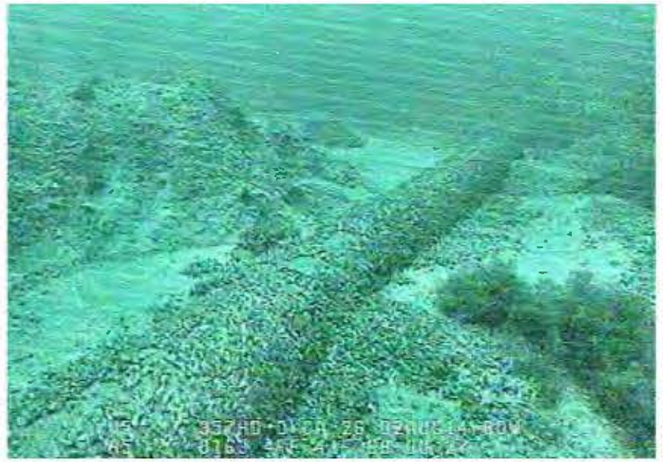


Photo 58 W KP 3.000



Photo 59 W KP 3.051



Photo 60 W KP 3.120



Photo 61 W KP 3.140



Photo 62 W KP 3.200



Photo 63 W KP 3.240



Photo 64 W KP 3.250

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #57-64

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Photo 65 W KP 3.280



Photo 66 W KP 3.330



Photo 67 W KP 3.365



Photo 68 W KP 3.440



Photo 69 W KP 3.480



Photo 70 W KP 3.530



Photo 71 W KP 3.610



Photo 72 W KP 3.625

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #65-72



Photo 73 W KP 3.725



Photo 74 W KP 3.770



Photo 75 W KP 3.810



Photo 76 W KP 3.825



Photo 77 W KP 3.880



Photo 78 W KP 3.935



Photo 79 W KP 3.940



Photo 80 W KP 3.975

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #73-80



Photo 81 W KP 4.025



Photo 82 W KP 4.090



Photo 83 W KP 4.130



Photo 84 W KP 4.200



Photo 85 W KP 4.215



Photo 86 W KP 4.280



Photo 87 W KP 4.300



Photo 88 W KP 4.325

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #81-88



Photo 89 W KP 4.345



Photo 90 W KP 4.390



Photo 91 W KP 4.415



Photo 92 W KP 4.440



Photo 93 W KP 4.485



Photo 94 W KP 4.520



Photo 95 W KP 4.580



Photo 96 W KP 4.590

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #89-96



Photo 97 W KP 4.740



Photo 98 W KP 4.835



Photo 99 W KP 5.000



Photo 100 W KP 5.080

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #97-100



Photo 101 E KP 1.510



Photo 102 E KP 1.675



Photo 103 E KP 1.740



Photo 104 E KP 1.780



Photo 105 E KP 1.800



Photo 106 E KP 1.835



Photo 107 E KP 1.880



Photo 108 E KP 1.900

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #101-108



Photo 109 E KP 1.920



Photo 110 E KP 1.950



Photo 111 E KP 1.970



Photo 112 E KP 1.975



Photo 113 E KP 2.030



Photo 114 E KP 2.175



Photo 115 E KP 2.212



Photo 116 E KP 2.215

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #109-116



Photo 117 E KP 2.220



Photo 118 E KP 2.270



Photo 119 E KP 2.300



Photo 120 E KP 2.370



Photo 121 E KP 2.380



Photo 122 E KP 2.405



Photo 123 E KP 2.415



Photo 124 E KP 2.420

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #117-124



Photo 125 E KP 2.425



Photo 126 E KP 2.440

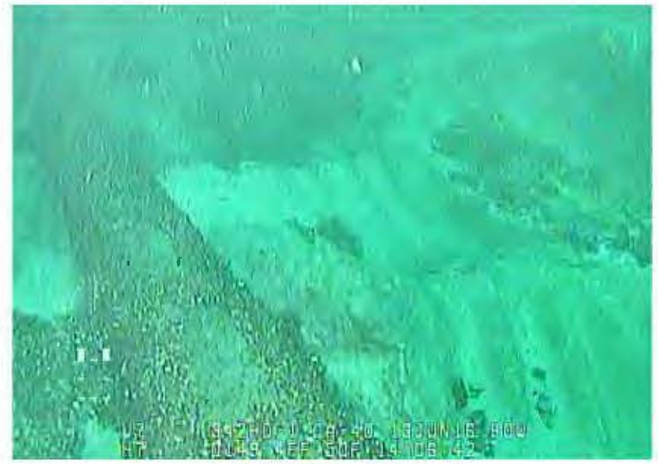


Photo 127 E KP 2.490



Photo 128 E KP 2.520

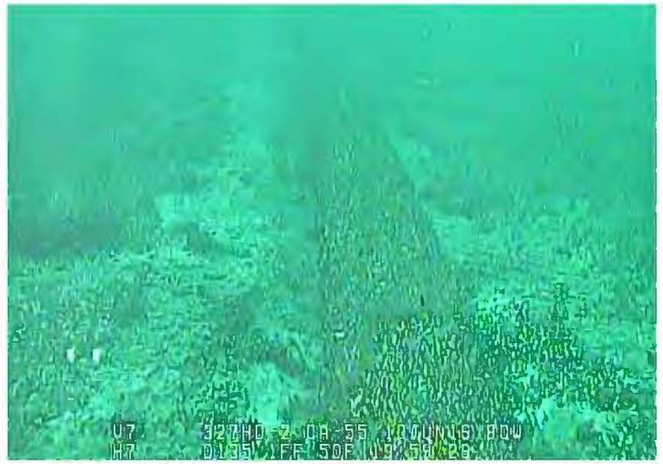


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Photo 130 E KP 2.615

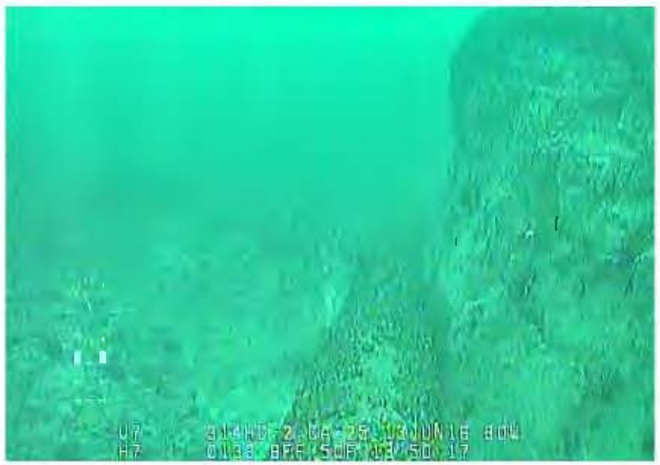


Photo 131 E KP 2.675



Photo 132 E KP 2.715

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Photo 133 E KP 2.720



Photo 134 E KP 2.775



Photo 135 E KP 2.935



Photo 136 E KP 2.945



Photo 137 E KP 2.970



Photo 138 E KP 3.010



Photo 139 E KP 3.020



Photo 140 E KP 3.030

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #133-140

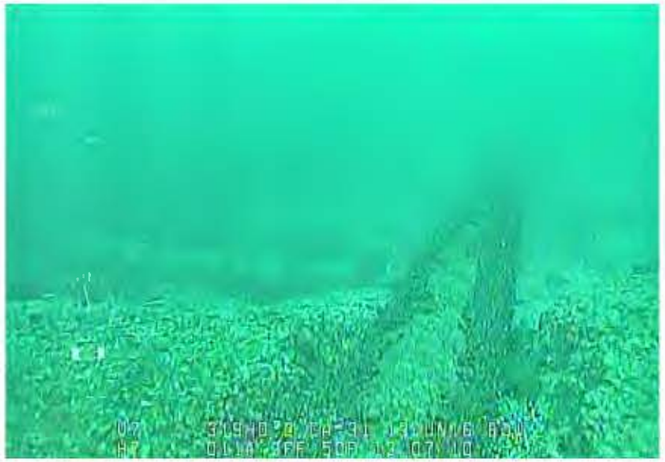


Photo 141 E KP 3.040



Photo 142 E KP 3.080

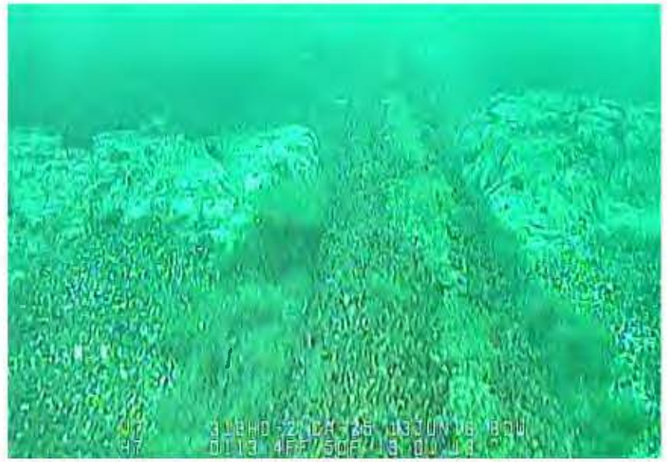


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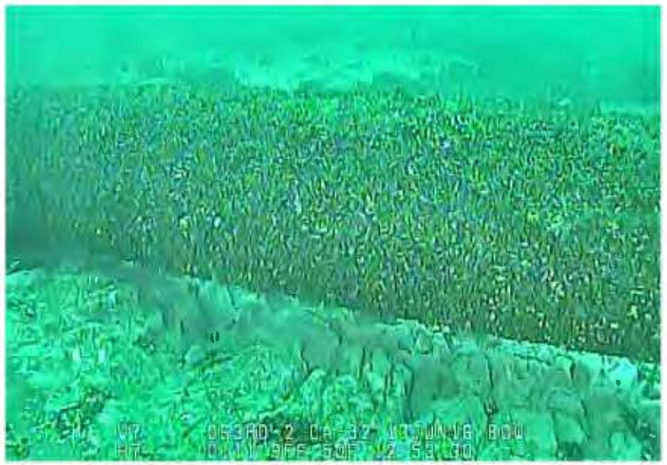


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Photo 145 E KP 3.170



Photo 146 E KP 3.180

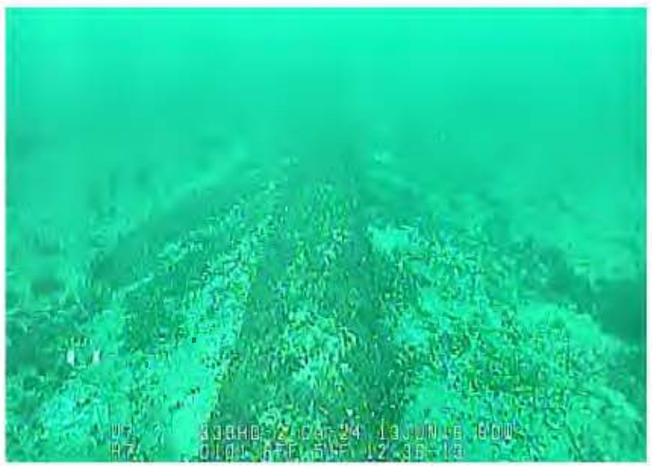


Photo 147 E KP 3.250



Photo 148 E KP 3.290

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #141-148

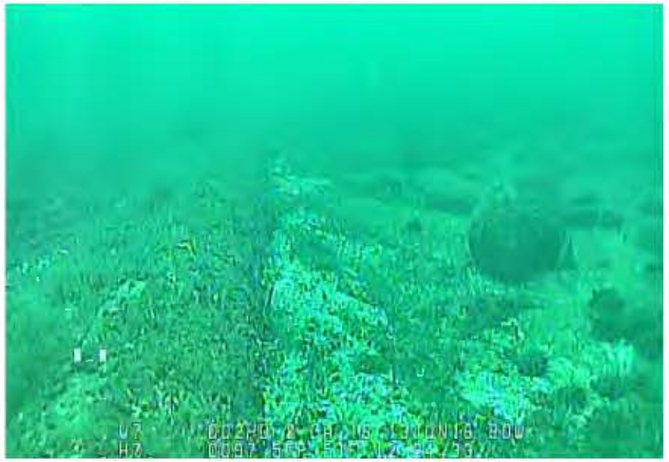


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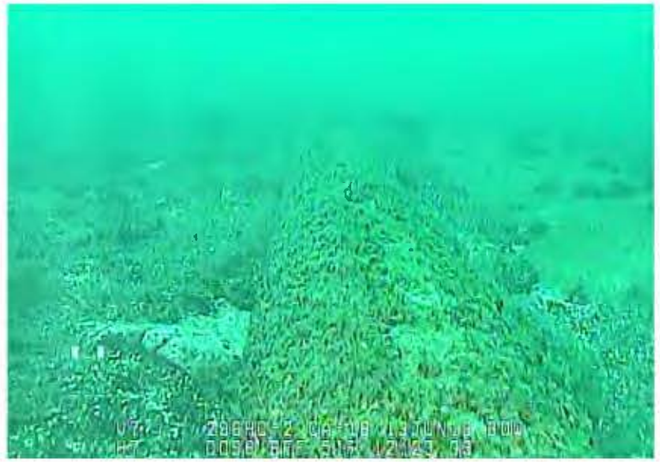


Photo 150 E KP 3.400



Photo 151 E KP 3.465



Photo 152 E KP 3.530



Photo 153 E KP 3.600



Photo 154 E KP 3.619



Photo 155 E KP 3.620



Photo 156 E KP 3.660

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #149-156



Photo 157 E KP 3.680



Photo 158 E KP 3.720



Photo 159 E KP 3.730



Photo 160 E KP 3.810



Photo 161 E KP 3.890



Photo 162 E KP 3.930



Photo 163 E KP 4.020



Photo 164 E KP 4.055

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #157-164



Photo 165 E KP 4.090



Photo 166 E KP 4.130



Photo 167 E KP 4.180



Photo 168 E KP 4.200



Photo 169 E KP 4.225



Photo 170 E KP 4.310



Photo 171 E KP 4.360



Photo 172 E KP 4.395

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #165-172



Photo 173 E KP 4.440



Photo 174 E KP 4.470



Photo 175 E KP 4.485



Photo 176 E KP 4.490



Photo 177 E KP 4.530

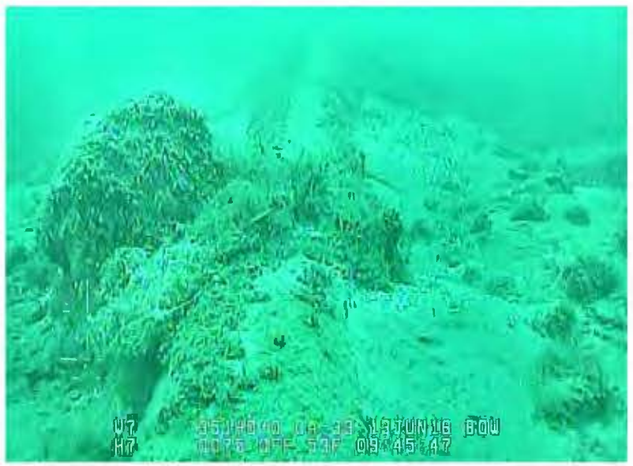


Photo 178 E KP 4.550



Photo 179 E KP 4.625



Photo 180 E KP 4.640

Client: Dynamic Risk Assessment Systems Inc.	Project: Independent Alternatives Analysis for the Straits Pipeline Geohazard Assessment Existing Pipeline	KELLY GEOTECHNICAL	Date: 2017-05-08 Photos Taken: Created By: Shane Kelly Project #: KGL-16-022 Photos: #173-180

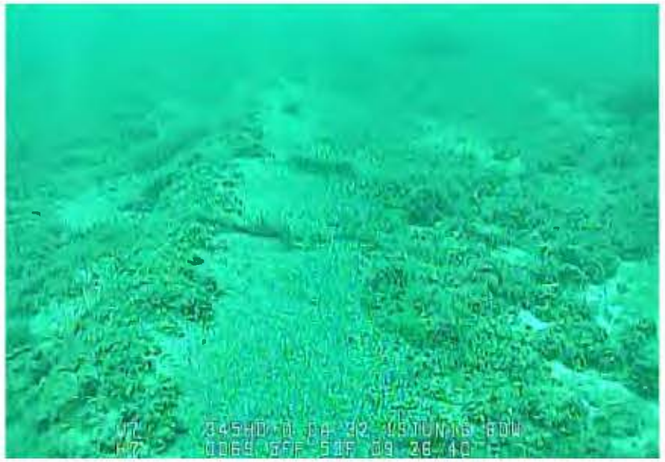


Photo 181 E KP 4.670



Photo 182 E KP 4.690



Photo 183 E KP 4.710



Photo 184 E KP 4.720



Photo 185 E KP 4.730



Photo 186 E KP 4.780



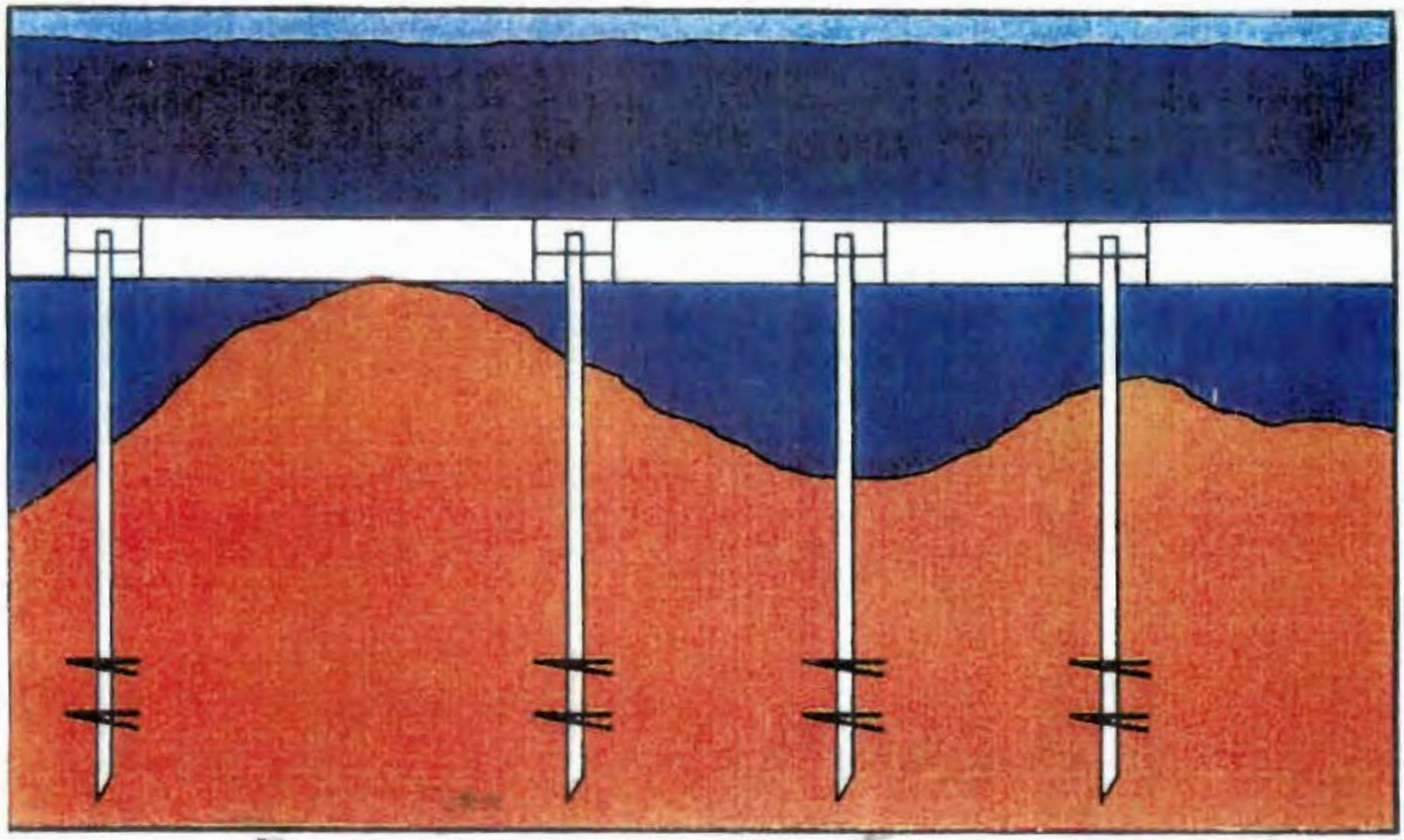
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APPENDIX D

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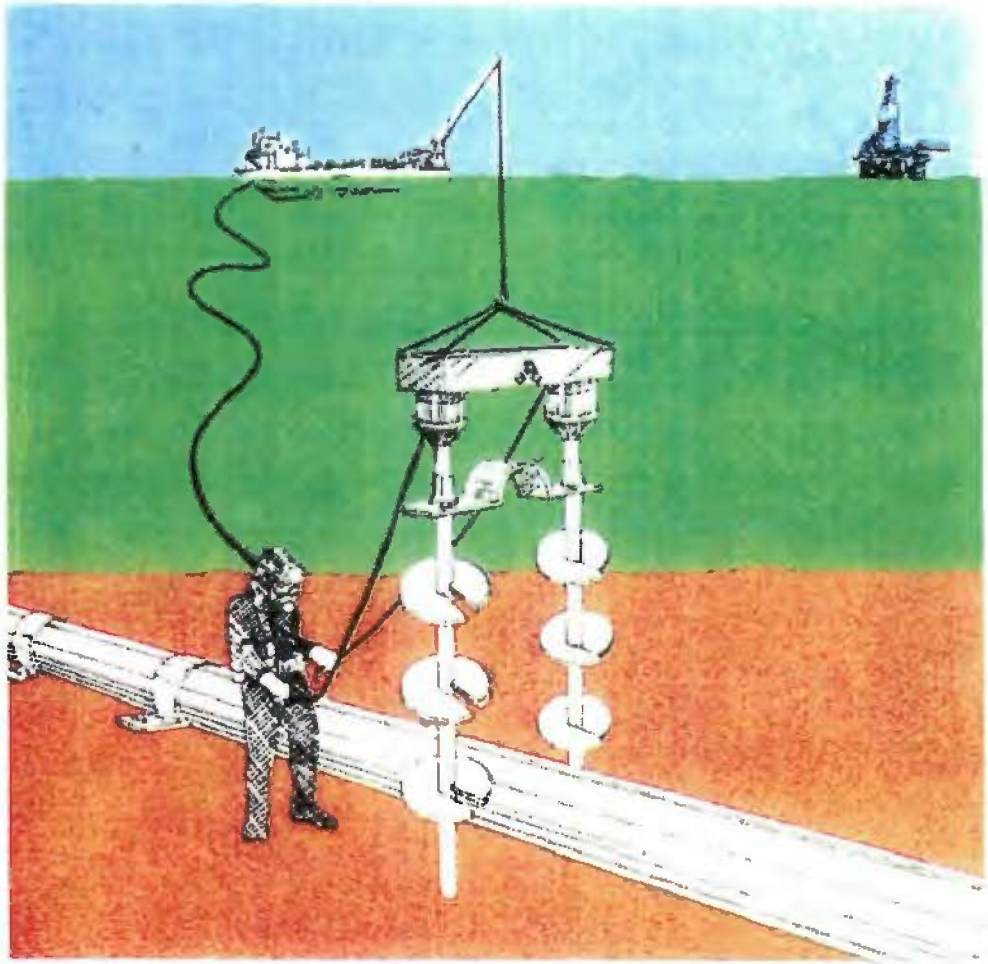
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Conceptual Design Installation

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DATE REVISED:	
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DRAWN BY: NREC	
SERIES: Underwater Inspections	

Natural Resources Engineering Co.
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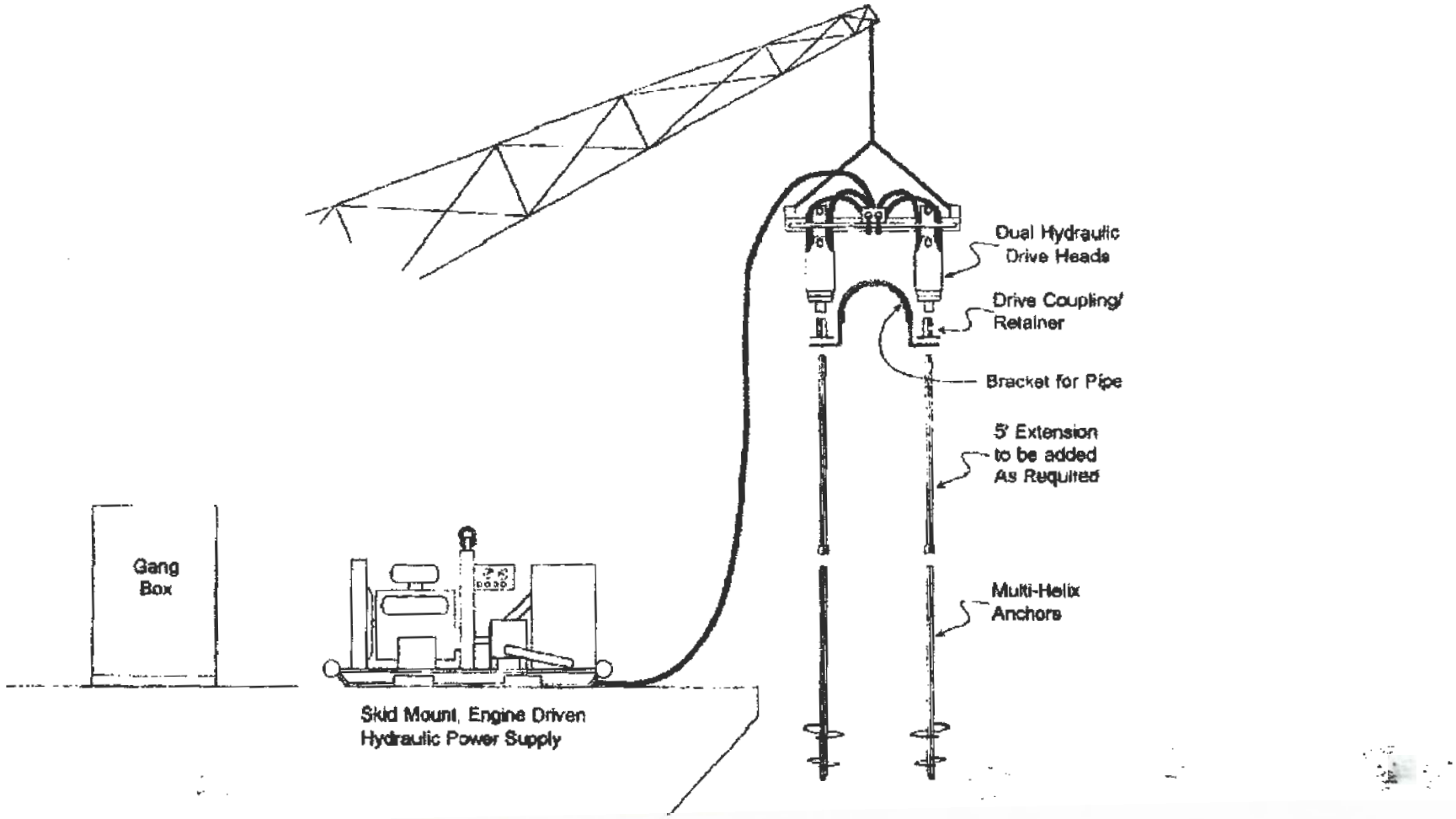
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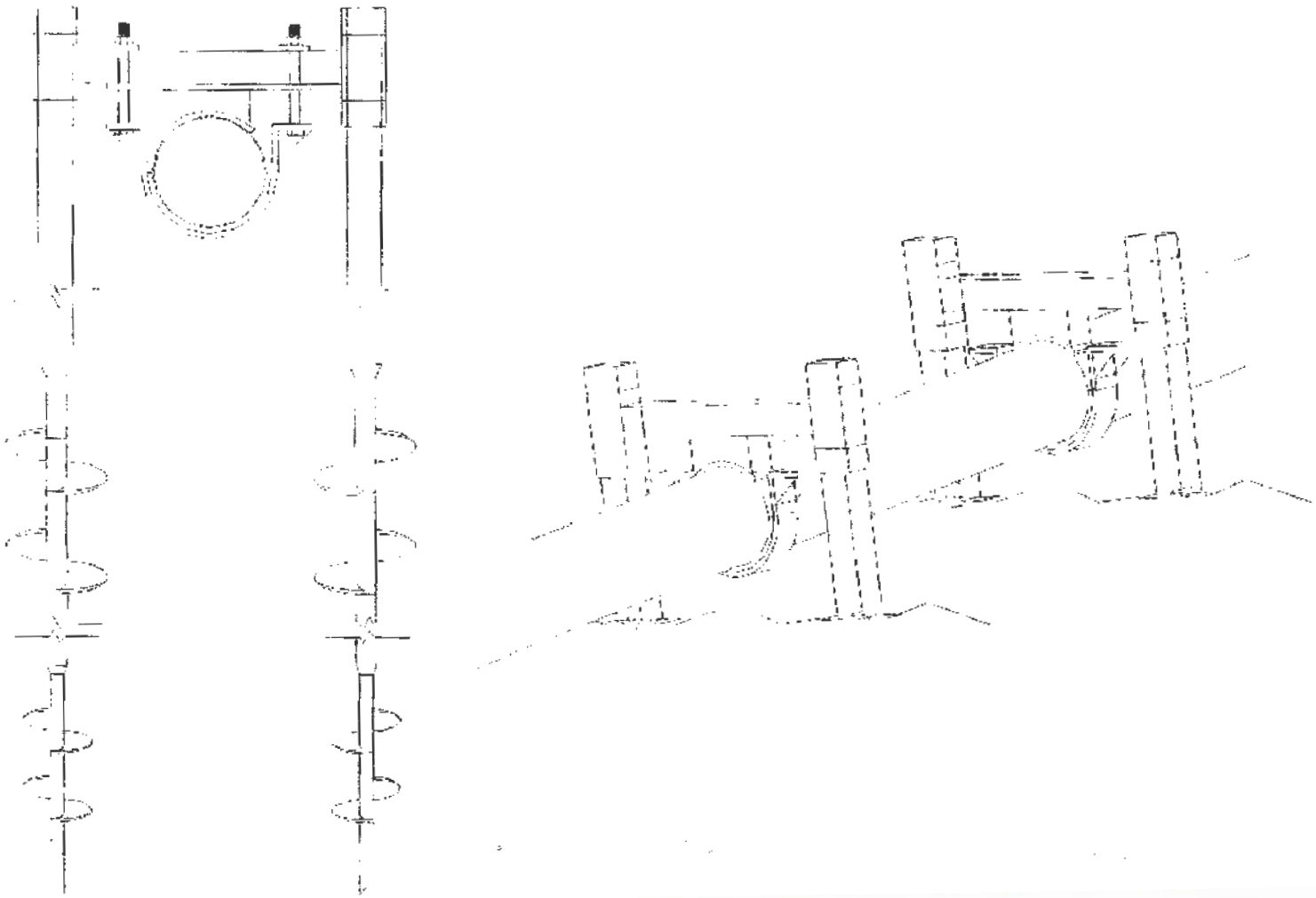
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Conceptual Design Equipment

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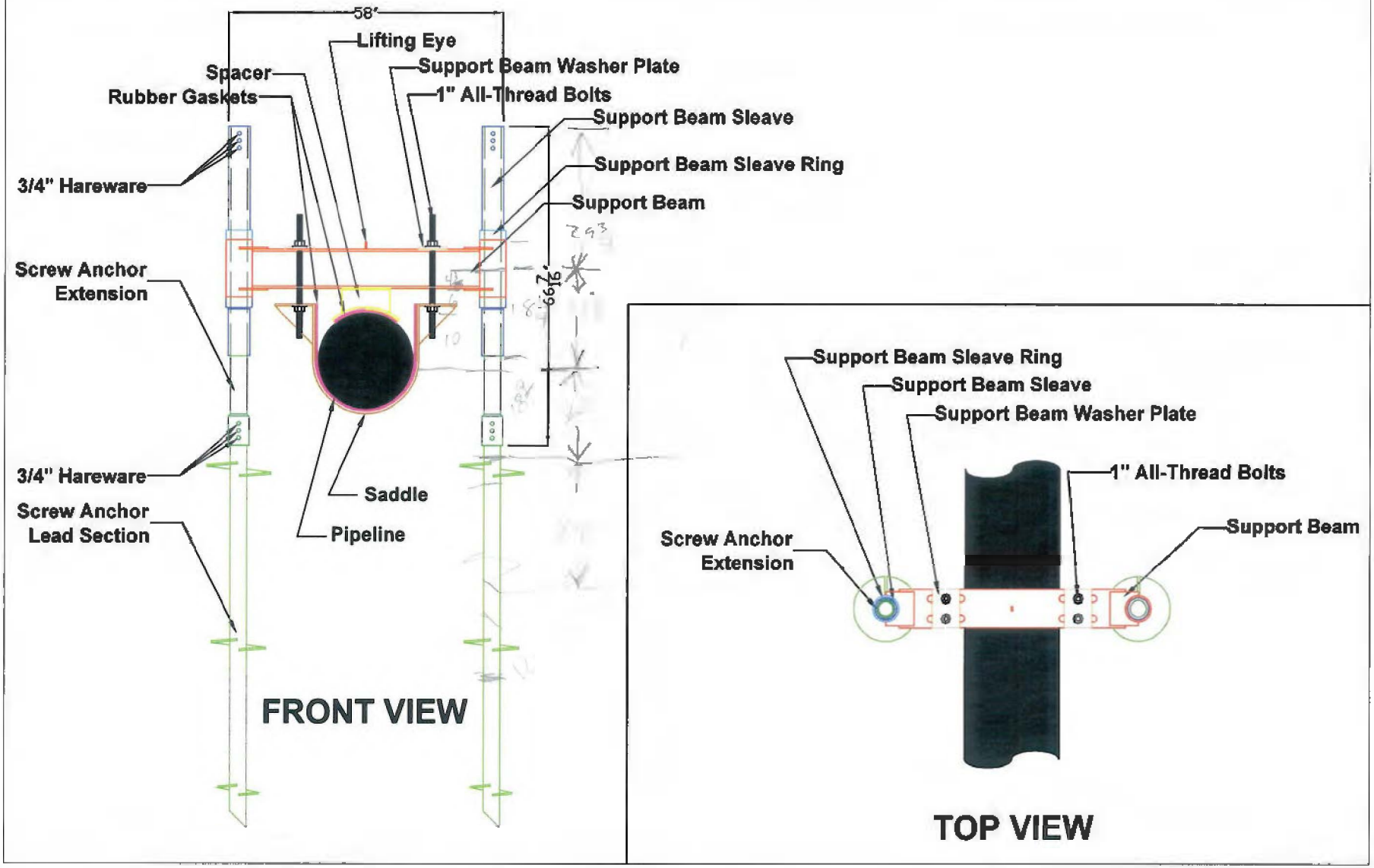
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Enbridge Pipelines (Lakehead), L.L.C.

Conceptual Design Installation

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DATE REVISED:	
SCALE:	Not to Scale
DRAWN BY:	NREC
SERIES:	Underwater Inspections

Natural Resources Engineering Co.
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ONYX

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Enbridge Energy
Pipeline Anchoring System
Straits of Mackinac

Drafter:	Trent Nedens
File Name:	Mack Screw Anchor Detail
Job #:	490159E.04.038
Date:	07/03/04
Drawing:	OSS - 001

ENBDNR0002481

APPENDIX E

ENBDNR0002482

GEOTECHNICAL REPORT

INDEPENDENT ALTERNATIVES ANALYSIS FOR THE STRAITS PIPELINE

GEOLOGICAL MODEL

PREPARED FOR

DYNAMIC RISK ASSESSMENT SYSTEMS INC.

CALGARY, AB

REVISION 1, 13 JUNE 2017

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1.0 INTRODUCTION

1.1 GENERAL

This report presents descriptions and summary geological conditions for a study area located within the vicinity of the Enbridge Line 5 pipeline corridor located within the Straits of Mackinac (the Straits). The purpose of the report is to provide summary references of data sources and conditions, and present a geological history of the ground conditions through the Straits. The term "Geological Model" is best used to summarize the content of the report as this definition describes a summary of conditions and spatial representation of geological materials within an area.

The information has been prepared by Kelly Geotechnical Ltd. (KGL) for Calgary, AB based Dynamic Risk Assessment Systems Inc. (Dynamic Risk) in support of a geohazard assessment for Dynamic Risk's project titled, "Independent Alternatives Analysis for the Straits Pipeline", (further referenced herein as the Project). This report has been prepared for the exclusive use of Dynamic Risk and its project team, and is intended to provide background geological information in support of a geohazard threat assessment. The report will be included as an appendix within an overall Geohazard Threat Assessment report by KGL.

1.2 DISSCUSSION ON DATA SOURCES

The geological information included has been taken from available desktop sources only. No fieldwork or field data collection has been undertaken, nor was any contemplated as part of this work.

The bedrock and surficial geology information presented in this report includes general geologic setting, geological history, formation descriptions, interpreted bedrock depth, and geomechanical properties and conditions from information available from existing published sources, with references noted through the report. It is noted that some data was collected from sources identified by the Michigan Department of Environmental Quality (DEQ), Office of Oil, Gas, and Minerals (OOGM) Digital Geology Library[1]. Descriptions, figures and tables extracted from this DEQ information are subject to a copyright notice[2]. Relevant findings from publicly-available documents related to detailed investigations for

[1] http://www.michigan.gov/documents/deq/GIMDL-Catalog-2010-01-20_307979_7.pdf

[2] Copyright © 2004 - 2013 by the Michigan Department of Environmental Quality (DEQ), Office of Oil, Gas, and Minerals (OOGM). The DEQ OOGM grants permission to publish or reproduce this document, electronically or in print, all or in part, for educational, non-profit purposes. The contents of this document or associated electronic documents, whole or in part, can be used if, and only if, additional fees are not associated with the use or

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Ontario Power Generation's (OPG'S) Deep Geologic Repository (DGR) for intermediate and low level waste at the Bruce nuclear site are also included. The Bruce DGR site, situated in the Municipality of Kincardine, Ontario close to the eastern shore of Lake Huron, is underlain by many of the same bedrock formations of the Michigan Basin as those at the Straits. The compiled information provides input and forms a geologic model of the Straits and a preliminary rock mechanics framework for evaluating tunneling options.

A specific location description of the Line 5 corridor and pipeline details are not provided in this report as it is restricted to the geological descriptions of the area only. The reader is referred to other project documents by Dynamic Risk that described the general Enbridge Line 5 pipeline system at the Straits.

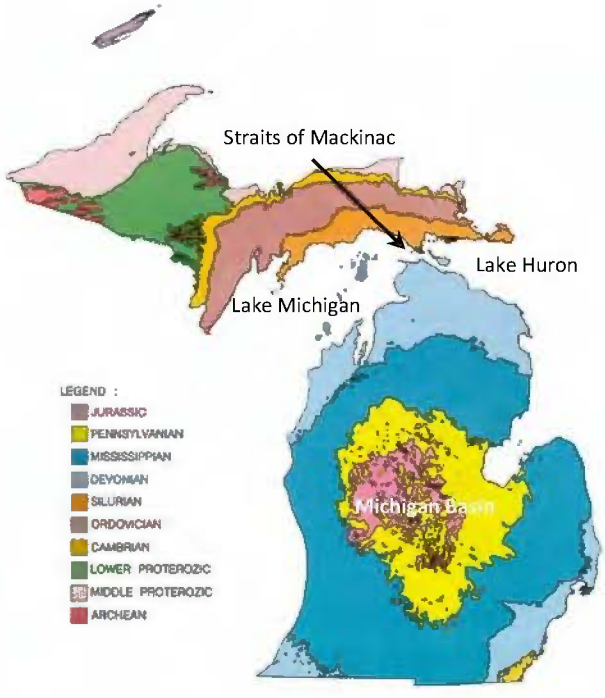


Figure 1 - General bedrock geology of Michigan showing location of Straits of Mackinac (http://www.michigan.gov/documents/deq/Bedrock_and_cross_section_301678_7.pdf)

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2.0 GEOLOGIC SETTING AND HISTORY

The Straits are located in the Michigan Basin between the northern Upper (St. Ignace) Peninsula and southern Lower (Mackinaw City) Peninsula of Michigan (Figure 1). The Straits and Peninsulas are underlain by sedimentary strata comprising limestones, dolomites, shales, and intergradations with salt and gypsum beds. Formations within the Michigan Basin dip gently toward a center about 170 miles south of the Straits. In the Straits area, the regional dip is gently southward at about 25 to 50 feet per mile from a point north of St. Ignace Peninsula, southward across the Straits (Berkey and Paige, undated). The boundary between Devonian (416.0 to 359.2 mya) and Silurian (443.7 to 416.0 mya) rock formations is located in the Straits. General stratigraphy and stratigraphic nomenclature for Michigan (Catacosinos et al., 2001) is shown in Figure 2.

The topography and overburden deposits that cover the bedrock in the Straits area were predominantly derived from glacial action in the region. One noteworthy condition that likely contributed to additional glacial scour and/or preferential erosion of the overall channel through the Straits area was the location of a brecciated bedrock zone that bounds the overall area. Kelley (1960) notes that Michigan area had been above sea level for about 200 my prior to glaciation, and thus the landscape was subject to erosion and it is suitable to assume that the great rivers and valley systems were present and draining eastward. The brecciated zone would have been exposed throughout this period. With the onset of glaciation across this ancient landscape, ultimately including all of Michigan, great ice sheets covered the area. The glaciers carved and deepened old valleys and rivers into wide basins.

During retreat of the ice, meltwater formed the first of the Great Lakes (Hough, 1953) about 24,000 years ago. Due to blocked drainage paths, a depressed-then-rebounding continental crust and episodic retreat of the ice front, the lakes were subject to significant change from their first emergence until they developed the present forms about 3,500 years ago. A US Army Corps of Engineers illustration of the major stages of the Great Lakes development is shown in Figure 3. The Mackinac Straits was consequently once the Mackinac River, draining eastward through a deep gorge from Lake Chippewa to the west into Lake Stanley to the east. It has also been in similar form, connecting the two lakes but at different elevations with the present channel exposed as valley slopes, and as well the area has been flooded to depths higher than the present-day lake level.

The processes driving these lake level changes led to the deposition of glacial drift, outwash deposits, and lacustrine materials that ultimately play important roles in the present-day overburden profile.

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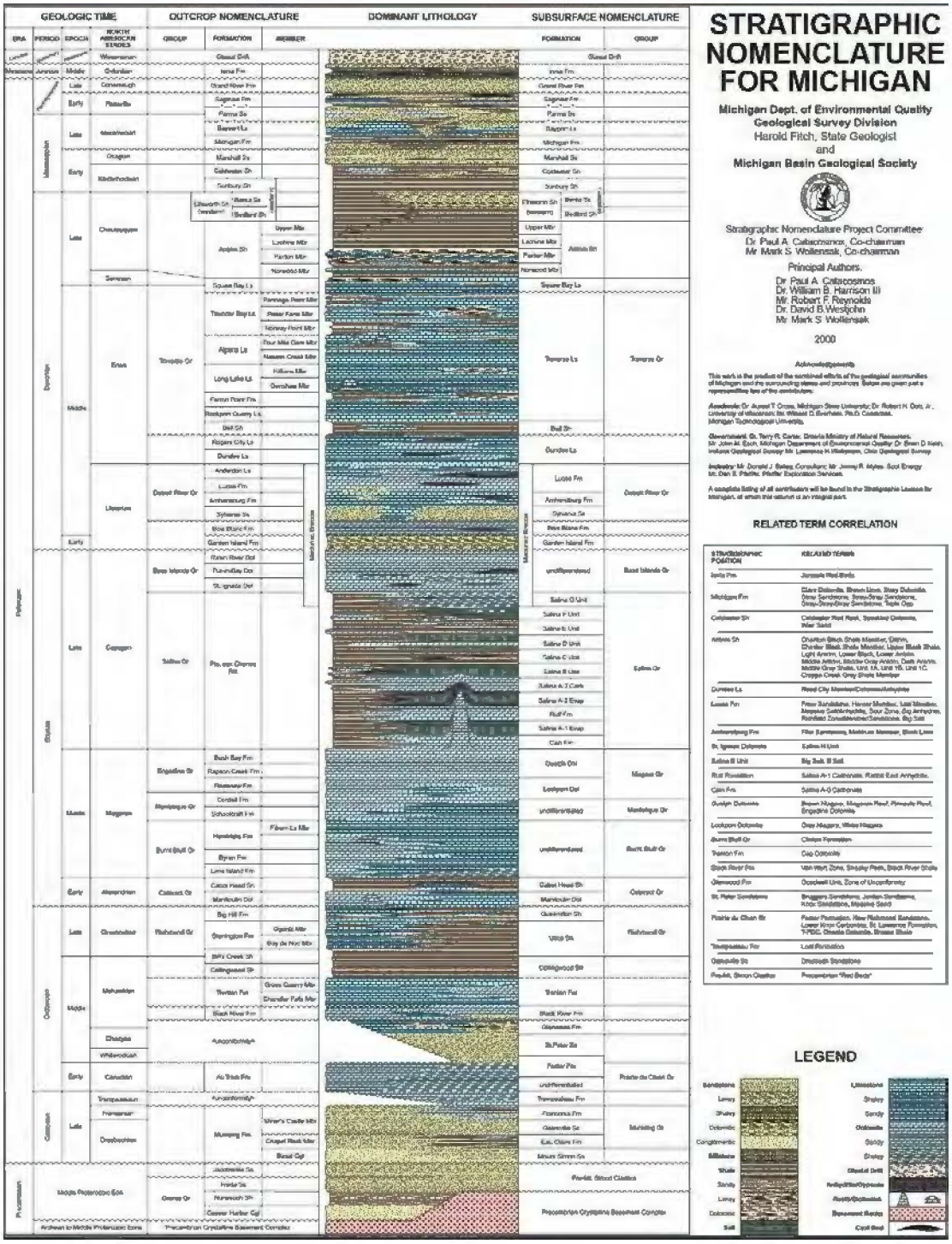


Figure 2- Stratigraphic nomenclature for Michigan (Catacosinos et al., 2001)

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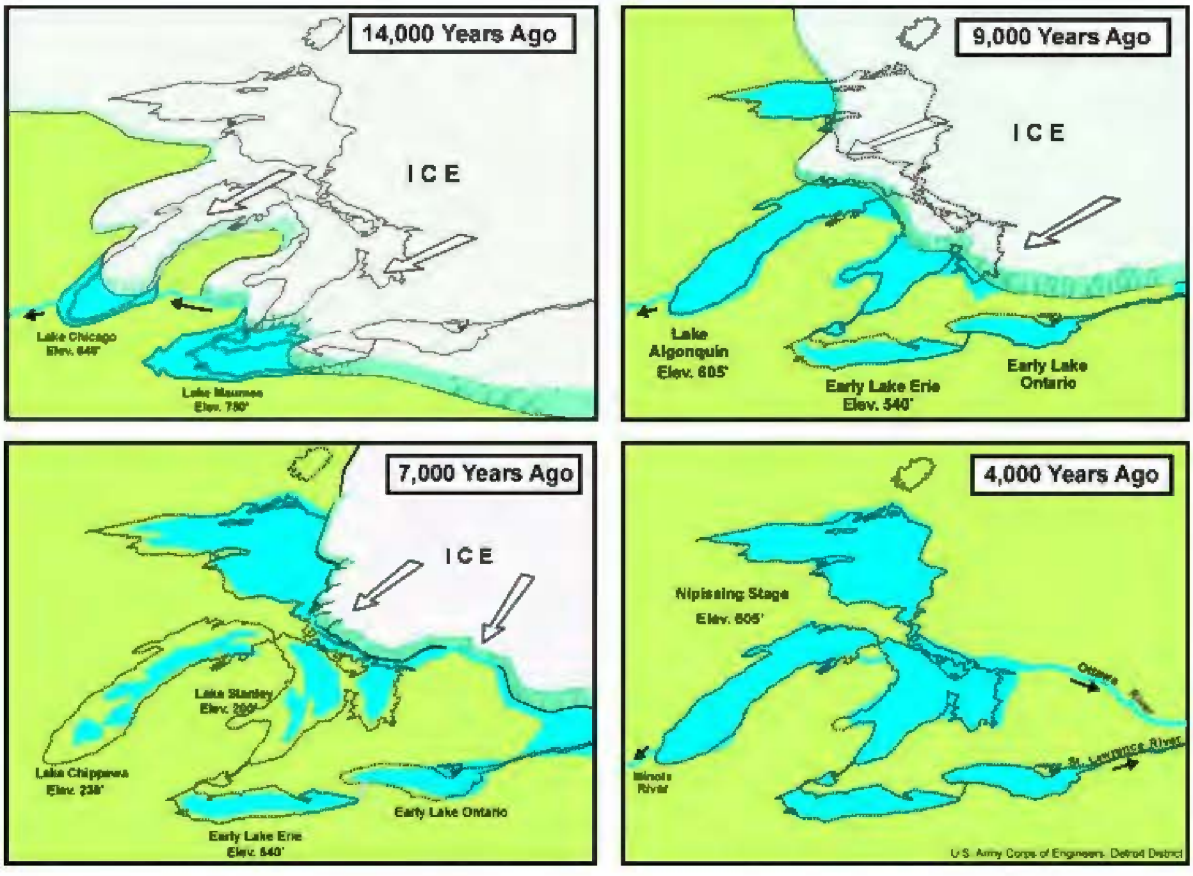


Figure 3 - Illustration of the development of the Great Lakes taken from US Army Corps of Engineers open source.

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3.0 BEDROCK GEOLOGY OF THE STRAITS

The bedrock strata of the Straits area occupy an interval between the Engadine Group dolomites of middle Silurian age at the base, and the Dundee Limestone (Cazenovia Group) of middle Devonian age at the top. This stratigraphic interval is about 1000 feet thick near the Straits.

The primary bedrock formations evident in outcrop near the Straits, from oldest to youngest, include the Pointe aux Chenes Formation (Salina Group), the St. Ignace Dolomite (Bass Islands Group), the Garden Island Formation (Deerpark Group), the Bois Blanc Formation (Onesquethaw Group), and the Dundee Limestone (Cazenovia Group) (Landes et al., 1945). Subsurface nomenclature differs somewhat from outcrop nomenclature, particularly with respect to the Salina Group and the Bass Islands Group formations (see Figure 2). The Mackinac breccia is a prominent formation in the area comprising constituents from older strata.

3.1 BEDROCK FORMATIONS

The bedrock formations in the Straits area are described in detail by Landes et al. (1945) based largely on outcrop mapping. Borings for the Mackinac Bridge crossing investigations (Ammann et al., 1951; Rosenau, 1956) and other borings provide subsurface information on bedrock formations[3].

Drilling and logging of 43 exploratory diamond drill core borings was completed in 1954 and 1955 as part of the crossing investigation (Rosenau, 1956). Borings were two inches or greater in diameter, and ranged from twenty to fifty feet in length. Six additional borings were completed at the bridge anchorage locations to check the effects of pressure grouting.

In addition to these borings, information from ten diamond drill core borings completed in 1939 for the Michigan Highway Department was summarized along with that from two deep water-well holes drilled at the site of the American Bridge field office on the north shore (Ammann et al., 1951). Figure 4 is a cross section at the Mackinac Bridge crossing location showing the conditions interpreted from 1939 borings and probings (from Ammann et al., 1951). Figure 5 provides an interpreted stratigraphic column at the crossing location based on all borings (Rosenau, 1956).

[3] Completed logs, data sheets, and core photographs submitted as part of the original investigations were not available to review. Reproduced figures of boring locations and borehole information are of variable quality.

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Based on Landes et al. (1945) and subsequent drilling investigations, bedrock formations that occur between the Engandine Group and the Dundee Limestone evident in outcrop and in boreholes in the Straits area, from oldest to youngest, are as follows:

- **Pointes aux Chenes formation (Salina Group)** – this formation underlies most of the St. Ignace Peninsula north of the Straits. Lithology includes green and red shale with intercalated thin beds of dolomite and irregular masses and beds of gypsum; no beds of salt were found in outcrop nor in the few deep wells in the area. The formation is estimated to range from 500 to 600 feet thick on the St. Ignace Peninsula based on information from deep wells.

  At the Mackinac Bridge crossing, drilling intersected this formation at three locations: near the north Tower Pier, at the north shore, and at two water wells located 700 feet north of the shore. No marker beds were identified, and bed orientation was not determined. The first red shale encountered (or red and blue-green mottled shale) was used as an indicator of the top of the formation. Based on tests summarized by Rosenau (1956), the shale of this formation is capable of carrying up to 60 tons/sq. ft. (5.7 MPa). A deep valley or gorge separating Mackinaw City and St. Ignace is cut down into Pointe aux Chenes rock (see Section 2.2).

- **St. Ignace formation (Bass Islands Group)** – according to Lilienthal (1978), this formation is also referred to in older publications as the Salina H Unit. It comprises large masses of strata within the Mackinac breccia on the St. Ignace Peninsula and Mackinac Island, but is not significantly disrupted by brecciation south of an east-west line passing between Mackinac and Round Islands and just north of Garden Island in Lake Michigan. Lithology of the upper part of the formation consists of thick-bedded dolomites; the remainder consists of even-bedded light-colored dolomite, intercalated with thin beds of bluish to greenish-gray shale. The estimated formation thickness from outcrop is between 200 and 300 feet in the Straits area.

  This formation was extensively drilled for the Mackinac Bridge crossing as most of the bridge piers are founded on it. As shown in Figure 4, the formation is estimated to be 203 feet thick at the crossing and consists of dolomitic limestone, shale, shaly limestones, "stack" or secondary limestone, and areas of breccia. The upper 75 feet is generally free of the brecciated "stack" condition and is capped by a 20-foot thick massive dolomitic limestone bed from which core recovery was excellent. A 4-foot thick zone of gray shale and shaly limestone with gray-black, banded, chert-nodule fragments, occurs 135 feet from the top of the formation. Immediately underlying it is a 10-foot thick zone of thinly-bedded, pale-orange, dolomitic limestone containing many small spherical calcite inclusions. These serve as the St. Ignace Formation marker beds with an average southerly dip of 52 feet per mile (0.6° dip).

Correlation of the St. Ignace formation from Pier 18 north to Pier 26 (inclusive) of the Mackinac Bridge was not possible due to some combination of poor core recovery, vertical displacement, or brecciation.

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An ancient fault zone is interpreted to exist at the South Cable Bent Pier between two borings with very dissimilar lithologies, with the west side appearing to be the down-thrown side. These types of conditions were not observed elsewhere in the crossing profile. Solution cavities thought to occur in the St. Ignace formation and in the "stack" areas prevalent throughout this formation were not found at the crossing. This was interpreted as evidence of cementation of the initially porous rock through secondary calcium carbonate deposition having taken place over geologic time. This conclusion was substantiated by pressure grouting, unconfined compression tests, study of surface outcrops, and drilling core logs (Rosenau, 1956).

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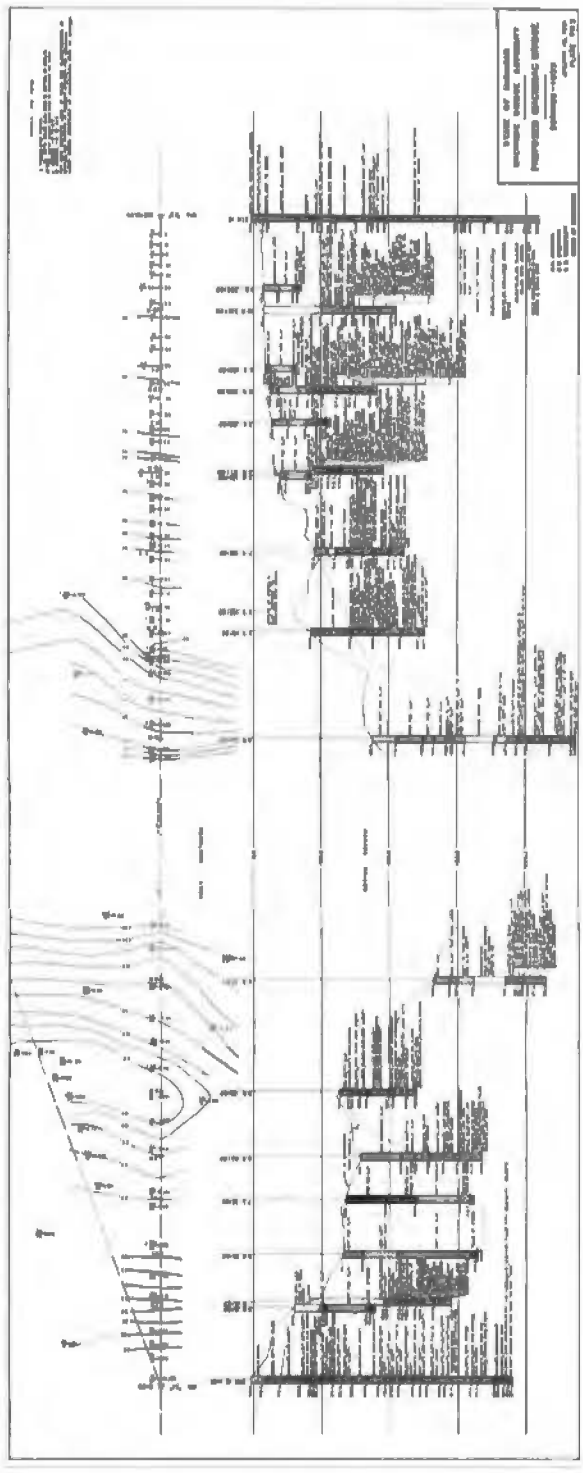


Figure 4- Interpreted cross section and 1939 borings at the Mackinac Bridge crossing (from Ammann et al., 1951)

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D. B. STEINMAN, CONSULTING ENGINEER
MACKINAC BRIDGE

GENERALIZED STRATIGRAPHIC COLUMN OF BEDROCK
PENETRATED CROSSING THE STRAITS OF MACKINAC

System	Group	Formation	Graphic Column	Footage	Bedrock Description	Comments
Devonian	Onesquethaw	Bois Blanc		142	142 ft. gray and yellowish-gray, very cherty dolomitic limestone, fossiliferous. Some thin seams of soft, argillaceous material. Many small fractures in limestone and chert filled with calcite.	Core recovery generally poor and badly broken. Very difficult drilling.
SILURIAN	Bass Island	St. Ignace		203	20 ft. pale-orange, massive crystalline dolomitic limestone, fossiliferous. Top 3 to 6 ft. of unit is oolitic.	Good to excellent core recovery.
					115 ft. yellowish-gray, fine-grained dolomitic limestones. Many acicular and rod-shaped calcite inclusions. Quartz oolites in irregular seams through top half of unit. Shaly seams in lower portion. Much secondary or "Stack" type limestone and limestone breccias present in lower half of unit.	Poor to fair core recovery.
					4 ft. gray shale and shaly limestone with included chert breccia. Chert fragments, gray and black banded with subvitreous luster, nodular.	Core recovery fair. This chert is unlike that found in the Bois Blanc formation.
					10 ft. pale-orange, fine-grained, thin-bedded, dolomitic limestone w/ small spherical calcite inclusions.	Good to excellent core recovery.
					54 ft. yellowish-gray to lt. brown, fine-grained dolomitic limestones with rod-shaped calcite inclusions, small spherical cavities and bituminous partings. Some "Stack" limestone and limestone breccia.	Poor to fair core recovery.
	Salina	Pointe Aux Chenes		114	50 ft. mottled green and red shale w/ thin Gypsum seams.	
					64 ft. interbedded lt. brown to brown dolomitic limestones and red and green shales. Thin Gypsum seams	Fair to good core recovery.

Figure 6. March, 1956

Figure 5 - Interpreted bedrock stratigraphy at the Mackinac Bridge crossing (from Rosenau, 1956)

- **Garden Island formation (Deerpark Group)** – the only known outcrops of this formation are along the westernmost point of Garden Island; it is interpreted to have been eroded away in the area adjacent to the Straits prior to deposition of the Bois Blanc formation. Lithology consists of

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dolomites, sandstones, and shale. Thickness may reach 25 feet, but average thickness is likely about 15 feet. This formation was not encountered during the Mackinac Bridge crossing investigations.

- **Bois Blanc formation (Onesquethaw Group)** - this formation underlies the southern part of Bois Blanc Island and a narrow belt of land along the northern shores of the southern Peninsula. Numerous large blocks of this formation are incorporated into the Mackinac Breccia on the St. Ignace Peninsula, but have not been mapped separately from the breccia. Lithology of the lower part of this formation consists of interbedded chert and limestone; the middle part consists of limestones and dolomitic limestones. The formation is estimated to range from 325 to 400 feet thick, and dips southward on average 55 feet per mile (0.6° dip). Drilling penetrated 142 feet into the formation but no marker beds were identified. The distinct lithologic contrast between the base of the Bois Blanc and the top of the St. Ignace formation was identifiable in core. The cherty dolomitic limestones show evidence of fracturing and re-cementation, but no signs of solution cavities. Seams of clay associated with the buff-argillaceous, soft material were logged as clay-carbonate. No faults or areas of vertical displacement were located. The irregular base of the formation was classified as a disconformable contact. This formation forms a resistant caprock for the highland between the major and secondary submerged valleys (see Section 2.2).

3.2 MACKINAC BRECCIA

According to Landes et al. (1945), the Mackinac Breccia, composed of fragments and masses of earlier strata that range in age from Silurian to mid-Devonian, is the most prominent bedrock formation in the Straits area. This formation occurs on both sides of the Straits and is the main component of outcrops on the St. Ignace Peninsula. The brecciated rock fragments range in age from the Pointes aux Chenes formation through the St. Ignace, Bois Blanc and Detroit River beds. The lowermost Pointe aux Chenes beds are not brecciated, nor are the Dundee limestones and younger overlying formations.

Landes et al. (1945) recognized three types of breccia in the Mackinac Straits area: megabreccia, intra-formational breccia, and trans-formational breccia. This latter type is subdivided into indurated and non-indurated sub-types. The three types of breccia are described as follows:

- Megabreccia comprises large tilted or down-dropped blocks of dislocated sedimentary strata ranging from a few feet up to hundreds of feet long. Observed blocks are randomly tilted at 6 to 25 degrees. The lateral boundaries of these blocks are marked by faults and slickensided surfaces. Larger tilted blocks may have dropped on the order of tens of feet.

- Intra-formational breccias sandwiched between undeformed strata occur within displaced blocks in some places. These breccias are postulated to have formed as a result of down-dropping of large megabreccia blocks, with weaker layers fracturing and fragmenting as a result.

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Most intra-formational breccia layers are only a few inches thick. This type of breccia is volumetrically insignificant compared to the megabreccia and the trans-formational breccia.

- Trans-formational breccia occurs as vertical bodies ranging from a few feet to hundreds of feet in width. These vertically-oriented breccias intersect the entire stratigraphic section between the Detroit River beds to the Pointes aux Chenes formation. Component fragments range in size from powder to rock slabs measuring over 20 feet in maximum dimension. Indurated breccia of this type occurs in locations where percolating groundwater has precipitated calcium carbonate, resulting in cementation of the breccia fragments. Breccias consisting of limestone fragments are more strongly indurated than those consisting of dolomite, chert or shale fragments. Indurated breccia is more resistant to erosion than non-indurated breccia. As a result, erosion and wave action during the fairly recent geologic past when higher post-glacial lakes were in existence have produced chimney rocks and stacks in more resistant breccia, and large pock-marks and other erosional features in less resistant breccia.

Landes et al. (1945) postulate that deposition of salt and gypsum beds in the Pointe aux Chenes formation in the area of the St. Ignace Peninsula, and later deposition of the overlying Bois Blanc and the Detroit River formations, was followed by emergence of the land above sea level and leaching of salt by groundwater to produce a network of caves and caverns. Collapse of these subterranean openings led to dislocation and brecciation of the associated bedrock formations. The process of collapse and subsequent erosion was complete before deposition of the Dundee Limestone.

In relation to the Mackinac Bridge crossing investigations, it was concluded that the Mackinac breccia has likely been re-consolidated by deposition of overlying strata and re-cemented by circulating water to a reasonably sound condition. However, it was also recognized that the breccia contains fault planes, gouge, joints, breccia fragments, all of which, even if sealed, are incipient planes of weakness that may affect rock strength.

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3.3 ANCIENT SUBMERGED RIVER VALLEYS

During the last glacial period, ice invaded and retreated from the Straits region several times. As a result, the shape, extent and elevation of glacial lakes in the area changed significantly over time. There is evidence that a river flowed eastward in recent glacial time through what is now the Straits of Mackinac. Soundings defined the position of the main river channel (Figure 6), and a partial rock profile of the submerged river valley between St. Ignace Peninsula and the tip of the Lower Peninsula was developed (Ammann, 1951). Detailed drilling and probing of the 4 mile Mackinac Bridge crossing of the Straits (Rosenau, 1956) indicated that bedrock depth is at least 290 feet below lake level. The greatest depth to rock is more than 350 feet at about mid-stream in the main submerged valley, and a secondary rock valley 237 feet deep is located about a half mile from the south shore. Both valleys were formed late in the glacial period and penetrate the Bois Blanc and the St. Ignace Formations, and the main channel cuts into the Pointe Aux Chenes Formation. The submerged valleys are evident from the results of the drilling program completed in 1954/55 (Figure 7). These results are re-plotted in Figure 8 at two different vertical exaggerations showing the interpreted formation boundaries and the regional southerly dip of strata.

