Trans Mountain Pipeline ULC
Trans Mountain Expansion Project
NEB Hearing Order OH-001-2014
Responses to Information Request from Raincoast Conservation Foundation

EFFECTS OF CLIMATE CHANGE ON THE PROJECT

2.01 Consideration of Climate Change in Model Inputs

Reference:

i) A3S0Y9, Application Volume 4A, Project Design and Execution – Engineering, Section 3.4.4.3.2, PDF page 3 of 35.

ii) Helm, K. P., N. L. Bindoff, and J. A. Church. 2010. Changes in the global hydrological cycle inferred from ocean salinity. Geophys. Res. Lett., 37, L18701, doi:10.1029/2010GL044222, online at http://onlinelibrary.wiley.com/doi/10.1029/2010GL044222/full.

iii) A3S0R0, Application Volume 2, Project Overview, Economics and General Information, Section 2.9.2, PDF page 5 of 43.

iv) A3S5G9, Volume 8C, Modeling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, PDF pages 18 to 42 of 72.

v) A3S5G9, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Sections 8 and 9, PDF pages 42 to 62 of 72.

vi) A3W9K1 to A3W9K9, Response to NEB IR 1.62b, Detailed Quantitative ecological risk assessment for loading accidents and marine spills.

vii) A3S5G9, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Section 3.1.1, PDF pages 19 and 20 of 72.

vii) A3S5G9, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Section 6, PDF pages 38 to 42 of 72.

Preamble:

Reference (i) states that a rise in water level due to the effects of climatic change is expected, and that “according to an assessment by DFO, by the year 2100, the Fraser River Delta could experience a mean relative sea level rise of 0.55 m with contributions of 0.29 m from global eustatic rise, 0.28 m from deltaic subsidence, and -0.02 m from glacial isostatic adjustment.” Reference (ii) provides an example of existing and predicted climate change on ocean temperature, density, salinity, oceanographic processes, and the hydrological cycle.

Reference (i) illustrates how climate change might affect model parameters and assumptions. References (i) and (ii) provide examples of future conditions under climate change. Models that are static to future conditions may lead to inaccurate results and inappropriate conclusions.

Reference (iii) states that the project infrastructure, and by association tanker traffic, is not expected to be abandoned for more than 50 years once operations commence.

Reference (iv) briefly describes the models H3D, SPILLCALC and SWAN.

Reference (v) provides an example of the kind of result that the H3D, SPILLLCALC and SWAN models combine to produce.

Reference (vi) provides an example of the kind of conclusions that are based on the results produced in reference (v).

Reference (vii) provides a description of the more detailed grids used in H3D.

Reference (viii) provides a description of the models CALMET and CALPUFF.

Request:

Please describe how predicted changes due to climate change including extremes of temperature, density, salinity, and weather, and changes to water chemistry and sea level, have been accounted for in models that predict the fate and behaviour of diluted bitumen and other petroleum pseudo-components. Specifically:

a. Please confirm whether the expected life of the project and its infrastructure is 50 years. If this is not the case, please provide the expected minimum and maximum range of the project's life expectancy.

b. Please use the project's planned years of operation as identified in 1a) to inform questions 1c through 1i.

c. Has variance in water temperature, including unprecedented extremes that are projected under climate change for the Fraser River, the Fraser River estuary, and the marine waters of the Salish Sea, as described in Reference (ii), been accounted for in the spill and oil dispersion models H3D, SWAN, and SPILLCALC?

    c1. If yes, please confirm this and provide an explanation as to how the model results (for example, Reference (v)), and the conclusions they support (for example, Reference (vi)), account for projected climate change scenarios and describe the attendant uncertainty this introduces to the conclusions supported, including the significance of risk informed by the model results.

    c2. If no, please confirm this and provide an explanation as to why greater variance in water temperature is not relevant to environmental risks to the project during the project's planned years of operation.

d. Has variance in water density in the Fraser River, Fraser estuary, and marine waters of the Salish Sea been accounted for in H3D, SWAN and SPILLCALC, including density changes associated with climate change?

d1. If yes, please confirm this and provide an explanation as to how the model results, and the conclusions they support, account for projected climate change scenarios and describe the attendant uncertainty this introduces to the conclusions supported, including the significance of risk informed by the model results.

d2. If no, please confirm this and provide an explanation as to why water density extremes are not relevant to environmental risk for the project's planned years of operation.

e. Have projected changes in water chemistry (e.g. salinity) that would accompany climate change in the marine and estuarine waters of the Salish Sea been accounted for in H3D, SWAN, and SPILLCALC?

e1. If yes, please confirm this and provide an explanation as to how the model results and the conclusions they support account for projected climate change scenarios, and describe the attendant uncertainty this introduces to the conclusions supported, including the significance of risk informed by the model results.

e2. If no, please confirm this and provide an explanation as to why salinity and other water chemistry changes are not relevant to environmental risk for the project's planned years of operation.

f. Have any projected changes in water levels and corresponding shifts in current and flow patterns with the study region, including those within the more detailed grids for the Strait of Georgia and Fraser River delta area, the Fraser River, and Burrard Inlet (Reference (vii)) been accounted for in H3D, SWAN, and SPILLCALC?

f1. If yes, please confirm this and provide an explanation as to how the model results, and the conclusions they support, account for projected climate change scenarios and describe the attendant uncertainty this introduces to the conclusions supported, including the significance of risk informed by the model results.

f2. If no, please confirm this and provide an explanation as to why changing water levels and corresponding shifts in current and flow patterns are not relevant to environmental risk for the project's planned years of operation.

g. Have natural cycles in marine waters, including El Niño and the Pacific Decadal Oscillation, which are patterns of temperature and pressure change that occur regularly and effect the Salish Sea, been accounted for in H3D, SWAN and SPILLCALC?

g1. If yes, please confirm this and provide an explanation as to how the model results, and the conclusions they support, account for decadal patterns and describe the attendant uncertainty this introduces to the conclusions, including the significance of risk informed by the model results.

g2. If no, please confirm this and provide an explanation as to why these cycles are not relevant to environmental risk for the project's planned years of operation.

h. Have projected changes in weather patterns, including extreme weather events, associated with climate change that can affect the Fraser River, Fraser estuary, and marine waters of the Salish Sea, been accounted for in H3D, SWAN, and SPILLCALC?

h1. If yes, please confirm this and provide an explanation as to how the model results, and the conclusions they support, account for extreme weather events and describe the attendant uncertainty this introduces to the conclusions supported, including the significance of risk informed by the model results.

h2. If no, please confirm this and provide an explanation as to why extreme weather events are not relevant to environmental risk for the project's planned years of operation.

i. Have projected changes in meteorological conditions, including extreme weather events, associated with climate change in the complex coastal terrain of the Salish Sea been accounted for in the air dispersion model CALPUFF and CALMET (Reference (viii))?

i1. If yes, please confirm this and provide an explanation as to how the model results, and the conclusions they support, account for extreme weather events and describe the attendant uncertainty this introduces to the conclusions supported, including the significance of risk informed by the model results.

i2. If no, please confirm this and provide an explanation as to why this is not relevant to environmental risk for the project's planned years of operation.

Response:

a. The expected life of the pipeline and proposed facilities is indefinite. Comprehensive programs are planned to maintain the pipeline and proposed facilities for safe and efficient operation. For more information on the integrity management program plans please refer to Volume 4C, Section 8 of the application (Filing ID A3S1L1).

b. Refer to the response to a) above.

c. No variance in water temperature that are projected under climate change for the Fraser River, the Fraser River estuary, and the marine waters of the Salish Sea has been accounted for in the spill and oil dispersion models H3D, SWAN, and SPILLCALC.

c1. N/A

c2. Climate change effects were not included in the models simulating the fate and behavior of diluted bitumen. Climate change was excluded from the modelling study for several reasons:

- The range of oceanographic conditions simulated is significantly larger than the predicted changes in local oceanographic properties due to climate change. Essentially, the alterations in mean and extreme levels of temperature, density, salinity, wind, water chemistry and sea level are insignificant as compared to the range of conditions under consideration in the stochastic simulations. Since a stochastic approach was conducted to assess the extent of a credible worst case scenario, various environmental conditions were considered (wind speed, water level…). The change brought by climate change to these conditions is not expected to impact the results of the spill modelling. The extent of shoreline being affected by an oil spill will still be very similar, even though sea level rise may locally affect the attributes of the shoreline.

- There is significant uncertainty in long term predictions of climate change and its impacts on local oceanographic processes. If estimates of climate change were included in the modelling study, an additional layer of uncertainty would be added to the results, such that the interpretation of 'typical' versus 'worst-probable-case' scenarios becomes difficult and, possibly, non-conservative.

- Given the exceedingly low and temporally constant probability of a spill incident, it is impossible to predict where along the climate change spectrum a potential spill could occur. The probability of spill occurrence is the same across all years of operation, including in the near term when climate change effects are negligible and the long term when climate change may be felt in coastal British Columbia. Therefore, including climate change effects provides a modelling approach no more valid than without them, even if the effects were non-trivial to the present modelling study.

As a consequence of the above three points, it was determined that, firstly, climate change effects on local oceanographic processes are not significant as compared to the simulated range of conditions and, secondly, the addition of climate change factors into the modelling study would only serve to cloud the representativeness of the results and add uncertainty to the results.

d. No variance in water density associated with climate change for the Fraser River, the Fraser River estuary, and the marine waters of the Salish Sea has been accounted for in the spill and oil dispersion models H3D, SWAN, and SPILLCALC.

d1. N/A

d2. Climate change effects were not included in the models simulating the fate and behavior of diluted bitumen. Climate change was excluded from the modelling study for several reasons:

- The range of oceanographic conditions simulated is significantly larger than the predicted changes in local oceanographic properties due to climate change. Essentially, the alterations in mean and extreme levels of temperature, density, salinity, wind, water chemistry and sea level are insignificant as compared to the range of conditions under consideration in the stochastic simulations. Since a stochastic approach was conducted to assess the extent of a credible worst case scenario, various environmental conditions were considered (wind speed, water level…). The change brought by climate change to these conditions is not expected to impact the results of the spill modelling. The extent of shoreline being affected by an oil spill will still be very similar, even though sea level rise may locally affect the attributes of the shoreline.

- There is significant uncertainty in long term predictions of climate change and its impacts on local oceanographic processes. If estimates of climate change were included in the modelling study, an additional layer of uncertainty would be added to the results, such that the interpretation of 'typical' versus 'worst-probable-case' scenarios becomes difficult and, possibly, non-conservative.
- Given the exceedingly low and temporally constant probability of a spill incident, it is impossible to predict where along the climate change spectrum a potential spill could occur. The probability of spill occurrence is the same across all years of operation, including in the near term when climate change effects are negligible and the long term when climate change may be felt in coastal British Columbia. Therefore, including climate change effects provides a modelling approach no more valid than without them, even if the effects were non-trivial to the present modelling study.

As a consequence of the above three points, it was determined that, firstly, climate change effects on local oceanographic processes are not significant as compared to the simulated range of conditions and, secondly, the addition of climate change factors into the modelling study would only serve to cloud the representativeness of the results and add uncertainty to the results.

e. No variance in water chemistry that would accompany climate change in the marine waters of the Salish Sea has been accounted for in the spill and oil dispersion models H3D, SWAN, and SPILLCALC.

e1. N/A

e2. Climate change effects were not included in the models simulating the fate and behavior of diluted bitumen. Climate change was excluded from the modelling study for several reasons:

- The range of oceanographic conditions simulated is significantly larger than the predicted changes in local oceanographic properties due to climate change. Essentially, the alterations in mean and extreme levels of temperature, density, salinity, wind, water chemistry and sea level are insignificant as compared to the range of conditions under consideration in the stochastic simulations. Since a stochastic approach was conducted to assess the extent of a credible worst case scenario, various environmental conditions were considered (wind speed, water level…). The change brought by climate change to these conditions is not expected to impact the results of the spill modelling. The extent of shoreline being affected by an oil spill will still be very similar, even though sea level rise may locally affect the attributes of the shoreline.

- There is significant uncertainty in long term predictions of climate change and its impacts on local oceanographic processes. If estimates of climate change were included in the modelling study, an additional layer of uncertainty would be added to the results, such that the interpretation of 'typical' versus 'worst-probable-case' scenarios becomes difficult and, possibly, non-conservative.