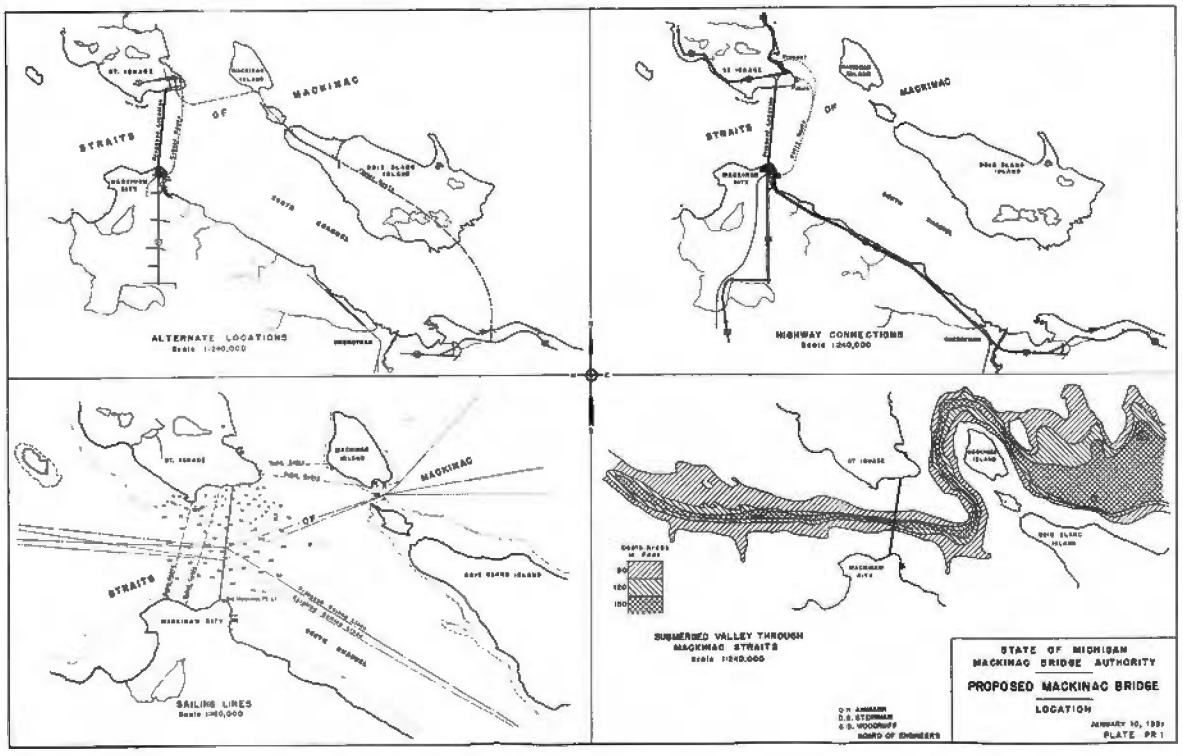
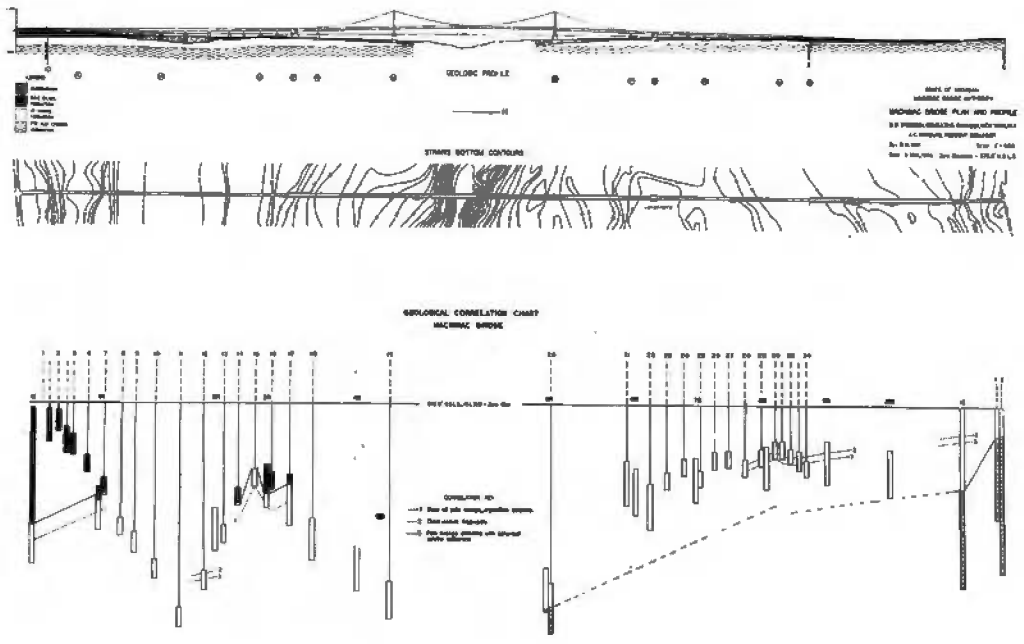


Figure 6 Proposed Mackinac Bridge crossing of the Straits showing main submerged valley location (Ammann et al., 1951)

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D. B. STEINMAN, CONSULTING ENGINEER
MACKINAC BRIDGE

GEOLOGICAL CORRELATION CHART DATA

Scale:
Horizontal: 1" = 500'
Vertical: 1" = 25'
Vertical exaggeration - 20X

Legend:
Bois Blanc
St. Ignace
Pointe Aux Chenes

Top row of numbers, 1 through 34, are bridge piers at which one or more borings were made during 1954 and 1955.

Lower numbers, beginning with 12 at left and ending with 13 at the north shore, were borings made for the Michigan State Highway Department in 1939.

Borings marked 1 and 2, on the right side of the drawing, are Water Well Borings made by the American Bridge Division, U. S. Steel Corporation, 1955.

J. C. Rosenau, Resident Geologist
D. N. Hart - March 1956

Figure 7 - Interpreted results of the 1954/55 drilling program at the Mackinac Bridge crossing (from Rosenau, 1956)

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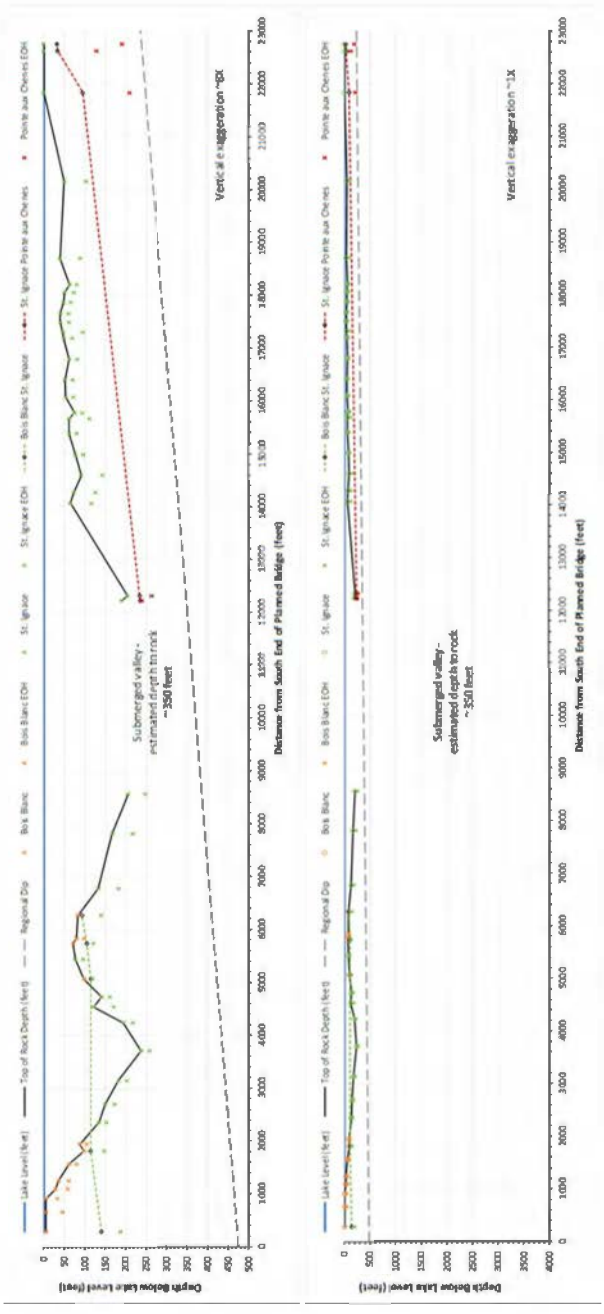


Figure 8 - Interpreted bedrock conditions from the 1954/55 drilling program at the Mackinac Bridge crossing (based on Rosenau, 1956)

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3.4 KARST

Although not explicit in their observations, Berkey and Paige (undated) point out the possibility of karst terrain in carbonate and anhydrite deposits that were exposed during the period associated with development of the river valleys now submerged in the Straits. Movement of groundwater within cracks and fissures during the period when the now-submerged river valley was formed may have dissolved carbonate and anhydrite rocks, resulting in cavities, sinkholes and other dissolution features. Indications of solution cavities in some borehole logs in Figure 3 confirm the presence of karst in the Straits area.

4.0 SURFICIAL GEOLOGY OF THE STRAITS

The published information predominantly available about the surficial geological materials within the Straits is as a result of field note comments available on Enbridge Line 5 "Straits of Mackinac Structural Integrity Support Span Repair Log", and the subsurface investigations carried out for the design and construction of the Mackinac Bridge in 1939 and 1954/1955 (Rosenau, 1956 and several others). The Mackinac Bridge is between 2 and 3 km east of the Enbridge Line 5 pipeline corridor through the Straits.

4.1 SUBMARINE TOPOGRAPHY

As previously noted, the development sequence of the Great Lakes in the region had a significant influence on the Straits. To illustrate the links between the submarine topography and the development of the Great Lakes (and by correlation the surficial geological conditions), the data in Figure 9 was plotted in Figure 10 against a cross section of the Straits along the Line 5 pipelines. This exaggerated section shows that the lake stages and the stepped profile of the submarine bathymetry on the south (left hand side) of the channel are similar; although these links do not appear on the north side. The deep remnant channel (Mackinac River) is clearly visible in the section down to an elevation of 100 m (about 76 m below the lake level).

Typically the lake stages were present for a sufficient period of time to develop defined beaches. The resultant erosion patterns such as steep slopes or cliffs develop above the beach elevation; a ridge of sand or sand and gravel defining beach line is coincident with the lake level, and gentler near-beach submarine slopes develop in the water adjacent to the beach. There is good correlation on the south side of the Straits to what appears to beach deposits coincident with the various submerged lake levels between the bottom of the channel and the modern lake elevation. The north side profile does not show any strong correlations. Note that the pipeline elevation data is general in nature only and is only expressed in detail for the portions of the pipeline not buried (i.e. those below about 20 m).

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Figure 11, is developed from Enbridge data to show reported occurrences of sand and clay at anchor installations along Line 5. This data does not directly correspond to any major topographic controls other than to suggest that below about a nominal depth of 100' (30 m), the span logs typically report clay and sandy clay conditions, while about 100' (30 m) the conditions are typically reported as sandy.

TABLE 1

	Elevation (Feet)
Lake Algonquin.....	605
Wyebridge (−90).....	515
Penetang (−130).....	475
Cedar Point (−150)...	455
Payette (−190).....	415
Chippewa (−375) and	230
Stanley (−425)....	180
then rise to	
Lake Nipissing.....	605

Figure 9 - Great Lakes elevation stages at the Straits taken from Table 1 (Melhorn, 1960)

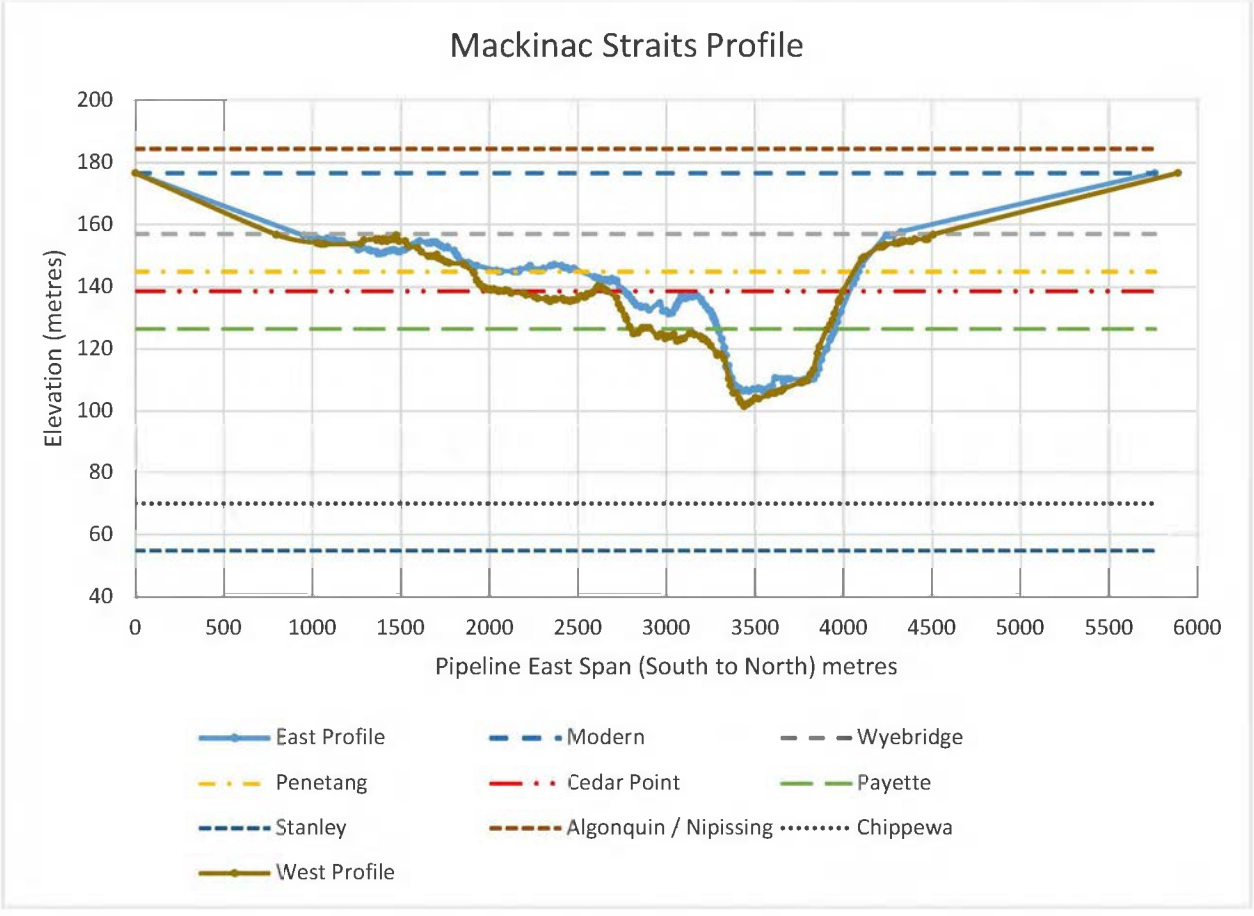


Figure 10 - Mackinac Straits cross section plotted against Melhorn (1959) reported Great Lakes elevations.

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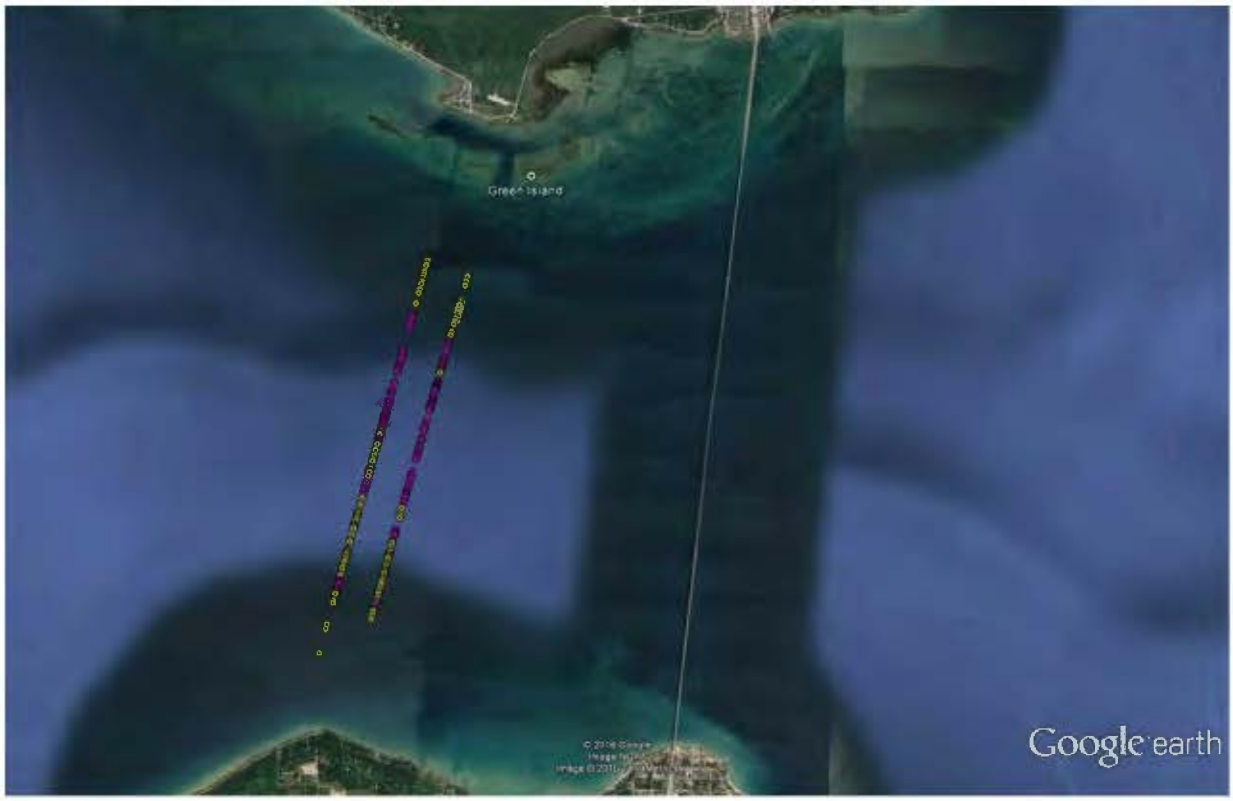


Figure 11 - Illustrative position of reported sand (yellow) and clay (purple) encountered at anchors along Line 5.

The Figure 11 data at the pipeline crossing was compared to Figure 4. The figure by Ammann et al, 1951 presents a geological cross section that includes the overburden materials summarized as a result of up to 53 drill holes drilled along the Mackinac Bridge site (Ammann et al, 1951). Melhorn summarized this data for the overburden materials as shown on Figure 12. Major surficial geological units include lacustrine silt and clay, glacial till, outwash deposits (sand, boulders), and a sandy clay (possibly till).

Some possible correlations to the general channel shape can be drawn between the profiles at Line 5 and at the bridge. Ammann et al (1951) shows a significant buried channel near the south shore, generally between the shoreline and a relatively shallow bedrock subcrop at the south anchorage pier, to a depth of 220' (67.1 m). There is insufficient data to examine or speculate a correlation here, although it should be considered a significant possibility and should be anticipated for tunnel alignments. This channel likely parallels the Mackinac River channel for some distance west (Melhorn, 1959).

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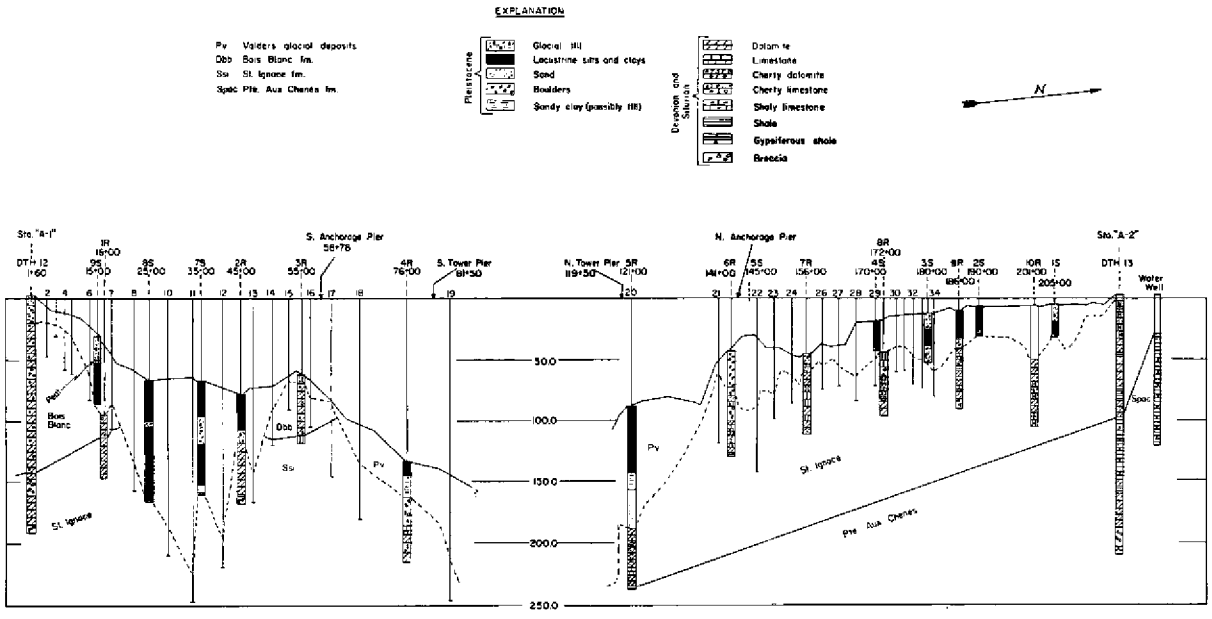


Figure 12 - Surficial Geology conditions at Mackinac Bridge (Melhorn, 1959)

4.2 SURFICIAL GEOLOGY MATERIALS – GLACIAL TILL

Glacial till is present throughout the region and is identified in the Straits. Ammann et al (1951) shows a significant intersection of Valders glacial deposits overlying the bedrock subcrop profile within the Mackinac River Channel. Melhorn (1959) describes the till as either soft red clays or hard silty, sandy, or pebbly red till. Higher pebble content is observed closest to the bedrock contact. The till is consistent with till encountered on the uplands to the south. The till is described as being relatively free of boulders, another important consideration in tunnel alignment selection.

Till is typically described as a relatively dense, poorly graded material derived and placed due to the scour and deposition under moving sheets. It has typical properties of high relative density, low permeability, and relatively high shear strength. Specific strength data is not available for the till at the Straits location. Till is expected to be present in direct contact with bedrock in most areas, with the exception of an area on the north side of the Mackinac River channel at the Mackinac Bridge. In this area a material similar to an outwash sand may be present between the till and the bedrock. Note that till is an advance phase deposit and was subject to significant aerial exposure and weathering during low-water phases of the Mackinac River channel. Weathered till is often less cohesive and beach and

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wave erosion can remove fines rendering the material somewhat sandier in texture. Transporting weathered till along a beach can concentrate sand and gravel along beach lines. The observation of sandy clay and sand throughout the shallower portions (about about 30 m or 100') of the Straits suggests that the surface materials are likely till or weathered till. Surface trenching for pipelines would expect to encounter till down to a proposed depth below the water of -30 m. Unweathered, more cohesive till would be expected to be encountered in deeper excavations such as a tunnel alignment.

4.3 SURFICIAL GEOLOGY MATERIALS – LACUSTRINE SILTS AND CLAYS

Initial Great Lake development stage Algonquin and late stage Nippising were separated by a protracted period of relatively low lake levels and potential channel cutting. The falling lake levels resulted in scour and sub-aerial erosion (sediment removal) of the landscape within the Straits. As noted in Ammann et al (1951), a significant buried channel appears to have been eroded adjacent to the south side of the Mackinac River channel. Once the lake levels returned from the low levels to flood the Straits again, the previous erosion forces were diminished and lacustrine deposition of fine sediments in the basin resumed. Evidence of sediment infill is present throughout the Straits, from the now backfilled channel near the south shore (up to about 40 m thickness of soft infill). In addition to deposition in the channel, soft sediments have accumulated near surface to depths of several 10's of feet in the deeper more quiescent sections of the basin, including the Straits (100' or 30 m nominally). Areas where the lacustrine sediments do not appear significant are around the raised subcrop separating the buried channel and the Mackinac River channel and the raised subcrop area flanking the north side of the Mackinac River Channel.

The soft infill silt and clay is described as glaciolacustrine silt and clay. No specific strength testing data is available. Typical properties include low shear strength, low relative density and relatively low permeability. This material would be considered (for a framing perspective only) as normally consolidated. Glaciolacustrine silt and clay would be considered to be the primary surficial material below -30 m, and would be expected to be several 10's of feet thick at minimum.

4.4 SURFICIAL GEOLOGY MATERIALS – OUTWASH DEPOSITS

Outwash deposits are identified by Ammann et al (1951) potentially underlying till on the north side of the Mackinac River channel and as a boulder sequence at, and above, the crest of the main north-side slope of the Mackinac River channel. Outwash deposits are typically described as coarse grained materials (sands to boulders) deposited by moving water (fluvial). Typical properties of outwash materials would include high shear strength and high permeability.

A field investigation program would need to be carried out to examine the potential for these materials to be present along the alignment of the pipelines. A conceptual allowance for such materials could be

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made, although the translation of limited data from the Mackinac Bridge location several kilometres to the west is not recommended.

4.5 OTHER INFORMATION

Other information related to the bedrock geology of the Straits is mentioned in the reports about the Mackinac Bridge drilling investigations. Recovery and review of the original core logs, driller's notes and core photographs for the borings and probings conducted in 1939 and 1954/55 mentioned by Ammann et al. (1951) and Rosenau (1956), and related interpreted geological cross sections, would provide greater confidence in the expected geologic conditions in the Straits area.

5.0 ROCK MECHANICS

Important considerations for underground excavations in rock include geomechanical properties of the rock mass, in situ stress conditions, faults, and seismicity. Only limited data were available from the Digital Geology Library for Michigan. Supplemental data from the Bruce DGR site in the Michigan Basin for the principal formations in common with the Straits area is summarized in this section, recognizing potential differences in degree of brecciation and other factors between the two sites.

5.1 GEOMECHANICAL PROPERTIES

Geomechanical properties of interest for assessing the stability of underground openings include density, Young's modulus, Poisson's ratio, unconfined compressive strength (UCS), tensile strength, and rock mass strength envelope parameters associated with either Mohr-Coulomb or Hoek-Brown failure criteria. Rock quality designation (RQD), core recovery, and natural fracture frequency are other parameters of interest, along with direct observations of discontinuity characteristics (e.g., planarity, roughness, persistence, aperture, infilling material, number and orientation of joint sets, block size, and degree of alteration).

5.1.1 Geomechanical Data from the Straits

Unconfined compressive strength tests were conducted on twelve bedrock core samples from the 1954/55 drilling program to estimate strengths of the sedimentary rocks beneath the piers of the Mackinac Bridge. Rock samples tested included re-cemented dolomitic-limestones, breccias and "stack" limestones with proportionately large void areas, and other rock types. All material tested was air dry and at room temperature, and the standard method for capping and testing of concrete cylinders was carefully followed.

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Results reported by Rosenau (1956) are shown in Figure 13, and are plotted in Figure 14 as a function of depth and rock type. The relative strength of samples increases as the sample lithology progresses from clay to shale to limestone to dolomite to chert. No results were obtained for one limy-shale sample that was damaged during handling.

D. B. STEINMAN, CONSULTING ENGINEER
MACKINAC BRIDGE

UNCONFINED COMPRESSIVE STRENGTH TESTS

February 6, 1956

Pier	Boring Number	Core Sample Elev.	Core Size Dia. x Length	Sample Characteristics	Failure Lbs./ sq.in.	Failure Tons/ sq.ft.	Breaking Characteristics
4	4-B1	-35.0	2-1/8" x 4-1/4"	Dolomite and chert: bedded, fine-grained, hardness-5 to 7	11,938	860	Shattered, many splintery vertical fractures
9	9-B1	-153.0	2-1/8" x 4-1/4"	Dolomitic Limestone: finely crystalline, dense, hardness-4 to 5	9,410	678	Vertical fractures
17	17-B2	-93.0	2" x 4"	Dolomitic Limestone: saccharoidal, porous, vertical calcite seam, hardness -4	8,280	596	Vertical fractures, no failure on calcite seam
17	17-G2	-98.0	2" x 4"	Dolomitic Limestone: finely crystalline, slightly porous, calcite inclusions, hardness-4	7,006	504	Vertical fractures
19	19-B3	-218.0	2-1/8" x 4-1/4"	Dolomite: fine-grained, dense, hardness-4	11,235	809	Vertical fractures
20	20-B1	-232.6	2" x 4"	Limy-Shale: hardness-2	——	——	Parted along bedding while handling
21	21-B1	-69.0	2-1/8" x 4-1/4"	Limestone: finely crystalline, small solution cavities, hardness-4	5,477	394	Vertical and transverse fractures
22	22-B1	-135.5	2-1/8" x 4-1/4"	Shaly-Limestone: fine-grained, hardness -2½ to 3	4,494	324	Shattered, wedge-like
25	25-SB1	-66.0	2-1/8" x 4-1/4"	Clay-pan: calcareous, pebbly, hardness-2 to 3	2,387	172	Vertical fractures
28	28-B1	-67.5	2" x 4"	Shaly-Limestone: finegrained, hardness-2½ to 3	8,917	642	Shattered, with conical break
33	33-B1	-57.0	2-1/8" x 4-1/4"	Clay-carbonate Breccia: chalky, hardness-2 to 3	3,511	253	Shattered, with conical break
34	34-B1	-65.0	2-1/8" x 4-1/4"	Dolomitic Limestone: fine-grained, calcite inclusions, hardness-3 to 4	8,427	607	Vertical fractures

Figure 13 List of Unconfined Compressive Strength (UCS) test results from the 1954/55 drilling program at the Mackinac Bridge crossing (from Rosenau, 1956)

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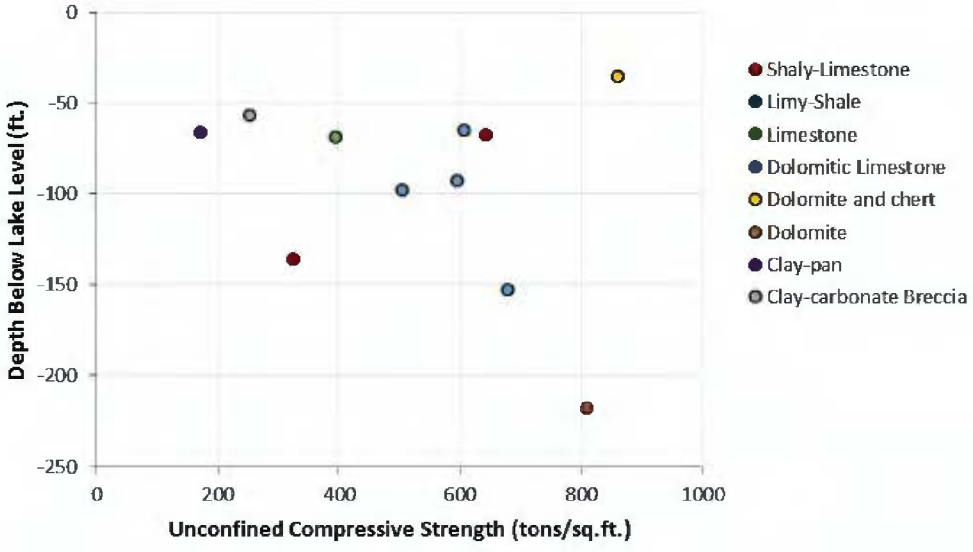


Figure 14 -Plot of UCS test results from the 1954/55 drilling program at the Mackinac Bridge crossing (based on Rosenau, 1956)

5.1.2 Lithology and Discontinuity Information from the Bruce DGR Site

Detailed characterization of lithology was undertaken at the Bruce DGR site, including mineralogical, petrographic, and geochemical evaluations to aid in rock classification. Observations of discontinuities intersected in boreholes were made on core and using downhole inspection techniques. Rock quality descriptions (Table 1) include Rock Quality Designation (RQD) determined from core logging data based on International Society for Rock Mechanics (1977), considering natural fractures in core. Core recovery is the length of core recovered per length of hole drilled per core run. Core runs were typically 3.05 m (10 ft.) in length. Natural fracture frequency was calculated as the total number of identified natural fractures divided by the length of recovered core.

RQD (%)	Core Quality Description	Natural Fracture Frequency (/m)	Formation Fracture Description
0-25	Very Poor	>10	Highly Fractured
25-50	Poor	>1.0-10	Moderately Fractured
50-75	Fair	0.5-1.0	Sparsely Fractured
75-90	Good	<0.5	Very Sparsely Fractured
90-100	Excellent	0	Unfractured

Table 1 - Summary of Rock Quality Descriptions and Fracture Frequency used at the Bruce nuclear site (from Intera Engineering Ltd., 2011)

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Most of the geoscientific data from the Bruce nuclear DGR site was obtained from four deep diamond-cored vertical boreholes, DGR-1, DGR-2, DGR-3 and DGR-4 and two deep inclined boreholes DGR-5 and DGR-6. These borehole provide subsurface coverage to a vertical depth of about 870 m (2850 ft.), and intersect strata from the Devonian to the Precambrian, including the Bois Blanc Formation, the Bass Islands Group, and the Salina Group. Descriptions are as follows:

- **Bois Blanc Formation** – this formation regionally is a greenish grey to brown, thin- to medium-bedded, fine- to medium-grained, fossiliferous, cherty dolostone about 50 m (164 ft.) thick, with a high natural fracture frequency, local dense bituminous laminations and occasional broken and rubble zones (Armstrong and Carter, 2006). Based on core logging and downhole video inspections of DGR boreholes, the Bois Blanc Formation dolostone is moderately to highly fractured with fair core quality. Zones of major borehole enlargement and intense fracturing, as well as frequent occurrence of vertical and horizontal fracturing and minor enlargements, were evident in downhole video inspections. A typical core sample photograph is shown in Figure 15.

- **Bass Islands Formation Dolostone** – this formation regionally is a brown to tan-grey, variably laminated, very fine- to fine-grained, argillaceous dolostone about 45 m (148 ft.) thick, with a high natural fracture frequency and occasional broken and rubble zones, particularly in the upper sections of the formation (Armstrong and Carter, 2006). At the Bruce DGR site, this formation is characterized by very fine-grained dolostone lacking chert and fossils. Based on core logging, the Bass Islands Formation dolostone is moderately to highly fractured with poor core quality.



Figure 15 - Core sample of Bois Blanc Formation cherty dolostone with bituminous laminations from borehole DGR-1 at Bruce DGR site (from Intera Engineering Ltd., 2011)

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The contact between the Bass Islands Formation and the overlying Bois Blanc Formation at the Bruce DGR site is a paleo-erosional unconformity that has resulted in enhanced weathering, dissolution, and permeability in the upper parts of the Bass Islands Formation. This feature is visible in core, characterized by a change from grey-brown to tan brown dolostone and moderate fracturing (Figure 16). Observations from several sources show that the upper 15 to 20 m (49 to 66 ft.) of the Bass Islands Formation at the Bruce DGR site is weathered, open and permeable due to the presence of this erosional unconformity. Rock quality in this weathered zone is fair to very poor with moderately to highly fractured intervals. Drilling fluid losses indicate that weathered bedrock near the Devonian-Silurian boundary will be a zone of significant groundwater inflow. The low mean core recovery of 77% and low mean RQD of 34% are attributed to difficult drilling conditions and to zones of intense fracturing and weathering associated with the regional erosional discontinuity.



Figure 16 - Devonian-Silurian unconformity in borehole DGR-4 at Bruce DGR site (from Intera Engineering Ltd., 2011)

- **Salina Formation, G Unit Argillaceous Dolostone** - the Salina Formation is a succession of evaporites and evaporite-related carbonate sediments that is subdivided into lettered units A through G based on subsurface stratigraphic characteristics. All of the units within the Salina Formation were deposited conformably, although small-scale disconformities occur due to post-depositional dissolution of evaporite beds in the Bruce DGR area (e.g., D Unit and B Unit salts). The G Unit in the Michigan Basin is a tan to grey, argillaceous dolostone, with shale and anhydrite layers, estimated to be 12 m (39 ft.) thick (Armstrong and Carter, 2006). At the Bruce DGR site, the G Unit is identified by the first presence of white, orange and pink anhydrite layers and nodules, and is logged as medium grey argillaceous dolostone with intermittent layers of medium grey fine-grained dolostone and grey dolomitic shale. White, orange and pink anhydrite/gypsum veins and layers are present through the Unit as secondary infilling of healed

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fractures. Based on core logging of DGR boreholes, the G Unit dolostone is moderately fractured with fair core quality.

- **Salina Formation, F Unit Dolomitic Shale** - the F Unit regionally is a grey/green to grey/blue dolomitic shale with shale and anhydrite about 30 m (98 ft.) thick, typically comprised of dark green shales with anhydrite in the upper half and mixed dolostones, shales and anhydrite in the lower half (Armstrong and Carter, 2006). The F Unit shale at the Bruce DGR site is predominately grey-blue shale, with the upper part grey to green fine-grained dolomitic shale with white and orange anhydrite/gypsum veins throughout (Figure 17). A thin layer of tan massive dolostone is a formation marker bed, below which the unit is often stained reddish-brown with increasing content of anhydrite in various forms. The lower part of the F Unit shale is tan brown brecciated dolostone with abundant veins and layers. The brecciation of the F Unit is attributed to the collapse of the formation caused by paleo-dissolution of the underlying Salina D Unit salt. Based on core logging, the F Unit shale is sparsely to moderately fractured with excellent core quality.



Figure 17 - Orange anhydrite veins cut by white gypsum veins in Salina F Unit Dolomitic Shale in borehole DGR-3 at Bruce DGR site (from Intera Engineering Ltd., 2011)

- **Salina Formation, E Unit Brecciated Dolostone and Dolomitic Shale** - the E Unit regionally is a brown/grey brecciated dolostone and dolomitic shale with anhydrite about 30 m (98 ft.) thick (Armstrong and Carter, 2006). The E Unit shale at the Bruce DGR site has a distinctive upper bed of grey-green dolomitic shale, and typically consists of grey-green dolomitic shale and brecciated dolostone, brecciated dolostone with anhydrite, and tan-grey dolomitic shale with anhydrite and gypsum. The middle zone is made up of brecciated angular fragments of tan and brown

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dolostone and grey shale in a grey anhydritic dolomudstone matrix. Based on core logging, the E Unit dolostone and shale is very sparsely to sparsely fractured with excellent core quality.

- **Salina Formation, D Unit Anhydritic Dolostone and C Unit Dolomitic Shale and Shale** - the D Unit at the Bruce DGR site is a blue-grey to brown fragmented tan to brown dolostone within a white to bluish grey anhydrite/gypsum matrix about 2 m (7 ft.) thick that represents the less soluble or non-salt constituents of the D Unit salt bed dissolved in the geologic past (Figure 18). The C Unit is an inter-layered red and green-grey shale with anhydrite veins and nodules that grades into a dolomitic shale or dolomite with depth (Armstrong and Carter, 2006). At the Bruce DGR site, the C Unit typically consists of an upper layer of red and green shale and a lower layer of dolomitic shale about 7 m (23 ft.) thick, with anhydrite veins and nodules common throughout. The lower section of the C Unit includes brecciated shale and dolostone infilled and healed with white to blue anhydrite as a secondary mineral. Based on core logging, the combined D and C Units are unfractured to very sparsely fractured with excellent core quality.



Figure 18 - Core sample of Salina D Unit Anhydritic Dolostone from borehole DGR-1 at Bruce DGR site (from Intera Engineering Ltd., 2011)

- **Salina Formation, B Unit Argillaceous Dolostone and Evaporite** - the B Unit comprises a grey-green argillaceous dolostone, a salt horizon and an underlying thin evaporite (i.e., anhydrite) and dolostone layer. The brecciation of the upper dolostone of the B Unit is a result of dissolution of the formerly underlying B Unit salt (Armstrong and Carter, 2006). The B Unit evaporite layer at the Bruce DGR site is the less soluble or non-salt constituents of the B Unit, and may also contain dolostone and shale. It is up to 44 m (144 ft.) thick. The B Unit typically

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consists of an upper layer of grey-green brecciated argillaceous dolostone consisting of angular tan to grey dolomitic mudstone and dolostone clasts in a grey dolomitic shale matrix infilled with secondary white to bluish-grey anhydrite/gypsum, and a basal bed of grey anhydrite with brown dolostone layers. Based on core logging, the B Unit argillaceous dolostone and anhydrite is unfractured to sparsely fractured with excellent core quality.

- **Salina Formation, A2 Unit Dolostone and Anhydritic Dolostone** - the A2 Unit regionally comprises a tan-grey argillaceous, laminated to thin-bedded dolostone (referred to as the A2 Unit Carbonate) and an underlying anhydritic dolostone (referred to as the A2 Unit Evaporite), in total about 30 m thick (Armstrong and Carter, 2006). At the Bruce DGR site, the A2 Unit Carbonate consists of grey fine-grained dolomite with black shale layers, dark grey dolomitic shale, tan-grey argillaceous dolostone, anhydritic dolostone and tan-grey argillaceous dolostone with bituminous laminations. The underlying A2 Unit Evaporite is light grey-blue anhydritic dolostone to dolomitic anhydrite (Figure 19). From core logging, the A2 Unit is unfractured to very sparsely fractured with excellent core quality.



Figure 19 - Core sample of Dolomitic Anhydrite of Salina A2 Unit Evaporite in borehole DGR-4 at Bruce DGR site (from Intera Engineering Ltd., 2011)

- **Salina Formation, A1 Unit Argillaceous Dolostone and Anhydritic Dolostone, A0 Unit Bituminous Dolostone -** the A1 Unit regionally is similar to the A2 Unit in that it is divided into an upper A1 Unit Carbonate and a lower A1 Unit Evaporite. The A1 Unit is composed of a grey-brown, argillaceous, bituminously laminated dolostone about 3 m (10 ft.) thick and an underlying anhydritic dolostone up to 5 m (16 ft.) thick. The A0 Unit is a thin bituminous dolostone up to about 4 m (13 ft.) thick that historically has been grouped with the underlying

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Guelph Formation dolostone in Ontario (Armstrong and Carter, 2006). The A1 Unit Carbonate logged in DGR boreholes is a thinly laminated, grey-brown dolostone with black bituminous layers and minor anhydrite layering. The upper portion of the A1 Unit Carbonate has open vuggy porosity and permeability (Figure 20). The underlying A1 Unit Evaporite is light grey-blue anhydritic dolostone. The A0 Unit dolostone at the DGR site is a massive, intact, dark brown-black, thinly laminated, fine-grained bituminous dolostone. Based on core logging, the A1 and A0 Units dolostone and anhydritic dolostone are unfractured to sparsely fractured with excellent core quality.



Figure 20 - Open vuggy porosity of Upper A1 Unit Carbonate in borehole DGR-4 at Bruce DGR site (from Intera Engineering Ltd., 2011)

Table 2 provides a summary of core recovery, RQD and natural fracture frequency by formation based on the DGR boreholes. Figure 21 shows the distribution of RQD and natural fracture frequency data with depth. Note that coring was not undertaken in the upper parts of boreholes DGR-5 and DGR-6. Results show that Devonian and Upper Silurian dolostones are very sparsely to highly fractured and of poor to fair RQD, whereas the deeper Silurian formations below the Salina G Unit are very sparsely fractured to unfractured with excellent RQD. Many of the low core recoveries and RQDs recorded for the Bois Blanc and Bass Islands formations were attributed to difficult drilling conditions created in part by alternating hard and soft beds within these formations. Occasional joints/natural fractures were also identified in the deeper Silurian formations from core logging and borehole geophysical logging. The core quality and natural fracture frequency characteristics of the various formations are very similar in all DGR boreholes. Although not reflected in the RQD or natural fracture frequency plots, the degree and extent of

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brecciation of the Salina B to E Units due to paleo-dissolution of the B and D Unit salts was more significant in borehole DGR-6 core than in other DGR cores.

Table 2 - Summary of core recovery, RQD, and natural fracture frequency from boreholes at the Bruce DGR site (from Intera Engineering Ltd., 2011)

Formation	% Recovery			% RQD			Natural Fracture Frequency (1/m)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Lucas + Amherstburg Formations	20%	100%	91%	0%	100%	47%	0.00	18.06	5.36
Bois Blanc Formation	24%	100%	92%	0%	100%	68%	0.00	12.00	3.61
Bass Islands Formation	0%	100%	77%	0%	96%	34%	0.00	5.71	2.75
Salina Formation - G Unit	33%	100%	72%	0%	98%	54%	0.00	13.11	3.79
Salina Formation - F Unit	0%	100%	94%	0%	100%	90%	0.00	7.50	0.88
Salina Formation - E Unit	97%	100%	100%	58%	100%	96%	0.00	2.62	0.77
Salina Formation - D Unit + C Unit	89%	100%	99%	87%	100%	98%	0.00	1.97	0.33
Salina Formation - B Unit	98%	100%	100%	71%	100%	97%	0.00	2.62	0.53
Salina Formation - A2 Unit	88%	100%	100%	59%	100%	96%	0.00	2.77	0.41
Salina Formation - A1 Unit + A0 Unit	78%	100%	100%	87%	100%	99%	0.00	2.95	0.21

The orientation of all fractures and inclined fractures in the Silurian formations determined from ATV logging are shown in Figures 22 and 23, respectively. These plots are corrected for Terzaghi (1965) sampling bias. Figure 22 indicates a single dominant sub-horizontal fracture set. Excluding fractures with dips less 35°, Figure 23 indicates NNE, NW, NNW and E striking fractures that dip vertically, moderately to the W, moderately to the SW and vertically, respectively.

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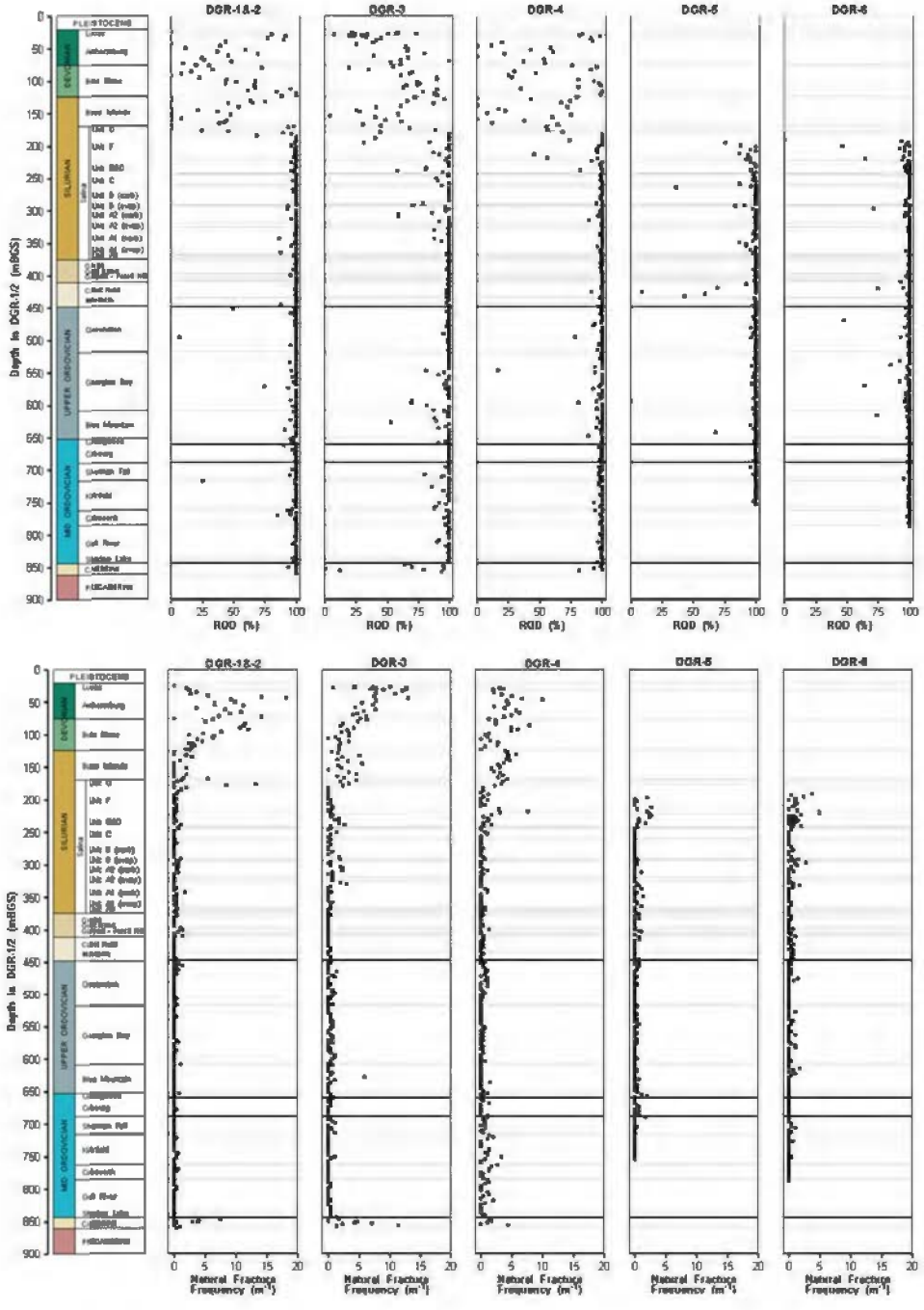


Figure 21 - Summary of RQD and natural fracture frequency from boreholes at the Bruce DGR site (from Intera Engineering Ltd., 2011)

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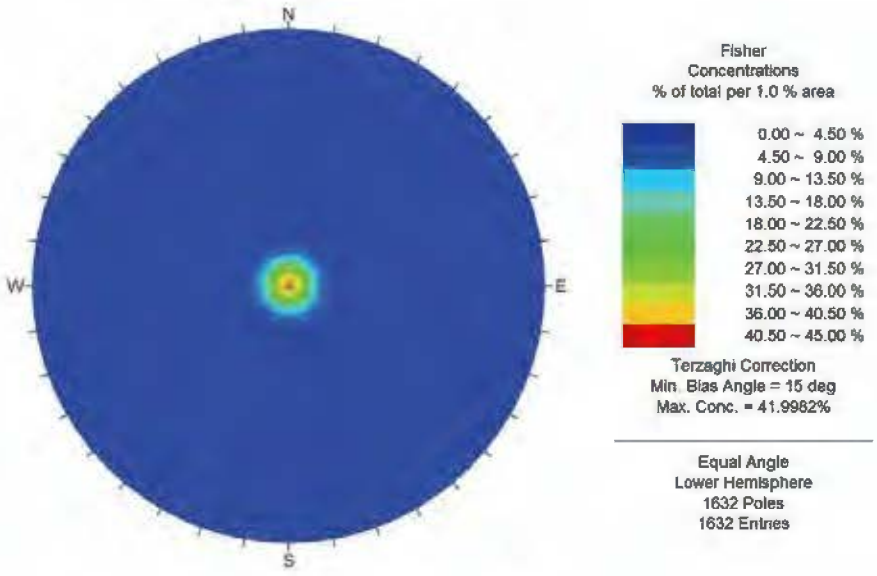


Figure 23 - Contoured equal-area polar plot of all fractures in Silurian Formations from ATV logging of all DGR boreholes at the Bruce DGR site (from Intera Engineering Ltd., 2011)

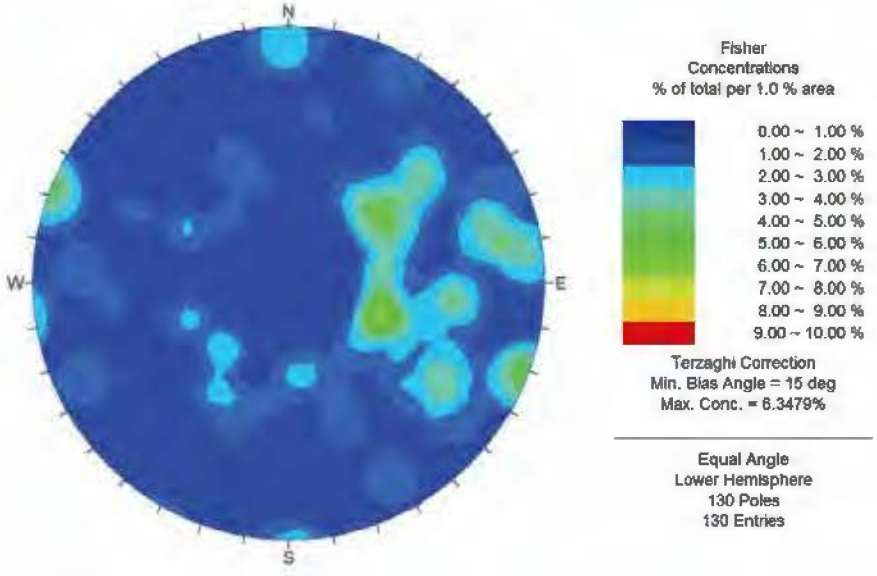


Figure 22 - Contoured equal-area polar plot of inclined fractures in Silurian Formations from ATV logging of all DGR boreholes at the Bruce DGR site (from Intera Engineering Ltd., 2011)

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5.1.3 Geomechanical Data from the Bruce DGR Site

Geomechanical data from the Bruce DGR site was examined in the context of underground excavation development and performance (Intera Engineering Ltd., 2011). Formations were grouped into several Mechano-Stratigraphic (MS) Units based on data from DGR boreholes. The upper two MS Units include formations relevant to the Straits. These are shown in Figure 24 and are described as follows:

- MS Unit 1 comprises mainly dolostones, and includes all Devonian formations encountered at the Bruce DGR site, as well as the Upper Silurian Bass Islands Formation and the Salina G Unit dolostone; depth 20 to 178.6 m (66 to 586 ft.) below ground surface in borehole DGR-1.
- MS Unit 2 comprises a sequence of interbedded shales, dolostones and anhydrites, and includes strata from the top of the Silurian F Unit to the base of the Silurian Fossil Hill Formation; depth 178.6 to 411 m (586 to 1348 ft.) below ground surface in borehole DGR-1.

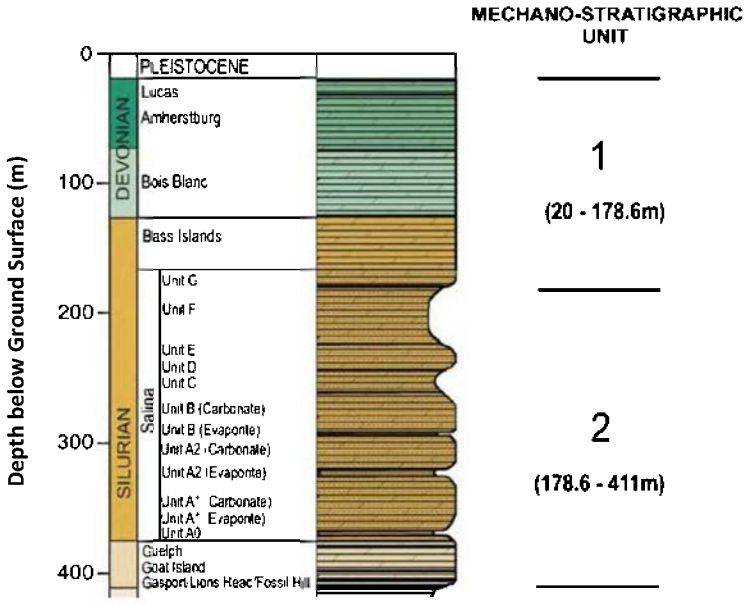


Figure 24 - Reference stratigraphic column showing upper two Mechano-Stratigraphic (MS) Units at the Bruce DGR site (after Intera Engineering Ltd., 2011)

Geomechanical testing of the two MS Units included the following:

- Uniaxial compression tests – used to determine peak uniaxial compressive strength (UCS), the percentage of UCS at which crack initiation and crack damage occur, and Elastic Modulus and Poisson's ratio values measured at 40% of UCS

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- Point load tests – used to determine axial and diametral point load test (PLT) index as an indicator of variability in unconfined compressive strength
- Slake durability tests – to determine slake durability index, a measure of strength degradation under wetting/drying cycles
- Free swell tests – to determine swelling potential in the vertical and horizontal directions
- Dynamic properties tests – to determine compression (P) and shear (S) wave velocity to estimate dynamic elastic constants on core and in situ from downhole geophysics

Other tests not undertaken in these two MS Units include direct or Brazilian tensile strength tests, direct shear tests, and abrasiveness tests. Rock mass geomechanical characteristics and rock mass classification were not determined owing to limited information on discontinuities.

Results from uniaxial compression tests are shown in Figures 25 and 26 for MS Units 1 and 2, respectively. The upper formations (Lucas, Amherstburg and Bois Blanc) are stronger than the lower Bass Islands Formation and Salina G Unit in MS Unit 1, with average UCS values of 96 MPa in the upper formations (range 65-127 MPa) and about 43 MPa in the lower formations (range 34-58 MPa). For MS Unit 2, significant lithological heterogeneity within the Salina Formation F to A0 units results in scatter in measured UCS values. In general, UCS values in the upper Salina B, C, D, E and F units are less than those in the lower Salina A units, with average UCS values of 18 MPa in the upper units (range 3-43 MPa) and about 123 MPa in the lower units (range 35-250 MPa).

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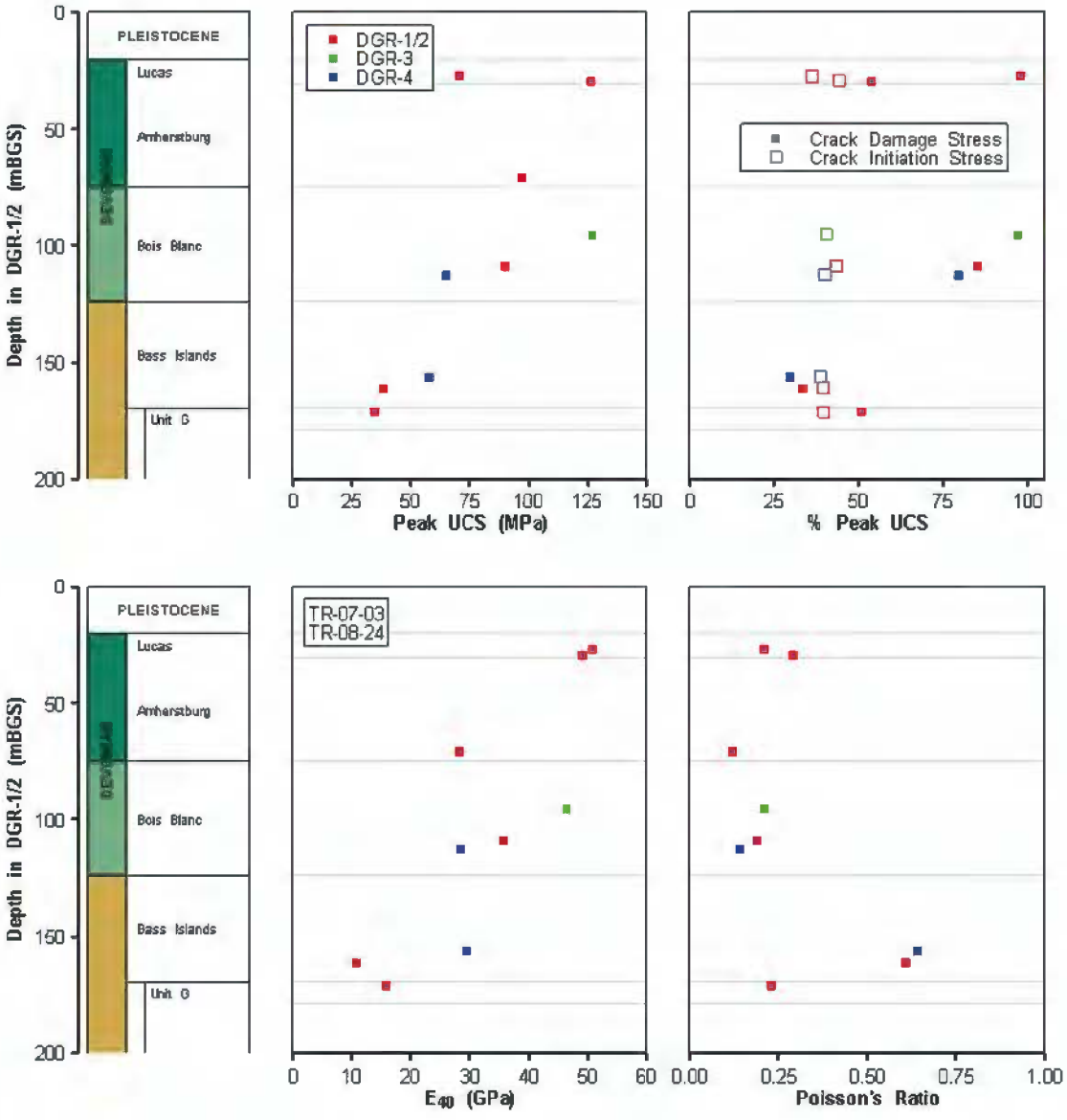


Figure 25 - Results from uniaxial compression tests in MS Unit 1 (from Intera Engineering Ltd., 2011)

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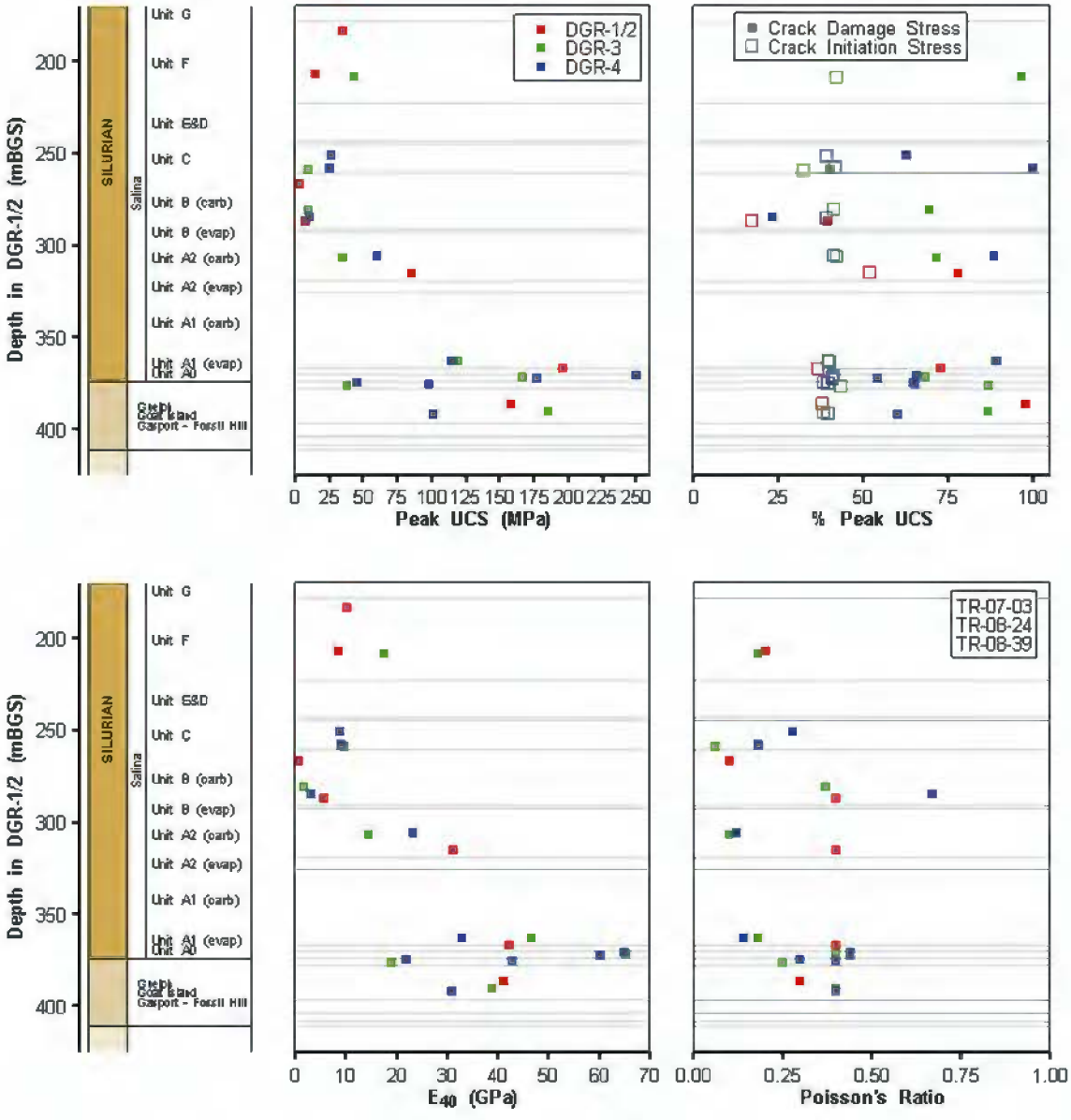


Figure 26 - Results from uniaxial compression tests in MS Unit 2 (from Intera Engineering Ltd., 2011)

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Results from point load tests are shown in Figures 27 and 28 for MS Units 1 and 2, respectively. These results generally support the trends from the UCS tests. For MS Unit 1, PLT index values for the upper formations (Lucas, Amherstburg and Bois Blanc) are about 5 MPa, and those for the lower Bass Islands Formation and Salina G Unit are about 1 MPa. For MS Unit 2, PLT index values for the upper Salina B, C, D, E and F units are about 1 MPa, and those for the lower Salina A units are about 5 MPa, with significant scatter in both cases. Based on the ratio of diametral-to-axial PLT results, rock materials in MS Unit 1 do not appear to be strongly anisotropic. However, some rock materials in MS Unit 2 appear to be quite strongly anisotropic with diametral-to-axial PLT index ratios of 0.1 to 1.5.

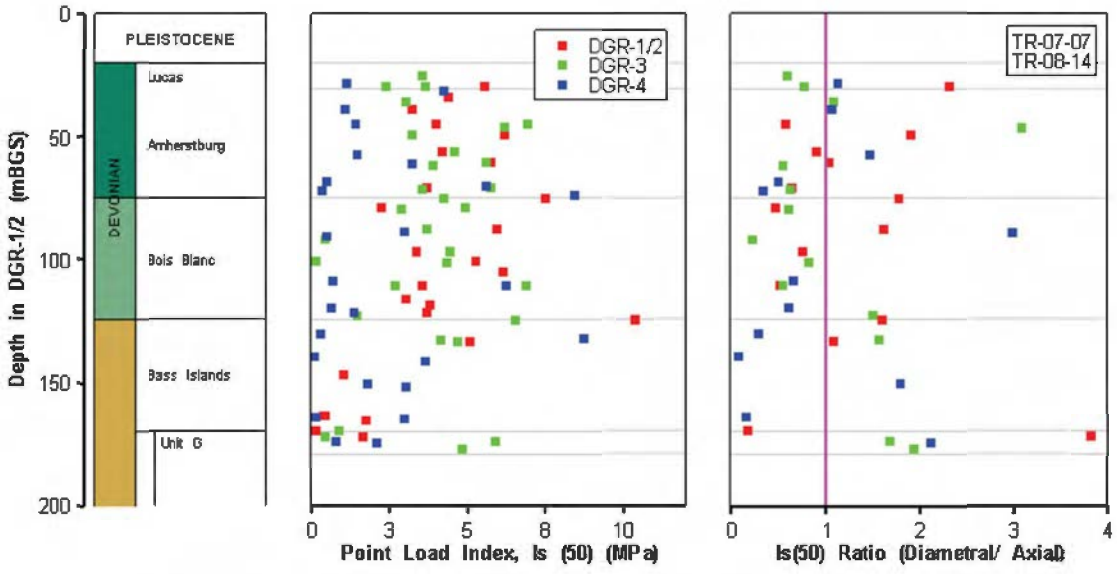


Figure 27 - Results from point load tests in MS Unit 1 (from Intera Engineering Ltd., 2011)

Results from slake durability tests are shown in Figures 29 and 30 for MS Units 1 and 2, respectively. In MS Unit 1, slake durability tests were conducted on argillaceous dolostone from the Salina G Unit, and dolostone that did not appear to be argillaceous. The non-argillaceous materials showed no significant degradation when subjected to wetting-drying cycles (Slake Durability Index 95-100%), whereas the argillaceous dolostone showed some degradation (Slake Durability Index 30-80%). For MS Unit 2, slake durability tests were conducted on materials with significant argillaceous (clayey) material, selected based on visual inspection. Results indicate that some slaking deterioration can be expected to occur in materials with shale content, with Slake Durability Index values ranging from about 33 to 90%.

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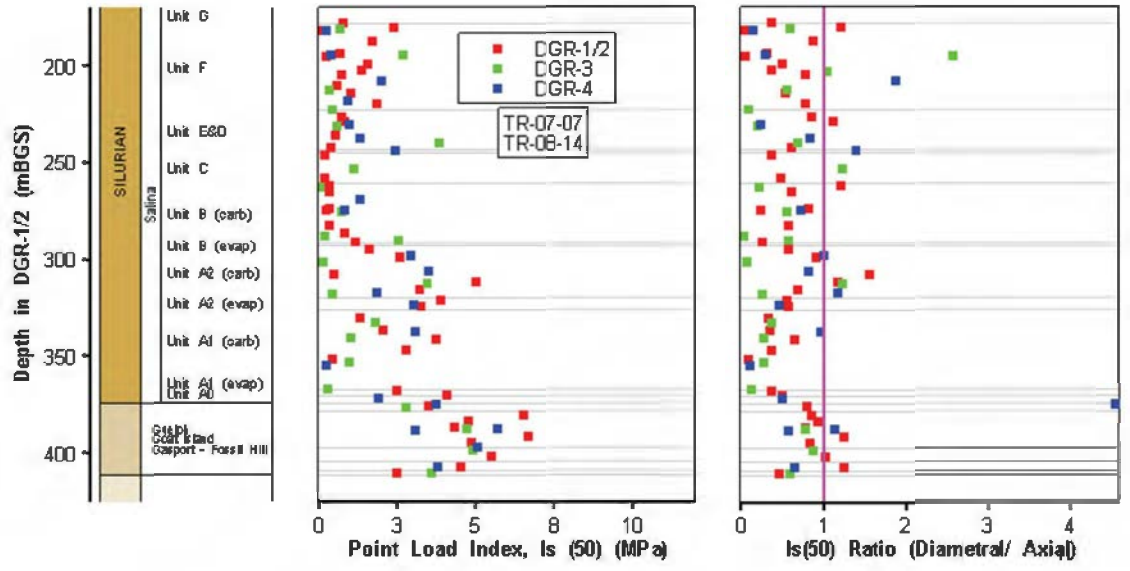


Figure 29 - Results from point load tests in MS Unit 2 (from Intera Engineering Ltd., 2011) -

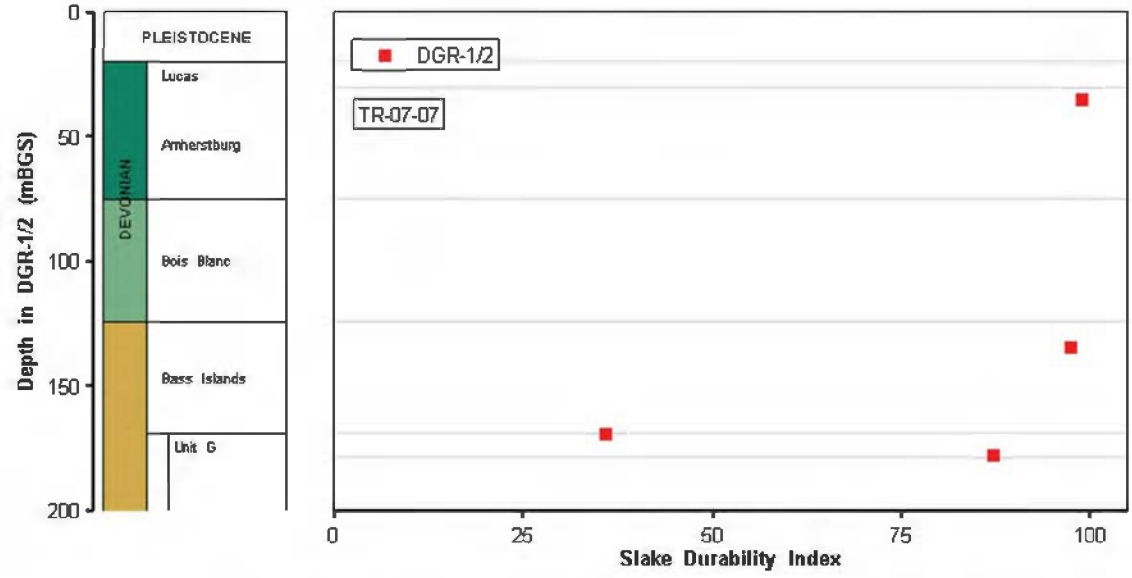


Figure 28 - Results from slake durability tests in MS Unit 1 (from Intera Engineering Ltd., 2011)

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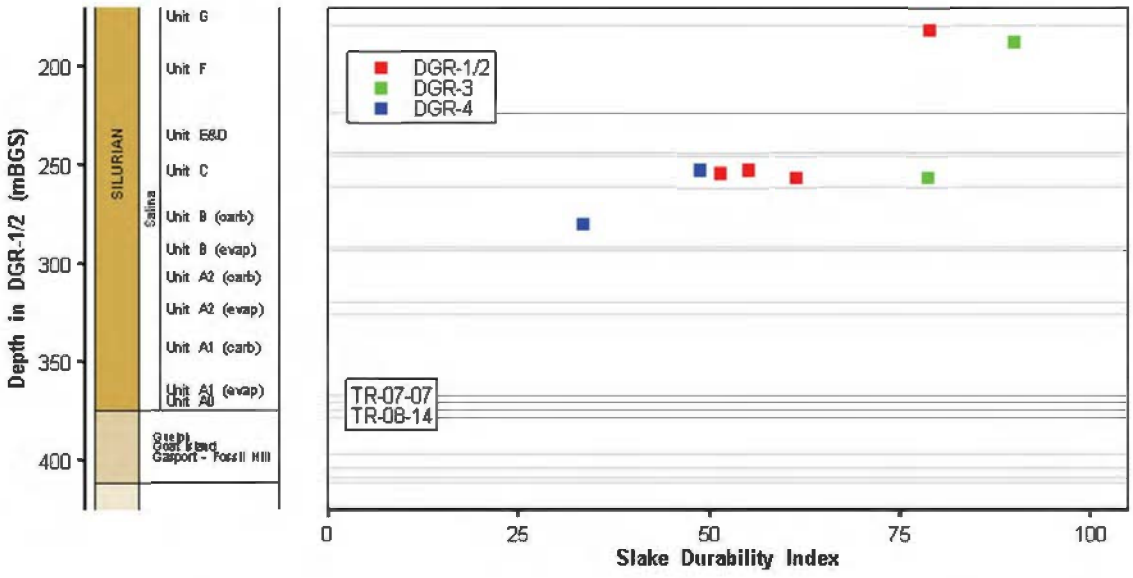


Figure 30 - Results from slake durability tests in MS Unit 2 (from Intera Engineering Ltd., 2011)

Results from free swell tests are shown in Figure 31 for MS Unit 2; no tests were conducted in MS Unit 1. Material from the Salina Group was tested using fresh water to determine swelling potential in the vertical and horizontal directions, respectively. Swelling potential was shown generally to increase with decreasing calcite content. Swelling potential in the horizontal direction was generally low, ranging from 0% per log cycle of time for all samples from borehole DGR-4, to a maximum of 0.9% per log cycle for one sample from borehole DGR-3 taken from the Salina F Unit. Swelling potential in the vertical direction was variable, ranging from 0% to 3.4% per log cycle of time.

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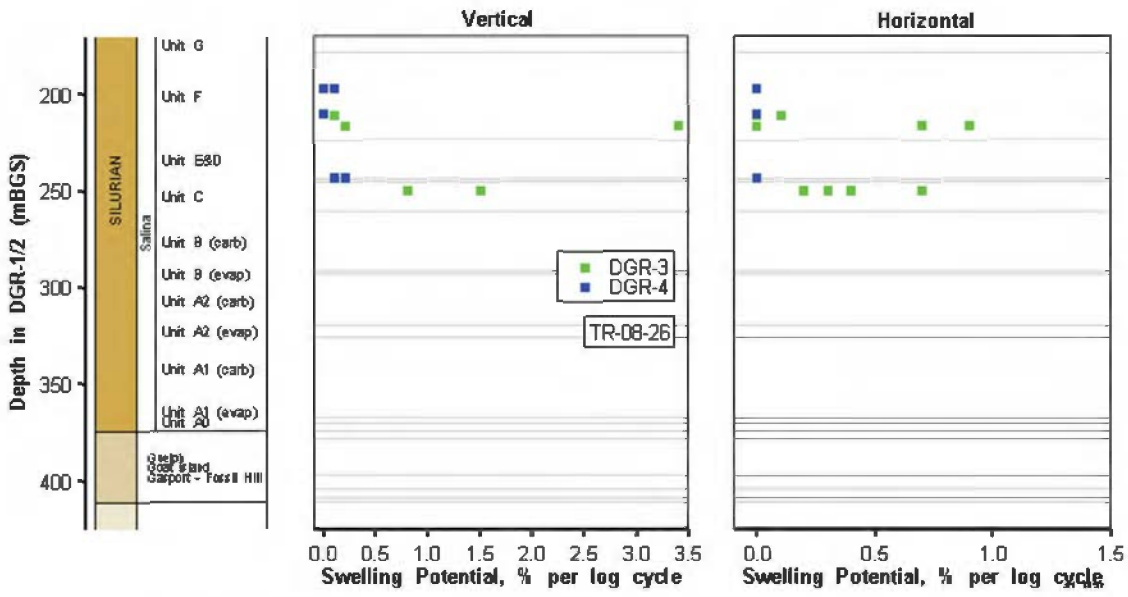


Figure 31 - Results from free swell tests in MS Unit 2 (from Intera Engineering Ltd., 2011)

Key static and dynamic geomechanical properties for stratigraphic units relevant to the Straits area evaluation are summarized in Tables 3 and 4 by formation and by mechano-stratigraphic unit.

In addition to geomechanical properties testing, formation hydraulic conductivity was estimated based on hydraulic straddle-packer tests, previous investigations, and observations of drilling fluid loss made during drilling (Intera Engineering Ltd., 2011). Hydraulic conductivity of the Bois Blanc and Bass Islands formations was estimated to be as high as 10^{-5} m/s overall. Of note were very permeable (10^{-4} m/s) sections of the upper 20 m of Bass Islands Formation that created significant drilling fluid losses.

The results of straddle-packer hydraulic testing of DGR boreholes are summarized versus depth and formation in Figure 32. Calculated test interval hydraulic conductivities below the Salina G Unit range from approximately 10^{-16} to 10^{-8} m/s. The highest test interval hydraulic conductivities in the Salina Formation involved porous and permeable sections of the Salina Upper A1 Unit (greater than 10^{-8} m/s).

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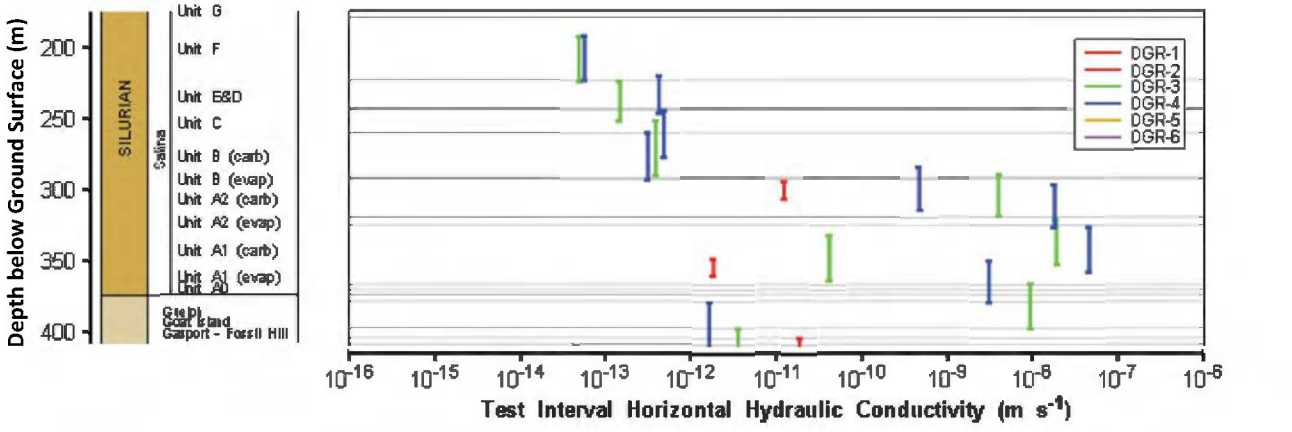


Figure 32 - Estimated interval hydraulic conductivity in DGR boreholes (modified from Intera Engineering Ltd., 2011)

Table 3 - Summary of Static Geomechanical Properties from Bruce DGR Site (after Intera Engineering Ltd., 2011)

Stratigraphic Subdivisions								Mean (Range) By Formation			Mean (Range) By Mechano-Stratigraphic Unit					
MS Unit	MS Subunit	Formation	Unit	Subunit	Top Depth (m)	Bottom Depth (m)	Thickness (m)	Peak UCS (MPa)	Elastic Modulus (GPa)	Poisson's Ratio	Peak UCS (MPa)	Elastic Modulus (GPa)	Poisson's Ratio	Crack Initiation Stress (% UCS)	Crack Damage Stress (% UCS)	PLT Anisotropy
1	a	Bois Blanc			75.0	124.0	49.0	94 (65-127)	37 (28-46)	0.18 (0.14-0.21)	96 (65-127)	40 (28-51)	0.19 (0.1-0.29)	40 (36-44)	Varies (33-98)	Low (Large scatter)
	b	Bass Islands			124.0	169.3	45.3	43 (34-58)	19 (11-29)	0.23 (N/A)	43 (34-58)	19 (11-29)				
2	a	Salina	G		169.3	178.6	9.3				18 (3-43)	6 (0.5-18)	0.31 (0.10-0.44)	39 (17-52)	Varies (23-100)	High (Large scatter)
			F		178.6	223.0	44.4	31 (15-43)	12 (8-18)	0.21 (0.18-0.24)						
			E		223.0	243.0	20.0									
			D		243.0	244.6	1.6									
			C		244.6	260.3	15.7	20 (9.6-26)	9 (9-10)	0.17 (0.06-0.28)						
			B	Carbonate	260.3	291.2	30.9	8 (3-11)	3 (0.5-6)	0.40 (0.11-0.67)						
				Evaporite	291.2	293.1	1.9									
	b		A2	Carbonate	293.1	319.7	26.6	48 (35-60)	19 (15-23)	0.11 (0.10-0.12)	123 (35-250)	38 (15-65)				
				Evaporite	319.7	325.5	5.8									
			A1	Carbonate	325.5	367.0	41.5	143 (115-196)	41 (33-47)	0.23 (0.14-0.36)						
				Evaporite	367.0	370.5	3.5									
			A0		370.5	374.5	4.0	198 (166-250)	63 (60-65)	0.43 (0.40-0.44)						

Note: Values shown are from the Bruce DGR site and may differ in other locations

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Table 4 - Summary of Dynamic Geomechanical Properties from Bruce DGR Site (after Intera Engineering Ltd., 2011)

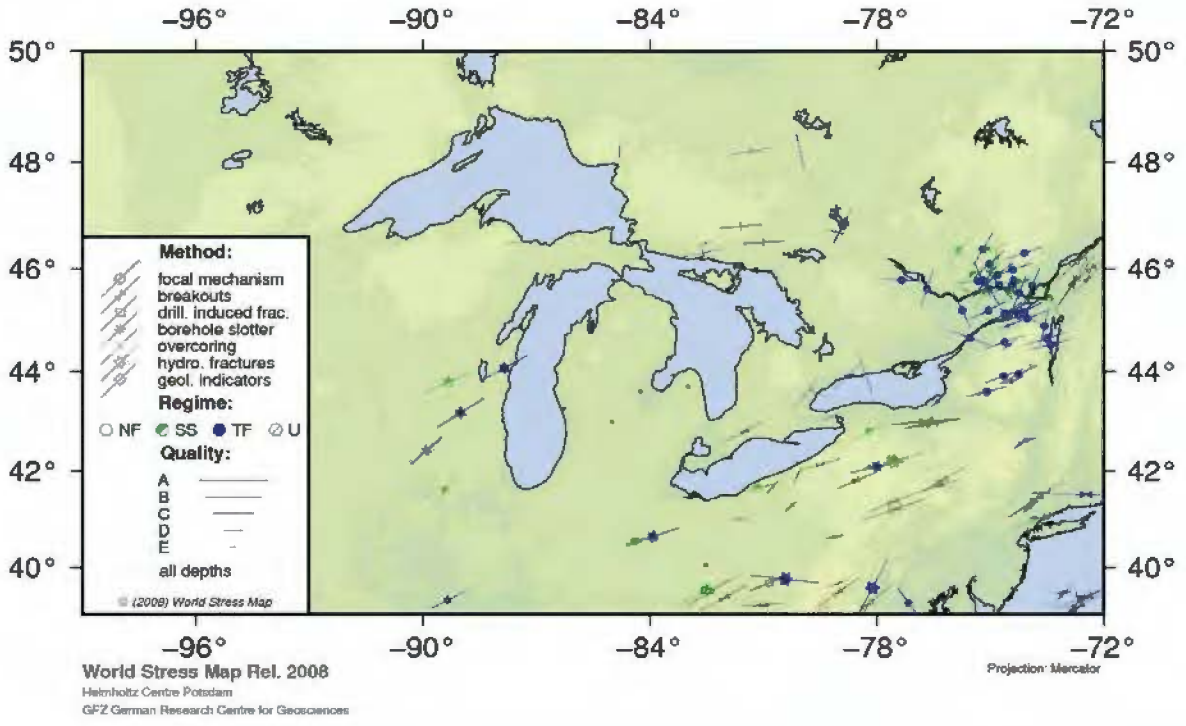
Stratigraphic Subdivisions								Mean from Downhole Geophysics				Mean from Core Samples				
MS Unit	MS Subunit	Formation	Unit	Subunit	Top Depth (m)	Bottom Depth (m)	Thickness (m)	P-wave Velocity (m/s)	S-wave Velocity (m/s)	Dynamic Elastic Modulus (GPa)	Dynamic Shear Modulus (GPa)	P-wave Velocity (km/s)	S-wave Velocity (km/s)	Dynamic Elastic Modulus (GPa)	Dynamic Shear Modulus (GPa)	Dynamic Poisson's Ratio
1	a	Bois Blanc			75.0	124.0	49.0	4376	2674	45.4	18.9	5.1	2.7	51	20	0.30
	b	Bass Islands			124.0	169.3	45.3	4378	2706	46.0	19.3	4.3	2.2	36	14	
		Salina	G		169.3	178.6	9.3	3666	2040	28.3	11.1					
2	a		F		178.6	223.0	44.4	4987	2775	33.1	15.6	3.7	2.1	27	11	0.26
			E		223.0	243.0	20.0	4890	2640	47.4	18.4					
			D		243.0	244.6	1.6	3820	1930	27.5	16.5					
			C		244.6	260.3	15.7									
			B	Carbonate	260.3	291.2	30.9	4010	2140	31.4	12.1					
				Evaporite	291.2	293.1	1.9	5720	2560	31.4	23.2					
	b		A2	Carbonate	293.1	319.7	26.6	4470	2380	38.7	15.2	5.0	2.7	52	20	
				Evaporite	319.7	325.5	5.8									
			A1	Carbonate	325.5	367.0	41.5	5110	2810	53.2	20.7					
				Evaporite	367.0	370.5	3.5	5940	3020	54.8	24.0					
			A0		370.5	374.5	4.0	5113	2750	51.7	19.9					

Note: Values shown are from the Bruce DGR site and may differ in other locations

5.2 IN SITU STRESS CONDITIONS

The in situ stress state is a critical geomechanical input affecting the design of underground excavations. The regional stress pattern for the Great Lakes area is shown in Figure 33. The Straits area is located in a stable part of the North American plate subjected to regional tectonic stresses, with the maximum horizontal stress oriented approximately WSW –ENE. Based on measurements elsewhere in the Michigan Basin and Appalachian Basin, the minimum principal stress is expected to be vertical and approximately lithostatic; the maximum and minimum horizontal stresses are generally expected to exceed lithostatic. This stress state represents a thrust fault regime.

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Notes: Figure based on Heidbach et al. 2009. NF = normal-fault regime, SS = strike-slip regime, TF = thrust fault regime, and U= regime unknown.

Figure 33 Regional stress conditions in the Great Lakes area (Heidbach et al., 2009)

As shown in Figure 34, overcoring and hydraulic fracturing tests have been conducted in the sedimentary rocks of the St. Lawrence Platform to a depth of about 300 m (984 ft.) (Adams and Bell 1991). Shallow overcore tests within 70 m (230 ft.) of ground surface show considerable scatter, with the maximum and minimum horizontal stresses typically much larger than the vertical stress. While there is some question about the validity of hydraulic fracturing tests in horizontally bedded sedimentary materials, hydraulic fracturing tests conducted below 70 m (230 ft.) show a similar in situ stress pattern. Scatter in the data of the maximum horizontal stress is possibly due to stress variations across stratigraphic units, with stiffer rock types interpreted to carry more stress than softer rock types.

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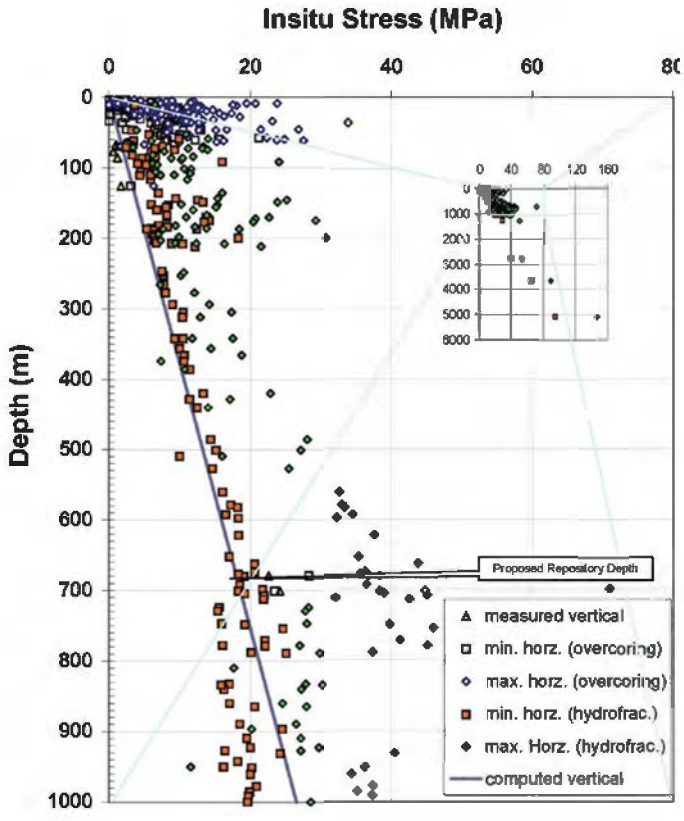


Figure 34 - Distribution of principal in situ stress with depth in the Appalachian and Michigan Basins (from NWMO and AECOM, 2011 based on Adams and Bell, 1991)

At the Bruce DGR site, the in situ stress state with depth was estimated based on several lines of reasoning. These included regional measurements, numerical modeling predictions, and back analysis of borehole breakout conditions. Stress ratios estimated based on regional data (NWMO and AECOM, 2011) show considerable scatter within about 200 m (656 ft.) of ground surface. In locations where there are no significant interruptions to stratigraphic continuity, the ratio of the maximum horizontal stress to vertical stress may range from 2 to 4 or greater above 200 m (656 ft.) depth; values between 1.5 and 2.5 are more common below 200 m (656 ft.) depth. Similarly, the ratio of maximum to minimum horizontal stress within about 70 m (230 ft.) of ground surface may range from about 1.5 to 5 or greater. Below this depth, values of approximately 1.2 to 2.2 are more common. Predicted values in the Salina Formation at the Bruce DGR site (NWMO, 2011) are shown in Table 5.

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Table 5 - Estimated In Situ Stress Ratios in the Saline Formation at the Bruce DGR Site based on Numerical Modeling (NWMO, 2011)

Depth (m)	Formation	σ_v (MPa)	σ_H/σ_v	σ_h/σ_v	σ_H/σ_h
200-228	Salina F	5.3-6.0	1.7-1.8 (1.75)	1.2-1.4 (1.3)	1.3-1.4 (1.35)
228-379	Salina E to A0	6.0-10.0	2.0-3.2 (2.3)	1.6-2.6 (1.9)	1.2-1.3 (1.25)

The in situ stress conditions in the Straits area are likely affected by interruptions in stratigraphic continuity associated with the Straits and submerged river valleys. These topographic low areas represent locations where rock formations have been removed by natural processes. This in turn provides a mechanism for horizontal stress relief above the elevation of the deepest point (i.e., the thalweg) of the submerged river valley, estimated to be 350 feet (107 m) or more (Rosenau, 1956). Below the thalweg, the rock formations may carry relatively high horizontal stresses similar to other locations in the Michigan Basin.

A simple approximation can be made to estimate the possible horizontal stresses beneath the thalweg of the Straits. Assuming a nominal depth of 400 feet (122 m) in a typical sedimentary rock column, and using an average density of 2.63 g/cm^3 for sedimentary rock and the stress ratios for the Salina E to A0 formations at the Bruce DGR site, the calculated in situ stresses are as follows:

- Vertical stress σ_v = 3.15 MPa
- Maximum horizontal stress σ_H = 3.15 x 2.3 = 7.24 MPa
- Minimum horizontal stress σ_h = 3.15 x 1.9 = 5.98 MPa

Accounting for the removal of rock above 350 feet (107 m) and replacement with water, and assuming an impermeable rock mass (i.e., total stress), the net reduction in vertical stress acting at 400 feet (122 m) is 1.7 MPa. The associated reduction in horizontal stress is given by:

$$\Delta\sigma_H = \frac{\nu}{1-\nu}\Delta\sigma_v \qquad \text{(Eq. 1)}$$

where ν is Poisson's ratio. Using a Poisson's ratio of 0.2 based on the Bruce DGR information, the net change in horizontal stress is 0.25 x 1.71 = 0.43 MPa. The estimated stress conditions at 400 feet (122 m) depth, accounting roughly for a 350 foot deep valley, are therefore

- Vertical stress σ_v = 1.44 MPa
- Maximum horizontal stress σ_H = 6.81 MPa
- Minimum horizontal stress σ_h = 5.55 MPa

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The calculated maximum horizontal to vertical stress ratio is 4.7, and the calculated minimum horizontal to vertical stress ratio is 3.9 under these stress conditions.

The actual in situ stress conditions in the Straits area are not known at this time. The foregoing should therefore be considered a preliminary screening level estimate of possible stress conditions at a specific depth below an assumed thalweg extending to 350 feet (107 m) depth. Stress conditions will vary along the alignment of a tunnel as a function of water depth and density of overlying materials, among other factors.

5.3 FAULTS

According to Bricker (1977), some fault zones in the Precambrian rock outcrop region of the western Upper Peninsula in Michigan have been mapped at surface and in mines. Less is known about fault traces in the Paleozoic sedimentary rocks of the eastern Upper Peninsula and the Lower Peninsula of the state, where bedrock is mantled by glacial deposits that obscure any surface evidence of faulting. Any fault zones in these areas are considered to be stable as most movement occurred in the distant geologic past. Limited seismic activity involving 30 fault slippage earthquakes with source depths of 95 to 110 kilometers is not believed to have involved faulting of the overlying Paleozoic sediments (Bricker, 1977). Local faulting associated with brecciation was noted in boreholes drilled for the Mackinac Bridge crossing investigations (Rosenau, 1956) in the Straits. While not considered active faulting, these relict features may contribute to zones of increased hydraulic conductivity and potentially weaker rock conditions locally.

5.4 SEISMICITY

The Straits are located within the tectonically stable interior of the North American continent. This region is characterized by low rates of seismicity. Figure 35 shows historic earthquakes of magnitude 3 or higher in or near Canada between 1627 and 2015, including the Straits area. The historical data suggests that, in general, the Straits area experiences sparse seismic activity. There is no indication of the existence of major seismogenic features or active faults in the area. Bricker (1977) summarizes the few relatively small magnitude local seismic events in the Upper and Lower Peninsula areas of Michigan.

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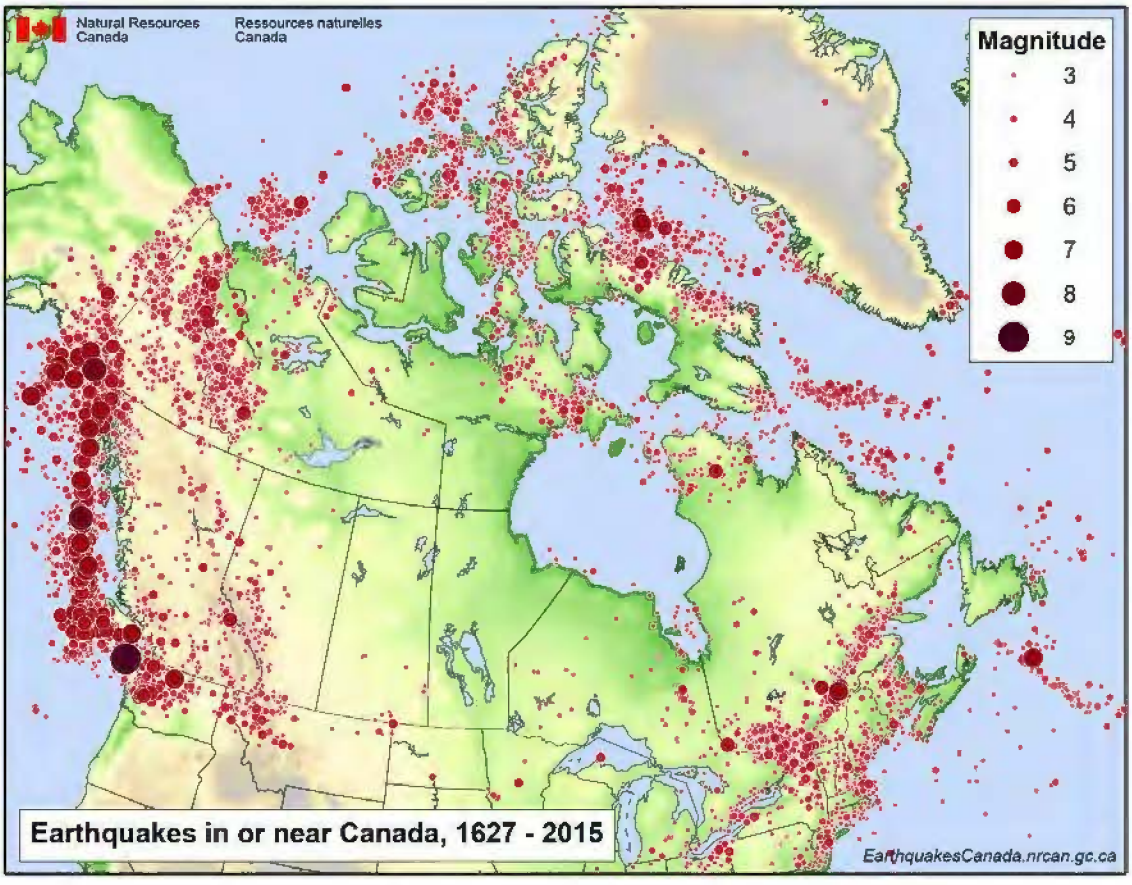


Figure 35 - Earthquakes with magnitude 3 or greater in or near Canada between 1627 and 2015 (Natural Resources Canada, 2015, http://www.earthquakescanada.nrcan.gc.ca/historic-historique/caneqmap-en.php)

The associated seismic hazard map of the continental United States (Figure 36) confirms that the Straits area is in a location of minimal seismic hazard, with peak ground acceleration values between 0.02 and 0.04 g for a 2% probability of exceedance in 50 years.

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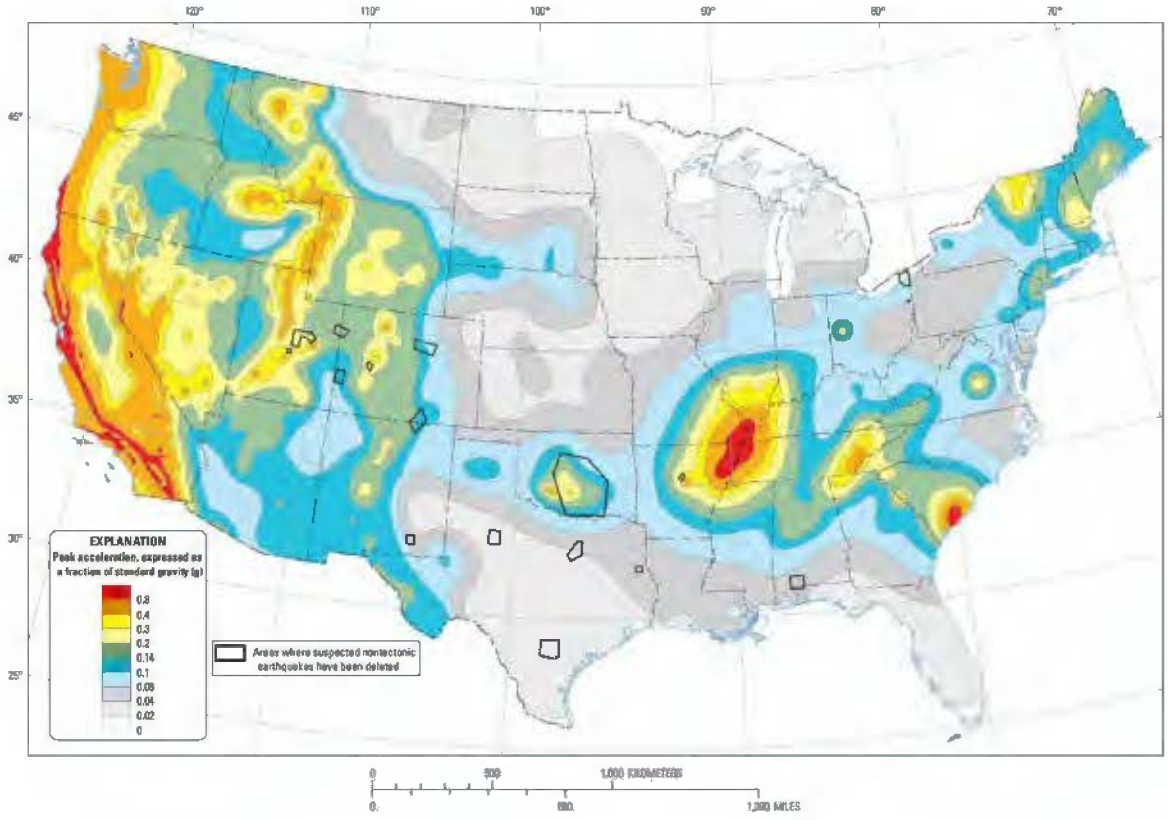


Figure 36 - Seismic hazard map for the continental United States for 2% probability of exceedance in 50 years (USGS, 2014; ftp://hazards.cr.usgs.gov/web/nshm/conterminous/2014/2014pga2pct.pdf)

6.0 STABILITY OF UNDERGROUND OPENINGS

4.1 ROCK MASS CLASSIFICATION

Rock mass classification systems are used to estimate rock-mass strength for the design of stable underground openings, and assessment of potential rock mass response to excavation under various in situ conditions. Three commonly-used systems are Rock Mass Rating (RMR), Rock Tunnel Quality Index (Q), and Geological Strength Index (GSI).

The Geomechanics Classification or Rock Mass Rating (RMR) system (Bieniawski, 1976a, b) was developed as a means of estimating strength of rock masses, and was successively modified based on case histories (Bieniawski, 1989). The following six parameters are used with the RMR system:

- Uniaxial compressive strength of rock material

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- Rock Quality Designation (RQD)
- Spacing of discontinuities
- Condition of discontinuities
- Groundwater conditions
- Orientation of discontinuities

To estimate the value of RMR, individual ratings for each of the six parameters are summed. The RMR value can then be related to support requirements for underground openings (Bieniawski, 1989).

The Tunneling Quality Index (Q) for the determination of rock mass characteristics and tunnel support requirements is based on a large number of case histories of underground excavations (Barton et al., 1974). The numerical value of the index Q varies on a logarithmic scale from 0.001 to a maximum of 1,000 and is defined as:

$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF} \qquad \text{Eq. 2}$$

where

RQD is the Rock Quality Designation
J_n is the joint set number
J_r is the joint roughness number
J_a is the joint alteration number
J_w is the joint water reduction factor
SRF is the stress reduction factor

Barton et al. (1974) describe the classification of individual parameters used to calculate the Tunnelling Quality Index Q for a rock mass. Figure 37 provides a chart for relating the value of Q to support requirements for conventional underground openings (after Grimstad and Barton, 1993).

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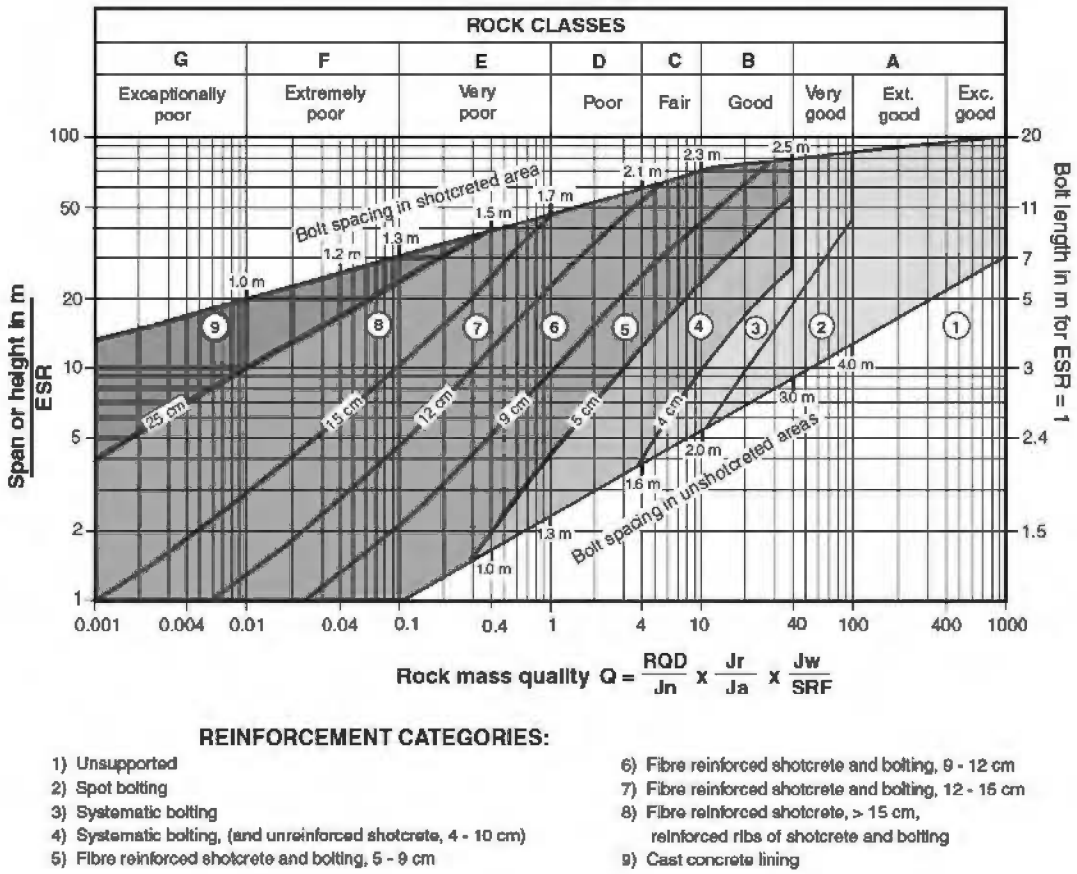


Figure 37 - Estimated support categories based on the Tunneling Quality Index Q (after Grimstad and Barton, 1993).

Hoek (1994) introduced the Geological Strength Index (GSI) to complement the Hoek-Brown failure criterion (Hoek and Brown, 1980) as a means of estimating the reduction in rock mass strength for different geological conditions. The GSI value is estimated based on structure and surface conditions of discontinuities in the rock mass. Table 6a is used to estimate GSI for blocky rock masses, and Table 6b is used for heterogeneous rock masses such as flysch. An earlier procedure of estimating GSI from RMR classification is no longer recommended practice.

Use of the GSI system is applicable where the discontinuity spacing is small compared with the size of the engineered structure under consideration. The GSI tables and the Hoek-Brown criterion should not be used if the discontinuity spacing is large compared with the dimensions of the engineered structure. In this case, the discontinuities should be treated individually. Where the block size is of the same order as that of the structure being analysed or when one of the discontinuity sets is significantly weaker than

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the others, the stability of the structure should be analyzed by considering failure mechanisms involving the sliding or rotation of blocks and wedges defined by intersecting structural features.

For the intact rock pieces that make up the rock mass, the rock strength can be defined using the Hoek-Brown criterion as follows:

$$\sigma_1^{'} = \sigma_3^{'} + \sigma_{ci}\left(m_i \frac{\sigma_3^{'}}{\sigma_{ci}} + s\right)^{0.5} \quad \text{Eq. 3}$$

where σ_1' and σ_3' are the maximum and minimum effective principal stresses at failure, σ_{ci} is unconfined compressive strength of intact core, and m_i and s are Hoek-Brown parameters. The parameter s is equal to 1 for intact rock. The parameter m_i is estimated from triaxial tests on core at different confining conditions, but can be based on typical values by rock types for an initial estimate. The generalized Hoek-Brown failure criterion for jointed rock masses is given by:

$$\sigma_1^{'} = \sigma_3^{'} + \sigma_{ci}\left(m_b \frac{\sigma_3^{'}}{\sigma_{ci}} + s\right)^{a} \quad \text{Eq. 4}$$

where m_b, s and a are Hoek-Brown parameters for the rock mass, and the other parameters are the same as above. Hoek et al. (2002) relate these various parameters to GSI as follows:

$$m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right) \quad \text{Eq. 5}$$

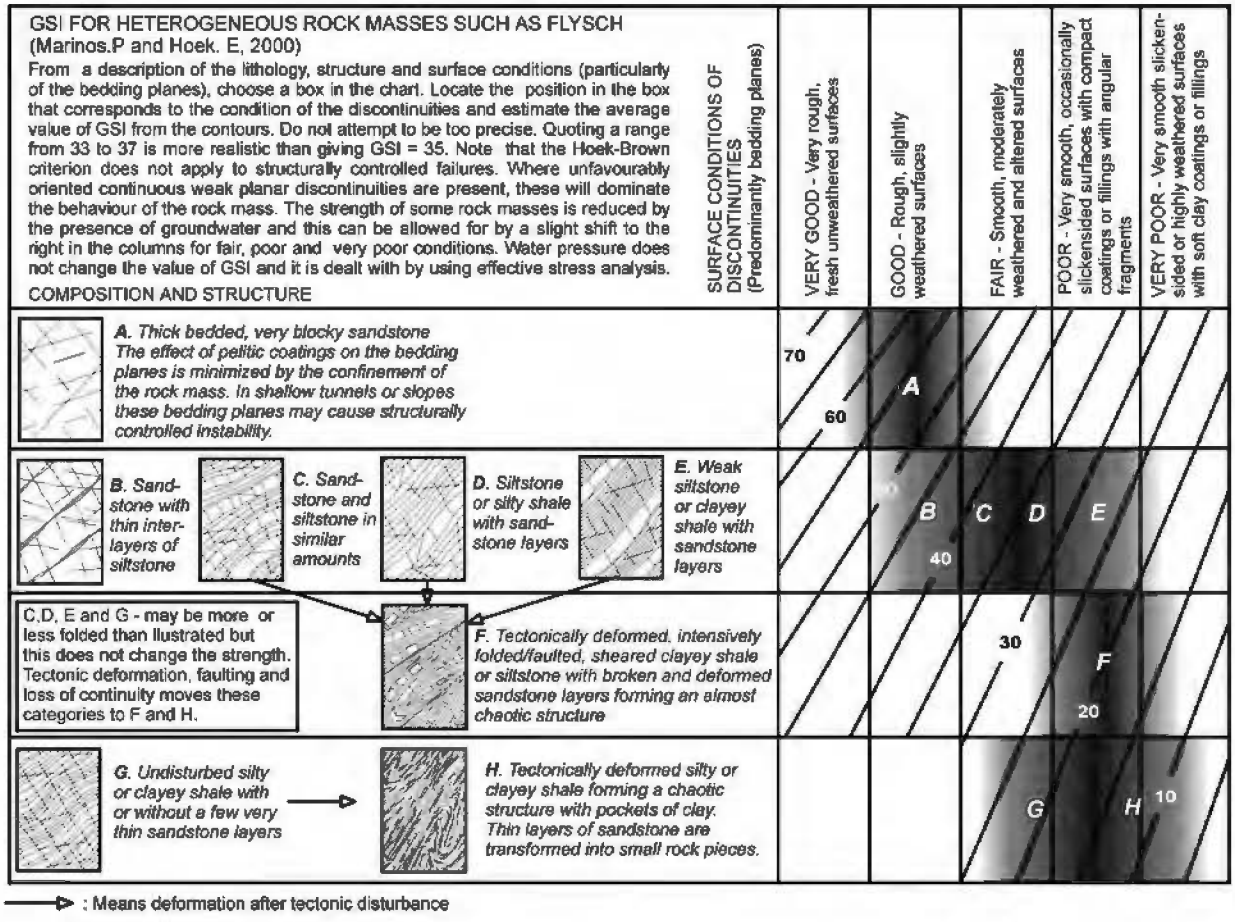
$$s = \exp\left(\frac{GSI - 100}{9 - 3D}\right) \quad \text{Eq. 6}$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \quad \text{Eq. 7}$$

The parameter D depends upon the degree of disturbance due to blast damage and stress relaxation. This parameter varies from 0 for undisturbed in situ rock masses to 1 for very disturbed rock masses. Note that D applies only to the blast damaged zone and it should not be applied to the entire rock mass. Excellent quality-controlled blasting or excavation by tunnel boring machine resulting in minimal disturbance to the confined rock mass surrounding a tunnel corresponds to $D = 0$.

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Table 6 - Basis for estimating GSI for a) blocky rock masses on the basis of interlocking and joint conditions, and b) heterogeneous rock masses such as flysch



a) Blocky rock masses with joints

b) Heterogeneous rock masses such as flysch (after Marinos and Hoek, 2001)

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Despite the extensive investigations conducted at the Bruce DGR site in the Michigan Basin, subsurface data obtained from the DGR boreholes was considered insufficient to provide reliable or complete estimates of all the parameter values required to determine the categories under these various rock mass classification systems. Preliminary descriptions of rock mass quality in the various MS units were not carried forward to develop rock mass classification ratings or indices for MS Unit 1 or 2.

Likewise, key characteristics of discontinuities are unknown in the Straits area, and particularly at depth in the rock mass at a new crossing alignment. Back analysis of required rock mass strength to maintain stability of a horizontal circular opening driven subparallel to the minimum principal stress direction can be used to frame the issue. Assuming linear elastic behaviour, the maximum and minimum tangential stresses around a circular opening with the vertical stress and maximum horizontal stress acting in the cross section orthogonal to the tunnel axis are given by:

$$\sigma_{\theta max} = 3\sigma_H - \sigma_v \quad \text{Eq. 8}$$

$$\sigma_{\theta min} = 3\sigma_v - \sigma_H \quad \text{Eq. 9}$$

where σ_θ is the tangential stress concentration at the periphery of the underground opening. The maximum tangential stress concentration in this case would be in the crown and invert of the underground opening. The minimum tangential stress concentration would be in the tunnel sidewall.

Assuming σ_v = 1.44 MPa and σ_H = 6.81 MPa as per the discussion in Section 3.2, the maximum and minimum tangential stresses at the tunnel periphery are estimated to be 19 MPa and -2.5 MPa, respectively. The tensile stress conditions at the springline in the tunnel sidewall may be sufficient to induce radial fracturing of the rock mass to some distance from the underground opening depending on in situ tensile strength and discontinuity characteristics.

The rock formation associated with these stress conditions beneath the thalweg of the submerged river valley in the Straits is the upper part of the Salina Group (Pointe aux Chenes Formation). Based on the Bruce DGR data, the mean UCS value for this unit is 31 MPa, and core quality ranges from excellent for Salina Unit F to fair for Salina Unit G, indicating sparsely to very sparsely rock mass conditions. Based on these qualitative descriptions, a representative GSI value could be on the order of 90. From Equations 6 and 7, the corresponding values for Hoek-Brown parameters s and a for a GSI value of 90 are 0.33 and 0.5, respectively. The calculated unconfined rock mass strength from Equation 4 is then 57% of the UCS value, or 18 MPa. This is very close to the calculated maximum tangential stress, suggesting that minor supporting pressure during tunnel excavation would be required to maintain stability, assuming all conditions included in this back analysis are representative of actual site conditions.

A tunnel beneath the Straits would also intersect the other overlying formations, which on the basis of the Bruce DGR data may have higher fracture frequency and lower rock quality than the Salina

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Formation. However, horizontal stress conditions in these units may be significantly reduced relative to the deeper formations as a result of stress relief associated with development of the Straits and associated submerged river valley. Support during tunneling would likely be required in these conditions to maintain stability given the possibility of intersecting brecciated rock.

Poorer rock quality and possibly increased hydraulic conductivity at the Devonian-Silurian unconformity between the Bois Blanc and Bass Islands (St. Ignace) formations, brecciation features in the rock mass, and possible karst solution features are other considerations in evaluating tunneling options at the site.

7.0 CONCLUDING REMARKS

The preliminary assessment of surficial and bedrock geology conditions in the Straits area, supplemented with information from detailed investigations for underground excavations at the Bruce DGR site, provides a starting point for evaluating potential constructability and tunneling options. Some information including core logs, core photographs and driller's reports identified in the 1950s reports on the Mackinac Bridge crossing investigations was not available to review for this report. That information would be useful to compare specific overburden test information to the general logs; and rock core data to the Bruce DGR data to assess consistency between the two sites, recognizing the advancements in drilling technologies since the 1950s. Additional detailed information from the proposed crossing alignment would be required to advance the actual design of a surface trenched or tunnel crossing, but the information contained herein is considered sufficient for the purposes of a preliminary scoping study.

Key considerations for tunneling include:

- The topography of the bedrock surface in the Straits, particularly the unknown depth and geometry of the main submerged river valley, and the approximately 4 mile shore-to-shore crossing distance
- The brecciated nature of the upper formations and related occurrence of local faults and general heterogeneity of lithological conditions
- Possible karst features in the carbonate and anhydrite formations that have been exposed to groundwater circulation
- Variability in geomechanical properties and conditions within and between the various units of the main formations
- A significant depth of water at the deepest point in the submerged river valley, and potentially high water pressure in permeable zones of the rock mass

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- Potentially poorer rock quality and possibly increased hydraulic conductivity at the Devonian-Silurian unconformity between the Bois Blanc and Bass Islands (St. Ignace) formations.

Key considerations for trenched pipeline solutions include:

- Assume construction trenching will encounter weathered glacial till at and just below mudline elevations for water depths between 0 and 30 m. Assume soft marine mud (lacustrine silt and clay) for trench conditions at depths below 30 m.

- Construction may encounter boulders or otherwise coarse grained ground conditions in terrain overlooking the south and north flanks of the Mackinac River valley slopes where bedrock subcrop is shallow.

- Weathered glacial till could be considered consistent with a loose to compact sand bottom conditions, and may encounter pebbles. Boulders are possible in the till but not typically in this region.

- The Mackinac River valley slopes are steepest on the north flank, up to about 13%.

- Beach deposits consisting of compact gravel ridges are likely present below steeper erosional slope steps present on the south side of the Straits.

Information available from the Michigan Department of Environmental Quality (DEQ), Office of Oil, Gas, and Minerals (OOGM) Digital Geology Library[4] was used for this report. Descriptions, figures and tables extracted from this information are subject to a copyright notice[5]. Similarly, extensive use was made of reports prepared for the Bruce DGR and many figures and photographs from those report were included in this report with acknowledgement to the respective sources. Re-use of this material should retain copyright notice and citations to the original reports.

[4] http://www.michigan.gov/documents/deq/GIMDL-Catalog-2010-01-20_307979_7.pdf

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8.0 LIMITATIONS & CLOSURE

KGL appreciates the opportunity to provide the comments and recommendations in this report to assist Dynamic Risk with the Independent Alternatives Analysis for the Straits Pipeline Project.

The recommendations provided are necessarily limited to the understanding that this report was prepared using the referenced desktop level data only as set out in this report. The nature of interpreting geological data between measured data points is specifically noted to include the potential for different conditions than those described, owing to natural variability that is otherwise difficult or unable to be measured or predicted.

The information contained in this report has been prepared using generally accepted engineering practices. No warranty, whether implied or explicit is given. This report was prepared for the purposes of supporting a hazard assessment and does not constitute an engineered design.

The report was prepared for the exclusive use of the clients named within and for the specific area and conditions as set out. KGL accepts no responsibility for damages or losses related to any third party reliance on any information or recommendations included in this letter, either in whole or in part.

Please contact the undersigned if conditions change or are discovered to be otherwise different than those described herein.

Respectfully Submitted

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REFERENCES

Adams, J. and J. B. Bell. 1991. Crustal stresses in Canada. In: Slemmons, D. B., E. R. Engdahl, M. D. Zoback and D. D. Blackwell (eds). Neotectonics of North America, Decade map volume to accompany the neotectonic maps, part of the Continent-scale maps of North America, Geological Society of America, 367 – 386

Ammann, O.H., D. B. Steinman, G.B. Woodruff. 1951. Proposed Mackinac Straits Bridge Preliminary Report. State of Michigan, Mackinac Bridge Authority. http://www.michigan.gov/documents/deq/Proposed_Prelim_Report_306067_7.pdf http://www.michigan.gov/documents/deq/Proposed_Prelim_Report_opt_306071_7.pdf

Armstrong, D.K. and T.R. Carter. 2006. An Updated Guide to the Subsurface Paleozoic Stratigraphy of Southern Ontario. Ontario Geological Survey, Open File Report 6191.

Barton, N.R., Lien, R. and Lunde, J. 1974. Engineering classification of rock masses for the design of tunnel support. Rock Mech. 6(4), 189-239.

Berkey, C. P. and S. Paige. Undated. Pier Foundations for a Proposed Bridge across the Straits of Mackinac - An Engineering Geologic Report. http://www.michigan.gov/documents/deq/Pier_Foundations_306062_7.pdf

Bieniawski, Z.T. 1976a. Rock mass classification in rock engineering. In Exploration for rock engineering, proc. of the symp., (ed. Z.T. Bieniawski) 1, 97-106. Cape Town: Balkema.

Bieniawski, Z.T. 1976b. Geomechanics classification of rock masses and its application in tunnelling. In Proc. 3rd Int'l. Congr. Soc. Rock Mech., Denver, 2, Part A, 27-32.

Bieniawski, Z.T. 1989. Engineering rock mass classifications. New York: Wiley.

Bricker, D.M. 1977. Seismic Disturbances in Michigan. Circular 14, Michigan Geological Survey Division. Lansing, Michigan. http://www.michigan.gov/documents/deq/GIMDL-CR14_216127_7.PDF http://www.michigan.gov/documents/deq/Circular14_301726_7.pdf

Catacosinos, P.A., W.B. Harrison III, R.F. Reynolds, D.B. Westjohn, and M.S. Wollensak. 2001. Stratigraphic Lexicon for Michigan. Bulletin 8, Geological Survey Division, Michigan Basin Geological Society. Lansing, Michigan. http://www.michigan.gov/documents/deq/GIMDL-BU08_216121_7.pdf http://www.michigan.gov/documents/deq/2000CHRT_301468_7.PDF

ENBDNR0002543

Grimstad, E. and Barton, N. 1993. Updating the Q-System for NMT. Proc. Int. Symp. on sprayed concrete - modern use of wet mix sprayed concrete for underground support, Fagernes. 46-66. Oslo: Norwegian Concrete Assn.

Heidbach, O., M. Tingay, A. Barth, J. Reinecker, D. Kurfeß, and B. Müller. 2008. The world stress map database release 2008, http://www.world- stress- map.org

Hoek, E. 1994. Strength of rock and rock masses, ISRM News Journal, 2(2), 4-16.

Hoek, E. and Brown, E.T. 1980. Empirical strength criterion for rock masses. J. Geotech. Engng Div., ASCE 106(GT9), 1013-1035.

Hoek, E., Carranza-Torres, C. and Corkum, B. 2002. The Hoek-Brown failure criterion –2002 Edition. Proc. 5th North American Rock Mechanics Sym. and 17th Tunneling Assn of Canada conf. pp.267-271. Toronto:NARMS-TAC.

Hoek, E., P.K. Kaiser and W.F. Bawden. 1998. Support of Underground Excavations in Hard Rock. A.A. Balkema, Rotterdam.

Hough, J.L. 1953. Pleistocene Chronology of the Great Lakes Region. Office of Naval Research, Project NR-018-122, University of Illinois, Urbana, IL. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=AD0011626

https://commons.wikimedia.org/wiki/File:Glacial_lakes.jpg . *This image or file is a work of a U.S. Army Corps of Engineers soldier or employee, taken or made as part of that person's official duties. As a work of the U.S. federal government, the image is in the* ***public domain****.*

Intera Engineering Ltd. 2011. Descriptive Geosphere Site Model. Nuclear Waste Management Organization Report NWMO DGR-TR-2011-24 R000, March 2011. Toronto, Canada http://www.opg.com/generating-power/nuclear/nuclear-waste-management/Deep-Geologic-Repository/Documents/Submission/18.DGSM.pdf

International Society for Rock Mechanics. 1977. Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses, Commission on Standardization of Laboratory and Field Tests, Int. J. Rock Mech. Min. Sci. & Geomech. Abstract 15, 319-368.

Kelley, R.W. 1960. A Glacier Passed this way. Michigan Conservation, Special Great Lakes Issue, July-August 1960, Vol. XXIX No. 4. Michigan Department of Conservation, Lansing, Michigan. [] http://www.michigan.gov/documents/deq/NSAGLAC_304646_7.pdf

ENBDNR0002544

Landes, K. K., G. M. Ehlers, and G. M. Stanley. 1945. Geology of the Mackinac Straits Region and Sub Surface Geology of the Northern Southern Peninsula. Publication 44: Geological Series 37. University of Michigan. Michigan Department of Conservation, Lansing, Michigan.
http://www.michigan.gov/documents/deq/GIMDL-PU44A_302655_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-PU44B_302676_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-PU44C_302679_7.pdf
http://www.michigan.gov/documents/deq/PU_44_Aopt_308594_7.pdf
http://www.michigan.gov/documents/deq/PU_44_Bopt_308595_7.pdf
http://www.michigan.gov/documents/deq/PU_44_Copt_308597_7.pdf

Lilienthal, R.T. 1978. Stratigraphic Cross- Sections of the Michigan Basin. Report of Investigation 19, Michigan Department of Environmental Quality, Geological and Land Management Division
http://www.michigan.gov/documents/deq/GIMDL-RI19A_302717_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19J_302736_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19B_302720_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19C_302723_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19D_302725_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19E_302726_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19F_302728_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19G_302730_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19H_302732_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19I_302734_7.pdf

Marinos, P. and Hoek, E. 2001. Estimating the geotechnical properties of heterogeneous rock masses such as Flysch. Bull. Engng. Geol. Env. 60, 85-92.

Melhorn, W. N. Geology of the Mackinac Straits in Relation to the Mackinac Bridge. Journal of Geology, Vol 67. No. 4 (Jul 1959) pp 403-416. University of Chicago Press.

Michigan Department of Environmental Quality (DEQ), Office of Oil, Gas, and Minerals (OOGM). 2014. Digital Geology Library Catalog.
http://www.michigan.gov/documents/deq/GIMDL-Catalog-2010-01-20_307979_7.pdf

Natural Resources Canada. 2015. Map of earthquakes with magnitude 3 or greater in or near Canada between 1627 and 2015.
http://www.earthquakescanada.nrcan.gc.ca/historic-historique/caneqmap-en.php

NWMO and AECOM. 2011. Regional Geomechanics – Southern Ontario. AECOM Canada Ltd. and Nuclear Waste Management Organization Report NWMO DGR-TR-2011-13 R000. Toronto, Canada.

ENBDNR0002545

NWMO. 2011. Geosynthesis. Nuclear Waste Management Organization Report NWMO DGR-TR-2011-11 R000, March 2011. Toronto, Canada. http://www.opg.com/generating-power/nuclear/nuclear-waste-management/Deep-Geologic-Repository/Documents/Submission/25.Geosynthesis.pdf

Rosenau, J.C. 1956. Mackinac Bridge Final Geological Report. D.B. Steinman, Consulting Engineer. http://www.michigan.gov/documents/deq/Final_Geological_Report_306059_7.pdf
http://www.michigan.gov/documents/deq/Final_Geological_Report_opt_306060_7.pdf

Terzaghi, R. D. 1965. Sources of error in joint surveys. Geotechnique 15, 287-304.