- Given the exceedingly low and temporally constant probability of a spill incident, it is impossible to predict where along the climate change spectrum a potential spill could occur. The probability of spill occurrence is the same across all years of operation, including in the near term when climate change effects are negligible and the long term when climate change may be felt in coastal British Columbia. Therefore, including climate change effects provides a modelling approach no more valid than without them, even if the effects were non-trivial to the present modelling study.

As a consequence of the above three points, it was determined that, firstly, climate change effects on local oceanographic processes are not significant as compared to the simulated range of conditions and, secondly, the addition of climate change factors into the modelling study would only serve to cloud the representativeness of the results and add uncertainty to the results.

f. No projected changes in water levels due to climate change has been accounted for in the spill and oil dispersion models H3D, SWAN, and SPILLCALC.

f1. N/A

f2. Climate change effects were not included in the models simulating the fate and behavior of diluted bitumen. Climate change was excluded from the modelling study for several reasons:

- The range of oceanographic conditions simulated is significantly larger than the predicted changes in local oceanographic properties due to climate change. Essentially, the alterations in mean and extreme levels of temperature, density, salinity, wind, water chemistry and sea level are insignificant as compared to the range of conditions under consideration in the stochastic simulations. Since a stochastic approach was conducted to assess the extent of a credible worst case scenario, various environmental conditions were considered (wind speed, water level…). The change brought by climate change to these conditions is not expected to impact the results of the spill modelling. The extent of shoreline being affected by an oil spill will still be very similar, even though sea level rise may locally affect the attributes of the shoreline.

- There is significant uncertainty in long term predictions of climate change and its impacts on local oceanographic processes. If estimates of climate change were included in the modelling study, an additional layer of uncertainty would be added to the results, such that the interpretation of 'typical' versus 'worst-probable-case' scenarios becomes difficult and, possibly, non-conservative.
- Given the exceedingly low and temporally constant probability of a spill incident, it is impossible to predict where along the climate change spectrum a potential spill could occur. The probability of spill occurrence is the same across all years of operation, including in the near term when climate change effects are negligible and the long term when climate change may be felt in coastal British Columbia. Therefore, including climate change effects provides a modelling approach no more valid than without them, even if the effects were non-trivial to the present modelling study.

As a consequence of the above three points, it was determined that, firstly, climate change effects on local oceanographic processes are not significant as compared to the simulated range of conditions and, secondly, the addition of climate change factors into the modelling study would only serve to cloud the representativeness of the results and add uncertainty to the results.

g. No natural multi-year cycles affecting water properties or currents in the Fraser River, the Fraser River estuary, and the marine waters of the Salish Sea have been accounted for in the spill and oil dispersion models H3D, SWAN, and SPILLCALC.

g1. N/A.

g2. The effects of multi-year marine cycles were not included in the models simulating the fate and behavior of diluted bitumen. Such effects were excluded from the modelling study because the range of oceanographic conditions over a simulated spill event is significantly larger than the typical changes in local oceanographic properties due to multi-year marine cycles. Essentially, the cyclic variations in mean and extreme levels of temperature, salinity and air pressure are insignificant as compared to the range of conditions under consideration in the stochastic simulations such as the passage of a wind storm, the influence of the seasonally-varying Fraser River flow, and the daily effect of tides on spill. Since a stochastic approach was conducted to assess the extent of a credible worst case scenario, various environmental conditions were considered (wind speed, water level…). The change brought by natural multi-year cycles to these conditions is not expected to impact the results of the spill modelling. The extent of shoreline being affected by a typical oil spill will still be very similar, even though local wind and current patterns may vary from year to year.

As a consequence, it was determined that the effects of natural multi-year marine cycles on local oceanographic processes are not significant as compared to the simulated range of conditions.

h. No projected changes in weather pattern associated with climate change which could affect the Fraser River, the Fraser River estuary, and the marine waters of the Salish Sea has been accounted for in the spill and oil dispersion models H3D, SWAN, and SPILLCALC.

h1. N/A

h2. Climate change effects were not included in the models simulating the fate and behavior of diluted bitumen. Climate change was excluded from the modelling study for several reasons:

- The range of oceanographic conditions simulated is significantly larger than the predicted changes in local oceanographic properties due to climate change. Essentially, the alterations in mean and extreme levels of temperature, density, salinity, wind, water chemistry and sea level are insignificant as compared to the range of conditions under consideration in the stochastic simulations. Since a stochastic approach was conducted to assess the extent of a credible worst case scenario, various environmental conditions were considered (wind speed, water level…). The change brought by climate change to these conditions is not expected to impact the results of the spill modelling. The extent of shoreline being affected by an oil spill will still be very similar, even though sea level rise may locally affect the attributes of the shoreline.

- There is significant uncertainty in long term predictions of climate change and its impacts on local oceanographic processes. If estimates of climate change were included in the modelling study, an additional layer of uncertainty would be added to the results, such that the interpretation of 'typical' versus 'worst-probable-case' scenarios becomes difficult and, possibly, non-conservative.

- Given the exceedingly low and temporally constant probability of a spill incident, it is impossible to predict where along the climate change spectrum a potential spill could occur. The probability of spill occurrence is the same across all years of operation, including in the near term when climate change effects are negligible and the long term when climate change may be felt in coastal British Columbia. Therefore, including climate change effects provides a modelling approach no more valid than without them, even if the effects were non-trivial to the present modelling study.

As a consequence of the above three points, it was determined that, firstly, climate change effects on local oceanographic processes are not significant as compared to the simulated range of conditions and, secondly, the addition of climate change factors into the modelling study would only serve to cloud the representativeness of the results and add uncertainty to the results.

i. No projected changes in meteorological conditions associated with climate change in the Salish Sea has been accounted for in the spill and oil dispersion models H3D, SWAN, and SPILLCALC.

i1. N/A

i2. Climate change effects were not included in the models simulating the fate and behavior of diluted bitumen. Climate change was excluded from the modelling study for several reasons:

- The range of oceanographic conditions simulated is significantly larger than the predicted changes in local oceanographic properties due to climate change. Essentially, the alterations in mean and extreme levels of temperature, density, salinity, wind, water chemistry and sea level are insignificant as compared to the range of conditions under consideration in the stochastic simulations. Since a stochastic approach was conducted to assess the extent of a credible worst case scenario, various environmental conditions were considered (wind speed, water level…). The change brought by climate change to these conditions is not expected to impact the results of the spill modelling. The extent of shoreline being affected by an oil spill will still be very similar, even though sea level rise may locally affect the attributes of the shoreline.
- There is significant uncertainty in long term predictions of climate change and its impacts on local oceanographic processes. If estimates of climate change were included in the modelling study, an additional layer of uncertainty would be added to the results, such that the interpretation of 'typical' versus 'worst-probable-case' scenarios becomes difficult and, possibly, non-conservative.
- Given the exceedingly low and temporally constant probability of a spill incident, it is impossible to predict where along the climate change spectrum a potential spill could occur. The probability of spill occurrence is the same across all years of operation, including in the near term when climate change effects are negligible and the long term when climate change may be felt in coastal British Columbia. Therefore, including climate change effects provides a modelling approach no more valid than without them, even if the effects were non-trivial to the present modelling study.

As a consequence of the above three points, it was determined that, firstly, climate change effects on local oceanographic processes are not significant as compared to the simulated range of conditions and, secondly, the addition of climate change factors into the modelling study would only serve to cloud the representativeness of the results and add uncertainty to the results.

CREDIBLE WORST CASE SCENARIO

2.02 Credible Worst Case Spill Size

Reference:

i) A3S5F6, Application Volume 8C TR 12 TERMPOL 3.15, Sections 9.1.1 to 9.1.5, PDF pages 35 to 41 of 100.

ii) A3S5F6, Application Volume 8C TR 12 TERMPOL 3.15, Section 9.9.1, Table 2.6, PDF page 35 of 100.

Preamble:

Reference (i) describes in part the methods used to derive the "credible worst case scenario" (CWC) and corresponding spill sizes for project related oil tankers. It states that "total loss" is not considered a viable scenario as there has never been such an event with a double-hulled tanker. In this case, the definition of a "credible worst case" scenario is not given in TERMPOL 2001 guidelines, and Trans Mountain Pipeline (TMP) has chosen a "90th percentile event causing uncontrolled outflow from a tanker's cargo oil tanks" as the definition of credible worst case scenario for this project. Reference (ii) shows the estimated cargo size for the Aframax tanker used in the scenarios.

Independent peer review and transparency is important for model and simulation verification and repeatability. Often, software packages such as the Naval Architecture Package (NAPA), which has been used in the determination of CWC oil cargo releases and which costs approximately $50,000-$150,000, is either proprietary or prohibitively expensive, thus precluding independent review. As other models (such as SPILLCALC) rely heavily on the CWC cargo sizes, this in turn precludes transparency for conclusions based on the determination of CWC cargo spill volumes.

Request:

a. Please confirm that the loss of less than approximately 14% of the cargo (16,500 m3 out of a total cargo of 120,263 m3) from a partially laden oil tanker is considered a "credible worst case scenario".

b. Please explain the assumption that because an event has not occurred to date (i.e. total loss of cargo from a double hull tanker), it is outside the realm of future possibility.

c. Please provide the rationale for using the 90th percentile, as opposed to the 95th or 99th percentiles as examples.

d. Figures 34 and 35 in Reference (i) refer to distributions of spill sizes generated by Monte Carlo simulations. Please provide information on the nature of the spills that are larger than the recommended 90th percentile credible worst-case spill size. This would include the input parameters of those simulations including penetration depth and hole sizes, and the curves (those taken from IMO MARPOL regulations) that they were drawn from.

e. Please provide a detailed and explicit description of all statistical/analytical data treatments, assumptions and/or algorithms used to derive the credible worst case spill sizes for oil tankers, for both grounding and collisions, including the statistical methods and parameterisations within the Naval Architecture Package (NAPA Ltd.) software package.

f. If the Monte Carlo simulations in reference (i) were initiated and/or constrained within a size range, please provide those numbers and methods.

g. Please provide validation of the spill volumes generated by using the Monte Carlo simulations as compared to historical accidents involving groundings and collisions with comparable tankers.

h. Please provide appropriate reference information, and the references themselves if not publicly available, for any peer review that has taken place on the determination of the credible worst case scenarios.

Response:

a. Yes, 16,500 m^3 is confirmed as being determined as the credible worst case spill (90^{th} percentile) from a partly laden Aframax tanker as proposed in the project. Please see Volume 8C, Termpol 3.15, Section 9.1.5 for details on how this was determined (Filing ID A3S5F8.)

b. Double hull oil tankers have been in operation for over 20 years. With no total loss of cargo event from a double hull oil tanker having occurred in the past 20 years, it is justifiable to consider such an event as not a credible event. Please refer to Section 9.1.5 in Volume 8C, TERMPOL 3.15, which describes the analysis of past oil spills and determination of the credible worst case scenario (Filing ID A3S5F6).

c. Please refer to Section 9.1.5 in Volume 8C, TERMPOL 3.15, which describes the analysis of past oil spills and determination of the credible worst case scenario as the 90^{th} percentile loss of cargo oil (Filing ID A3S5F6). The 90^{th} percentile reflects the loss of the entire cargo from two cargo tanks; incidents involving more than the equivalent of more than two tanks was found to be highly improbable. Thus the 90^{th} percentile is determined as the credible scenario for risk mitigation and response planning purposes.

d. The complete NAPA model output results (*i.e.*, oil spill probability modeling results for grounding and collisions) can be found in Attachment 1 to Trans Mountain's response to Tsawout FN IR No. 1.30x (Filing ID A3Y3U5).

e. Trans Mountain respectfully notes that the requested information is confidential and not publicly available.

f. The complete NAPA model output results (*i.e.*, oil spill probability modeling results for grounding and collisions) can be found in Attachment 1 to Trans Mountain's response to Tsawout FN IR No. 1.30x (Filing ID A3Y3U5). These were run basis an Aframax size tanker.

g. The probabilities that an oil cargo tank will breach in case of a collision or grounding are very conservative, as the method applies 10 years of damage statistics from 1980 to 1990 during which period the majority of the tankers that had a breach in the hull causing oil spills were single hull tankers, whereas in this study all tankers are double hulled. This conservatism has been partly compensated for by transferring the statistical damage extents (indentation depth and hole extents) to a modern double hull tanker in a NAPA model, to model if the damage would have caused a breach in one or more tanks of a modern double hull tanker. Further, the damage extent and oil spill volumes estimated are the 90% worst case impact (credible worst case) where oil is spilled. This impact and oil spill modeling does not take into account any reduced speed of the vessel or speed reduction due to tug support, which makes the analysis even more conservative. Volume 8C TERMPOL 3.15 (Filing ID A3S5F6) provides further detail.

h. The marine risk assessment was submitted to the TERMPOL Review Committee (TRC) along with other studies according to the TERMPOL Review Process guidance document (2001). Section 9.1.5 of TERMPOL 3.15: General Risk Analysis and Intended Methods of Reducing Risk (Filing ID A3S5F6), discusses the derivation of the credible worst case oil spill. Trans Mountain's Response to NEB IR regarding TERMPOL Report and Outstanding Filings (Filing ID A4G3U5) provides updated results, taking into account the TERMPOL Review Committee's (TRC) endorsement of specific risk reduction measures, and refinements from studies in response to the first round of IRs and presented to the TRC.