USGS. 2014. Seismic hazard map for the continental United States for 2% probability of exceedance in 50 years. ftp://hazards.cr.usgs.gov/web/nshm/conterminous/2014/2014pga2pct.pdf

References from Michigan Department of Environmental Quality (DEQ), Office of Oil, Gas, and Minerals (OOGM) Digital Geology Library Catalog (subject to copyright notice)

Bulletin 08: Stratigraphic Lexicon for Michigan; P. A. Catacosinos, 2001; A comprehensive compilation of stratigraphic terms with accompanying stratigraphic chart All counties, Nomenclature, Stratigraphy http://www.michigan.gov/documents/deq/GIMDL-BU08_216121_7.pdf

Bulletin 08: Chart Stratigraphic Nomenclature for Michigan; P. A. Catacosinos, 2001; 1 colored sheet 17" by 22" folded to 8.5" by 11", included as part of Bulletin 8 All counties, Nomenclature, Stratigraphy http://www.michigan.gov/documents/deq/2000CHRT_301468_7.PDF

Bedrock Geology Map 1987; S. E. Wilson, 1987; Colored map of the aerial extent of geologic formations. Includes both Peninsulas; 2 colored sheets, 1:500, 000 map of Northern Peninsula http://www.michigan.gov/documents/deq/1987_Bedrock_Geology_Map_301466_7.pdf

Bedrock and Cross Section http://www.michigan.gov/documents/deq/Bedrock_and_cross_section_301678_7.pdf

Proposed Mackinac Straits Bridge Preliminary Report; O. H. Ammann, D. B. Steinman, G. B. Woodruff, 1951
http://www.michigan.gov/documents/deq/Proposed_Prelim_Report_306067_7.pdf
http://www.michigan.gov/documents/deq/Proposed_Prelim_Report_opt_306071_7.pdf

Pier Foundations for a Proposed Bridge Across the Straits of Mackinac; C. P. Berkey, S. Paige, ND
http://www.michigan.gov/documents/deq/Pier_Foundations_306062_7.pdf
http://www.michigan.gov/documents/deq/Pier_Foundations_opt_306063_7.pdf

ENBDNR0002546

Mackinac Bridge Final Geological Report; J. C. Rosenau, 1956
http://www.michigan.gov/documents/deq/Final_Geological_Report_306059_7.pdf
http://www.michigan.gov/documents/deq/Final_Geological_Report_opt_306060_7.pdf

Publication 44: Geological Series 37. Geology of the Mackinac Straits Region and Sub Surface Geology of the Northern Southern Peninsula; K. K. Landes, 1945; Charlevoix Co., Cheboygan Co., Dolomite, Emmet Co., Gas, Gypsum, Limestone, Mackinac Co., Mackinac Island, Monroe Co., Oil, Presque Isle Co., Salt, Water;
http://www.michigan.gov/documents/deq/GIMDL-PU44A_302655_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-PU44B_302676_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-PU44C_302679_7.pdf
http://www.michigan.gov/documents/deq/PU_44_Aopt_308594_7.pdf
http://www.michigan.gov/documents/deq/PU_44_Bopt_308595_7.pdf
http://www.michigan.gov/documents/deq/PU_44_Copt_308597_7.pdf

Report of Investigation 19: Stratigraphic Cross- Sections of the Michigan Basin; R. T. Lilienthal, 1978; 89 electric log cross sections
http://www.michigan.gov/documents/deq/GIMDL-RI19A_302717_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19J_302736_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19B_302720_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19C_302723_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19D_302725_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19E_302726_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19F_302728_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19G_302730_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19H_302732_7.pdf
http://www.michigan.gov/documents/deq/GIMDL-RI19I_302734_7.pdf

Circular 14: Seismic Disturbances in Michigan; D. M. Bricker, 1977; An introduction with description of causes and types of earthquake activity, maps. 2 tables All counties, Earth Quakes;
http://www.michigan.gov/documents/deq/GIMDL-CR14_216127_7.PDF
http://www.michigan.gov/documents/deq/Circular14_301726_7.pdf

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Dynamic Risk

Attachment 4: RIAM Environmental Scores

Attachment 04, RIAM Environmental Scores.pdf

Attachment

RIAM Environmental Scores

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1 The RIAM Approach

DHI has used the well-recognised Rapid Impact Assessment Matrix (RIAM) methodology for assessing and summarising the overall significance of impacts related to the project. This methodology allows for rapid transparent presentation and summary of the overall project impacts and ultimately aids in pinpointing which impacts are most significant.

RIAM Methodology in Brief

With RIAM, the significance of an impact is determined by translating an environmental score (ES) to impact significance ('Slight,' 'Minor,' 'Moderate,' etc.), via a predetermined list of impact levels that corresponds to a range of ESs. The main thrust of the RIAM tool is therefore, to assign an environment score to each relevant environmental component of a project. The formula for determining the ES is as follows:

$$\text{Environmental Score (ES)} = I*M*(P+R+C)$$

The formula variables are defined as:

- (I) Importance – Assigns a level of importance in terms of variables such as spatial extent and socio-political interests related to the impact
- (M) Potential Impact Magnitude– Expresses the level of impact (i.e. deviation from baseline in relation to an established evaluation framework) in a physio-chemical parameter, risk abatement benchmark, or the scale of loss/change to ecological and socio-economic receptors
- (P) Permanence – Assign a score based on the duration of an impact
- (R) Reversibility – The score expresses whether an impact is permanent or reversible
- (C) Cumulativity – A score is defined based on the cumulative potential of an impact

Influence of RIAM Methodology throughout the Report

The RIAM approach uses analysis of change in the state/impact magnitude (M) of a pollutant/environmental aspect to determine the impact significance. This is determined by coupling the impact (or change) at the sensitive receptor(s) in question with an assessment of the Importance (I), Permanence (P), Reversibility (R) and Cumulativity (C) in the ES formula.

Given the above, impact assessment sections focus on analysing the potential 'Impact Magnitude' (M) of a certain impact. Textual descriptions of significance judgements are given, but always confirmed and underpinned by the final RIAM process and results.

The full definition of 'Impact Magnitude' (M) terminology is provided below in order to allow the reader to understand the assessment terminology used in the impact analysis sections.

1.1 RIAM Rationale

An integrated assessment is carried out using the Rapid Integrated Assessment Matrix (RIAM) approach in order to provide an overall transparent assessment of the Project impacts.

It is noted that the integrated assessment concentrates both compliance with standards and guidelines and the eventual impact on receptors (e.g. ecological systems).

1.2 RIAM Methodology

The RIAM assessment approach assigns an environmental score to each environmental component. The score is calculated as:

$$\text{Environmental Score (ES)} = I*M*(P+R+C)$$

For the importance, magnitude, permanence, reversibility and cumulativity, the scales are defined in Table 1.1 to Table 1.3.

Importance Definition and Scoring

Table 1.1 Importance scoring

Score	Importance
4	Important to national/international interests that could pose cross-border impacts to neighbouring countries
3	Important to regional/ state-level interests
2	Important to the local condition (within a large direct impact area, e.g. 5km from Project footprint)
1	Important only to the local condition (within a small direct impact area, within 1km of Project footprint)
0	No importance

Magnitude Definition and Scoring

Table 1.2 Magnitude scoring

Score	Magnitude
+3	Major positive benefit
+2	Significant improvement in status quo
+1	Improvement in status quo
0	No impact /status quo
-1	Negative change to status quo
-2	Significant negative dis-benefit or change
-3	Major dis-benefit or change

Permanence, Reversibility and Cumulativity Definitions and Scoring

Permanence (P) is a description of whether a condition is temporary or permanent, and should be considered a measure of the temporal status of the condition.

Reversibility (R) is a description of whether the condition can be changed and is a measure of the control over the effect of the condition. It should not be confused or equated with permanence. For example, an accidental toxic spillage into a river is a temporary condition (P=2) but its effect (i.e. death of fish) is irreversible (R=3).

Cumulativity (C) is a measure of whether the effect will have a single direct impact or whether there will be cumulative effect over time, or a synergistic effect depending on other related conditions. For example, the compounding effect of bioaccumulation is considered cumulative as its effects are realised in many trophic levels along a complex ecological food web.

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Table 1.3 Permanence, Reversibility and Cumulativity Scoring

Score	Permanence (P)	Reversibility (R)	Cumulativity (C)
1	No change/Not applicable		
2	Temporary	Reversible (or controllable through EMMP)	Non-cumulative/single
3	Permanent	Irreversible	Cumulative/secondary

According to the environmental score, range bands were established and impact indicators are assigned to the different range bands. Table 1.4 shows the range bands and impact descriptions used for the RIAM assessment.

Table 1.4 Range bands used for RIAM

Range Bands for RIAM ES	Description of Range Band
72 to 108	Major positive impact
36 to 71	Significant positive impact
19 to 35	Moderate positive impact
10 to 18	Minor positive impact
1 to 9	Slight positive impact
0	No Impact/Status quo/Not Applicable
-1 to -9	Slight negative impact
-10 to -18	Minor negative impact
-19 to -35	Moderate negative impact
-36 to -71	Significant negative impact
-72 to -108	Major negative impact

Dynamic Risk

Attachment 5: Oil Spill Modeling for Straits of Mackinac, Michigan: Hydrodynamic and Spectral Wave Numerical Modeling

Hydrodynamic and Spectral Wave Numerical Modeling.pdf

Rev. 1 (June 27, 2017)

Oil Spill Modeling for Straits of Mackinac, Michigan

Hydrodynamic and Spectral Wave Numerical Modeling

Final Report



Oil Spill Modeling for Straits of Mackinac, Michigan

Hydrodynamic and Spectral Wave Numerical Modeling

Final Report

Prepared for Dynamic Risk



Project Manager	Dale Kerper, Senior Coastal & Marine Engineer, DHI US

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1 Introduction

Dynamic Risk contracted DHI to assess the fate of oil spill on the aquatic environment and terrestrial ecological environment associated with six alternative schemes to the existing Line 5 pipeline crossing of the Mackinac Straits. The current location of Line 5 across the straits is shown in Figure 1-1 below.

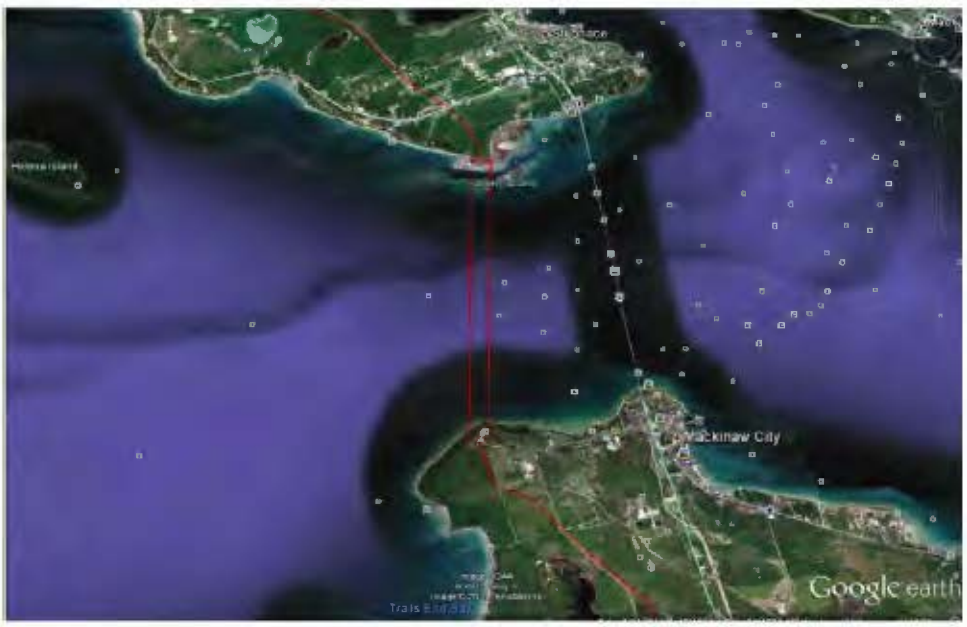


Figure 1-1 Location of Line 5 crossing Mackinac Straits.

The present report describes the setup and validation of the numerical hydrodynamic (HD) and spectral wave (SW) models that have been used as the engine for the oil spill assessments. Data used to setup and validate the models are also presented and described.

2 Data Collection and Processing

2.1 Background

DHI has an operational forecast model for the Great Lakes area. The model was originally developed for Ontario Ministry for Natural Resources and Forestry (Petersborough, ON) to understand flooding issues of communities along the shorelines of the Great Lakes.

The two dimensional model is set up for Lake Superior, Lake Huron, Lake St. Clair, Lake Erie and Lake Ontario and includes a calibrated hydrodynamic model and a wave model for each lake. DHI's existing model for Lake Michigan could be readily integrated into the existing model setup, if so desired.

The existing two-dimensional wave and hydrodynamic models were used as a starting point for the preparation of the dedicated hydrodynamic and wave models that will be used for the oil spill modeling analyses. The existing hydrodynamic model of Lakes Michigan and Huron were upgraded from their current two-dimensional (i.e. depth-averaged) version to fully three-dimensional, in order to ensure a realistic representation of an oil spill due to pipeline failure.

Additional bathymetry information was sourced in the area of the pipeline to increase resolution and existing water level, wave and current datasets were sourced for model validation purposes. These datasets are described in additional detail in the following sections of this report.

2.2 Bathymetry and Topography

Digital Elevation Models (DEMs) of Lake Huron and Lake Michigan were downloaded from NOAA's Bathymetry and Global Relief Datasets. The data can be downloaded from NOAA's website at https://www.ngdc.noaa.gov/mgg/greatlakes/huron.html and https://www.ngdc.noaa.gov/mgg/greatlakes/michigan.html, respectively. The Digital Elevation Models (DEMs) for Lake Huron and Lake Michigan are shown in Figure 2-1 and Figure 2-2, respectively.

Both DEMs have a horizontal resolution of 3 arcsecs (~90 m). Bed elevations are in meters and relative to Low Water Datum (LWD), which for both lakes is 577.5 feet or 176.0 m above International Great Lakes Datum 1985 (IGLD85).

The topographic and bathymetric data stored in the DEMs of Lakes Michigan and Huron were post-processed into DHI's MIKEZero software format and used for the creation of the model mesh as described in Section 3 of this report.

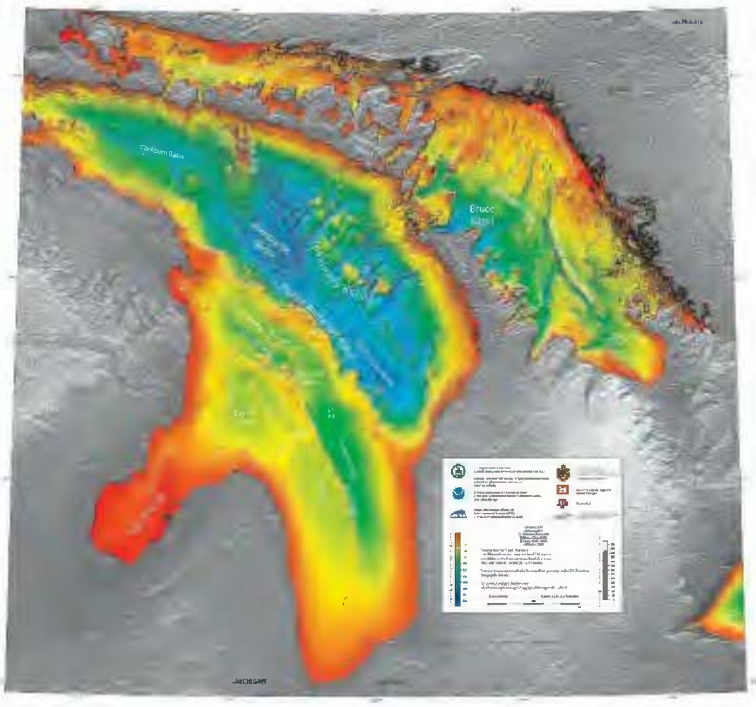


Figure 2-1 DEM of Lake Huron (Image downloaded from NOAA's webpage)

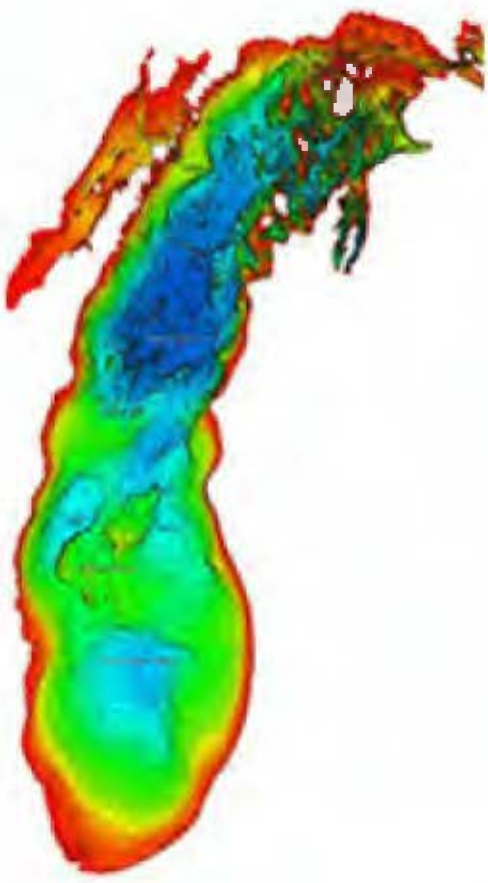


Figure 2-2 DEM of Lake Michigan (Image downloaded from NOAA's webpage)

2.3 Wind Data

Wind constitutes the main driving force for the water levels and currents that have been calculated by the numerical hydrodynamic model of Lakes Michigan and Huron for the assessment of the impact of oil spill for different scenarios. Wind also is the driving force generating the waves in the spectral wave model of both lakes, which is a component of the oil spill assessment modeling system.

Hourly wind hindcast data were downloaded from the National Center for Environmental Prediction (NCEP) webpage located at NOAA's website at https://nomads.ncdc.noaa.gov/modeldata/cfsv2_analysis_timeseries/. Results from the Climate Forecast System Reanalysis (CFSR) version 2 were adopted for the present analyses, since this dataset has the highest temporal and spatial resolution among all those available. The CFSR2 data covers the entire globe with a spatial resolution of 0.204545 degrees in East-West direction and 0.204423 degrees in North-South direction. The Universal Time Coordinate (UTC) is used for all dates and times.

Wind velocity components 10 m above the ground and atmospheric pressure at Mean Sea Level were downloaded from the forecast system at 1-hour time interval, post-processed into MIKEZero compatible format and stored for later use in the numerical modeling analyses.

2.4 Water Level Data

Verified hourly water levels from NOAA stations 9075080 Mackinaw City, MI, 9075065 Alpena, MI, 9075099 De Tour Village, MI, 9087096 Port Inland and 9087023 Ludington, MI were downloaded and post-processed into MIKEZero compatible format for the period January 1, 1998 through October 1, 2016.

Figure 2-3 shows the location of NOAA's tide stations in Lakes Huron and Michigan.

All water levels were referenced to the LWD vertical datum and to the UTC time coordinate.

NOAA's verified water levels were primarily used as guidance when defining the initial surface elevation in the hydrodynamic model simulations.

2.5 Current Data

Point measurements of current speed and direction at different depths/levels above the bottom were collected from three data sources:

1. A two-month long deployment of ADCPs LM01 and LM02 in June-August 1990
2. An approximately one-year deployment of ADCPs 1087 and 3748 from June 11, 2014 to May 21, 2015
3. An ADCP meter mounted on NDBC's Buoy 45175 with available current measurements in September and October 2015 and mid-May to mid-October 2016



Figure 2-3 Position of NOAA stations around Mackinac Straits

The horizontal location of the ADCP instruments is shown in Figure 2-4 below. All measurements have a bin size of 1 meter. Additional information about ADCP measurements has been summarized in Table 2-1.



Figure 2-4 Location of ADCP current meters in Mackinac Straits

Table 2-1 Overview of current measurements in Mackinac Straits

ADCP #	First record (UTC time)	Last record (UTC time)	Latitude	Longitude	Position
LM01	June 16, 1990 11:05 AM	August 18,1990 9:05 PM	45°48'55.44"N	84°44'56.40"W	Surface, downward facing
LM02	June 16, 1990 11:05 AM	October 10, 1990 12:05 PM	45°49'19.20"N	84°45'7.80"W	Surface, downward facing
wh1087	June 11, 2014 9:52:59 PM	May 21, 2015 10:52:59 AM	45°48'56.58"N	84°49'17.22"W	45m above bottom, upward facing
wh3748	June 11, 2014 9:49:33 AM	May 21, 2015 10:49:33 AM	45°48'56.58"N	84°49'17.22"W	4m above bottom, upward facing
NDBC 45175	August 28, 2015 4:00 PM	October 10, 2016 9:10 PM	45°49'31"N	84°46'20"W	Surface, downward facing

The measured current data was used to validate the three-dimensional hydrodynamic model MIKE 3 HD FM. Additional details about the hydrodynamic model, its validation and model-data comparisons are provided in Section 3.3 of this report.

2.6 Wave Data

Wave parameters (significant wave height H_{m0}, peak wave period T_p and mean wave direction MWD) at 10 minutes interval were obtained from NDBC Buoy 45175 for the same period as the ADCP measurements listed in Table 2-1. As mentioned before, there is a significant data gap between late October 2015 and mid-May 2016.

The wave data were used to validate the spectral wave model MIKE 21 SW, as described in Section 3.4 of this report.

2.7 Ice Cover Data

Gridded ice concentration data at a spatial resolution of 1800 m were downloaded from NOAA Great Lakes Environmental Research Laboratory (GRERL) web page http://www.glerl.noaa.gov/data/pgs/glice/glice.html. Except for a few missing datasets, daily maps of ice concentration for all the Great Lakes were available.

Ice cover data were post-processed into MIKEZero compatible format and stored for later use as input for the hydrodynamic and spectral wave models MIKE 3 HD FM and MIKE 21 SW.

3 Model Setup and Validation (Hydrodynamic and Spectral Waves)

3.1 Background and Adopted Approach

The hydrodynamic and wave models used in the present study are based on the operational forecast model DHI developed for the Great Lakes. However, these models are 2 dimensional (2D: depth-integrated) and, in order to ensure a realistic representation of the transport mechanism of an oil spill due to pipeline failure, a three dimensional (3D) model was required. Therefore, DHI's in-house three-dimensional software MIKE 3 has been used to upgrade the existing MIKE 21 hydrodynamic model and to increase resolution in the relevant areas. As it was the case for the 2D model, the 3D hydrodynamic model does not include:

- Long-term (>1 year) water level variations
- Riverine inflows

MIKE 3 HD FM is based on the numerical solution of the three-dimensional (3D) incompressible Reynolds-averaged Navier-Stokes equations subject to the assumptions of Boussinesq and hydrostatic pressure. The model solves the continuity and momentum equations and utilizes an unstructured mesh, consisting of triangular and/or quadrangular elements to provide a spatial representation of the solution domain (the model bathymetry). This approach allows for increased resolution in areas of interest, while providing for larger elements/lower resolution in other model areas. The free surface is taken into account using either a sigma-coordinate transformation approach or a combination of a sigma and z-level coordinate system.

The wave model applied in the present study is DHI's spectral wave model MIKE 21 SW. The oil spill model uses wave data to determine the amount of oil dispersed into the water column. The existing forecast model of the Great Lakes has been extended to include Lake Michigan. The wave model is based on the following data, which has been described in further detail in Section 2 of this report:

- CFSR2 wind data from NCEP
- Ice coverage from GRERL

MIKE 21 SW is a spectral wind-wave model that simulates the growth, decay and transformation of wind-waves and swell in offshore and coastal areas. The wave model applies an unstructured mesh, consisting of triangular and/or quadrangular elements of different shape and size, to resolve the local bathymetry upon which the waves propagate.

MIKE 21 SW accounts for the following physical phenomena:

- Wave growth by action of wind
- Non-linear wave-wave interaction
- Dissipation due to white-capping
- Dissipation due to bottom friction

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- Dissipation due to depth-induced wave breaking
- Refraction and shoaling due to depth variations
- Wave-current interaction
- Effect of time-varying water depth and flooding and drying

It should be mentioned that rigorous calibration/validation of the hydrodynamic and wave models has not been carried out, since this was beyond the present scope of work. Instead, model results have been compared to available measured data to validate that the adopted model parameters (inherited from existing model setups or developed as part of the present analyses) provided satisfactory agreement between measurements and model results. Additional details about the model parameters and the results from the validation exercises are provided in the following sections of this report, after the description of the model mesh and bathymetry.

3.2 Generation of Model Mesh and Bathymetry

An unstructured mesh consisting of 30093 nodes and 52852 triangular elements of different sizes and shapes was adopted to resolve the bathymetry of Lakes Michigan and Huron. The model bathymetry, which was obtained by interpolating bed elevations from NOAA's DEMs of Lake Huron and Lake Michigan (see Section 2.2 for more details) is shown in Figure 3-1.

The adopted mesh resolution (i.e. size and number of mesh elements) is a necessary compromise between desired resolution and model runtimes, with runtimes increasing with more and smaller mesh elements. The size/length of the triangular mesh elements ranges from ~150 m to ~6,600 m. Figure 3-2 shows the model mesh, while Figure 3-3 zooms into the area of higher mesh resolution around the straits.

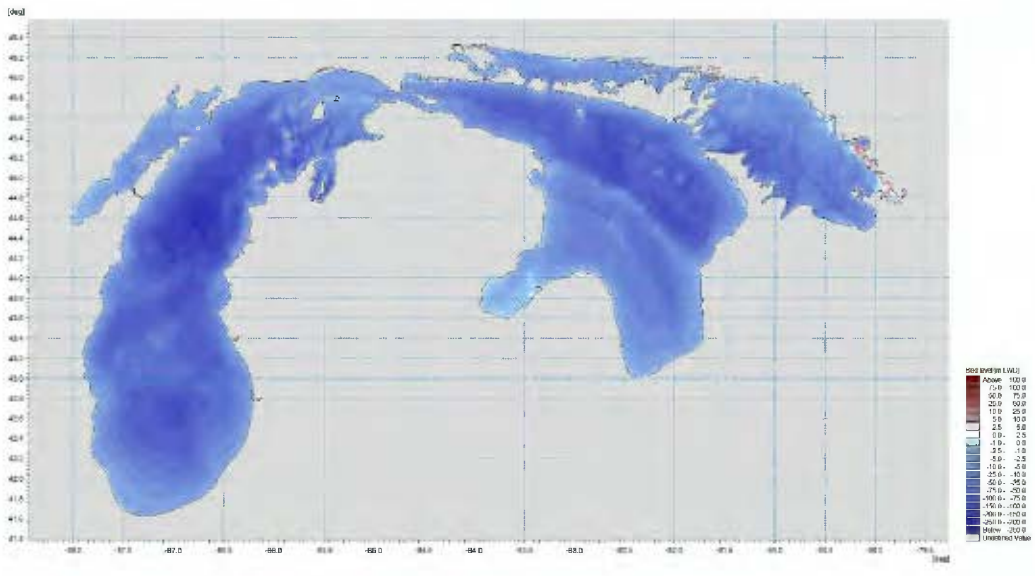


Figure 3-1 Model bathymetry of Lakes Michigan and Huron. Horizontal coordinates are longitude/latitude in degrees. Bed elevations in meters and relative to LWD

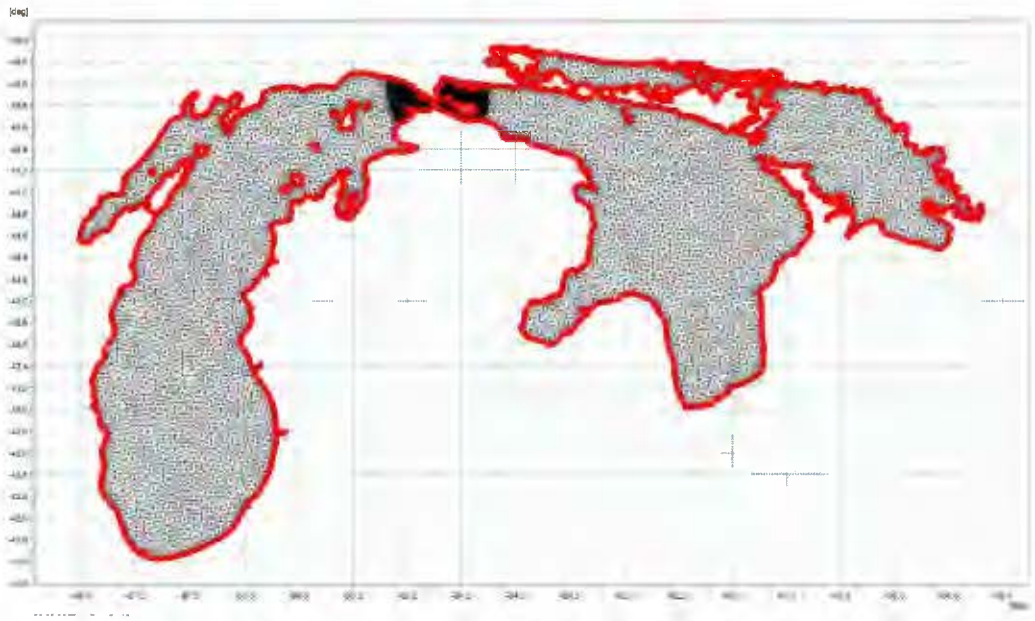


Figure 3-2 Model mesh of Lakes Michigan and Huron. Horizontal coordinates are longitude/latitude in degrees

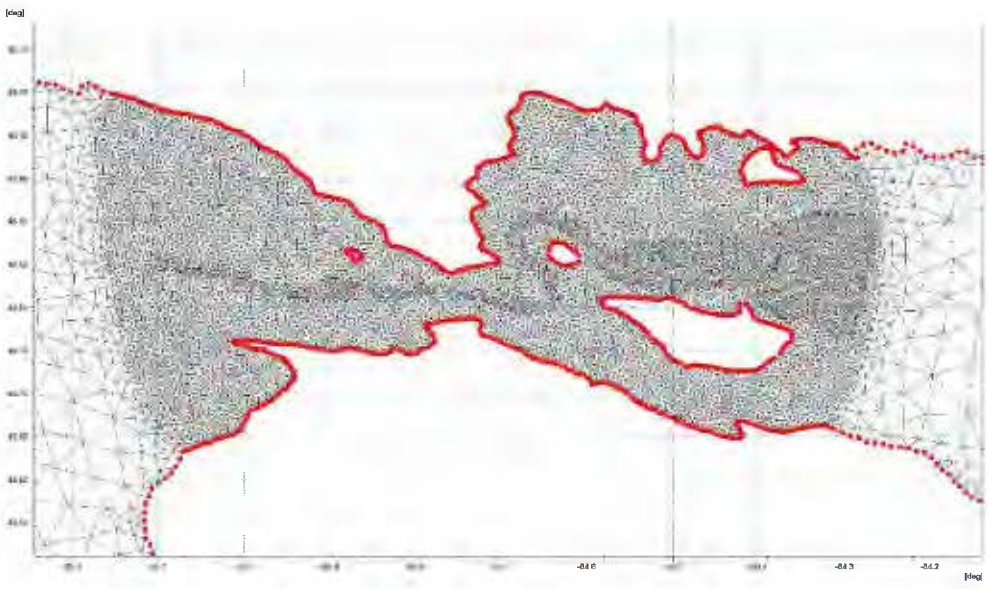


Figure 3-3 Detail of the model mesh of Lakes Michigan and Huron in the area of the Straits of Mackinac. Horizontal coordinates are longitude/latitude in degrees

The mesh doesn't have any open boundaries, since the flow in the hydrodynamic model and the waves in the spectral wave model are internally forced by the wind. The model bathymetry and mesh shown in Figure 3-1 through Figure 3-3 was used in the model validation and production runs by both the 3D hydrodynamic model MIKE 3 HD FM and the spectral wave model MIKE 21 SW.

3.3 Validation of the MIKE 3 HD FM Hydrodynamic Model

Model parameters from the existing 2D model of the Great Lakes developed by DHI were adopted for the 3D model, and the model results were compared to available current velocity measurements as a way of validating the 3D model's performance.

Four validation periods were adopted for model validation, based on the availability of ADCP data presented in Section 2.5 of this report. The start and end date of the four adopted simulation periods, as well as other simulation specific parameters, are listed in Table 3-1 below.

Table 3-1 Simulation specific parameters - MIKE 3 HD FM hydrodynamic model

Start date and time (UTC)	End date and time (UTC)	Number of time steps (-)	Ice coverage	Initial surface elevation (m, LWD)
October 15, 2015 12:00 AM	October 28, 2015 12:00 AM	1872	No ice coverage	+0.54
June 16, 1990 12:00 PM	August 18, 1990 12:00 PM	9072	No ice coverage	0.0
September 02, 2016 12:00 AM	September 30, 2016 12:00 AM	4032	No ice coverage	+0.71
March 01, 2015 12:00 AM	March 31, 2015 12:00 AM	4320	Specified ice concentration varying in time and domain, critical value = 0.90	+0.54

Apart from the parameters listed in Table 3-1 (start and end date, number of time steps, ice coverage and spatially constant initial surface elevation), all remaining model parameters were kept unchanged in the four validations runs. These parameters have been summarized in Table 3-2 for the sake of reference.

Table 3-2 Generic parameters - MIKE 3 HD FM hydrodynamic model

Vertical mesh	20 sigma layers, distributed equidistantly across the water depth
Maximum time step (s)	600
Solution technique for time integration	Higher order
Solution technique for space discretization	Higher order
Flood and dry	Standard with default values for parameters
Density	Barotropic
Eddy viscosity	Smagorisnky formulation, Cs = 0.28
Bed resistance	Roughness k_N = 0.05 m, constant
Coriolis forcing	Varying in domain
Wind forcing	Varying in time and domain. Neutral pressure = 1013 hPa
Wind friction factor f_w	Varying with wind speed W_s. f_w = 0.001255 for $W_s \leq 7$ m/s, f_w = 0.002425 for $W_s \geq 25$ m/s, with linear variation between these limits
Tidal potential	Not included
Precipitation and evaporation	Not included
Wave radiation stresses	Not included
Sources	Not included
Structures	Not included
Initial conditions	Constant water level. Zero velocity everywhere

The first three hydrodynamic model validation runs do not include ice coverage, while the fourth simulation does. For this run, input to the hydrodynamic model consisted of the daily maps of spatially varying total ice concentration that were described in Section 2.7 of this report. Whenever the total ice concentration exceeds the critical value in Table 3-1, the wind stress is excluded from the model calculation; that is, the wind speed is set to zero.

Figure 3-4 through Figure 3-9 show a comparison of horizontal velocity components (U: East-West component, V: North-South component), current speed and direction to

measurements from NDBC Buoy 45175 (see Figure 2-4 for the location of the instrument) during the model validation period in October 2015.

Figure 3-10 through Figure 3-14 show the comparison between measured and calculated current parameters at the location of ADCP LM01 for the model validation period in June-August 1990, while Figure 3-15 through Figure 3-20 show similar comparison to current measurements at ADCP LM02.

Figure 3-21 through Figure 3-25 show a comparison of horizontal velocity components, current speed and direction to measurements from NDBC Buoy 45175 during the model validation period in September 2016.

Finally, Figure 3-26 through Figure 3-31 compare measured currents to model results calculated at several elevations above the seabed (ASB) at the position of ADCPs wh1057 and wh3748 during the validation period in March 2015.

All the figures show good agreement between measurements (at different levels below the surface or elevations above the bed) and the corresponding model results.

This assessment is further supported by the root-mean-square error (RMSE) values calculated at different depths below surface or elevations above the seabed for measured and calculated current speeds and listed in Table 3-3 through Table 3-7 below. The tables also list the calculated RMSE as a percentage of the maximum current speed measured during the model validation period.

Reference is made to Table 2-1 for additional details about the ADCP current measurements and to Table 3-1 for the extent of the model validation periods used in the RMSE analyses.

It should be mentioned that the current speeds measured by ADCP wh1057 at an elevation of 50 m above the seabed are in general terms lower than the speeds recorded by ADCP wh3748 30 m above the seabed and by ADCP wh1057 itself 55 m above the seabed, which explains the outlier for RMSE% 50 m above seabed in Table 3-7.

Table 3-3 RMSE for current speeds at NDBC Buoy 45175 – October 2015

Current speed - NDBC Buoy 45175 - Oct 2015			
Level below surface (m)	**RMSE (m/s)**	**Max. measured speed (m/s)**	**RMSE %**
2	0.14	0.95	14.5%
3	0.14	0.95	14.6%
4	0.14	0.93	14.9%
5	0.14	0.95	14.7%
10	0.12	0.91	13.7%
20	0.12	0.87	13.4%

Table 3-4 RMSE for current speeds at NDBC Buoy 45175 – September 2016

Current speed - NDBC Buoy 45175 - Sep 2016			
Level below surface (m)	**RMSE (m/s)**	**Max. measured speed (m/s)**	**RMSE %**
2	0.10	0.93	10.8%
3	0.12	0.98	12.3%
5	0.12	0.98	12.1%
10	0.10	0.94	10.6%
20	0.10	0.89	11.5%

Table 3-5 RMSE for current speeds at ADCP LM01 – June-August 1990

Current speed - ADCP LM01			
Level below surface (m)	**RMSE (m/s)**	**Max. measured speed (m/s)**	**RMSE %**
2	0.11	0.63	18.3%
5	0.10	0.63	16.4%
10	0.09	0.64	14.3%
20	0.10	0.63	15.6%
30	0.10	0.55	18.0%

Table 3-6 RMSE for current speeds at ADCP LM02 – June-August 1990

Current speed - ADCP LM02			
Level below surface (m)	**RMSE (m/s)**	**Max. measured speed (m/s)**	**RMSE %**
4	0.11	0.62	17.2%
5	0.10	0.58	16.4%
10	0.10	0.66	14.8%
20	0.11	0.71	15.3%
30	0.11	0.68	16.4%
40	0.11	0.63	17.8%

Table 3-7 RMSE for current speeds at ADCPs wh1057 and wh3748 – March 2015

Current speed - ADCPs wh1057 and wh3748			
Level above sea bed (m)	**RMSE (m/s)**	**Max. measured speed (m/s)**	**RMSE %**
7	0.06	0.38	15.6%
10	0.06	0.39	16.4%
20	0.07	0.44	16.0%
30	0.07	0.67	10.4%
50	0.08	0.32	24.0%
55	0.06	0.44	13.0%

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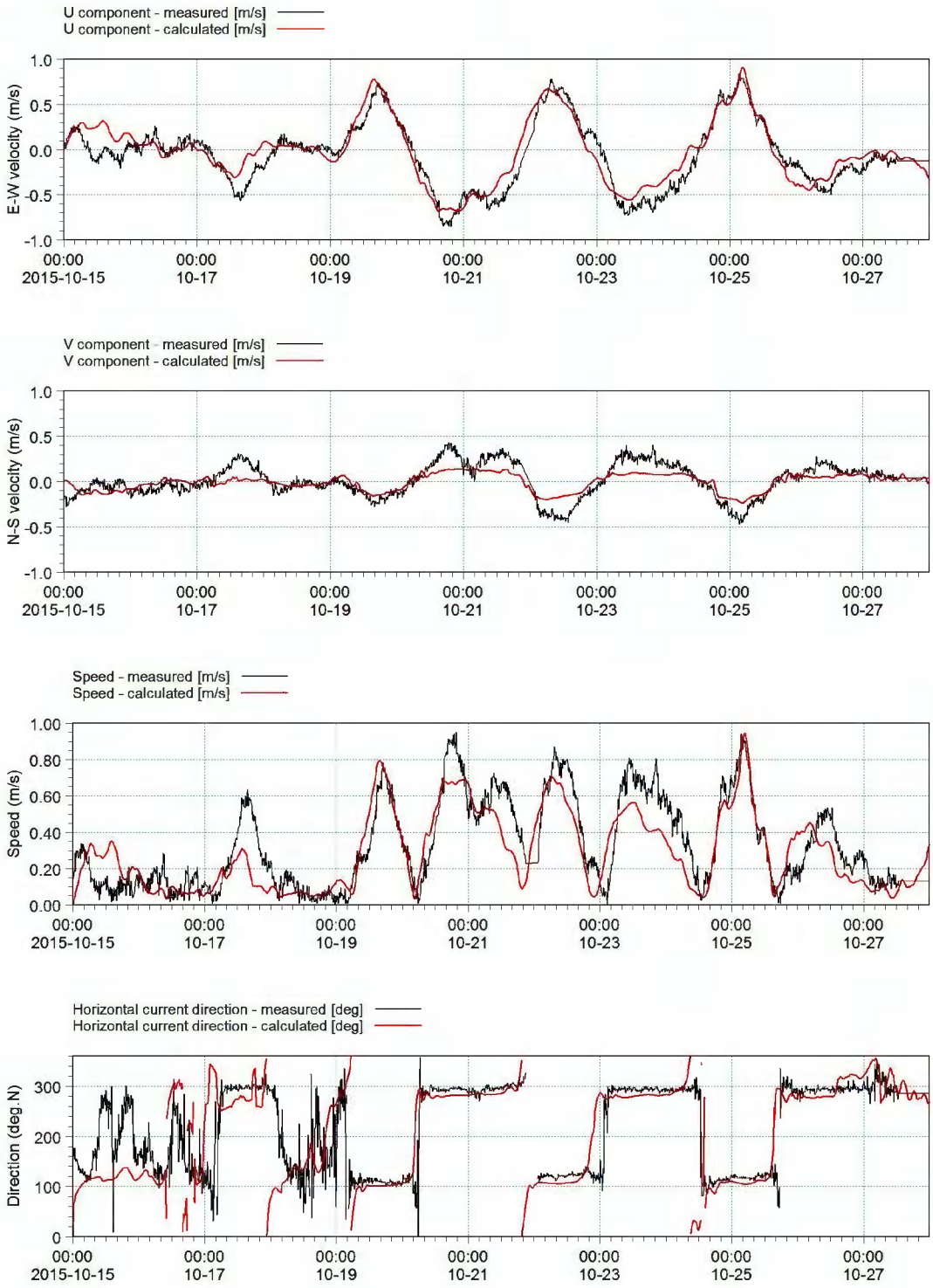


Figure 3-4 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 2 m below surface

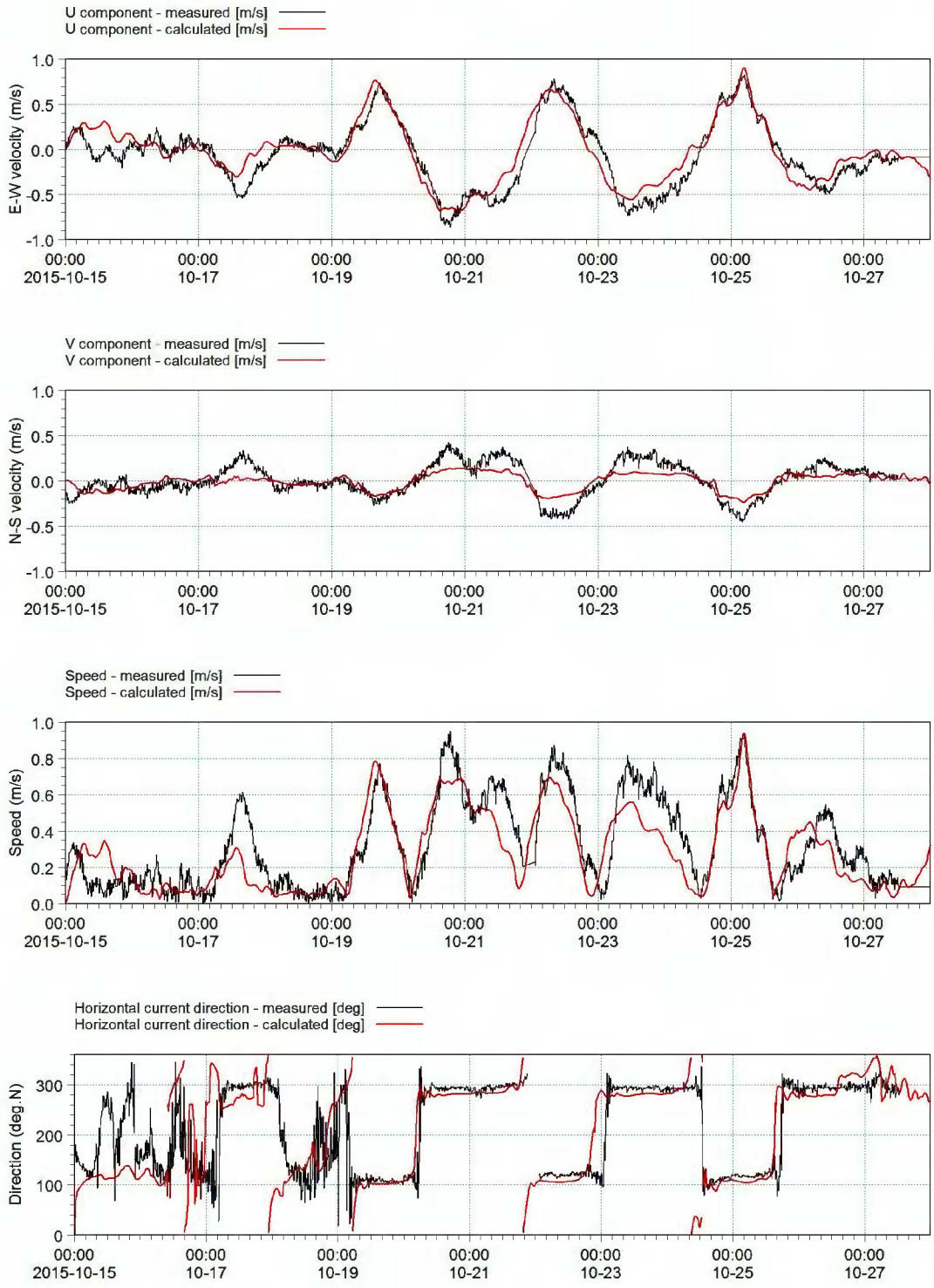


Figure 3-5 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 3 m below surface

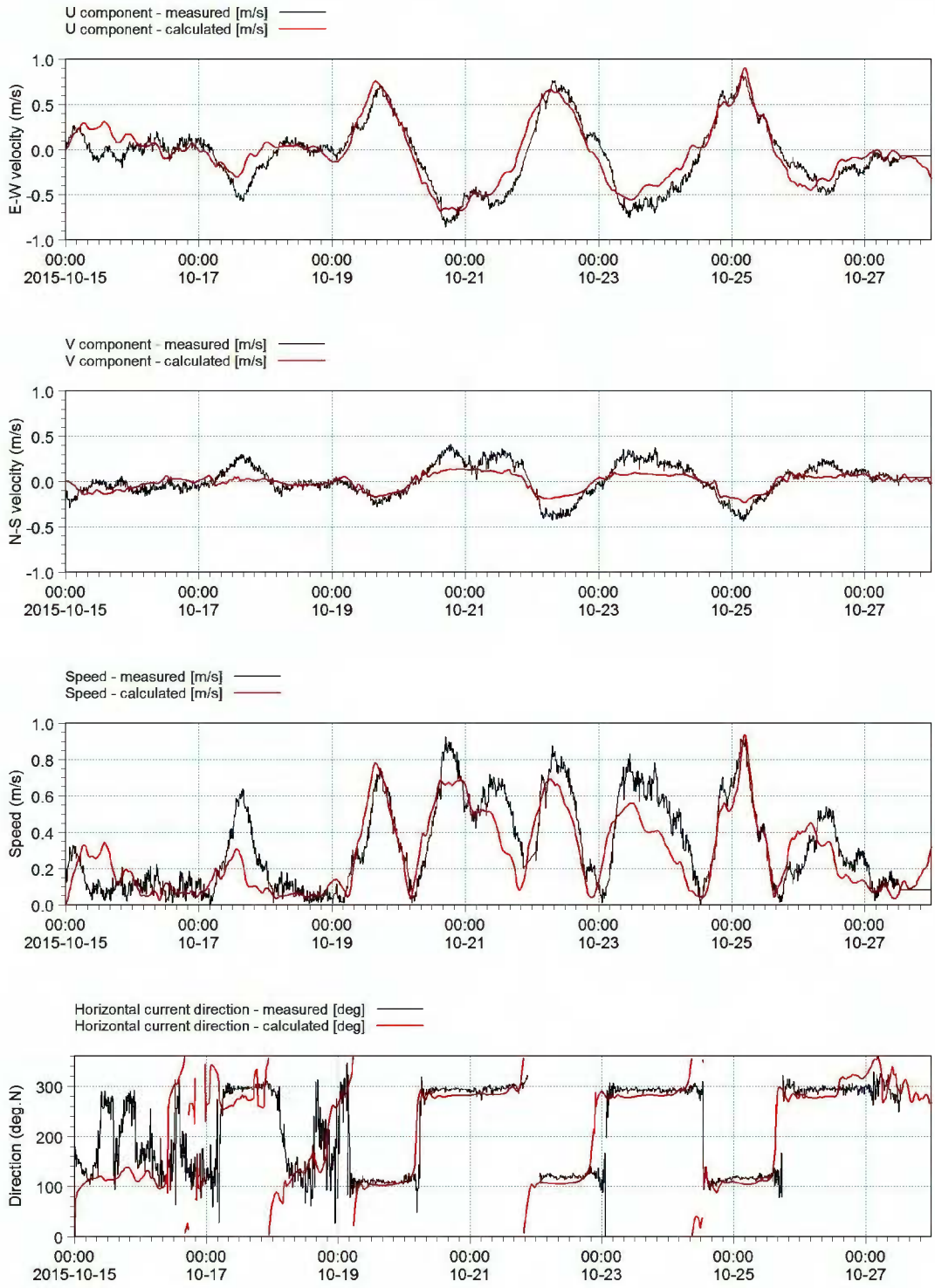


Figure 3-6 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 4 m below surface

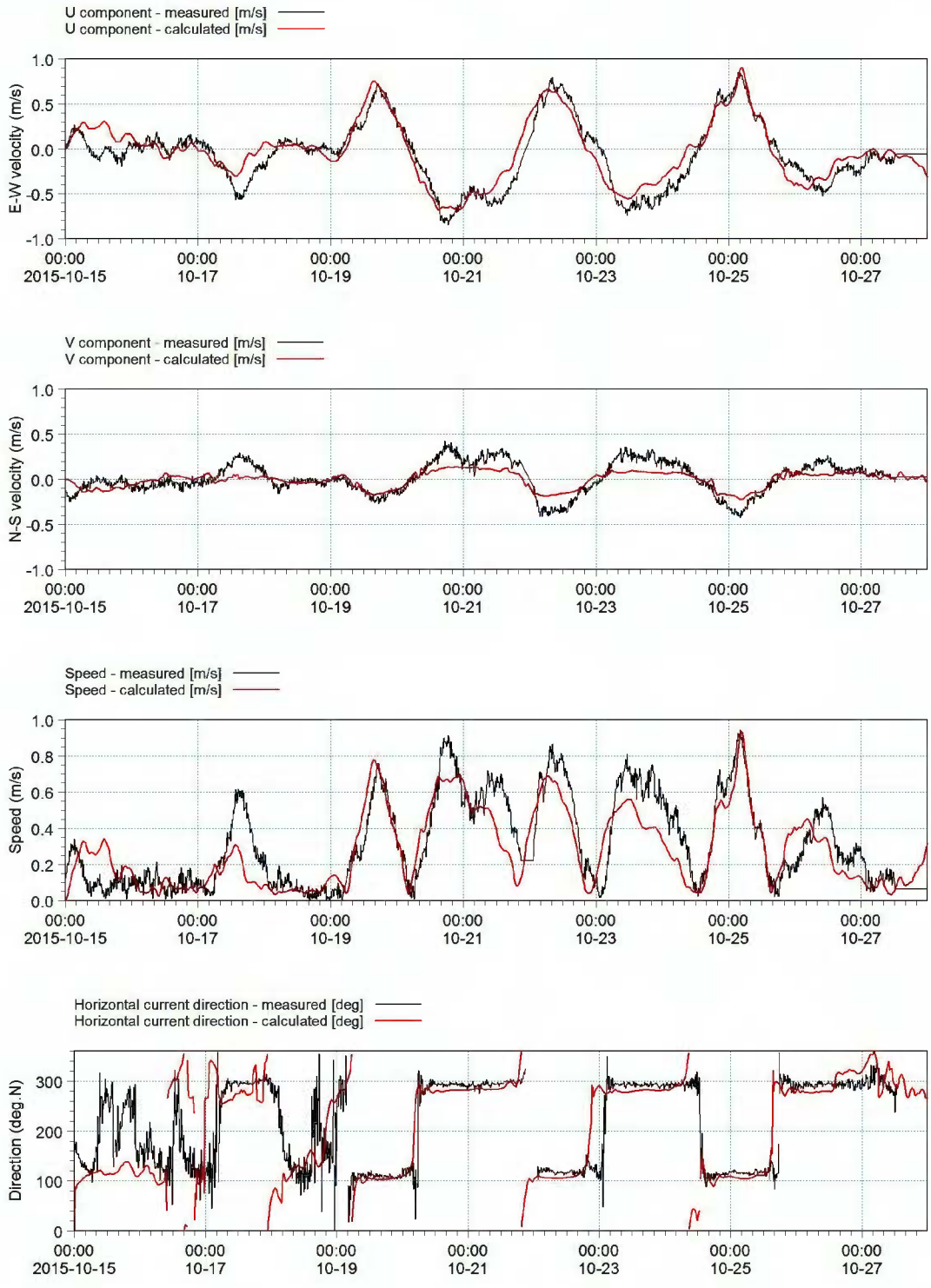


Figure 3-7 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 5 m below surface

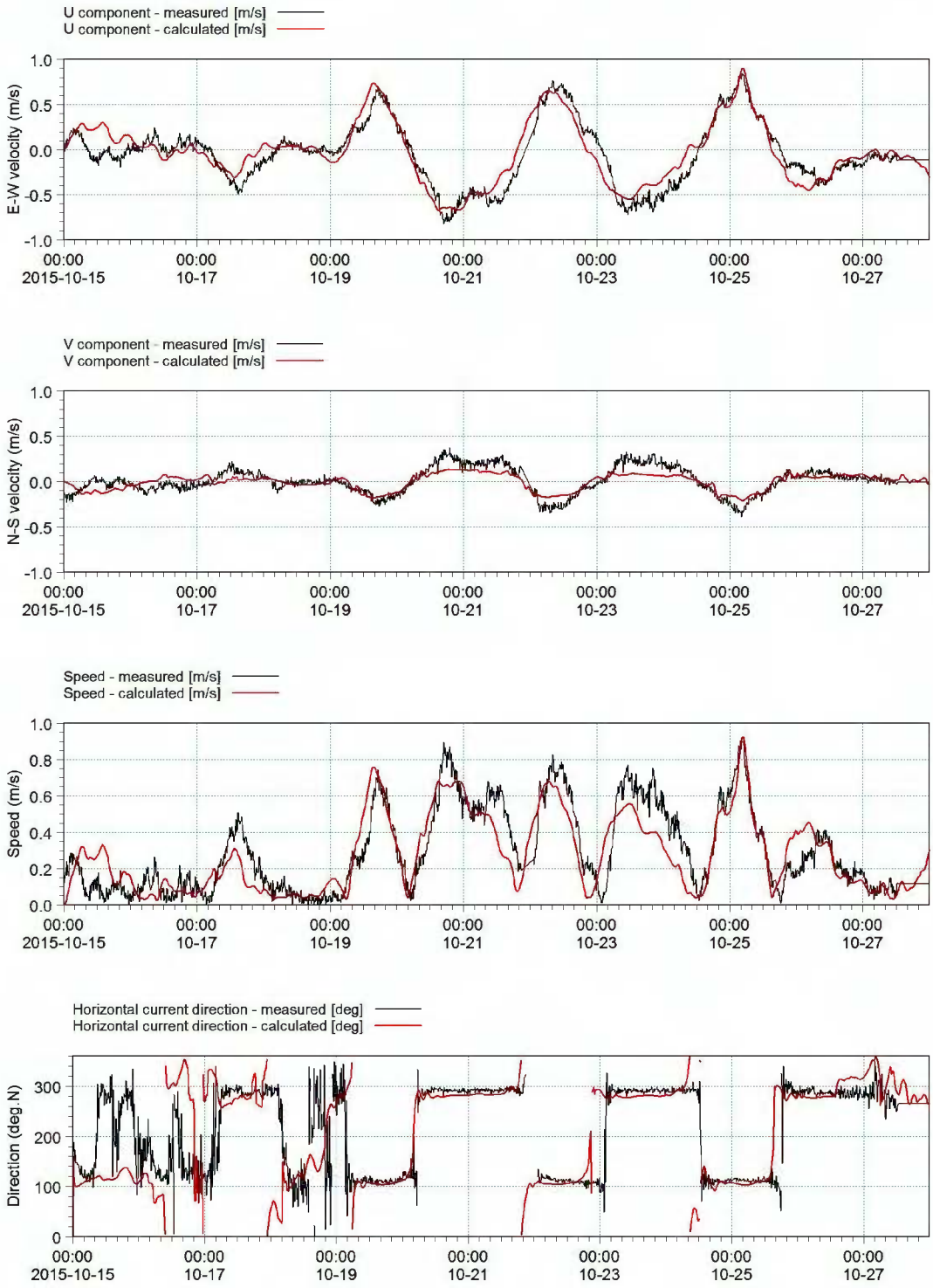


Figure 3-8 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 10 m below surface

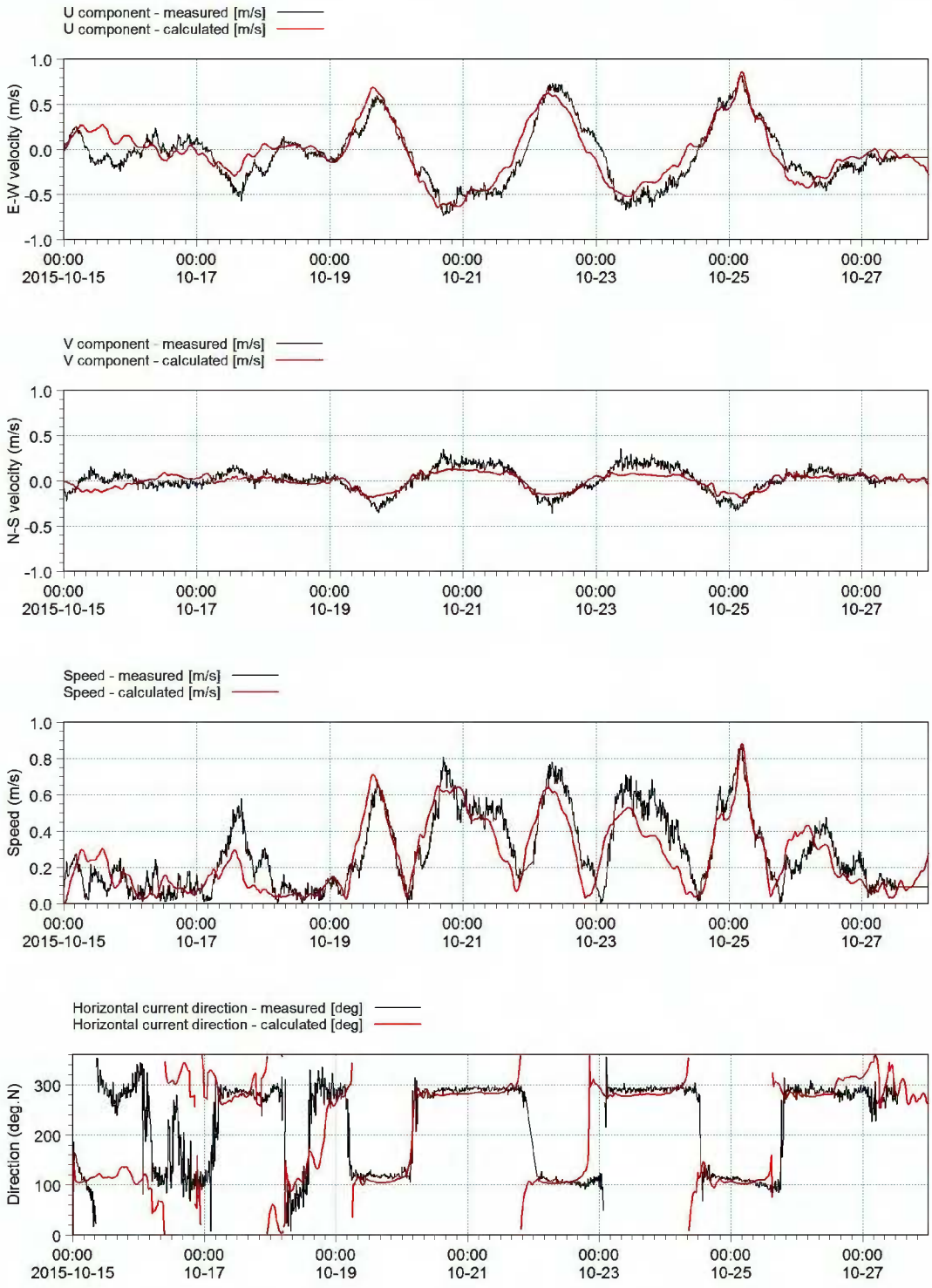


Figure 3-9 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 20 m below surface

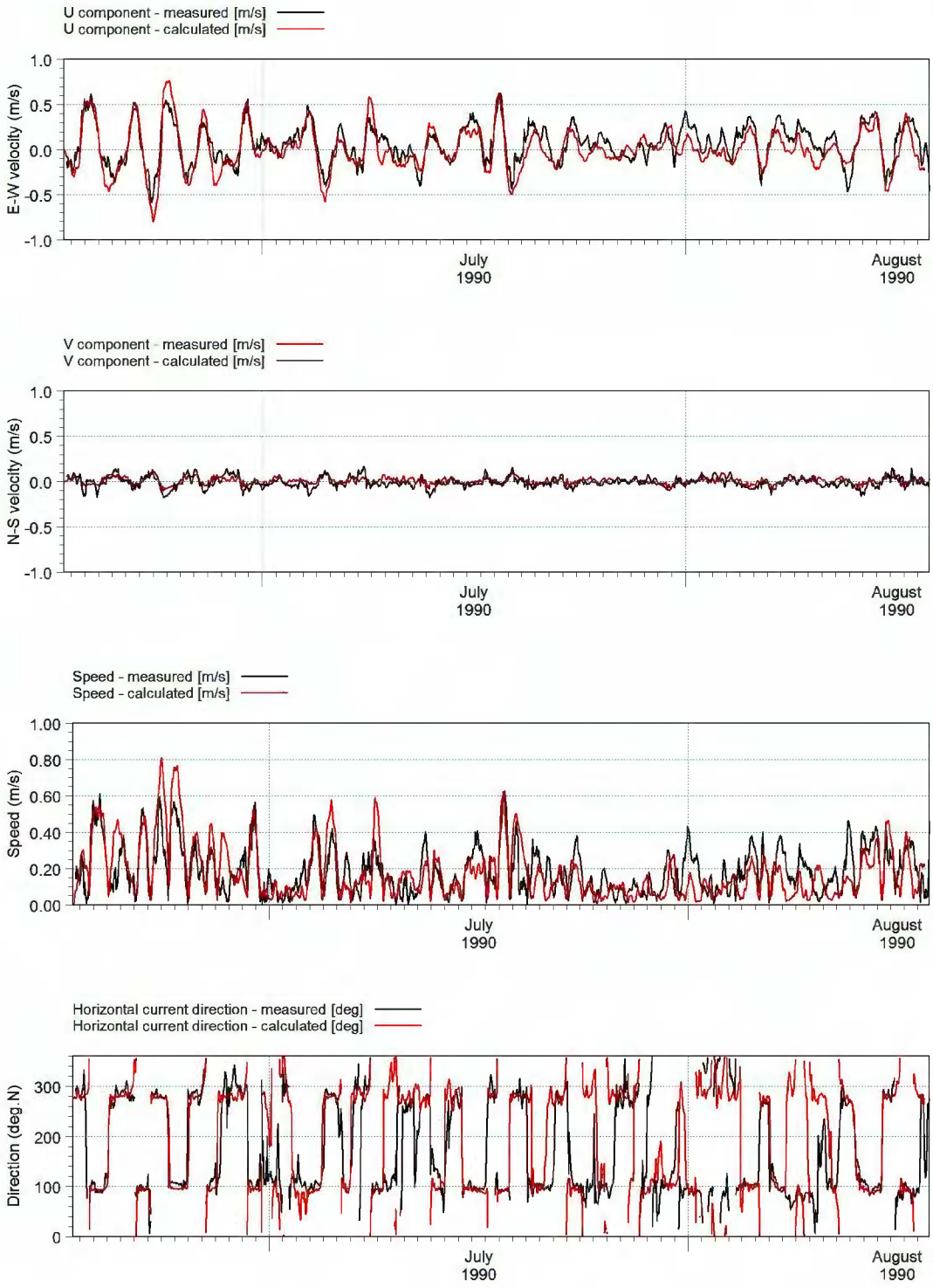


Figure 3-10 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM01. 2 m below surface