Trans Mountain believes that it has applied due diligence and rigour to undertaking a review of marine risks associated with increased tanker activity in the study area using MARCS, and that additional reviews are not needed. Trans Mountain is confident that the evaluation of potential environmental effects undertaken by Trans Mountain fulfills NEB requirements (Filing ID A3V6I2) and describes the range of environmental effects that could result from an oil spill along the marine shipping route. Trans Mountain has carefully evaluated the risk of oil spills due to the Project and proposed measures that adequately address the risks, including the risk of a credible worst case oil spill.

MODEL PERFORMANCE

2.03 Risk Analysis

Reference:

i) A3S5F6, Application Volume 8C TR 12 TERMPOL 3.15, Section 11.2, PDF page 53 of 100.

ii) A3S5F6, Application Volume 8C TR 12 TERMPOL 3.15, Appendix 1, PDF page 70-85.

iii) A3Y3W4, Trans Mountain Response to Weaver IR No. 1, IR 1.10.g, PDF page 99 of 148.

iv) A3Y3W4, Trans Mountain Response to Weaver IR No. 1, IR 1.10.5x, PDF page 104 of 148.

v) A3Y3W4, Trans Mountain Response to Weaver IR No. 1, IR 1.10.5k.1-k.3, PDF page 100-101 of 148.

vi) A3Y3W4, Trans Mountain Response to Weaver IR No. 1, IR 1.11 c5, PDF page 121 of 148.

vii) A3Y3W4, Trans Mountain Response to Weaver IR No. 1, IR 1.10.5, IR 1.11 a5, and IR 1.11 c4, PDF pages 103, 117, and 120 of 148, respectively.

viii) A3Y3W4, Trans Mountain Response to Weaver IR No. 1, IR 1.10k1 and IR 1.11 cc3.iii, PDF pages 100 and 106 of 148, respectively.

ix) A3Y3W4, Trans Mountain Response to Weaver IR No. 1, IR 1.10k4, PDF page 101 of 148.

Preamble:

The repeatability of study results is paramount to the integrity of the scientific process. Principally, the findings of a study are accepted as valid if they can be reproduced independently. Through this iterative process the body of science is advanced with bidirectional exchange of ideas, critique, and adoption of proven methods. Theories and study findings are accepted only until refuted by follow up investigation. For the scientific model to work properly and effectively, the process must be transparent allowing the data to speak for itself. If independent teams are restricted access to datasets, model environments, or information describing modelled input parameters, refuting or accepting statements and conclusions generated from model output is impossible.

Reference (i) states that the MARCS model was first developed in the 1990s and has been used extensively and peer reviewed since that time. Det Norske Veritas (DNV) states that following significant modifications of risk models, discrepancies between subsequent model versions are understood and either eliminated or documented.

Reference (ii) describes the organization and operation of the MARCS model. The MARCS model provides a general framework for the performance of marine risk calculations.

Without having a full understanding of the uncertainty and sensitivity of these models, it is impossible for the public and the NEB to have a sense of the confidence they should have in the model outputs, conclusions drawn, and ultimately the calculation of risk to the marine environment. Previous Information Requests (References (ii) through (ix)) aimed at evaluation of model confidence for MARCS, including uncertainty, sensitivity, robustness, precision, accuracy or suitability, have been:

1) denied on the basis of proprietary information (ex Ref iv),

2) referred back to material in the application that generated the question (ex Ref iii),

3) countered, based on professional opinion of the applicant or its consultants (ex Ref vii),

4) deemed adequate based on professional opinion of applicant or its consultants (ex Ref viii),

5) deemed not necessary to determine marine risk (ex Ref ix); or

6) deemed as appropriate and credible information to determine marine risk (ex Ref vii).

The rejection of requests to evaluate the model and its components run counter to transparency and peer review. The ability to repeat study results is critical in demonstrating scientific rigor.

Request:

a. Please provide full citations for third party academic peer review(s) of MARCS methods and results conducted by the US National Academy of Science (Reference (i): 1996 and 2010 projects).

b. Please provide appropriate reference information, and the references themselves if not publicly available, for any other peer review of the MARCS model and its use. Please confirm whether or not these publications are from a peer-review and refereed process such as academic journals.

c. Please identify if MARCS uses classical (frequentist), Bayesian, or information theoretic statistical approaches as part of the modelling process.

d. Please provide the revision history of the MARCS model. This “log file” should include information on temporal updates, as well as any changes in statistical approaches and algorithms.

e. Please confirm that the current version of the MARCS model attempts to account for human error of maritime crew as a factor in risk analysis. If so, how?

f. Please confirm that the current version of the MARCS model is best described as a static model, as opposed to employing dynamic modelling.

g. Please list all statistical analytic tests employed by the MARCS model.

h. Please provide site-specific fault tree symbolic logic diagrams for the Collision Model and Powered Grounding Model including the probabilities of all primary faults (lowest tiers).

i. Please provide Unified Modelling Language (UML) activity diagrams for all algorithms employed by the MARCS model. The product(s) should indicate flow of work, indicating model inputs, actions, and decisions from initial to final state(s).

j. Please provide a list of all peer-reviewed and refereed journal articles that introduce, describe the modelling environment, attempt to validate with historical data, or provide critical review of the MARCS model.

k. Please explain the decision to only model frequency assessments of marine traffic for years 2018 and 2028, when the expected life of the project and its infrastructure is no less than 50 years.

Response:

a. The Technical Review of the Aleutian Islands Risk Assessment (AIRA) Phase A Draft Summary Report of the Semi-Quantitative Traffic Study Report and the Baseline Spill Study Report (Attachment 1 of Trans Mountain's Response to Tsawout FN IR No. 1.30n, Filing ID A3Y3U3) is a peer reviewed document. Det Norske Veritas' List of Previous Projects Using the Marine Accident Risk Calculation System (Attachment 2 of Trans Mountain's Response to Tsawout FN IR No. 1.30n (Filing ID A3Y3U4) is a list of projects where MARCS has been used, including various national projects. It is assumed that the results of MARCS for these projects have been thoroughly reviewed and considered to be of sufficient diligence and rigour to be accepted for future decision making on risk mitigation.

The names of reviewers are shown in the Technical Review of the AIRA reports (Filing ID A3Y3U3). All DNV GL project reports have been reviewed to different degrees by clients, governmental and non-governmental agencies and peers. Names of reviewers from different projects cannot be provided.

b. The following reviews of the MARCS model and its use may be considered:

- Fowler T.G. and Sørgård E. 2000. Modeling Ship Transportation Risk. Risk Analysis:20(2). pp.225-244. (Please refer to Raincoast IR No. 2.03b – Attachment 1).
- Fowler, T.G., Grabowski, M. and Harrald, J., "Overview of Prince William Sound Risk Assessment Project". Presented at Marine Risk Assessment: A better way to manage your business, Institute of Marine Engineers, 4-5 May 1997. (Please refer to Raincoast IR No. 2.03b – Attachment 2).

In understanding and evaluating a marine risk assessment methodology Trans Mountain is of the opinion that a peer-review process can extend beyond academics and researchers and include publicly available comments from experts in the field of marine safety, such as those comments regarding the DNV risk assessment model found in the following document:

- North-East Shipping Management Group 2013. Australian Government Draft North-East Shipping Management Plan. (Please refer to Raincoast IR No. 2.03b - Attachment 3).

c. The MARCS model uses the classical (frequentist) approach.

d. Trans Mountain respectfully notes that this is DNV proprietary information and cannot be shared. Key improvements to the MARCS model that have been used for the Trans Mountain Expansion Project (TMEP) are:

- dynamic use of AIS data, including critical scrutiny of traffic patterns;
- application of dynamic and area specific vessel speeds;
- statistical 3D modeling of oil outflow for project specific vessels; and
- area-specific studies of Vessel Traffic Services (VTS).

e. The potential for human error to influence the risk is correctly taken into account in the marine accident risk calculation system model (MARCS) through 3 distinct mechanisms. First, the model is based on historical accident data, as a proportion of historical accidents have been caused by human error. Second, the fault trees in the model have explicit inputs for human performance error rates (*i.e.,* mistakes) and for human reliability error rates (*e.g.,* incapacitation due to heart attack). Fault trees are used in the model to identify sources of potential risks. Third, parameters are selected towards the conservative end of credible ranges so that risks are not underestimated (*e.g.,* under best case conditions a free escort tug should be able to take control of a tanker within 10 minutes, but the risk model assumes this takes at least 30 minutes) (Please refer to Volume 8C TERMPOL 3.15, Filing IDs A3S5F4, A3S5F6, A3S5F8). Please also refer to Raincoast IR No. 2.03b – Attachment 1 to Attachment 3.

f. The MARCS model as employed by DNV GL in the risk assessment for the Trans Mountain Expansion Project is a semi-static (and semi-dynamic) model. The model considers ship movements, but does not directly represent some types of correlated parameters. When factors are identified as important, MARCS represents their influence in an approximate and conservative manner.

All models have strengths and weaknesses. One of the weaknesses of MARCS is that it is less able to directly represent certain types of time-dependent behaviours, such as closure of waterways due to high wind or correlated traffic movements. Such omissions are generally a source of conservatism (*i.e.,* overestimation of risk). One of the significant improvements made to the MARCS model is that MARCS now utilizes AIS data from the study area, rather than the original assumptions of average vessel speed, in order to better analyze and replicate the actual traffic pattern and activity in the model. Please refer to Appendix 1 of Volume 8C TERMPOL 3.15 for a full description of the MARCS model used by DNV GL in the marine risk assessment (Filing ID A3S5F6).

Results of MARCS are conservative and this has been appreciated by a number of DNV clients who have appointed DNV to assess the marine risks, including in their national waters. Please refer to the response to Tsawout FN IR No.1.30n (Filing ID A3Y3T9).

g. This information is already provided in Appendix 1 of TERMPOL 3.15 (Filing ID A3S5F6). Please note that MARCS is DNV's proprietary risk assessment model and certain information cannot be provided due to commercial confidentiality reasons.

h. Trans Mountain respectfully notes that this is DNV proprietary information and cannot be shared.

i. Trans Mountain respectfully notes that this is DNV proprietary information and cannot be shared.

j. Please see Trans Mountain's responses to Raincoast IR No. 2.03a and 2.03b.

k. To assist in developing the Trans Mountain Expansion Project (the Project) Application to the National Energy Board, Trans Mountain Pipeline, ULC engaged Det Norske Veritas (DNV) to undertake a study in accordance with the TERMPOL Review Process (2001) that estimates the risk of marine incidents as a result of the increase in tanker traffic expected due to the project, mainly due to collisions and groundings, in the agreed marine regional study area (RSA) and thereafter calculate the risk of an oil spill involving a Project tanker, including the risk of a credible worst case size oil spill. The project is expected in service, subject to approval, in 2018. A forecast of marine traffic in 2028 was developed and assessed as well. Tanker traffic from the project is not expected to change during the period, only other traffic. Given the long term and short term economic cycles that drive marine traffic to the region it is not feasible to forecast beyond 2028 based on current information. The project is commercially viable based on the existing long term contracts by shippers that vary between 15 and 20 year duration. Life of the project and its infrastructure beyond the existing contracts is speculative.

Trans Mountain is confident that the evaluation of potential environmental effects applying this methodology fulfills NEB requirements (Filing ID A3V6I2) and describes the range of environmental effects that could result from an oil spill along the marine shipping route.

2.04 Modeling of Marine Oil Spills

Reference:

i) A3S5G9, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, PDF pages 18 to 42 of 72.

ii) A3Y3W4, TM IR response to Weaver No 1.11 5c, PDF page 121 of 148.

Preamble:

The repeatability of study results is paramount to the integrity of the scientific process. Principally, the findings of a study are accepted as valid if they can be reproduced independently. Through this iterative process the body of science is advanced with bidirectional exchange of ideas, critique, and adoption of proven methods. Theories and study findings are accepted only until refuted by follow up investigation. For the scientific model to work properly and effectively, the process must be transparent allowing the data to speak for itself. If independent teams are restricted access to datasets, model environments, or information describing modelled input parameters, refuting or accepting statements and conclusions generated from model output is impossible.

SPILCALC is a proprietary model that requires a wave model (SWAN) and a 3D hydrodynamic model (H3D) to simulate the fate and behaviour of oil spills. These models are briefly described in Reference (i).

Previous questions aimed at evaluating the models' confidence, including uncertainty, sensitivity, robustness, precision, accuracy or suitability, have yet been unanswered. For example, see Reference (ii). Without a full understanding of the uncertainty and sensitivity of these models, it is impossible for the public and the NEB to have a sense of the confidence they should have in the model outputs, conclusions drawn, and the reality of oil spill scenarios portrayed.

2.04.1 H3D

Request:

a. Please confirm whether the H3D model structure in Reference (i) employs classical (frequentist), Bayesian, or information theoretic statistics. If so, what are the specific statistical approaches?

   Reference (ii) states that H3D was derived from GF8 in 1993.

b. Please provide the current revision history of the H3D model. This "log file" should include information on temporal updates and changes in statistical algorithms, and show how the model has adapted with advances in statistical modelling design and periodic model testing and evaluation.

c. Please list all statistical analytic tests employed by the H3D model.

d. Please provide Unified Modelling Language (UML) activity diagrams for all algorithms employed by the H3D model. The product(s) should indicate flow of work indicating model inputs, actions, and decisions from initial to final state(s).

e. Please provide a list of all peer-reviewed and refereed journal articles that introduce, describe the modeling environment of, attempt to validate with historical data, or provide critical review of the H3D model.

Response:

a. H3D is a three-dimensional numerical hydrodynamic simulation model: it uses the laws of physics as well as theoretical formulations to predict the motions of a body of water over time. <u>It is not a statistical model.</u> Statistical terms, such as averages, described in the documents mentioned above refer to statistics distilled from the results of multiple model simulation runs.

b. The H3D model is not a statistical model, so updates and changes in statistical algorithms, advances in statistical model design and periodic model testing and evaluation are not part of the H3D maintenance process. The current status of H3D's numerical algorithms is described in the Application.

In addition, the H3D model has been developed and tailored to respond to specific clients needs over the years. Even though a proper "log file" was not created, the model has been tested and calibrated at each stage of its development and multiple validations conducted for various projects have been produced. Several of these validations are provided in the Application. Several papers have been published, demonstrating H3D's usage and validations. These papers are listed in response to Raincoast IR No. 2.04.1e.

c. As noted in the response to Raincoast IR No. 2.04.1a, H3D is not a statistical model. No statistical analytic tests are employed by the H3D model.

d. The UML diagram is attached (refer to Raincoast IR No. 2.04.1d - Attachment 1). The model is a time-stepping model, so that all cells are repetitively updated, based on values form the preceeding timestep; the UML is essentially one long loop, with some initialization tasks at the start of the run.

e. The following papers about the H3D model have been published:

Hay and Company. 2000. Influence of Limnology on Domestic Water Intakes. Report to the City of Kelowna, BC.

Hay and Company. 2002. Oceanographic Studies in the Malaspina/Okeover/Lancelot/ Theodosia System. Report to the BC Ministry of Agriculture, Food and Fisheries.

Meselhe E.A. and J.A. Stronach. 2001. Brown Lake Hydrologic Restoration Study. ASCE Proceedings.

Meselhe E.A., E.H. Habib, A.G. Griborio, C. Chen, S. Gautam, J.A. McCorquodale, I.Y. Georgiou and J.A. Stronach. 2005. Multidimensional Modeling of the Lower Mississippi River. Proceedings of the Ninth International Conference on Estuarine and Coastal Modeling, published by ASCE.

Rego J.L., E. Meselhe, J.A. Stronach and E. Habib. 2010. Numerical Modeling of the Mississippi-Atchafalaya Rivers Sediment Transport and Fate: Considerations for Diversion Scenarios. Journal of Coastal Research Vol. 26 No. 2, pp.212-229.

Saucier, F.J. and J. Chasseé. 2000: Tidal Circulation and Buoyancy Effects in the St. Lawrence Estuary. Atmosphere-Ocean, 38, 505-556.

Stronach, J.A., J.O. Backhaus, and T.S. Murty. 1993. An Update on the Numerical Simulation of Oceanographic Processes in the Waters between Vancouver Island and the Mainland: the GF8 model. Oceanography and Marine Biology Annual Review, 31:1-86.

Zaremba, L., E. Wang, and J. Stronach, 2005. The physical limnology of Okanagan Lake. In “Water – Our Limiting Resource”: Towards Sustainable Water Management in the Okanagan, Proceedings of Canadian Water Resources Association B.C. Branch Conference, Feb. 23-25, 2005, Kelowna, BC. ISBN 1-896513-28-X.

2.04.2 SWAN Wave Model

Request:

a. Please confirm whether the SWAN model structure in Reference (i) relies on classical (frequentist), Bayesian, or information theoretic statistical modelling.

b. Please provide the current revision history of the SWAN model. This "log file" should include information on temporal updates and changes in statistical algorithms, and show how the model has adapted with advances in statistical modelling design and periodic model testing and evaluation.

c. Please list all statistical analytic tests employed by the SWAN model.

d. Please provide Unified Modelling Language (UML) activity diagrams for all algorithms employed by the SWAN model. The product(s) should indicate flow of work indicating model inputs, actions, and decisions from initial to final state(s).

e. Please provide a list of all peer-reviewed, refereed journal articles that introduce, describe the modelling environment of, attempt to validate with historical data, or provide critical review of the SWAN model.

Response:

a. The SWAN model is a numerical model that simulates physical processes using accepted numerical formulations of these processes. <u>It is not a statistical model.</u> The introduction to the SWAN Scientific and Technical Documentation (ref) begins by indicating that solving the spectral action balance equation without any *a priori* restrictions on the spectrum for the evolution of wave growth is the main goal of the SWAN model. This equation represents the effects of spatial propagation, refraction, shoaling, generation, dissipation and nonlinear wave-wave interactions. (Delft University of Technology, 2011) Statistical terms, such as averages, described in the documents mentioned above refer to statistics distilled from the results of multiple model simulation runs.

Reference:

Delft University of Technology. 2011. SWAN Scientific and Technical Documentation – SWAN Cycle III version 40.85. Delft, the Netherlands.

b. The following revision history was acquired from the SWAN model website on 22 January 2015. SWAN version 40.72 was applied in the simulations described in the references above. As noted in the response to Raincoast IR No. 2.04.2a, SWAN is not a statistical model.

Modifications

The current version number of SWAN is 41.01. This page contains a list of additions, changes, compatibility, implementation issues and bug fixes (affecting the user) since version 30.51 (first FTP-release).

Additions

Version 41.01:

- The so-called β-kd model for surf breaking based on the work of Salmon and Holthuijsen (2011) is included as an option. This model determines the breaker index γ based on the bottom slope β and the dimensionless depth *kd*.
- An alternative for triad wave-wave interactions is added. This alternative is the Stochastic Parametric model based on the Boussinesq-type wave equations (SPB) of Becq-Girard et al. (1999).
- Interaction of waves with fluid mud is included as an option. Fluid mud affects waves through viscous damping and alters the dispersion relation and thereby the change in wave number and group velocity. These are obtained from the model of Ng (2000). Details on the implementation and application of fluid mud-induced wave dissipation can be found in Rogers and Holland (2009).
- A movable bed roughness model through ripple formation is included as an alternative. This model is implemented in SWAN as described in Smith et al. (2011), in which bottom friction depends on the formation process of bottom ripples and on the grain size of the sediment.

Version 40.91:

- New limiters are included to handle refraction and frequency shifting on *coarse meshes* in a proper way.
- Output data from a parallel, unstructured mesh simulation are *automatically* merged.
- A new concatenation program, called HottifySWAN, for collecting hotfiles after a parallel, unstructured SWAN simulation.
- An alternative to the well-known Wu (1982) winddrag parameterization is added. It is based on a review of a large number of more recent observations, and will gives lower drag values for relatively high wind speeds (compared to Wu (1982)). This parameterization has been published recently in the following paper: Zijlema *et al.* (2012).

Version 40.85:

- Inclusion of parallel, unstructured mesh implementation utilizing the parallel infrastructure from ADCIRC.

- Inclusion of hooks for tightly coupled ADCIRC and SWAN models.
- New pre-defined curves for outputting: `BOUNDARY`, `BOUND_01`, `BOUND_02`, etc. See command `CURVE` in the User Manual.
- A new output quantity for TABLE and BLOCK: peak wave length named as LWAVP.

Version 40.81:

Wave damping due to vegetation (mangroves, salt marshes, *etc.*) at variable depths is included as an option. The calculation of this type of dissipation is specified by the drag coefficient, the stem diameter of plant (schematised as a cylinder), the number of plants per square meter and the vegetation height. In addition to the vertical variation, the possibility of horizontal variation of the vegetation characteristics is included as well. This inclusion enables the vegetation in a given region to be varied so as to reflect real density variations in the field.

Version 40.72:

- The use of unstructured mesh in the geographical domain is included. The grid may be comprised of triangular cells only. The following grid generators are supported by SWAN:
  - ADCIRC (use of the file fort.14 generated by SMS)
  - Triangle
  - Easymesh
- For the computation of the integral parameters (e.g. significant wave height, directional spreading, etc.) for output purposes, the choice for carrying out the integration over a user-defined interval [fmin,fmax] is included.

Version 40.51:

- An alternative of the whitecapping expression based on Alves and Banner (2003) is included. This dissipation term depends on quantities that are local in the frequency spectrum, as opposed to ones that are distributed over the spectrum, as in the Komen formulation (1984). This dissipation formulation can also be combined with the adapted formulation of Yan (1987) for wind growth. This alternative formulation is more accurate for young waves than the default expression of Komen et al. (1984). The combination of the alternative wind input and whitecapping expressions is able to correct both the tendency towards underprediction of wave periods in SWAN and the erroneous overprediction of wind-sea energy under combined swell-sea conditions occurring in nearshore zones. This combination can be obtained with the command GEN3 WESTH (instead of GEN3 KOM).
- Three new output quantities for TABLE and BLOCK: water level, bottom level and smoothed peak period named as WATLEV, BOTLEV and TPS, respectively. Besides

the water depth, you can also output the water level and/or bottom level. Whereas RTP (relative peak period) is calculated in an discrete manner (only function of frequency bins), the computation of TPS is made more smoother (i.e. can be a function of any frequency).

- The SWAN documentation is extended and improved. The old User Manual has been split up into two new documents: the *actual* User Manual and the Technical documentation. Moreover, the Programming rules and the manual LaTeX for dummies is added.
- Introduction of the online documentation. The abovementioned documents are also available online.