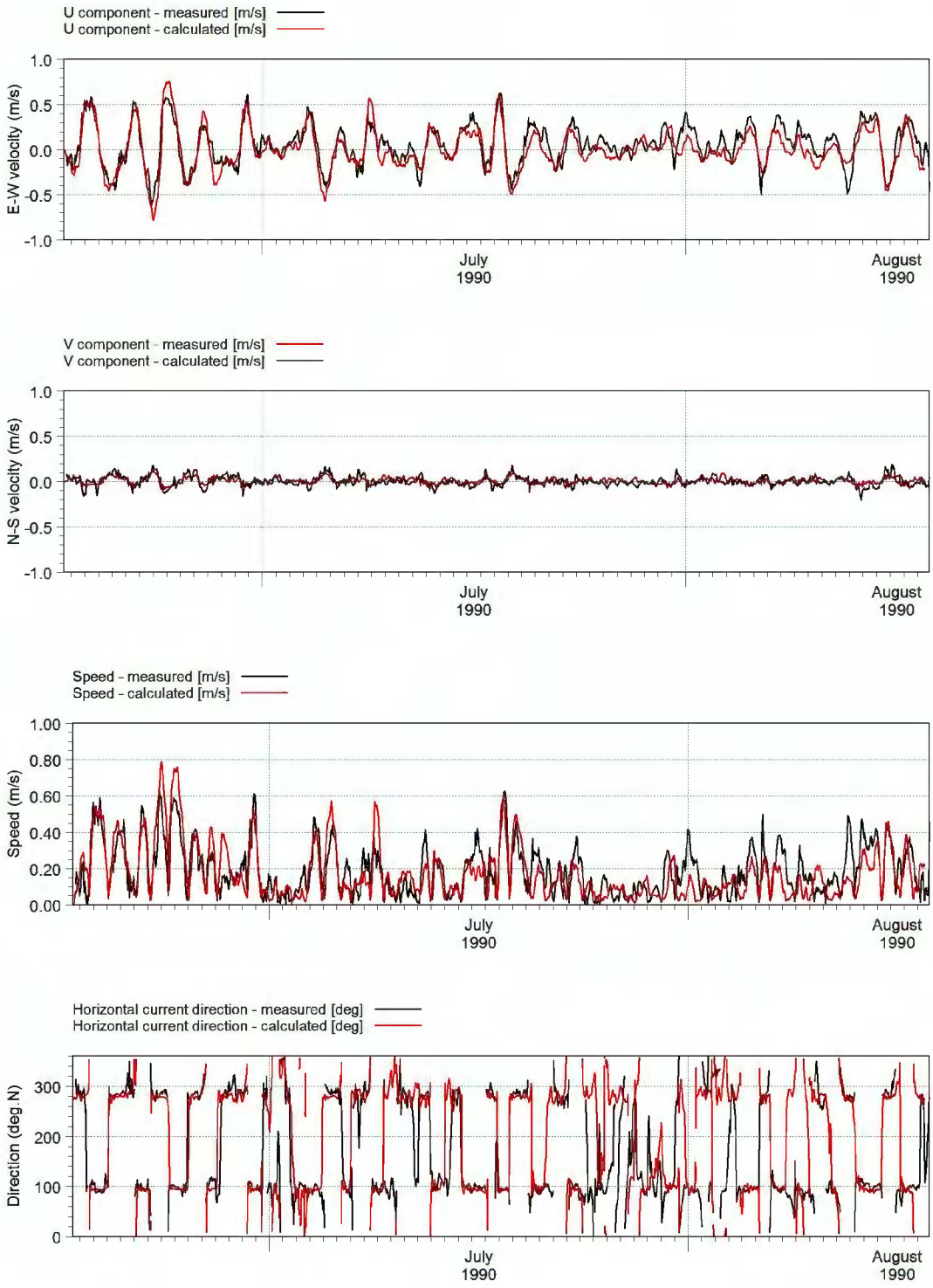


Figure 3-11 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM01. 5 m below surface

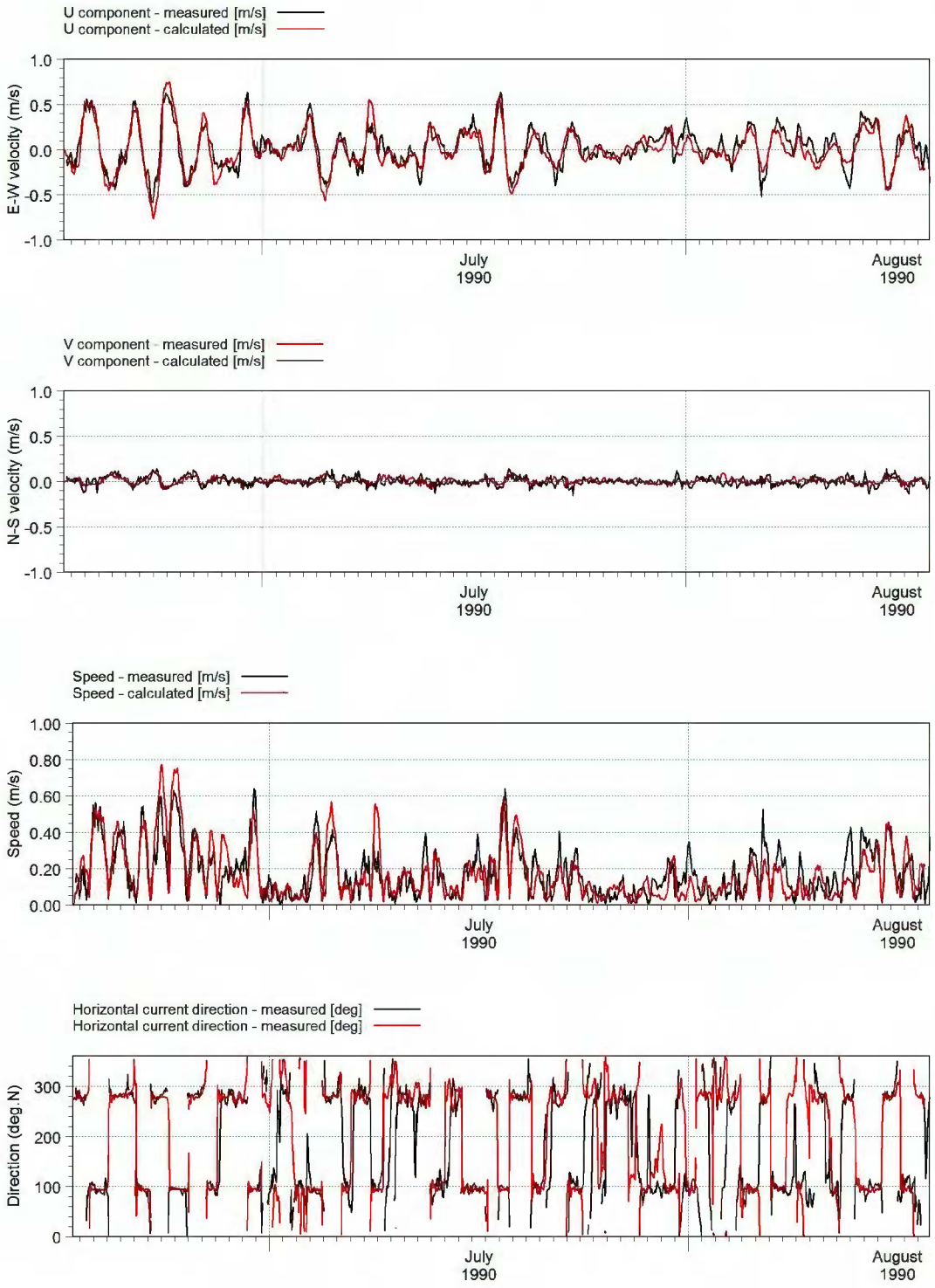


Figure 3-12 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM01. 10 m below surface

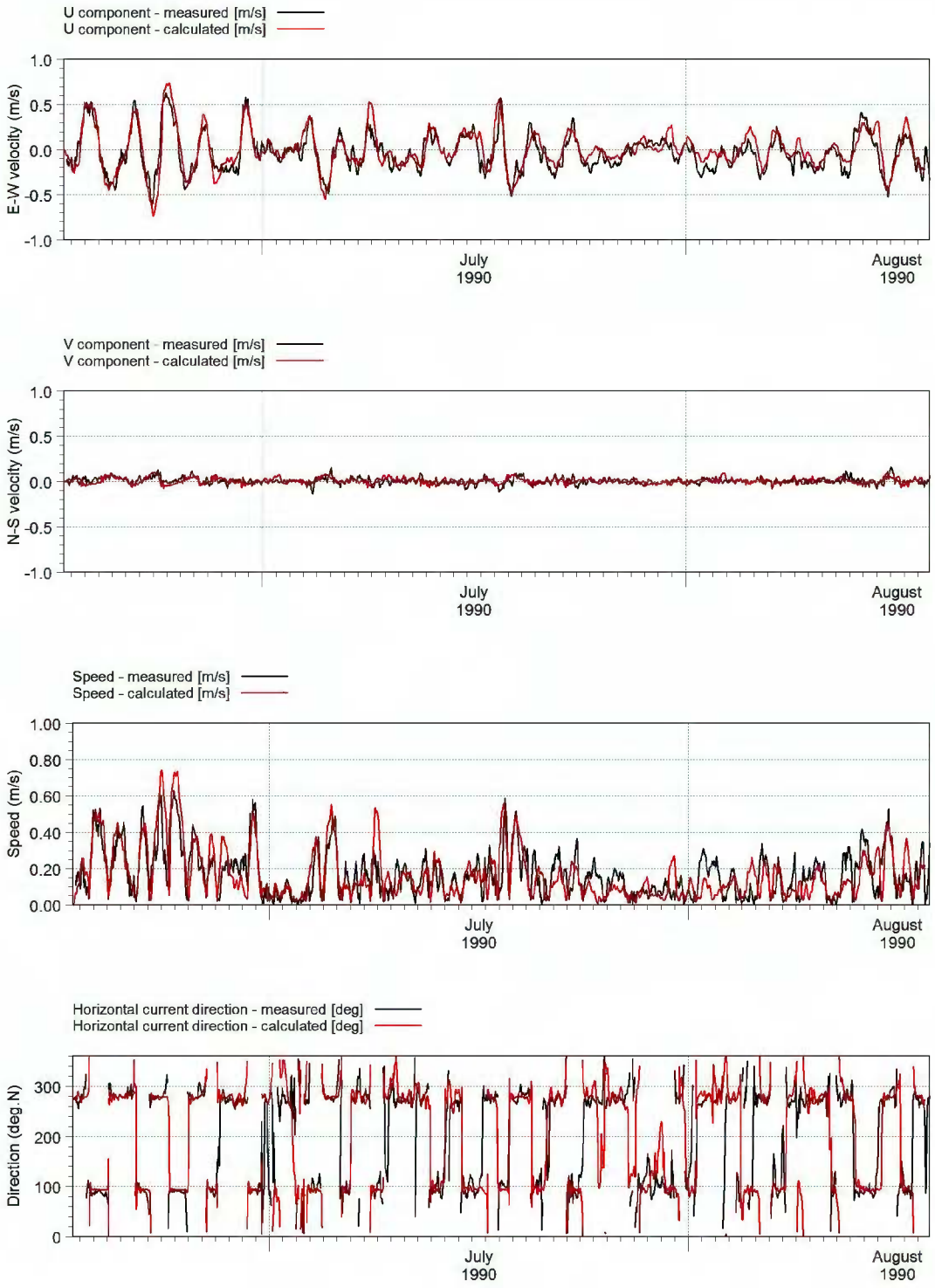


Figure 3-13 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM01. 20 m below surface

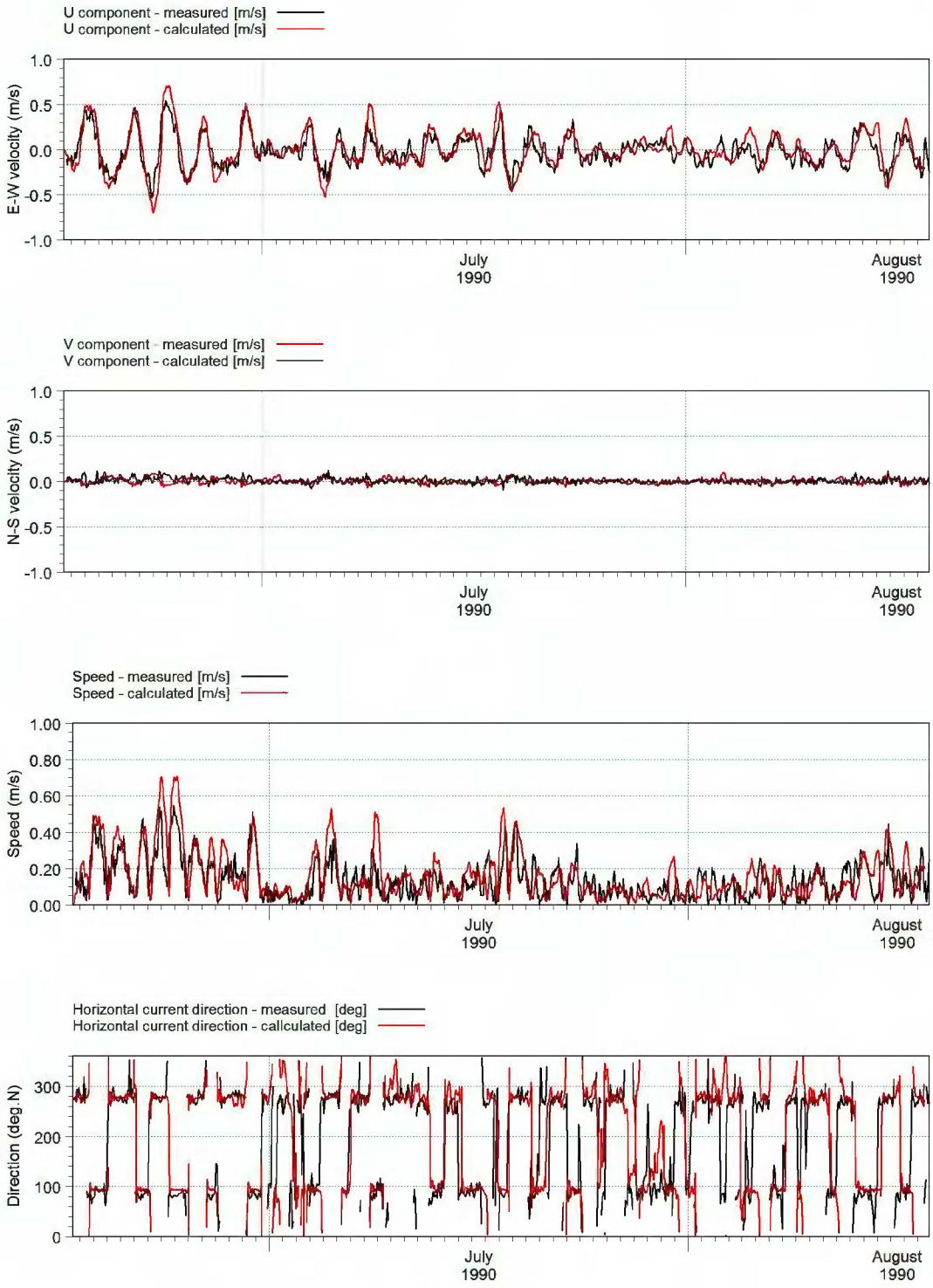


Figure 3-14 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM01. 30 m below surface

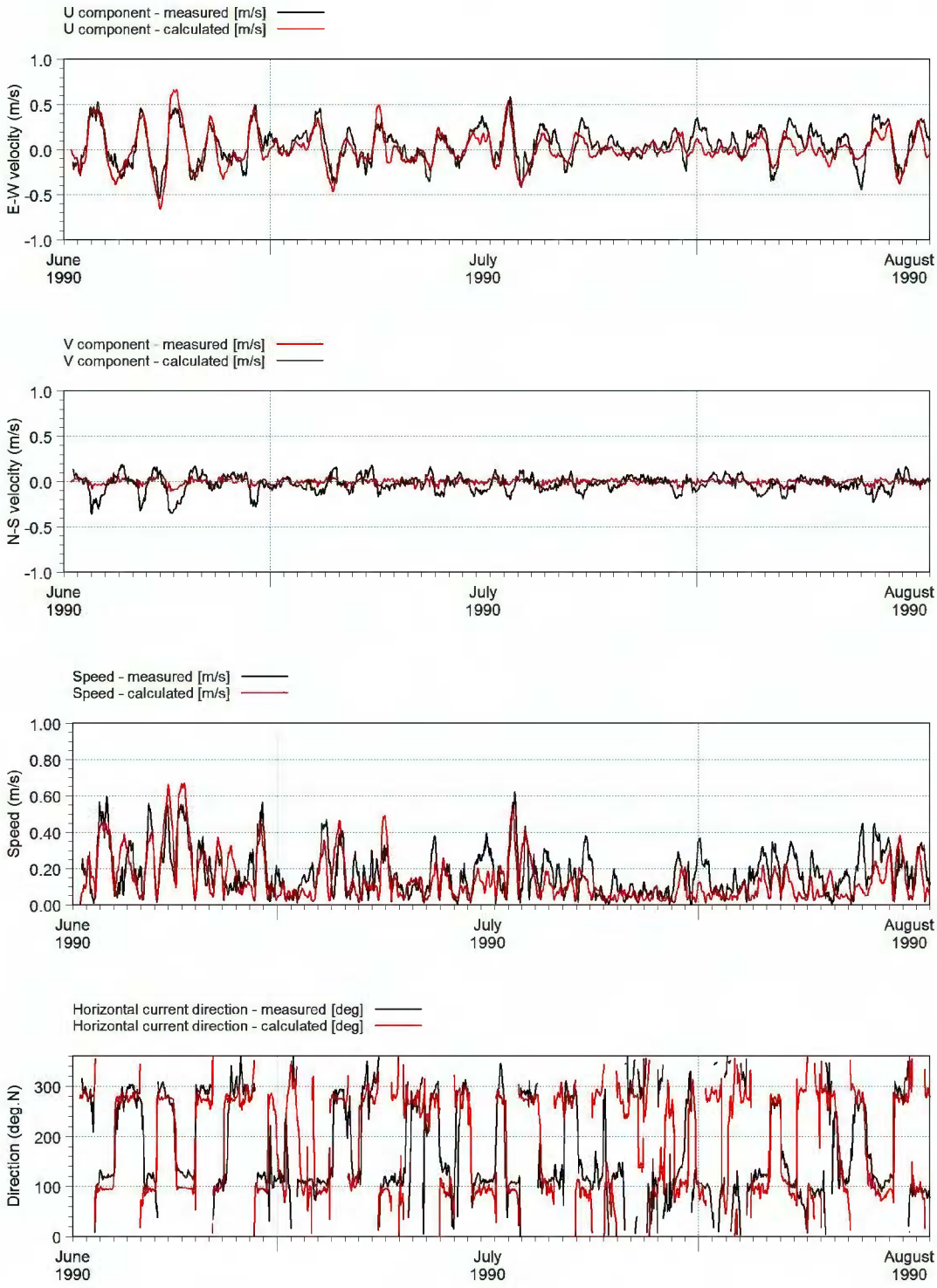


Figure 3-15 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM02. 4 m below surface

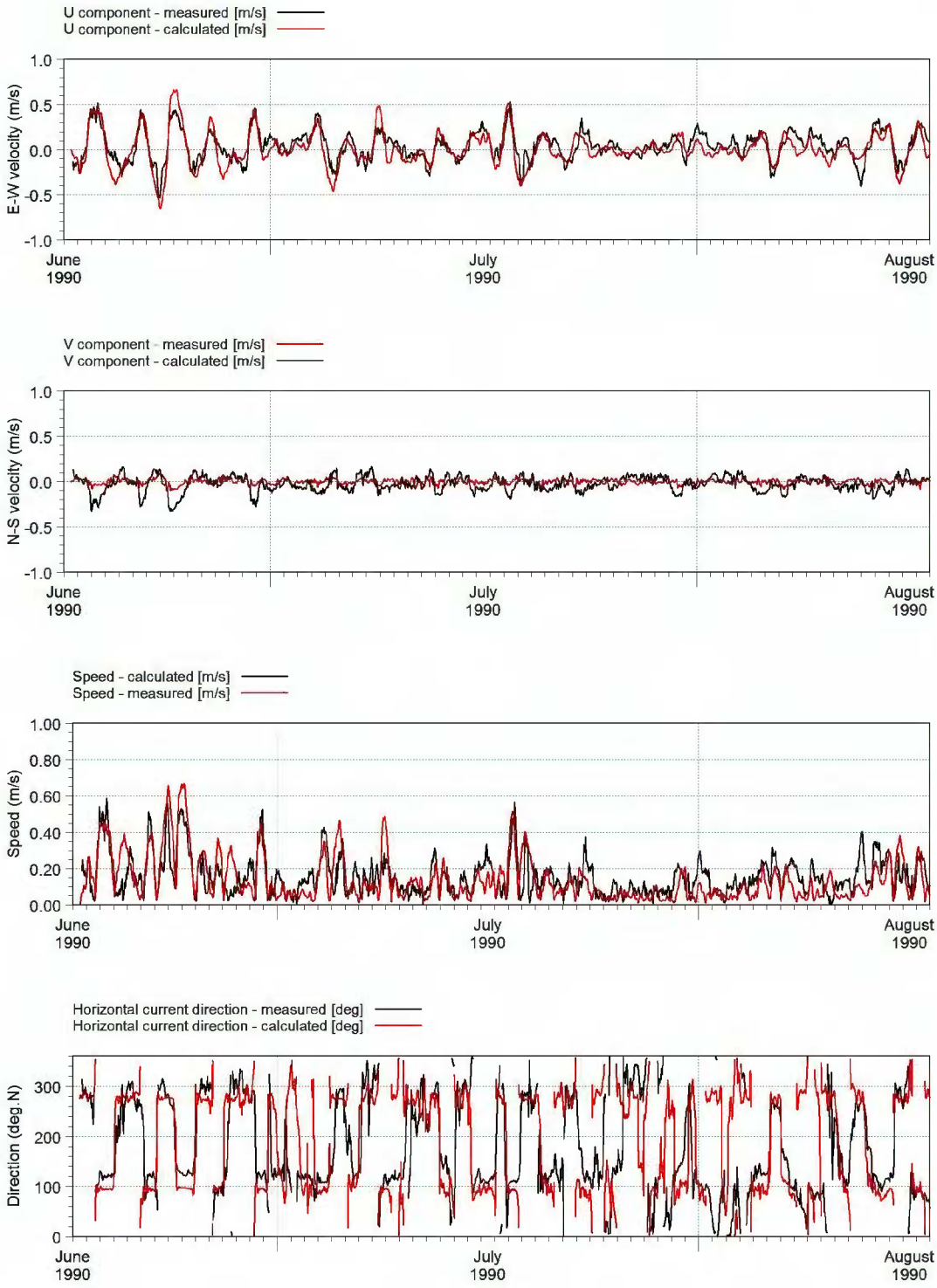


Figure 3-16 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM02. 5 m below surface

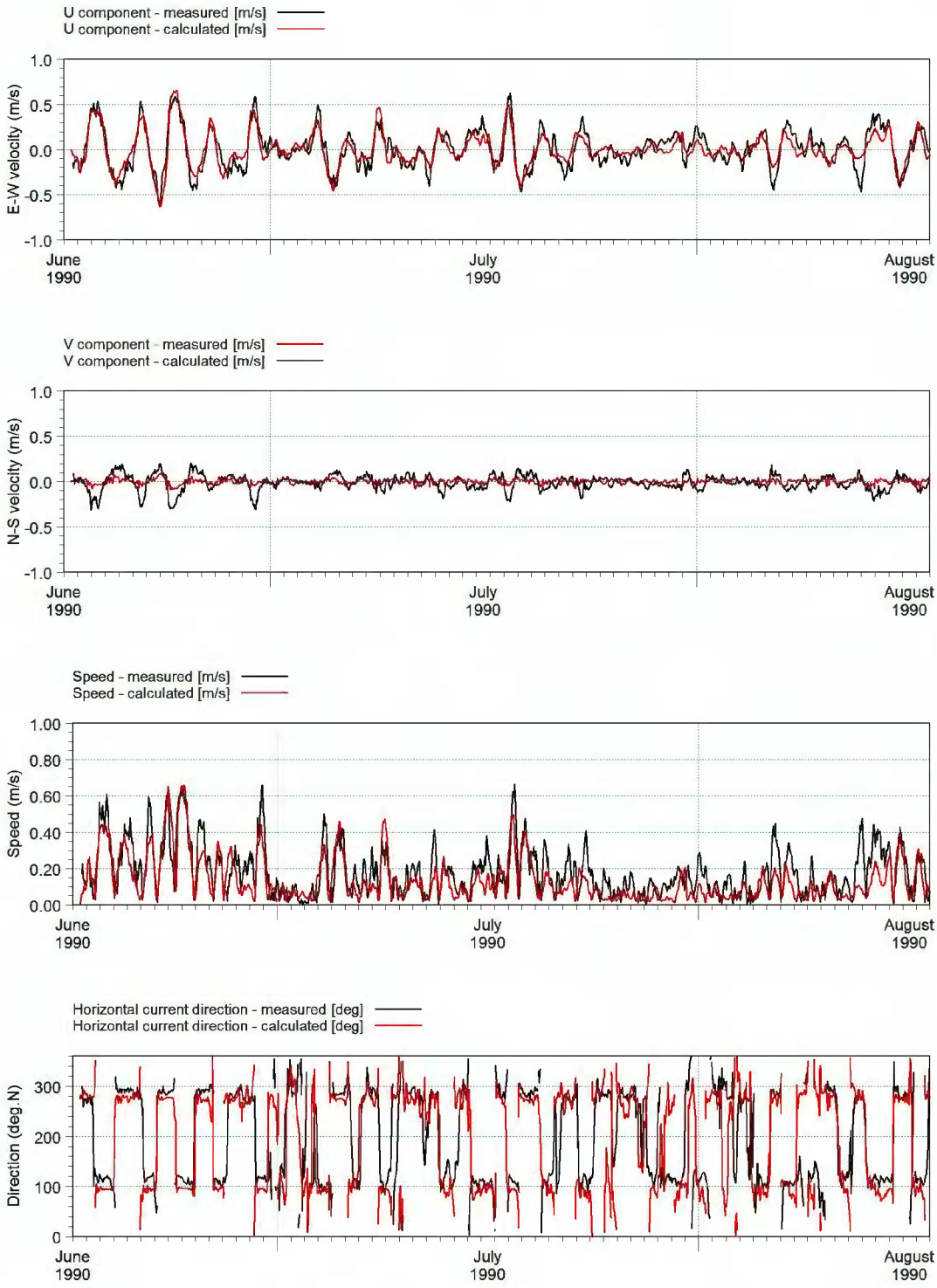


Figure 3-17 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM02. 10 m below surface

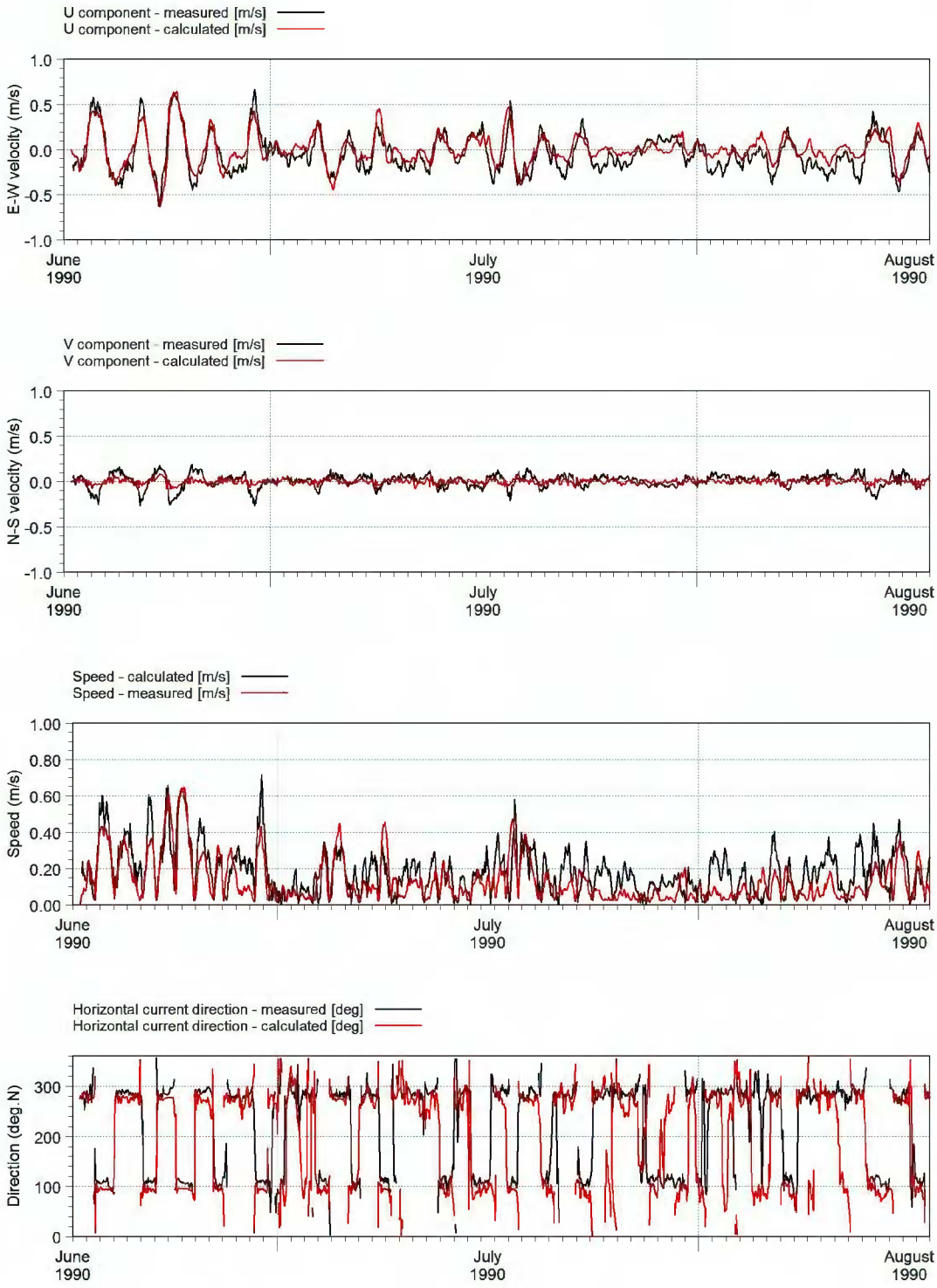


Figure 3-18 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM02. 20 m below surface

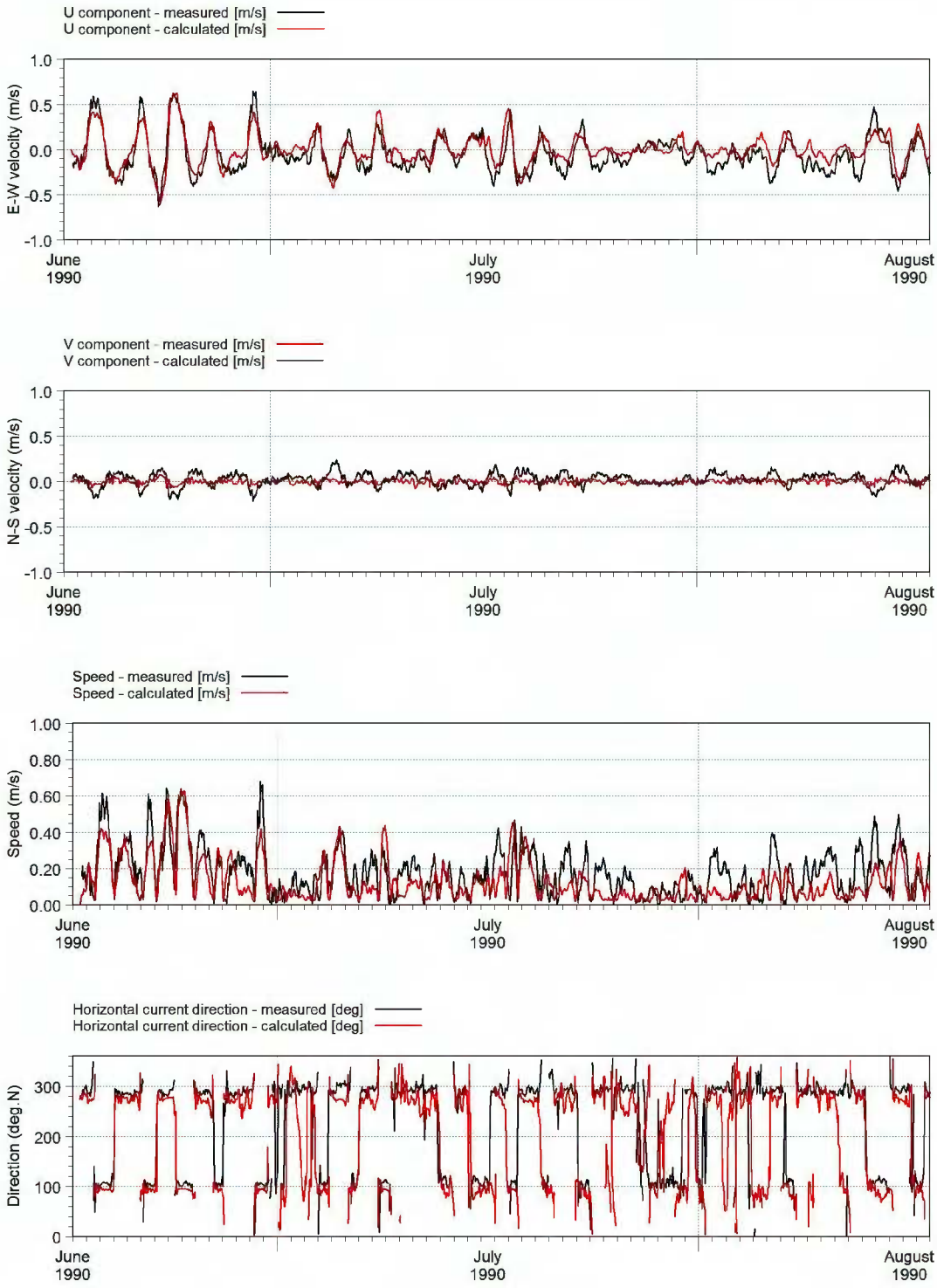


Figure 3-19 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM02. 30 m below surface

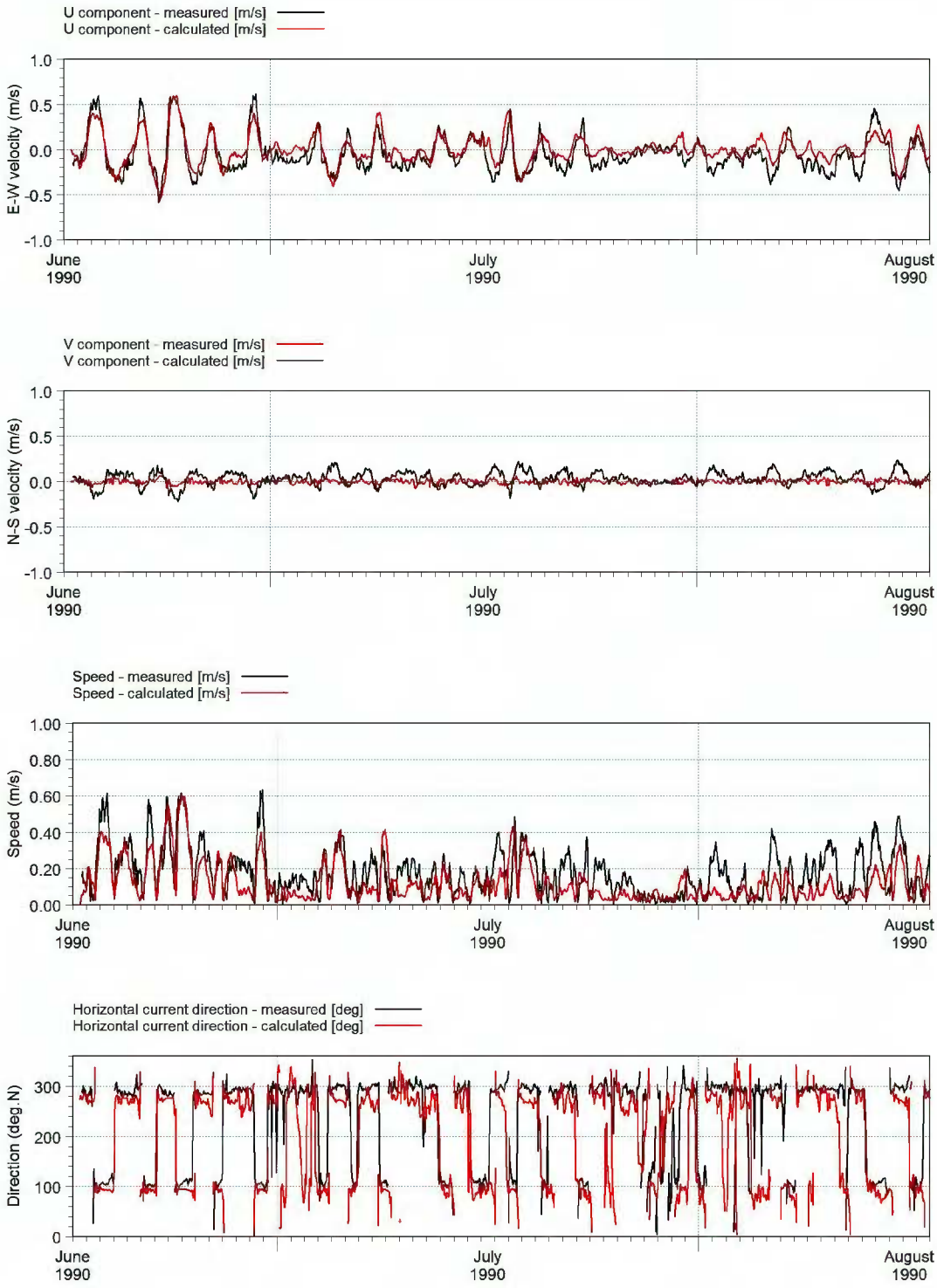


Figure 3-20 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCP LM02. 40 m below surface

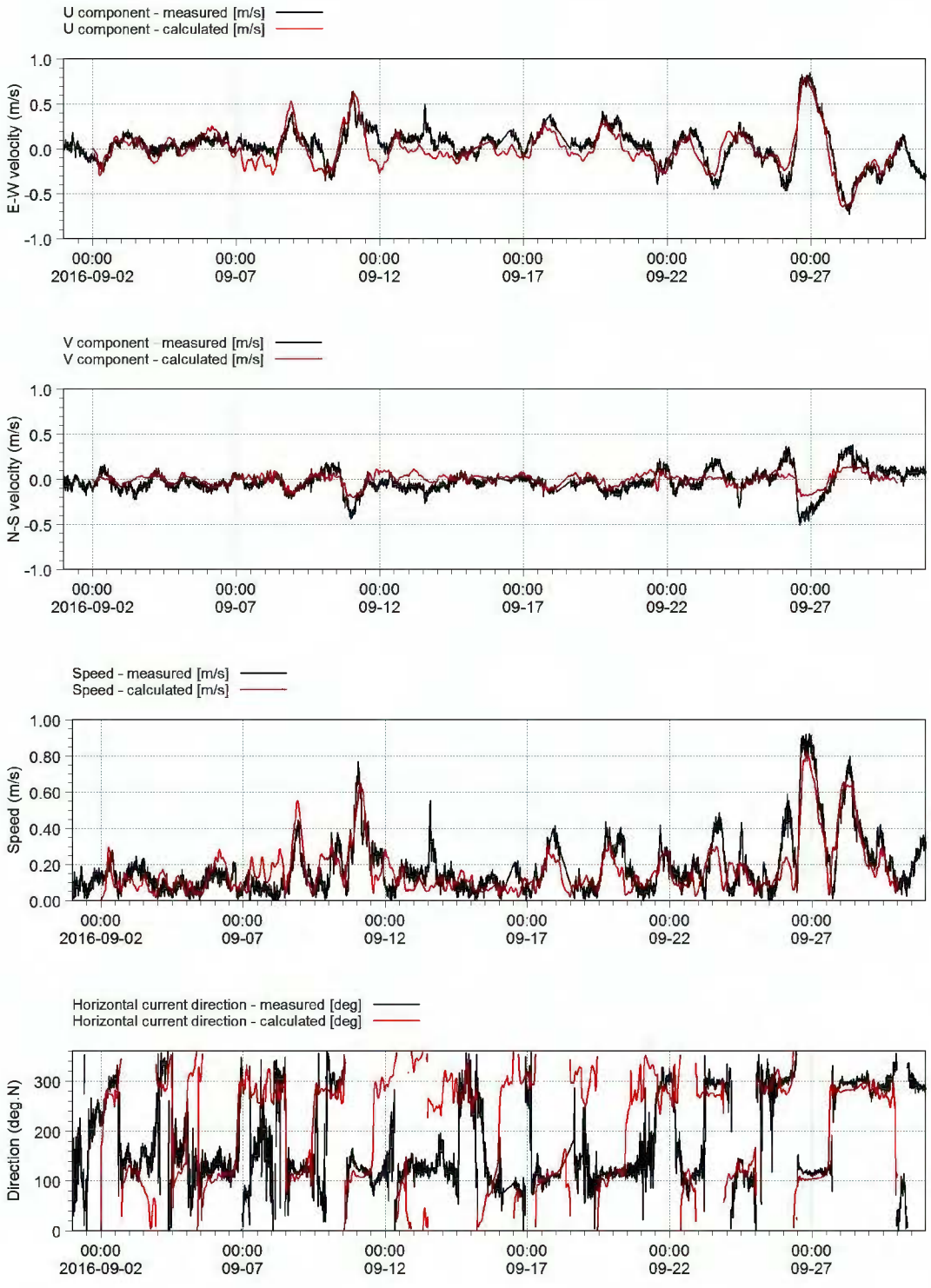


Figure 3-21 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 2 m below surface

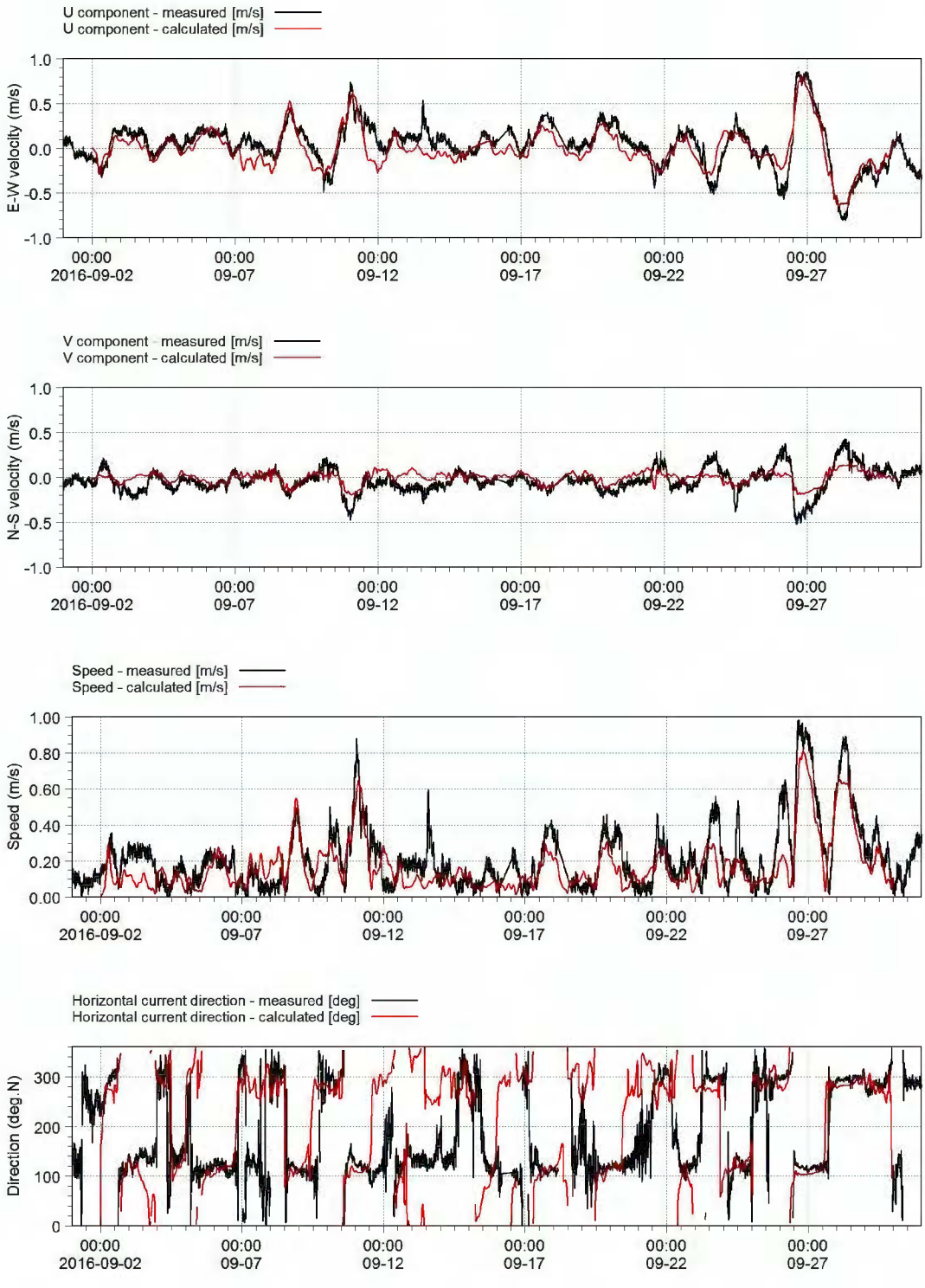


Figure 3-22 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 3 m below surface

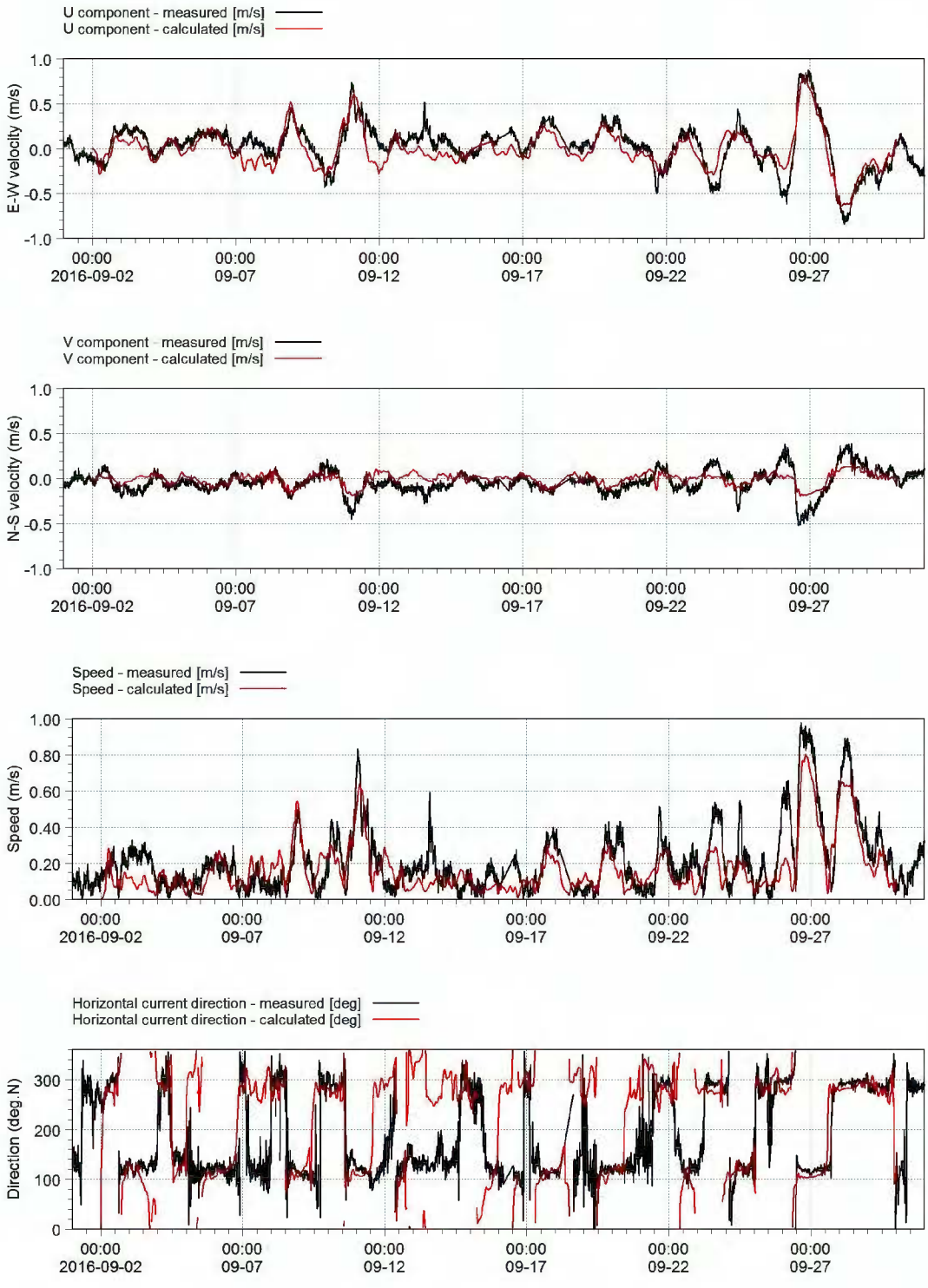


Figure 3-23 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 5 m below surface

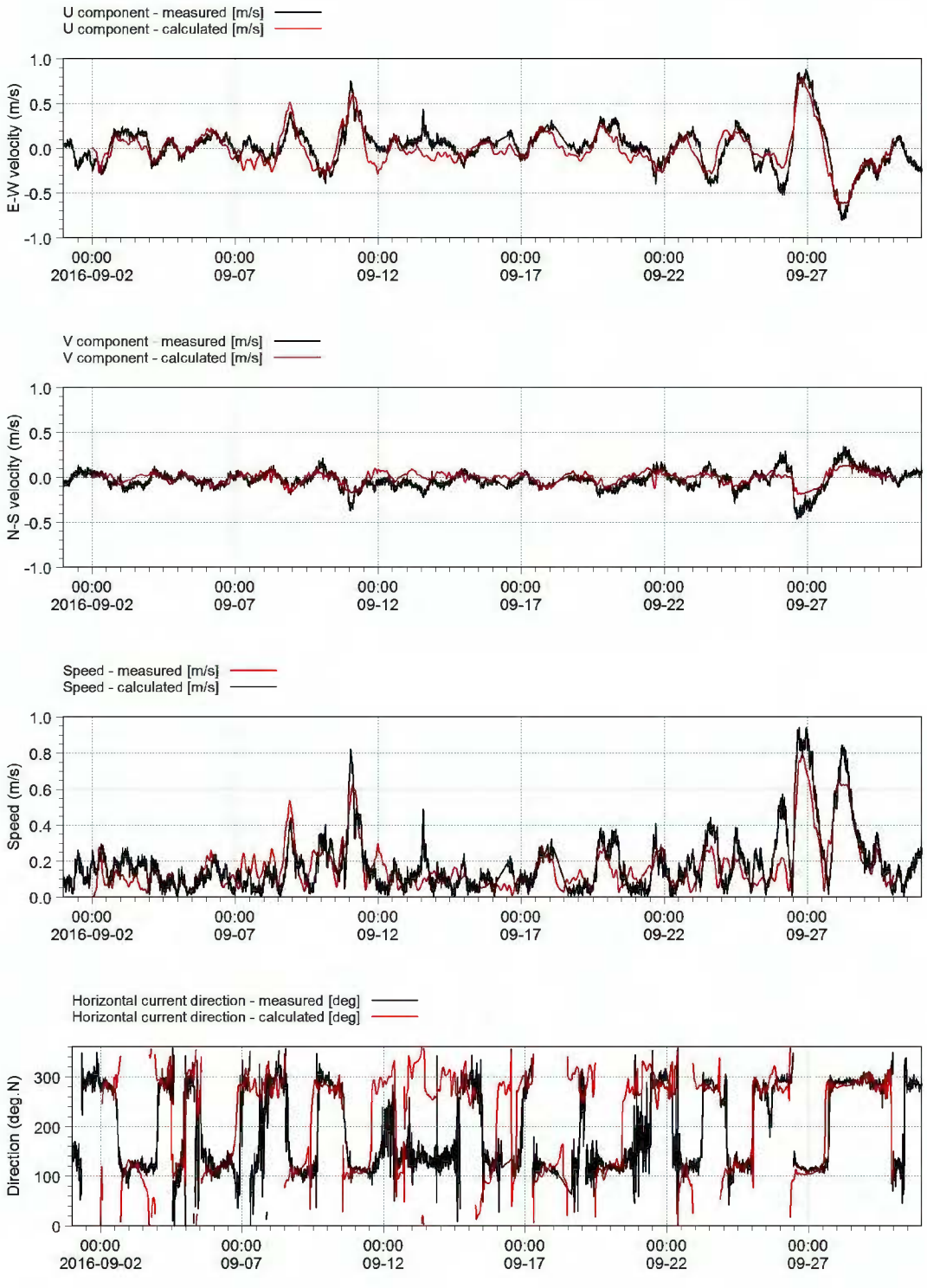


Figure 3-24 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 10 m below surface

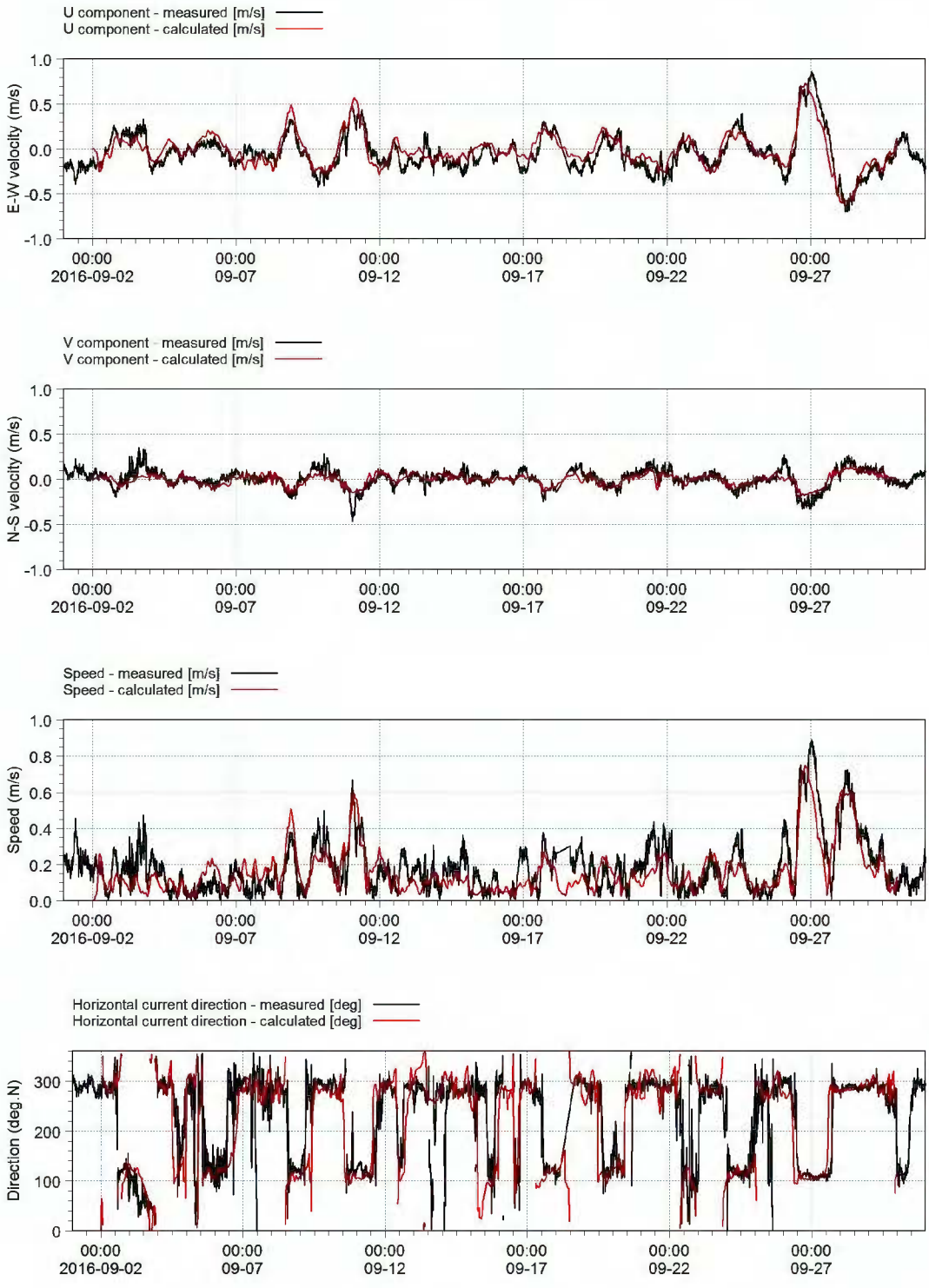


Figure 3-25 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of NDBC Buoy 45175. 20 m below surface

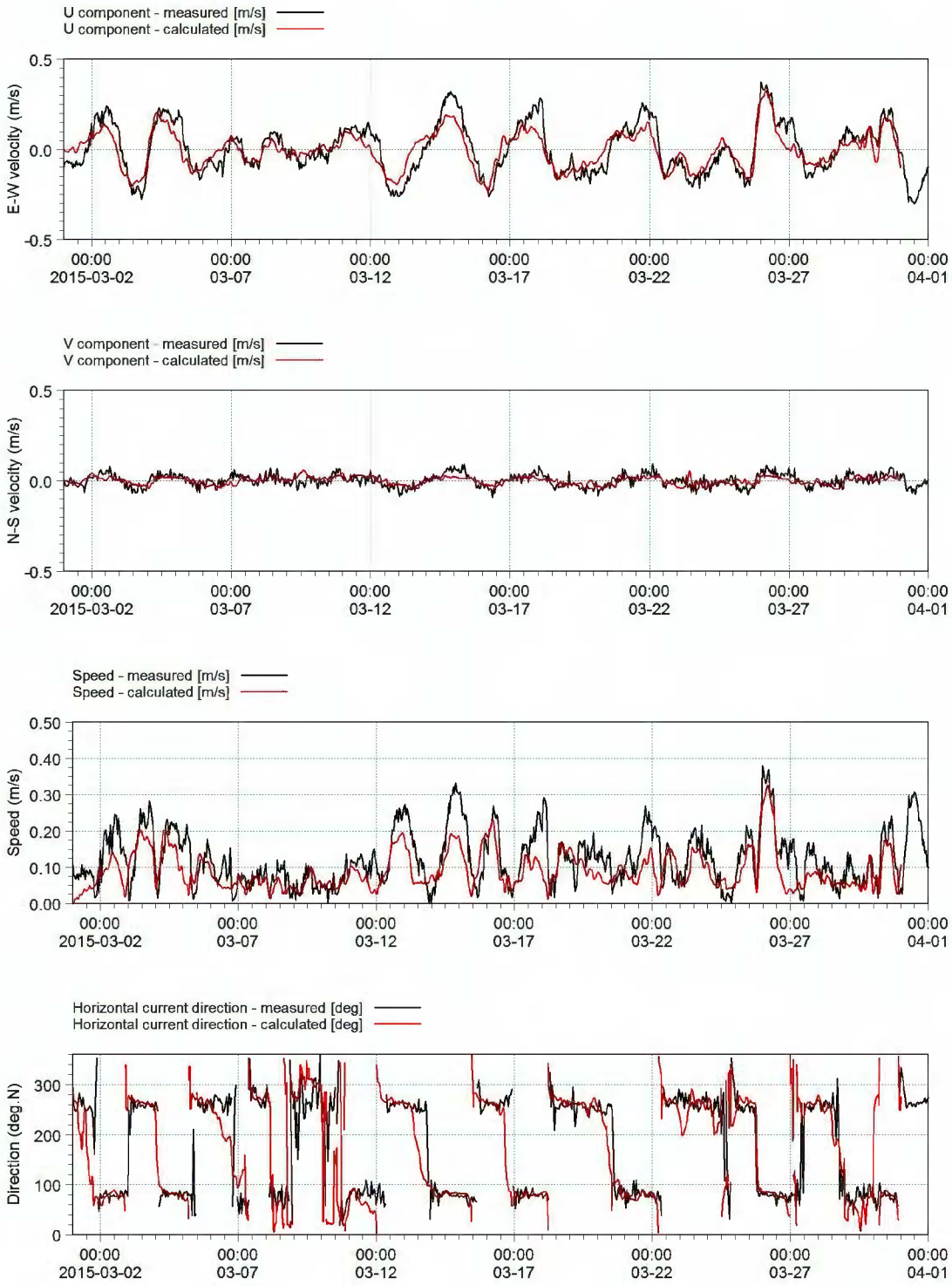


Figure 3-26 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCPs 1057 and 3748. 7 m ASB

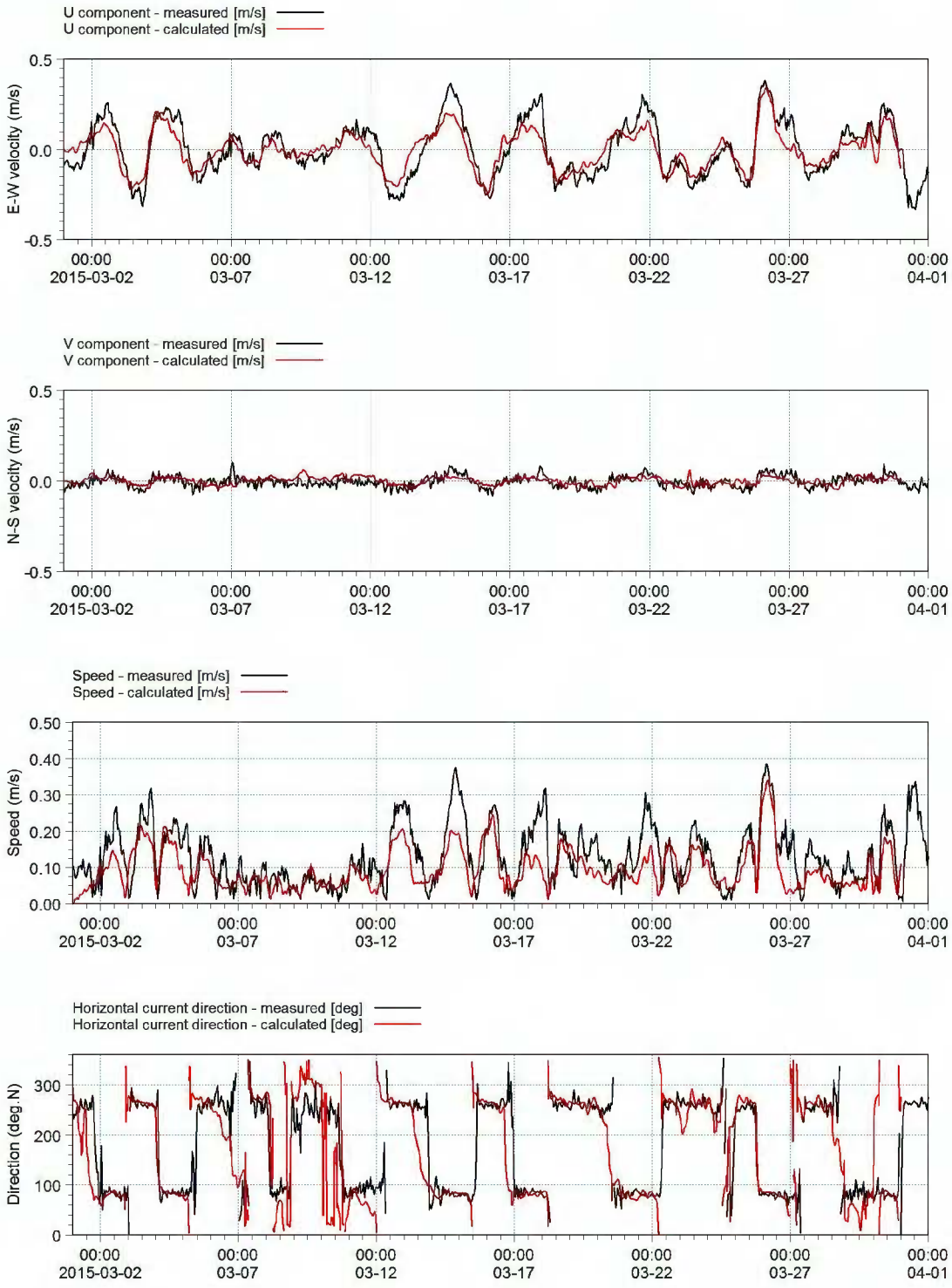


Figure 3-27 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCPs 1057 and 3748. 10 m ASB