Version 40.41:

- Effects of diffraction is included. The approximation of these effects is based on the mild-slope formulation for refraction and diffraction but with omission of phase information.
- Introduction of scattered and diffuse reflections.
- An alternative stopping criterion is implemented and is based on the curvature of the iteration curve of the significant wave height. It is found to be more effective in locating the point of model convergence, yielding results that are closer to the fully-converged solution.
- A fast version of the DIA approximation for quadruplets is included. Neighbouring interactions are interpolated in a piecewise constant manner instead of linear one. Moreover, the DIA calculation is carried out in the full spectral circle per iteration (instead of a quadrant per iteration). As a result, a significant speed-up in the computation can be obtained. Use of this technique can be realised by setting QUAD IQUAD = 8. This approach has almost no effect on the model results compared to the default method (IQUAD = 2).
- The Xnl exact method for computing quadruplet interaction, appropriate for finite-depth water, is implemented. This method is, however, extremely time consuming.
- Extra output in PRINT file concerning convergence progress in user-selected geographic points. (Already introduced with patch H of the previous version 40.31.)
- Two new output quantities for TABLE and BLOCK: absolute and relative average wave period Tm-1,0 named as TMM10 and RTMM10, respectively. (Already introduced with patch H of the previous version 40.31.)

Version 40.31:

- For the specification of the discrete frequency space, SWAN permits the user to choose one of the following options:

  - The lowest frequency, the highest frequency and the number of frequencies can be specified. This choice is the usual one in the previous versions of SWAN.
  - The lowest frequency and the number of frequencies can be specified. The highest frequency will be computed by SWAN such that the ratio of frequency resolution is 10%. This is required by the DIA method.
  - The highest frequency and the number of frequencies can be specified. The lowest frequency will be computed by SWAN such that the ratio of frequency resolution is 10%. This is required by the DIA method.
  - The lowest and the highest frequencies can be specified. The number of frequencies will be computed by SWAN such that the ratio of frequency resolution is 10%. This is required by the DIA method.
- An exact method called the FD-RIAM, for the computation of the nonlinear 4-wave interactions in finite-depth water, is implemented. This method is extremely time consuming. Hence, it should not be used for production runs.

Version 40.20:

- The SWAN code is parallelized both using MPI and OpenMP.
- Alternative approximations for two physical processes are available:
  - M(ultiple) DIA for quadruplets and
  - Cumulative Steepness Method for white-capping.
- The Stone's SIP solver is implemented for solving action density equation, in case of non-stationary depth or ambient current. This solver is 4 to 5 times faster than the preconditioned BiCGSTAB solver.
- A frequency-dependent under-relaxation technique is implemented.

Version 40.11:

- SWAN allows nesting in WAVEWATCH III.
- Spherical co-ordinates are available.
- The user can define obstacles at which waves are reflected.
- A higher order propagation scheme is introduced for both the stationary and non-stationary modes.

Version 40.01:

- SWAN permits the calculation of wave-induced set-up. It is exact in 1D cases and approximate in 2D cases.

- Non-stationary boundary conditions are introduced.
- Initial conditions for a stationary or non-stationary computation can now be defined by the user.
- SWAN now also permits a "hotstart", i.e. using a initial condition computed by a previous SWAN run ("hotfile").
- The new version also permits the user to combine stationary and non-stationary computations.
- Source terms can be inspected since they are written to file at (user) selected geographic points.

Version 30.75:

- SWAN can now read and write wind and wave directions using both nautical and Cartesian conventions. The command SET NAUT switches to the nautical convention.
- It is now possible to impose stationary boundary conditions defined by wave spectra that vary along the boundary. The model interpolates between the boundary conditions at given points. The command BOUNDSPEC controls this.
- SWAN now produces a warning if the computed significant wave height differs from the prescribed significant wave height at the up-wave boundary. The command SET [hsrerr] controls the error margin for this warning.
- SWAN can now run in one dimensional stationary mode. The features specific for two dimensional calculations are not available when running in one dimensional mode. The command MODE STAT ONED switches to one dimensional mode.
- When calculating in one dimensional mode, the model can optionally include the effects of wave-induced setup. The command SETUP controls this.

Version 30.62:

- SWAN now accounts for sub-grid obstacles, that may (partially) transmit waves (no reflection). The command OBSTACLES controls this.
- SWAN is now more efficient and requires less memory, because exception values are now allowed in the CGRID command (land grid points are not computed and stored).

Version 30.51:

First release of SWAN.

Changes

Version 41.01:

- For computing wind drag the second order polynomial fit is the default instead of the well-known Wu (1982) parameterization. At the same time the value of the Jonswap bottom friction is set to 0.038 m^2/s^3. This is default irrespective of swell and wind-sea conditions.
- The stopping criterion of Zijlema and Van der Westhuysen (2005) is the default. This criterion is based on the curvature of the iteration curve of the significant wave height. The former stopping criterion (activated though `NUM ACCUR`) will become obsolete.
- The LTA formulation for triad-wave interactions is made consistent with the uni-directional approximation in the limit of directional spreading to zero. This is particularly meant for e.g. swell or in (nearly) 1D conditions.

Version 40.85:

- Length of character string of date-time for WAM nesting can be specified through variable [lwdate] with command `BOUND WAMNEST`. Note that the format of CDATE **cannot** be specified at the compile level anymore.
- The definition of the RMS orbital velocity has been reviewed. See the documentations.

Version 40.81:

- The RIAM approach for calculating the nonlinear 4-wave interactions has been removed.
- The format of CDATE for WAM nesting can be specified at the compile level. See the Implementation Manual.

Version 40.72:

- Interpolation of a wave parameter in a user-defined output location near an obstacle is improved. This means that this interpolation over the obstacle will be prevented.
- The default value of maximum number of iterations for a stationary computation is 50 (instead of 15).

Version 40.51:

The numerical implementation of triads is improved. It is energy-conservative and more stable.

Version 40.41:

- The implementation of 2D set-up is considerably improved. This version is much more robust than the previous one.
- The SWAN code is considerably cleaned up and optimized. As a consequence, a significant speed-up is obtained.
- Nesting in both SWAN and WWIII is further improved.
- Due to an update of WAM, the format of CDATE is changed from YYMMDDHHMM (10 characters) into YYMMDDHHMMSS (12 characters). SWAN enables to interpret the new format in case of nesting with WAM.
- Computing the dispersion relation is now based on a Pade approximation for the wave celerity instead of an old-fashion table look-up.
- The SIP solver is considerably improved. (Already done with patch C of the previous version 40.31.)
- The CSM white-capping formulation contains normalisation. (Already introduced with patch F of the previous version 40.31.)
- SWAN enables generation of binary MATLAB files for instationary computations. (Already introduced with patch F of the previous version 40.31.)
- More than 1 non-stationary computation is allowed in a parallel computation. (Already carried out with patch H of the previous version 40.31.)
- Maximum number of output requests increased from 50 to 250. (Already done with patch H of the previous version 40.31.)
- SWAN can read HOTFILE that contains variance density instead of action density. Furthermore, first direction in HOTFILE need not to be equal to the first direction defined by CGRID command. (Already introduced with patch H of the previous version 40.31.)

Version 40.31:

- The HPGL-functionality has been removed. This functionality is out-dated, is not maintained and is not supported on several platforms (*e.g.,* Windows XP, Linux, *etc.*). For this reason, SWAN 40.31 is not compatible with version 40.20!
- The command BOUND SIDE cannot be used in case of curvi-linear grids, because it does not work properly. Note that it works fine for recti-linear grids! For curvi-linear grids, the command BOUND SEGMENT should be employed.

- Both quadruplets and triads are activated simultaneously. Moreover, in case of decreasing wave height due to the depth-induced breaking, the limiter stay active. This will enhance the stability of the computation.

Version 40.20:

- It is possible to activate both quadruplets and triads at the same time.
- On request, spatial distribution of several quantities can be saved into binary MATLAB files.
- On request, detailed information concerning CPU- and wall-clock timings of several parts of the SWAN calculation is obtainable. Also, information on frequency use of limiting and rescaling (in terms of percentage of wet gridpoints) is provided.
- A number of small changes is made which does not have effect on the model results nor the performance.

Version 40.11:

- The approximation of the bathymetry in the refraction computations is improved. To give robust results (but not necessarily accurate results) in case of poor resolution in bathymetry, currents or the wave field itself, the user can activate a limiter to avoid waves turning over more than 90 degrees in one spatial grid step.
- The limiter on the refraction is switched off on default.
- In stationary mode the second order upwind (SORDUP) is chosen as default, while in non-stationary mode the S&L scheme is default. In the previous versions of SWAN only the backward space, backward time (BSBT) scheme was available. BSBT is still available optionally.

Version 40.01:

- For reasons of consistency the 2D spectral densities, used for input and output are now represented per frequency per directional degree (40.01) instead of per frequency per directional radian (30.75).
- The numerical approximation of the fraction of breakers in the surfzone has changed (more accurate).
- The primary task of the limiter is to stabilize the quadruplet wave-wave interactions (as approximated by the DIA). However, in SWAN 30.75, it also but unduly dampened the triad wave-wave interactions. If in SWAN 40.01 these triad interactions are active the quadruplet interactions and the limiter are de-activated. The coefficients of the triad interactions have been given correspondingly new default values.

- For very strong refraction the value of c_q is reduced in each grid point and for each wave component individually with the square of the fraction of the grid spacing over which kd<3.0.
- To improve the convergence characteristics of SWAN, the first-guess (in stationary mode) and the break-off criteria for the iterative procedure have been changed. The effects of these changes are usually hardly noticeable in field conditions whereas the computations are more accurate in laboratory conditions.

Version 30.75 (not compatible with version 30.62):

- Modified the handling of choosing physics for the model. Error messages warn the user regarding erroneous choices in the physics. In previous versions SWAN would automatically correct erroneous choices in the physics, this is now left to the user.

Compatibility

Version 41.01:

SWAN 41.01 is fully compatible with version 40.91ABC.

Version 40.91:

SWAN 40.91 is fully compatible with version 40.85.

Version 40.85:

SWAN 40.85 is fully compatible with version 40.81.

Version 40.81:

SWAN 40.81 is fully compatible with version 40.72ABCDE.

Version 40.72:

SWAN 40.72 is fully compatible with version 40.51AB.

Version 40.51:

SWAN 40.51 is fully compatible with version 40.41AB.

Version 40.41:

SWAN 40.41 is fully compatible with version 40.31. Due to several changes, a comparison between versions 40.41 and 40.31 may show small differences in the results.

Version 40.31:

Because of the removement of the HPGL-functionality, the commands LINE, SITES and PLOT... cannot be used.

Version 40.20:

SWAN 40.20 is fully compatible with version 40.11.

Version 40.11:

SWAN 40.11 is fully compatible with version 40.01. Due to the changes in SWAN, a comparison between versions 40.11 and 40.11 may show differences in the results.

Version 40.01:

SWAN 40.01 is fully compatible with version 30.75 except for

- command BOUNDPAR old version still accepted.
- command BOUNDSPEC old version not accepted!
- command BOUNDNEST1 old version not accepted!
- command GEN3 old version with limiter option not available.

Conversion programs are provided to convert the old spectra files into the new format.

Implementation

Version 41.01:

This version supports netCDF output (both integrated parameters and spectra).

Version 40.91:

Four different wizards for installing SWAN on your Windows PC are available on the SWAN website. They are tailored to your needs and specific requirements. There is a setup wizard for serial runs and there are wizards for parallel runs (e.g. OpenMP and MPI).

Version 40.85:

The hidden commands have been cleaned up. Only well-proven hidden commands may be used.

Version 40.72:

The source code of the unstructured grid functionality is written in free form Fortran90 style. Moreover, each file with extension f90 contains at most one subroutine or function.

Version 40.51:

- Automatic installation of SWAN on a Macintosh is available.
- On Linux platforms the SWAN source code can also be compiled with free GNU Fortran90 compilers, namely g95 and gfortran.

- An option is available to switch off the timing calls entirely inside SWAN. See Implementation Manual.

Version 40.41:

- The source code does not contain common blocks. The common variables are now resided in modules.
- For a heterogeneous machine, the sizes of the subdomains depend on the speed of the processors. This is accounted for in SWAN. A list of non-default processor speeds can be specified in the initialisation file SWANINIT. For details, see the Implementation Manual.
- Parallel MPI runs on Windows 2000/NT/XP are possible. (Already introduced with patch E of the previous version 40.31.)

Version 40.31:

- The program does not contain the POOL mechanism. As a consequence, the user may generate the executable once. Computation of problems with arbitrary sizes can be carried out with this executable. However, these sizes are restricted by the internal computer memory.
- For a number of computer platforms, the installation of SWAN can be done fully automatically. Further details can be found in the Implementation Manual.

Version 40.20:

- Add of OpenMP compiler directives.
- A set of generic subroutines based on MPI is devised that hide the technical details of local data exchange, gathering data, global reductions, etc. from SWAN subroutine calls. These can be found in swanparll.for.
- A Perl script called switch.pl is provided that enables the user to quickly select the switches to be removed for a correct installation of SWAN. These switches deals with the choice of a platform, notably Windows and Linux, usage of Fortran 95 features, enabling compilation with the MPI-library, etc. See the Implementation Manual for further information.

Version 40.11:

- All but one obsolescent FORTRAN 95 features have been removed to avoid compiler warnings.
- Allocatable arrays have been introduced to avoid the use of the POOL array for newly introduced arrays.
- Modules have been introduced to avoid lengthy argument lists of subroutines.

- The use of FORTRAN 90 features implies that SWAN will not compile under FORTRAN 77.

Version 40.01:

- Equivalent logical, real and integer POOL arrays have been introduced to avoid a frequently occurring compiler warnings.
- All STOP statements have been replaced by improved error handling to allow SWAN being used as a subroutine in a larger system.

Version 30.75:

All common blocks used in the source code have been moved to INCLUDE files. This makes it for developers easier to modify SWAN.

Bug fixes

The purpose of describing the bug fixes in terms of problems solved, is to enable the user to identify previous SWAN runs that may have encountered these problems (noticed at the time of running or in hindsight with this (new) information). All the bug fixes are implemented in the current version 41.01.

Solved in version 41.01:

- many bug fixes in netCDF implementation
- correction Gregorian date of December 31 for years 1599, 1999, 2399, etc.
- some bug fixes in outputting (e.g. spectra and date) for parallel unstructured mesh

The following fixes and (small) extensions were introduced with patch A.

- Spectra and maps can be outputted in netCDF format
- Parameter delta of whitecapping of WAM Cycle III is now set to 1 (this change is known as the Rogers' trick)
- Option to read/write hotfiles in binary format is included
- Small bug fix in output block in case of unstructured MPI run

The following fixes and (small) extensions were introduced with patch B.

- General bug fixes:
  - definition of TMBOT is corrected
  - small bug fix in interpolation routine
- Bug fixes with respect to netCDF implementation:

- SWAN does not restart after being killed
- add flow, fhigh and msc to frequency variable
- compile errors netCDF code
- when Cartesian convention is set, standard names should be modified accordingly
- add 'standard_name' to time, longitude and latitude
- set calendar attribute of time to 'gregorian' instead of 'julian'
- variable names in netCDF code (hswe, spread)
- add PROJ, RUNID and SWAN version as attributes to netCDF file

The following fixes and (small) extensions were introduced with patch C.

- upgraded and improved netCDF stuff
- very small corrections
- some textual changes in the manuals

Solved in version 40.91:

- fix in Janssen formulation for wind input
- small fix in Xnl formulation for quadruplets
- merging FRAME output data in case of parallel computing is corrected
- improvement in listing boundary vertices for unstructured grids
- unexpected behaviour removed when first output time is before start of computation
- open statement for existing Matlab file which should be replaced
- Julian date conversion is corrected (in particular for years 101, 102 and 103)
- several uninitializations removed
- inconsistency in case of reading WAM4.5 boundary conditions removed
- use of data type MPI_REAL4 instead of MPI_REAL to force the buffer size to be correct in the parallel communication in ADCIRC+SWAN environment
- hcat: lines extended from 256 to 1024 characters long

Solved in version 40.85:

- reading TPAR files is corrected
- nesting of unstructured grid is improved
- correction computation of dn/dh

Solved in version 40.81:

- computation of dissipation contributions for outputting corrected
- correction of format of spherical coordinates in swanhcat
- correction of "divide by zero" in case of WLEN and STEEPNESS

Solved in version 40.72:

- Maximum length of the lines in the output TABLE file is 720 (instead 360).
- Some small corrections:
  - computation of output parameter Hswell corrected
  - exception value for BOTLEV/WATLEV corrected

The following fixes and (small) extensions were introduced with patch A.

- Extensions and improvements to unstructured mesh implementation:
  - Handling holes in an unstructured grid is improved,
  - Creating data structures for elements and edges is more faster,
  - Prevention of interpolation over an obstacle is also included.
- The stopping criterion based on the curvature of Hm0 is extended with the curvature of Tm01.
- Each term of the action balance equation, i.e. time derivative of wave action, xy-propagation, θ-propagation, σ-propagation, wind input, quadruplets, whitecapping, surf breaking, friction and triads, can be outputted by means of the TABLE and BLOCK commands. Moreover, the so-called work done by the radiation stress (a rest term in the energy(!) balance equation) can be plotted as well.
- Bug fixes:
  - interpolation near an obstacle for spectra is corrected,
  - interpolation near a dry point is corrected,

  - small correction in output in case of MPI parallel runs.

The following fixes and (small) extensions were introduced with patch B.

- Extensions to unstructured mesh implementation:
  - Alleviation of the garden-sprinkler effect,
  - Phase-decoupled diffraction.
- An alternative to the JONSWAP formulation for bottom friction is included (friction coefficient depends on the frequency-dependent directional spreading).
- The SORDUP scheme is made more simpler and more consistent.
- Bug fixes:
  - correction of outputting the wave force on unstructured meshes in the case of spherical coordinates,
  - remove small inconsistency in the concatenation program for hotfiles,
  - small correction in collecting data for MPI parallel runs,
  - no use of the Hersbach and Janssen limiter in the case of stationary runs,
  - the user-value of water density will not be overwritten with the default value 1025 kg/m3.

The following fixes and (small) extensions were introduced with patch C.

- Unstructured mesh computation is made more efficient, i.e. only a few sweeps per iteration or time step is needed.
- Original fort.14 file can also be dealt with in SWAN. Boundary markers will be derived from the ADCIRC boundary information.
- Block outputting for unstructured mesh cases is considerably optimized.
- The default advanced stopping criterion (NUM STOPC) is based on the curvature of Hm0 only for reasons of robustness. However, the curvature of Tm01 can be included as an option.
- Technical documentation is extended with useful information.
- Bug fixes:
  - never-ending sweep in unstructured mesh cases is prevented,
  - assign reference point to deepest point in case of no boundary condition in unstructured mesh cases,

    - 2 small corrections in collecting data for MPI parallel runs.

The following fixes and (small) extensions were introduced with patch D.

- Computation with unstructured grids is parallelized using OpenMP directives.
- For writing block output to a Matlab binary file, the old format (Level 4) is replaced by the new one (Level 5 MAT-file format).

The following fixes and (small) extensions were introduced with patch E.

- Some adaption to Makefile and perl script plaform.pl.
- The so-called CSM formulation for whitecapping is removed.
- Reading input fields and block outputting for unstructured mesh cases is made more efficient.
- Technical documentation is extended with useful information.
- Bug fix in calculation of the orbital velocities.

Solved in version 40.51:

- total dissipation splitted out into 3 parts for output purposes
- improvements of WAM4 based on WAM Cycle 4.5 included (by Roop Lalbeharry)
- nesting of WAM in SWAN based on WAM Cycle 4.5 (by Roop Lalbeharry)
- Hersbach-Janssen limiter included in case of Janssen formulation for wind and whitecapping (by Roop Lalbeharry)
- improvements to reflection w.r.t. functionality and code (by Nico Booij)
- small changes in triad parameters (by Andre van der Westhuysen)
- User Manual adapted (items 1, 5 and 6)
- Technical documentation extended with various subjects
- bug fixes:
    - correction: initialisation of energy transport due to transmission
    - correction: do-loop in computing velocities in case of current
    - correction: in case of triads without quadruplets limiter should not be activated
    - correction: error message "spherical coordinates must be given in uniform, recti-linear computational grid" removed

    - small correction in interpolation technique in case of curvi-linear grids
    - small correction in offset coordinates in case of curvi-linear grids
    - small correction in discretisation of diffraction parameter
    - small correction in computing wave-driven forces in case of spherical coordinates

The following fixes and (small) extensions were introduced with patch A.

- hotstart functionality modified to handle reading from a single hotfile or from multiple hotfiles when running in parallel with MPI
- new transmission formula for low-crested structures
- two output quantities added:
    - the peakedness of the wave spectrum (Qp)
    - the Benjamin-Feir index (BFI) for quantifying the probability of freak waves
- computation of diffraction in spherical coordinates
- XNL implementation in Fortran90 style
- use of Intel Fortran compiler for Windows with OpenMP functionality included for dual-core PC's
- User Manual adapted
- Technical documentation adapted
- bug fixes in:
    - the Alves and Banner whitecapping formula
    - reading WAM boundary conditions
    - outputting 3 parts of dissipation
    - outputting WATLEV and BOTLEV

The following fixes and (small) extensions were introduced with patch B.

- some inconsistency in interpolation tools of SWAN is corrected. This is only significant in case of curvi-linear grids
- some small corrections:
    - remap input spectra to computational grid is corrected

  - correction with test points
  - correction to windgrid coordinates as set of output locations
  - remove error in case of more than one COMPUTE in parallel nested run
  - correction to bottom dissipation due to current
  - no warning "Hsig=0" in routine SSHAPE in case of specifying initial conditions

Solved in version 40.41:

- re-design of post-processing in parallel mode such that the performance is significantly improved
- a new output quantity is added for TABLE and BLOCK: bottom wave period named as TMBOT
- some small corrections:
  - correction to building matrix and right-hand side in case of sub-command SECTOR in command CGRID
  - small change in the 2D set-up equation
  - correction to generation of binary Matlab files in case of non-stationary computation
  - improving the determination of number of crossing points for searching a location in curvilinear grid
  - correction to coordinates in curvilinear grid with offset values in case of exception value equal to zero

These fixes were introduced with patch A.

- correction to computation TMBOT, square root added
- correction to location points equal to offset values
- correction to output processing in parallel mode
- correction to memory allocation wrt. obstacles
- other small corrections

These fixes were introduced with patch B.

Solved in version 40.31:

- Problem occur when reading a space-varying water level field. This is due to a wrong array name WLEV that is pass to the routine FLFILE in swanpre2.ftn, while it should be WLEVL. (Introduced with patch A.)
- When imposing a Jonswap spectrum at an open boundary with a given MEAN period it turns out that SWAN returns the Jonswap spectrum at the regarding boundary but with a lower mean period! This will not occur when choosing a PEAK period. The origin of this problem is that the variable FSHAPE (indicating the type of the spectrum shape) get the wrong sign when choosing the keyword MEAN. (Introduced with patch B.)
- Problem occur when imposing 1D spectrum at open boundaries in 2D case. SWAN executable created with Compaq Visual compiler will crashed. This is due to not allocating an array for direction whereas such an array will be used elsewhere regardless the use of 1D spectrum. (Introduced with patch D.)
- A small bug in test output for non-linear interactions if fixed. (Introduced with patch E.)
- The problem of the use of the command COMPUTE more than once in case of instationary computations. (Introduced with patch F.)
- The problem of parallel computing with small grids and array bounds violation. (Introduced with patch G.)
- The problem with reading a WAM boundary file in case of nesting. (Introduced with patch G.)
- A small problem when using FD-RIAM for computing quadruplets. (Introduced with patch G.)
- Dummy points in HOTFILE should be filled with exception values as given in command CGRID. (Introduced with patch H.)
- Correction to GROUP command: ix1=xi2 and iy1=iy2 are allowed. (Introduced with patch H.)
- Small correction with respect to writing coordinates in output spectra files in case of parallel computations. (Introduced with patch H.)
- Correction to FRCOEF in TABLE/BLOCK: correct values instead of not a numbers. (Introduced with patch H.)

Solved in version 40.20:

- Problems with OpenMP functionality.
- Collection of BLOCK data in non-stationary mode in parallel MPI runs.
- Determining names of binary Matlab files for vectorial quantities.