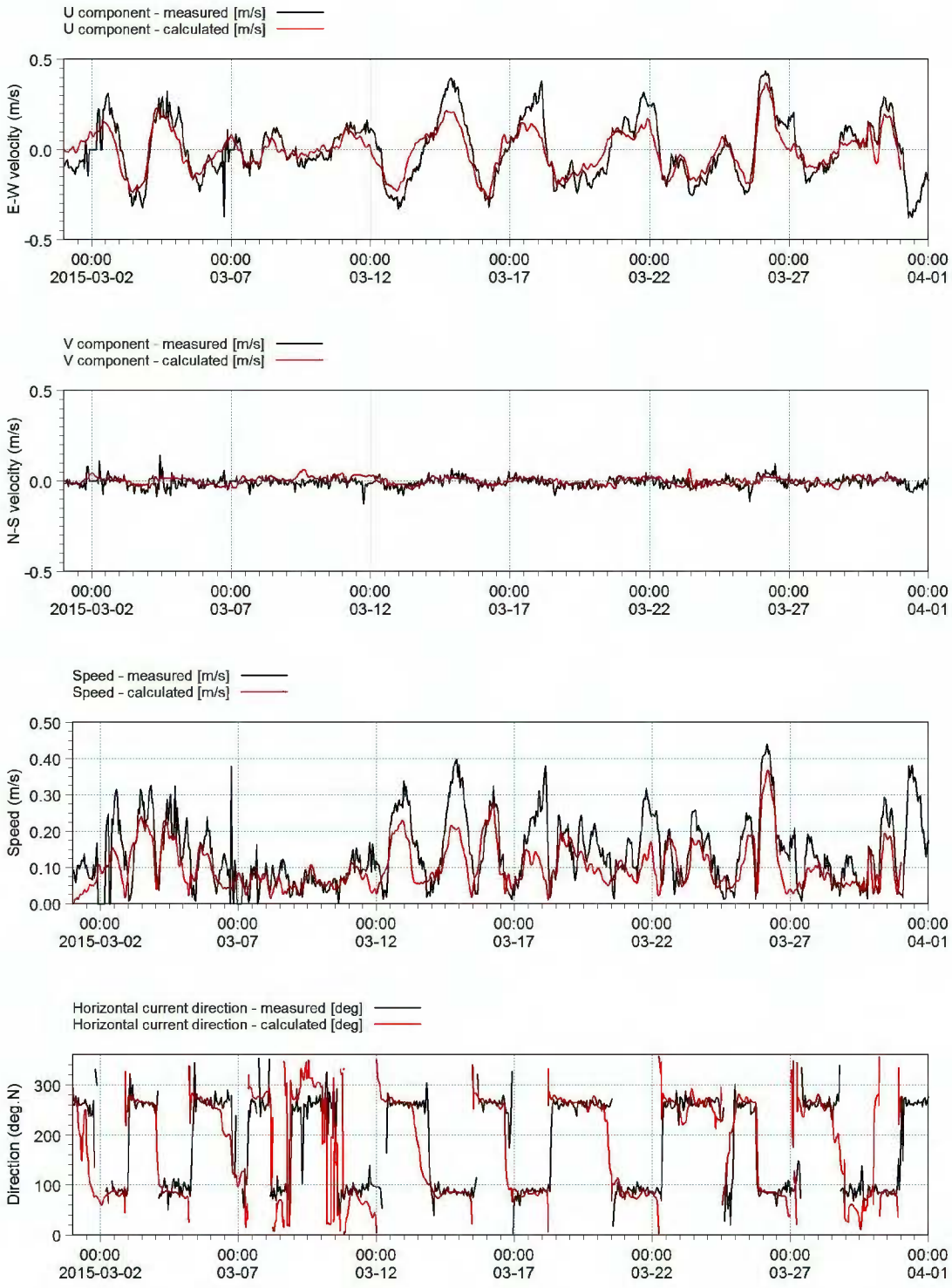


Figure 3-28 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCPs 1057 and 3748. 20 m ASB

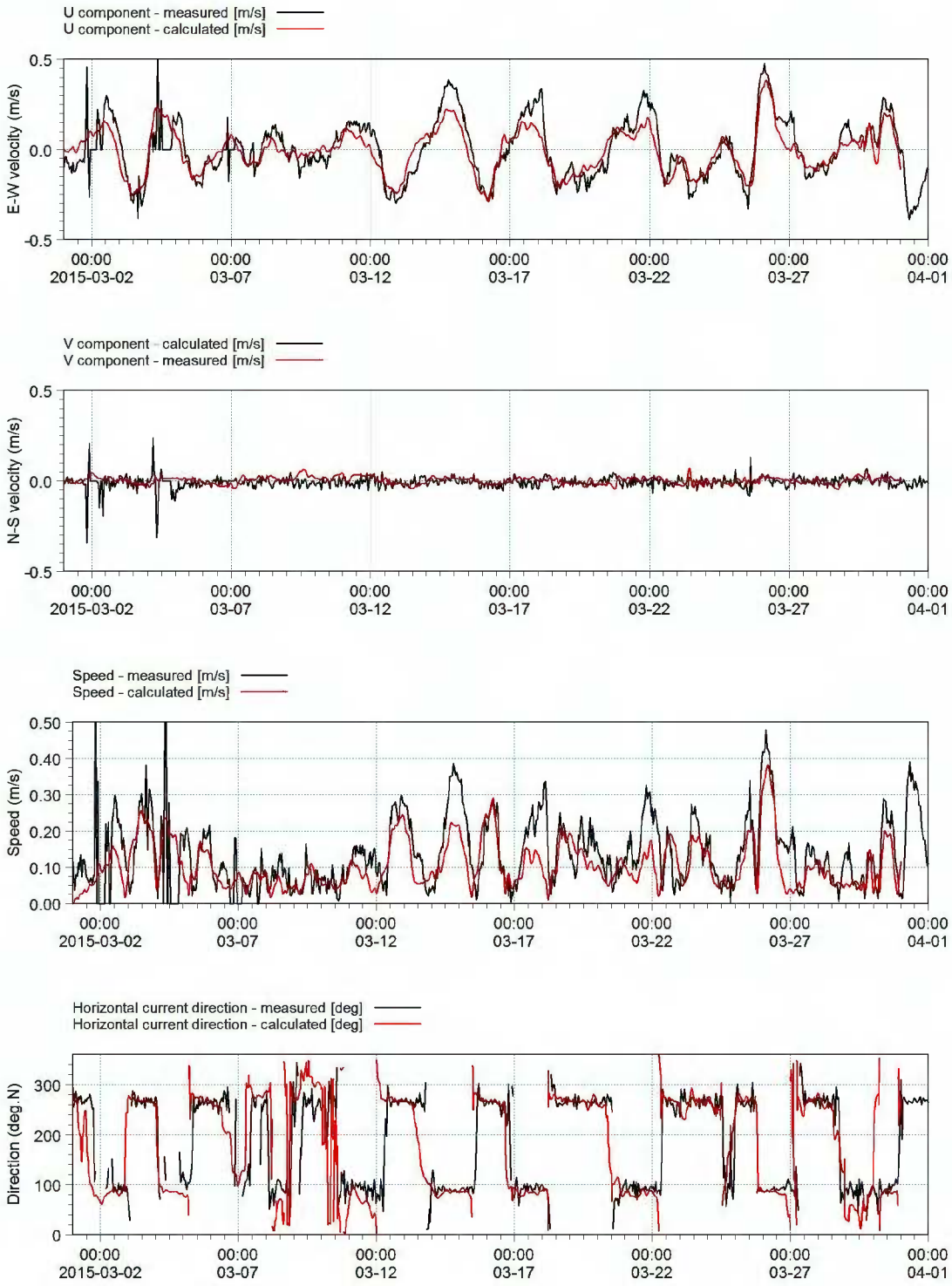


Figure 3-29 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCPs 1057 and 3748. 30 m ASB

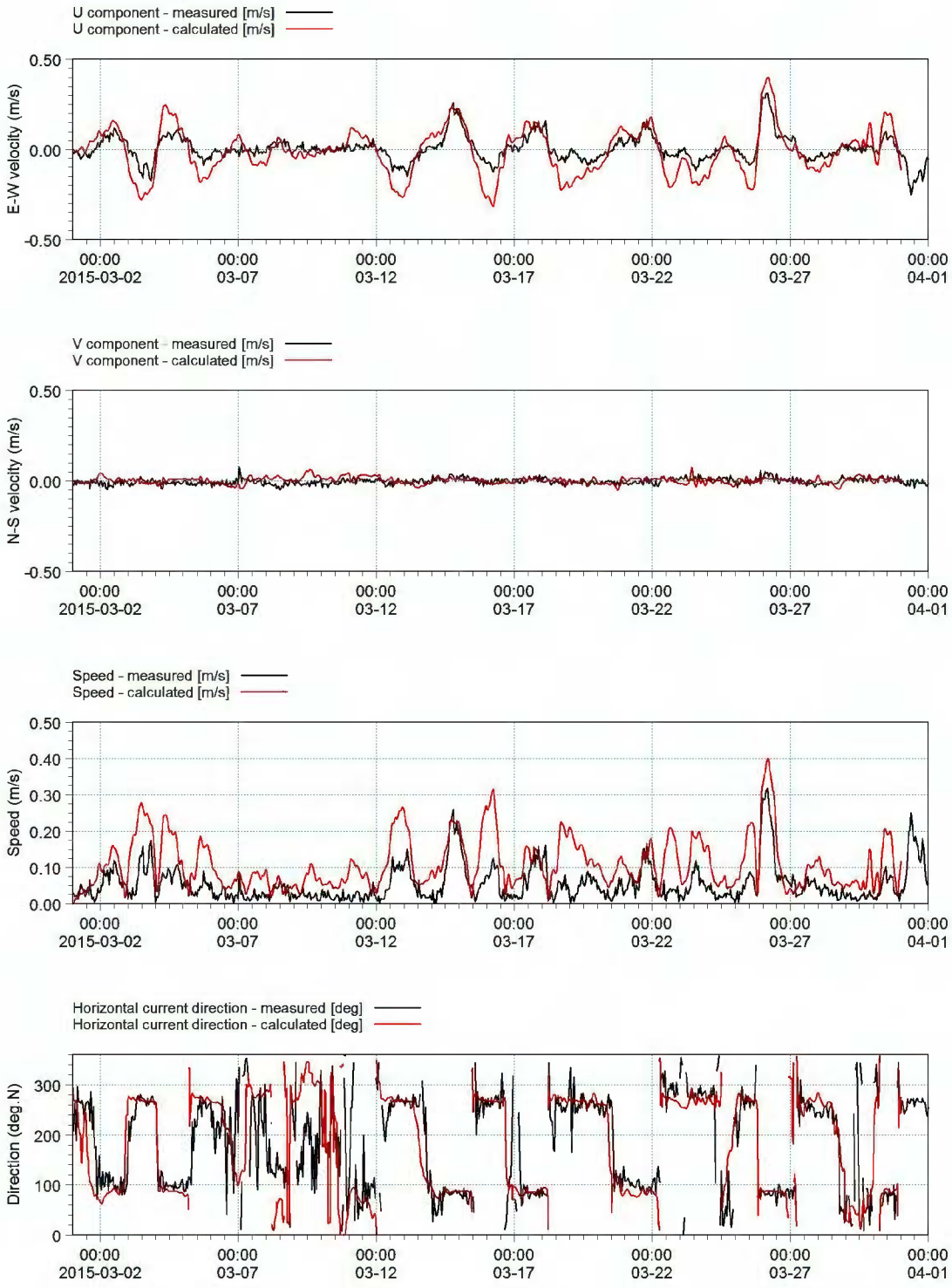


Figure 3-30 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCPs 1057 and 3748. 50 m ASB

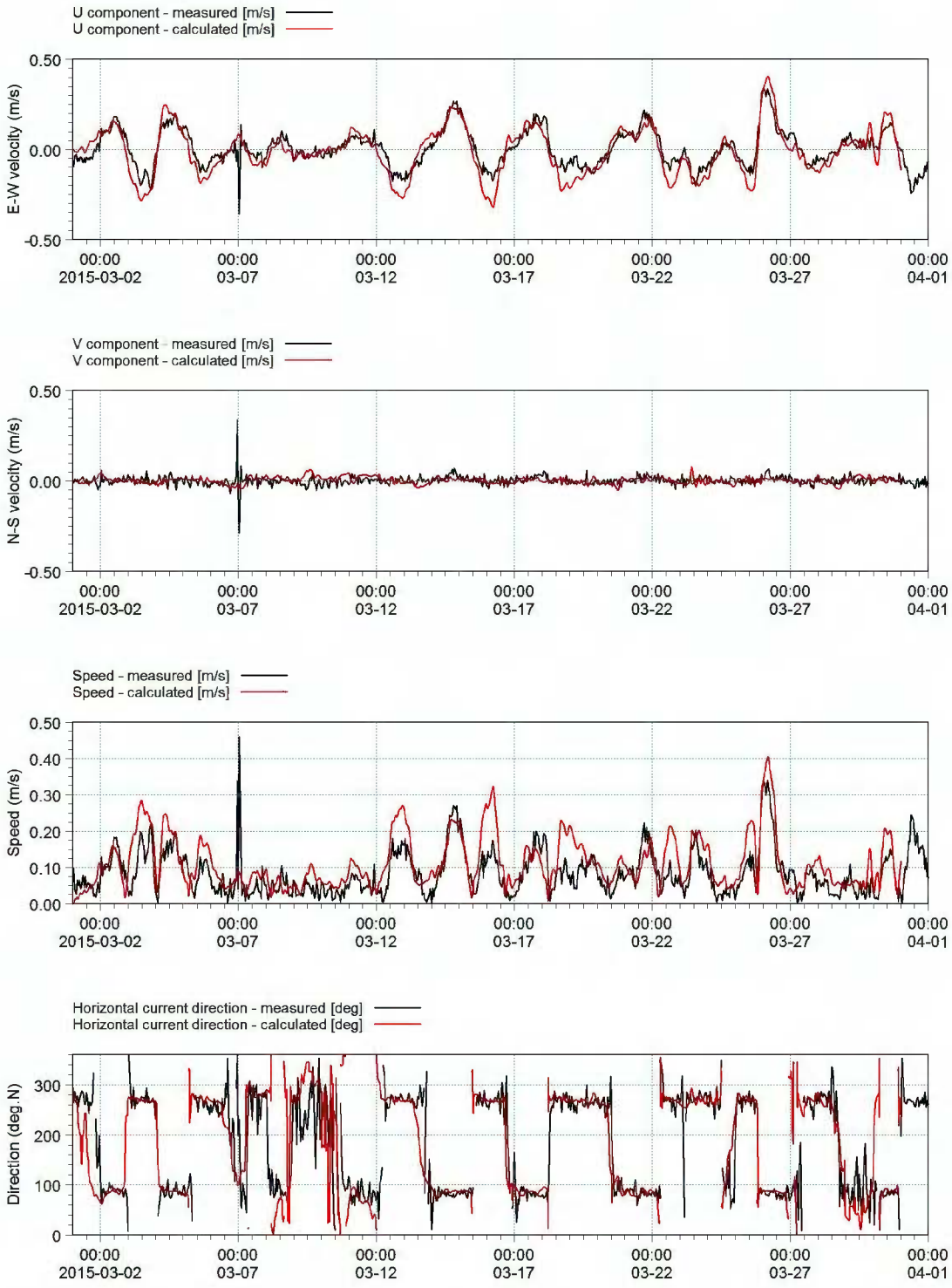


Figure 3-31 Measured (black line) and calculated (red line) horizontal velocity components, speed and direction at the position of ADCPs 1057 and 3748. 55 m ASB

3.4 Comparison to University of Michigan – NOAA - FVCOM Model

The University of Michigan (UM) and the National Oceanographic and Atmospheric Agency (NOAA) have developed a 3D hydrodynamic model of Lakes Michigan and Huron (Anderson & Schwab, 2013) to predict currents to calculate oil spill trajectories (Schwab, 2016) using the Finite Volume Coastal Ocean Model (FVCOM) model. The FVCOM hydrodynamic model is similar to DHI's MIKE 3 HD FM model in that it uses a flexible mesh of ~31000 surface elements, with 20 vertical layers, compared to ~53000 surface elements and 20 vertical layers in the DHI model. Element sizes in the UM-NOAA model are reported to range from about 100 m to 2.5 km compared to about 150 m to 6.6 km in the DHI model. One notable difference between the models is that DHI's MIKE 3 model includes the ability to account for ice on the lake surface, whereas the UM-NOAA FVCOM model was reported to neglect ice. Bathymetric elevations were interpolated to both meshes using the same 3-arc second DEMs from NOAA. Both models used the same CFSR2 wind fields from NCEP. DHI received model output from the UM-NOAA model for the period 01/01/2012 through 01/01/2016. A comparison of results between the two models was made in the Mackinac Straits area. A yearly time series comparison of current speeds extracted at a point at the deepest part of the channel near the pipeline (-84.75948 degE, 45.82047 degN) is shown in Figure 3-32. Figure 3-33 shows the location where the comparison of current speeds is made. Comparisons show similar predictions of currents at the surface and the bottom. The main differences can be seen in the period of January through March where FVCOM predicts higher currents. This is explained by the difference in the models, where DHI's MIKE 3 considers ice cover during this period, but the FVCOM model from UM-NOAA does not consider ice.

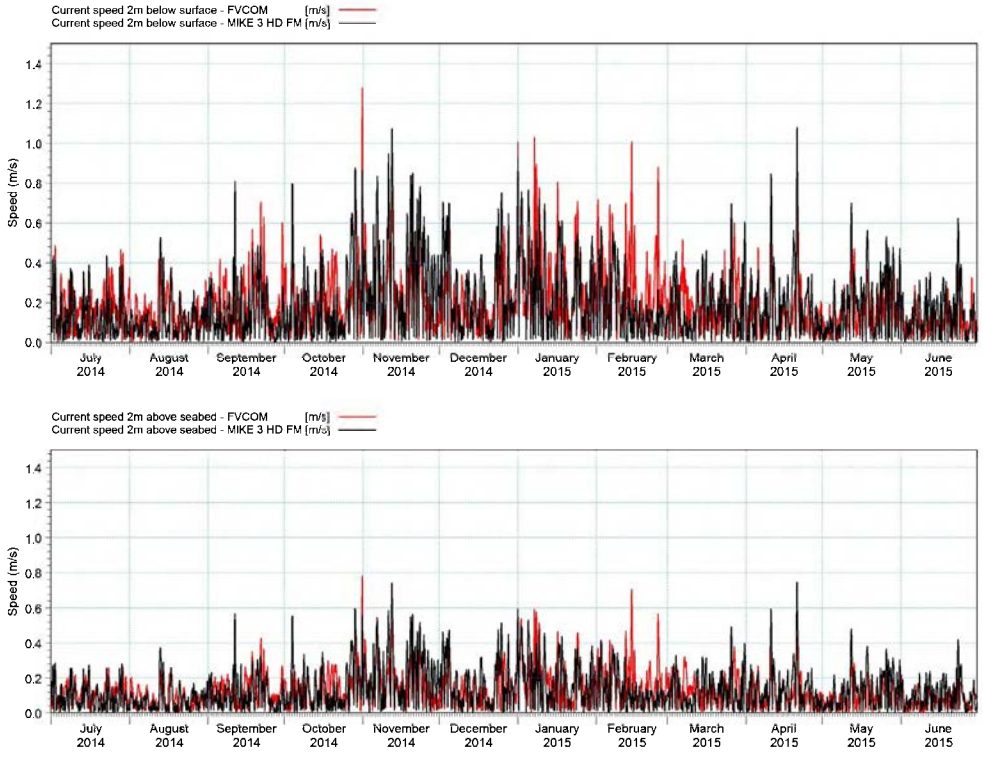


Figure 3-32 Comparison between MIKE 3 FM HD and FVCOM modeled currents at 2 m below surface (top) and 2 m above seabed (bottom) at a point along the pipeline route.

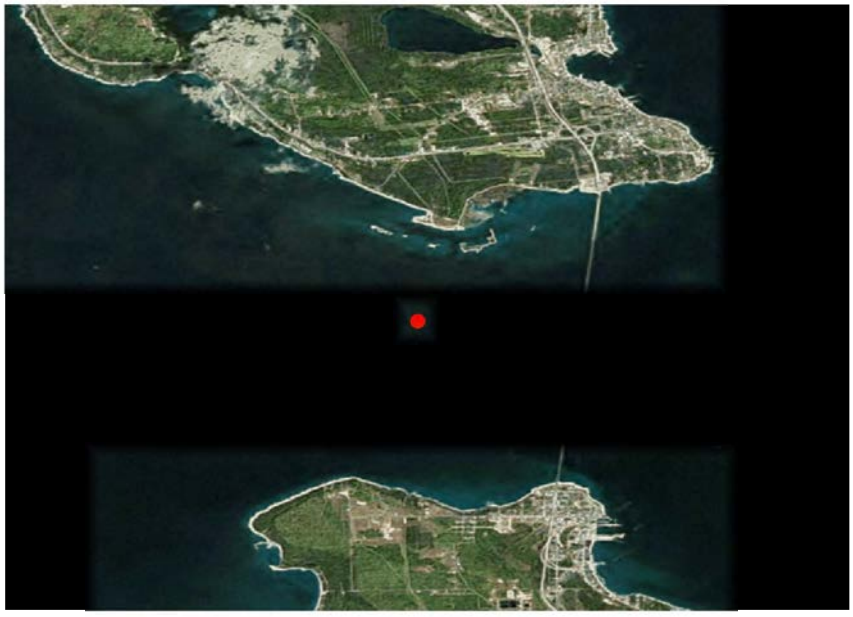


Figure 3-33 Location of point for comparing MIKE 3 FM and FVCOM model results. (-84.75948 degE, 45.82047 degN).

3.5 Validation of the MIKE 21 SW Spectral Wave Model

Available wave measurements from NDBC Buoy 45175 were used to validate the setup of the spectral wave model MIKE 21 SW used for the oil spill simulation runs. As mentioned in Section 2.6 of this report, wave measurements are available during the period August 2015 – October 2016, with a significant data gap between late October 2015 and mid-May 2016. Measured wave data parameters consist of significant wave height H_{m0}, peak wave period T_p and mean wave direction MWD.

The two simulation periods listed in Table 3-8 below were selected based on the availability of measured wave data and model runtimes consideration.

Table 3-8 Simulation specific parameters - MIKE 21 SW spectral wave model

Start date and time (UTC)	End date and time (UTC)	Number of time steps (-)
October 01, 2015 12:00 AM	October 31, 2015 12:00 AM	1440
August 01, 2016 12:00 AM	September 30, 2016 12:00 AM	2880

Model parameters were initially adopted from the existing forecast system for the Great Lakes developed by DHI. Since the initial comparison between measurements and model results were not deemed as being satisfactory, because different wind data source were used for that study, several model parameters (minimum frequency and frequency factor in the spectral discretization, number of directions in the directional discretization, the bottom friction, the background Charnok's parameter, among others) were tuned until satisfactory agreement between measured wave data and model results was achieved.

The model parameters finally adopted for the production runs with the spectral wave model have been summarized in Table 3-9 for the sake of convenience.

Figure 3-34 and Figure 3-35 show a comparison between the wave measurements and the model results that were obtained by running MIKE 21 SW for the two simulation periods listed in Table 3-8 using the model parameters in Table 3-9.

In general terms, there is good agreement between measured and calculated wave parameters during both simulation periods in Table 3-8, which is further supported by the RMSE analyses for significant wave height H_{m0} reported in Table 3-10.

Table 3-9 Generic parameters - MIKE 21 SW spectral wave model

Maximum time step (s)	1800
Spectral formulation	Higher order
Time formulation	Higher order
Spectral discretization	Logarithmic, 25 frequencies, f_{min} = 0.15 Hz, frequency factor = 1.07
Directional discretization	360° rose, 32 directions
Water level conditions	Hourly time series of water levels recorded at NOAA station 9075080 Mackinaw City, MI
Bottom friction	Nikuradze's roughness k_N = 0.02m, constant
Current conditions	No currents
Wind forcing	Varying in time and domain
Type of air-sea interaction	Coupled. Background Charnok's parameter = 0.02
Ice coverage	No ice coverage [1]
Wave diffraction	Not included
Energy transfer	Include quadruplet-wave interaction
Wave breaking	User specified, constant γ_2 = 0.80

White capping	Constant C_{DIS} dissipation coefficient = 1.75 Constant Δ_{DIS} dissipation coefficient = 0.25
Structures	Not included
Initial conditions	Spectra from empirical formulas, JONSWAP fetch growth expression with default parameters

Notes:

1. Specified ice concentration varying in time and domain, with a critical value = 0.33 is used in the spectral wave model production runs

Table 3-10 RMSE for significant wave height H_{m0} at NDBC Buoy 45175

Measured vs calculated Hm0 at NDBC Buoy 45175			
Period	**RMSE (m)**	**Max. measured Hm0 (m)**	**RMSE % (-)**
October 2015	0.20	1.80	11.0%
Aug-Sep 2016	0.11	1.85	6.1%

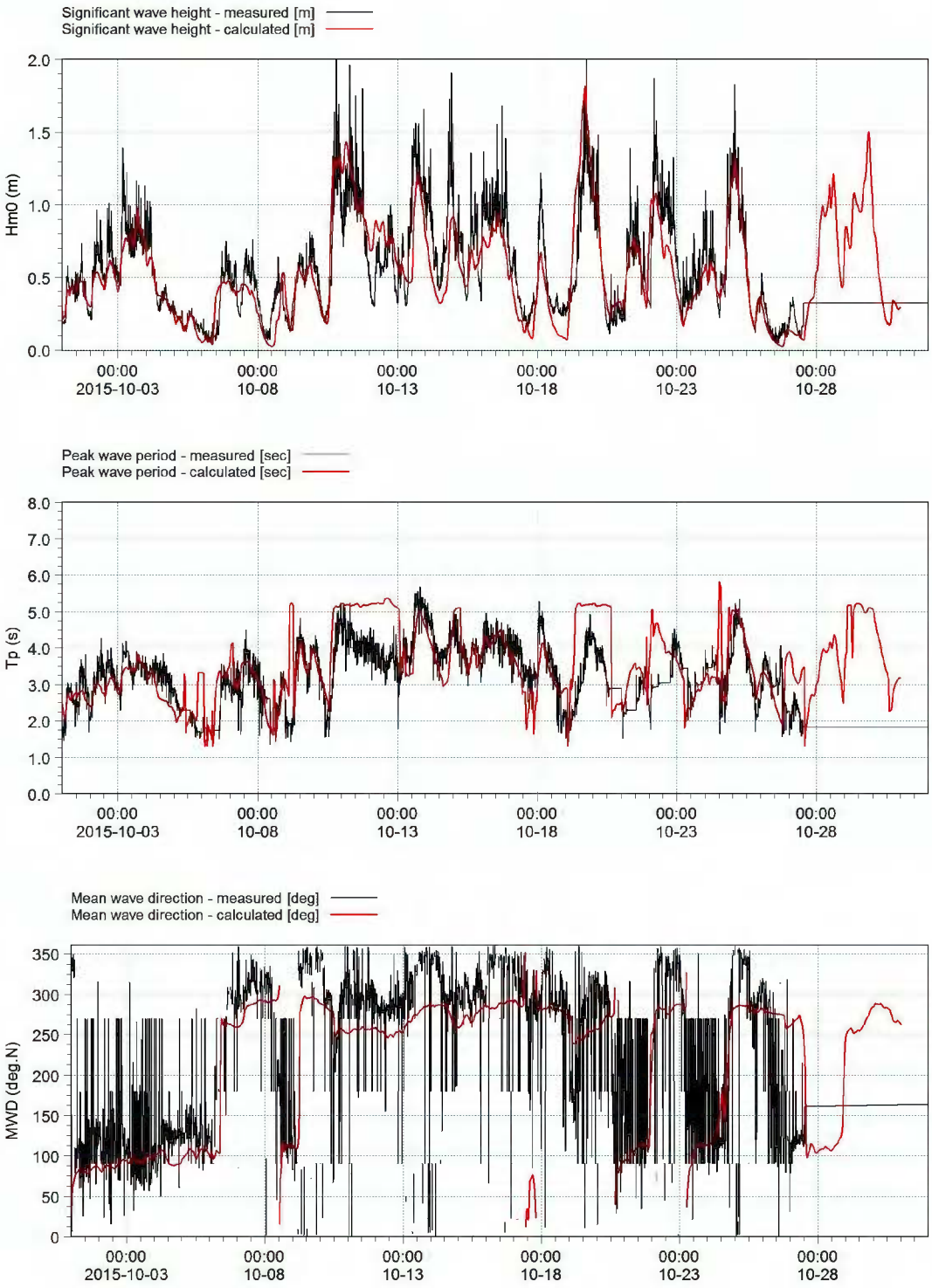


Figure 3-34 Measured (black line) and calculated (red line) significant wave height, peak wave period and mean wave direction at the position of NDBC Buoy 45175. October 2015

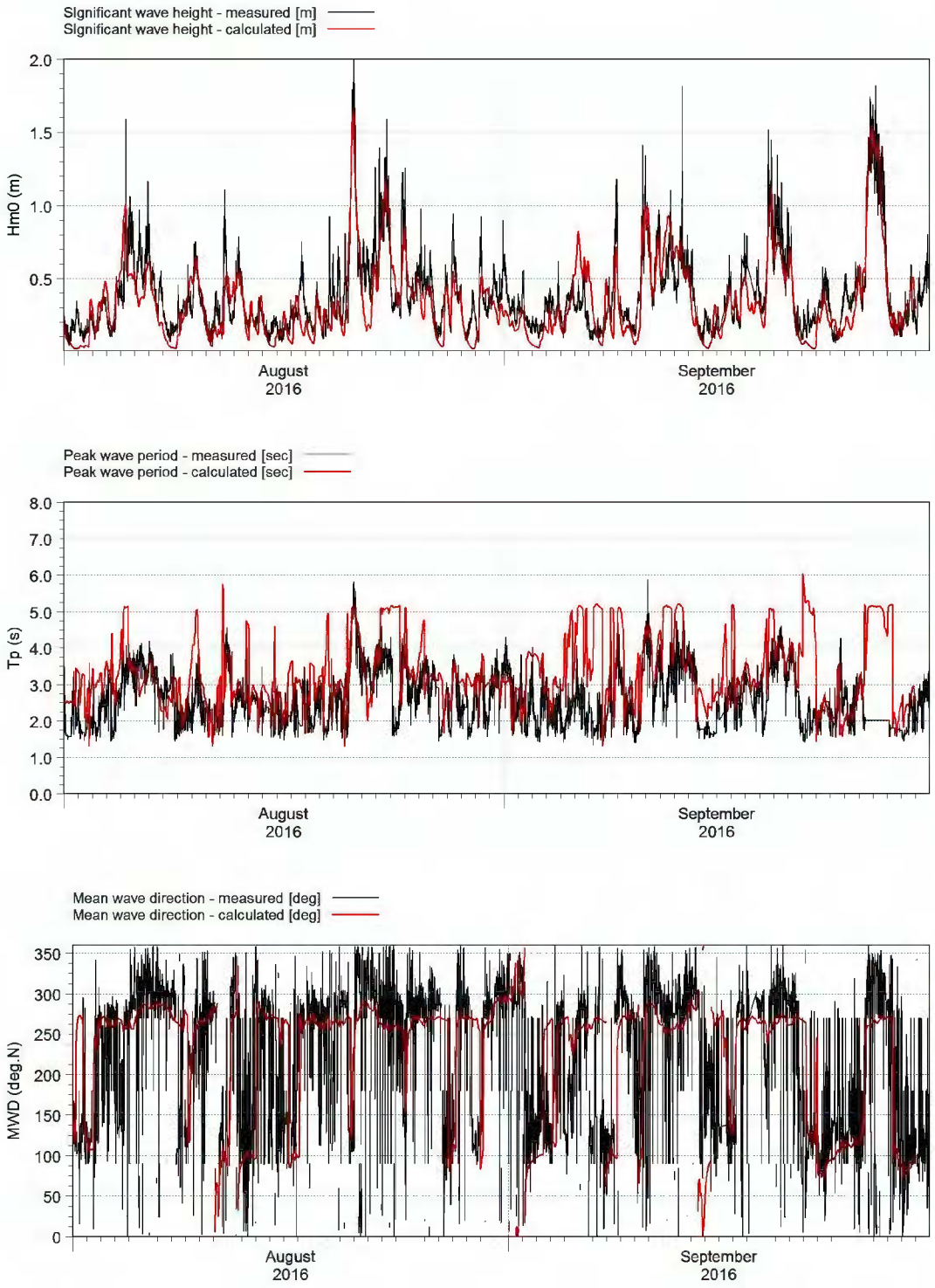


Figure 3-35 Measured (black line) and calculated (red line) significant wave height, peak wave period and mean wave direction at the position of NDBC Buoy 45175. August-September 2016

4 Model Production Runs

4.1 Selection of Production Period

Following consultation with the project team, the 1 year time period of time extending from 1st of July 2014 to 30th of June 2015 was adopted for the model production runs. The following considerations were put forward when selecting this timeframe:

- Advantageous to start the model simulation in summer to allow a well-developed model solution (in terms of flow and water levels) prior to any ice effects influencing the model results
- Ice cover: the winter of 2014/2015 is a winter with fairly high ice coverage in Lakes Michigan and Huron; however, the period with significant ice cover is brief (not like in winter 2013/14, for example, with a prolonged period of ice cover)
- Wind conditions are fairly average compared to other years, without any particular high wind events or extreme situations.
- The selection of the simulation period has been based on the last 10 years, rather than further in the past

Later on, the simulation period was extended through to the 30th of September 2015 due to modeling considerations.

4.2 Hydrodynamic (HD) Model Production Runs

The production simulations of the hydrodynamic model MIKE 3 HD FM were run in monthly periods to keep the runtimes and file sizes within manageable limits. A seven-day warm-up period was applied to the first month simulation to ensure the model stabilized before the period of interest.

Generic model parameters as listed in Table 3.2 were used in all MIKE 3 HD FM production runs. Model outputs were saved at ½ hour time steps at every element of the model mesh. The model outputs include the u-velocity, v-velocity, w-velocity and water level, which were used as inputs for the oil spill simulations.

Figure 4-1 shows iso-contours of the maximum current speed over the 1-year simulation period, showing the higher currents occurring in the Straits, just east of the pipeline location. The figure also shows three locations where time series of currents were extracted near the bottom. The time series of currents at the 3 points are presented in Figure 4-2 through Figure 4-4.

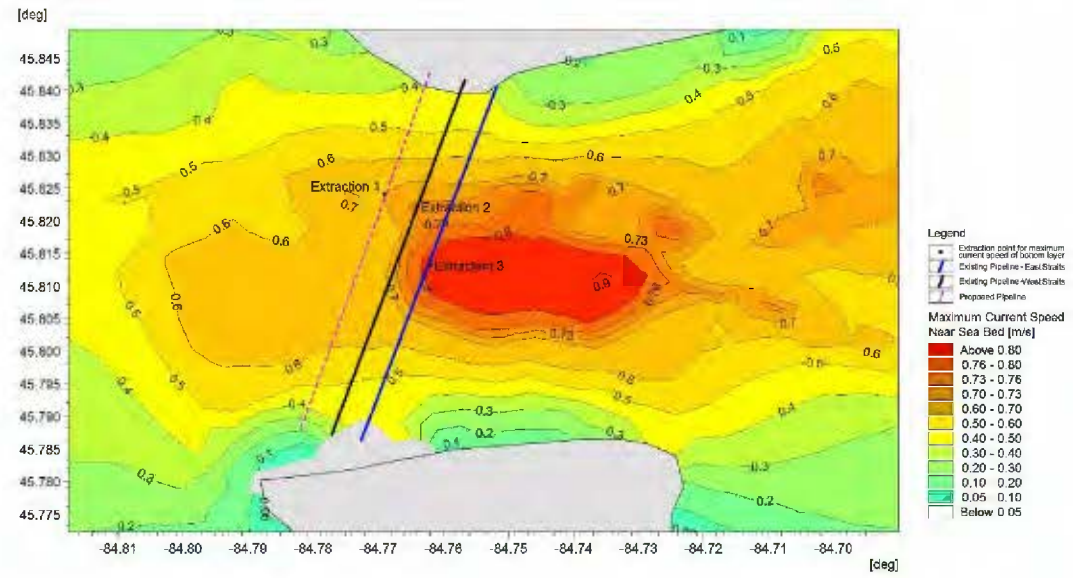


Figure 4-1 Iso-contours of the maximum current speed from the one-year hydrodynamic simulation.

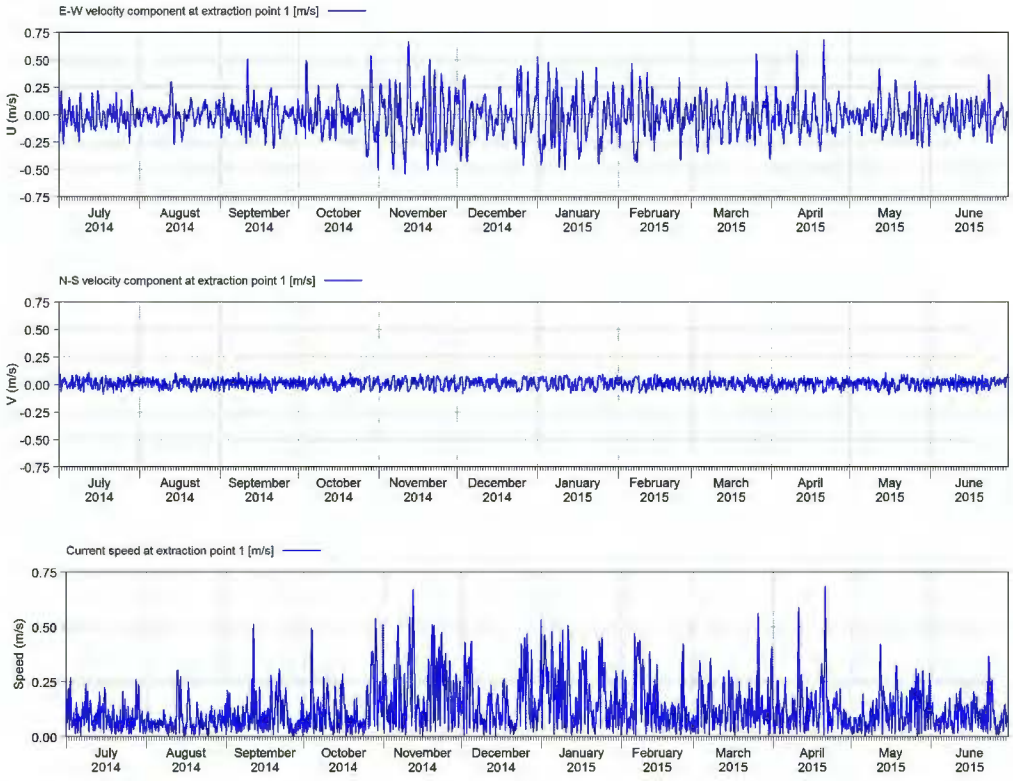


Figure 4-2 Time series of near bottom currents at extraction point 1.

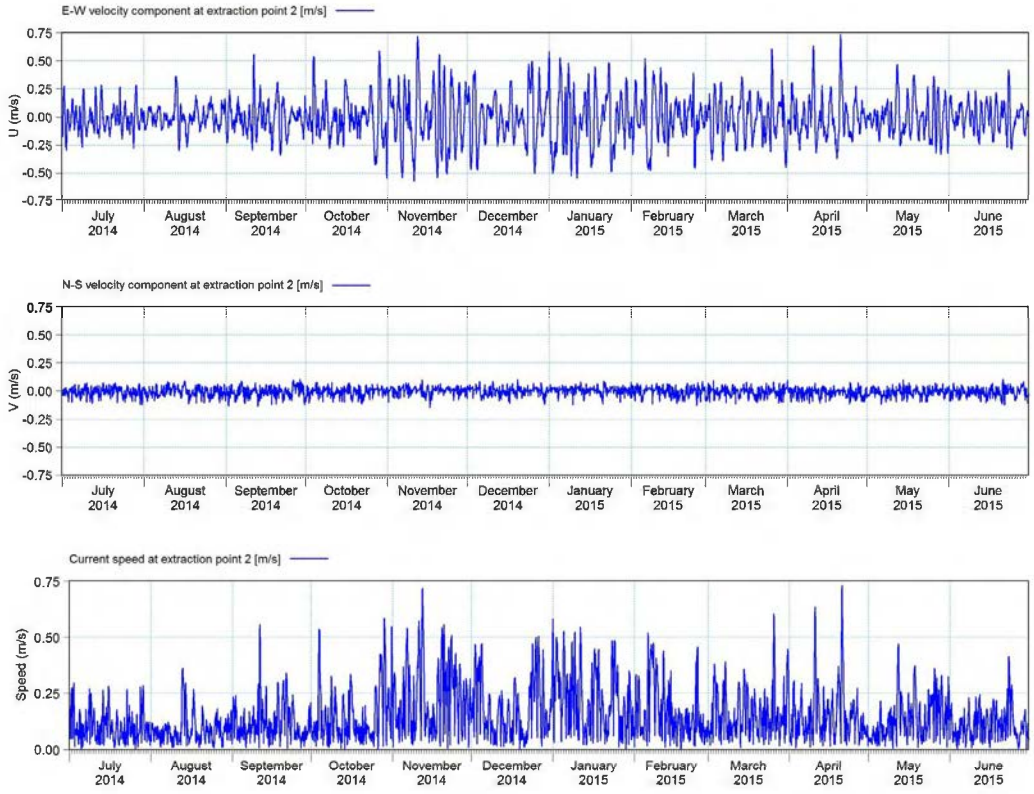


Figure 4-3 Time series of near bottom currents at extraction point 2.

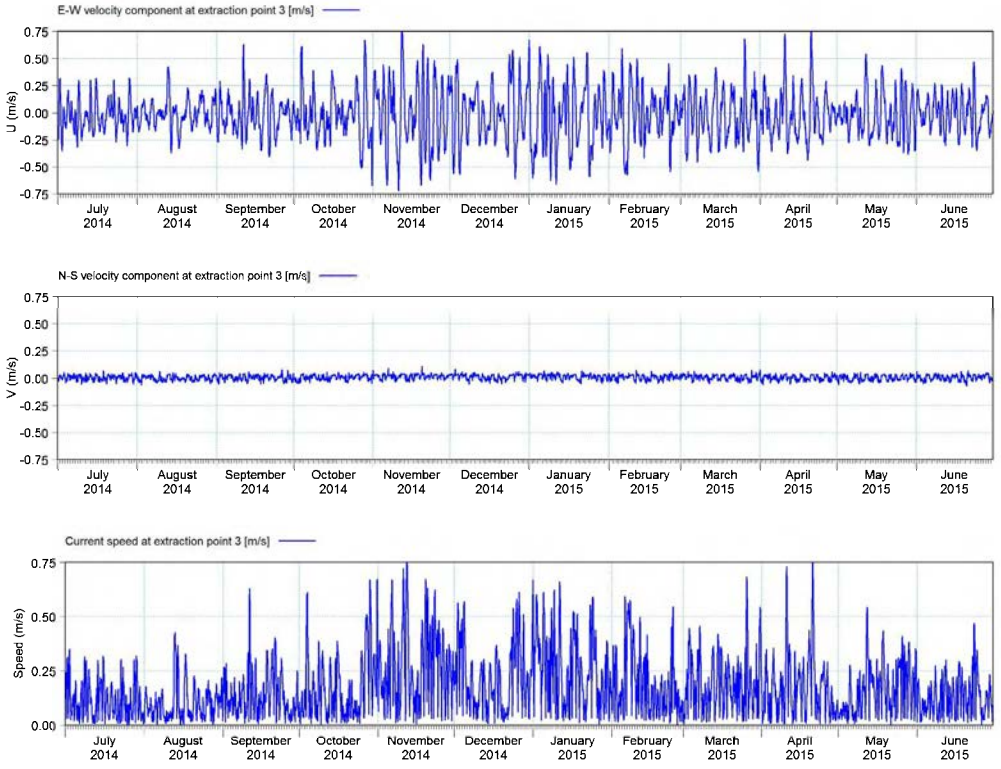


Figure 4-4 Time series of near bottom currents at extraction point 3.

4.3 Spectral Waves (SW) Model Production Runs

The production runs of the spectral wave model MIKE 21 SW were executed in monthly periods in order to keep runtimes and output file sizes within manageable limits. A three-day period was inserted before every month and used to spin-up the model solution, meaning that the production run for e.g. October 2014 extended from September 28, 2014 00:00 through November 1, 2014 00:00. Model results generated during the spin-up period were not saved.

Generic model parameters as listed in Table 3-9 were used in all MIKE 21 SW production runs. Model output consisted of wave parameters (significant wave height H_{m0}, peak wave period T_p, energy mean wave period T_{02} and mean direction of wave propagation MWD) stored at ½ hour time step at every element of the model mesh. It should be mentioned that only H_{m0} and T_{02} are required as input for the oil spill simulations.

Figure 4-5 shows time series variation of H_{m0} and T_{02} for the 1-year simulation period at extraction point 3 shown in Figure 4-1. The period shown without waves indicates that ice has covered the straits. Maximum H_{m0} for the period is about 2 m with and associated wave period is 4 seconds.

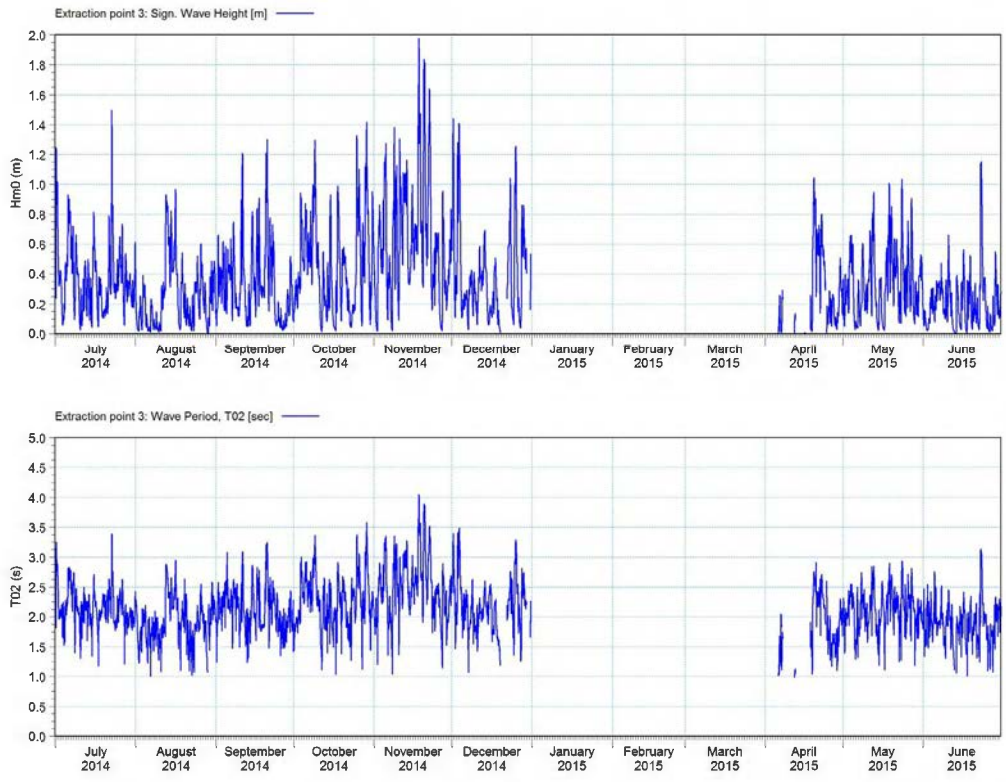


Figure 4-5 Time series plot of significant wave height (H_{m0}) and mean period T_{02} from extraction point 3. Note: period of time with no waves indicates ice coverage in the area.

5 References

/1/ Anderson, E.J., and D.J. Schwab, 2013. Predicting the oscillating bi-directional exchange flow in the Straits of Mackinac. Journal of Great Lakes Research 39(4):9 pp.(DOI:10.1016/j.jglr.2013.09.001).

/2/ Schwab, David, "Statistical analysis of Straits of Mackinac Line 5 Worst Case Spill Scenarios," University of Michigan Water Center, Graham Sustainability Institute, March 2016. http://graham.umich.edu/media/pubs/Mackinac-Line-5-Worst-Case-Spill-Scenarios.pdf

/3/ National Center for Environmental Prediction (NCEP) https://nomads.ncdc.noaa.gov/modeldata/cfsv2_analysis_timeseries/.

/4/ NOAA Great Lakes Environmental Research Laboratory (GRERL) web page http://www.glerl.noaa.gov/data/pgs/glice/glice.html.

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Dynamic Risk

Attachment 6: Review of Timm Documents

Attachment 06, Review of Timm Documents.pdf

Rev. 0 (October 11, 2017)

Dynamic Risk

Final Report

Attachment 06, Review of Timm Documents

October 11, 2017

Prepared for

State of Michigan

Prepared by

Dynamic Risk Assessment Systems, Inc.

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Document number	SOM-2017-01-RPT-001
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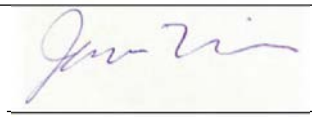
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Figure 2 – Reproduction of Errors and Omissions Document Figure 4 7

Introduction

As part of the public review process for the Line 5 Straits of Mackinac Alternatives Assessment, a number of documents were submitted by Dr. Edward E. Timm, who, according to the website of For Love of Water (FLOW), is a FLOW adviser and former Dow Chemical engineer. Within Dr. Timm's CV provided on the FLOW website, no mention is made of any background in fields that are related to pipeline design, operation, risk & reliability or stress analysis. That said, Dr. Timm has submitted a number of technical reports ('the Timm Reports') that relate to those fields as they pertain to the July 27 2017 Draft Report 'Alternatives Analysis for the Straits Pipeline' ("the July 27 Draft Report").

The number and nature of claims made within the Timm Reports warranted an in-depth review of those documents. This was particularly so, since, as was evidenced by some of the comments submitted by others during the course of the public review process, the Timm Reports were being perceived as the product of a particular subject matter expertise in fields related to pipeline reliability assessment.

As will be demonstrated later, the Timm Reports are characterized by an apparent lack of working knowledge of applicable codes and standards and pipeline stress analysis, the mischaracterization of data, and an apparent lack of familiarity on topics related to pipeline design, construction, operations, and inspection.

To date, the following documents have been submitted by Dr. Timm as part of the public review process (presented in chronological order):

- 8/20/2016 "Technical Note Regarding Enbridge Line 5 Non-Compliance with 1953 Easement Requirements A Mechanistic Analysis of Straits Pipeline Washout Phenomena" ("the Easement Non-Compliance document")
- 3/5/2017, "Technical Report An Investigation into the Effect of Near Bottom Currents on the Structural Stability of Enbridge Line 5 in the Straits of Mackinac" ("the Currents document")
- 6/27/2017, "June 18, 2017 Supplemental Addendum to Technical Note Regarding Enbridge Line 5 Non-Compliance with 1953 Easement Requirements A Mechanistic Analysis of Straits Pipeline Washout Phenomena" ("the Washout Phenomena document")
- 7/20/2017 "Technical Note An Analysis of Errors and Omissions in the Dynamic Risk, Inc. Line 5 Alternatives Analysis, Option 5" ("the Errors and Omissions document")
- 8/2/2017 "Technical Note A Lower Bound Examination of the Monte Carlo Analysis for Spanning Risk in the Dynamic Risk, Inc. Line 5 Alternatives Analysis, Option 5" ("the Examination of the Monte Carlo Analysis document")

A number of themes and associated claims have emerged from the above-referenced documents, relating to the following topic areas:

- Spanning Stresses
- Water Currents
- Fatigue Life
- Failure Probability
- Presence of Corrosion

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Reviews of the commentary provided in the above-referenced documents as they pertain to each of the above topic areas are provided in the sections below.

Spanning Stresses

Stress Analysis Methodology and Accuracy

One feature that all of the above-referenced documents have in common is the lack of detailed description showing the basis for any of the calculations performed. By convention, the authors of technical papers are expected to provide detailed descriptions of their analysis methodology (including equations, assumptions used, etc.) to facilitate the peer review process of their work. This convention was not adopted in any of the documents submitted, and in fact not one mathematical expression that was used as the basis for the calculations performed appears in any of the documents. It was therefore very challenging to perform quality control checks on the calculations (including the stress calculations) that serve as the underlying basis for the conclusions advanced, or to identify the sources of the numerous errors found.

Nevertheless, the text relating to Figure 31 of the Currents document provided sufficient information to facilitate an attempt to reproduce the results contained in that Figure. Stress values reported in Figure 31 were checked against values generated by the stress analysis software tool that served as the basis of the span analysis contained in the Alternatives Analysis[1]. Section 2.4.1.1.2.1.3 of the Alternatives Analysis report provides a detailed description of the approach, references, equations used, etc. in this software tool. This software tool was validated against the stress calculation approaches detailed in the references cited in Section 2.4.1.1.2.1.3 of the Alternatives Analysis report. In addition, the independent results reported by Rosenfeld[2] were readily reproduced using this software tool, thereby providing further validation of that tool.

Using information found in the text relating to Figure 31 of the Currents document, it was not possible to reproduce the results shown in that Figure. The stress results reported in Figure 31 were found to be high on a consistent basis, relative to check values, with the stress values found in Figure 31 exceeding check values by as much as a factor of 1.73. In the absence of a detailed description of approach used, it is impossible to know the underlying basis for the considerable departures from the check values.

Furthermore, because the Straits pipelines are subject to longitudinal bending, axial, and hoop stresses, they operate in a multi-axial stress state. This fact has been ignored in the stress analysis found in the Currents document. As a result, within that document, material yield behavior is characterized as that which would occur only under uni-axial loading (a condition that is inconsistent with the conditions found in the Straits Crossing pipeline segments). While this simplification makes the analysis more accessible to practitioners not familiar with piping stress analysis, this aspect of the stress analysis represents a procedural error that violates basic stress analysis methodology, as well as the requirements for combining stresses as prescribed in ASME B31.4.

[1] Dynamic Risk Report to State of Michigan "Alternatives Analysis for the Straits Pipeline – Draft Final Report", June 27, 2017.
[2] Rosenfeld, M. "Assessment of Span Exposures on the 20-inch Petroleum Pipelines Crossing the Straits of Mackinac", October, 2016.

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The apparent presence of very significant errors in the stress analysis methodologies found in the documents submitted by Dr. Timm are of some consequence to his conclusions regarding the potential for yielding to occur in spans, since these conclusions are predicated on the accuracy of the stress calculations that he performed. Among the conclusions so affected are those contained in the Examination of the Monte Carlo Analysis document, in which the following assertions are made:

That the Monte Carlo analysis used in the Alternatives Analysis results in an estimate that is inconsistent with a simple calculation of the lower bound for spanning risk due to the force of gravity, implies that either a mathematical error or unstated assumption exists in this risk analysis.

and;

a complete explanation for why the spanning risk calculated in the Alternatives Analysis is so completely inconsistent with the simple calculation for the lower bound for that number discussed here is required before even limited credibility can be given to Dynamic Risk's calculation of this risk.

In pipeline stress analysis, a variable known as the 'drag coefficient' plays a significant role in determining drag forces on a pipeline associated with the flow of water around a pipe. This drag coefficient is a function of several variables, including pipe surface roughness, pipe diameter, current velocity, proximity of the pipe to the lakebed, and cross-flow vortex-induced vibration amplitude. On p. 24 of the Currents document, it was described that the drag coefficient that was used for the purposes of performing stress calculations was derived from a journal article published in 1981 (Achenbach and Heinecke). Specifically, the drag coefficient was obtained from a Figure from that journal article that depicts drag coefficient as a function of Reynolds number for cylinders having specific surface roughness values. It is important to note that this Figure does not address lakebed proximity or vortex induced vibration amplitude, which normally are significant factors in determining drag coefficients for spanned pipelines lying in proximity to lakebed.

Nevertheless, having selected a surface roughness value of $30x10^{-03}$ (corresponding to very rough pipe), and having established that the appropriate Reynolds number is in the range of 10^5 – 10^6, a drag coefficient was selected using the Figure published by Achenbach and Heinecke:

The Reynolds numbers calculated for velocities in the range of interest range from 10^5 to 10^6, a range where the Cd's determined from Figure 17 are reliable.

The Figure published by Achenbach and Heinecke clearly shows that the drag coefficient relationship for surface roughness values of $30x10^{-03}$ is valid only at Reynolds numbers below 10^5, and not for Reynolds numbers in the range of 10^5 - 10^6, as had been established to be the applicable range. It is not possible to know the magnitude of effect that this improper application of the drag coefficient variable has on drag forces and stresses that are calculated and used as the basis of the conclusions found in the documents submitted.

As with all fields of engineering, piping stress analysis is a field that requires some background and training, an understanding of best-practices, and a working knowledge of applicable codes and standards. With respect to the last point, on p. 36 of the Currents document, as part of a discussion pertaining to longitudinal stress due to axial and bending loads, an assertion is made that ASME B31.4 requires a maximum stress of 72% SMYS. This assertion regarding the requirements of ASME B31.4 is

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incorrect. In fact, the 72% SMYS stress limit prescribed within ASME B31.4 applies specifically to stresses arising from internal and external pressures. Other criteria exist for installation stresses, additive longitudinal stresses, combined longitudinal stresses from sustained and occasional loads, and equivalent combined stresses.

On p. 33 of the Currents document, a description is offered as to how a stress analysis was conducted by taking measurements from an off-perspective photo taken during installation in 1953:

By carefully scaling the photo, it is clear that the pipe was yielded during launch by bending to a radius of curvature of ~300 feet.

There is no reasonable means by which the scaling exercise described in the Currents document can be characterized as credible or accurate. Regardless, as those familiar with pipeline design and construction practices will know, the installation methods depicted in the Figure are not uncommon in modern pipe-laying practices (particularly in J-Lay and S-Lay offshore techniques), and installation stresses and strains are accommodated in the ASME B31.4.

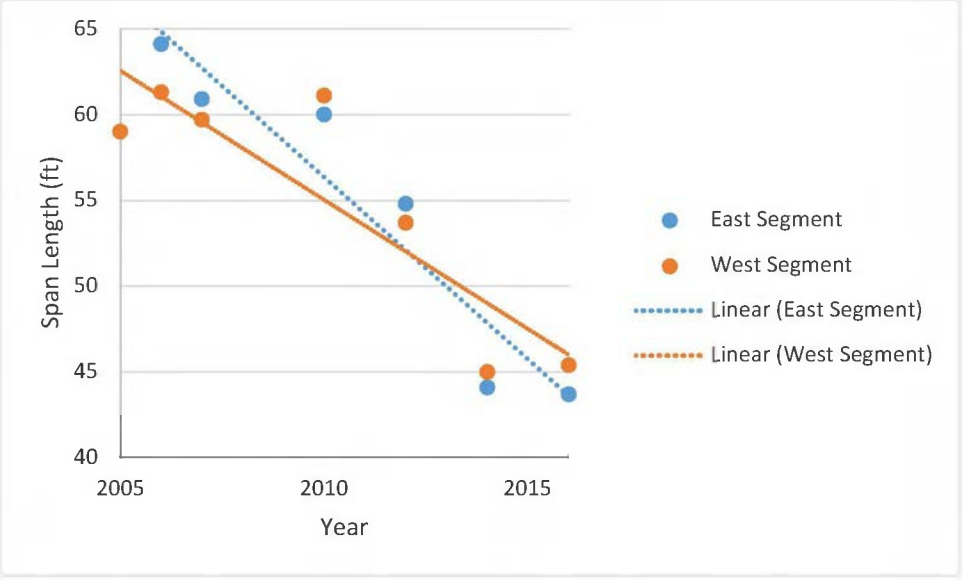
Statements Regarding Lack of Conservativism

With respect to the purported lack of conservativism in the stress analysis, the following statement is found on p. 13 of the Errors and Omissions document:

These distributions are a very good fit to the span data revealed in Reference 21 but when used in a Monte Carlo analysis to estimate risk, the authors of the Alternatives Analysis appear to have made a serious mathematical error. The 715 East Leg span length measurements and the 691 West Leg span length measurements result from pooling data taken during inspections in 2005, 2006, 2007, 2010, 2012, 2014 and 2016. Each individual dataset contains a differing number of spans both because of new washouts and the addition of new supports. This means that while the distribution functions plotted above may be relatively time invariant over the period 2005-2016, the ensemble of spans existing during each time interval between inspections is different. Because a random selection of current velocity in the Monte Carlo impacts all the spans in an ensemble, each span in that ensemble must be tested for the failure criteria not just one randomly selected span. Because extreme current events are quite rare but each such event tests a large number of spans, multiple failures may occur for each random current velocity selection. ***This physical fact results in a much larger number of failures than the Monte Carlo implementation apparently done in the Alternatives Analysis and the estimates of risk derived from this analysis are erroneously underestimated by a large margin!*** *This problem affects both the spanning risk Monte Carlo and the vortex induced vibration Monte Carlo analysis.*

Although nested within the above statement is the assertion that span length distributions are relatively invariant over the period 2005-2016, a review of the span data reveals that this is not so. Based on a review of the span data collected from 2005-2016, the Figure below illustrates a general trend for individual span lengths to get shorter with time (possibly, in part due to span management intervention activities).

Figure 1 – Average Span Length Vs. Year



This represents one of the conservative aspects of the span analysis contained in the Alternatives Analysis report, since no credit is given for the trend towards shorter span lengths on a go-forward basis. In respect of that analysis, the following factors collectively contribute to that conservativism:

- Current velocity data were derived from modeled results corresponding with the location along both the East and West segments that is associated with the maximum current velocity for the entire pipe segment.
- Although this maximum current velocity is associated at only one point along the East and West pipe segments, it was taken to be representative of the entire un-trenched portions of each pipeline.
- Although a trend of decreasing span length was noted for the time period from which the data was collected, this trend was not accounted for on a go-forward basis. The span distribution for the period 2005 – 2016 that is used for the purposes of the analysis includes span lengths that are in excess of 130 feet. As the span distributions that are fitted to the data are open-ended (i.e., they have no upper-bound limit), this enables Monte Carlo simulations to consider span lengths that are even longer than this largest span length encountered in the 2005 -2016 data set. Therefore, incorporated into the analysis is the underlying assumption that such span lengths will be experienced in the future, and no credit is given to the span management plans currently being implemented, which endeavor to limit span lengths to the 75-ft maximum limit. In particular, the Consent Decree between the United States of America and Enbridge (dated 05/23/17) mandates that henceforth, Enbridge must at all times support and anchor the pipelines with a series of screw-anchor supports that are placed so that the maximum distance between adjacent screw anchors does not exceed 75 feet.
- In the vortex-induced vibration analysis, fatigue life values that fall within the time period of the analysis (prior to the year 2053) were dominated by extreme values of current velocity in

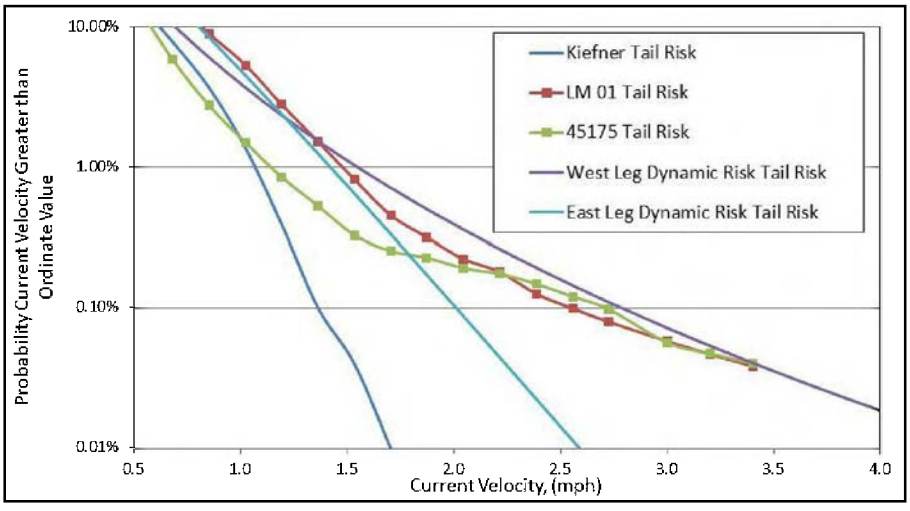
conjunction with extreme values of span length. Although extreme values of current velocity are known to be transient (short-term) events, and although longer span lengths get remediated through the installation of screw anchors, it was assumed that these extreme values persisted for the time period of the evaluation. In other words, in simulations involving high currents and long span lengths, no span management intervention activities were assumed, and extreme current values were assumed to last indefinitely, resulting in fatigue loading conditions that reflect those extreme values of current velocity and span length that extend through time, uninterrupted until failure is predicted.

- The vortex-induced vibration analysis was modeled in such a way that fatigue damage was accumulated from the start of operation in 1953 and the fatigue analysis was run over a 100-year period from 1953 to 2053, with failure probability results being reported for the period 2018-2053. In reality, any failure occurring over the near term would be associated with near-critical fatigue cracks that would be detectable by non destructive inspection. Such non-destructive testing was recently undertaken on both the East and West segments using the Oceaneering tethered tool. This automated inspection system utilizes time of flight diffraction (TOFD) and phased array (PA) pulse-echo ultrasonic techniques that are configured to detect and size surface breaking defects such as fatigue cracks residing in girth welds and their associated heat affected zones, where the potential for fatigue cracking to initiate and propagate exists. In the analysis, no credit was given to the fact that these inspections showed no evidence of sub-critical fatigue damage or cracking of any kind.