Solved in version 40.11:

- The output in the form of starplots on a rotated output frame.
- The implementation of the QUANTITY command.
- Spectral output of source terms on land points.
- The output of 2D spectra in combination with rotated grids or a directional sector.
- The interpolation for test points too close to land points.

Solved in Version 40.01:

- Imposing parametric boundary conditions, using a mean period.
- Quadruplets in combination with obstacles.
- Transmission coefficient in the OBSTACLE command.
- Reading 2D-spectra with SECTOR option in CGRID command.
- File name referred in error message in the print file.
- Zero wave conditions for computations with currents.
- Exception values on wave boundaries.

Solved in version 30.75:

- No plot output for the commands ISOLINE and RAY.
- Initial state for non-stationary mode not as described in manual.
- Several data transfer problems between WAM (local version) and SWAN.
- Wave transmission through sub-grid obstacles not as intended.
- Lay-out of print and plot output.
- Output at last time step was equal to output at one-but-last time step.
- Millenium problem (see User Manual).

- HPGL plot code was not correctly imported into WP7 and MS Word7.

Solved in version 30.62:

- Interpolation problems for output points too close to the boundary of the computational grid.
- SWAN-SWAN nesting not operating.
- Output problem for curvi-linear grid computations.
- Compiler dependent problems for DEC and Silicon Graphics systems.

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c. As noted in the response to Raincoast IR No. 2.04.2a, SWAN is not a statistical model. No statistical analytic tests are employed by SWAN.

d. The SWAN technical manual (Delft University of Technology, 2008a) and user manual (Delft University of Technology, 2008b) provide detailed descriptions of the SWAN model inputs, capabilities, and outputs. However, a UML diagram is not available.

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Marcel Zijlema, Gerbrant van Vledder, Leo Holthuijsen, James Salmon and Pieter Smit, 2013, SWAN and its recent developments. 13th International Workshop on Wave Hindcasting and Forecasting & 3rd Coastal Hazard Symposium, Banff, Canada.

Adem Akpinar and Gerbrant Van Vledder, 2013, On the development of an operational SWAN model for the Black Sea. 13th International Workshop on Wave Hindcasting and Forecasting & 3rd Coastal Hazard Symposium, Banff, Canada.

Huang, Y., Weisberg, R.H., Zheng, L., and Zijlema, M., 2013, Gulf of Mexico Hurricane Wave Simulations Using SWAN: Bulk Formula Based Drag Coefficient Sensitivity for Hurricane Ike, JGR - Oceans, 118, 3916-3938.

2.04.3 SPILLCALC Oil Spill Model

Request:

a. Please identify if the SPILLCALC model structure relies on classical (frequentist), Bayesian, or information theoretic statistical modelling.

b. Please provide the current revision history of the SPILLCALC model. This “log file” should include information on temporal updates, changes in statistical algorithms, and infer how the model has adapted with advances in statistical modelling design and periodic model testing and evaluation.

c. Please list all statistical analytic tests employed by the SPILLCALC model.

d. Please provide Unified Modelling Language (UML) activity diagrams for all algorithms employed by the SPILLCALC model. The product(s) should indicate flow of work indicating model inputs, actions, and decisions from initial to final state(s).

e. Please provide a list of all peer-reviewed and refereed journal articles that introduce, describe the modelling environment of, attempt to validate with historical data, or provide critical review of the SPILLCALC model.

Response:

a. SPILLCALC is a two-dimensional Lagrangian tracking model with specialized capabilities related to hydrocarbon weathering: it uses the laws of physics as well as theoretical formulations to predict the motions and weathering over time of hydrocarbons spilled in water. Various weathering processes such as evaporation were calibrated based on large scale laboratory experiments. <u>It is not a statistical model.</u> Statistical terms, such as averages, described in the documents mentioned above refer to statistics distilled from the results of multiple model simulation runs.

b. First it should be noted that SPILLCALC is not a statistical model, so questions regarding statistical algorithms and statistical modelling design are not relevant. The output from several independent simulations can be combined in a statistical manner, the stochastic results presented in the Application. For the stochastic simulations, the only statistical design consideration is that all combinations of tide, wind and season are properly represented. This was achieved by using a “grid”, for parameters such as wind and tide, rather than random sampling. Spills were initiated every 6 hours (the time grid), and about 364 simulations were used to define a 3-month season, ensuring that all combinations of wind, tide, river flow and stratification were represented.

The following bullet points describes briefly the revision history of SPILLCALC:

- 2005:

  Developed and primarily used for the Northern Gateway Project. SPILLCALC is an oil spill trajectory model which assimilated oil weathering data from another model operated by a third party, as SPILLCALC didn’t include weathering algorithms at that time. Surface currents were provided by 3-D hydrodynamic model. Winds were provided by an interpolated scheme based on oil location and location of coastal meteorological stations. Retention by shore was simulated. The model was used in the stochastic form (combining thousands of simulations to provide statistical information).

- 2008:

  Addition of two weathering mechanisms: evaporation and vertical dispersion. Evaporation process based on pseudo-component method. Products primarily modelled were jet fuel, hence the short residence time on the water surface, and the need for a limited number of weather processes. Coupling of SPILLCALC with air dispersion model CALPUFF to assess the fate of evaporated hydrocarbons in the air was added at this time.

- 2012-2013:

  Addition of the following weathering modules: biodegradation, dissolution, OMA formation, emulsification and sinking. Addition of the molecular diffusion process in the evaporation module (when the slick is too thick, the evaporation flux will be limited by diffusion within the slick layer). Calibration of the model to diluted bitumen type product. Coupling of SPILLCALC with a 3-D hydrodynamic model to assess the fate of the oil in the water column.

- 2014

  Ingestion of surface currents in a NetCDF format. Development of an oil/ice interaction module. Addition of a viscosity module that computes the evolution of oil as it weathers.

c. As noted in the response to Raincoast IR No. 2.04.3a, SPILLCALC is not a statistical model. No statistical analytic tests are employed by the SPILLCALC model.

d. The UML activity diagram for the SPILLCALC model is in the document attached to this information request (refer to Raincoast IR No. 2.04.3d - Attachment 1).

e. Three papers have been published about the SPILLCALC model.

1. Stronach, J.A. and A. Hospital, 2014, Simulating the Behaviour and Fate of an Oil Spill Using a Coupled Three-Dimensional Hydrodynamic Model", Proceedings of the International Oil Spill Conference, Savannah, Georgia, pp. 901-918.

2. Stronach, J.A. and A. Hospital, 2014, The Implementation of Molecular Diffusion to Simulate the Fate and Behaviour of a Diluted Bitumen Oil Spill and its Application to Stochastic Modelling, Proceedings of the 37th Arctic and Marine Oil Spill Program Technical Seminar, Canmore, Alberta, pp. 353-373.

3. Hospital, A., J.A. Stronach, M.W. McCarthy and M. Johncox, 2014, Spill Response Plan Evaluation Using an Oil Spill Model, Proceedings of the International Oil Spill response Technical Seminar, Yantai, China, Available in March 2015 on Elsevier Science Direct Aquatic Procedia.

2.05 Oil Retention on shorelines in SPILLCALC

Reference:

i) A3S4Y5, Volume 8A, Marine Transportation, Section 5.4.4.4.4, PDF page 30 of 43.

Preamble:

The repeatability of study results is paramount to the integrity of the scientific process. Principally, the findings of a study are accepted as valid if they can be reproduced independently. Through this iterative process the body of science is advanced with bidirectional exchange of ideas, critique, and adoption of proven methods. Theories and study findings are accepted only until refuted by follow up investigation. For the scientific model to work properly and effectively, the process must be transparent allowing the data to speak for itself. If independent teams are restricted access to datasets, model environments, or information describing modelled input parameters, refuting or accepting statements and conclusions generated from model output is impossible.

In Reference (i), the description of the algorithm used to calculate the amount of oil transferred to sediment upon contact with beach and intertidal shoreline indicates that there was no provision to refloat trapped oil. This was deemed likely to over estimate the amount of oil that is stranded.

Request:

a. Please confirm that overestimating the amount of oil trapped on or in shorelines would result in an underestimation of oil that would be left on the water surface in later time-steps.

Response:

a. Yes. Considering that the total mass of spilled hydrocarbon is a fixed quantity in any simulation, if the portion retained on shore is overestimated, the portion remaining on water is necessarily underestimated. The oil spill model implemented this approach.

2.06 Discrepancy between modeled and observed results

Reference:

i) A3S5H1, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Figure 3.2.3, PDF page 4 of 9.

ii) A3S5G9, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Section 3.2.2, PDF page 23 of 72.

Preamble:

The repeatability of study results is paramount to the integrity of the scientific process. Principally, the findings of a study are accepted as valid if they can be reproduced independently. Through this iterative process the body of science is advanced with bidirectional exchange of ideas, critique, and adoption of proven methods. Theories and study findings are accepted only until refuted by follow up investigation. For the scientific model to work properly and effectively, the process must be transparent allowing the data to speak for itself. If independent teams are restricted access to datasets, model environments, or information describing modelled input parameters, refuting or accepting statements and conclusions generated from model output is impossible.

Figure 3.2.3 in Reference (i) shows observed versus predicted along-channel currents for the H3D model. The bottom panel in this figure shows the difference between the model and observed values, where the discrepancy is near 20% in many instances, lasting for many hours at times. In most cases, the magnitude (either positive or negative) of the predicted current speed is less than the observed. Reference (ii) states that the current meter validation in the Burrard Inlet 125 m grid serves as a proxy to the 1 km model.

Request:

a. Please explain how the discrepancy displayed in Figure 3.2.3 might affect the transfer of spilled oil modelled in SPILLCALC from one grid square to the next within the Burrard Inlet 125 m grid.

b. Please confirm that the speed of oil movement as predicted and modeled by SPILLCALC would be necessarily underestimated, and if this is not the case, provide explanation as to why not.

c. Please explain if this type of discrepancy is expected, has been tested for, or has been identified in other areas where spill modeling was completed, given that this current meter validation serves as a proxy to the 1 km grid.

Response:

a. The validation of the hydrodynamic models has no effect on the transfer of oil between grid cells within SPILLCALC.

As noted in *Application Volume 8C S9-Modeling the fate and behaviour of marine spills for the Trans Mountain Expansion Project (*Filling ID A3S5G9*)*, the validation summarized in Figure 3.2.3 displays well simulated currents, with little variation in phase and a RMS error of 5.8 cm/s. The model skill is 0.947 out of a possible score of 1.000.

b. Please refer to Appendix D of Technical Report TR 8C 12 Supplemental TR S9, Modelling the Fate and Behaviour of Marine Oil Spills for TMEP (Filing ID A3S5I1). Appendix D presents the model validation study conducted for Burrard Inlet in which the modelling framework was validated against a 2007 spill from Kinder Morgan's Westridge Terminal. In this validation the models (SPILLCALC, H3D and SWAN) reproduced the distribution of oil within Burrard Inlet to a high degree of accuracy.

When oil spill modelling is conducted for Project Evaluation and ESA, one doesn't require 100% accuracy in the spatial distribution of surface currents, especially since a wide range of environmental conditions will be considered, but sufficient accuracy that environmental assessment can be made, such as during the permitting process. This is the reason why some other spill models available on the market would only consider basic current speed and direction with no hourly variability. Once the proposed expansion receives a permit, modelling can help with assessing spill response, either during the planning phase, or during an actual spill event. Model results can be touched up and interpreted by responders in the field, but it is important to have an initial objective overview and prediction of spill movement.

Regarding the accuracy of the modelled currents, much of the difference between modelled and observed currents is related to the difference in phase between these two time-series, i.e., the timing of the peak current in each tide cycle. When integrated over a drift of a few hours, which is the operational application of the model predictions, these differences are considerably reduced. SPILLCALC and H3D are not known to systematically underestimate oil movement.

c. The level of accuracy achieved by the 125 m grid Burrard Inlet model is excellent as compared to the level of accuracy both expected of and typically achieved by hydrodynamic models. Validation by current meter is one of the more difficult validations to achieve within a hydrodynamic model, and the outcome of the validation is within an acceptable range of accuracy.

Further validations with current meter data has been undertaken at the following locations:

- Roberts Bank
- Juan de Fuca Strait
- Haro Strait

A summary of these validations can be found in the Tetra Tech EBA technical report *Additional Validations of the Hydrodynamic Model, August 2014* (Filling ID A4A2A1).

2.07 Sensitivity Analysis

Reference:

i) A3S5G9, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Volume 8C TR 12 TR S9, Section 3.1.1, PDF page 19 of 72.

ii) A3S5G9, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Section 3.1, PDF page 18 of 72.

Preamble:

The repeatability of study results is paramount to the integrity of the scientific process. Principally, the findings of a study are accepted as valid if they can be reproduced independently. Through this iterative process the body of science is advanced with bidirectional exchange of ideas, critique, and adoption of proven methods. Theories and study findings are accepted only until refuted by follow up investigation. For the scientific model to work properly and effectively, the process must be transparent allowing the data to speak for itself. If independent teams are restricted access to datasets, model environments, or information describing modelled input parameters, refuting or accepting statements and conclusions generated from model output is impossible.

Reference (i) provides a description of the hydrodynamic grids used in the four model implementations of H3D used by SPILLCALC. Reference (ii) states that “The selection of grid size is based on consideration of the scale of the phenomena of interest, the grid domain, and available computational resources.”

Request:

a. Please confirm if any sensitivity analysis was done on the grid square size for any of the four grids (Strait of Georgia 1 km grid, Strait of Georgia 200 m grid, Fraser River grid, or Burrard Inlet 125 m grid) used in the H3D simulations. For example, was the 1 km Strait of Georgia grid always run at 1 km or were the grid sizes altered during different model runs to assess the sensitivity of modeled results to grid square size?

b. Please provide the statistical methods used in Reference (ii) to select the grid size in the four model implementations used in H3D.

Response:

a. An ideal grid for a hydrodynamic model consists of grid cells that are the maximum size that will still resolve the relevant processes to the water mass in question. While a finer-resolution grid may resolve the properties of a water body with greater detail, it is up to the judgement of the engineers and scientists to determine whether the level of detail provided by the numerical models is sufficient for the task at hand.

The grids employed in the H3D simulations are the result of several decades of model development. The 1 km grid size has been arrived at following several earlier studies and validations in which a 1 km grid size was found to balance, on the one side, computational time and, on the other, accurate representation of the physical characteristics of the Salish Sea. The 1 km grid size is sufficient to represent flows within most major waterways in the Salish Sea, including Juan de Fuca Strait, Haro Strait and the Gulf Islands.

Because of the Fraser River, the Strait of Georgia represents a somewhat special case. While the 1 km model is sufficiently resolved to capture the vast majority of processes within the Strait of Georgia (*e.g.,* tides, tidal currents, stratification, temperature) and provide boundary conditions to the Burrard Inlet, Strait of Georgia and Fraser River subgrids, the details of the Fraser River plume necessitate a separate Strait of Georgia model at finer resolution. Consequently, the Strait of Georgia requires a fine resolution model while the similarly sized Juan de Fuca Strait and the smaller Haro Strait and Gulf Island passages do not.

In regions in which a finer grid size is required, the hydrodynamic were nested down to achieve higher resolution. For the purposes of oil spill modelling, these areas were the Strait of Georgia, Fraser River and Burrard Inlet. The sizes of these models have been refined across many previous processes to balance run time and resolution. In each model region, resolution of the following physical processes were used to determine if the selected grid size was appropriate:

- **Strait of Georgia:** The behaviour of exchange flows (*i.e.,* upwelling, flooding and drying) at Roberts Bank and Sturgeon Back, and the behavior (*i.e.,* mixing, extent, trajectory) of the Fraser River plume across the annual range of flows.
- **Fraser River:** Helicoidal flow through bends at which this phenomenon is expected (this is particular importance for mixing), the structure and penetration of the salt wedge and water levels at gauged sites along the river.
- **Burrard Inlet:** Water levels and currents in Burrard Inlet, acceleration of tidal flows beneath the Lions Gate and Iron Workers Memorial Bridges and stratification resulting from interactions with the relative fresh Indian Arm.

b. Statistical methods are not commonly applied in the determination of model grid size for the hydrodynamic modelling of water bodies such as the Salish Sea, Burrard Inlet, Fraser River or Strait of Georgia.

The use of a statistical measure is not required for this sort of hydrodynamic model for several reasons:

- Hydrodynamic models such as H3D are not particularly sensitive to grid size. The use of, for example, a 1100 m grid versus a 900 m grid will not have an appreciable effect on the model results. Therefore, the fine-scale grid size tuning is based largely on experience and the best fit for local bathymetric features.

In other classes of numerical models, computational fluid dynamics (CFD) models for example, the model outcomes are more sensitive grid size because of numerical diffusion. For these models, several grid sizes (*e.g.,* ½x, x and 2x) are tested, but for numerical artifacts, rather that arriving statistically at an 'optimum' grid size.

- The selection of a general grid size (*e.g.,* 1000 m versus 200 m versus 50 m) is determined, for the most part, by the required model domain and the available computational power. The model domain is generally set by the project extent and the placement of reasonable boundaries (*i.e.,* it is preferable to have boundaries at which flows enter and exit perpendicular to the boundary), while the computational power is generally fixed by available technology. In some instances, where 20 years ago a 5 km grid would be considered sufficient due to limitations on computational power, now we would consider a 1 km grid (125 times more computationally intensive) sufficient due to more modern computational limits. In both cases, however, the big-picture results of the models would be similar, with a modern 1 km model yielding higher resolution local results.

- Grid size is not readily changed within a hydrodynamic model. The crafting of an appropriate hydrodynamic grid is a labour intensive process of, partially, trial-and-error and judgement to arrive at a grid that accurately represents the local bathymetric features of a region while resulting in stable computations. The use of a poorly constructed grid can result in an unstable model or, in the worst case, inaccurate model results. As a consequence, the most fruitful use of time when setting up a hydrodynamic model is in constructing a robust, accurate and well-crafted grid, rather than fine-tuning an optimal grid size (*e.g.,* 75 m versus 90 m). In short, accurate results are more readily achieved from a well made grid of sub-optimal size than from a hastily constructed grid of optimal size.

2.08 Slicklets in SPILLCALC

Reference:

i) A3S5G9, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Section 5.1, PDF page 26 of 72.

ii) A3S5G9, Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Section 5.2.7, PDF pages 32 to 36 of 72.

Preamble:

The repeatability of study results is paramount to the integrity of the scientific process. Principally, the findings of a study are accepted as valid if they can be reproduced independently. Through this iterative process the body of science is advanced with bidirectional exchange of ideas, critique, and adoption of proven methods. Theories and study findings are accepted only until refuted by follow up investigation. For the scientific model to work properly and effectively, the process must be transparent allowing the data to speak for itself. If independent teams are restricted access to datasets, model environments, or information describing modelled input parameters, refuting or accepting statements and conclusions generated from model output is impossible.

Reference (i) describes how oil released on the water is represented by a large number of independent floating particles called “slicklets”. Reference (ii) describes the various physical weathering processes that are included within the model SPILLCALC.

Request:

a. Please explain why dividing the spilled oil total aliquot into 50,000 identical slicklets is appropriate, given that many of the algorithms for the physical weathering processes listed in Reference (ii) would likely be different for different sized “slicklets”.

b. If this is limited by computational resources please indicate that, and confirm that this may not be representative of real-world spills, where the initial oil slick may break up into any number of uniquely sized smaller slicks.

c. Please explain how differing slicklet size may affect each of the weathering process listed in reference (ii).

Response:

a. Individual slicklets are not intended to be physically meaningful, but they do carry significant information regarding their aliquot of the total spill, such as density, and pseudo component composition. The cloud of particles as a whole represents the area covered by the spill, and its progress is the spill’s dispersion and trajectory.

   Weathering processes, such as evaporation, depend on surface area, which is not a property of individual slicklets. This is the reason why their agglomeration was considered for weathering purposes. All slicklets within each model cell were agglomerated to provide meaningful physical properties for weathering purposes.

The modelling follows documented and peer-reviewed methods for the advection, i.e. trajectory, and weathering of the oil. Hence, it is believed the modelling to be representative of real-world spills.

The degree of error associated with representing a slick using an agglomeration of slicklets is generally inversely proportional to the square root of the number of slicklets within a model cell. To minimize such approximation errors, a total of 50,000 slicklets was selected so that, at any time, most SPILLCALC cells would contain a substantial number of individual slicklets.

b. Refer to response to Raincoast IR No. 2.08a.

c. Refer to response to Raincoast IR No. 2.08a.

FIGURES ILLUSTRATING SPILL MODEL OUTCOMES

2.09 Figure Corrections

Reference:

i) A3S5G8 - Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Appendix, Figure FR 1-2, PDF page 1 of 11.

ii) A3S5H0 - Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Appendix, Figure FR 2-2, PDF page 1 of 11.

iii) A3S5H2 - Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Appendix, Figure FR 3-2, PDF page 1 of 7.

iv) A3S5H5 - Volume 8C, Modelling the fate and behaviour of marine oil spills for the Trans Mountain Expansion Project, Appendix, Figure FR 4-2.PDF page 6 of 14.

Preamble:

Stochastic modeling was completed for spills on the Fraser River. The figures in References (i)-(iv) have layers representing the probability of oil presence. In each of these figures, the 1% line is very difficult to discern and in some cases not visible. It is important that the information be visible.

Request:

a. Please provide updates to the figures in References (i)-(iv) listed below where all the layers are clearly visible, or, alternatively, provide the shapefiles for the probability of oil presence in the listed figures: FR 1-2, FR 2-2 both large and small scale, FR 3-2 and FR 4-2.

Response:

a. Figures in References (i)-(iv) listed above are provided in the attached document to this information request (Raincoast IR No. 2.09a - Attachment 1). For a better clarity, contour lines were filled, so that the Intervener can clearly see the different probability contours and especially the 1% probability contour. Note that these maps are the results of hundreds of spill simulations combined together. They do not reflect the extent of a single spill.

WORLD-LEADING SPILL RESPONSE

2.10 World Class Oil Spill Response

Reference:

i) A3S4V5 - Application Volume 7, Risk Assessment and Management of Pipeline and Facility Spills, PDF page 65 of 84.

ii) A3SOQ7 - Application Volume 1, Province of BC pipeline conditions, PDF page 103 of 113.

Preamble:

Reference (i) refers to Trans Mountain's commitment to meet the Province of British Columbia's conditions for oil pipeline approval, as set out in Reference (ii). Requirement 2 calls for "World-leading marine oil spill response, prevention and recovery systems for B.C.'s coastline and ocean to manage and mitigate the risks and costs of heavy-oil pipelines and shipments." Requirement 3 demands "World-leading practices for land oil spill prevention, response and recovery systems to manage and mitigate the risks and costs of heavy-oil pipelines."

Request:

Can Trans Mountain confirm whether its understanding of "world-leading" marine oil spill response, recovery and prevention is that it should be based on "credible worst case" spill volumes rather than worst case scenarios?

Response:

The term "world-leading" is an effective means to express a worthy objective which Trans Mountain supports. However, it must be recognized that because of differences in geographic, commercial, technical and political settings around the world, there is no single formula or example of a standard that can be copied from another regime and directly applied to the Canadian context. Trans Mountain is confident that the enhanced oil spill regime as proposed in Volume 8a, Table 5.5.3 (Filing ID A3S4Y6) is a worthy example in this respect.

The proposal addresses oil spill risk concerns in a comprehensive risk informed manner based upon diligent and credible evaluation of oil spill risk from project tankers. Using credible worst case as a planning standard as shown in Volume 8A, Table 5.5.3 (Filing ID A3S4Y6) is a responsible approach and does not mean that larger spills cannot be responded to using the same equipment. Similarly the response plan allows for cascading in additional equipment from other sources and areas that are accessible and have arrangements with Western Canada Marine Response Corporation. Such a plan can be used most adequately for response to larger spills as well within an ICS response structure.

A total loss scenario is not a viable scenario, as it is not considered credible and not consistent with the National Energy Board "Filing Requirements Related to the Potential Environmental and Socio-Economic Effects of Increase Marine Shipping Activities, Trans Mountain Expansion Project" dated 10 September, 2013 (Filing ID A3V6I2).