Water Currents

In the Errors and Omissions document, a great deal of discussion was devoted to assertions that the current velocity distributions used in the Alternatives Analysis do not appropriately characterize actual values. Figure 4 of that report (reproduced below) was presented in order to support the contention that extreme values of the distributions used in the Alternatives Analysis do not adequately or accurately reflect extreme values recorded in ADCP buoy data.

Figure 2 – Reproduction of Errors and Omissions Document Figure 4



With respect to the above Figure, the following statement is found on p. 7 of the Errors and Omissions document:

Figure 4 is a cumulative probability plot of data taken from buoys 45175, LM 01 and the unreported measurements revealed in the Kiefner report with the current velocity fits resulting from the one year duration run of the MIKE 3 model. This figure shows that the tail risk for current velocity between data taken from Buoys 45175 and LM 01 is similar to the risk calculated from the MIKE 3 model for the West Leg of Line 5. The agreement between the buoy data and the MIKE 3 model for the East Leg as well as the Kiefner data is not nearly so impressive.

The basis for the above statement regarding the current velocity distribution derived from the MIKE 3 model (employed in the Alternatives Assessment) for the East Leg is that the modeled results do not reflect high current velocity data derived from ADCP buoys LM 01 and 45175. This claim is demonstrated by the fact that at current velocity values above approximately 1.8 mph, the line on the above chart that represents the modeled current velocity distribution for the East segment (turquoise line) falls below the ADCP data (red and green lines).

Data for buoy 45175 is available on line at the Michigan Technological University's Great Lakes Research Centre website[3]. For the lowest-bin (representing measurements obtained closest to lake bottom) the highest recorded East-West water velocity has a magnitude of 2.33 knots (2.68 mph), corresponding roughly with a modeled probability of occurrence on the East Leg of 0.01% in the above Figure (see turquoise line).

The Alternatives Analysis project team obtained ADCP current velocity data for buoy LM 01 from Dr. E.J. Anderson, of the National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory. These data indicate that for buoy LM 01, the lowest-bin (representing measurements obtained closest to lake bottom) maximum measured water velocity is 1.35 mph, having a maximum E-W velocity component of 1.33 mph.

[3] http://uglos.mtu.edu/station_page.php?station=45175, accessed August 3, 2017.

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These results call into question the validity of the data displayed in Figure 4 of the Errors and Omissions document which show velocity values attributed to buoys 45175 and LM 01 that range in values of up to approximately 3.5 mph. Any calculations performed on the basis of those data, and the conclusions derived from those calculations are equally suspect.

Of note, the maximum near-lakebed velocities modeled by the MIKE 3 model at the locations of buoys LM 01 and 45175 were 1.88 mph and 1.70 mph, respectively, reflecting a conservative result relative to measured data.

Also of note, as has been noted previously, for the purposes of performing the spanning analysis, current velocity values were derived from modeled results corresponding with the location along both the East and West segments associated with the maximum current velocity for the entire pipe segment. These locations are different from the buoy locations.

Fatigue Life

The following is reproduced from p. 14 of the Errors and Omissions document:

Therefore, it is necessary to know the stress-strain history of the pipe in order to know if the pipe is close to its fatigue limit. A heavily fatigued pipe may well fail at a stress well below the elastic limit of virgin material so the failure criteria must take into account what has gone before. Similarly, the vortex induced vibration failure criteria is based on the number and severity of vibratory cycles. Again, the analysis must start from a time when the material in the pipe has zero fatigue cycles so that cycles can be accurately counted as the fatigue failure limit is approached.

From the preceding discussions, one problem with the Monte Carlo risk estimates in the Alternatives Analysis is that they don't start from the pipeline's construction in 1953. Instead, Dynamic Risk assumes the material making up the pipe is in virgin condition when they start their analysis in 2018 and use it to predict a risk of rupture extrapolated to 2053. In fact, the pipe has endured five different periods of spanning history with each adding its quanta of damage as the years pass. Essentially, Dynamic Risk has chosen to ignore the first 50 years of Line 5 under the Straits history, a history that includes little or no span maintenance with spans growing to at least 286', and then begins its calculations starting in 2018 assuming virgin material properties. Any risk estimate based on this methodology is so erroneous an equally accurate estimate could be produced using black cat bones and fuzzy dice! A correct Monte Carlo risk estimate would require doing separate year by year analyses each featuring a realistic current velocity distribution, span length probability distribution and number of spans. This would result in over sixty different Monte Carlo risk estimates which could be added up starting in 1954 to the current date then projected forward to get a realistic estimate of risk for any year in the future.

The assertion that the fatigue analysis didn't start from the pipeline's construction in 1953 is incorrect. In fact, in the analysis, fatigue damage was accumulated from the start of operation in 1953 and the fatigue analysis was run over a 100-year period from 1953 to 2053. Although the fatigue analysis was performed for this full time period, results were reported only for the years 2018 – 2053 for the simple reason that failure probability is known with 100% certainty for past years of operation. It would therefore be nonsensical to report predicted probability of failure for past years of operation.

It should be pointed out that any failure occurring over the near term would be associated with near-critical fatigue cracks that would be detectable by non destructive inspection. Such non-destructive testing was recently undertaken on both the East and West segments using the Oceaneering tethered tool. This automated inspection system utilizes time of flight diffraction (TOFD) and phased array (PA) pulse-echo ultrasonic techniques that are configured to detect and size accuracy for surface breaking defects such as fatigue cracks residing in girth welds and their associated heat affected zones, where the potential for fatigue cracking to initiate and propagate exists. These inspections showed no evidence of sub-critical fatigue damage or cracking of any kind that has occurred as a result of past operations.

Failure Probability Estimation

As an alternative to the threat-based evaluation of failure probability described in the Alternatives Analysis, the following approach and corresponding results are offered on p. 14 of the Errors and Omissions document:

*A very simple risk estimate for the whole of the underwater section of Line 5 can be done based on the average failure rate for all DOT 195 pipelines from all causes. This risk is given as 0.89 failures/(1000 mi * yr)23. Using this figure, the risk of failure for the 8.15 miles of twinned lines under the Straits gives a failure rate of $7.25*10^{-3}$ per year. Adding up the failure probability on a yearly basis gives the 2017 failure probability at 46.4% and the 2053 failure probability at 72.5%. These figures are very different from the Alternatives Analysis estiof 1.6% by 2053. This means that Line 5 under the Straits is 45 times safer than a typical buried DOT 195 pipeline, a conclusion that defies sense.*

No mention was made of the exact dataset that was employed for the purposes of the above analysis. Nevertheless, good practice dictates that when using industry incident data to estimate failure probability along specific infrastructure, the underlying incident database should replicate, as much as possible, the characteristics of the pipe segment being modeled. Nevertheless, as no mention was made of any attempt to ensure that this basic tenet of good practice was adhered to, it is likely that this analysis mixed failures that occurred in onshore environments with those that occurred in offshore environments. It is also likely that this analysis mixed failures that occurred within pipeline rights-of-way with failures that occurred within terminals, tank farms, offshore platforms, below-ground storage piping, etc., as the PHMSA Hazardous Liquids Incident Database contains data for all this infrastructure. Furthermore, equipment failure (defined as failures occurring within non-pipe components, such as seals, gaskets, instrument tubing, o-rings, etc.) represents the biggest single cause of failure within the PHMSA Hazardous Liquids Incident Database. There is no non-pipe equipment within the Straits Crossing segment. Therefore in the absence of any effort to ensure that the incident data reflect characteristics of the Straits Crossing segments, failure rates will be skewed by failures that occur in infrastructure that isn't represented within those pipe segments. Finally, this simplistic approach ignores specific threats that have been identified, and which may be applicable to the segments of interest (such as anchor interaction, geohazards, etc.), and conversely, the failure rates will reflect threats that have been shown to be not applicable to these segments (such as selective seam corrosion, landslides, etc.).

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Presence of Corrosion

The following is reproduced from p. 20 of the Errors and Omissions document:

Although numerous MFL inspections of the Straits sections of Line 5 have been conducted that show little metal loss corrosion it should be noted that MFL technology has a limit of detection for metal loss of about 10% of the wall thickness of the pipe. Because of the extremely thick walls of Line 5 (0.812"), this limitation means that corrosion damage of 0.080" is the detection threshold in this situation and significant metal loss and pitting could exist just below the detection threshold of MFL inspection technology. Further information will be available regarding corrosion and the condition of the coating on Line 5 under the Straits following the completion of the ongoing Biota[25] report.

In fact, the minimum detection capabilities for general metal loss of the Magnescan tool that was deployed in 2013 is 5% of wall thickness at 90% probability of detection, and metal loss below that performance threshold is routinely reported in pipelines where such corrosion exists. Had external corrosion been an active and ongoing process in the 60 years of operation prior to that inspection, then evidence of it would be expected. As is documented in the Alternatives Analysis report, to date, no external corrosion features have been detected in the Straits Crossing segments by any of the metal loss inspections performed.

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Dynamic Risk

Attachment 7: Ecological Baseline & Basis for Analysis

Attachment 07, Ecological Baseline & Basis for Analysis.pdf

Rev. 1 (October 13, 2017)

Oil Spill Modeling for Straits of Mackinac, Michigan

Ecological Baseline & Basis for Analysis

Final Report



Oil Spill Modeling for Straits of Mackinac, Michigan

Ecological Baseline & Basis for Analysis

Final Report

Prepared for Dynamic Risk



Straits of Mackinac

Project Manager	Dale Kerper, Senior Coastal & Marine Engineer, DHI US

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LIST OF ABBREVIATIONS

ZOE - Zone of exposure

HCA - High consequence area

EIA - Environmental Impact Assessment

CITES - Convention on International Trade in Endangered Species of Wild Fauna and Flora

IUCN - International Union for Conservation of Nature

1 Introduction

This document provides an overview of relevant environmental baseline features within a Zone of Exposure (ZOE) as determined in the risk analyses of alternatives to the existing Line 5 pipeline. The segments of the pipelines that cross the Straits of Mackinac lay at the bottom of the Straits and transport approximately 540,000 barrels of crude oil and natural gas liquids (product) every day from Superior, Wisconsin to Sarnia, Ontario, Canada. The document also provides an explanation of oil spill tolerance levels of certain ecological receptors and how this information is used in the impact analyses.

Information presented in this document was used to underpin calculations and/or discussions related to ecological consequences of the most plausible oil spill scenarios associated with considered alternatives.

To a lesser extent the document also addresses wetland environments related to rail and pipeline alternatives (i.e. Alternatives 3 and 1) that transect the southern portions of Michigan State, as well as through the neighboring States of Indiana, Illinois and Wisconsin.

1.1 Additional Explanation

Information presented in this document was used in various Line 5 Alternatives Analyses. An important costing consideration in a risk analysis is whether oil spill impacts would occur in a 'High Consequence Area' (HCA) (1). While the definition of an HCA extends to socio-economic factors such as population density and drinking water resources, in terms of ecological receptors, a HCA can be defined as an 'an unusually sensitive area' (2), which is further defined as:

- Area with one or more species or natural community that can be critically imperilled by impact associated with the assessed alternatives;
- Area with concentration of resident and/or migratory water birds;
- Area with species or ecological populations that are threatened, endangered or of special concern, or are limited in habitat and foraging range; or
- Area with species or natural populations that are threatened, endangered or of special concern where the site of species or community occurrence considered to be viable, and in high quality or condition.

This document, therefore, supports decision-making in terms of whether potential or theoretical oil spill scenarios in the Strait of Mackinac would lead to ZOEs at such High Consequence Areas.

A significant amount of information, including data in geospatial format, is publicly available for the Straits of Mackinac, and the surrounding waters for Lake Michigan and Lake Huron. Given the importance of spatially diverse and sensitive biodiversity and habitats within the potential oil spill impact area, the primary approach in this baseline study was to gather relevant ecological and environmental information of sensitive species and habitats from reliable data sources and present key information via maps, tables or analyses suitable for an environmental risk assessment. It is noted here that the study does not go to the depth of information that one may expect of a site-specific environmental impact assessment (EIA) or academic research paper. It is emphasized, thus, that the information presented in this document is sufficient for proper understanding of the scale of risk for general planning and costing purposes. It is acknowledged that more detailed information may be required for other purposes, e.g. oil spill contingency planning used by response personnel.

1.2 Outline of this Document

This document consists of:

- **Section 2:** A review of the study location and ecologically relevant receptors in the Strait of Mackinac, including those related to certain ecologically relevant socio-economic or socio-cultural aspects of the area

  Section 3: A description of Lake Michigan, Straits of Mackinac or Lake Huron baseline biodiversity at risk as it relates to the following categories:
  - Birds
  - Fish
  - Herpetofauna (amphibians and reptiles)
  - Mammals
  - Other Flora and Fauna (i.e. plants and aquatic vegetation, and invertebrates)

- **Section 4:** An overview of the pertinent wetland habitat in relation to the Southern Pipeline and Rail Alternatives

- **Section 5:** An overview of typical impacts and tolerance levels of biodiversity to oil spills or oils and the corresponding limits used in mapped modeling results and associated analyses.

2 Overview

The Straits of Mackinac is a narrow waterway between lower Michigan and the upper peninsula. The Straits are crossed by the Mackinac Bridge and connect Lake Michigan and Lake Huron, both of which are freshwater lakes that are inter-connected with other Great Lakes in the larger region. Although characterized as separate lakes, Lakes Huron and Michigan may be considered as one hydrological body of water connected by the Straits of Mackinac.

The hydrodynamic conditions of the Straits are seasonally variable, with strong currents running in opposite directions. The hydraulic regime of the Straits is essential to the exchange of water between Lake Michigan and Lake Huron, and is highly influential to water quality and ecological processes.

Islands in this area include Saint Helena Island to the west, Green Island to the south of the northern peninsula, as well as Mackinac Island, Round Island, Bois Blanc Island to the east. Mackinac Island and Bois Blanc Island are populated and accessible by ferries.

The coastal areas surrounding the Straits are predominantly rural, and sparsely populated. The nearest populated areas along the coast are Saint Ignace City (located at the southern tip of the upper peninsula), Mackinaw and Cheboygan cities (lower Michigan), and several other small cities within close proximity.

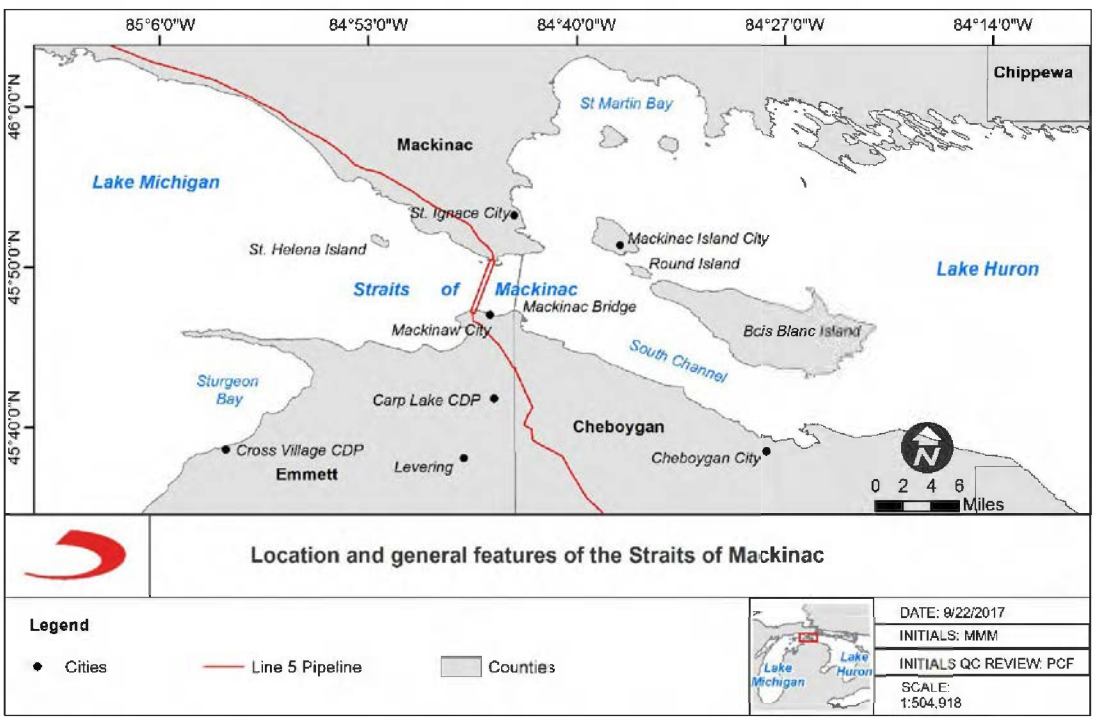


Figure 2.1 Location and general features of the Straits of Mackinac

The Line 5 Pipeline, (depicted in Figure 2.1), was built in the early 1950s and cuts across the Straits at an angle, over a distance of approximately 3.9 miles. For the bulk of its 645 miles (1038 km), Line 5 consists of a single 30-in diameter buried pipeline, but splits into twin 20-inch diameter parallel pipelines through the Straits crossing.

2.1 Relevant Habitat

The benthic, pelagic and littoral environments of the Straits of Mackinac contain diverse sensitive habitats that support resident and migratory biodiversity. The area's geomorphic site includes open lake areas, protected embayments and connecting channels.

Figure 2.2 below provides an overview of coastal habitats in the Straits of Mackinac and surrounding waters of North Lake Michigan and Lake Huron. NOAA ESI mid-1990s data for birds, fish, terrestrial mammal and plant habitats are shown in the map (3). Based on the NOAA ESI data, coastline types most frequently encountered west of Mackinac Bridge include mixed sand and gravel beaches, gravel beaches, sand beaches and fringing wetlands. East side of the Mackinac Bridge, coastline types most frequently encountered are mixed sand and gravel beaches, gravel beaches, fringing wetlands, sand beaches, and extensive wetlands. The NOAA ESI ranked coastline types in terms of susceptibility to oil spill. Sand and gravel beaches were considered to have mid-range susceptibility, while coastlines with wetlands were considered to have high susceptibility.

Based on MNFI's biotics data provided for this project (4), terrestrial communities that line the shoreline of the Straits and connected waters are diverse, and include Coastal Fen, Boreal Forest, Great Lakes Marsh, Open Dunes, Great Lakes Barrens, Interdunal Wetland, Limestone Cobble Shore, Northern Fen, Emergent Marsh, Poor Fen, Rich Conifer Swamp, Northern Wet Meadow, Mesic Northern Forest, Dry-mesic Northern Forest and Sand and Gravel Beach. These communities are generally protected by 'barriers' (including sand spits, shoals, sand dunes) and have a reduced potential of impact from an oil spill in the Straits. Wetlands that are directly exposed to nearshore processes have very thin bands of emergent vegetation.

The bottom substrate of the lakes is sedimentary, with nearshore habitats generally associated with clay / sand substrate.

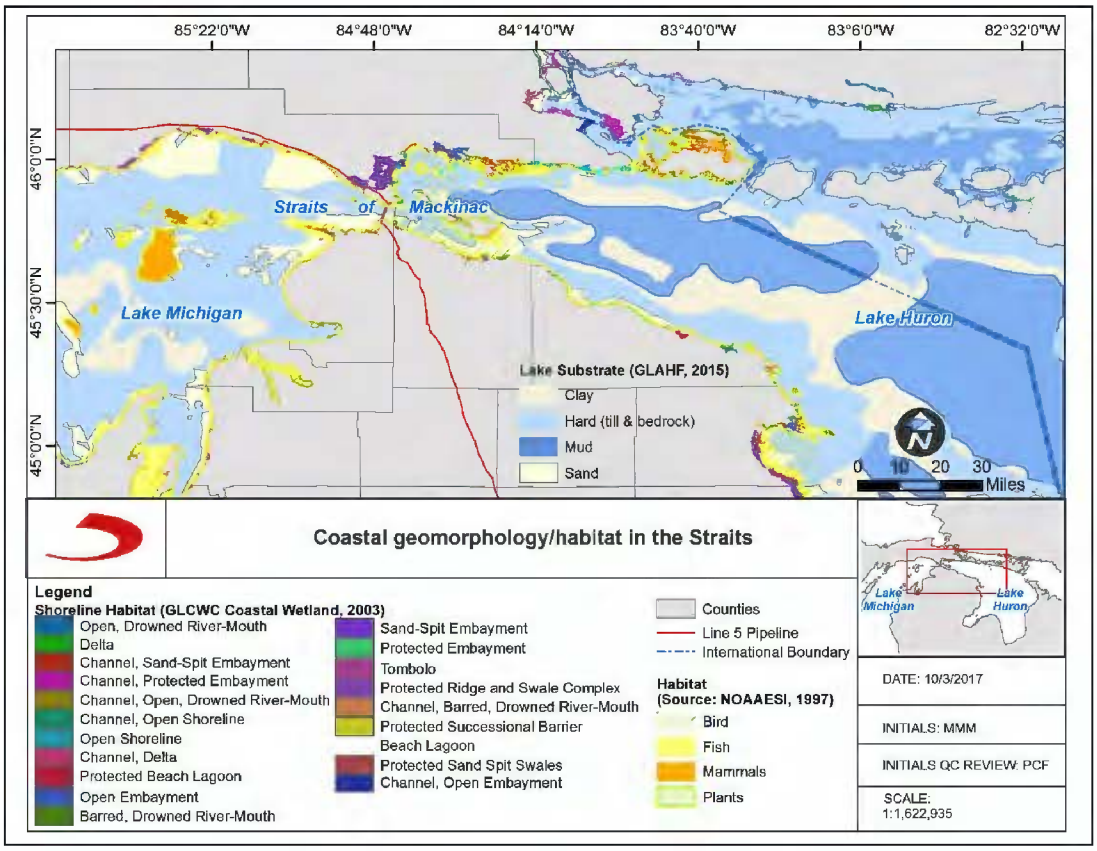


Figure 2.2 General habitat map

In the above map, the NOAA ESI habitat data layers were overlaid with more recent shoreline habitat data layers from the GLCWC 2003 Coastal Wetlands Inventory and Classification (5). The map points to the importance of both littoral and offshore areas for fish and birds. As illustrated throughout this document, these habitats support several important and/or rare plant and animal species; some of which are of conservation relevance at regional or global levels.

It is also important to establish that the ecological importance of this area led to various areas being legally designated as wildlife conservation or preserves, as shown in Figure 2.3, below.

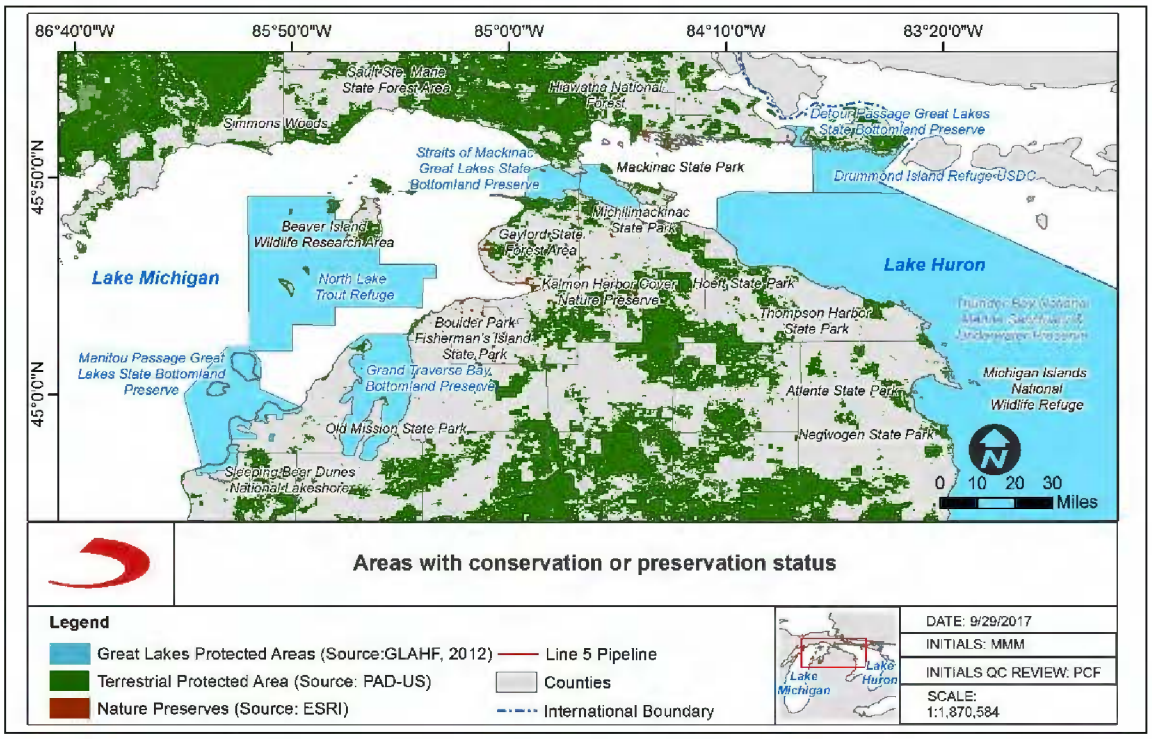


Figure 2.3 Conservation or preservation delineations in and surrounding the Straits of Mackinac

The Straits of Mackinac and its surrounding Lake Michigan and Lake Huron waters contain several terrestrial and aquatic areas of conservation or preservation status (6) (7) (8). For example, Line 5 pipeline crosses the 'Straits of Mackinac Great Lakes State Bottomland preserve'. Sault Ste. Marie State Forest Area, Hiawatha National Forest, Mackinac State Park and Wilderness State Park all have shorelines that are within the vicinity of the Straits. Several other designated areas, such as the Thunder National Marine Sanctuary and Underwater Preserve and North Lake Trout Refugee, can also be considered to be within the statistical range of oil spills that were considered.

It should also be noted that non-governmental designations have also been assigned to the Straits. For example, the National Audubon Society (Audubon) partners BirdLife International in designating Important Bird Areas (IBAs). This is further illustrated and discussed in Section 3.1.

2.1.1 Environmental Stressors

In reviewing general sources of information of the Great Lakes, it is evident that the lake ecosystem of the Straits of Mackinac and the surrounding waters are not immune to well-known environmental stressors. The lakes experience pressure from habitat fragmentation and loss from coastal developments; point and non-point pollutant / contaminant /sediment discharges from urban, industrial, and agricultural activities; and aquatic invasive species such as zebra mussels or round gobies.

Significant levels of information are publicly available on how these threats manifest themselves in various levels and areas within the Great Lakes system. While it is beyond the analysis scope of this document to fully explore their influence on baseline environmental trends of the Straits of Mackinac, publicly available information on invasive wildlife species in the Straits of Mackinac and surrounding waters have been reviewed to allow for a basic discussion on cumulative impacts related to the combination of these and oil spill stressors.

With information sourced from GLANSIS, EDDMapS, GLIN and USGS sites (9) (10) (11) (12) Figure 2.4, below, provides an indicative overview of where invasive species have been documented.

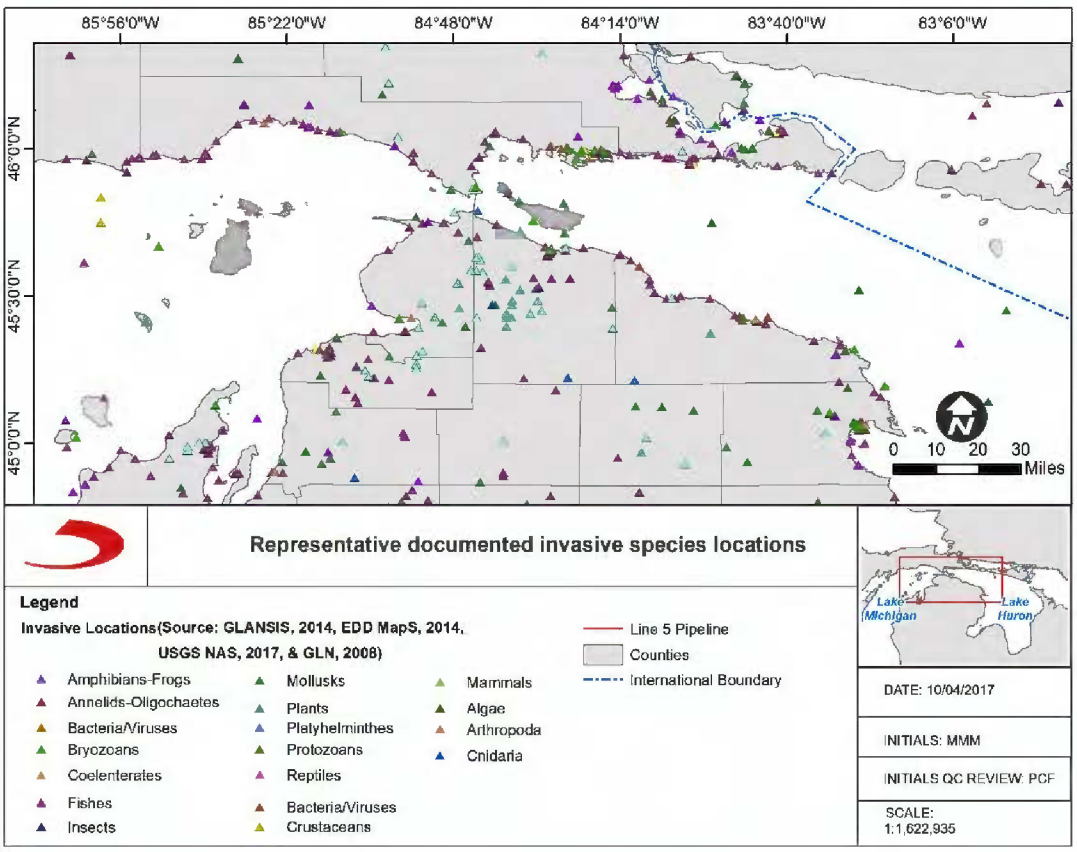


Figure 2.4 Representation of documented locations of invasive species

Both Lake Michigan and Lake Huron have 'Lakewide Action and Management Plans' (LAMPs). In Lake Michigan alone, 185 aquatic nuisance species were documented, of which many are considered invasive. These species cause significant impacts to the aquatic environment and Lake Fisheries as they aggressively compete with native species. For example, the invasive Zebra and Quagga mussels have seriously impacted fish populations as they reduced offshore availability of zooplankton by reducing their food supply (phytoplankton); and similarly reduced the abundance of "mud scuds" (amphipods) as food to juvenile fish in near-shore and offshore bottom habitat' (13).

2.2 Relevant Socio-economic Receptors

The rich natural characteristics of the Straits of Mackinac are also integral to several socio-economic / socio-cultural features of both upper and lower peninsulas of Michigan. The sub-sections that follow provide selected context relevant to socio-economic analyses through spatial illustration and/or discussion of ecologically-based designations relevant to the Tribes of Michigan and in relation to fisheries and tourism / recreational activities in the area.

2.2.1 Michigan Tribes

State and Federally recognized treaty tribes resident in Michigan and signatory to the 1836 Treaty and the related 2000 *Consent Decree* have significant access to, and authority over

the management of, the fisheries in Great Lakes areas adjacent to Michigan. For this document it is only relevant to note that Treaty waters include: the Michigan side of Lake Michigan through the Straits, into the northern part of Lake Huron, northwest up the St Mary's River into Lake Superior as far west as Baraga County; and southeast down into Lake Huron as far as the county of Alpena. Subject to certain regulations, tribal subsistence fishing is permitted in all Treaty waters which typically occur in littoral zones or in tributaries.

It is evident that treaty waters relevant to the Line 5 Alternatives Analysis will consist of the northern waters of Lake Michigan and Lake Huron.

2.2.2 Management of Commercial, Recreational and Subsistence Fisheries

The authority of the Treaty-tribes mentioned above extends to Fisheries management. In collaboration with the State of Michigan, the Chippewa Ottawa Resource Authority (CORA) manages fisheries in the Treaty waters. The State licenses and regulates non-natives and members of non-treaty tribes for commercial and recreational fishing, while CORA licenses and regulates Treaty-tribe fishers for commercial and subsistence fishing.

The Treaty waters are divided into management units (MUs). The MUs of most interest in this report are those that include the northern area of Lake Michigan into the Straits and over into the northern area of Lake Huron.

Fisheries within these areas, including whitefish, lake trout, walleye, yellow perch, chinook, and coho, are regulated for allowable gear, depth, area, season, and size. Additionally, annual harvest limits are applied to whitefish and lake trout. An indication of these areas and other important fisheries receptors, such as hatcheries, is illustrated in Figure 2.5, below.

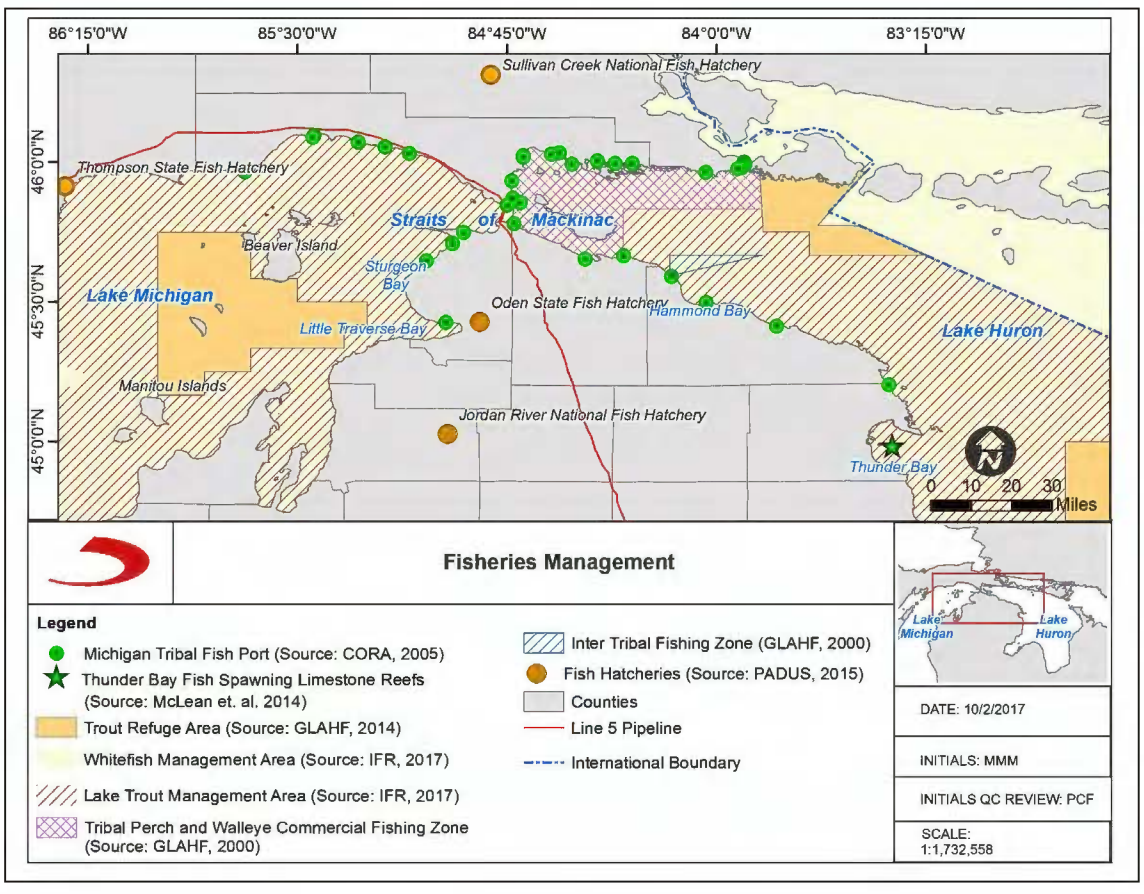


Figure 2.5 Fisheries management designations / receptors in the vicinity of the Straits of Mackinac

2.2.3 Tourism and Recreational Activities

Tourism and related recreational activities in and around the areas adjacent to the Straits are closely tied to the natural environment. They include opportunities to engage in – e.g. often in national parks - water-based recreational activities (boating, fishing, swimming), eco-tourism (camping, hiking, nature viewing), winter sports (skiing), and cultural and historical interests as shown in Figure 2.6). In recognition of the importance of these activities, local governments often develop land use plans and regulations that preserve and protect local natural, cultural and historic features.

The importance of nature is further emphasized through the State of Michigan's allocation of "ecological jewels"; as loosely illustrated in Figure 2.6, below. These "ecological jewels" include Hiawatha Dunes and Pointe Aux Chenes along the coast of Lake Michigan; Les Cheneaux region, Wilderness State Park and Grass Bay Nature Preserve along the coast of Lake Huron. These areas are managed by the State, the US Forest Service, The Nature Conservancy, and/or by private entities (14).

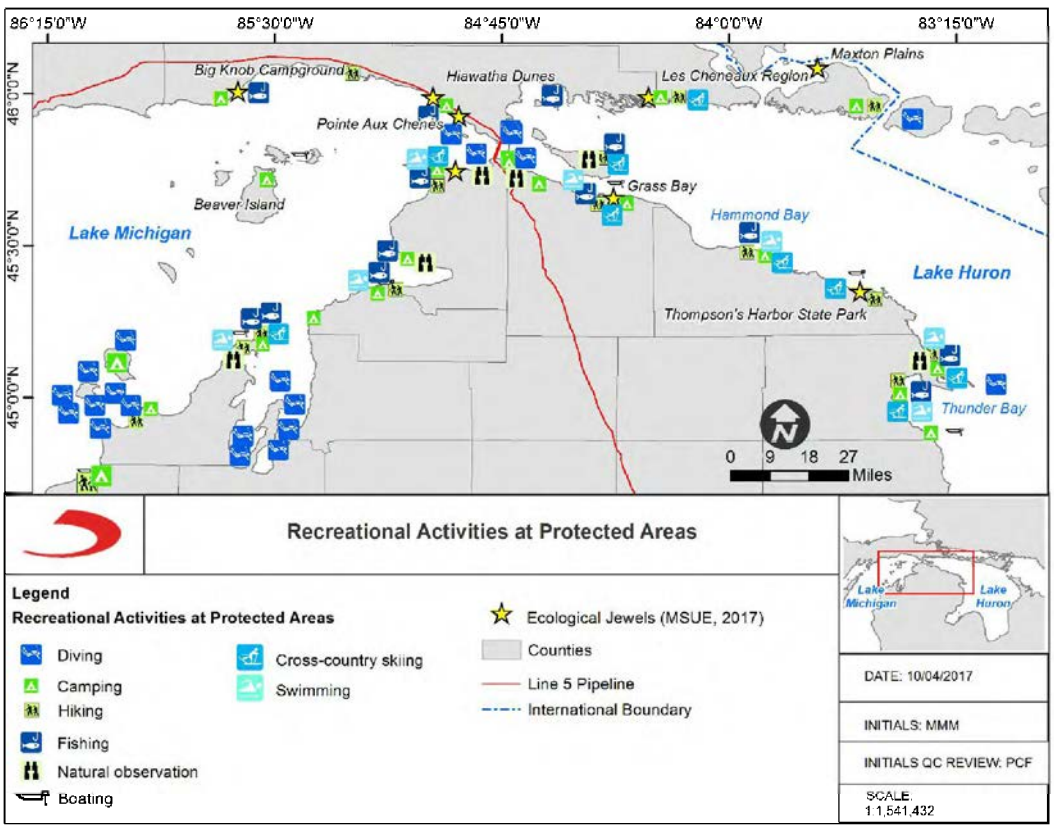


Figure 2.6 Selective tourism and recreational features

Although not a nature-based draw, a selection of important cultural and historical features within and surrounding the Straits and northern portions of Lake Michigan and Lake Huron are shown in Figure 2.7, below. The archaeological exploration site layer represents locations where ancient carvings, Stonehenge-like structures and potential ancient Caribou trails have been discovered and investigation is ongoing.

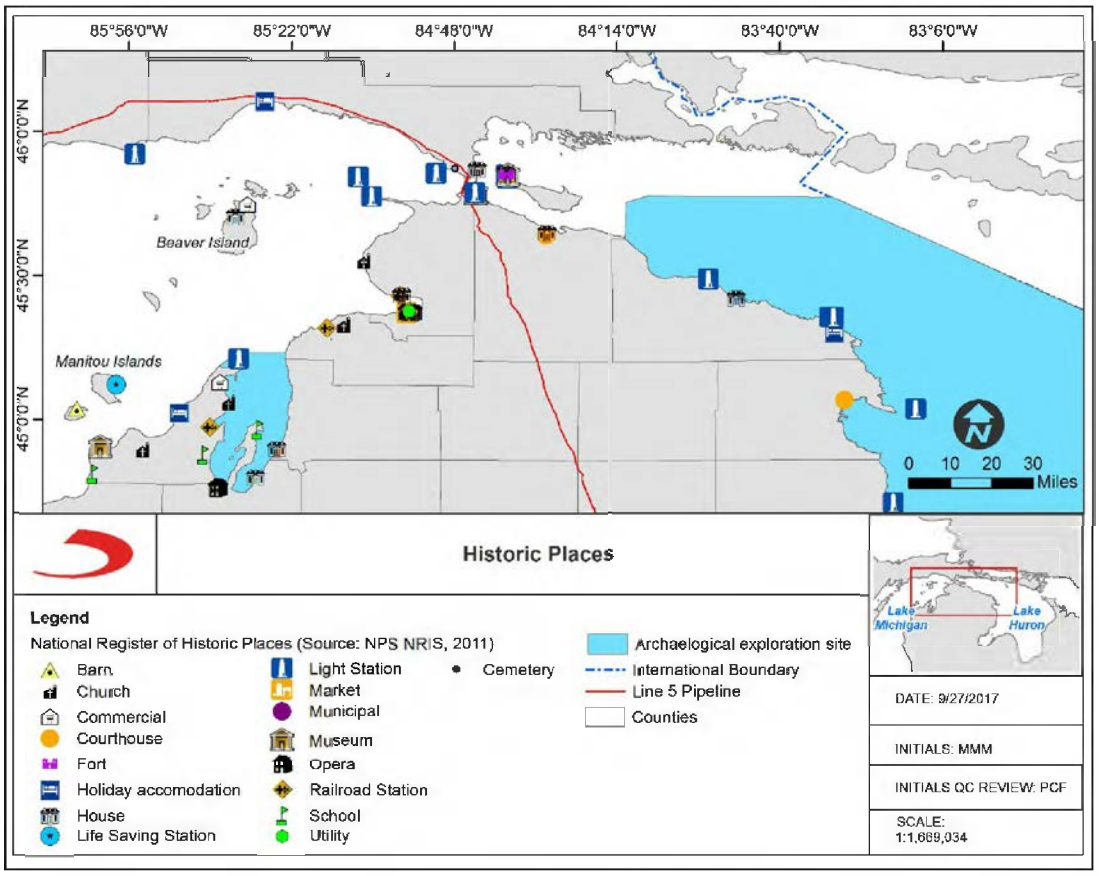


Figure 2.7 Selective historical and cultural features along the lake shore

It should be noted that many of the above mapped tourism, recreational, historic or cultural sites extend well beyond a probable Zone of Exposure (ZOE) of a Straits of Mackinac oil spill.

3 Straits of Mackinac - Biodiversity at Risk

To more thoroughly address specific risk exposure for biodiversity within the Straits of Mackinac from an oil spill from Line 5 pipeline or Alternative 4, it is necessary to better understand the baseline biodiversity within an oil spill ZOE and to further classify it in relation to its particular significance (e.g. conservation status) and oil-spill-impact pertinent life strategy characteristics.

To achieve this, a team of biologists sourced information from various online publicly available data sources, including NOAA's Environmental Sensitivity Index (ESI) metadata, data and maps for Northern Lake Michigan and Lake Huron (3). The NOAA ESI data were generated in mid 1990s and provide concise summaries of coastal lake resources at risk if an oil spill occurs in the vicinity. While the NOAA ESI information was created about three decades ago, the data were created based on aerial and ground surveys designed to help oil spill responders and planners identify vulnerable coastal locations to establish protection priorities and cleanup strategies; thereby making the data very relevant for the current study.

To complement the NOAA ESI information, reliable publicly available data were sourced to develop a good understanding and representation of the biodiversity and habitats at risk (15) (16) (17) (18) (19) (20) (21) (22). Multiple online Michigan State and Great Lakes databases were consulted, including GLAHF (6), GLANSIS (9), and GLIN (11). A dedicated dataset that was provided for use in this project, MNFI's biotics dataset (4), was also consulted.

The Michigan Natural Features Inventory website was also a key resource for understanding the vulnerability of species (23). Matrixes of species found in the Straits and neighboring waters were developed[1], and made available in this document under the categories of Birds, Fish, Herpetofauna, Mammals, and 'Other Flora and Fauna'. The data reviewed also covered species vulnerability status in terms of IUCN / CITES / Michigan / US, and aspects of their habitat or life strategy characteristic that may make them susceptible to an oil spill impact. For example, their habitats, foraging or nesting areas, seasonal or life stage presence in the Straits, and mobility. In addition, they were also assigned importance in relation to their keystone functionality to the Straits of Mackinac ecosystem and commercial relevant.

The sections below present an overview of baseline species of particular relevance of risk exposure to potential oil spill in the Straits of Mackinac. Where geospatial data is available, maps are presented to illustrate the spatial distribution of key species and habitats.

[1] This was based to a significant extent (e.g. birds, fish, and terrestrial mammals) on the NOAA ESI mid-1990s species list.

3.1 Birds

The coastal wetlands, beaches, sand dunes and remote islands in and around the Straits of Mackinac provide food and shelter for both resident and migratory birds, and serve as a key North American migratory bird flyway. The NOAA ESI mid-1990s data identifies 80 species of birds at North Lake Michigan, and 62 bird species at Lake Huron.

Table 3.1, below, provides a specific sub-list of these bird species in relation to their conservation status; particular habitats or characteristics that expose them to an oil spill (see section 5.1; e.g. waders, divers, shoreline nesting); as well as their migratory or keystone 'importance'.

As apparent, there are significant numbers of sensitive bird species that would be especially exposed to an oil spill. All of the listed species are waders, divers, and/or shoreline nesters (e.g. Great blue heron, Osprey, Herring gull, Ring-billed gull); and, as such, would be particularly vulnerable to contact with open water slicks or oil washed up in shoreline / littoral vegetation.

Table 3.1 Species Matrix – Birds

Name		Conservation Status				Habitat (Y/N)				Importance	
Common name	Species name	IUCN	CITES	MICHIGAN	US	Waders	Divers	Shoreline nesters	Requirements	Migratory	Keystone
American Bittern	*Botaurus lentiginosus*	LC	-	SC	-	Y	N	Y	Shallow wetlands	B	-
American Black Duck	*Anas rubripes*	LC	-	-	-	N	Y	Y	Coastal marshes	B	-
American Coot	*Fulica americana*	LC	-	-	-	N	Y	N	Wetland	B	Mainly feed on aquatic and terrestrial plants
American golden plover	*Pluvialis dominica*	LC	-	-	-	Y	N	Y	Shoreline	M	Affect prey population
American Wigeon	*Anas americana*	LC	-	-	-	N	Y	Y	Shoreline	B	-
American woodcock	*Philohela minor*	LC	-	-	-	Y	N	Y	Forest; open	B	Affect insect and earthworm population
Bald Eagle	*Haliaeetus leucocephalus*	LC	II	SC	D	N	Y	N	Forested coastal wetlands	R	Mainly piscivore; top predator
Belted kingfisher	*Megaceryle alcyon*	LC	-	-	-	N	Y	Y	Forested shoreline	B	Top predators in marine freshwater
Black Tern	*Chilidonias niger*	LC	-	SC	-	N	Y	Y	Vegetated shoreline	B	-
Black-crowned Night-heron	*Nycticorax nycticorax*	LC	-	SC	-	Y	N	Y	Coastline Great Lakes	B	-
Blue-winged Teal	*Anas discors*	LC	-	-	-	N	Y	Y	Wetland; marshes	B	Impact populations of aquatic invertebrates and vegetation
Bonaparte's gull	*Larus philadelphia*	LC	-	-	-	N	Y	Y	Lakes; marshes	M	-
Bufflehead	*Bucephala albeola*	LC	-	-	-	N	Y	Y	Shoreline; marshes	M	Disperse seeds
Canada Goose	*Branta canadensis*	LC	I	-	D	Y	Y	Y	Shoreline; covers	B	Important prey for many predators
Caspian Tern	*Sterna caspia*	LC	-	T	-	N	Y	Y	Open shoreline	B	-
Common goldeneye	*Bucephala clangula*	LC	-	-	-	N	Y	Y	Shoreline; shallow	B	-
Common Gull	*Larus delawarensis*	LC	-	-	-	N	Y	Y	Wet meadows	B	-
Common Loon	*Gavia immer*	LC	-	T	-	N	Y	Y	Undeveloped shoreline	B	-
Common merganser	*Mergus merganser*	LC	-	-	-	N	Y	Y	Clear lakes	B	Control fish population
Common moorhen	*Gallinula chloropus*	LC	-	T	E	N	Y	Y	Vegetated wetland	B	-
Common Snipe	*Capella gallinago*	LC	-	-	-	Y	N	Y	Sedge fens	B	-
Common Tern	*Sterna hirundo*	LC	-	T	-	N	Y	Y	Gravel shoreline	B	-
Double-crested Cormorant	*Phalacrocorax auritus*	LC	-	-	-	N	Y	Y	Open shoreline	B	-

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Name		Conservation Status				Habitat (Y/N)				Importance	
Common name	Species name	IUCN	CITES	MICHIGAN	US	Waders	Divers	Shoreline nesters	Requirements	Migratory	Keystone
Dunlin	*Calidris alpina*	LC	-	-	-	Y	N	Y	Wetland; mudflat	M	-
Eurasian teal	*Anas crecca*	LC	-	-	-	N	Y	Y	Wetland; vegetated	B	-
Forster's tern	*Sterna forsteri*	LC	-	E	-	N	Y	N	Wetland ; marshes	M	Significant predator and prey
Gadwall	*Anas strepera*	LC	-	-	-	N	Y	Y	Wetland; vegetated	B	-
Gray Duck	*Aythya valisineria*	LC	-	-	-	N	Y	Y	Large lakes	M	Canvasbacks form large foraging groups in the non-breeding season, these large numbers of animals feeding on aquatic plants and animals can have a substantial effect on local aquatic ecosystems.
Great Blue Heron	*Ardea herodias*	LC	-	-	-	Y	N	Y	Shoreline trees	B	Control insect and fish prey population
Greater scaup	*Aythya marila*	LC	-	-	-	N	Y	Y	Coastal; shallow	M	-
Greater Yellowlegs	*Tringa melanaleuca*	LC	-	-	-	Y	N	N	Shoreline; marsh	M	-
Grey plover	*Pluvialis squatarola*	LC	-	-	-	Y	N	Y	Mudflat; beach	M	-
Herring Gull	*Larus argentatus*	LC	-	-	-	N	Y	Y	Open shoreline	B	-
Hooded merganser	*Lophodytes cucullatus*	LC	-	-	-	N	Y	Y	Forested waterways	B	-
Horned Grebe	*Podiceps auritus*	V	-	-	-	N	Y	N	Not relevant	R	-
Killdeer	*Charadrius vociferus*	LC	-	-	-	Y	N	Y	Dry, open beach	B	Major insectivorous
King Rail	*Rallus elegans*	NT	-	E	-	Y	N	Y	Vegetated; marshes	B	-
Least bittern	*Ixobrychus exilis*	LC	-	T	-	Y	N	Y	Marshes	B	-
Least Sandpiper	*Calidris pusilla*	NT	-	-	-	Y	N	Y	Wet meadows	B	Highly insectivorous and eats other invertebrates
Least sandpiper	*Calidris minutilla*	LC	-	-	-	Y	N	Y	Shoreline; mudflat; beach	M	-
Lesser scaup	*Aythya affinis*	LC	-	-	-	N	Y	N	Vegetated wetland	M	-
Lesser Yellowlegs	*Tringa flavipes*	LC	-	-	-	Y	N	Y	Grassy meadows	B	-
Long-tailed duck	*Clangula hyemalis*	V	-	-	-	N	Y	N	Inland lakes	M	Significant predator and prey
Mallard	*Anas platyrhynchos*	LC	-	-	-	N	Y	Y	Wetland	B	-
Mute swan	*Cygnus olor*	LC	-	-	-	N	Y	Y	Vegetated wetland	R	-

Name		Conservation Status				Habitat (Y/N)				Importance	
Common name	Species name	IUCN	CITES	MICHIGAN	US	Waders	Divers	Shoreline nesters	Requirements	Migratory	Keystone
Northern Harrier	*Circus cyaneus*	LC	II	SC	-	N	N	Y	Undisturbed wetlands; prairies	B	Carnivorous primarily on mammals
Northern pintail	*Anas acuta*	LC	-	-	-	N	Y	Y	Vegetated wetland	B	-
Northern shoveler	*Anas clypeata*	LC	-	-	-	N	Y	N	Shallow wetland	M	-
Pectoral sandpiper	*Calidris melanotos*	LC	-	-	-	Y	N	Y	Wetland; mudflat	M	-
Peregrine falcon	*Falco peregrinus*	LC	I	E	-	N	Y	N	Wetland	M	Top predator of other birds
Pied-billed Grebe	*Podilymbus podiceps*	LC	-	-	-	N	Y	Y	Vegetated marshland	B	-
Piping Plover	*Charadrius melodus*	NT	-	E	ET	Y	N	Y	Interdunal wetlands	B	-
Red-breasted merganser	*Mergus serrator*	LC	-	-	-	N	Y	Y	Wooded shorelines	B	Highly piscivorous
Redhead	*Aythya americana*	LC	II	-	-	N	Y	N	Lakes; marshes.	M	-
Red-necked grebe	*Podiceps Grisegena*	LC	-	-	-	N	Y	Y	Wetland; lakes	M	Control fish population
Ring-billed gull	*Larus delawarensis*	LC	-	-	-	N	N	Y	Associated with water	R	-
Ring-necked duck	*Aythya collaris*	LC	-	-	-	N	Y	Y	Wetland; marshes.	B	-
Ruddy duck	*Oxyura jamaicensis*	LC	-	-	-	N	Y	Y	Wetland; marshes	M	-
Ruddy Turnstone	*Arenaria interpres*	LC	-	-	-	Y	N	Y	Rocky shoreline	B	Highly insectivorous and eats other invertebrates
Sanderling	*Calidris alba*	LC	-	-	-	Y	N	Y	Lakes	M	-
Sandhill crane	*Grus canadensis*	LC	I & II	-	E	Y	N	Y	Wetland; marshes	B	Affect prey population
Semipalmated plover	*Charadrius semipalmatus*	LC	-	-	-	Y	N	Y	Shoreline; lakes	M	Control insect population
Snow goose	*Chen caerulescens*	LC	-	-	-	Y	Y	Y	Wetland; marshes	M	Affect population of habitat vegetation
Solitary sandpiper	*Tringa solitaria*	LC	-	-	-	Y	N	Y	Vegetated wetland	M	-
Sora	*Porzana carolina*	LC	-	-	-	Y	N	N	Wetland; vegetated	B	-
Spotted Sandpiper	*Actitis macularius*	LC	-	-	-	Y	N	Y	Grassy meadows	B	-
Surf scoter	*Melanitta perspicillata*	LC	-	-	-	N	Y	Y	Wetland; littoral	M	-
Tundra swan	*Olor columbianus*	LC	-	-	-	N	Y	Y	Wetland; shores	M	-
Virginia Rail	*Rallus limicola*	LC	-	-	-	Y	N	N	Wetland; vegetated	B	-
Western Cattle Egret	*Bubulcus ibis*	LC	-	-	-	Y	N	Y	Wetlands	B	-

Name		Conservation Status				Habitat (Y/N)				Importance	
Common name	Species name	IUCN	CITES	MICHIGAN	US	Waders	Divers	Shoreline nesters	Requirements	Migratory	Keystone
Western Osprey	*Pandion haliaetus*	LC	II	SC	-	N	Y	Y	Forested wetlands	B	Bio-indicator for aquatic ecosystem
White-winged scoter	*Melanitta deglandi*	LC	-	-	-	N	Y	Y	Wetland; shallow	M	-
Wood duck	*Aix sponsa*	LC	-	-	-	N	Y	Y	Wetland; vegetated	B	-
Yellow rail	*Coturnicops noveboracensis*	LC	-	T	-	Y	N	Y	Wetland; marshes	B	-

Legend

Conservation Status			Migratory	
IUCN	LC	Least Concern	R	Resident
	V	Vulnerable	B	Breeding migration
	NT	Near Threatened	M	Migratory route
CITES	-	Not listed		
	I	Appendix I		
	II	Appendix II		
MICHIGAN	-	Not listed		
	SC	Special Concern		
	T	Threatened		
	E	Endangered		
US	-	Not listed		
	D	Delisted due to recovery		
	E	Endangered		
	ET	Endangered & Threatened		

Several of the listed birds have elevated levels of international, federal or state conservation status. Among these, include:

- Common Loon
- Horned Grebe
- Black Tern
- Sandhill crane
- Caspian Tern
- Least Sandpiper
- Common Tern
- Canada Goose
- Bald Eagle
- Redhead
- Long-tailed duck
- Northern Harrier
- Western Osprey
- Sandhill crane
- Piping Plover
- American Bittern
- Black-crowned Night-heron
- King Rail
- Common moorhen
- Forster's tern
- Peregrine falcon
- Least bittern
- Yellow rail
- Black-crowned Night-heron

Based on the MNFI biotics dataset provided for the project, the bald eagle, which has both global and state conservation status, was documented in at least 12 locations along the coastline of the Straits and surrounding waters. Also documented in the same area were the Piping plover, Caspian tern and Peregrine falcon, with estimates of fair to poor population viability.

Additional insight into the risk exposure to birds in an oil spill ZOE can be derived from publicly available data on bird sightings, nesting areas and habitat, i.e. see Figure 3.1.

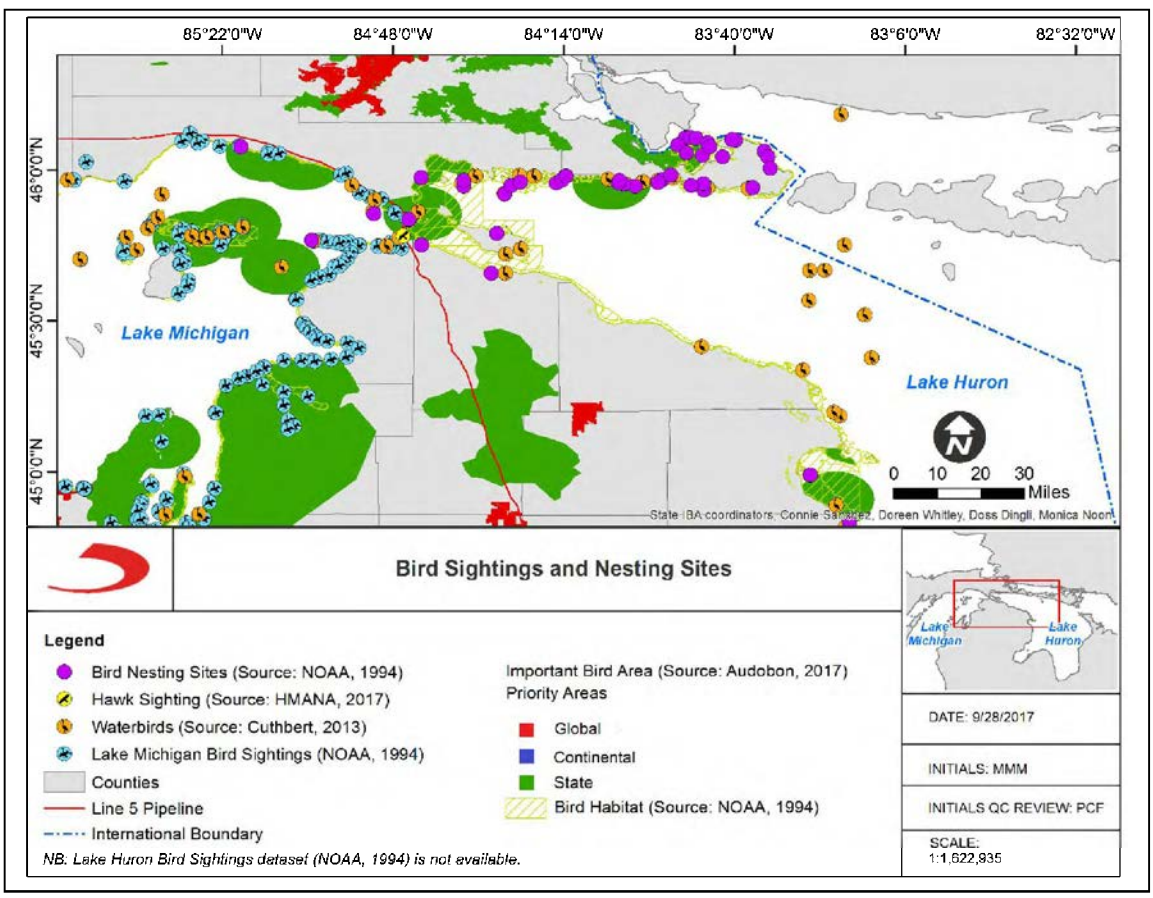


Figure 3.1 Bird species presence in the Straits of Mackinac

The above map illustrates the close proximity of particularly sensitive bird species (e.g. water birds, bird nesting sites) and habitat in and surrounding the Straits. The map also highlights the fore-mentioned Important Bird Areas (IBAs) designated by the National Audubon Society (NAS) (24). The IBAs were designated by NAS in partnership with BirdLife International, using standardized scientific criteria applied globally, and represents a collaborative effort of

the state, national, NGOs, academics and birders. Five state-level IBAs can be found in and within vicinity of the Straits, including Mackinac Straits Hawk Watch (which include the waters where the Line 5 pipeline is situated), as well as Sand Products and Epoufette Island shoal, Beaver Islands Colonial Waterbirds IBA, Mackinac Straits to St. Martin's Bay, Helmet Shoal and Saddlebag Island. There are Global-level IBAs representing sites important for globally rare species further inland on both sides of the Straits.

Combined, the presented baseline biodiversity and its distribution information provide abundant evidence that the Straits of Mackinac represent a very important bird area and therefore meets the definition of a High Consequence Area (HCA).

3.2 Fish

Based on the NOAA ESI mid-1990s data, 31 fish sensitive species could be found in Lake Michigan, and 32 fish species in Lake Huron. The fish are from various Trout, Minnow, Bass, Carp and Salmon families. Many of the fish in Lake Huron and Lake Michigan are species that migrate up the rivers to spawn. There are also, however, many important fish spawning locations within the Straits, Lake Huron and Lake Michigan.

Table 3.2, below, provides a specific list of these fish species in relation to their conservation and commercial status; as well as particular habitat preferences in one of the statistically derived oil spill 'Zone of Exposures' (ZOE).

Table 3.2 Species matrix - Fish

Name		Conservation Status				Commercial Value			Spawning		Habitat	Importance	
Common name	Species name	IUCN	CITES	MICHIGAN	US	Fisheries	Aquaculture	Gamefish	Pelagic	Littoral	Requirement	Migratory	Keystone
Alewife	*Alosa pseudoharengus*	LC	-	-	-	/	-	-	-	/	Shallow beaches	RB	-
American Burbot	*Lota lota*	LC	-	-	-	-	-	/	-	/	Deep cold lakes	RB	Keystone predator
Atlantic Salmon	*Salmo salar*	LC	-	-	E	-	-	-	-	-	Rocky	M	-
Black Crappie	*Pomoxis nigromaculatus*	LC	-	-	-	-	-	/	-	/	Warm; clear	R	-
Bluegill Sunfish	*Lepomis macrochirus*	LC	-	-	-	-	-	/	-	/	Shallow; aquatic vegetation	R	Important prey and impact insect populations
Brook Trout	*Salvelinus fontinalis*	-	-	-	-	-	-	/	-	/	Clear lakes	RB	Strong negative effects on tertiary consumers
Brown Trout	*Salmo trutta*	LC	-	-	-	-	/	/	-	-	Littoral; benthic	R	Strong negative effects on tertiary consumers
Bullhead	*Ictaluras melas*	LC	-	-	-	-	-	-	/	-	Benthic; vegetated	RB	Important demersal predator in high turbid areas
Channel Catfish	*Ictalurus punctatus*	LC	-	-	-	/	-	/	-	/	Benthic	RB	-
Cisco	*Coregonus artedii*	LC	-	T	-	/	-	/	-	/	Pelagic	RB	-
Coho Salmon	*Oncorhynchus kisutch*	-	-	-	ET	/	/	/	-	-	Shoreline; pelagic	R	-
Common Carp	*Cyprinus carpio*	V	-	-	-	/	-	/	/	/	Vegetated	RB	May contribute to algal bloom
King Salmon/Chinook Salmon	*Oncorhynchus tshawytscha*	-	-	-	ET	/	-	/	-	-	Pelagic	R	Control non-native fish species such as Alewife.
Lake Sturgeon	*Acipenser fulvescens*	LC	II	T	-	-	-	-	-	/	Clear; littoral	RB	Maintain population of smaller vertebrates & invertebrates
Lake Trout	*Salvelinus namaycush*	-	-	-	-	/	-	/	-	/	Mid-water	RB	Keystone predator
Lake Whitefish	*Coregonus clupeaformis*	-	-	-	-	/	-	/	-	/	Cold; benthic	RB	-
Largemouth Bass	*Micropterus salmoides*	LC	-	-	-	-	-	/	-	/	Vegetated; shallow	RB	Top predator

Name		Conservation Status				Commercial Value			Spawning		Habitat	Importance	
Common name	Species name	IUCN	CITES	MICHIGAN	US	Fisheries	Aquaculture	Gamefish	Pelagic	Littoral	Requirement	Migratory	Keystone
Longnose Sucker	*Catostomus catostomus*	LC	-	-	SU	/	-	/	-	/	Cold; benthic	RB	-
Muskellunge	*Esox masquinongy*	LC	-	-	-	-	-	/	-	/	Benthopelagic	RB	Top predator
Northern Pike	*Esox lucius*	LC	-	-	-	-	-	/	-	/	Shoreline; vegetated	RB	Keystone piscivore
Pink Salmon	*Oncorhynchus gorbuscha*	-	-	-	-	/	-	/	-	-	Benthopelagic	R	-
Pumpkinseed	*Lepomis gibbosus*	LC	-	-	-	-	-	/	-	/	Vegetated; limnetic	RB	-
Rainbow Smelt	*Osmerus mordax*	LC	-	-	-	/	-	-	-	-	Benthopelagic	R	-
Rainbow Trout	*Oncorhynchus mykiss*	-	-	-	ET	-	/	/	-	-	Benthopelagic	R	Important predator and prey
Rock Bass	*Ambloplites rupestris*	LC	-	-	-	/	-	/	-	/	Littoral	RB	Maintains population of crayfish
Round Whitefish	*Prosopium cylindraceum*	-	-	-	-	/	-	-	-	/	Benthopelagic	RB	-
Smallmouth Bass	*Micropterus dolomieu*	LC	-	-	-	-	-	/	-	/	Clear; shoreline	RB	Top predator
Spottail Shiner	*Notropis hudsonius*	LC	-	-	-	-	-	-	-	/	Shoreline; gravel	RB	-
Walleye	*Stizostedion vitreum vitreum*	LC	-	-	-	/	-	/	-	/	Rocky shoreline; benthopelagic	RB	-
White Bass	*Morone chrysops*	LC	-	-	-	-	-	/	-	/	Benthopelagic	RB	Important intermediate predators
White Sucker	*Catostomus commersoni*	LC	-	-	-	/	-	/	-	/	Benthopelagic	RB	-
Yellow Perch	*Perca flavescens*	LC	-	-	-	/	-	/	-	/	Benthopelagic	RB	-

Legend

Conservation Status			Migratory	
IUCN	LC	Least Concern	R	Resident
	V	Vulnerable	B	Breeding migration
CITES	-	Not listed	M	Migratory route
	II	Appendix II		
MICHIGAN	-	Not listed		
	T	Threatened		
US	-	Not listed		
	SU	Status Undefined		
	ET	Endangered & Threatened		

As evident, there is a significant list of fish species that have some level of international, state or national conservation status (endangered or threatened), or have features that makes them susceptible to oil spills. With regards to the latter, Lake Trout and Yellow Perch provide good examples of the level of risk exposure to important species. Lake Trout spawn in shallow water and offshore reef habitats, which include important spawning locations to the west, east and in the direct vicinity of Mackinac Straits. Yellow Perch spawn in near-shore rocky areas, forage in offshore regions as fish fry, and later return to near-shore bottom habitats. Thus, these species are exposed to littoral zones that are of oil spill risk in two stages of their life history (25).

To illustrate exposure of fish species and fish spawning locations from potential of oil spill in the Straits, information has been compiled from various data sources, including NOAA ESI and GLAHF. This is illustrated in Figure 3.2, below.

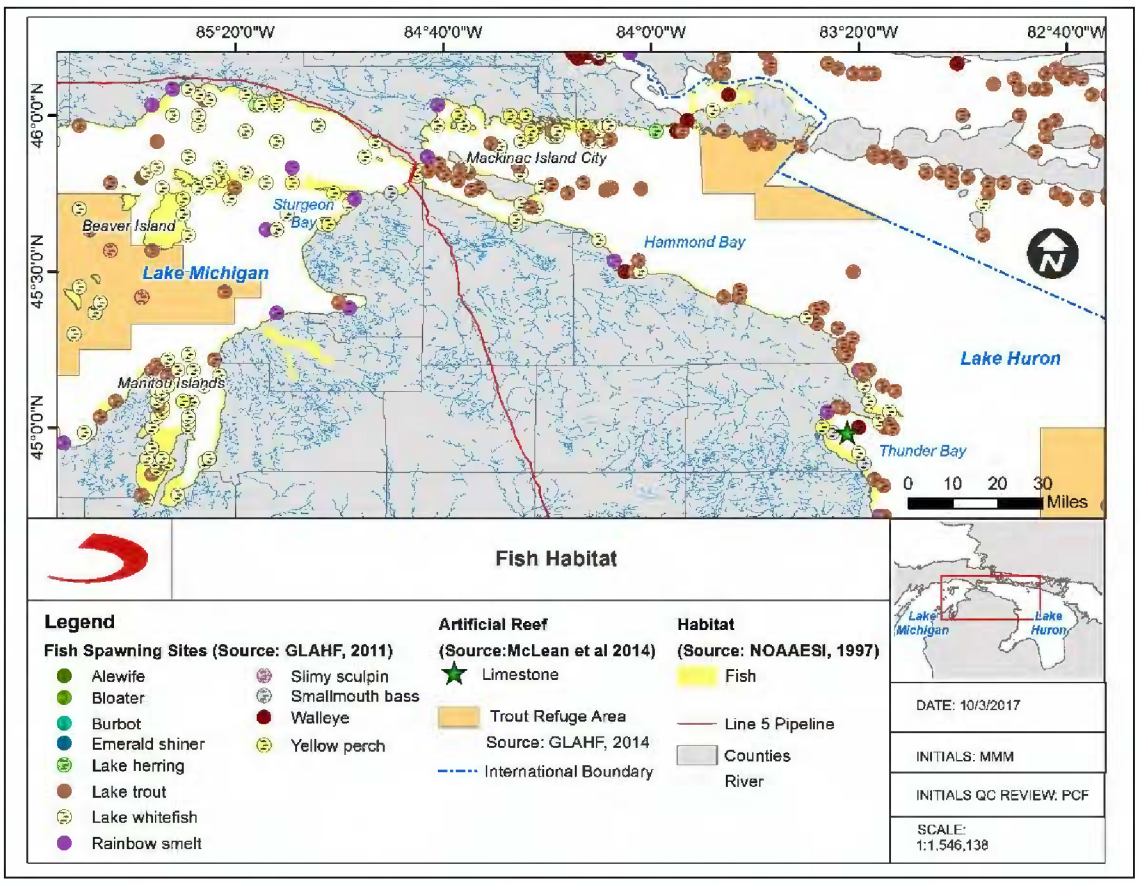


Figure 3.2 Fish species / habitat in the Straits of Mackinac and surrounding waters

The map above illustrates that the Line 5 pipeline is in direct or close proximity of sensitive fish spawning areas within the Straits that are pertinent for, among others, Rainbow Smelt, Lake Trout, Lake Whitefish, and Burbot.

The combined fish biodiversity baseline information provides ample evidence that the Straits of Mackinac and surrounding areas are ecologically significant for fish populations in Lake Michigan and Lake Huron. As such, the entire area also meets the definition of a 'High Consequence Area'.

3.3 Herpetofauna

Based on a 2016 publication on geographic distributions of Michigan Herpetofauna (26), at least 21 of 55 Michigan's known species of reptiles and amphibians have been documented within counties and islands within vicinity of the Straits. Of these, the Eastern Massasauga rattlesnake, primarily associated with wetland habitats, has global and state conservation status. The same species, documented in MNFI's biotics dataset provided for this project, is stated to have excellent viability in the coastal habitats of the Straits and surrounding waters.

Based on iNaturalist research-grade sighting data (27), Blanding's turtle have been sighted in year 2005 near St. Ignace city. Other turtles documented include eastern snapping turtles, painted turtles (26). Research found that these turtles tended to be found at drowned river mouth wetlands, as well as areas with submersed aquatic vegetation (28).

Other reptiles found in the area include snakes such as the eastern milk snake; and salamanders such as the eastern red-backed salamander and spotted salamander.

Table 3.3, below, lists a subset of Herpetofauna that would or could inhabit one of the statistically derived oil spill ZOE. No map is produced for this section as there was insufficient publicly available geospatial information.

Table 3.3 Species Matrix - Herpetofauna

Name		Conservation Status				Requirement		Importance
Common name	Species name	IUCN	CITES	MICHIGAN	US	Area	Spawn	Keystone
Blanding's turtle	*Emydoidea blandingii*	E	II	SC	UR	B	Aquatic vegetation; near the surface	-
Cope's Gray Treefrog	*Hyla chrysocelis*	LC	-	-	-	B	Pelagic; herbaceous ephemeral pond	-
Eastern American Toad	*Anaxyrus americanus*	LC	-	-	-	B	Temporary waters	-
Eastern Massasauga Rattlesnake	*Sistrurus catenatus catenatus*	LC	-	SC	T	B	Wetland; woody	-
Eastern Red-backed Salamander	*Plethodon cinereus*	LC	-	-	-	B	Coastal woodland; no need for water to reproduce	Keystone predator
Fowler's toad	*Anaxyrus fowleri*	LC	-	SC	-	M	Dunes	-
Gray Treefrog	*Hyla versicolor*	LC	-	-	-	B	Wooded areas near temporary and permanent waters	
Painted Turtle	*Chrysemys picta*	LC	-	-	-	B	Sunny sandy spots	
Pickerel frog	*Lithobates palustris*	LC	-	SC	-	B	Dunes; Shoreline	-
Spotted Salamander	*Ambystoma maculatum*	LC	-	-	-	B	Near pond	Keystone predator

Legend

Conservation Status			Area	
IUCN	LC	Least Concern	B	Both Lake Huron and Lake Michigan
	E	Endangered	M	Lake Michigan
CITES	-	Not listed		
	II	Appendix II		
MICHIGAN	-	Not listed		
	SC	Special concern		
US	-	Not listed		
	T	Threatened		
	UR	Under Review		

3.4 Mammals

Based on NOAA ESI's data, the selection of mammals that live along the coastlines of the Straits and could be exposed to an oil spill in the Straits include river otter, beaver, muskrat, mink and northern raccoon. Figure 3.3, below, illustrates the NOAA ESI delineation of habitat where populations of these animals could be exposed. This includes, for example, Bois Blanc Island and around De Tour village - both well inside a potential ZOE.

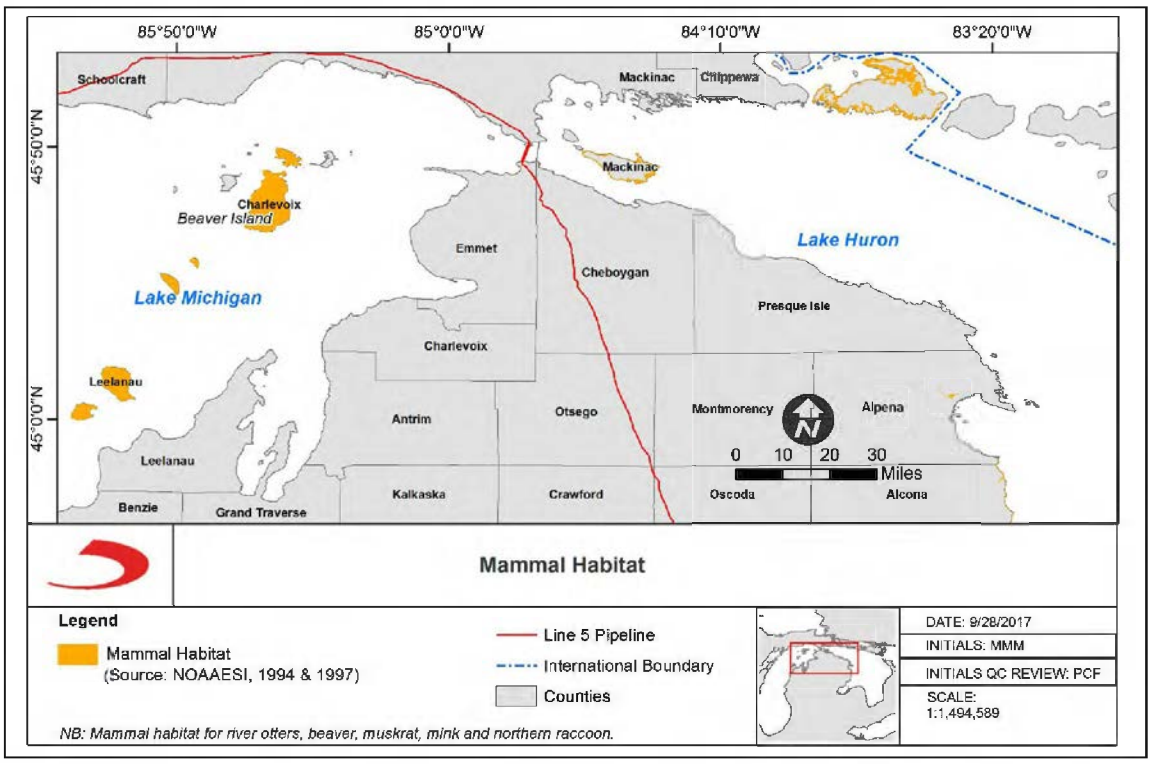


Figure 3.3 Terrestrial mammal habitat

The biodiversity classification exercise generated additional conservational relevance and habitat information on the above-mentioned relevant mammals that inhabit the statistically derived oil spill extent. As apparent, they all occupy littoral or coastal areas for foraging, breeding and brooding purposes.

In addition to those listed in the NOAA ESI list, it should also be noted the MNFI's biotics data provided for the project indicates that the northern long-eared bat, which has global and state conservation status, is also found at the coastal habitats of the Straits and islands.

Table 3.4 Species Matrix - Mammals

Name		Conservation Status				Habitat			Importance
Common name	Species name	IUCN	CITES	MICHIGAN	US	Forage	Breed	Brood	Keystone
American mink	*Mustela vison*	LC	-	-	-	Littoral	Littoral	Littoral	Important predators of small mammals
Muskrat	*Ondatra zibethicus*	LC	-	-	-	Littoral	Coast	Coast; Littoral	Important prey and predator
North American Beaver	*Castor canadensis*	LC	-	-	-	Littoral	Littoral	Littoral	Alter abundance of plants and animals
North American River Otter	*Lutra canadensis*	LC	II	-	-	Littoral	Coast; Littoral	Coast; Littoral	Maintains ecological health of area
Raccoon	*Procyon lotor*	LC	-	-	-	Littoral	Coast	Coast	Impact prey population

Legend

Conservation Status		
IUCN	LC	Least Concern
CITES	-	Not listed
	II	Appendix II
MICHIGAN	-	Not listed
	SC	Special Concern
US	-	Not listed
	T	Threatened

3.5 Other Flora and Fauna

Larger or 'flagship' species are often the focus of oil spill impact analyses or research, but oil spill consequences to other lake flora and fauna can also lead to detrimental impacts to individual species with ecosystem wide consequences. The subsections that follow, therefore, provide baseline information on invertebrates and aquatic plants.

3.5.1 Plants

A Straits of Mackinac a Line 5 oil spill would expose various shoreline, littoral, floating and submerged vegetation; including phytoplankton, to contact with oils. No attempt has been made in this baseline to establish all known aquatic species in this area, but Figure 3.4 does provide a general overview of the distribution of prevalent aquatic plants and communities.

For example, Typha (cattails), Schoenoplectus (bulrush) and kelp beds are shown to be distributed throughout varying shorelines. The distribution of conservationally relevant plant species discussed later in this sub-section is also illustrated.

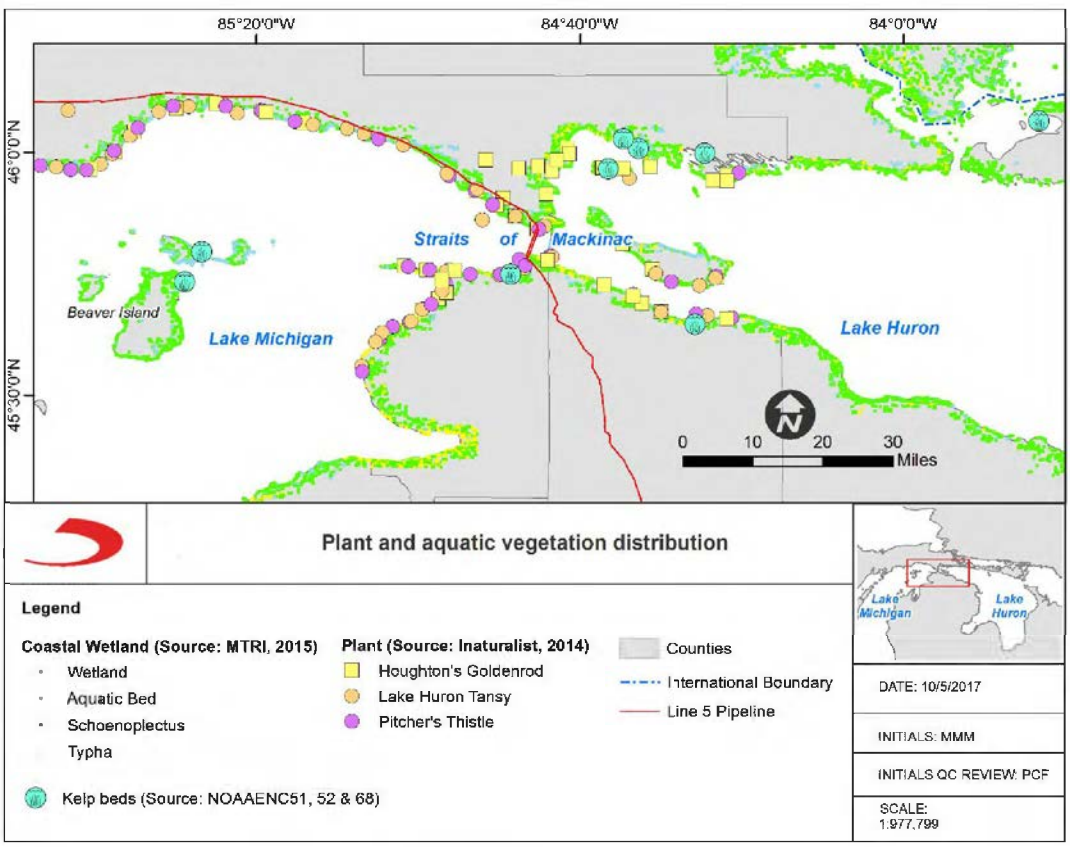


Figure 3.4 Plant and aquatic vegetation distribution

Research by Michigan Tech Research Institute (MTRI) provides further evidence of aquatic plants (29). They show, based on satellite-derived data (see Figure 3.5), that submerged aquatic vegetation (SAV) in the nearshore areas is dominated by Cladophora, which grows attached to solid substrates.



Figure 3.5 MTRI's satellite-derived Submerged Aquatic Vegetation (SAV) classification map

In terms of conservational relevance, Lake Huron tansy (*Tanacetum huronense*) and Pitcher's thistle (*Cirsium pitcheri*), both state and federally protected species, are known to occur amongst the dune systems of north Lake Michigan and Lake Huron, including the islands and nature preserves, e.g. Petritz Nature Preserve. Pitcher's thistle is relatively common along the north shores of Lake Michigan and scattered along north Lake Huron (30).

Table 3.5 Species Matrix - Aquatic Vegetation

Name		Conservation Status				Requirement	Importance
Common name	Species name	IUCN	CITES	MICHIGAN	US	Habitat / Range	Keystone
Houghton's Goldenrod	*Solidago houghtonii*	NT	-	T	LT	Calcerous/cobbly Beach; Shallow inter-dunal wetlands.	-
Lake Huron Tansy	*Tanacetum bipinnatum ssp. huronense*	-	-	T	-	Calcareous established dunes; Sandy beach	-
Pitcher's Thistle	*Cirsium pitcheri*	-	-	T	LT	Great Lakes endemic; Entire shoreline in Lake Michigan; Limited dunes in Lake Huron.	Vital in plant-insect dune ecosystem

Legend

Conservation Status		
IUCN	NT	Near Threatened
CITES	-	Not listed
MICHIGAN	T	Threatened
US	-	Not listed
	LT	Listed Threatened

3.5.2 Invertebrates

3.5.2.1 Insects

Insects in the ZOE include a wide variety of bees, hornets, wasps, butterflies, moths, beetles, flies, dragonflies, damselflies, spiders, mites, that provide abundant food for birds, fish, herpetofauna, mammals, and other invertebrates.

Based on the MNFI biotics dataset and iNaturalist dataset provided / gathered by the project team, conservationally important insects documented along the coastlines of the Straits and the northern waters of Lake Michigan and Lake Huron include the Hine's emerald dragonfly, Lake Huron locust and Leafhopper. These invertebrate species have global and state conservation status, and the Hine's emerald dragonfly is recorded to have fair to poor viability. Figure 3.6 shows the distribution of the fore-mentioned insects and other insects sighted in recent years, and documented in iNaturalist research-grade data.

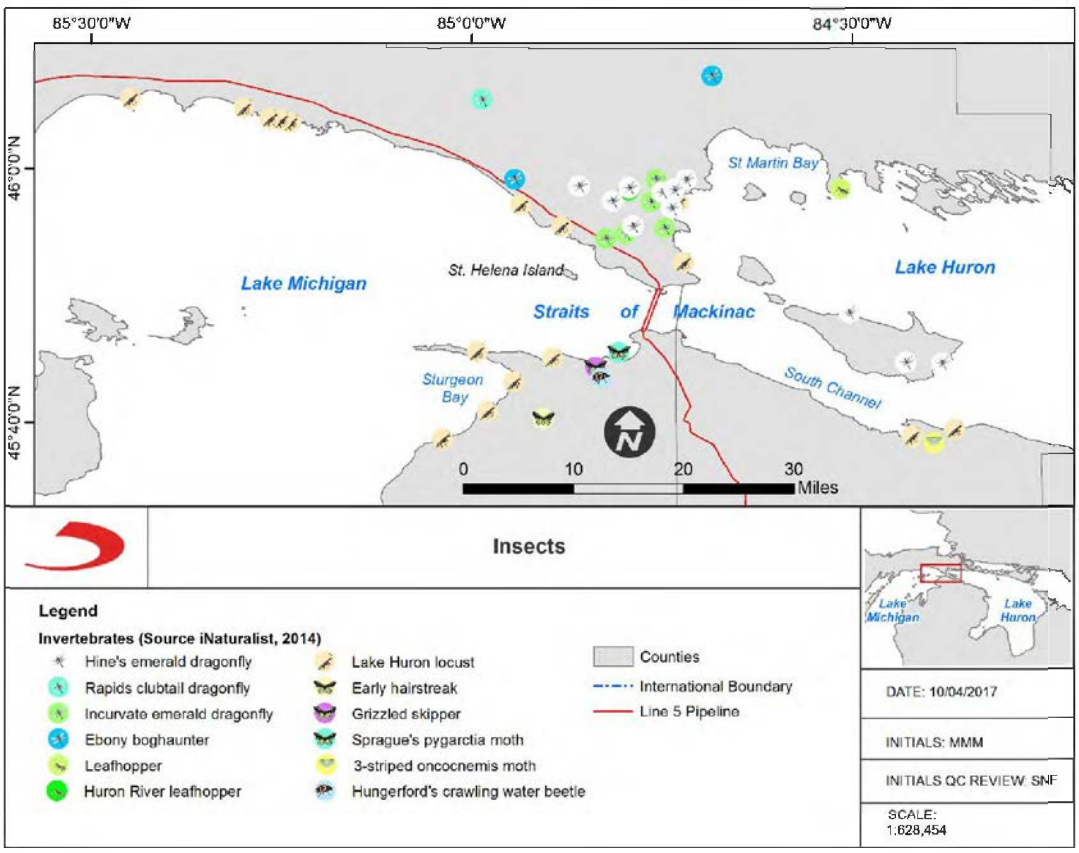


Figure 3.6 General insect distribution

The importance of invertebrates in wetlands in maintaining healthy fisheries have long been recognised. Recent research show that midges in nearshore habitats provide important early season food resource, and thus high quality stopover habitat, for migrating birds, e.g. American Redstarts (*Setophaga ruticilla*) and Black-throated Green Warblers (*Dendroica virens*). Midges may also be an important food source for foraging fish, and even more so with the decline of Diaporeia from the Lakes (31).

3.5.2.2 Benthic Invertebrates

In the shallower areas, sediments provide surfaces for substrate-associated micro-invertebrates. Diporeia, also known as amphipods, scuds, side swimmers, beach hoppers, and sand fleas, is a keystone group of invertebrates that live in the muddy lake bottom. Their viability, however, has plunged with aggressive competition of invasive species. The larval state of the midge fly, often referred to as a bloodworm, live in the lake bottom and are vulnerable to fish predators when they venture up the water column. Figure 3.7 shows the distribution of benthic species documented in GLAHF and EPA databases.

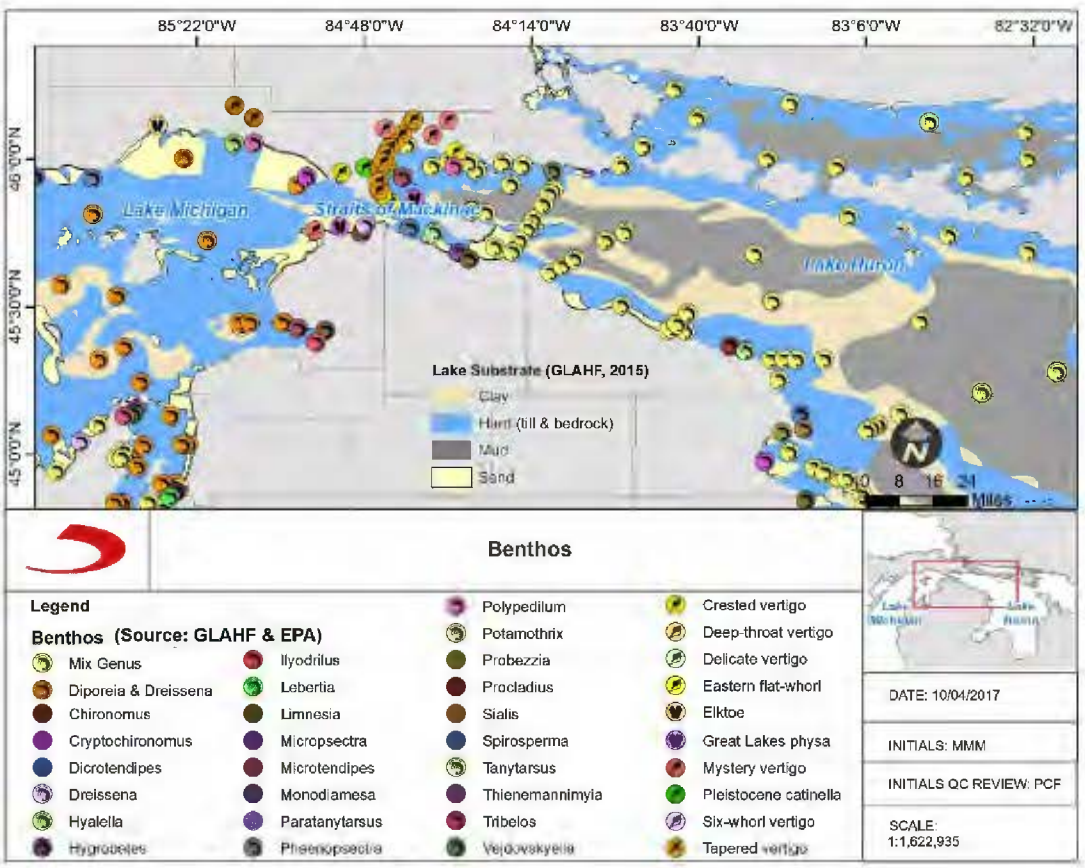


Figure 3.7 Benthic community

3.5.2.3 Plankton

In open water areas, microscopic planktonic organisms, including both plant (phytoplankton) and animal (zooplankton) forms, float or swim weakly in the water column. These organisms sit at the base of the aquatic food web, and are keystone in supporting the fish and bird populations higher up the food web. There is ample research that shows how introduction of invasives (e.g. “Dreissenid” zebra and quagga mussels) and changes in land use practices have led to reductions of zooplankton levels and associated foraging fish (e.g. yellow perch) (32).

3.5.2.4 Invertebrates of Conservation Relevance

The biodiversity classification exercise generated the following list of conservationally relevant invertebrates that could be exposed to a Straits of Mackinac oil spill.

Table 3.6 Species Matrix - Invertebrates

Name		Conservation Status				Habitat in Water (Y/N)			Keystone
Common name	Species name	IUCN	CITES	MICHIGAN	US	Adult	Larvae	Requirements	Role
Hungerford's Crawling Water Beetle	*Brychius hungerfordi*	-	-	E	E	Y	Y	Cool water; beaver dams	-
Hine's Emerald dragonfly	*Somatochlora hineana*	NT	-	E	E	Y	N	Cool; shallow; wetland	-
Incurvate emerald dragonfly	*Somatochlora incurvata*	LC	-	SC	-	Y	N	Wetland; vegetated	-
Rusty crayfish	*Orconectes rusticus*	LC	-	-	-	Y	Y	Rocky lakes	-

Legend

Conservation Status		
IUCN	LC	Least Concern
	NT	Near Threatened
CITES	-	Not listed
MICHIGAN	-	Not listed
	SC	Special Concern
	E	Endangered
US	-	Not listed
	E	Endangered

4 Southern Alternative Wetlands

This section presents a brief review of wetland datasets referenced to assess southern rail and pipeline Alternatives crossings and, ultimately, if the areas were considered 'High Consequence Areas'.

Wetland habitat geospatial data was sourced from two different sources, namely the Michigan DEQ's Wetland Map Viewer website (33) and the National Wetland Inventory (NWI) dataset sourced from U.S. Fish and Wildlife Service website (34). The latter entails comparable data across the States of Indiana, Illinois and Wisconsin and Michigan. It was therefore used as the base source of data comparison for the overall analysis of all four states.

In the interest of thoroughness, however, the Michigan DEQ 'Wetland NWI+ Current' dataset was also used to illustrate Michigan State-derived wetland results specific to Michigan. The Michigan DEQ's NWI+ dataset is a combination of the FWS NWI dataset and 2 additional data sources: Land Cover data by Michigan's Department of Natural Resources' Michigan Resource Inventory System (MIRIS), and Soil data by US Department of Agriculture.

GIS maps of the wetland datasets that were applied in the analysis are presented below.

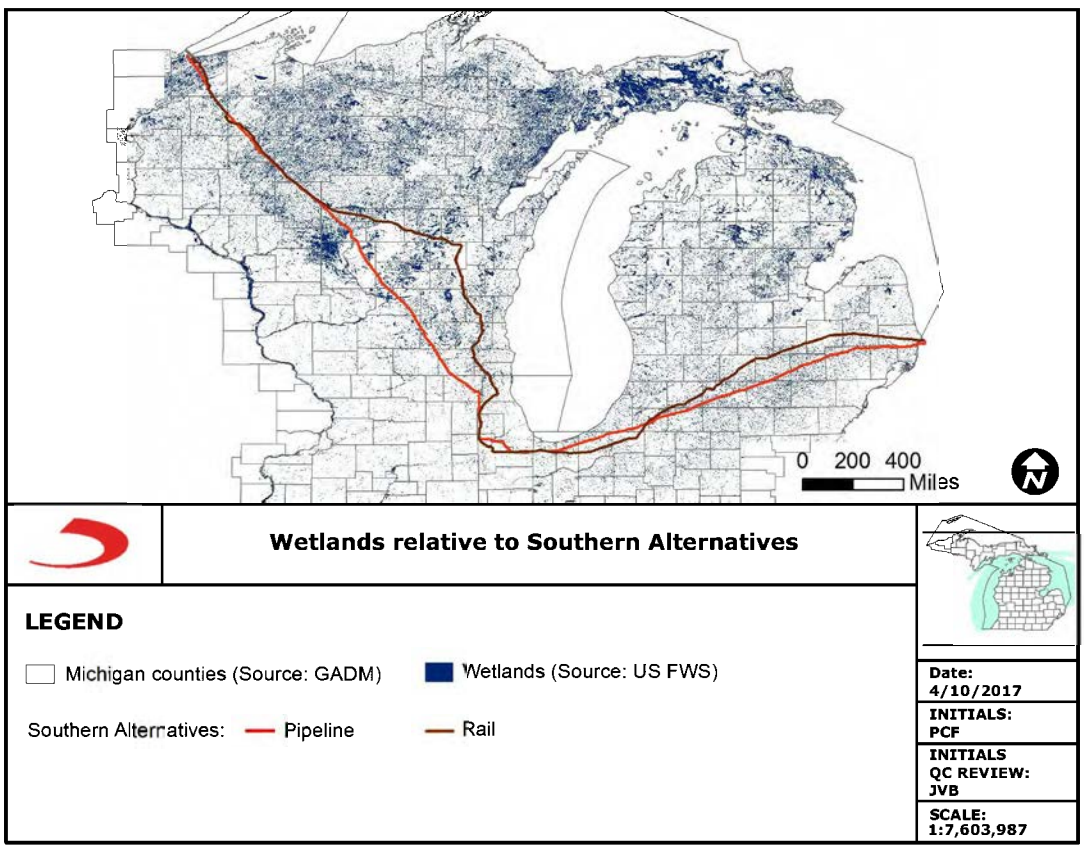


Figure 4.1 Wetlands in the different states relative to the Southern Alternatives

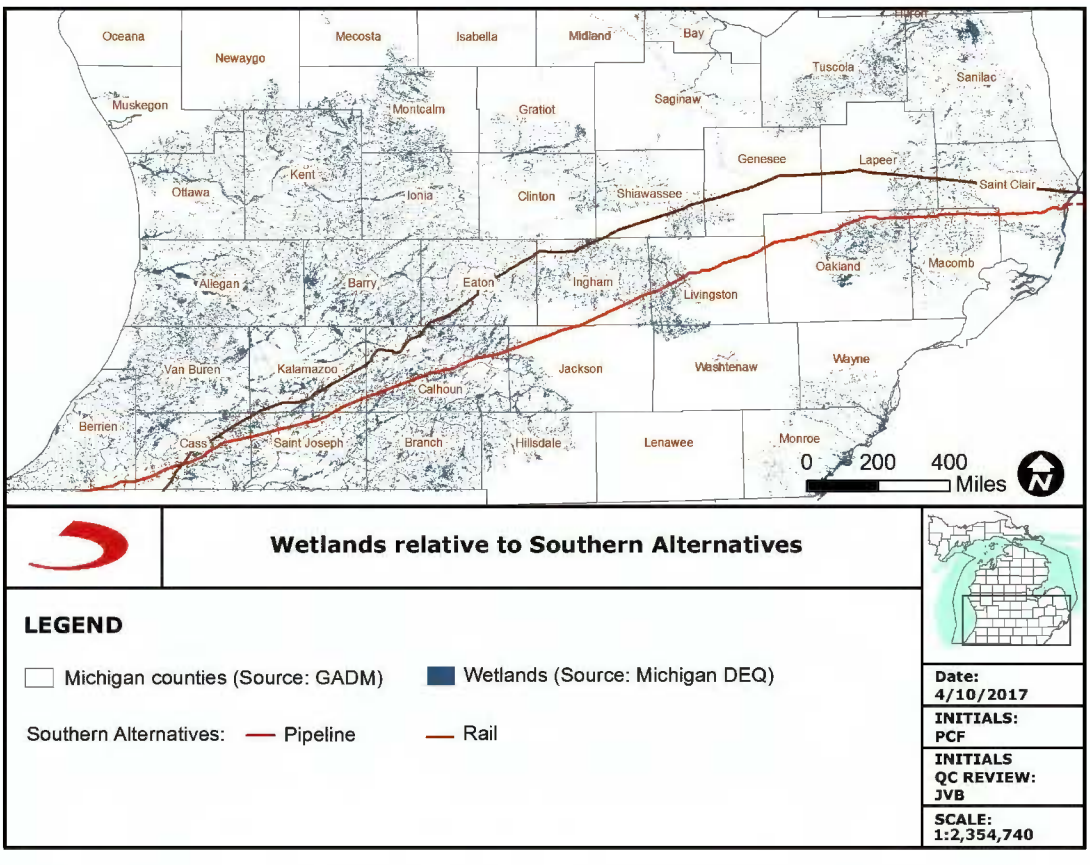


Figure 4.2 Wetlands in Michigan Counties relative to the Southern Alternatives

5 Tolerances of Sensitive Exposed Species

The impact of oil from a spill on different species varies with exposure, which in turn is a function of oil type, oil weathering and the physiological and life strategy characteristics of each species. As such, a review of documented oil spill related impacts and the associated tolerance levels were carried out for the above-described baseline habitat and 'biodiversity at risk'.

This analysis was outlined as a means to support the actual general impact tolerances levels that were applied to demonstrate scales of impact associated in oil spill modelling results (i.e. plots) and associated analyses generated in the main document.

5.1 Birds

The exposure of a bird to an oil spill depends very much on its preferred habitats for foraging, nesting or resting. Birds are typically exposed to oil from an open water spill from a slick (e.g. floating or diving) or where it washes up on shore (e.g. foraging or nesting). As such, water fowl and/or shorebirds are particularly at risk.

Acute mortality of birds from oil occurs when it contacts a bird's feathers, impairing it's' ability to repel water, fly, float and thermoregulate. Oil diminishes the natural waterproofing of feathers (e.g. causing drowning) and corresponding skin exposure affects heat regulation (i.e. resulting in hypothermia or hyperthermia). In relation to the Straits of Mackinac, effects would be particularly severe during the winter months and along migration flyways in spring and fall (35). Acute impacts can also be experienced through ingestion (36), as a bird attempts to preen oil from its' plumage oil, which can then be ingested and lead to direct toxicity or internal bleeding, i.e. depending on the type of oil.

In terms of sub-lethal impacts, one source points out 'that a 'few microlitres of oil transferred from a nesting parent to the surface of incubating eggs can be absorbed and cause developmental deformities depending on the toxicity of the oil and applied dispersant' (35). They also refer to studies that indicate significant reductions in the long term survivability of certain water fowl in oil spill impacted areas.

Documented (see section 5.7) oil spill tolerance limits include:

- for diving birds (i.e. oiled when diving through the oil slick layer on the water surface) the exposure threshold to oil is known to be 10 g/m^2
- for birds that forage in the shallow waters (waders) tolerance is higher 100g/m^2 as they do not fully emerge in the oil.

The mortality of individual birds can have secondary or cumulative impacts to population dynamics and abundance on a large scale (regional or continental) and the related chronic consequence can also be felt throughout the ecosystem.

5.2 Fish

While fish can demonstrate avoidance behavior to oil polluted waters (35), exposure to acute and chronic lethal or non-lethal oil spill related impacts are influenced by a suite of different factors.

Fish can incur lethal or sub-lethal impacts from soluble oil toxins, and/or other pathways of sub-lethal exposure to toxins that impact the developmental health or fitness of the fish (37). Risk of acute exposure occurs directly following a spill and a fish's ability to apply avoidance response behavior will depend on spill characteristics, its' proximity from the spill location, its mobility and/or developmental stage, and the room it has to avoid the oil. One source affirms that avoidance behavior is not apparent in shorelines where oiling, emulsifying and large oil deposits may impede escape (35).

Oil spill 'fish kills' do occur but are often brief as spill sources can usually be arrested and the acute lethality of lighter toxic fractions of oil (e.g. components such as BTEX, naphthalene and alkyl naphthalene's, short-chain alkanes) and heavy metals generally diminish with oil weathering factors, such as evaporation. Fish that inhabit enclosed freshwater environments, juvenile fish and fish spawning grounds are particularly susceptible to acute lethal toxic effects and possible non-lethal impacts from this exposure.

Chronic and sub-lethal effects of oil (e.g. due primarily to PAHs in heavier oils) on fish occur through chronic exposure or with the delayed effects of acute exposures (35). Chronic exposure can occur in various forms, i.e. and latent toxicities, of weathered oil (e.g. entrained oils, tar balls, emulsified, etc.) and can lead to respiratory or dietary uptake, direct contact (e.g. droplets), and maternal transfer to eggs. As such, fish that frequent Straits of Mackinac shoreline wetlands or protected coves would be exposed to chronic oil spill impacts. These impacts can affect fish at a cellular level and negatively influence rates of reproduction, growth, disease and survival.

In terms of tolerances, French et al (38) and French-McCay (39) (40) showed that sensitivity to toxicity varied for fish (e.g. and invertebrates) and under different environmental conditions ranged between 6 and 400 µg/l (ppb) (dissolved aromatic exposure > 4 days) with an average of 50 µg/l. This also included species during sensitive life stages (eggs and larvae). The lower exposure tolerance was determined as 6 ppb over a 4 day period (96 hours) Tsvetnenko (41). Acute lethal threshold for environmental receptors has been set to 50 ppb and 400 ppb reflecting acute lethal threshold for 5% and 50% of biota respectively (see French - McCay (39)).

Lee et al. (35), point to a review of EC50 and LC50 values (i.e. laboratory measures of responses – lethality) from total Polyaromatic Hydrocarbons (PAH) and Total Petroleum Hydrocarbons to uncover various acute and chronic exposure thresholds of marine and freshwater species of fish to oil; as illustrated in Figure 5.1.

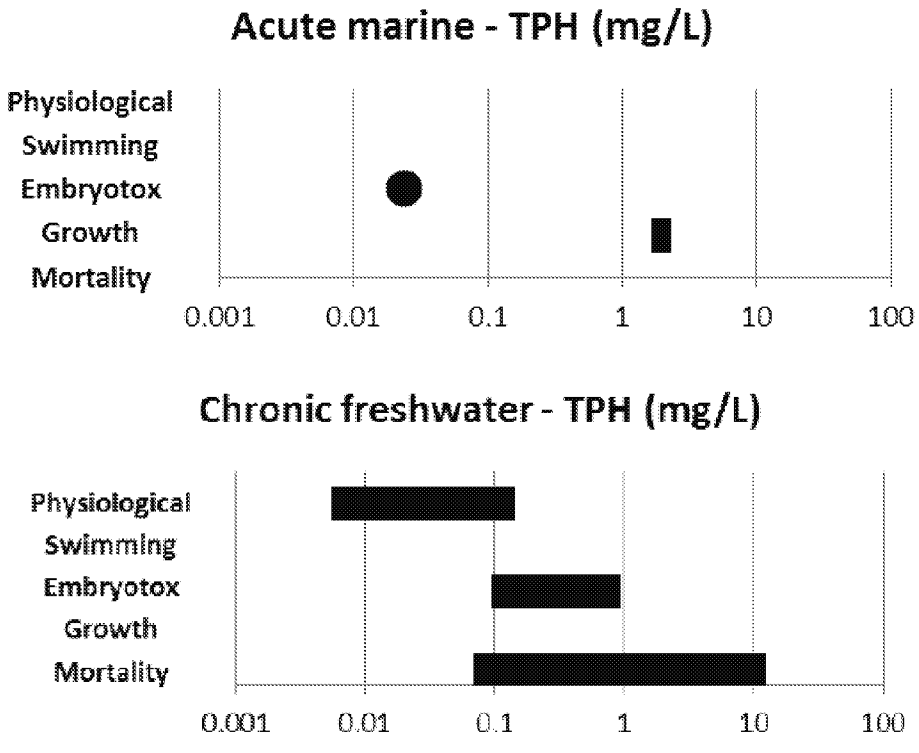


Figure 5.1 Example of impact tolerances / response ranges from oil (i.e. dissolved fractions)

What is most important from this information for the current study is the assertion that the concentrations (e.g. in relation to embryotoxicity) were within the range of concentrations anticipated in surface waters near slicks of un-dispersed and dispersed oils (42). As these tolerance concentrations provide indicative levels of fish tolerances to various thicknesses of oil slicks, it is clear that applied oil slick related tolerance (threshold) limits should entail some level of conservatism.

It should also be stressed that one of the major impacts on fish will be the reduction in population levels due to reduction in suitable habitat and carrying capacity of an area due to reduced food supply and significant reduction in the availability of nursery and spawning areas that are often located in the shallows.

5.3 Herpetofauna

Herpetofauna, i.e. reptiles and amphibians, are at risk from an oil spill as their 'aquatic ecosystems and riparian lands' are exposed to dispersed oils. For example, some studies have shown that amphibians that spawn in clear, shallow ponds may be subject to photo-enhanced toxicity. Also, aquatic turtles can become coated with oil or inhale aerosols when they surface in an oil slick. Here, deformities in species that spawn on shore and bioaccumulation in long-lived marine turtle species have been recorded. Varying evidence suggests, however, that the same acute and chronic impacts relevant for birds and fish may not be as prevalent for some Herpetofauna. For example, a study on the dilbit spill at Talmadge Creek and the Kalamazoo River suggests that juvenile and adult species of turtle were less susceptible to impact after individual turtle were rescued, washed and released several times. (35)

In general, it is difficult to directly describe the possible effects of oil on herpetofauna, as evidence is mixed and no related tolerance limits could be found.

5.4 Mammals

As with birds, oil spills can have lethal acute impact or lethal and sub lethal chronic impacts to mammals. If the fur of mammals, especially aquatic mammals, becomes oiled it prohibits proper insulation and water repellant functionality of the fur. Despite some evidence of avoidance behavior, it is clear that aquatic mammals are particularly susceptible to oil impacts while surfacing to breathe or via accessing oiled littoral zones or shorelines. As they lose the functionality of their fur, acute or chronic mortality can occur through hypothermia, drowning; slower chronic respiratory damage; or starvation through the inability to feed properly.

Mammals can also ingest oil via grooming or via consumption of fish or invertebrates exposed to oil. This is especially true for top predator mammals, such as river otters, thus making these species particular sensitive to oil spills in the long-term. While the oils can be metabolized, toxins can bioaccumulate and cause physiological stresses and become bioavailable and toxic to the fetus or nursing newborns. (35)

Given that oils can be ingested through consumption it is also equally possible that applicable terrestrial mammals that forage along shorelines would also be at risk of acute and chronic impacts of an oil spill. For example, raccoons that scavenge for food in intertidal areas and use them for shelter may ingest oil while eating exposed prey and may become coated in oil while exploring exposed flats and grass beds.

It has been found that the threshold for an impact on shoreline living mammals is 100 g/m^2 (43) (44) (45).

5.5 Other Aquatic Flora and Fauna

An overview of possible oil spill related impacts to aquatic plants and invertebrates is provided in the subsequent subsections.

5.5.1 Aquatic Vegetation

Water plant exposure to an open water oil spill is generally more pronounced in the littoral zone, although phytoplankton, floating plants and algae can also be at risk.

The direct effect of an oil spill on phytoplankton is smothering through adhesion, but population wide impacts seem to be mitigated by oil dispersion and weathering; as well as recruitment of unexposed organisms and rapid growth rates. Observations provide evidence, however, that marine shoreline or marsh plant species are more susceptible, with partial die- off or, in the case of root exposure, complete mortality. Further community wide impacts also occurred from subsequent erosion. Aquatic shoreline vegetation are thought to be more tolerant due to observations of species of bulrush that appear to be unaffected despite heavy oiling. Some aquatic Macrophytes, however, are cited as being highly sensitive to oil, particularly at the margins of open water, with implications for overall productivity of wetlands and the destruction of habitat for aquatic or semiaquatic animal species. (35)

Other ecosystem wide impacts result from the capacity of algae to absorb oil and transport within the ecosystem as a result of filter feeding and/or sedimentation processes (46).

5.5.2 Invertebrates

The lethal concentration of oil to many species of invertebrate are known (e.g. lethal dose studies), but the lethality of an oil spill to invertebrates various among species with different habitats, life histories and developmental stages. In terms of acute lethality (35), the following brief points can be made:

- Physical smothering occurs

- invertebrates sensitivity to an oil spills toxicity may be as comparable to a variety of fish species e.g.
  - dissolved petroleum hydrocarbons appear more bioavailable
  - oil dispersants may enhance exposure, uptake and toxicity
- invertebrate embryo development is particularly sensitive to oil exposure (e.g. photo-enhanced toxicity), including zooplankton, as evident by increased rates of deformities, reduced overall survival and reduced activity of survivors.

It is also important to note that invertebrates do not metabolize or excrete petroleum hydrocarbons quickly and can therefore contribute to the dietary exposure of predators. In relation to recovery, some field observations show that the community characteristics of the zooplankton did not incur significant change from an oil spill. (35)

5.6 Important Impact Relationships

From the analysis of typical impacts to the above categories, there are selections of impact relationships that are important to consider in any analysis. These generally entail:

- Oil can smother species (e.g. birds, marine mammals and reptiles) that are sessile or cannot readily avoid contact with oil, e.g.:
  - species that forage or nest on beaches or in littoral zones (e.g. shorebirds and wading birds)
  - species that spawn in littoral zone or benthic substrates (e.g. fish)
  - animal that forage or predate through diving into pelagic water (e.g. birds and mammals)
  - invertebrates or plants that inhabit the littoral zones

- Acute lethality from dissolved concentrations of soluble oil toxins in the water column can led to acute or chronic mortality to many species (e.g. fish kills)

- Ingestion through preening or grooming, and/or physical contact with to oil immediately after a spill or after weather (e.g. secondary nesting contact), can lead to bioaccumulation and a series of lethal and non-lethal developmental or physiological impairments that also inhibit a species ability to carry out normal life strategy activities
  - Larger animals are better able to metabolize and excrete ingested oils but can still incur physiological affects

- Oil will impede the movements of organisms to feed, reproduce and avoid predation

- Oils impacts can be evident through biomagnificaiton in food webs

- Oil impacts to individuals can have population and ecosystem wide implications felt on a regional or global scape, e.g. to migratory bird species.

5.6.1 Marine versus Freshwater Exposure

From a review of oil spill literature on related tolerances and impacts, it is clear that most relates to marine oil spills. Specific literature (35) regarding the differences suggests, however, that to a large extent the pathways of impacts are similar. Variations are related to the physical properties of dispersion and weathering of oils from, among others, the effects of salinity and physical dispersion processes (wind/wave action). For example, the source suggests that toxic oil related impacts may be more prevalent in especially low energy freshwater environments, as evaporate rates are slower. In large freshwater bodies such as the Great Lakes, however, these variations are not considered of significant relevance due to strong lake currents and wind/wave interactions.

Lee et al. (35), ultimately point out that 'Overall, oil spill effects will be site- and species-specific, depending on how the biology and ecology of each species interact with the potential for oil exposure. In both marine and freshwater ecosystems, impacts will vary with seasonal aggregations of species for spawning, synchronized hatching of eggs, schooling behavior and habitat selection'.

The applied tolerance levels and impact examples applied in the analyses were specific to freshwater were available, and otherwise considered – as suggested – the appropriate levels of detail on exposed biodiversity and habitats.

5.7 Applied Analysis Tolerance Limits

With the above explanations of possible impacts and related tolerance levels for the biodiversity at risk, the following subsections outline the actual tolerance limits and justification for using them. These tolerances, or thresholds, were applied to oil spill modeling result plots and in consequence analyses.

5.7.1 Open Water Tolerances

Open water slick thickness was chosen as a representative tolerance limit as it relates to surface exposure of a number of key receptors. It was decided to apply a set of commonly used tolerance limits applied in other studies (47) (48), given their general acceptance and alignment with tolerances described in this document.

The applied tolerances are shown in Table 5.1, below.

Table 5.1 Threshold classification to assess zones of sea surface contact

Hydrocarbon Concentration [g/m^2]	Impact Level	Description of Impact
> 0.01	Low	- Barely visible sheen - Likely results in closure of fisheries - Fishing is prohibited - Socio-economic impact
10-25	Moderate	- Mortally impact sea birds and other wildlife associated with water surface - Ecological impact
>25	High	- Harmful to all birds that contact with the slick - This is used to define the zone of potential high exposure

The value used to represent low levels of impact was 0.01 g/m^2, which represents an equivalent slick thickness of approximately 0.01 µm oil. According to the Bonn Agreement Oil Appearance Code, this oil thickness would appear as a grey sheen with a rainbow sheen developing with a thickness of approximately 1 µm. A 1 µm slick thickness is close to the practical limit of observing oil in the marine environment (49). However, newer technologies can now observe oil films thinner than 0.1 µm. In the Canadian Atlantic Ocean Environment Canada recorded sheens thinner than 0.1 µm using a state-of-the-art laser oil detection system called a Scanning Laser Environmental Airborne Fluorosensor (SLEAF).

From an environmental or ecological perspective this a very conservative threshold, as apparent in cited tolerances for birds (sections 3.1) and mammals (section 3.5). However, given that even low levels of oil slick thickness may result in some impact on the feathers of birds (50), and other possible ranges of low exposure levels, it was felt that it would was appropriately robust.

The next level of ecological thresholds was set to 10 g/m^2 or approximately 10 µm in line with observations from French et. al. (51) that suggest that this level may be lead to mortality in some bird species and other wildlife that come into contact with the water surface.

5.7.2 Shoreline Thresholds

Oil contact with shorelines was chosen as a representative tolerance limit as it related to a number of impact possibilities to key receptors. It was decided to apply a set of commonly used tolerance limits applied in other studies as thresholds in this study. These tolerances, expressed in g/m^2, are shown in Table 5.2.

Table 5.2Threshold classification to assess zones of shoreline contact

Hydrocarbon Concentration [g/m^2]	Impact Level	Description of Impact
> 1	Low	- Socio-economic impact on land - Need for shoreline cleanup on amenity beaches and coastal recreational zones - Less likely to have effect on animals
100-1000	Moderate	- Also called hydrocarbon 'coat' - Likely to have impact on animal survival and reproductive capacity - Lethal threshold for invertebrates living in intertidal habitats
>1000	High	- Impact marsh plants and mangroves significantly during the growing season. - Higher level of ecological impacts

A conservative tolerance for oil deposits on the shoreline is 10 g/m^2 (52) (53). This threshold relates to enough oil to require shore clean up on beaches or man-made structures (e.g. jetties). A deposit of 10 g/m^2 would also trigger the closure of fisheries. This is described as a low impact zone.

The threshold for shorebirds and wildlife is set to 100g/m^2 which is based on studies for sub-lethal and lethal impacts e.g. French-McCay et al. (43) (44) (45). This threshold is more appropriate for wildlife that enters the water from the shore rather than diving into the surface water. The oil can be described as an oil coat.

6 References

1. **Cornell Law School.** [Online] https://www.law.cornell.edu/cfr/text/49/195.450.
2. —. Legal Information Institute. [Online] https://www.law.cornell.edu/cfr/text/49/195.6.
3. **National Oceanic and Atmospheric Administration.** NOAA Office of Response and Restoration. [Online] https://response.restoration.noaa.gov/maps-and-spatial-data/environmental-sensitivity-index-esi-maps.html.
4. **Michigan Natural Features Inventory.** *Biotics Geodatabase.* 2017.
5. **Great Lakes Inform.** Data Catalog - GLCWC Coastal Wetlands Inventory & Classification Data. [Online] https://greatlakesinform.org/data-catalog/item/1447.
6. **Great Lakes Aquatic Habitat Framework.** Data - an aquatic, geospatial database for the Great Lakes. [Online] https://www.glahf.org/data/.
7. **U.S. Geological Survey, Gap Analysis Program (GAP).** Protected Areas Database of the United States (PAD-US). [Online] https://gapanalysis.usgs.gov/padus/data/.
8. **National Conservation Easement Database.** NCED Mapping Application. [Online] https://www.conservationeasement.us/interactivemap/.
9. **GLANSIS.** GLANSIS Map Explorer. [Online] https://www.glerl.noaa.gov/glansis/mapExplorer.php.
10. EDDMapS. [Online] https://www.eddmaps.org/distribution/.
11. **Great Lakes Commission.** Great Lakes Mapping and GIS. [Online] http://maps.glin.net/index.php.
12. **NAS - Nonindigenous Aquatic Species.** [Online] https://nas.er.usgs.gov/queries/default.aspx.
13. **United States Environmental Protection Agency.** Lakewide Action and Management Plans. [Online] https://www.epa.gov/greatlakes/lakewide-action-and-management-plans.
14. **Michigan Natural Features Inventory, Michigan State University Extension.** Ecological Jewels of the Straits. [Online] https://www.michigan.gov/documents/deq/lwm-czm-ecological-jewels_265855_7.pdf.
15. The Birds of North America. [Online] Academy of Natural Sciences and the American Ornithological Society. https://birdsna.org/Species-Account/bna/home.
16. Second Michican Breeding Bird Atlas. [Online] Kalamazoo Nature Center. https://www.mibirdatlas.org/MichiganBreedingBirdAtlasII/AlphabeticListing.aspx.
17. Michigan's Special Animals. [Online] Michigan Natural Features Inventory. https://mnfi.anr.msu.edu/data/specialanimals.cfm.
18. [Online] Michigan Department of Natural Resources. http://www.michigan.gov/dnr/.
19. Encyclopedia of Life. [Online] http://eol.org/.
20. Michigan's Special Plants. [Online] Michigan Natural Features Inventory. https://mnfi.anr.msu.edu/data/specialplants.cfm.
21. All About Birds. [Online] Cornell University. https://www.allaboutbirds.org/.
22. *Updated Geographic Distibutions of Michigan Herpetofauna: A Synthesis of Old and New Sources.* **Phillips, John G.** 1094-2246, 2016, The Journal of North American Herpetology, Vol. 2016(1), pp. 45-69.
23. **Extension, Michigan State University.** Michigan Natural Features Inventory. [Online] http://mnfi.anr.msu.edu/.
24. **National Audubon Society.** Conservation - Important Bird Areas. [Online] http://www.audubon.org/important-bird-areas.
25. **Victor J. Santucci, Jr., et al., et al.** Wissonsin DNR: Department of Natural Resources. [Online] March 22, 2014. http://dnr.wi.gov/topic/fishing/Documents/Lake Michigan/LakeMichiganYellowPerchSummitReport.pdf.
26. **Phillips, J.G.** Updated Geographic Distributions of Michigan Herpetofauna: A Synthesis of Old and New Sources. [Online] The Journal of North Amercia Herpetology, July 5, 2016. http://www.cnah.org/pdf/88547.pdf.
27. **iNaturalist.** iNaturalist. [Online] https://www.inaturalist.org/.
28. **Wieten, A.C. Cooper, M.J.,Parker, A.D. et al.** [Online] https://link.springer.com/article/10.1007/s11273-011-9240-4.

29. **MichiganTech Research Institute.** Great Lakes Coastal Wetland Mapping. [Online] http://www.mtri.org/coastal_wetland_mapping.html.
30. **Michigan Natural Features Inventory.** Cirsium pitcheri (Torrey and Gray) - Pitcherís thistle. [Online] https://mnfi.anr.msu.edu/abstracts/botany/Cirsium_pitcheri.pdf.
31. *Stopover habitat along the shoreline of northern Lake Huron, Michigan: Emergent aquatic insects as a food resource for spring migrating landbirds.* **R.J. Smith, F.R. Moore, and C.A. May.** January 2009, The American Ornithologists' Union, pp. 107-121.
32. **Lake Michigan Forum.** Lake Michigan Lakewide Management Plan. [Online] 2008. https://www.epa.gov/sites/production/files/2015-11/documents/lake-michigan-lamp-2008-233pp.pdf.
33. **DEQ, Department of Environmental Quality (Michigan).** Wetlands Map Viewer. [Online] hhtp://www.mcgi.state.mi.us/wetlands/mcgiMap.html.
34. **U.S. Fish & Wildlife Service.** National Wetlands Inventory. [Online] https://www.fws.gov/wetlands/.
35. **Lee, Kenneth (Chair), Michel Boufadel, Bing Chen, Julia Foght, Peter Hodson, Stella Swanson, Albert Venosa.** *Expert Panel Report on the Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments.* Ottawa, On : Royal Society of Canada, ISBN:978-1-928140-02-3, 2015.
36. How Oil Effects Birds. [Online] International Bird Rescue. https://bird-rescue.org/our-work/research-and-education/how-oil-affects-aspx. .
37. Delayed effects of oil spill compromise long-term fish survival. [Online] September 8, 2015. http://phys.org/news/2015-09-effects-oil-compromise-longterm-fish.htm#Cp..
38. *Probabilities of oil exceeding thresholds of concern: examples from an evaluation for Florida Power and Light.* **French, D, Schuttenberg, H & Isaji, T.** Alberta : Proceedings of the 22nd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Environment Canada, 1999. Proceedings of the 22nd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar.
39. *Development and application of an oil toxicity and exposure model, OilToxEx.* **French-McCay, DP.** 10, 2002, Environmental Toxicology and Chemistry, Vol. 21, pp. 2080-2094.
40. *Development and application of damage assessment modelling: example assessment for the North Cape oil spill.* **French-McCay, DP.** 9, 2003, Marine Pollution Bulletin, Vol. 47, pp. 9-12.
41. *Derivation of Australian tropical marine water quality criteria for protection of aquatic life from adverse effects of petroleum hydrocarbons.* **Tsvetnenko, Y.** 4, 1998, Environmental Toxicology and Water Quality, Vol. 13, pp. 273-284.
42. *Toxicity of dispersed crude oil to early life stages of Atlantic herring (Clupea harengus).* **McIntosh, S., King, T., Wu, D. and P.V. Hodson.** 2010, Environmental Toxicology and Chemsitry , Vol. 29, pp. 1160-1167.
43. *Oil spill modeling input to the offshore environmental cost model (OECM) for US-BOEMRE's spill risk and costs evaluations.* **French-McCay, D, Reich, D, Rowe, J, Schroeder, M & Graham, E.** Ottawa : s.n., 2011. Proceedings of the 34th Arctic and Marine Oil Spill Program (AMOP) Technical Siminar, Environment Canada.
44. *Oil spill consequence analysis of potentially-polluting shipwrecks.* **French-McCay, D, Reich, D, Michel, J, Etkin, DS, Symons, L, Helton, D, & Wagner J.** Ottawa : s.n., 2012. Proceedings of the 35th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Environment Canada.
45. **NOAA.** *Screening level risk assessment package Gulf state.* Washington DC : Office of National Marine Sanctuaries & Office of Response and Restoration, 2013.
46. *Environmental effects of the Deepwater Horizon oil spill: a review.* **Beyer, J., Trannum, H.C., Bakke, T. and P.V. Hodson.** s.l. : Marine Pollution Bulletin, 2015, Marine Pollution Bulletin.
47. **NOAA, Office of National Marine Sanctuaries / Office of Response and Restoration.** *Screening Level Risk Assessment Package Bunker Hill.* s.l. : NOAA, 2013.
48. *Comprehensive Approach to Risk Analysis of Sunken Shipwrecks: The Use of Trajectory, Fate and Effects Modelling.* **French-McCay, D., et al., et al.** Gotenborg : s.n., 2015, 12-13 October . Wrecks of the World III: Shipwreck Risk Assessment .
49. **(AMSA), Australian Maritime Safety Authority.** Australian Maritime Safety Authority Technical Guideline for the Preparation of Marine Pollution Contingency Plans for Marine and Coastal Facilities Australian Maritime Safety Authority. [Online] 2012. [Cited: January 15, 2017.] https://www.amsa.gov.au/forms-and-publications/Publications/AMSA413_Contingency_Planning_Guidelines.pdf .
50. **Patrick D. O'Hara, Lora A. Morandin.** Government of Canada Publications. [Online] May 2010. http://publications.gc.ca/collections/collection_2016/one-neb/NE23-186-2010-eng.pdf.

51. **French, D, Reed, M, Jayko, K, Feng, S, Rines, H, Pavignano, S, Isaji, T, Puckett, S, Keller, A, French III, FW, Gifford, D, McCue, J, Brown, G, MacDonald, E, Quirk, J, Natzke, S, Bishop, R, Welsh, M, Phillips, M, Ingram, BS.** *The CERCLA Type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), Technical Documentation, Volume I - Model Description, Final Report.* Washington DC : Office of Environmental Policy and Compliance, U.S. Department of the Interior, 1996.

52. *Modeling the fates of hypothetical oil spills in Delaware, Florida, Texas, California, and Alaska waters, varying response options including use of dispersants.* **French-McCay, D, Whittier, N, Dalton, C, Rowe, J, Sankaranarayanan, S & Aurand, D.** Washington DC : s.n., 2005a. Proeceedings of the International Oil Spill Conference 2005, American Petroleum Institute.

53. *Use of probabilistic trajectory and impact modeling to assess consequences of oil spills with various response strategies.* **French-McCay, D, Whittier, N, Rowe, J, Sankaranarayanan, S, Kim, H-S & Aurand, D.** Ottawa : s.n., 2005b. Proceedings of the 28th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Environment Canada.

54. **Herpetological Resource and Management.** [Online] LCC Box 110 Chelsea, MI 48118. https:www.rivercare.org/local/upload/file/HRM_Beaver_Island_Report_2015_0pt.pdf..